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For Decades, The Department of Defense Knew Fire Fighting Foams With PFAS Chemicals Were Dangerous But Continued Their Use

As far back as 1970s, studies conducted by the Department of Defense showed that the firefighting foam used on military bases and ships known as Aqueous Film Forming Foam (AFFF) that contain fluorinated chemicals now known as PFAS were toxic. By the 1980s, animal studies conducted by the Air Force revealed that PFAS chemicals could pose environmental and health risks.

Here is a timeline of internal DoD studies and reports detailing just how much they knew about the dangers of using AFFF.

1963 – Navy scientists seek patent for AFFF.

1966 – Navy granted patent for AFFF.

1967 – Fire on the USS Forrestal kills 34 sailors.

1967 – The Navy and Marine Corps require the use of AFFF.

1973 – Air Force report, citing toxic effects of AFFF, calls for carbon filtration.

1974 – Air Force report cites toxic effects of AFFF on fish, suggests treatment of AFFF waste.

1976 – Navy scientists cite toxic effects of AFFF.

1978 – Navy study cites toxic effects of AFFF.

1983 – Air Force technical report finds PFDA has toxic effects in mouse studies.

1985 – Navy report again cites toxic effects of AFFF.

1989 – Citing toxic effects, Air Force calls for better management of AFFF waste.

1991 – Army urges Fort Carson to stop using "hazardous" AFFF.

2000 – DOD alerted that PFOS is "bioaccumulative" and "toxic."

2001 – DOD memo finds PFOS "persistent, bioaccumulating, and toxic."

2001 – DOD and EPA hold meeting on military use of PFAS in AFFF.

2011 - DOD releases a Chemical and Material Emerging Risk Alert for AFFF, citing "human health and environmental risks."

2016 - Assistant secretary of Defense directs branches of the military to prevent uncontrolled environmental releases of AFFF and to dispose properly of PFOS containing AFFF.

June 28, 1966 R. L. TUVE ET AL **3,258,423**

METHOD OF EXTINGUISHING LIQUID HYDROCARBON FIRES

Filed Sept. 4, 1963

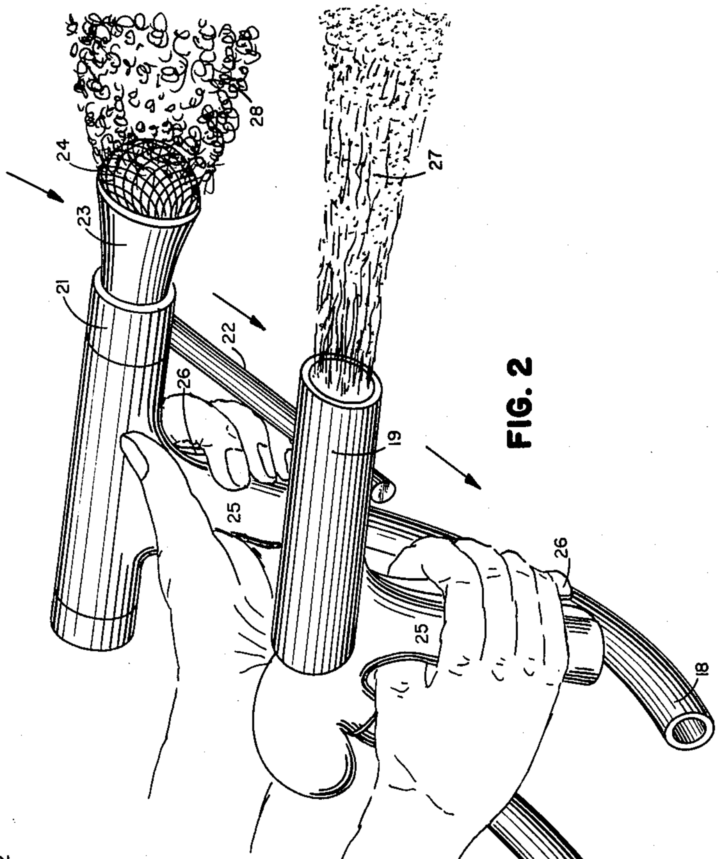

FIG. 2

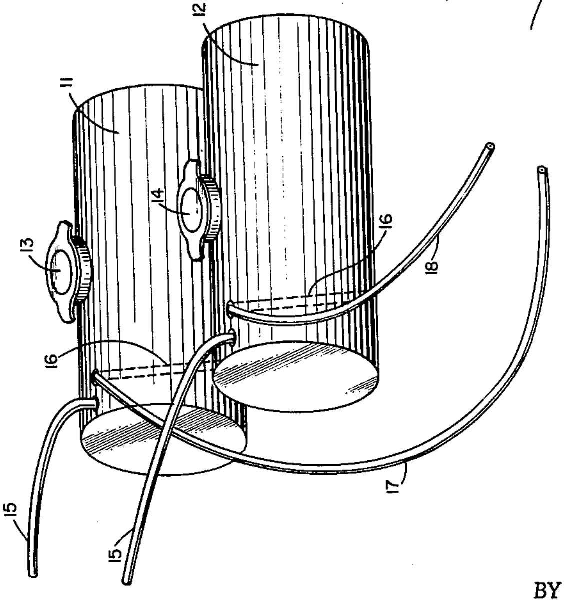

FIG. 1

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United States Patent Office

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3,258,423

METHOD OF EXTINGUISHING LIQUID HYDROCARBON FIRES

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Filed Sept. 4, 1963, Ser. No. 306,665
9 Claims. (Cl. 252—3)

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

This invention relates to novel compositions for covering a low flash point flammable liquid to prevent ignition or reignition of the same when exposed to a nearby flame or source of ignition. More particularly, it relates to a method for using prior art fire extinguishing agents in conjunction with novel foam compositions for blanketing newly extinguished fuel surfaces which are susceptible to fire flashback.

Heretofore, finely-divided dry chemicals, such as sodium and potassium bicarbonate have been used as fire extinguishing agents due to their fast and efficient flame-suppressing ability. The superiority of potassium bicarbonate as a fire extinguishing agent over the previously employed sodium bicarbonate has been demonstrated and reported in a Naval Research Laboratory Report 5183 on August 21, 1958, by R. R. Neill. The dispersion of a finely divided mass of powder directly within the combustion zone of a flaming fuel provides rapid extinguishment of the flames, but the occurrence of flashbacks over the extinguished area is certain unless the fire has been completely extinguished and no possible source of reignition remains.

Methods have also been devised for the application of fire-fighting foams by spraying or by injecting a coherent foam blanket on the surface of a burning fuel. Stable foams which were spread in sufficient thickness over the entire burning area have been capable of resisting the heat and flame attack to suppress and smother a conflagration. Prior art foams which have been used for fire-fighting purposes were formed of proteinaceous substancs, such as, keratins, albumins, globulins, hemoglobins, seed meal, etc., which were modified by hydrolysis and stabilized with salts of polyvalent metals, e.g., ferrous sulfate.

Protein foams, however, are disadvantageous for fighting hydrocarbon fires because of the heavy blanket of foam which must be spread over the entire burning surface, while any disruption of the foam barrier results in a flare-up of burning fuel. Protein foams have also been found to be adversely affected by finely-divided dry chemicals which have been treated with a silicone film; the silicone acts as a defoamer and causes the protein foam to collapse at a high rate.

Dry chemical agents are treated with a silicone surface to provide free-flowing, moisture-resistant powders, to act in the nature of a fluid, said powders being readily discharged by pressure from a hose line or nozzle.

The present invention provides novel foam compositions which have proven to be effective in extinguishing fires when utilized singly or in combination with other fire extinguishing agents. The present foam compositions display a remarkable effect in their ability to protect newly extinguished flammable fuel surfaces from possible recurrence of fire. In this respect, the novel foams have been found to be especially useful in combating fires in gasoline, naphtha, ether, benzene and other combustibles of a highly flammable vapor; they are also useful in combating fires in other hydrocarbons, which are capable under the heat conditions of a fire to give

off considerable vapor, for example, kerosene, jet fuels, diesel oils, etc.

The present foams serve the fire extinguishing process in two ways: they block the feedback of radiant energy to a fuel surface and they also prevent further release of flammable vapor after the flames have been suppressed.

The foams disclosed herein are suitably employed with dry chemical agents, in particular potassium bicarbonate powder, the foams displaying complete stability in the presence of silicone-coated powder. Moreover, foams by their very nature, enhance the extinguishing properties of $KHCO_3$ powder by eliminating the possibility of flashbacks. With rampart fuel fires such as those occurring at aircrash sites where a powder cloud of $KHCO_3$ is applied, the present foam is then sprayed on the surface of the fuel to secure the extinguishment of the fire. The foam spray will prevent flashbacks on the extinguished fuel surface while the remainder of the flames are extinguished. Thus, the chief limitation of $KHCO_3$ powder, because of its inability to cope with flashbacks, has now been successfully overcome as a result of the present powder-foam method of combating fires.

A further desirable effect noted in the use of the present foam compositions is based on their remarkable ability to extend their usefulness even after the air-liquid bubbles are disintegrating. The foams release a thin surface film which persists on the fuel surface and which has been found to be impervious to flammable fuel vapors. The thin film is capable of spreading over the fuel-foam interface and also over fuel areas which are not fully covered with foam. The film is quickly reformed whenever it becomes ruptured. Thus, the thin film is equally effective as the foam itself in preventing the release of fuel vapor. Previous foams cannot be utilized in this manner, for the foamy coating is somewhat transient and can be ruptured, and previous foams are therefore susceptible to reignition of fuel.

Thus, it is an object of the present invention to provide a more efficient foam composition for suppressing and extinguishing fires.

Another object of the invention is to provide a fire extinguishing technique which employs a foam to prevent flammable vapor release from a fuel surface after the flames have been suppressed.

A further object of the invention is to provide novel foam compositions that can be used effectively with any dry powder agents to effect rapid and complete extinguishment of hydrocarbon fires.

A further object of the invention resides in the formation of a water-containing film which prevents the release of flammable vapor from a hydrocarbon surface.

Other objects and advantages of the invention will become more fully apparent from the following detailed description and as illustrated in the accompanying sheet of drawings in which:

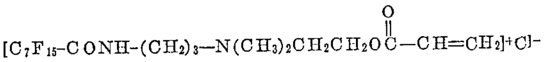
FIG. 1 schematically illustrates a system by which a dry powder and a foam composition are delivered to twin discharge nozzles for combating hydrocarbon fires in accordance with the teachings of the present invention; and

FIG. 2 is a view of the twin discharge nozzles under operating conditions.

In accordance with the present invention, novel foam compositions are formed from solutions containing therein as foaming agents one or more fluorocarbon compounds; said compositions are capable of forming a frothy mass when blown or mixed with air, Freon–12, nitrogen, or other suitable gaseous media. The fluorocarbon foam-formers of the present invention are derivatives of the perfluorocarboxylic and perfluorosulfonic acids, represented by the general formula, R_fCO_2H and R_fSO_2H, respectively. In the carboxylic acid molecule, the R_f is a perfluoroalkyl chain of seven carbon atoms, C_7F_{15}—, and in the sulfonic acid molecule, the R_f is a perfluoroalkyl chain of eight carbon atoms, C_8F_{17}—. The perfluoroalkyl R_f may be a straight chain or a branched chain. Preferred fluorocarbons which are useful for the purposes of the present invention comprise the following quaternary nitrogen compounds which have in their molecular structure an intermediate amidopolymethylene linkage:

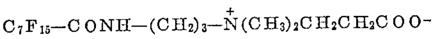
$$[C_8F_{17}{-}SO_2NH{-}(CH_2)_3{-}N(CH_3)_3]^+I^- \qquad (A)$$

$$[C_7F_{15}{-}CONH{-}(CH_2)_3{-}N(CH_3)_3]^+I^- \qquad (B)$$



$$[C_7F_{15}{-}CONH{-}(CH_2)_3{-}N(CH_3)_2CH_2CH_2O\overset{\overset{\displaystyle O}{\|}}{C}{-}CH{=}CH_2]^+Cl^-$$

(C)



$$C_7F_{15}{-}CONH{-}(CH_2)_3{-}\overset{+}{N}(CH_3)_2CH_2CH_2COO^-$$

(D)

An additional fluorocarbon which is also suitable for the preparation of the present foam is the sulfonamido aliphatic acid salt represented by the formula:

$$C_8F_{17}SO_2N(C_2H_5)CH_2COOK \qquad (E)$$

The above fluorocarbon compounds provide long-chain, surface active cations and anions which have a terminal perfluoroalkyl chain that is both hydrophobic and oleophobic and therefore repellant to water and to hydrocarbons. The molecules are capable of concentrating on the surface of water or hydrocarbon fuel and form an oriented surface film with the perfluorocarbon end pointed upward.

The molecular structures (A), (B), (C) and (D) consist of an anion electrostatically united to a long chain cation, owing to the positive charge of the quaternary nitrogen atom. The molecule (D) is cationic, but it is also anionic due to the presence of the carboxylic group which is able to release hydrogen atoms in aqueous solutions. The ionized (D) molecule is amphoteric and ampholitic and thus presents both cationic and anionic properties, since both positive and negative ionization sites exist in the ion. The molecule (E) is a carboxylic acid salt, and the carboxylate group in this compound is anionic.

Other perfluoro compounds showing similar characteristics may be used as the foam formers in accordance with the invention.

When the present fluorocarbons are used in relatively small concentration in water, they are capable of forming frothy emulsions that are especially useful as fire extinguishing foams. The present fluorocarbons possess the necessary thermal and chemical stability which is essential for foam compositions. The fluorine-carbon bond provides improved stability to the molecule. The fluorine in the terminal portions renders the molecules more stable in the presence of heat. Moreover, the above molecular structures possess extraordinary activity in reducing the surface tension of solutions even when they are present in very small concentrations.

The fluorocarbon compounds are especially useful in foams which are designated as vapor-controlling or securing agents concomitant with the use of flame-suppressing dry powders. The present foams do not disintegrate nor react with a dry powder such as the Purple-K Powder (P-K-P). Purple-K Powder is a term used to designate potassium bicarbonate fire extinguishing agent which is free-flowing and easily sprayed as a powder cloud in flammable liquid and other fires.

Features of this invention relate to the water-containing film at the foam-fuel interface, and to the ability of the film to persist during and after the foam has disintegrated due to external effects. The fluorocarbon film, which retains a certain amount of water on its surface, is capable of preventing vapor release from the fuel surface. Additionally, the surface film exhibits a great

mobility and self-sealing ability and is thus capable of resealing the surface after it has been pierced. Previous fire-fighting foams provide an initial foam blanket, but once the foam layer is broken the surface is open to reflash.

The foams pertaining to this invention are prepared by forming a water solution containing the perfluoro compound in a sufficient amount when suitably acted upon to form a foamy mass. Foams of good water retention and adequate resistance to breakdown contain the perfluoro compounds in concentrations of about 0.10 to about 10% or more by weight, depending on the particular compound used for this purpose. At higher concentrations, the solutions have a tendency to gel and become stratified. Preferably, the foam compositions contain one or more of said fluorocarbon compounds in concentrations in the range of from about 0.25 to about 4% by weight of solution.

Solutions containing a perfluoro compound, for example the compound designated (A) in concentrations of 0.25% or more, will form a frothy mass by aerating with a gas, such as Freon-12 or with air to form relatively stable foams. The solutions may be readily expanded to volumes as high as 40-50, based on the ratio of air to liquid.

Freon-12 is a trade name for the low-boiling difluoro dichloro methane commonly known as a refrigerant gas.

The water content in foams determines their ability to withstand thermal shock and also their ability to spread and level off readily, consequently, volume expansion plays a very important role in providing good fire extinguishing properties. Therefore, it is preferred to employ the present foams at volume expansions of approximately 8 or 10, that provide thereby a water content of about 0.025 gal./ft.^{2} of surface area. The lower volume expansion displays good action in flowing around and up against surfaces.

The compounds designated (A) and (D) have been found to be more effective in their ability to form resistant foams capable of protecting low flash point fuels from ignition or reignition for periods of from 5 to 10 minutes or more. Compounds (A) and (D) may be used in about 0.5% concentration to form foams of maximum stability.

Alternately, compounds (A) and (D) may be combined in a single solution in any relative amount up to 4%, but, preferably, they form foams of maximum usefulness by using equal amounts of compounds (A) and (D) in a total concentration of about 0.50%, consisting of 0.25% of (A) and 0.25% of (D) by weight of solution, based on a final foam volume expansion of 8 to 10.

Improved stability in the present foams, especially with the lower expansion foams, is obtained by means of an additive that improves the resistance of the foam to heat and its capacity to maintain its surface and liquid content. A foam improver in the form of a water-soluble polymeric material combined in solution before foaming will increase the stability of the foam. Foam improvers which may be advantageously combined in solution involve the high molecular weight polymers of ethylene oxide, polyvinyl resins, polyglycols, carboxy vinyl polymer, etc. A polymer containing between 2000-4000 units of ethylene oxide has been found to be a useful additive, imparting greater resistance to foam distintegration. A polyethylene polymer commercially available is the Polyox WSR-35 manufactured by the Union Carbide Chemical Co. Foam additives of this type are included in the foam composition in an amount in the range of from about 0.5 to 5% by weight of the final solution.

A preferred foaming composition in accordance with the invention has the following composition by weight:

Component:	Percentage
(A)	0.25
(D)	0.25
Polyox WSR-35	0.50
Water	99.0

The above solution is blown or mixed with Freon–12 or any other gas (including air) to form a gas-liquid emulsion.

The following test procedures are illustrative of the fire extinguishing characteristics of the present foam compositions. The presence of the film barrier which forms on the fuel surface and its effective interference with the ignition and propagation of flame is hereby vividly demonstrated.

Test 1

The compound (A) is formed into a 1% aqueous solution and expanded with air to a volume of about 10. The foam is then applied as a thin layer of about ¼ inch to the surface of motor grade gasoline. The foam prevented ignition by an open flame and when ignition was finally effected only a small amount of vapor was present to permit a brief flash across the surface. Agitation with a probe disclosed that it was difficult to break open the barrier to get a sustained flame. When exposed surfaces of fuel was finally obtained, the exposed fuel would not take fire until repeated agitation in one area and then it was quickly extinguished. This test indicated the presence of a useful film that forms a surface barrier capable of suppressing fuel vaporization.

Test 2

The formation of a surface film was further demonstrated by means of a small amount of fluorescent material in the foam solution employed in Test 1. A small amount of foam containing the fluorescent material, sodium fluorescein, was placed on the surface of gasoline, and the area of foam and surrounding surface were observed under ultraviolet light. The green glow of the foam was soon observed spreading in all directions on the surface of the gasoline. As the foam began to disintegrate with time, the green glow on the surface grew larger. After the foam had completely disintegrated, the green coloration had spread out over an area many times larger than the area previously occupied by the foam.

Test 3

In a field scale test involving a 14-foot diameter gasoline fire, the presence of the film barrier along with its mobility and self-sealing ability was further demonstrated. A container lid 19 inches in diameter was placed in the gasoline fire prior to the application of foam. A foam containing about 0.5% of compound (D) was blown with air and applied to give a density of about 0.06 gallon of solution per square foot of fuel surface over the entire burning surface until the fire was extinguished. After a lapse of about one minute, a torch was brought over the opening left by the lid. The surface could not be ignited even with agitation. Gaps also occurred in the foam blanket, and the foam was subject to considerable movement by the wind. However, the open surfaces could not be ignited even with agitation proving that the surface film had formed and held together by resealing itself throughout the period in which the gasoline surface was being agitated.

The present fire extinguishing method is best disclosed by a certain illustrative embodiment which will now be described in detail.

Illustrated in FIG. 1 is a pressurized system for discharging a dry chemical and a perfluorocarbon foam of the type described herein from a dry chemical container **11** and a solution container **12**; said containers may form a part of a mobile unit that can be readily dispatched to the scene of hydrocarbon fire. The dry chemical in container **11** may be potassium or sodium bicarbonate, ammonium dihydrogen phosphate or CO_2 gas under pressure. In container **12**, the foam solution may consist of a mixture of the perfluoro compounds (A) and (D) in a concentration of about 0.25% of each compound and including therein a foam stabilizer, such as a polyethylene polymer, and a pour point depresent, such as ethylene glycol. The dry chemical and solution are charged through openings **13** and **14** in the respective containers. The containers are then suitably provided with means for pressuring said containers through pressure lines **15**; the discharge pressure forces the contents through outlet lines **16** near the bottom of said containers.

The powder and foam are conveyed through discharge lines **17** and **18**, respectively, and discharged as a spray through separate nozzles, as shown in FIG. 2. The solution is made into a foaming mass by mechanically mixing with air or other gas. More conveniently, the foam may be readily formed by adding a suitable amount of Freon liquid to discharge line **18**. Upon leaving the nozzle **21**, the Freon flashes into the vapor phase forming a foaming mixture **28**.

Turning now to FIG. 2, the powder nozzle **19** and the foam nozzle **21** are mounted in a fixed position relative to each other on a rod holder **22**. The foam nozzle **21** is equipped with a discharge tip **23**, which may be the fog-foam tip SG–2559, manufactured by the Rockwood Sprinkler Corporation, said tip being rated at 50 gallons per minute at 100 p.s.i. The tip has a convex screen **24** mounted in the front to cause the foam to fan out in a wide arc upon discharge.

The dual nozzle arrangement is designed with pistol grips **25** that have trigger type shut-off valves **26** to permit an easy on-off operation with one hand on each pistol grip. The operator begins with the dry chemical discharge **27** initially and moves in a given direction. He then directs the foam discharge **28** over the area covered by the powder until the entire area is blanketed successively with dry chemical and with foam. The foam covers the area after the dry chemical has extinguished the flames.

150 square feet of gasoline fire may be extinguished with about 20 lbs. of $KHCO_3$ powder and 5 gallons of perfluorocarbon foam. The foam is preferably applied with a water density of 0.03 gal./ft.^{2}.

The present foams constitute essentially air-water emulsions that display a substantial capability to distribute a thin layer of water in an active film. The term "light water" has been coined to describe the present foamy mass with its active film. The oriented, surface-active film is capable of distributing a useful water content which does not drain rapidly from a hydrocarbon surface. This water-containing film with a specific gravity of nearly 1.0 is capable of floating on a hydrocarbon surface with a specific gravity of only 0.7 and to persist thereon for an extended period. A further distinction of "light water" is its ability to foam from very dilute solutions containing a small concentration of the perfluorocarbon foaming materials. The complete disintegration of these foams results essentially in water deposition containing a soluble compound.

Past experience has shown that the water content of foams is of great importance in determining their ability to withstand thermal shock. The breakdown of foam involves evaporation from the surface; it also involves drainage of liquid from the bubble wall and interstices. The retardation of foam decay is thus affected by the volume of water in the foam. A unique property of the fluorocarbon foams is that their heat resistance is not entirely related to their water content. The present foams lose their water liquid phase at a higher rate than protein foams, but they exhibit good heat resistance and vapor suppression qualities.

The present fluorocarbon composition may be formulated more conveniently as concentrates which may then be diluted with water to form the active foaming solution to generate the foam. The concentrate may also contain stabilizers and pour point depressants and other additives.

In a projected fire-fighting situation a hydrolyzed protein foam and the perfluoro, "light water" foam may be used simultaneously or successively in a single locale. The two foams may also be combined and applied as a mixed blanket of foam without adverse effects. When the mixed foam is employed on a fuel surface, the vapor-suppressing film of "light water" is clearly evident and equally effective in preventing reignition.

The invention therefore provides novel perfluorocarbon foams which have been found to be very advantageous in combating fuel fires, especially hydrocarbon fuel of high flammable vapor. In addition, the present invention provides an improved method for combating hydrocarbon fires by discharging a flame-suppressing dry powder and then blanketing the extinguished flames with a perfluorocarbon foam to prevent further flashbacks.

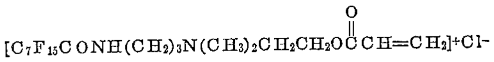
Obviously many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

What is claimed is:

1. A method of extinguishing a liquid hydrocarbon fire which comprises covering the burning area of the liquid hydrocarbon with an aqueous foam having a non-combustible gas phase and an aqueous liquid phase which contains in solution from about 0.1 to 10% by weight thereon of a surface active fluorocarbon compound selected from the group consisting of

$$[C_8F_{17}SO_2NH(CH_2)_3N(CH_3)_3]^+I^-$$

$$[C_7F_{15}CONH(CH_2)_3N(CH_3)_3]^+I^-$$



$$[C_7F_{15}CONH(CH_2)_3N(CH_3)_2CH_2CH_2O\overset{\overset{O}{\|}}{C}CH{=}CH_2]^+Cl^-$$

$$C_7F_{15}CONH(CH_2)_3\overset{+}{N}(CH_3)_2CH_2CH_2COO^-$$

and

$$C_8F_{17}SO_2N(C_2H_5)CH_2COOK$$

2. A method as defined in claim 1, wherein the concentration of surface active fluorocarbon compound in the aqueous liquid phase of the foam is from about 0.25 to 4% by weight thereon.

3. A method as defined in claim 2, wherein the aqueous foam has a gas to liquid volume ratio of from about 8 to 10.

4. A method as defined in claim 3, wherein the surface active fluorocarbon compound in the aqueous liquid phase of the foam is

$$C_7F_{15}CONH(CH_2)_3\overset{+}{N}(CH_3)_2CH_2CH_2COO^-$$

5. A method of extinguishing a liquid hydrocarbon fire which comprises covering the burning area of the liquid hydrocarbon with an aqueous foam having a non-combustible gas phase and an aqueous liquid phase which contains in solution about 0.25% by weight thereon of each of the surface active fluorocarbon compounds

$$[C_8F_{17}SO_2NH(CH_2)_3N(CH_3)_3]^+I^-$$

and

$$C_7F_{15}CONH(CH_2)_3\overset{+}{N}(CH_3)_2CH_2CH_2COO^-$$

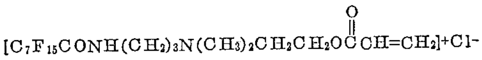
and the gas to liquid volume ratio thereof is about 8 to 10.

6. A method as defined in claim 5, wherein the gas phase of the aqueous foam is difluorodichloromethane.

7. A method of extinguishing a liquid hydrocarbon fire which comprises covering the burning area of the liquid hydrocarbon with a dry powder capable of extinguishing flames at the surface of the liquid hydrocarbon and in amount to extinguish said flames and immediately thereafter covering the dry powder covered area of the surface of the liquid hydrocarbon with an aqueous foam having a non-combustible gas phase and an aqueous liquid phase which contains in solution from about 0.25 to 4% by weight thereon of a surface active fluorocarbon selected from the group consisting of

$$[C_8F_{17}SO_2NH(CH_2)_3N(CH_3)_3]^+I^-$$

$$[C_7F_{15}CONH(CH_2)_3N(CH_3)_3]^+I^-$$



$$[C_7F_{15}CONH(CH_2)_3N(CH_3)_2CH_2CH_2O\overset{\overset{O}{\|}}{C}CH{=}CH_2]^+Cl^-$$

$$C_7F_{15}CONH(CH_2)_3\overset{+}{N}(CH_3)_2CH_2CH_2COO^-$$

and

$$C_8F_{17}SO_2N(C_2H_5)CH_2COOK$$

8. A method as defined in claim 7, wherein the aqueous foam contains in solution a foam stabilizer which is a water-soluble high molecular weight polymer and in a small amount sufficient to improve the thermal stability of the foam.

9. A method as defined in claim 7, wherein the dry powder is potassium bicarbonate powder and the aqueous liquid phase of the foam contains in solution about 0.25% by weight thereon of each of the surface active fluorocarbon compounds

$$[C_8F_{17}SO_2NH(CH_2)_3N(CH_3)_3]^+I^-$$

and

$$C_7F_{15}CONH(CH_2)_3\overset{+}{N}(CH_3)_2CH_2CH_2COO^-$$

and the gas to liquid volume ratio of the foam is about 8 to 10.

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THE IMPACT OF THE USS *FORRESTAL'S* 1967 FIRE ON UNITED STATES NAVY SHIPBOARD DAMAGE CONTROL

A thesis presented to the Faculty of the U.S. Army
Command and General Staff College in partial
fulfillment of the requirements for the
degree

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ABSTRACT

THE IMPACT OF THE USS *FORRESTAL'S* 1967 FIRE ON UNITED STATES NAVY SHIPBOARD DAMAGE CONTROL, by LCDR Henry P. Stewart, United States Navy, 112 pages.

This thesis examines the impact of the 1967 flight deck fire on the aircraft carrier USS *Forrestal (*CVA 59*)* and the resulting two investigations, on the development of US Navy damage control doctrine and equipment. The first investigation focused solely on the *Forrestal* fire; the second assessed the safety of aircraft carrier operations throughout the US Navy. Both investigation reports included several proposals to improve shipboard damage control. The thesis found that most of these recommendations were successfully implemented, substantially enhancing shipboard damage control capability over the long term. Successful implementation of these proposals depended on the following: strong support by, long-term involvement of, and resourcing by the Chief of Naval Operations, as well as broad agreement by senior Navy leaders that the proposed changes were necessary based on lessons learned from the two investigations. Training and material deficiencies appeared to be noncontroversial and thus relatively easy to correct; proposals that did not mesh well with Navy culture and existing personnel practices appeared especially controversial and were not successfully implemented.

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ACRONYMS

CASS	Carrier Aircraft Support Study
CCOL	Compartment Check-Off List
COMNAVAIRLANT	Commander, Naval Air Force, US Atlantic Fleet
COMNAVAIRPAC	Commander, Naval Air Force, US Pacific Fleet
CVA	Carrier Vessel Attack
JAGMAN	Manual of the Judge Advocate General
NSTM	Naval Ship's Technical Manual
OBA	Oxygen Breathing Apparatus
OPTAR	Operating Target
PKP	Potassium Bicarbonate
PLAT	Pilot Landing Aid Television
PRSACO	Panel to Review Safety in Aircraft Carrier Operations
SHIPALT	Ship Alteration

CHAPTER 1

INTRODUCTION

One of the most serious disasters in modern naval history began just before 11:00 a.m. on 29 July 1967. On that morning, one of the United States Navy's most modern aircraft carriers, USS *Forrestal* (CVA 59) was operating in waters off the coast of Vietnam.

The Ship

Forrestal was the first of the "supercarriers" of the US Navy. Commissioned in 1955, she was the first US aircraft carrier specifically designed to operate jet aircraft, and was the first carrier the United States built following World War II. Her namesake was James V. Forrestal, a former naval aviator, and our nation's first Secretary of Defense. *Forrestal* was 1,076 feet long, 252 feet wide at her flight deck, and displaced over 79,000 tons. In comparison, the *Essex* class aircraft carriers built during World War Two only displaced 41,000 tons. *Forrestal*'s flight deck had approximately 250,000 square feet of area. Her engineering plant was able to produce 260,000 horsepower and consisted of oil-fired boilers and steam turbines. She had four propellers, and could achieve a top speed of greater than 30 knots (approximately 35 miles per hour). She had 19 separate levels (called "decks" in naval terminology), and over 2,000 separate compartments, or "spaces." A crew of 3,000 men operated the ship, and 2,500 more men operated and maintained the embarked aircraft. *Forrestal* had her own post office, laundry rooms, and ship's store (selling cigarettes, snacks, and personal items for crew members), staterooms for officers, and lounges for the crew. She produced her own electricity and distilled approximately 200,000 gallons of fresh water daily for drinking, washing, and cooking. Many of her interior compartments were air-conditioned. She was a virtual "city at sea."

The Incident

The *Forrestal* had recently arrived in the waters off Vietnam, and had been bombing targets in North Vietnam for the previous four days. *Forrestal* launched and recovered all aircraft from the first strike of the day without incident, and the crew prepared the second strike group's aircraft for launch. Crewmen staged 27 aircraft on the flight deck. The fully armed planes were crowded together on deck as the crew conducted final preflight checks. Each aircraft carried a full load of bombs, rockets, and ammunition, and the fuel tanks of each plane were full. In addition, crew members staged several tons of bombs on the flight deck on wooden pallets.

The *Forrestal* accelerated to nearly 30 knots and turned into the wind as she prepared to launch the second strike of the day (she was generating high relative winds over her flight deck to provide sufficient lift to safely launch her aircraft.) Several of the jets started their engines in preparation for launching. Without warning, a rocket was accidentally fired from one of the F-4 Phantom fighter planes on the deck. The rocket struck a crewmember on deck before striking and ripping open an A-4 Skyhawk staged on the opposite side of the flight deck. The rocket passed through the aircraft without exploding and hit the ocean. However, several hundred gallons of jet fuel poured from the Skyhawk's punctured fuel tank and quickly ignited by particles of burning rocket propellant left on the flight deck. The burning fuel from the stricken jet was pushed aft (back) by the heavy winds across the flight deck. The burning fuel quickly engulfed several other aircraft staged on the flight deck. Within seconds, these aircraft began burning, and the fire continued to spread. The officer of the deck (the officer on watch responsible to the commanding officer for safe operation of the ship) immediately sounded General Quarters. This was a shipwide announcement that the ship was experiencing an emergency. He quickly followed this up with a verbal report over the 1MC (the shipwide general announcing system) notifying the crew of the fire on the flight deck. The *Forrestal's* crew moved toward their assigned "battle stations."

When General Quarters was set, *Forrestal's* crew members fully manned all positions in the ship's damage control organization. The crew also set Material Condition Zebra. This compartmentalized the ship by closing doors and hatches throughout the ship. Many of these hatches were normally open to facilitate crew movement throughout the ship. Closing them would help to limit the flow of smoke, fire, and firefighting water through the ship. The Commanding Officer ordered the ship to stop, to reduce the wind across the flight deck that was fanning the blaze. However, the fire continued to spread quickly.

The heat of the fire exploded a bomb on the flight deck approximately ninety seconds after the fire began, and a second bomb exploded a few seconds later. These explosions severely damaged the carrier and killed several sailors on the flight deck. The fuel tanks of several other planes ruptured, adding to the intensity of the blaze. The exploding bombs created several holes in the flight deck, allowing fire and smoke to spread into the interior of the ship.

Forrestal's crew feverishly battled and eventually extinguished the fire. It took over twenty-four hours to extinguish the fires that spread below the flight deck. The losses caused by this incident were high. One hundred thirty-four sailors were killed by the fire, and 161 more were injured. Over twenty aircraft were lost. The damage forced *Forrestal* to suspend combat operations and conduct temporary repairs in the Philippines before returning to the US for permanent repair. Repairs to the ship cost approximately $72 million, and took approximately two years to complete.

Purpose of This Research

Sailors have feared fires at sea since the days of the earliest ships. Even in modern times, ship's crews had to depend on each other to save their ship (and their own lives) when disaster struck. Every sailor had to be a firefighter as well. Proficiency was important, since fire could quickly spread in the hazardous shipboard environment. It remains vital for the Navy to accurately assess the cause of disasters and apply lessons learned to prevent similar situations from recurring. Failure to do so can result in many lives lost, millions of dollars in damages, and even the loss of a ship.

The purpose of this thesis is to examine how the Navy applied lessons learned from the USS *Forrestal* conflagration on 29 July 1967 to improve fleetwide damage control capability (training, doctrine, installed equipment, and warship design). The primary research question is: Did this fire have significant influence on the US Navy's damage control doctrine and training, shipboard firefighting equipment, and warship construction? Secondary research questions include: If so, what specific changes resulted from this disaster? Were these changes significant and permanent? Does historical evidence show that these changes were effective?

The thesis statement of this research is that the US Navy significantly improved damage control training, damage control equipment, and warship design as a direct result of lessons learned from the fire on USS *Forrestal*.

Methodology

Numerous historical documents were examined to prove the thesis and answer the research questions. The official investigation report of the incident was studied to learn about the damage control organization on *Forrestal* in 1967. This thesis reviewed what damage control equipment was available to *Forrestal's* crew, what survivability features were included in *Forrestal* by designers, and what damage control doctrine existed to guide her crew. The thesis also examined the issue of whether the Navy built damage control improvements into *Forrestal* because of lessons learned from previous disasters or battle damage.

Two official Navy investigation panels were convened as a direct result of the fire on *Forrestal*. This thesis reviewed the recommended changes to improve damage control on US Navy ships submitted by these panels. The following specific areas were examined: What specific changes did the panels recommend? Were they implemented? Were these changes effective? Did shipbuilders apply lessons learned from the *Forrestal* fire to incorporate design changes into future warships? If so, what changes did they make, and how did these changes improve a ship's damage control capability? Did the Navy only apply design changes to ships built after the *Forrestal* fire, or did they make some changes to improve the damage control capability of existing ships?

The thesis examined a similar fire that occurred on the US Navy aircraft carrier *Enterprise* in 1969 (approximately eighteen months after the *Forrestal* fire) to assist in assessing whether lessons learned from the *Forrestal* were significant and enduring.

This thesis answered the following questions. Did the damage control organizations of these ships benefit from lessons learned from *Forrestal's* fire? Did shipbuilders incorporate improved damage control features into these ships? If so, did these changes serve to mitigate the effects of damage?

Limitations

There were numerous limitations to this research. The study focused on the specific lessons learned from the fire on USS *Forrestal* on 29 July 1967, and how these lessons were applied by the US Navy to improve damage control capabilities on its warships in later years. Major themes of interest included examining what damage control doctrinal, shipboard firefighting and damage control systems changed from analysis of this fire. This research also discussed design changes the Navy made to its warships after analyzing this disaster. This study briefly examined incidents that occurred on US Navy warships after the *Forrestal* incident to determine if the US Navy successfully applied these lessons. This research did not study damage control doctrine, equipment, or ship design in foreign navies. The study was limited to the impact that this incident had on damage control on US Navy surface warships. This study relied on official Navy accounts of the fire, reports of official Navy panels convened to review the fire, and Navy damage control doctrine and instructions.

CHAPTER 2

DAMAGE CONTROL DOCTRINE

Firefighting and damage control have been important to the US Navy since the age of sail. This concern remained vitally important in 1967, since naval ships contained large quantities of fuel, oils, weapons, ammunition, paint, and many other hazardous and flammable materials. Other factors also elevated the risk of fire and damage--ships launched and recovered helicopters and other aircraft, frequently maneuvered at high speeds in close proximity to other vessels, and steamed in widely variable weather and sea conditions. The danger to ships from accidental fires and flooding was high whether the ship was operating in home waters or was forward deployed to war zones. Fire or other damage usually struck suddenly, and had to be quickly controlled to prevent extensive damage to the vessel and minimize injuries to her crew. Perhaps the most important aspect of damage control was that any ship sustaining damage often had to rely completely on its own crew to take responsive action. Operational circumstances demanded that naval vessels often operated independently of other ships, and weather could prevent other ships from assisting.

Well-known naval authorities and retired US Navy Captains John V. Noel and Edward L. Beach provide one authoritative definition of damage control. Captain Noel revised *Knight's Modern Seamanship, The Division Officer's Guide*, *The Watch Officer's Guide, Ship Handling*, and coauthored *Naval Terms Dictionary* with Captain Beach. Captain Noel commanded a destroyer, supply vessel, and cruiser during his long career. Captain Beach served as a damage control assistant and chief engineer in submarines, and also commanded several submarines. He wrote several fictional and nonfiction works, and was well known for his novel *Run Silent, Run Deep*. Captains Noel and Beach define damage control as "Measures necessary to preserve and reestablish shipboard watertight integrity, stability, maneuverability and offensive power; to control list and trim; to make rapid repairs of materiel, to limit the spread of and provide adequate protection from fire; to limit the spread of, remove the contamination by, and provide adequate protection from toxic agents; and to provide for care of wounded personnel."[1] Although many of the procedures used to combat damage control changed substantially over time, the basic problems remained constant. The US Navy relied on training (damage control schools, shipboard drills) and doctrine (official publications promulgating techniques and procedures to be used in controlling damage). Doctrine evolved over the years to reflect advances in damage control equipment technology, changes in ship design, and to incorporate lessons learned from earlier incidents.

World War II Damage Control Doctrine

US Navy damage control doctrine in effect during the 1967 *Forrestal* fire evolved from the Navy's World War Two era damage control doctrine. The American Navy's primary shipboard firefighting doctrine during the Second World War was the *Fire-Fighting Manual (Naval Ships Publication 688)*. This 133-page manual was published in 1943 to provide a sound basis for naval firefighting and damage control to the many inexperienced personnel joining the rapidly expanding wartime navy. It described the nature and hazards of the shipboard environment, explained how to use the Navy's shipboard damage control and personnel protective equipment, and detailed the techniques and procedures necessary to fight fires and control damage. Although the *Fire-Fighting Manual* was useful in familiarizing Navy officers and enlisted men with the equipment, techniques, and procedures necessary to combat fires and damage on ships, the Navy also operated seven major shipboard Fire Fighter's Schools on the larger naval bases. The Navy's Bureau of Ships developed and prescribed the course of instruction taught at these schools to standardize the training. Course lengths of one to ten days were available. The full (ten-day) course included instruction on the various types of fires likely to be encountered on ships, training on all Navy damage control equipment (instructor would demonstrate how to use each item, and students would then practice using it), and extinguishment of actual fires and repair of simulated damage in simulated ship compartments. The shorter courses focused on familiarization and practice with shipboard damage control equipment. In 1943, approximately 600 students per month were attending each of the seven Navy Fire Fighter's Schools.[2]

Shortly before the war ended, the Bureau of Ships published a *Handbook of Damage Control* that detailed many of the damage control lessons that had been learned by the Navy during the war years. The first nine pages of this manual were exclusively composed of excerpts from US Navy war damage reports. These excerpts provided examples of a warship's inherent resistance to damage, the importance of maintaining watertight integrity, particularly effective fire prevention measures and firefighting actions taken by the crews of several warships, and the importance of damage control training and personnel protection.[3]

In addition to the *Handbook of Damage Control*, the Navy's Bureau of Ships compiled several reports in the mid-to-late 1940s analyzing the damage incurred on US Navy ships during the Second World War. These reports were based on accounts of shipboard personnel, reports of observers stationed on other ships, and assessments of damage conducted by Bureau of Ships and shipyard personnel when damaged ships returned to port. Each volume in this series of damage reports was dedicated to a particular type of ship, such as destroyers, cruisers, battleships, or aircraft carriers. These reports described the types of damage sustained by each ship, what weapons caused the damage, what structural and hull damage was sustained, how buoyancy and stability were affected and what fires and flooding resulted and analyzed the performance of the crews in controlling the damage. These reports also detail some of the improvements in damage control procedures and equipment developed as a result of wartime experience.[4]

The report on destroyers is particularly illuminating because destroyers were the most numerous type of combatant vessel in the US Navy during the Second World War (377 were in commission in 1945). The *Destroyer War Damage Report* stated that the Navy suffered severe losses due to fires during the first year of the war. The report also stated that firefighting performance improved throughout the war as a result of several factors. First, avoidable fire hazards (excess flammable materials) were removed from Navy ships. Second, ships were given an increased allowance of firefighting equipment. This new equipment tended to be more effective than the old equipment, and was widely dispersed throughout the ship to increase rapid accessibility when needed. Third, damage control lessons learned were reinforced in the Navy's firefighting schools. Finally, the *Destroyer Report* concluded that:

> In general, the firefighting performance of destroyer crews in the latter part of the war, utilizing their improved training and newly developed equipment, was very encouraging. Their record proved that speed in getting water to the fire is all-important and is the mark of effective drilling. One hose stream brought to the scene of the fire within a minute often proved more valuable than several a few minutes later. Drills in immediately running hose and rigging portable pumps

> for use in the damage area and in promptly checking the intactness of the firemain repeatedly proved their value.[5]

Postwar Doctrine Revision

The next major revision of US Navy firefighting doctrine was issued in May 1951, when *Bureau of Ships Manual Chapter Ninety-Three: Fire Fighting – Ship* was published. This new manual replaced the old *Fire-Fighting Manual*, which was last revised in 1944. The new manual reflected more changes in equipment and procedures made as a result of lessons learned from the Second World War. *Chapter Ninety-Three* consisted of 113 pages, broken down into three sections. The first section discussed the firefighting and damage control equipment available to the shipboard firefighter. The second section described how to properly use shipboard personnel protective equipment, and the final section prescribed firefighting techniques and procedures.[6]

The next version of the Navy's firefighting manual, *Naval Ships Technical Manual Chapter 9930: Fire Fighting – Ship* (referred to hereafter as *NSTM 9930*) was issued approximately one month after the *Forrestal* fire, on 1 September 1967. Although it was not in effect during the *Forrestal* fire, it does illustrate the state of development of Navy Damage Control doctrine at the time of the incident (It didn't include any lessons learned from the *Forrestal's* fire, since that incident was still under active investigation). This initial version of *NSTM 9930* contained the same three sections as *Bureau of Ships Chapter 93*, but Section Two (Protective Equipment) was a placeholder, with no information included. The overall document was reduced to ninety-nine pages. The first seventy-three pages were dedicated to the nature of fire and firefighting equipment; the remainder dealt with firefighting techniques and procedures.[7] Significantly, most of the material describing fire, firefighting agents and shipboard firefighting equipment included in *NSTM 9930* was virtually identical to discussions in the older doctrine. Although warships had dramatically increased in size and complexity since World War Two, it seemed that the damage control tools available to sailors had not significantly changed.

It is important to note that the 1967 version of *NSTM 9930* was not designed as a stand-alone reference document for shipboard firefighting. For the first time, the 1967 edition of *NSTM 9930* directed ships to establish and maintain a reference library of damage control publications, and contained a list of forty-six separate publications to be included in this library. This list included a Ship's Damage Control Book (tailored to each type of Navy ship in service), a complete set *of Naval Ship's Technical Manuals* (each volume, or chapter, provided information on a particular aspect of Navy operations), instruction manuals on damage control and personnel protective equipment used aboard naval vessels, and naval regulations and instructions governing damage control.[8] Of course, the usefulness of this reference library depended largely on how effectively each ship's senior damage control experts integrated the material into their damage control training program.

NSTM 9930 stressed the importance of reducing fire hazards to decrease the risk of shipboard fires and to minimize the damage sustained when a fire did occur. It prescribed four basic principles to reduce unnecessary fire hazards: first, proper stowage of combustible materials; second, regular and frequent inspections of shipboard spaces by shipboard leaders; third, training all personnel on the importance of reducing fire hazards; and finally, strict enforcement of fire prevention policies and practices.[9]

NSTM 9930 also placed heavy emphasis on the importance of frequent, realistic training drills to improve the efficiency of a ship's damage control organization:

> Every man in the organization must know where to go, how to get there, what may be needed, and what to do upon arriving at the scene of a fire. It is only by constant drilling that fire-fighting parties can learn to function as teams. Men must be trained to act immediately and use the proper equipment and correct procedure. . . . Drills uncover weaknesses and failures of personnel and material which can be eliminated or recognized as a possible source of danger should an actual fire occur in the area. . . . An effective protection against fires in ships in the quantity and quality of training before a fire starts.[10]

The third section of the 1967 *NSTM 9930, Fire Fighting and Fire Hazards*, was significantly different than earlier doctrine. In the older doctrine, this section discussed the nature of shipboard fires and the effectiveness of extinguishing agents, such as solid-stream water, water fog, foam, carbon dioxide, and others. After this discussion, the doctrine stipulated appropriate techniques and procedures to combat several common types of shipboard fires (such as flight deck fires, engine room fires, and fires in electronic equipment rooms). The 1967 *NSTM 9930* contained this information as well, but it also included an entirely new subsection on the configuration of the ship's damage control organization. It directed each ship to implement tailored "Fire Bills." Fire Bills were published lists that assigned specific duties and responsibility to specific crew members in the event of a fire. Rudimentary fire bills had been in use since the Age of Sail, but the increased size and complexity of modern warships demanded a highly specialized list. Examples of positions on a typical fire bill include nozzlemen (responsible for manning the nozzle end of the hose and attacking the fire), hosemen (who maneuvered the hose to support the nozzleman), plugmen (who opened valves charging the hoses), investigators (who rapidly surveyed the ship to determine the location and extent of damage), and scene leaders (who directed local damage control efforts and reported status of those efforts up the chain of command). Crew members received training to qualify for positions on the fire bill. Sailors were required to qualify for these positions sequentially. For example, a newly reported sailor could quickly qualify as a plugman. As a plugman, this junior sailor would only be responsible for operating a valve feeding a single fire hose. With more experience, the plugman would qualify to serve as a hoseman, then as a nozzleman. A scene leader was required to be proficient in all of these junior positions. Separate Fire Bills were required for periods when the ship was at sea and when the ship was inport. The entire ship's company was available to participate in damage control efforts while the ship was underway, but a much smaller number of personnel were available inport. While the ship was inport, the majority of crew members departed the ship after normal working hours. The ship's company was split into several "duty sections." Each duty section would spend the night aboard to oversee the ship until relieved by the next duty section the following day. These duty sections were comprised of relatively small portions of the overall ship's company, and would only man a single repair locker to respond to emergencies (all repair lockers were manned if required during emergencies at sea). The duty section would frequently be augmented during fires inport (many sailors lived aboard ship), but the fire bill provided supervisory personnel with a formal list of qualified sailors charged with responding to damage occurring during their duty day. The engineer officer (officer in charge of the Engineering Department, and the individual who, by Navy Regulations, was also designated as the damage control officer) was responsible for supervising the Fire Bills and ensuring that assigned personnel were properly trained and qualified for their positions.[11] *NSTM 9930* also provided several examples of typical shipboard damage control organizations, defining required positions and responsibilities of assigned personnel and delineating necessary types and quantities of damage control equipment.

The next chapter examines the survivability features that were included in US Navy warships in general and the *Forrestal* in particular as a result of experience and lessons learned from previous incidents and battle damage. The chapter also describes the damage control equipment and personnel protective gear used by shipboard firefighters in 1967.

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[1] John V. Noel and Edward L. Beach, *Naval Terms Dictionary* (Annapolis, MD: UNITED STATES Naval Institute, 1971), 83.

[2] Navy Department, *Fire-Fighting Manual: NAVSHIPS PUB 688* (Washington, D.C., Bureau of Ships, 1943), 132.

[3] Navy Department, *Handbook of Damage Control: NAVPERS PUB 16191* (Washington, D.C., Bureau of Ships, 1945), 1-9.

[4] Navy Department, *War Damage Report No. 51, Destroyer Report: Gunfire, Bomb, and Kamikaze Damage, Including Losses in Action, 17 October, 1941 to 15 August, 1945* (Washington, D.C., Bureau of Ships, 1947), 1.

[5] *War Damage Report No. 51*, 17-19.

[6] Navy Department, *Bureau of Ships Manual Chapter 93: Fire Fighting – Ship* (Washington, D.C., Bureau of Ships, 1951), 1.

[7] Naval Ship Systems Command, *Naval Ships Technical Manual Chapter 9930: Fire Fighting – Ship* (Washington, D.C., Naval Ship Systems Command, 1967), 1.

[8] Ibid., 1-2.

[9] Ibid., 1.

[10] Ibid., 2-3.

[11] Ibid., 75.

CHAPTER 3

WARSHIP SURVIVABILITY FEATURES AND DAMAGE CONTROL GEAR

Survivability was one of the warship’s primary design considerations. Warships were designed to survive and operate effectively in extremely inhospitable conditions at sea. Heavy seas exerted tremendous stress on a ship’s structure, and were often encountered with little warning. In February 1933, the USS *Ramapo* survived an encounter with a 112 feet high wave in the Pacific Ocean (the highest ever reliably reported, according to Professor Jerome Williams, who published several works on oceanography and originated the oceanography course at the US Naval Academy).[1] Although this is an extreme example, it illustrates the harshness of the marine environment even in the absence of accidental fires or enemy action. All ships that are expected to perform well in these demanding conditions require a high degree of buoyancy and stability. However, naval vessels must be built stoutly enough to sustain damage and remain operational, so they require even greater protection than would normally be expected. The elements of survivability considered by naval architects that designed warships such as the *Forrestal* included compartmentalization, seagoing capability, and improvements based on experience gained during the Second World War.

Compartmentalizaton

Shipbuilders have always been concerned with the hazards of flooding and sinking. Even wooden ships would easily sink if their interior compartments were flooded. This concern intensified as ships were built with steel hulls, and their size increased dramatically. Disasters such as the loss of the *Titanic* emphasized the importance of compartmentalization, or subdividing a ship's structure into numerous watertight compartments.

Warships required an inherent ability to resist damage caused by underwater attack (such as damage from naval mines or torpedoes). Transverse watertight bulkheads (connecting the port and starboard sides of the hull) are effective in containing flooding along the length of a ship's hull after underwater damage is sustained. By the time *Forrestal* was built, all warships contained a series of numerous transverse bulkheads extending from the keel (bottom) of the ship to the main deck (frequently termed the damage control deck). The forward most transverse bulkhead was generally placed several feet abaft (behind) the bow. It was specifically designed to reduce a ship's vulnerability to flooding as a result of collisions, and was termed the collision bulkhead.[2] The exact location of the collision bulkhead varied widely depending on the ship's length. Designers termed the imaginary vertical line extending through the point where the ship's bow met the sea the "forward perpendicular." Similarly, the vertical line extending through the point where the stern touched the water was termed the "after perpendicular." The length between these two imaginary lines was referred to as the "length between perpendiculars," and the collision bulkhead was located at least 5 percent of this length abaft the forward perpendicular. Longitudinal watertight bulkheads ran fore and aft between main transverse bulkheads. Longitudinal bulkheads were often used to protect vital spaces (containing equipment essential to operate the ship) from flooding. Longitudinal bulkheads had to be carefully designed to minimize unsymmetrical spaces in the ship's hull. Unsymmetrical spaces resulted when the compartmentalized spaces on one side of the ship's centerline were not identical in volume to those on the other side. The ship's stability decreased if an unsymmetrical space flooded.

In addition to limiting progressive flooding (the spread of flooding throughout the ship), compartmentalization was useful in limiting the spread of fire and smoke through the ship's interior spaces. The Navy developed several procedures and requirements designed to maximize the effectiveness of compartmentalization. Many compartments had necessary fittings, such as doors, hatches, ventilation ducts, and electrical cables that passed through watertight bulkheads. Regular inspection and maintenance was required to ensure that these fittings did not reduce a ship's watertight integrity. Compartment Check-Off Lists (CCOLs) were developed, listing each of these fittings in every compartment. Regular inspections of items listed on the CCOLs were required, and periodic maintenance was required on items susceptible to wear, such as door gaskets.[3]

The US Navy also developed three major material conditions of readiness for all vessels. Each material condition provided a different degree of tightness and protection. Crew members labeled all fittings (sometimes referred to as closures) to facilitate rapid identification. Condition "X-Ray" allowed the most fittings, such as doors, hatches, and scuttles, to remain open. This increased the convenience and ease with which personnel could transit throughout the ship, but also provided the least degree of protection against the spread of fire, smoke, or flooding. Condition "X-Ray" was normally set inport during normal working hours when the ship was not believed to be at risk from attack. Condition "Yoke" required more fittings to be closed, and consequently provided more protection. Condition "Yoke" was typically set at all times while the ship was at sea and after normal working hours in port. Condition "Zebra" provided the most protection, and required most fittings to be closed. Condition "Zebra" was normally set when the ship expected to enter combat soon (General Quarters was set), or in the event of fire and flooding in the vessel. Condition "Zebra" was not normally set for long periods at sea, since it significantly hampered the movement of crew and material throughout the ship, and reduced crew comfort since most ventilation was secured during Condition "Zebra." Modifications of these three basic conditions, such as "Circle X-Ray, Yoke, and Zebra" permitted certain predesignated closures to be opened by crew members. This allowed crew members to transit through zones, and facilitated moving ammunition and other supplies throughout the ship. "William" fittings were essential to the ship's mobility and fire protection. These fittings were marked with a black "W," and were kept open during all material conditions. Fire pump and other vital pump cutout valves were classified as "William" fittings.[4]

Enhanced Seagoing Capabilities

When she was commissioned in 1955, *Forrestal* was the world's largest aircraft carrier. Her large size greatly enhanced *Forrestal's* seagoing capabilities, since a warship's inherent survivability and seaworthiness tend to increase with the vessel's size. For example, a larger ship generally has more watertight compartments than a smaller ship. Reserve buoyancy, the volume of the watertight portion of the ship above the waterline, is also usually greater for larger ships.[5] As a result, larger ships are inherently able to sustain more damage and remain afloat. Larger ships also enjoy several other characteristics useful in naval vessels. A smaller fraction of the ship's displacement is required for propulsion equipment and fuel storage on larger ships (or a greatly extended range is possible if the same percentage of fuel to ship's displacement is maintained), and larger ships generally are capable of higher speeds in rough seas.[6] Larger ships are also capable of carrying more weapons, equipment, and stores. Naval vessels were limited in size by treaties for much of the interwar period, but began to increase in size in the late 1930s. This trend toward increasing warship size was still continuing when *Forrestal* was built in the early 1950s. The Forrestal displaced 79,000 tons and contained 1,240 watertight compartments; while the Essex Class carriers built during World War Two displaced less than 40,000 tons and contained 750 watertight compartments.[7] The trend toward increasing warship size was not limited to aircraft carriers – many combatant ships in the US Navy were increasing with size during this period. For example, the *Porter* class destroyers of the 1930s displaced approximately 1,850 tons, the *Fletcher* class destroyers of the 1940s displaced over 2,500 tons, and the early 1960s *Charles F. Adams* class of destroyers displaced nearly 3,400 tons.[8]

Survivability Enhancements Based on World War II Experience

Several survivability features recommended by the Navy's World War Two damage reports were incorporated in *Forrestal*. *Forrestal* was built with an armored flight deck, constructed of thick, high-strength steel. World War Two experiences showed that this would decrease the amount of structural damage sustained in interior compartments from explosions or fires on the flight deck.[9]

Forrestal was also equipped with a firemain loop. The firemain loop was designed to correct a serious deficiency observed during the Second World War, when many crews were unable to combat shipboard fires because firemain pressure was lost as a result of damaged piping. In several instances fire pumps continued to run and the ship's stability was reduced by tons of seawater flowing into interior compartments from damaged piping.[10] A firemain loop was a line of saltwater piping that ran continuously around the vessel. The loop also incorporated several runs of piping running athwartships (connecting the firemain piping on the ship’s port side with that on the starboard side). These transverse piping runs were placed near the bow, amidships (near the center of the vessel), and aft. The loop could be charged with several fire pumps, located in numerous compartments throughout the ship. Cutout valves were placed at regular intervals in the piping runs. This arrangement enabled the ship’s crew to isolate damaged portions of the firemain, while still supplying firefighting water where needed. The dispersion of multiple firefighting pumps helped to ensure that adequate firemain pressure could be maintained even if some pumps were damaged or inoperable. If the ship expected to enter combat, several isolation valves would be closed near the transverse piping runs to create several smaller firemain loops. This would ensure firemain pressure to most of the ship in the event of firemain piping damage, and would limit the amount of flooding sustained from broken piping. A diagram of a typical firemain loop is included in Appendix A.

Flight deck and hangar deck sprinkler systems were also installed on *Forrestal* to cool ordnance during fires (to prevent cook-off) and to help prevent the spread of fires in these areas. Several high capacity foam-generating stations were also installed. These stations were capable of generating large amounts of firefighting foam to help smother fires in the hangar deck or on the flight deck. US Navy damage reports from the Second World War indicated that all of these features proved to be effective in limiting damage during actual fires.[11]

Forrestal was also designed to carry aircraft using JP-5 for fuel. JP-5 was much less volatile than the aviation gasoline that had been carried aboard aircraft carriers in World War Two, and was considered to be less hazardous for shipboard use.

As the last several pages have shown, naval warships such as *Forrestal* were designed to sustain damage and survive. However, another significant component of damage control was found in the development of an extensive array of specialized equipment. This equipment ranged from items designed to be operated by individual crew members, to larger systems operated by a team. Some of this equipment was used to control and extinguish fires, combat flooding, and isolate damaged systems. Personnel protective equipment helped reduce the risk to crew members as they fought to control damage in hazardous environments. The next two sections of this chapter will examine the damage control and personnel protective equipment available to *Forrestal's* crew.

Damage Control Equipment

The equipment shipboard firefighters used to extinguish fires depended largely on the class, or type, of fire. Class Alpha fires involved combustible materials such as bedding, books, and clothing. Class Alpha fires left embers, which made these fires highly susceptible to rekindling. Water was the firefighting agent of choice for Class Alpha fires, since it lowered the temperature of the burning items and helped prevent reflashes.

Class Bravo fires involved burning flammable liquids, such as fuel oils, paint, and lubricants. They did not leave embers, and could be effectively extinguished by using firefighting foam to create a barrier between the burning liquid and the air needed for continued combustion.

Class Charlie fires occurred in electrical equipment. Carbon dioxide was the agent of choice for Class Charlie fires for two primary reasons: it would not damage the equipment, and it reduced the hazard of electrical shock for firefighters.

Class Delta fires occurred when metals such as magnesium ignited. NSTM 9930 stated that no effective firefighting agents existed for Class Delta fires. Burning metals were generally jettisoned if possible.[12]

To combat this array of possible conflagrations, shipboard firefighters had an extensive amount of available equipment. The fire main delivered firefighting water to fireplugs and sprinkler systems throughout the ship. Most fireplugs on aircraft carriers had outlets 2 ½ inches in diameter. Some plugs had 1 ½ inch reducing connections installed. These reducing connections would either have a single outlet, or would use a double Y-gate connection with two 1 ½-inch outlets. The fireplugs on *Forrestal* were positioned so that any point on the ship could be reached with a one hundred-foot length of hose from at least two separate locations. One hundred feet of hose was always connected to each fireplug. Specialized wrenches, termed spanners, were placed near each fireplug to connect additional hose sections as needed.

A Navy all-purpose nozzle was attached to the end of each hose connected to the ship's firemain. All-purpose nozzles could deliver either solid streams of firefighting water, or fog. Four, ten, and twelve-foot long applicators could be inserted into the end of an all-purpose nozzle to provide low-velocity fog. Solid streams of firefighting water were effective against Class Alpha fires, while water fog was useful against both Class Alpha and Bravo fires. Water fog was also used to help shield personnel from the heat of shipboard fires, and to cool munitions to prevent cook-off.[13]

Firefighting foam was very useful in fighting Class Bravo fires. In 1967, two basic types of foam were available in the US Navy. One type was termed protein foam since it consisted of a hydrolyzed protein base; the other type was called “Light Water,” and was composed of a mixture of fluorinated surfactants. Both types came in concentrated liquid form, and six parts of concentrate were mixed with ninety-four parts of water to create firefighting foam. The two types of foam were fully compatible, but the Navy planned to gradually phase out the protein foam since it had a limited shelf life. The Light Water concentrate could be stored indefinitely before use.[14]

Naval vessels had several means of generating and delivering firefighting foam. The simplest piece of equipment used was a mechanical-foam nozzle with a pickup tube. A firefighting hose was connected to the nozzle, and the pickup tube was inserted into a five-gallon foam concentrate container. When the hose was charged, water flowing through the nozzle would create suction, drawing the concentrate up into a mixing chamber in the nozzle. The mixing chamber was sized to mix air, water, and foam concentrate together in the proper proportions to create firefighting foam. The mechanical-foam nozzle would empty a five-gallon foam container in about ninety seconds, producing approximately 660 gallons of foam in that time. Additional concentrate cans could be placed nearby if more foam was required.[15]

Larger pieces of equipment, known as proportioners, were used to protect machinery spaces, aircraft hangars, and flight decks. Proportioners used water motors and liquid foam pumps to generate foam. The size of the motors and pumps were designed to maintain the necessary proportion of foam concentrate to water. These proportioners consisted of dedicated firemain piping to supply water, fixed foam concentrate tanks, and supplied foam to hose stations as well as sprinkler heads. Although the larger foam stations could be started remotely, a crew of three or four sailors was assigned to monitor and operate each station. This crew would establish communications with the hose station near the fire, and would replenish the foam tank with additional concentrate as needed. The size of the tank varied by station--smaller proportioners had fifty-gallon liquid concentrate tanks, while the larger stations had 300-gallon tanks. The high-capacity foam stations serving the hangar and flight decks could produce 5,700 gallons per minute of foam at maximum output. The 300-gallon foam concentrate tank would be emptied in just over five minutes at this rate. Sailors would have to continuously empty five-gallon cans of concentrate into the liquid foam tank (at the rate of fifty-seven gallons per minute) to keep each high-capacity foam station operating.[16]

Two common types of portable fire extinguishers were also carried aboard Navy ships. These extinguishers used carbon dioxide or dry chemicals as extinguishing agents, and were placed at frequent intervals along the bulkheads of passageways and in many compartments throughout naval vessels.

Standard navy portable carbon dioxide extinguishers contained fifteen pounds of pressurized agent. They were effective against small Class Alpha, Bravo, or Charlie fires, had an effective range of three to five feet, and lasted forty to forty-five seconds. The carbon dioxide provided very little cooling effect, so larger fires were very susceptible to reflash after being extinguished. However, their small size and ubiquity throughout naval vessels allowed crew members to rapidly deploy them against small fires before the ship's damage control organization could respond with more substantial equipment.[17]

Portable dry chemical extinguishers, known as PKP extinguishers, were also installed in large numbers throughout naval vessels. These extinguishers used a small carbon dioxide charge to expel eighteen pounds of potassium bicarbonate based agent. The dry chemical extinguishers had an effective range of eighteen to twenty feet, and would last from eighteen to twenty seconds. These extinguishers were primarily intended for use against small Class Bravo fires, but could also be used to extinguish Class Charlie fires. The dry chemical agent was approximately four times more effective than an equal weight of carbon dioxide against flammable liquid fires, but left a fouling residue on electrical equipment when used on Class Charlie fires. Like carbon dioxide extinguishers, the dry chemical agent provided very little protection against reflash. It was intended only to extinguish small fires, or to help extinguish larger fires in conjunction with firefighting foam.[18]

The *Forrestal* was also equipped with emergency pumping equipment, intended to augment or temporarily replace damaged portions of the ship's firemain system. The largest of these pumps was the gasoline powered P-250 portable pump. The P-250 weighed over 150 pounds with fuel, and was capable of supplying 250 gallons per minute of firefighting water to either three 1 ½-inch hoses or a single 2 ½ inch hose. The P-250 could also be used to remove 250 gallons per minute of water from compartments. A smaller gasoline powered pump, the "handybilly," was also carried aboard naval vessels. The handybilly weighed 106 pounds and could supply firefighting water to a single 1 ½-inch hose or remove water at the rate of sixty gallons per minute. The handybilly could also be connected to a mechanical-foam nozzle to produce firefighting foam.

Naval vessels were equipped with numerous items designed to remove water from compartments. Portable electric submersible pumps could be dropped into a flooded compartment. A 2 ½-inch hose was connected to the pump discharge and carried water to the nearest available overboard discharge fitting. Overboard discharge fittings were fitted into the hull at frequent intervals to facilitate removal of firefighting and floodwater from internal compartments. They were usually located just above the ship's waterline, and were covered with watertight caps except while in use. These overboard fittings enhanced the efficiency of dewatering pumps by reducing the head pressure on the discharge side. If the discharge line from a portable pump were simply run overboard from the main deck, the higher head pressure would significantly reduce the pumping rate. For example, standard submersible pumps discharged 140 gallons per minute with a discharge head of seventy feet. If the discharge head was reduced to fifty feet, the same pump discharged 200 gallons per minute.[19]

Naval vessels carried an extensive array of eductors to remove water from internal compartments. These eductors varied widely in size and capacity, but all functioned on the same principal firefighting water was supplied to nozzles, or jets in the eductor body. As the water flowed through these jets, a vacuum was created in the eductor body. Water in the flooded compartment would be drawn up a suction line connected to the eductor body by this vacuum, and would mix with the firefighting water. This water mixture would then be discharged overboard. Fixed eductors were permanently installed in compartments and were fitted with permanent firemain supply, suction, and overboard discharge piping. Portable eductors could be carried where needed. They used firefighting hoses to supply water and carry water to overboard discharge connections.

Smaller eductors removed less than one hundred gallons of water per minute; larger eductors had a capacity of well over 1,000 gallons per minute.[20]

Other significant equipment carried aboard naval ships for controlling damage included tools to access locked or damaged compartments, such as bolt cutters, fire axes, and crowbars. Portable oxyacetylene cutting apparatus was used to cut holes in decks and bulkheads and to remove debris. Portable battery operated lanterns were invaluable, as were portable blowers and ducts to remove smoke and toxic gases from internal compartments.[21]

Personnel Protective Equipment

Protective gear was designed to reduce the hazards to crew members as they fought fires and damage aboard naval vessels. The protective gear available to *Forrestal's* crew was essentially identical to that used by US Navy sailors during the Second World War.

Uniforms worn aboard ship were designed to provide some protection against fire. Enlisted crew members wore cotton chambray shirts, dungaree pants, and steel-toed boots. Officers wore cotton khaki colored shirts and trousers and steel toed boots. During fires, crew members would button the top buttons on their shirts and tuck their trouser bottoms into their socks to minimize the amount of exposed flesh. However, the effectiveness of this procedure, which was already marginal, was reduced even more for the many crew members that frequently wore short sleeve shirts during warm weather. Personnel attacking the fire would also don asbestos gloves and helmets with a small attached battery operated lantern, known as a "miner's lamp."

Breathing apparatus was available to protect naval firefighters from hot, toxic gases. The most common type of breathing apparatus used for fighting fires on *Forrestal* was the “Oxygen Breathing Apparatus,” or OBA. The OBA was a self-contained unit for individual firefighters. It consisted of a canister holder, two neoprene breathing bags (one on each side of the canister holder), a facepiece with inhalation and exhalation tubes, a timer, and a breastplate with webbing to attach the unit to the wearer. The firefighter wore the OBA on the front of his body. A fresh canister was inserted into the OBA before use. When activated, chemicals in the canister reacted with moisture from the firefighter’s breath to produce oxygen and absorb carbon dioxide. The breathing bags held and cooled the oxygen. The firefighter manually set a timer to activate an audible alarm several minutes before the canister’s chemicals were exhausted. The firefighter had to return to a clean atmosphere to change canisters. Each canister supplied approximately thirty minutes of oxygen.[22] Tending lines could be connected to the OBA to maintain lifeline signals with personnel remaining in safe atmospheres.

Aluminized asbestos “proximity suits” were carried aboard naval vessels. These protected personnel against high heat, but were not designed for direct contact with flames. Proximity suits were frequently used to rescue personnel, such as aircrew members involved in accidents on the flight deck.[23]

The preceding chapters have described the survivability features incorporated in warships operated by the US Navy in the 1960s, the damage control doctrine developed over the years, and the specialized damage control and personnel protective gear available to sailors. Although the “supercarriers” of the 1960s had dramatically increased in size and complexity compared with aircraft carriers that operated during World War

Two, the damage control tools available to sailors had not significantly changed. The Navy's World War Two damage reports clearly described the massive fuel, ordnance, and aircraft fires that occurred on carriers as a result of mishaps and enemy attacks, and *Forrestal* carried more aircraft, ordnance, and fuel than any aircraft carrier built before her. Unfortunately, her crew members were equipped with virtually the same equipment that their fathers had used to fight shipboard fires over twenty years earlier. This damage control equipment was not faulty or poorly designed; it had simply been rendered obsolete, and was not capable of quickly and effectively extinguishing a massive conflagration on the flight deck. The protective gear available to *Forrestal's* crew was woefully inadequate. Although the OBAs effectively protected firefighter's lungs, the non-fire retardant cotton uniforms worn by sailors provided virtually no protection against burns.

After the 1967 fire on *Forrestal*, the Navy took a hard look at the adequacy of damage control tools available to shipboard firefighters. Two investigations were convened shortly after this fire. The first of these focused solely on the *Forrestal* fire, but the second investigation examined the safety of aircraft carrier operations throughout the US Navy. These investigations developed numerous recommendations to improve shipboard damage control readiness. The next chapter examines the most significant of these proposed improvements.

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[1] Jerome Williams, John J. Higginson, and John D. Rohrbough, *Sea and Air: The Marine Environment*, 2nd ed. (Annapolis, MD: UNITED STATES Naval Institute, 1975), 306-307.

[2] Thomas C. Gillmer, *Modern Ship Design*, 2nd ed. (Annapolis, MD: UNITED STATES Naval Institute, 1986), 88.

[3] G. C. Manning and T. L. Schumaker, *Principles of Warship Construction and Damage Control* (Annapolis, MD: UNITED STATES Naval Institute, 1935), 300-304.

[4] Bureau of Naval Personnel, *Principles of Naval Engineering* (Washington, D.C.: US Navy, 1970), 63-64.

[5] Ibid., 36.

[6] Ibid., 15-16.

[7] Kit Bonner and Carolyn Bonner, *Great Naval Disasters: U.S. Naval Accidents in the 20th Century* (Osceola, WI: MBI Publishing, 1998), 93.

[8] Norman Friedman, *U.S. Destroyers: An Illustrated Design History* (Annapolis, MD: UNITED STATES Naval Institute, 1982), 85, 118.

[9] Navy Department, *War Damage Report No. 56* (Washington, D.C.: US Navy, 1946), 22.

[10] Navy Department, *War Damage Report No. 51* (Washington, D.C.: US Navy, 1947), 18-19.

[11] *War Damage Report No. 56*, 26-29.

[12] Naval Ship Systems Command, *Naval Ships Technical Manual Chapter 9930: Fire Fighting – Ship* (Washington, D.C., Naval Ship Systems Command, 1967), 77-78.

[13] Ibid., 11-18.

[14] Ibid., 7-9.

[15] Ibid., 24-25.

[16] Ibid., 25-35.

[17] Ibid., 39-43.

[18] Ibid., 53.

[19] Ibid., 70.

[20] Ibid., 70-71.

[21] Ibid., 72-75.

[22] US Maritime Administration, *Marine Fire Prevention, Firefighting, and Fire Safety* (Washington, D.C., UNITED STATES Maritime Administration, 1987), 327-336.

[23] Ibid., 366-367.

CHAPTER 4

RECOMMENDATIONS FROM INVESTIGATING PANELS

Soon after the fire aboard USS *Forrestal,* two separate investigation panels were formed. The first of these investigations was required by naval regulations, and was conducted in accordance with instructions contained in the *Manual of the Judge Advocate General*. The purpose of the Judge Advocate General Investigation was to determine what caused the fire, and who was responsible. Rear Admiral Forsyth Massey headed this investigation, and produced a 7,500-page report containing the evidence he reviewed, along with his findings of fact, opinions, and recommendations. Admiral Massey found that serious deficiencies existed in *Forrestal's* damage control related design features. He also stated that the damage control and firefighting equipment carried aboard *Forrestal* was inadequate, and many members of *Forrestal's* damage control organization were poorly trained. His report included thirty-one proposals to correct these deficiencies.

The senior officer in the US Navy ordered the second of these investigation panels to be convened, shortly after Rear Admiral Massey's team began their work. Admiral Thomas Moorer, Chief of Naval Operations, appointed recently retired four-star Admiral James S. Russell as director of this panel. Admiral Russell was a former naval aviator, and had served as the Vice Chief of Naval Operations prior to his retirement. Admiral Russell was directed to examine aircraft carrier operations throughout the Navy, with the goal of assessing safety hazards and proposing ways to improve shipboard damage control effectiveness. Admiral Russell generally concurred with Admiral Massey's recommendations, and included them as proposed improvements in his report as well. However, Admiral Russell's report also included several proposals to improve personnel protective equipment available to shipboard personnel. Admiral Russell wrote that the Navy's available personnel protective gear was poor, and that more effective equipment was needed as soon as it could be developed.

This chapter will examine how these two panels conducted their investigations, the facts they discovered, the opinions they formed based on these facts, and the solutions they proposed to improve the deficiencies they perceived to exist.

The Judge Advocate General Investigation

Following the fire, the *Forrestal* steamed to Naval Air Station Cubi Point, Republic of the Philippines to conduct repairs. Although the scope of required repair work was too extensive to be accomplished at Cubi Point, inspections and basic repairs were made to ensure that *Forrestal* was able to safely return to the United States.

Vice Admiral Charles T. Booth, the US Atlantic Fleet Naval Air Force Commander, immediately ordered a *Manual of the Judge Advocate General* investigation into the *Forrestal* fire. Rear Admiral Forsyth Massey was appointed Senior Member of this Informal Board of Investigation on 30 July 1967. Rear Admiral Massey's primary assistants during the investigation were Captains A.K. Earnest and M.J. Stack. Commander Joseph H. Baum and Lieutenant Commander Edward T. Boywid provided legal counsel for the board. The members of the board arrived at NAS Cubi Point on 3 August 1967. The members began the investigation while temporary repairs were in progress, and remained aboard for the thirty-two-day transit back to *Forrestal's* homeport of Norfolk, VA.

Captain Beling's Immediate Superior in Command (ISIC), Rear Admiral Harvey P. Lanham, Commander of Carrier Division Two (COMCARDIVTWO), ordered his staff to conduct a preliminary investigation on 30 July. *Forrestal* was serving as Rear Admiral Lanham’s flagship, and he and his staff were aboard during the fire. Rear Admiral Lanham’s investigating team, headed by Captain William Morton, presented Rear Admiral Massey and his board with a background brief on the fire upon their arrival. Three members of COMCARDIVTWO’s preliminary investigation team assisted Rear Admiral Massey’s board throughout their investigation. These three officers included Commander Roger Carlquist, Commander Roger Weeks, and Ensign David Jacobs.[1]

The first significant task faced by Rear Admiral Massey’s investigating board was the identification of “parties.” The board members examined the duties and responsibilities inherent in billets of service members assigned to *Forrestal* during the fire. If the board determined that a service member’s duties and responsibilities related to either the initiation of the fire or controlling the resulting damage, that serviceman was designated a party. Twenty personnel were designated as parties, and all were offered legal counsel. Rear Admiral Massey designated these parties shortly after his arrival to allow adequate time to embark desired legal counselors aboard Forrestal prior to the long transit back to Virginia.

After the parties were identified, the Investigating Board began taking statements from parties and witnesses. The board used formal hearing room procedures when taking statements, and all statements were taken under oath. During the investigation, the board read approximately 1,900 statements from 136 parties and witnesses.[2]

The investigating board also spent time touring the damaged areas of the ship and reviewed the Pilot Landing Aid Television (PLAT) camera film carefully. The PLAT camera was used to film all planes as they launched from or landed on the *Forrestal's* flight deck. When the fire began, the PLAT camera was filming a KA-3B aircraft as it prepared to launch. The camera recorded the accidental launch of the Zuni rocket. The PLAT operator then turned the camera and recorded the burning A-4 shortly after the Zuni rocket struck it. The camera's position was not changed again for the duration of the fire. The camera recorded the spread of the fire, the exploding ordnance, and the crew's firefighting efforts. The PLAT camera also recorded the time of these events by filming an integrated clock face. This footage proved invaluable to the investigators.[3]

Rear Admiral Massey submitted his investigation report to the commander of the US Atlantic Fleet Naval Air Force on 19 September 1967. The report consisted of approximately 7,500 pages, divided into thirteen volumes. Volume One contained the board's preliminary statement, findings of fact, opinions, and recommendations. The remaining volumes contained testimony and statements presented by witnesses.

Findings of Fact

The Investigating Board determined that the fire began at 10:52 a.m. local time on 29 July when a Zuni rocket struck A-4 aircraft number 405, puncturing its external 400-gallon fuel tank. A fragment also punctured the external fuel tank of nearby A-4 number 310. The burning fuel quickly spread to the after portion of the flight deck, pushed by thirty-two knots of wind and the exhaust of several jets positioned ahead of the stricken aircraft. General Quarters was sounded at 10:53 a.m., and material condition Zebra was set throughout the ship at 10:59 a.m. However, the crew left some Zebra fittings open to facilitate rapid evacuation of injured personnel.[4] The investigators found many of the high capacity foam and firefighting hoses on the port side of the flight deck were engulfed in flames and unusable. A 1,000-pound bomb fell from A-4 number 405 when it was struck by the rocket, and rolled into a pool of burning jet fuel. The casing of the bomb, which was split by the fall, quickly began to heat up. Fifty-four seconds after the fire began, Chief Petty Officer G.W. Farrier attempted to extinguish the burning pool of fuel around the bomb with a portable PKP dry chemical extinguisher. Approximately one minute and twenty seconds after the fire began; crew members attacked the forward boundary of the fire with firefighting water. One minute and thirty-four seconds into the fire, the first bomb exploded. This explosion killed Chief Farrier and twenty-six other fire fighters in the vicinity, and spread the fire to a group of three A-4 aircraft stationed near the after end of the flight deck. Several other hose teams continued to advance on the fire immediately after this explosion, but a second bomb exploded nine seconds after the first. The second bomb's explosion spread the fire to ten additional aircraft. Seven additional major explosions occurred in the next five minutes, severely hampering firefighting efforts on the flight deck.

Several of these explosions penetrated the armored steel flight deck and spread the fire to the three decks below the flight deck in the aft portion of the ship. The board determined that the burning aircraft contained a total of approximately 40,000 gallons of JP-5 fuel, and that this burning fuel spread the fire to the ship's sides, stern, and through holes in the flight deck into the hangar bay below. These bombs killed fifty night crew personnel who were sleeping in berthing compartments below the after portion of the flight deck. Forty-one additional crew members were killed in internal compartments in the after portion of *Forrestal*. The investigation found that firefighting foam and sprinklers effectively prevented the spread of fire in the hangar bay.

The investigators assessed the crew's firefighting efforts as effective after the nine major explosions subsided. "That once fire boundaries were established there was no further spread of the fire. Thereafter, the fire was fought aft progressively, compartment by compartment, on each deck in textbook fashion until it was finally extinguished. The only secondary damage was that caused by fire fighting water."[5] The flames on the flight deck were extinguished by 11:40 a.m., but fires in the internal compartments were not entirely extinguished until approximately 4:00 a.m. the morning of 30 July.[6] One hundred thirty-four crew members perished, and the fire and explosions injured 161 more. The estimated damage to the ship (not including damage to aircraft) was $72.1 million.[7]

Rear Admiral Massey's Board of Investigation dedicated a section of their findings to damage control and firefighting-related training, procedures, and material condition. First, the report stated that the normal damage control refresher-training period (REFTRA) was shortened from six weeks to four weeks for *Forrestal* prior to her deployment. Second, *Forrestal* received a grade of "unsatisfactory" in setting material condition Zebra during refresher training, but achieved a satisfactory grade during her predeployment Operational Readiness Inspection (ORI). Third, 37 percent of the ship's damage control personnel who attended refresher training transferred prior to *Forrestal's* deployment. At the time of the fire 1,610 crew members (57 percent of the ship's company) had attended firefighting school in the previous three years. Of course, this meant that 43 percent of the ship's company had not attended firefighting school in that time period. *Forrestal* conducted General Quarters drills fifty-seven times in the 106 days that she was at sea prior to the fire.[8]

The report also identified several fundamental training deficiencies that hindered firefighting efforts. The board found that numerous personnel on the flight deck were unfamiliar with firefighting procedures and equipment, and were unable to effectively contribute to firefighting efforts. For example, investigators discovered that at least one firefighting foam station was not initially charged because crew members were unsure how to activate the system. Rear Admiral Massey’s team noted that the physical configuration and activation procedures varied considerably among *Forrestal’s* different foam stations. This lack of standardization could easily prove confusing to sailors who were not thoroughly familiar with the foam generation stations. Another significant hindrance to effective firefighting efforts resulted because many crew members did not report to their assigned general quarters stations (some were unable to because of injuries, some were impeded by the ship’s physical damage, some were already heavily involved in the firefighting efforts, and others simply made no attempt to reach their stations).[9]

The investigation report also noted several problems with Oxygen Breathing Apparatus (OBAs). “Significant numbers” of personnel assigned to Forrestal’s air wing were not trained in using OBAs, some personnel experienced difficulty in activating the oxygen generating canisters in the OBAs, and some canisters did not last for the rated thirty-minute time period.[10]

Opinions and Recommendations

Rear Admiral Massey’s report included 116 opinions based on the facts uncovered during the investigation. Many discussed the need to improve ordnance handling safety procedures, but a substantial number of opinions related to damage control. Although the report acknowledged several shortcomings in the crew’s firefighting performance, it was particularly critical of the damage control equipment available aboard *Forrestal*:

> With existing installed fire fighting equipment, the fire could not have been extinguished prior to the explosion of major ordnance (ninety-four seconds after initiation of the fire) regardless of the aggressiveness, readiness, response and expertise of personnel and readiness of equipment…the design and operating procedures of fire fighting equipment currently available in attack carriers is totally inadequate to the needs generated by modern combat operations and the concentrations of very large quantities of ordnance and fuel on jet aircraft. [11]

The members of the board, based on their investigation into the fire, translated these opinions into sixty-two recommendations. Thirty-one of these recommendations were damage control related, and focused on improving training, damage control equipment, and warship design. To improve the performance of the shipboard damage control organization, the investigators recommended minimizing the transfer of trained personnel prior to a ship's deployment. This recommendation was especially pertinent since 37 percent of Forrestal's trained firefighters transferred from the ship prior to deployment.

Rear Admiral Massey also recommended that aircraft carrier air wing personnel receive increased firefighting and damage control training. Air wing personnel comprised nearly 40 percent of the deployed aircraft carrier's crew. These sailors operated and maintained the aircraft, and did not move aboard the ship until after the ship had completed a great deal of predeployment training. The air wings were not permanently attached to particular ships, and frequently deployed on different classes of aircraft carriers. As a result, the air wing sailors tended to be somewhat unfamiliar with the location and operation of firefighting and damage control equipment peculiar to the ship they were serving on. However, since these sailors primarily worked on and near the flight deck, it was essential for them to have a thorough understanding of firefighting techniques and equipment. The investigators specifically called for increasing instruction for air crew personnel in the following areas: shipboard damage control organization, principles of damage control, shipboard orientation (including traffic flow patterns during emergencies and escape routes, and how to activate and use damage control equipment such as OBAs, firefighting foam stations, the ship's firemain, and sprinkler systems.[12] The investigation report also recommended that all personnel assigned to aircraft carriers (including air wing personnel) achieve basic qualifications in damage control and firefighting prior to embarking their ships.

Rear Admiral Massey's team members also felt shipboard flight deck firefighting training drills were inadequate. They recommended that the Navy develop realistic training exercises based on fires of the magnitude experienced on *Forrestal*, simulating the hazards of live ordnance and the loss of key personnel and equipment.

As stated earlier, the investigating board believed that the fire on *Forrestal's* flight deck could not have been extinguished prior to the ordnance explosions with the equipment available onboard. To correct this unacceptable situation, the panel recommended that the Navy commission a study to examine improvements to increase the effectiveness of shipboard firefighting and damage control equipment. Specifically, the report recommended that this study focus on potential improvements to firefighting foam stations, firefighting nozzles, and fire hose storage.

Recommended improvements to foam stations included standardizing controls to reduce operator confusion. The investigation had discovered that the operating controls varied with the different foam stations located throughout the ship. This lack of standardization was especially confusing for members of the embarked air wing, who were often unfamiliar with a particular ship's equipment idiosyncrasies. The report also recommended increasing the number of remote activation controls for each firefighting foam station to improve response time. Testing completed during the course of the investigation revealed significant delays between activation of the foam stations and delivery of firefighting foam to the flight deck hoses. Investigators tested the performance of ten foam stations without providing advance warning to the *Forrestal's* crew. One station produced foam after seventeen seconds had elapsed, another station failed to develop foam at all, and one station generated foam after four minutes. The remaining seven stations produced firefighting foam thirty to forty-five seconds after they were activated.[13] Since the first bomb exploded on *Forrestal's* flight deck one minute and thirty-four seconds into the conflagration, investigators recommended that the Navy examine the feasibility of modifying the foam stations to reduce the time required to deliver foam to flight deck hoses.

As the *Forrestal's* crew battled fires that had spread into compartments below the flight deck, they were forced to cut small access holes into several bulkheads and decks to insert nozzles and hoses. This technique proved useful in cooling compartments to prevent the spread of fire, and fighting fires where the normal entry points were inaccessible because of damage or high intensity fires. The panel recommended that the Navy develop and issue small omni-directional nozzles, especially designed to spray all areas within a compartment when inserted through a small hole in a bulkhead or deck.

Rear Admiral Massey's investigators discovered that the heavy firefighting hoses used on the flight deck were very susceptible to getting tangled up as they were deployed. If a hose developed a significant kink while being used to fight fire, the flow of water or foam would be interrupted. The sudden loss of agent would render the hose ineffective until the kink was removed, and could easily endanger firefighters if they were in close proximity to a large fire. The report recommended that the Navy study ways of improving hose storage to reduce tangling during hose deployment.

Rear Admiral Massey also proposed significantly increasing the allowance of firefighting foam, OBAs, and OBA canisters carried aboard *Forrestal*. The board opined that the existing allowance of foam and OBA canisters was insufficient for combating serious fires, and believed that *Forrestal's* crew would have been forced to simply contain the fires until they burned out if other ships in the vicinity had not replenished these items. *Forrestal's* existing allowance included 1,220 five-gallon containers of firefighting foam concentrate, 550 OBAs, and 3,300 OBA canisters. The board recommended increasing this allowance to 2,500 containers of foam, 620 OBAs, and 8,000 OBA canisters.[14]

Rear Admiral Massey also recommended that the Navy consider employing armored fire fighting vehicles on the flight decks of aircraft carriers. The report noted that such vehicles would provide carriers with several useful capabilities. They could be used to push burning wreckage (such as damaged planes) over the side, they could closely approach fires while protecting operators from the hazards of ordnance detonation and resulting shrapnel, and supervisors could direct their employment by radios.

Finally, the initial investigation report into the fire on *Forrestal* recommended several modifications to the Navy's carriers to improve survivability and enhance the damage control efforts of crew members. The report noted that approximately 40,000 gallons of fuel from burning aircraft contributed significantly to the intensity of the fire.

The burning fuel also entered interior compartments through bomb holes and other opening in the flight deck, spreading the fire and damage. Rear Admiral Massey recommended that the Navy add large sprinkler systems specifically designed to quickly wash large quantities of fuel off carrier flight decks. He noted that a large system of drains would have to be added as well to accommodate large volumes of fuel and water. These drains would have to be designed to divert fuel and water over the side while minimizing fuel intrusion into interior compartments. The board also recommended extending the length of flight decks over the stern of aircraft carriers to eliminate another potential route for burning fuel to enter the ship. Finally, the board recommended incorporating jettison ramps into the flight deck so that ordnance, flammable materials, and even aircraft could be quickly pushed over the side when necessary.

During the *Forrestal's* fire, ninety-one crew members died in compartments below the flight deck. Some crew members were trapped in compartments because the explosions damaged a single exit. Others died because they were unable to reach the nearest exit before toxic gases and heat overcame them. To reduce similar casualties in the future, the board recommended that the Navy construct alternate escape exits in compartments of all vessels, where possible.

Numerous crew members stated that the shipwide general announcing system, the "1MC," was nearly impossible to hear in the hangar bay during the fire. This announcing circuit was critical, since senior officers frequently used it to provide direction and status updates to the crew during emergencies. Testing by the investigators confirmed that the system was unintelligible throughout much of the hangar bay, so they recommended that this deficiency be corrected.

While Rear Admiral Massey's team was crossing the Atlantic and continuing their investigation, the Chief of Naval Operations, Admiral Thomas Moorer, decided to establish a panel to review the safety on aircraft carriers throughout the Navy. As discussed earlier, Admiral Moorer selected recently retired former Vice Chief of Naval Operations and naval aviator Admiral James S. Russell to head this panel.

The Russell Report

Admiral Russell's panel convened in Washington, D.C. on 15 August 1967, just over two weeks after the *Forrestal's* fire. In addition to Admiral Russell, who served as the Director, the Office of the Chief of Naval Personnel assigned eleven officers and civilians to this Panel to Review Safety in Aircraft Carrier Operations (PRSACO). These panel members were selected based on their professional expertise and experience with aircraft carrier operations and equipment design. The PRSACO members conducted a series of organizational meetings during their first five days together, then split into two groups. The first group was comprised of Admiral Russell, Rear Admiral Buie, Captain McCall, Commander Engel, Commander Charles, and Mr. Bee. This group visited the headquarters of the Pacific Fleet's Commander in Chief and spent a week assessing four aircraft carriers as they conducted combat operations in the Gulf of Tonkin, off Vietnam.

While Admiral Russell's group was conducting its tour, the remaining panel members conducted a review of available literature on the topic. When Admiral Russell returned from his tour, the entire panel reconvened in San Diego, California. The panel then conducted conferences with personnel serving on the staff of the Commander, Naval Air Forces Pacific (COMNAVAIRPAC) and the Pacific Training Command (COMTRAPAC). After these conferences, the panel members returned to the Pentagon for a series of briefings and discussions. Top Navy leaders considered the briefings presented to Admiral Russell's panel important. The Naval Material Command, the Bureau of Naval Personnel, and the Office of the Chief of Naval Operations produced the majority of briefings. The Chief of Naval Operations wrote letters to the Chiefs of Naval Material and Personnel requesting briefings on subjects of interest to the panel. He also wrote internal memorandums directing his staff to provide desired briefings for Admiral Russell's panel. The members of the panel received seventy-six separate briefings. A short description of each of these briefings was included in the panel's report. During their review of carrier operations safety, PRSACO members studied a bibliography of eighty-one pertinent books, articles, and reports. Items in this bibliography discussed ordnance safety, personnel issues such as training, organization, and personal protective equipment; damage control doctrine, World War Two battle damage reports, reports of fires on aircraft carriers after the Second World War, and other ship systems. A brief synopsis of each item in the bibliography was included in Admiral Russell's report. The *Russell Report* (as Admiral Russell's *Report of the Panel to Review Safety in Carrier Operations* was frequently referred to in Navy memorandums) included a list of forty-six interviews that panel members conducted. This extensive series of interviews included discussion with the Navy's top leaders and carrier aviation experts, including the Secretary of the Navy and thirty-nine separate flag officers (admirals). Panel members interviewed several of these senior leaders on more than one occasion. Most of them had extensive experience with aircraft carrier operations, and several were former commanding officers of carriers. The positions of these senior leaders were diverse -- some were responsible for training, many supervised technical research and ship construction programs, and others commanded operational units. The panel members interviewed Rear Admiral Massey to discuss insights he gained while investigating *Forrestal's* fire. They also interviewed the former Commanding Officer of *Forrestal*, Captain John Beling, and *Forrestal's* Chief Engineer, Commander Merv Roland. Finally, the panel visited *Forrestal* while it was docked in Norfolk, Virginia to examine the damage caused by the fire.

Admiral Russell's team completed their *Report of the Panel to Review Safety in Carrier Operations* on 16 October 1967. In the abstract, Admiral Russell stated that his review identified several serious deficiencies:

> Deficiencies were identified, however, that, though largely beyond the ability of the ships to correct, do affect the ability of CVAs (aircraft carriers) to carry out their assigned combat missions with a reasonable degree of safety to themselves. The most serious of these deficiencies are inadequate fire protection for the flight deck and to a lesser extent the hangar deck. . .personal equipment for fighting fires and for individual survival,…inadequate individual and team training.[15]

Admiral Russell provided eighty-six recommendations to improve aircraft carrier safety in his report. Many of these recommendations, as in Rear Admiral Massey's report, were focused on improving damage control training, increasing the capability of shipboard firefighting and other damage control equipment, and modifying warship design to further enhance survivability. However, it is important to note that Admiral Russell's panel had a much broader point of view than Rear Admiral Massey's team. Rear Admiral Massey was appointed to determine what caused the fire on *Forrestal*. His recommendations were based on facts discovered during his investigation and opinions that he formed after closely studying that single incident. Rear Admiral Massey had at least some incentive to moderate his recommendations – any harsh criticism of the performance of *Forrestal's* crew members would be damaging to the careers of officers serving on *Forrestal* (Rear Admiral Massey specifically stated in his report that he did not recommend placing blame on any *Forrestal* crew members for the conflagration). On the other hand, the highest ranking officer in the United States Navy, Admiral Moorer, appointed Admiral Russell to undertake a comprehensive study of how safely all American aircraft carriers were being operated. Although his project was important to the Navy, Admiral Russell was not as constrained by the need to quickly complete an investigation before eyewitness accounts of a single disaster deteriorated. Admiral Russell's panel visited five aircraft carriers to gain firsthand knowledge of how they were operated. The Navy's leading experts on firefighting and damage control, warship design and construction, and procurement briefed the PRSACO members. They were granted virtually unlimited access to interview Navy uniformed personnel and Department of the Navy civilians to capitalize on their tremendous experience and gain insight from their opinions. A final significant factor was that Admiral Russell's panel was well designed to assure a thorough, honest look at existing flaws in aircraft carrier operations safety. Admiral Moorer's decision to appoint a retired officer avoided the possible negative career implications an active-duty officer might face if he chose to advocate politically unpopular recommendations. Each panel member was allowed and encouraged to present possible recommendations to be considered for inclusion in the final report. However, only Admiral Russell had authority to approve what recommendations were included in his report. This enabled panel members to present honest and critical recommendations without concern for their own careers. Additionally, the presence of a retired four-star admiral on the panel (with obvious strong support from the Chief of Naval Operations) helped ensure that the panel would receive a high degree of cooperation from the busy officials they chose to interview.

Each of the eighty-six recommendations proposed by Admiral Russell was accompanied by an explanation of why they were considered important by the panel. The panel used information gathered from the sources mentioned earlier to justify their recommendations. Admiral Russell included proposals to assign cognizance for each of his recommendations to a specific naval command. For example, he proposed that the Naval Material Command be assigned responsibility for improving fire hoses used aboard ships. Three days after Admiral Russell submitted his report, the Chief of Naval Operations forwarded the report to an extensive distribution list of naval commands.

Admiral Russell’s panel grouped their recommendations into nine separate categories--ship’s material, personal equipment, aircraft systems, weapons, training, documentation, personnel, organization, and operations. This thesis will not examine those recommendations related to aircraft systems, weapons, or documentation (since the recommendations in this category related to ordnance safety publications). The recommendations in the remaining six categories that pertain to damage control improvement will be examined.

Recommendations to Improve Warship Survivability Features

In his most significant recommendation for improving ship’s material, Admiral Russell proposed developing advanced flight deck fire fighting systems for carriers. Many of the elements of this proposed system were initially included in Rear Admiral Massey’s report, such as remote control, rapid response time, and massive firefighting agent delivery capability. This *Russell Report* recommendation also incorporated another consequential proposal from Rear Admiral Massey's initial report--that it was important to incorporate means for quickly draining large quantities of spilled fuel from flight decks into this advanced fire fighting system.[16] Admiral Russell provided strong supporting rationale for including this recommendation in his report:

> Development of an advanced flight deck fire fighting system is of prime importance. Principal attention in aircraft carrier fire fighting has been focused in the past on the hangar deck. Adoption of the steel ballistic deck in *Midway* Class and later carriers, and the trend toward elimination of aviation gasoline, tended to support the belief that control of fire on the flight deck was not a serious problem. The *Forrestal* incident proved that it is. Modern carrier aircraft are capable of carrying large quantities of fuel and weapons. The strike group on *Forrestal* was estimated to be loaded with approximately 40,000 gallons of JP-5 (jet fuel) when the accident occurred. Modern aircraft and weapons complexities combine with environmental conditions on a flight deck to provide an ever-present possible source of ignition. Presently installed equipment is not capable of handling a conflagration of the magnitude of that which developed on *Forrestal*.[17]

Admiral Russell provided three pages of justification detailing why he considered it vitally important to develop an advanced firefighting system for carrier flight decks. He concurred with Rear Admiral Massey's assessment that existing flight deck fire fighting equipment was simply inadequate, and proposed that the Naval Material Command immediately begin research and development on an improved system.

The *Russell Report* recommended that the Naval Material Command develop a standardized system for marking and illuminating emergency escape routes from interior compartments. The report noted that personnel experienced difficulty in escaping from smoke-filled compartments in many previous shipboard fires, including the one on *Forrestal*. PRSACO members believed two critical factors increased the difficulty crew members experienced when attempting to evacuate dark, smoke filled compartments during emergencies: aircraft carriers were extremely large, and many crew members were not familiar with all sections of their ships. During their visit to four deployed carriers, panel members observed various markings designed to help personnel evacuate compartments during emergencies; they also noted that some carriers had no markings at all. The panel recommended that the Naval Material Command investigate which colors and types of paint and lights were most effective in helping personnel evacuate shipboard compartments, and then develop an effective, standardized system to mark evacuation routes.[18] The PRSACO members proposed implementing a closely related recommendation originally made by Rear Admiral Massey, increasing the number of exits from compartments. They noted that US Navy ship design specifications required two exits from all stations normally manned by ten or more crew members. However, this requirement did not apply to berthing compartments or workshops. Admiral Russell's team proposed extending this requirement to include all berthing compartments and working areas that were sometimes occupied by ten or more crew members. They recommended that all new ships be constructed to this standard, and that existing ships be altered to meet this new requirement where feasible.[19]

Admiral Russell also concurred with the assessment of *Forrestal* fire investigators that the general announcing system was difficult to hear and understand in some locations on aircraft carriers. The investigation into *Forrestal's* fire determined that personnel in the hangar deck directly below the flight deck had difficulty hearing and understanding the ship's general announcing system, or "1 MC." Admiral Russell's report noted that this problem was not confined to *Forrestal*:

> The complaint concerning the inadequacy of the 1 MC General Announcing System is universally supported by Yankee Station CVAs visited by the Panel. There are many working and living areas where the 1 MC simply cannot be heard. . . . A space-by-space survey should be conducted on each ship in order to determine what must be done to provide a system that will be adequate

> for passing important information or orders during an emergency. It is equally important to insure that the General and Chemical Alarms may be heard in every normally inhabited space throughout the ship and that the inhabitants of these spaces may also communicate the existence of a fire or other emergency in the space to the bridge. In short, command cannot function properly without adequate command and control communications.[20]

Remembering that fifty crew members died while sleeping in their berthing compartments after the General Alarm had been sounded over *Forrestal's* 1 MC system, it is hard to overemphasize the importance of this recommendation. Admiral Russell proposed that the Naval Material Command should conduct surveys on all US Navy aircraft carriers to discover and correct instances where 1 MC speakers were inaudible or unintelligible in inhabited compartments.

Admiral Russell recommended that the Naval Material Command review all pending repair requests for the Navy's carriers. He proposed that all items affecting fire fighting or damage control should be considered critical to the safety of these ships, and should be given high priority during each ship's maintenance periods. His included rationale noted that there is always limitations on how many items can be repaired or upgraded during any given maintenance period, and there is heavy competition about which items are given priority. Damage control improvements and repairs competed with areas such as propulsion machinery and command and control equipment. Admiral Russell stated that damage control items often lost out in this competition for limited resources:

> This fact, combined with Navy-wide apathy toward damage control over the past years, has resulted in the low state of material readiness in this important area.[21]

Admiral Russell cited excerpts from Inspector General assessments of five aircraft carriers conducted in May and June 1967 to support his harsh comment:

> Fire fighting equipment in 3 of the 5 carriers inspected was in satisfactory or better condition. An examination of watertight inspection records and watertight boundaries revealed: watertight inspections were logged in 4 of 5 carriers; watertight boundaries were unsatisfactory in all 5 ships.[22]

PRSACO members believed that placing damage control repair requests in the "safety to ship" category would highlight their importance to senior officials, and help ensure that they received a higher priority in future maintenance periods.

The final significant recommendation by Admiral Russell's panel related to ship's material proposed establishing an exploratory program to study means of improving survivability of ships. To bolster this recommendation, the report stated that the Navy had great need for such a program: "As an example of the need, present-day shipboard fire fighting and damage control are essentially based on means available in World War Two."[23]

The panel theorized that this program could incorporate computer simulations to model damage that could occur from both accidents and enemy action, and that computers could also be used to evaluate the effectiveness of proposals designed to increase warship survivability.

Recommendations to Improve Personal Protective and Damage Control Equipment

The need for improved personal protective equipment was the one area where Admiral Russell's report made significant recommendations not originally proposed by Rear Admiral Massey's team. The PRSACO members, based on their broader view, realized that shipboard emergency personal protective equipment was woefully inadequate. As Admiral Russell stated in the conclusion to his report:

> Of great importance in the handling of emergencies resulting from fire and explosion on a carrier is the personal equipment available for use in combating

> the situation and in individual survival in a smoke/fire environment. Not much improvement has been made in these equipments since World War II. Major improvements are required and, with the advanced technology now available, these improvements should not be too difficult.[24]

Perhaps the most important personal protective equipment recommendation submitted by PRSACO members was the need for a more effective escape-breathing device. At the time of the *Forrestal's* fire, crew members often wore gas masks as they attempted to escape smoke-filled compartments during shipboard fires. These gas masks, primarily intended to protect crew members against attacks from chemical weapons, also provided some protection against hot smoky environments--they filtered solid particulate matter from the air, reduced the temperature of the air slightly, and served as a heat shield for the wearer's face. However, they provided no protection against toxic gases such as carbon monoxide, and were worthless to the wearer if a compartment's oxygen level was depleted by fire. The Navy's *World War II Damage Reports* found that the gas masks were often useful to personnel evacuating smoke-filled interior compartments: "On the basis of the service experience it is apparent that Navy Service Gas Masks are reasonably effective against smoke. Personnel must be thoroughly acquainted with their limitations, however."[25]

Admiral Russell concurred with this assessment, and recommended that the Naval Material Command distribute information throughout the Navy explaining the capabilities and limitations of the gas mask when used as an escape breathing device. He also stated that gas masks had been issued to the crew of only one of the carriers he observed off the coast of Vietnam. The gas masks of the remaining three carriers were stowed in storerooms, inaccessible to their crews in the event of sudden emergencies.[26]

Although he agreed with the twenty year old *World War II Damage Reports* that gas masks provided useful protection to personnel evacuating smoke-filled compartments, Admiral Russell felt that a more effective device was needed. He noted that personal emergency air masks were available to US Navy submarine sailors, and proposed that the Naval Material Command modify gas masks by adding small portable air cylinders. These cylinders would supply gas mask wearers with clean air for several minutes and increase their chances of escaping from compartments filled with toxic gases.

Admiral Russell also proposed that the Naval Material Command establish a program to improve the OBAs used by shipboard firefighters. His report stated that the OBAs were excellent tools, but noted that several deficiencies had been discovered during fires on naval vessels. Rear Admiral Massey's investigators discovered that many of the OBA canisters used to combat *Forrestal's* fire did not last the rated thirty minutes. *Forrestal* fire investigators also believed that many parts of the OBA were susceptible to deterioration over time, and were subject to breakage as a result of rough handling. The investigation team that studied a major fire on the carrier USS *Oriskany* had reached similar conclusions in 1966. PRSACO members suggested that research could result in OBA canisters with longer lives, and that design improvements could produce smaller, simpler, and more rugged OBAs.[27]

Finally, Admiral Russell proposed improving the clothing worn by personnel responding to fires on flight decks. He recommended upgrading the proximity suit used by sailors to rescue personnel from burning aircraft by improving its resistance to wear and tear, making it more flexible, and increasing its ability to reflect heat. He noted that several research reports confirmed that vastly improved aluminized fabrics were available and could be used to improve proximity suits.[28] He also noted that the jerseys worn by personnel working on the flight deck were not flame retardant, and their shoes were soft-toed and had poor treads on their soles. The *Russell Report* cited research demonstrating that it was feasible to treat clothing to make it flame retardant, and proposed that the Navy issue flame retardant clothing and improved footwear to shipboard sailors.

The *Forrestal* fire investigation team originally proposed many of the improvements to shipboard damage control equipment Admiral Russell recommended. For example, building on a recommendation made by Rear Admiral Massey, the *Russell Report* proposed improving shipboard fire hoses. The *Forrestal* investigators discovered that the cotton-jacketed hoses used throughout the ship were very susceptible to becoming tangled. PRSACO members confirmed this during their visits to four operational carriers, and also noted that the cotton-jacketed hoses were quickly worn out by being dragged across abrasive decks during training drills. The *Russell Report* described a project where improved hoses were being tested aboard another carrier, US*S America*. *America* had tested 235 lengths of neoprene-wrapped hose, and found that these new hoses did not tangle up and were significantly more wear-resistant than the cotton-jacketed hoses. Admiral Russell recommended that all aircraft carriers be equipped with neoprene-wrapped hoses in their hangar and flight decks. He also recommended that the Naval Material Command develop quick-disconnect couplings for these hoses to facilitate rapidly adding sections of hoses when needed.[29]

In a similar vein to his recommendation that repairs to damage control equipment be given a high priority in the competition for limited resources, Admiral Russell proposed that a portion of each ship's operating funds be allocated solely for the purchase of damage control and firefighting equipment. His supporting rationale clearly illustrated the many items that competed for funding priority and provided strong justification for why he considered this recommendation important:

> Operating funds are allocated to individual ships in the form of and Operating Target (OPTAR) by the type commander. Normal practice is for the ships to further sub-allocate amounts to each department. Out of each OPTAR must be obligated funds for such things as spare parts, consumables such as paper and soap, maintenance items such as wire and sheet metal, habitability items such as paint and deck tile, and replacement of equipage such as worn out fire hose and lost battle lanterns. The amount of the OPTAR is never enough to cover all of a ship's operating needs. Normal practice is to establish a priority list and fund down the list to the point where money runs out. In this system, the completeness of the inventory and the good material condition of damage control equipment must compete with all other consumables, spares, and equipage replacement, for funds. The tendency has been in the recent past, to place damage control gear low on the priority list. This has meant that inventories and material condition of damage control equipment were generally poor.[30]

In addition to establishing a separate pool of money for damage control equipment, the *Report of the Panel to Review Safety in Carrier Operations* recommended the Naval Material Command conduct further analysis of shipboard fires to determine a more appropriate allowance of OBAs and their canisters, fire fighting foam, fire extinguishers, and hoses. The report noted that both *World War II Damage Reports* and more recent investigations following major shipboard fires recommended significantly increasing the number of OBAs and OBA canisters.[31]

Recommendations to Increase Damage Control Awareness and Training

The remaining recommendations made by Admiral Russell's panel emphasized the urgent need to improve the level of damage control awareness and training throughout the fleet. The foremost recommendation Admiral Russell proposed to alleviate this situation was for the Chief of Naval Operations to ensure that air wing personnel received damage control training prior to deploying with an aircraft carrier. His report noted that sailors in the air wing comprised approximately 40 percent of the personnel on deployed carriers, and that an even higher percentage of air wing sailors were involved in fire fighting efforts on the *Forrestal* because most of them worked in the vicinity of the flight deck. However, his report was highly critical of the effectiveness of these sailors during the conflagration:

> Many of these air wing personnel, despite their courageous acts and strong desire to help, were ineffective and in some cases a hindrance to the fire fighting effort. These men had received no formal training in fire fighting or the principles of damage control. During a carrier's refresher training period, which is primarily devoted to ships damage control training, the air wing is not aboard, and no substitute damage control training is provided.[32]

Admiral Russell observed that requirements did exist for these sailors to receive damage control training. However, he found that the requirements were not being met for a variety of reasons, such as insufficient school capacity, high personnel turnover rates, lack of realistic training aids, insufficient attention by commanding officers, and insufficient requirements for ships to conduct periodic drills. His report included several proposals designed to alleviate these shortfalls.

Based on briefings he received from the Commanders of the Atlantic and Pacific Naval Air Forces and the Commanders of the Atlantic and Pacific Training Commands, Admiral Russell recommended increasing the throughput capability of damage control training schools by adding more instructor billets. He also proposed sending damage control training teams to assist deployed ships. The briefings presented to Admiral Russell indicated that vastly increased student throughput was required to meet existing training requirements. Officials estimated that school capacity was only sufficient to meet approximately 60 percent of the training requirements for the Pacific Fleet, and approximately 32 percent of the Atlantic Fleet's training requirements.[33] However, even this meager capability was severely underutilized, as the *Russell Report* clearly shows:

> COMNAVAIRPAC requires that the executive officer, and all repair party personnel attend a five-day fire-fighting course and all other personnel, including the Air Wing attend the two-day course…During FY '67 only 226 Air Wing personnel were trained. COMNAVAIRLANT requires that all repair party and in-port firefighting party members attend the five-day fire-fighting course, all air department personnel attend a three-day course, and half the ship's company attend a two-day fire-fighting course. In FY '67, no air-group personnel attended basic or refresher fire-fighting courses.[34]

The impact of these depressing macrolevel statistics were evident in the investigation reports of shipboard fires, which concurred that a dire need for increased damage control training existed:

> About 25 percent of the *USS Oriskany* crew and apparently none of the Air Wing personnel had received fire-fighting training prior to the October 1966 fire. Only 150 personnel were trained in the use of the OBA. On *USS Forrestal* about 50 percent of the crew and none of the Air Wing personnel had fire-fighting training prior to the fire. Both reports of these incidents recommended full-crew training in fire-fighting.[35]

To increase the awareness of the importance of damage control training on aircraft carriers, Admiral Russell's report recommended incorporating damage control training into the precommand training pipeline given to aircraft carrier commanding officers. His report noted that commanding officers of carriers were aviators with little or no prior damage control training or experience, and speculated that this could result in decreased command emphasis on the importance of damage control:

> This lack of experience in damage control on the part of the commanding officer is most critically reflected in a generally low level of command interest in damage control matters, and a failure to appreciate the importance of damage control training. Regardless of the enthusiasm and ability of the DCA (Damage Control Assistant), ship-controlling drills in damage control are not going to be included in an already-too-full schedule, unless the commanding officer recognizes the importance of damage control and the necessity for continued damage control training.[36]

Admiral Russell recommended that the training provided to future carrier commanding officers should include instruction on the principles of damage control, review of significant previous shipboard fires and battle damage, and participation in fire fighting and damage control training exercises. His report also proposed that newly enlisted personnel receive damage control training prior to reporting aboard, and recommended that officer-commissioning programs increase their emphasis on damage control training. His report stated that a decision had been recently made to eliminate the sole course on damage control principles included in the Naval Academy's curriculum, and he strongly advised reversing that decision.[37]

Finally, the *Russell Report* recommended that the Naval Material Command create improved damage control training aids for shipboard personnel. He proposed incorporating the PLAT camera footage into a training film to give shipboard firefighters a sense of the magnitude of fires they could encounter. He also proposed developing reusable training canisters for OBAs, so that ships could conduct OBA familiarization training without decreasing the amount of canisters available during actual fires.

As the preceding chapter illustrated, Admiral Russell's *Report of the Panel to Review Safety in Carrier Operations* proposed a plethora of possible means to improve damage control and firefighting capability on US Navy ships. Many of his suggestions incorporated recommendations originally included in Rear Admiral Forsyth Massey's investigation into the *Forrestal's* fire. The next chapter examines how the Navy implemented these important recommendations.

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[1] Department of the Navy, *Manual of the Judge Advocate General Basic Final Investigative Report Concerning the Fire on Board the USS Forrestal (CVA-59) on July*

29, 1967. (Washington, D.C.: US Navy Office of the Judge Advocate General, 1968), 1-2.

[2] Ibid., 6.

[3] Ibid., 34.

[4] Ibid., 35.

[5] Ibid., 38.

[6] Ibid.

[7] Ibid., 33.

[8] Ibid., 77.

[9] Ibid., 81.

[10] Ibid., 83.

[11] Ibid., 112.

[12] Ibid., 129.

[13] Ibid., 82.

[14] Ibid., 126.

[15] Admiral James S. Russell, *Report of the Panel to Review Safety in Carrier Operations* (Washington, D.C.: Office of the Chief of Naval Operations, 1967), I-1.

[16] Ibid., A-1.

[17] Ibid., A-1.

[18] Ibid., A-12.

[19] Ibid., A-36.

[20] Ibid., A-15.

[21] Ibid., A-17.

[22] Ibid., A-18.

[23] Ibid., A-47.

[24] Ibid., V-1-V-2.

[25] Ibid., A-50.

[26] Ibid.

[27] Ibid., A-57.

[28] Ibid., A-58.

[29] Ibid., A-16.

[30] Ibid., A-33.

[31] Ibid., A-32.

[32] Ibid., A-73.

[33] Ibid., A-74--A-75.

[34] Ibid., A-74.

[35] Ibid., A-75.

[36] Ibid., A-76.

[37] Ibid., A-80.

CHAPTER 5

IMPLEMENTATION OF REPORT RECOMMENDATIONS

As the previous chapter discussed, two significant investigation panels convened shortly after the July 1967 fire aboard USS *Forrestal*. Both of the reports produced by these panels included numerous proposals to improve the effectiveness of damage control efforts on US Navy ships. However, Admiral Russell's broader investigation into the safety of carrier operations throughout the Navy appears to have had greater impact on damage control improvements in the US Navy. This chapter examines how the Navy implemented these recommendations included in the *Basic Final Investigative Report Concerning the Fire on Board the USS Forrestal* and the *Report of the Panel to Review Safety in Carrier Operations*.

Implementation of *Forrestal Fire Investigative Report's* Recommendations

The first of these panels, headed by Rear Admiral Forsyth Massey, conducted an investigation into the fire following the Navy's *Manual of the Judge Advocate General*. This type of investigation was commonly referred to as a "JAGMAN" investigation within the Navy. The primary purpose of a JAGMAN investigation was to determine the causes of an accident, and who should be held responsible for the resulting damage. Rear Admiral Massey did this, but he also provided thirty-one recommendations aimed at improving damage control deficiencies he observed during his investigation. The preceding chapter discussed fourteen of the most significant recommendations proposed by this investigation. Rear Admiral Massey completed his investigative report on 19 September 1967, and submitted it to Vice Admiral Charles T. Booth, Commander of the US Atlantic Fleet Naval Air Force, for review. Vice Admiral Booth approved the vast majority of recommendations proposed by Rear Admiral Massey, dissenting with only two of the damage control related proposals. The first of these two not approved recommendations had proposed minimizing the transfer of trained personnel prior to a ship's deployment. To justify their proposal, the investigation team noted that 37 percent of *Forrestal's* trained firefighters transferred prior to her deployment, and opined that these transfers had a significant negative impact on *Forrestal's* overall damage control readiness.[1] Vice Admiral Booth's endorsement letter on the investigation stated that high personnel turnover rates were common throughout the fleet because relatively few sailors assigned to aircraft carriers were re-enlisting after the expiration of their terms of required service. He further emphasized his point by stating that:

> These (fleet manpower) resources are not adequate to the task of stabilizing ship and squadron personnel from commencement of refresher training to completion of deployment. Indeed, when two or three aircraft carriers are scheduled to deploy in a two or three month time frame, fleet manpower resources are hard put to provide even the minimum manpower requirements.[2]

In short, although he had no objection to the concept of stabilizing manning on aircraft carriers, Vice Admiral Booth did not believe the Navy had sufficient manpower available to make this idea feasible.

Vice Admiral Booth also decided against immediately increasing the allowance of OBAs, OBA canisters, and firefighting foam concentrate carried aboard aircraft carriers. Rear Admiral Massey's team had proposed increasing the allowance of foam concentrate from 1,220 five-gallon cans to 2,500; increasing the number of OBAs from 550 to 620; and increasing the number of OBA canisters from 3,300 to 8,000. His report noted that *Forrestal* received substantial quantities of these items from other US Navy ships in her vicinity during her fire, and stated that he believed it would have taken significantly more time to extinguish the blaze without those supplements.[3] Admiral Booth did not completely discount this proposal, but he decided that detailed analysis was required prior to increasing allowance of these items. His letter stated that this analysis would have to include the increased cost of constructing stowage facilities for these items. Admiral Booth recommended delaying implementation of this recommendation even if higher authority decided to increase the allowance of these items until additional dedicated funds could be budgeted for these items.[4]

In his two-page long endorsing letter, Vice Admiral Booth praised the thoroughness of the report and the worth of recommendations presented by the investigating board. He noted that since the report contained so much important information, he was forwarding complete copies to the Commander in Chief of the Pacific Fleet, the Commander of Naval Air Forces in the Pacific, and the Seventh Fleet commander (under whose control carriers operated while prosecuting the war in Vietnam). He also forwarded excerpts of the report containing the investigation board's findings of fact, opinions, and recommendations to all Carrier Division commanders in the Atlantic Fleet. Vice Admiral Booth completed his review of the report on 26 September 1967 and forwarded it to his boss, Admiral Ephraim P. Holmes, Commander in Chief of the US Atlantic Fleet.

In contrast to Vice Admiral Booth's quick review of the report, which only lasted one week, Admiral Holmes took approximately two months to analyze the contents of Rear Admiral Massey's report. Admiral Holmes did not complete his endorsing letter until 1 December 1967. Admiral Holmes's eight-page endorsing letter was much more critical of the investigative report than that of Vice Admiral Booth. Admiral Holmes disagreed with the investigation board's assessment that the fire and resulting deaths and destruction were not the fault of any of Forrestal's crew members:

> The Commander in Chief U.S. Atlantic Fleet, therefore, specifically does not concur in Opinion 115 of the *Report of Investigation* wherein it is stated "That the deaths and injuries resulting from the fire aboard the *Forrestal* on 29 July 1967 were not caused by the intent, fault, negligence or inefficiency of any person or persons embarked in the *Forrestal*." Further, the Commander in Chief U.S. Atlantic Fleet specifically does not concur in Opinion 4 of the *Report* which states "That no improper acts of commission or omission by personnel embarked in *Forrestal* directly contributed to the inadvertent firing of the Zuni rocket from F-4 Number 110."[5]

Admiral Holmes also questioned the accuracy of the Investigation Board's finding that the state of *Forrestal's* material readiness and firefighting and damage control training were acceptable at the time of the fire. He noted that the Inspector General of the US Atlantic Fleet conducted a short-notice evaluation of *Forrestal's* damage control readiness on 10 May 1967. The purpose of this visit was to assess the carrier's ability to maintain watertight integrity, fight fires, and repair damage. The Inspector General found *Forrestal's* damage control readiness to be unsatisfactory, and noted that the damage control parties were disorganized and were not knowledgeable. Admiral Holmes's endorsing letter stated that this information was not included in Rear Admiral Massey's *Investigation Report*, although his board was provided with a copy. The admiral's letter further criticized the investigators for not stating whether the unsatisfactory conditions found by the Inspector General were corrected prior to the conflagration in July.[6]

In his endorsing letter, Admiral Holmes stated that although he was concerned with the high turnover rate of enlisted personnel in operational units, he concurred with Admiral Booth that it would be difficult to stabilize manning. He wrote that the low reenlistment rates cited by Admiral Booth were exacerbated by the Navy's low overall manning of enlisted supervisory personnel (enlisted pay grades E5 to E9 were only manned at 82 percent of allowance in August 1967).[7] Other factors that Admiral Holmes assessed as negatively impacting manning stabilization on ships included high operational tempo to support the Navy's heavy commitment in Southeast Asia, and the need to man a larger fleet as the number of ships that were commissioned and reactivated increased.[8]

Admiral Holmes approved all other damage control related recommendations included in Rear Admiral Massey's *Investigation Report*, and forwarded the report to the Navy's Judge Advocate General. The Judge Advocate General reviewed the investigation report and endorsing letters, found that the investigation had been conducted in accordance with naval regulations, and forwarded the entire package to the Chief of Naval Operations. The Judge Advocate General also sent copies of the report and endorsing letters to the commanders of the Naval Air Systems Command, the Naval Ship Systems Command, the Naval Ordnance Systems Command, and the Chief of Naval Personnel for their information. After the Chief of Naval Operations reviewed the report, it was returned to the Judge Advocate General's office.

When the Chief of Naval Operations returned the original copy of Rear Admiral Massey's investigation into *Forrestal's* fire, the Judge Advocate General's office placed it in their long-term storage facility.[9] It appears that the Navy never tracked the status of recommendations made in this report.[10] Fortunately, all but one of the damage control related recommendations first proposed by Rear Admiral Massey were also included in Admiral Russell's report. The sole recommendation excluded by Admiral Russell was the proposal to stabilize manning on Navy ships from the period of Refresher Training through deployment. Perhaps Admiral Russell omitted it since Vice Admiral Booth and Admiral Holmes had already rejected it as infeasible. In any event, Admiral Russell's recommendations were targeted at improving damage control training without the benefit of manning stabilization.

In contrast, the recommendations proposed by Admiral Russell were tracked very closely for several years, as the remainder of this chapter will show.

Implementation of the *Russell Report's* Recommendations

The scope of Admiral Russell's panel was much broader than the investigation into *Forrestal's* fire, as discussed earlier. The Chief of Naval Operations to appointed Admiral Russell:

> Examine actual and potential causes of fires and explosions in aircraft carriers with object of minimizing their occurrence, limiting injuries and damage that result when they occur, and greatly improving the effectiveness of firefighting capability and the control of explosive damage particularly on the flight deck and in the hangar bays.[11]

Admiral Russell submitted his report to Admiral Moorer, the Chief of Naval Operations, on 16 October 1967. Three days later, Admiral Moorer forwarded the report to an extensive array of naval commanders, including the Atlantic and Pacific Fleet Naval Air Force Commanders, all fleet commanders, all aircraft carrier division commanders, all aircraft carrier commanding officers, the Chief of Naval Material, the Chief of Naval Personnel, Naval Ship Systems Command, Naval Ordnance Systems Command, and the Naval Air Systems Command. Admiral Moorer appointed one of the senior officers on his staff, Rear Admiral Edward C. Outlaw, to coordinate implementation of the recommendations submitted by Admiral Russell.[12] Each of the recommendations included in the Russell Report included a proposal for a designated naval command to assume cognizance for further study and implementation if feasible. Admiral Moorer instructed these commands to provide him with their comments on each of these items by 25 November 1967.[13]

Only one of the seventeen significant damage control recommendations included in Admiral Russell's report and discussed in the previous chapter was quickly rejected as infeasible. The discarded recommendation proposed that the Navy allocate a portion of each ship's operating funds solely for the purchase of damage control items. The prioritization of operating funds was traditionally decided by each ship's commanding officer. The commanding officer was in a better position to understand his ship's requirements than higher headquarters staff officers, and was also responsible for everything aboard his ship--the condition of all equipment and the safety of the crew. Additionally, the operating funds were distributed to ships on a quarter-annual basis. It would be exceedingly difficult for outsiders to predict how much damage control equipment would have to be replaced in a given quarter, since wear and tear varied widely according to the ship's operational tempo, how often the gear was used, and how recently it had been replaced. The Navy's leaders decided to leave responsibility for allocation of damage control funding from operating funds with each ship's commanding officer.[14]

Feedback from the offices charged with studying the feasibility of implementing the recommendations put forth in the *Russell Report* indicated that substantial time would be required to perform the required analysis. As a result, in July 1968 the Chief of Naval Operations directed the Chief of Naval Material to provide quarterly reports updating the status of the proposed recommendations. These quarterly status reports were submitted to the Chief of Naval Operations from 1968 until 1972 and detailed progress made in analyzing and implementing the recommendations.

In August 1972, the Chief of Naval operations relaxed the reporting requirement, directing that progress reports be submitted on a semi-annual basis. The Chief of Naval Operations rescinded the reporting requirement entirely in November 1974, since significant progress had been made in implementing the Russell Report recommendations:

> In view of the considerable progress to date implementing Russell Panel/CASS recommendations, it is considered that the periodic status reports have served their intended function and are no longer necessary on a regularly scheduled basis. . . . Ongoing and open-ended recommendations will continue to be monitored and coordinated as normal NAVMAT management actions.[15]

Although the Navy had made enormous progress in implementing Admiral Russell's recommendations by late 1974, interim status updates to the Chief of Naval Operations showed that financial costs proved to be an enormous obstacle to analyzing and implementing the proposed improvements. To ensure that available funding was applied in the most critical areas, the Chief of Naval Operations assigned a relative priority to each recommendation. Three categories of priority were established. The highest category was termed "urgent"; the second, "priority"; and the lowest, "desirable."

Impact of the *Enterprise* Fire on Russell Panel Recommendations

Soon after the Navy began to seriously study the Russell Panel's recommendations, another serious shipboard fire dramatically underscored the need to improve shipboard damage control and firefighting capability. On 14 January 1969, in a tragic parallel to the *Forrestal* fire, a Zuni rocket accidentally ignited on an F-4 Phantom aircraft staged on the aircraft carrier USS *Enterprise's* flight deck. Twenty-seven sailors perished in the resulting blaze, and 344 others were injured (sixty-five seriously). Damage to the ship was estimated to be just below eleven million dollars and the cost of replacing the fifteen destroyed aircraft and associated aviation equipment was estimated to be approximately 45.5 million dollars.[16] The following day, the Pacific Fleet Naval Air Force Commander directed Rear Admiral Frederic A. Bardshar to investigate the fire. Rear Admiral Bardshar's panel also consisted of two Navy Captains, one Commander, and a Lieutenant. Lieutenant Commander Thomas E. Flynn was assigned to provide legal counsel for the investigating board.

Admiral Bardshar completed his report on 11 February 1969. A brief examination of his report is useful for three reasons – first, because the topic of investigation was a similar fire on an aircraft carrier similar to *Forrestal*. Secondly, since the *Enterprise* fire occurred approximately eighteen months after the conflagration on *Forrestal*, sufficient time had elapsed to determine if any suggested improvements had been implemented. Finally, a section of Admiral Bardshar's report commented directly on his opinions of specific *Russell Report* recommendations, based on his investigation of *Enterprise's* fire.

Admiral Bardshar's investigation revealed that although the majority of recommendations proposed to improve shipboard damage control equipment had not yet been implemented, many of the training deficiencies noted by Admirals Massey and Russell had been corrected. In fact, Admiral Bardshar's report vividly illustrates that Enterprise's crew exhibited high levels of damage control awareness and was well trained in damage control and firefighting. In the abstract to his report, Admiral Bardshar stated that although serious firefighting equipment deficiencies existed, "solid damage control organization, training, and execution" minimized casualties and limited the fire's spread and resulting damage.[17] Admiral Bardshar praised the performance of *Enterprise's* firefighters in his report:

> The high state of training which existed aboard *Enterprise* produced the individual leadership at all levels which is necessary to an effective damage control organization. . . . After each major explosion hose teams regrouped and resumed their efforts. When men fell, trained backup men took their place. In any event, the aggressive but controlled efforts of these fire fighting crews prevented the explosions of more 500 pound bombs which almost certainly would have occurred had the fires been allowed to burn unopposed.[18]

This description presented a stark contrast to firefighting efforts on *Forrestal*, where men with little or no formal training took the place of fire fighters who were killed in the initial explosions on that vessel. On *Forrestal*, approximately 50 percent of the ship's crew and none of the air wing sailors had attended firefighting school. When *Enterprise's* fire erupted, 2,997 of the 3,123 sailors in her ship's company (96 percent) had attended firefighting school, and 1,753 of 2,039 air wing personnel (86 percent) had attended firefighting school. *Enterprise* had sent 1,091 officers and men to firefighting school during August and September 1968. The carrier also had developed a damage control training team to instruct and evaluate the performance of its damage control organization during drills. *Enterprise* had also established a competitive program between its repair parties to increase effectiveness, and conducted frequent training drills.[19] Clearly, on *Enterprise* at least, the importance of an effective, highly trained damage control organization was well recognized.

In the portion of his report commenting on the Russell Panel's recommendations, Admiral Bardshar generally concurred with the proposed solutions. He concurred with the first recommendation included in Admiral Russell's report, the need to develop an advanced flight deck fire fighting system for carriers. Admiral Bardshar wrote that although Enterprise’s well-trained crew quickly employed all available firefighting equipment in accordance with sound, prescribed doctrine, the firefighting equipment was simply insufficient. As a result, the crew’s efforts failed to prevent ordnance cook-off and the significant damage resulting from these explosions. These comments on the *Enterprise* fire were an almost identical echo to those made seventeen months earlier by Rear Admiral Massey. Admiral Bardshar wrote that an advanced flight deck fire system, originally proposed by Rear Admiral Massey, and further endorsed by Admiral Russell, was badly needed. He made this his foremost recommendation, and defended his rationale in the strongest terms:

> A fresh concept of dealing with a massive flight deck fire (whether self or enemy inflicted) involving exploding fuel and ordnance should be developed. The system derived must include massive cooling as well as rapid extinguishment. It must provide flexibility, selectivity, and redundancy. The system must not compete with other systems for power, water, or extinguishing agents. Controls must provide for remote activation and response must be immediate. . . . The requirement for this system is documented by 161 lives, some 200 million dollars, and the loss of 8 CVA months of operating time since 29 July 1967. The system should be a military characteristic for all CVAs and rank in importance with the armament and aircraft launch and recovery systems…Anything less will not be satisfactory.[20]

Admiral Bardshar also agreed that the Navy needed most of the improvements proposed in the *Russell Report*. He opined that a standardized marking and lighting system for escape routes would be desirable, as would the neoprene hoses described by Admiral Russell. At the time of *Enterprise’s* fire, the improved neoprene hoses were approved for use on naval vessels. However, the *Enterprise* was not yet fitted with them. Admiral Bardshar also wrote that although improvements to OBAs would be desirable, he felt that improved training (and the resulting increased familiarity sailors had with the equipment’s capabilities and limitations) had alleviated many of the perceived shortcomings of OBAs. Admiral Bardshar's panel wrote that the *Enterprise's* crew members were aware of the limitations of using the gas masks as escape breathing devices, and effectively used the gas masks during the blaze. The *Enterprise* fire investigators did agree that improved personnel protective equipment was needed. They noted that two sailors wearing aluminized proximity suits were injured after the hoods were blown off their suits by the concussion from explosions on the flight deck. They also stated that more fire resistant clothing and use of gloves would have reduced the severity and number of burns suffered by *Enterprise's* firefighters. They recommended that the Navy issue and require all personnel working on flight decks to wear hard shell helmets and gloves.[21]

The only *Russell Report* recommendation Admiral Bardshar's investigators disagreed with was the need to increase the allowance of OBA canisters and containers of foam concentrate. *Forrestal* carried 3,300 OBA canisters and 1,220 five-gallon containers of foam concentrate at the time of her fire. *Enterprise's* allowance was virtually identical to this when her fire erupted. Enterprise's crew members expended 900 of their 3,300 OBA canisters and 811 of 1,080 foam concentrate containers while fighting the conflagration.[22] In view of this, Admiral Bardshar wrote that the existing allowance for these items was adequate.

The *Enterprise* investigation indicated that the Navy had made substantial progress in improving personnel training. It also demonstrated that the existing firefighting doctrine was adequate, when used by a highly proficient damage control organization. However, the investigation report also reinforced the assertions contained in the *Forrestal Investigation Report* and the *Russell Repor*t that existing firefighting and damage control equipment was inadequate. Training had improved human performance, but the Navy's technical experts still had to improve the tools available to shipboard firefighters.

In 1968, the Naval Air Systems Command, operating under authority of the Chief of Naval Material, established the Carrier Aircraft Support Study (CASS). The purpose of the study was to assess aircraft carrier operations, and to recommend improvements to increase effectiveness and safety. CASS was a mammoth study (comprising fourteen volumes; the volume on safety alone contained over 500 pages), and examined nearly every aspect of aircraft carrier operation. The Navy contracted Systems Associates, Incorporated (SAI) to perform the study. SAI subcontracted several major defense-related corporations to provide technical assistance and analysis. Some of the subcontractors who contributed to CASS were FMC Corporation, Grumman Aerospace, Hughes Aircraft, McDonnell Aircraft, and the Western Gear Corporation.[23]

In February 1969 the Chief of Material, acting with the concurrence of the Chief of Naval Operations, directed that follow-up study of recommendations resulting from the *Enterprise* fire be assigned to CASS:

> The recent *Enterprise* incident indicates lessons learned from *Forrestal* contributed to minimizing damage. CASS has been reoriented with OPNAV concurrence to give top priority to *Enterprise*. Coordinated follow-up of *Enterprise* for both short and long term necessary actions are now assigned to CASS. The CASS Steering Committee has been augmented by 2 Flag Officers from OPNAV (OP-03V and OP-50) and the working group is being expanded.[24]

Since several damage control recommendations included in the *Enterprise Investigation Report* were originally included in the *Russell Report*, this action increased the attention accorded to important recommendations that had not yet been implemented. It also provided funding for those recommendations, such as the advanced flight deck firefighting system, that needed significant research and analysis prior to development. The Chief of Naval Material also included the status of recommendations assigned to CASS for further study in the periodic update of *Russell Report* recommendations to the Chief of Naval Operations.[25]

A review of these periodic updates on the status of analysis and implementation of Russell Report recommendations shows that steady progress was made. For instance, by January 1971, fifty separate SHIPALTS (alterations designed to improve Navy ships) based on improvements recommended by Admiral Russell had been approved.[26] Perhaps the most important of these new SHIPALTS was a newly designed Advanced Flight Deck Fire Fighting System for aircraft carriers. However, SHIPALTS had also been developed to improve shipboard "1MC" general announcing systems and increase the number of exits from carrier working and berthing spaces. Unfortunately, the cost of altering the Navy's ships was high, and some SHIPALTS other than those developed from Russell Report recommendations were given higher priority.[27] The May 1971 status update to the Chief of Naval Operations stated that the two aircraft carriers that were being constructed (USS *Nimitz* and USS *Eisenhower*) would have the new damage control improvements built into them, at an estimated additional cost to the Navy of five million dollars per ship.[28] According to that document, approximately $21.5 million were required to complete the fifty SHIPALTS generated by *Russell Report* recommendations on the Navy's existing ships. The Navy had budgeted approximately $13.2 million for this over the next five fiscal years, leaving an unfunded shortfall of approximately $7.3 million.[29] The same report stated that a shortage of research and development funds had slowed implementation of several other important *Russell Report* recommendations. The most significant of these affected recommendations were standardized marking of escape routes from shipboard compartments, development of an emergency escape breathing device, and OBA improvement. The report stated that the Chief of Naval material had requested $4.25 million for research and development of these items in fiscal years 1970 through 1972, but was only granted $2.8 million.[30]

The following year, on 29 October 1972, a machinery space fire in the aircraft carrier USS *Saratoga* killed three sailors and injured twelve others. The deaths were caused by smoke inhalation, and the injuries consisted of burns and smoke inhalation. On 1 November 1972, the Chief of Naval Operations directed his staff to provide him with a status report on the development of *Russell Report* recommendations.[31]

The November 1972 update revealed substantial additional progress on many *Russell Report* recommendations, including the three that had been funded at lower levels than requested the previous year. The Chief of Naval Material had completed evaluation of a standardized marking and lighting system for shipboard escape routes, and was preparing the specifications needed to create a SHIPALT. Research, development, testing, and evaluation (RDT&E) had also been completed on an improved "Variable-fog" nozzle for Navy firefighting hoses. Specifications for the new nozzle were complete, and the Navy was preparing to purchase and equip its ships with them. An emergency escape breathing device had also been developed. This device provided shipboard personnel with eight minutes of clean breathing air to allow them to escape smoke-filled compartments. The Navy had awarded a contract for production of these devices, and was expecting them to be delivered to its ships by late 1973. The report also noted that a permanent flight deck personnel protective equipment program had been established by the Naval Air Systems Command, and that testing of Nomex fire retardant clothing was in progress. Finally, the 1972 status report described an improved OBA that was being evaluated and refined.[32]

The Chief of Naval Material published the final status report on Russell Report recommendations in March 1974. This update showed that, although many research and development efforts were still underway, the Navy had made enormous overall progress in implementing the *Russell Report* recommendations. An advanced flight deck fire fighting system had been installed in nine aircraft carriers, and installation was expected to be completed on the seven remaining carriers by late 1974. A SHIPALT was authorized to standardize shipboard escape route marking, and funding was allocated for ten carriers to receive the alteration in fiscal year 1974. A SHIPALT to improve the "1MC" general announcing system was funded for all Navy ships. SHIPALTS were funded to improve exits from carrier working and berthing spaces. Four carriers were equipped with newly developed emergency escape breathing devices, and funding was allocated for further refinement of these devices. Funding was allocated to replace all of the Navy's OBAs with an improved model over a three-year period. Improved proximity suits were being provided to carriers, although development of improved, fire retardant clothing for sailors was still in progress. Finally, a training film incorporating footage of the *Forrestal* fire had been issued to all Navy fire fighting schools.[33]

This chapter has shown that the vast majority of damage control improvements first proposed by Rear Admiral Massey were eventually implemented, particularly those that called for more effective equipment. Dramatic improvements are difficult to quickly accomplish in a large bureaucratic organization, but several important factors fostered improved damage control throughout the US Navy. Admiral Russell endorsed Admiral Massey's recommendations, and the high degree of interest exhibited by the Chief of Naval Operations helped sustain the necessary resources required to evaluate and implement the recommended improvements. Finally, fires on the carriers *Enterprise* and *Saratoga* underscored the vital, continuing need for the proposed improvements.

The final chapter examines the lasting impact the *Forrestal* fire had on US Navy shipboard damage control, and what implications this fire and its aftermath have for damage control today.

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[1] Department of the Navy, *Manual of the Judge Advocate General Basic Final Investigative Report Concerning the Fire on Board the USS Forrestal (CVA-59) on July 29, 1967*. (Washington, D.C.: US Navy Office of the Judge Advocate General, 1968), 112, 125.

[2] Vice Admiral Charles T. Booth, *First Endorsement on RADM F. Massey, USN letter of 19 September 1967* (Norfolk, VA: Commander Naval Air Force, US Atlantic Fleet, 26 September 1967), 1.

[3] *Manual of the Judge Advocate General Basic Final Investigative Report Concerning the Fire on Board the USS Forrestal (CVA-59) on July 29, 1967*, 114, 126.

[4] Vice Admiral Booth, 2.

[5] Admiral Ephraim P. Holmes, *Second Endorsement on RADM F. Massey, USN letter of 19 September 1967* (Norfolk, VA: Commander in Chief, US Atlantic Fleet, 1 December 1967), 3.

[6] Ibid., 5-6.

[7] Ibid., 6.

[8] Ibid.

[9] A letter from the Chief of Naval Operations to the Judge Advocate General, dated 21 August 1969, states that Rear Admiral's Massey's *Investigative Report* was returned to the Judge Advocate General on that date. A letter to the author from the Judge Advocate General's office on 23 September 2003 stated that the report is still held in their long–term storage facility in Suitland, Maryland.

[10] The author could not locate any evidence that recommendations proposed in Rear Admiral Massey's *Investigative Report* were tracked by the Navy after the report was given to the Judge Advocate General for safekeeping. Fortunately, many of these recommendations were included in Admiral Russell's report, which was tracked closely for several years.

[11] Naval Safety Center, *Survey of Selected Aircraft Carrier Accidents* (Washington, D.C.: US Naval Safety Center, 1971), 30.

[12] Admiral James S. Russell, *Report of the Panel to Review Safety in Carrier Operations* (Washington, D.C.: Office of the Chief of Naval Operations, 1967), cover letter.

[13] Ibid.

[14] Chief of Naval Material, *Milestone Schedule and Status Report for Implementing the Recommendations of the Russell Panel Report and the Carrier Aircraft Support Study (CASS)* (Washington, D.C.: Chief of Naval Material, 20 March 1974), 3.

[15] Chief of Naval Material, *Periodic Status Reports on Russell Panel/CASS Report* (Washington, D.C.: Chief of Naval Material, 18 November 1974), 1.

[16] Rear Admiral Frederick A. Bardshar, *Record of Proceedings: Formal Board of Investigation Convened by Order of Commander Naval Air Force United States Pacific Fleet to Inquire into the Circumstances Surrounding a Fire Which Occurred on Board USS Enterprise (CVAN 65) on 14 January 1969 Ordered on 15 January 1969* (San Francisco, CA: Rear Admiral Bardshar, 11 February 1969), 21-22.

[17] Ibid., 1.

[18] Ibid., 37.

[19] Ibid., 26.

[20] Ibid., 2, 38.

[21] Ibid., 38-39.

[22] Ibid., 27.

[23] Systems Associates, *Final Report: Carrier Aircraft Support Study (CASS)* (Long Beach, CA: Systems Associates, December 1971), ii-iii.

[24] Chief of Naval Material, *Carrier Aircraft Support Study (CASS) Enterprise Responsibilities, Assignment of* (Washington, D.C.: Chief of Naval Material, 3 February 1969), 1.

[25] Chief of Naval Material, 18 November 1974, 1.

[26] Chief of Naval Material, *Budgetary and Cost Summary Russell Panel/CASS Recommendations* (Washington, D.C.: Chief of Naval Material, 17 May 1971), 1-3.

[27] Ibid.

[28] Ibid., 4.

[29] Ibid.

[30] Ibid., 5.

[31] Office of the Chief of Naval Operations, *RDT&E Efforts Associated with the Russell Panel Report* (Washington, D.C.: Office of the Chief of Naval Operations, November 1972), 1. Research at the Naval Sea Systems Command headquarters at the Washington Navy Yard revealed a memo from the Chief of Naval Operations requesting this special update "in view of the *Saratoga* fire."

[32] Ibid., 5-8.

[33] Chief of Naval Material (20 March 1974), 4-8.

CHAPTER 6

CONCLUSION

Lasting Impact of the *Forrestal* Fire

This thesis examined what lessons the Navy learned in the area of damage control from the July 1967 fire on USS *Forrestal*, and how the Navy applied these lessons to improve fleetwide damage control capability (doctrine, warship construction features, and damage control equipment). The research has demonstrated that the damage control capability of US Navy ships was significantly improved as a direct result of lessons learned from the July 1967 fire on USS *Forrestal*. Significant changes in the area of damage control resulted from analysis of this disaster, and these changes had lasting positive impact on US Navy damage control capability.

The tremendous loss of life, high number of injured sailors, extensive property damage to the ship and its complement of aircraft, and the loss of several months of operating time for a capital ship captured the attention of the Navy's top leaders. These leaders ordered a thorough investigation into the *Forrestal* fire. Although the resulting 7,500-page report highlighted several serious deficiencies in *Forrestal's* damage control capabilities, the scope of Rear Admiral Massey's investigation was necessarily limited. The Chief of Naval Operation's appointment of retired Admiral James Russell to review safety of aircraft carrier operations throughout the Navy had a much greater impact on improving damage control throughout the fleet. Admiral Russell found that most of the deficiencies found by the *Forrestal* fire investigators also existed aboard the Navy's other aircraft carriers. As a result, Admiral Russell incorporated all but one of Admiral Massey's thirty-one damage control improvement recommendations into his own report.

Lasting Impact on Doctrine

The fire had a relatively minor impact on damage control doctrine, which was fundamentally sound. The Navy's damage control doctrine had evolved with its ships over the years, and incorporated hard-learned lessons from earlier fires and battle damage sustained by Navy vessels.

However, Rear Admiral Massey and Admiral Russell discovered that the damage control proficiency of US Navy aircraft carrier crews was low because of inadequate training. For example, only 50 percent of *Forrestal's* crew members, and none of the embarked air wing personnel (who comprised approximately 40 percent of the sailors aboard *Forrestal*) had completed fire fighting training courses.[1] Admiral Russell wrote that the Navy's existing damage control training requirements were not being met because of insufficient damage control school capacity, high personnel turnover, and the low priority given to damage control readiness by many aircraft carrier commanding officers.[2] Poorly trained sailors were simply not able to competently fight serious fires in accordance with established doctrine.

These training deficiencies were relatively easy to correct in a short period of time. Damage control training facilities were expanded, and senior leaders directed Commanding Officers to ensure that their crews were properly trained. Rear Admiral Massey's investigation report into the *Forrestal* fire was widely distributed throughout the fleet. All of these measures increased damage control awareness throughout the fleet, at least in the short term. The similar fire on USS *Enterprise* nearly eighteen months later provided evidence that many training deficiencies had been corrected. The investigation report into the *Enterprise* fire praised crew members for efficiently fighting the conflagration in accordance with prescribed doctrine to minimize damage.[3] However, this report highlighted the Navy's dire need for the improvements in damage control and personnel protective equipment proposed in Admiral Russell's report.

Lasting Material Impact

Much of the long-term impact of the *Forrestal* fire can be found by examining the improved material items (warship construction features, damage control and personnel protective gear) that were proposed and developed in response to lessons learned from that event. These important developments were built into newly constructed vessels, and many existing ships were altered to incorporate the new technology. Refined versions of this equipment can be found on today's naval warships.

Successful material achievements included development of an advanced flight deck firefighting system, improved personnel protective equipment (including fire retardant uniforms, emergency escape breathing devices, and improved OBAs), improved hoses and nozzles. Navy officials also approved a standardized marking and lighting system for escape routes from interior compartments, and additional exits were constructed for many of these interior compartments.

Like the proposed training improvements, these material improvements were also relatively easy for the Navy to implement. Admiral Russell had access to the Navy's top military and civilian experts while developing his recommendations and substantial evidence indicated that they were necessary. The senior officer in the US Navy, Admiral Moorer, demanded frequent updates on the status of implementing *Russell Report* recommendations. As a result, there was little controversy over and broad support among the Navy's leadership for the vast majority of these proposed material improvements.

These recommendations were also prioritized to meet funding limitations. The January 1969 fire aboard *Enterprise* provided additional evidence of the validity of the proposed improvements. Although funding constraints, research, development, and testing all slowed implementation of these recommendations, the most significant recommendations were all incorporated into US Navy ships within a few years.[4]

Unsuccessful Damage Control Improvement Ideas

The preceding paragraphs have shown that training deficiencies and material deficiencies were rectified relatively easily. There was ample evidence that these deficiencies existed, and clear-cut solutions were readily developed to mitigate them. Most of the proposed solutions were noncontroversial, and enjoyed broad support from senior Navy leaders. However, recommendations that did not have such clear-cut technical solutions and challenged existing policies and organizational culture proved much more difficult to successfully implement.

Three significant recommendations proposed to improve shipboard damage control readiness in the wake of the *Forrestal* fire never materialized. Rear Admiral Massey proposed that the Bureau of Naval Personnel should stabilize manning of trained personnel on ships and air wings by minimizing personnel transfer from these units prior to deployment.[5] However, the two senior admirals who endorsed his report prior to its submission to the Chief of Naval Operations rejected this proposal, primarily because of low manning levels at that time. Admiral Moorer did not insist that his subordinates find a way to stabilize manning. This recommendation was the one significant damage control improvement recommendation first proposed by the *Forrestal* fire investigators that Admiral Russell did not include in his report. Perhaps Admiral Russell sensed or was told that manning stabilization was not feasible during his interviews with the senior officers who rejected the concept after Admiral Massey first proposed it. Admiral Russell's report did include several recommendations designed to ameliorate damage control training proficiency without manning stabilization. These proposals included increasing the emphasis on damage control training for officers and enlisted personnel prior to reporting to their first ships, and increasing the capacity of the fleet damage control training schools. Senior Navy leaders quickly accepted these alternative proposals. Still, Admiral Russell's failure to recommend manning stabilization reduced the visibility of this proposal.

Admirals Massey and Russell both recommended increasing the number of OBAs, OBA canisters, and containers of firefighting foam concentrate carried aboard Navy ships, citing shortages of these items during the *Forrestal's* fire. Vice Admiral Booth objected to immediately implementing this proposal, writing that additional analysis was required before dedicating additional funding and limited shipboard storage areas to these items.[6] In his investigation report on the *Enterprise* fire, Rear Admiral Bardshar flatly rejected the need for additional quantities of these items, writing, "the *Enterprise* allowance for OBAs, canisters, foam, fire extinguishers and hoses was adequate."[7] It appears likely that *Enterprise's* crew used less of these items in a fire very similar to that on *Forrestal* due to their higher training proficiency. In any event, the conflicting data on whether additional quantities of these items were actually required appears to have shifted the focus of Navy leaders to other recommendations with broader support.

The final significant recommendation not implemented by Navy leaders, dedicated funding for replacement of damage control items, was proposed solely by Admiral Russell. The *Russell Report* noted that damage control funding competed with all of the other requirements each ship had, and asserted that many Commanding Officers failed to place a high priority on damage control equipment. Admiral Russell wrote that this frequently resulted in poor material condition of damage control gear.[8]

Although Admiral Russell's logic was sound, this recommendation did not mesh well with Navy culture and tradition. Navy commanding officers were traditionally given complete authority to decide how to allocate limited operational funding for their ship. Many valid reasons existed for this arrangement--commanding officers were held completely responsible for the safety of the ship and its crew. Commanding officers also were presumed to have a much more intimate picture of their ship's condition and requirements, and were thus in a better position to determine allocation of operational funding than outsiders were. It appears likely that senior Navy officials were unwilling to take this decision-making authority away from commanding officers, or allocate additional dedicated funding for damage control items.[9]

Implications for Today's Navy

In July 1967 many people in the Navy thought that a flight deck fire on the magnitude of that on *Forrestal* was unlikely to occur. It was easy for them to believe that technological innovations such as armored flight decks and replacement of highly flammable aviation gasoline with less flammable jet fuel significantly reduced the risk of serious fire. However, the *Forrestal's* fire demonstrated that fire at sea remains a serious and enduring threat to the safety of ships and sailors.

Forrestal's designers built a ship that carried more aircraft, fuel, and ordnance then any earlier aircraft carriers. Unfortunately, the July 1967 fire on *Forrestal* provided strong evidence that these designers failed to ensure that her damage control capability was adequate for these increased hazards. The tragedy illustrated the vital, continuing need to assess damage control capability in new ship designs.

The fires on the *Forrestal* and *Enterprise* also demonstrated the importance of a well-trained and equipped damage control organization. The investigation reports into those incidents provide strong evidence that many sailors died needlessly on *Forrestal* because of poor training. Although it is true that their damage control equipment was inadequate, the fact remains that most sailors aboard *Forrestal* were not trained to effectively use the tools available to them. Conversely, *Enterprise's* well-trained crew was able to effectively fight a similar fire in January 1969, when the events on *Forrestal* were still very fresh in the minds of Navy personnel.

The events following the *Forrestal* fire also provide useful insight into one way to successfully implement change in a large, bureaucratic organization. The tremendous loss of life and high property damage certainly provided a sharp warning that the status quo of damage control on aircraft carriers was inadequate. Senior Navy leaders acted decisively to improve this situation. The Navy's senior officer appointed a retired four-star admiral to head a panel tasked with examining the safety of aircraft carrier operations. This officer, Admiral James Russell, was granted unfettered access to the Navy's top ship construction and damage control experts and the most experienced naval officers while developing proposals to improve damage control readiness. The Chief of Naval

Operation's strong personal commitment to the project sustained momentum throughout the several years required to implement the proposed solutions.

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[1] Admiral James S. Russell, *Report of the Panel to Review Safety in Carrier Operations* (Washington, D.C.: Office of the Chief of Naval Operations, 1967), A-73--A-74.

[2] Ibid., A-74-A-76.

[3] Rear Admiral Frederick A. Bardshar, *Record of Proceedings: Formal Board of Investigation Convened by Order of Commander Naval Air Force United States Pacific Fleet to Inquire into the Circumstances Surrounding a Fire Which Occurred on Board USS Enterprise (CVAN 65) on 14 January 1969 Ordered on 15 January 1969* (San Francisco, CA: Rear Admiral Bardshar, 11 February 1969), 1-2, 26.

[4] Chief of Naval Material, *Milestone Schedule and Status Report for Implementing the Recommendations of the Russell Panel Report and the Carrier Aircraft Support Study (CASS)* (Washington, D.C.: Chief of Naval Material, 20 March 1974), 1-8.

[5] Department of the Navy, *Manual of the Judge Advocate General Basic Final Investigative Report Concerning the Fire on Board the USS Forrestal (CVA-59) on July 29, 1967* (Washington, D.C.: US Navy Office of the Judge Advocate General, 1968), 125.

[6] Vice Admiral Charles T. Booth, *First Endorsement on RADM F. Massey, USN letter of 19 September 1967* (Norfolk, VA: Commander Naval Air Force, US Atlantic Fleet, 26 September 1967), 2.

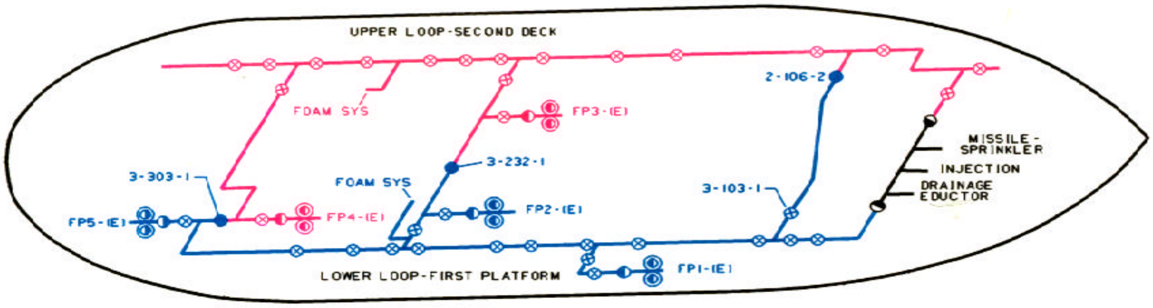
[7] Rear Admiral Bardshar, 39.

[8] Admiral Russell, A-33.

[9] Chief of Naval Material document of 20 March 1974, page 3, simply states that this proposal was rejected as "not feasible." A search of the Navy Operational Archives and records at the Naval Sea Systems Command at the Washington Navy Yard failed to provide any further details on why this proposal was considered infeasible.

APPENDIX A

TYPICAL NAVY FIREMAIN “LOOP” DIAGRAM



ALL PUMPS AVAILABLE FOR OPERATION OF THE MK13 GUIDED MISSILE LAUNCHING SYSTEM, SPRINKLER SYSTEM, BOOSTER SUPPRESSION & DRAINAGE EDUCTORS

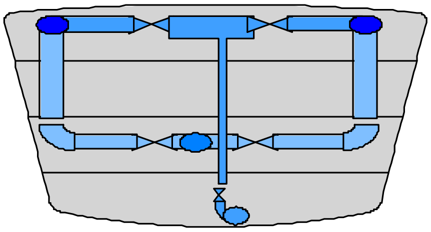
LOWER LOOP - FP1-(E), FP2-(E), & FP5-(E)

UPPER LOOP - FP3-(E), & FP4-(E)

THE FIREMAIN LOOP IS SEGREGATED INTO TWO SECTIONS. IN CONDITION “ZEBRA” AS INDICATED ABOVE. TO ESTABLISH CONDITION “ZEBRA” FROM CONDITION “X-RAY” OR ”YOKE”, THE FOLLOWING THREE “ZEBRA” VALVES ARE CLOSED.

VALVE NO.	LOCATION	REMOTE CONTROL
2-106-2	2-100-4-L	2-292-01-C
3-232-1	5-212-0-E	2-292-01-C
3-303-1	5-292-0-E	2-292-01-C
3-103-1	3-100-1-L	

Cutaway View of Loop



Source: These diagrams originally appeared in a training presentation prepared by the US Navy’s Surface Warfare Officer School at the Naval Education and Training Center, Newport, Rhode Island.

APPENDIX B

CHRONOLOGY OF EVENTS

This timeline was developed using the official Navy records in the Bibliography as references.

October 1955 – USS *Forrestal (CVA-59)* was commissioned.

April 1966 – January 1967 – *Forrestal* docked in Norfolk Naval Shipyard for extended maintenance and overhaul.

May 1966 – Captain John K. Beling assumed command of *Forrestal*.

January – May 1967 – *Forrestal* conducted predeployment training.

6 June 1967 – *Forrestal* departed Norfolk for deployment to Western Pacific.

24 July 1967 – *Forrestal* arrived on Yankee Station, Gulf of Tonkin, off coast of North Vietnam.

25 – 28 July 1967 – *Forrestal* launched air strikes against targets in North Vietnam.

29 July 1967 – A Zuni rocket accidentally fired from an F-4 Phantom jet staged on *Forrestal's* flight deck struck a nearby A-4 Skyhawk aircraft and started a large conflagration aboard the ship at 1051 local time. 134 personnel died; 161 others were injured.

30 July 1967 – The fires aboard *Forrestal* were extinguished by 0400 local time. Rear Admiral Lanham, commander of Carrier Division Two (Captain Beling's Immediate Superior in Command), who was embarked in *Forrestal* during the fire, ordered his staff to conduct a preliminary investigation into the fire. Vice Admiral Charles T. Booth, commander of the US Atlantic Fleet Naval Air Force, appoints Rear Admiral Forsyth Massey as senior member of the board of investigation into the *Forrestal* fire.

31 July 1967 – *Forrestal* arrived at Naval Air Station Cubi Point, Republic of the Philippines, for temporary repairs.

3 August 1967 – Rear Admiral Massey and his team of investigators arrived at Naval Air Station Cubi Point and began work. Rear Admiral Lanham's preliminary investigation ended; all information gathered was turned over to Admiral Massey's team.

21 August 1967 – Admiral Thomas Moorer, Chief of Naval Operations, appointed retired Admiral James S. Russell as director of a panel charged with reviewing safety in aircraft carrier operations.

19 September 1967 – Rear Admiral Massey completed his investigation and forwarded his report to Vice Admiral Booth.

26 September 1967 – Vice Admiral Booth completed his review of Rear Admiral Massey's report and forwarded it to Admiral Ephraim P. Holmes, Commander in Chief of the US Atlantic Fleet.

16 October 1967 – Admiral Russell completed his *Final Report of Panel to Review Safety in Carrier Operations* and submitted it to the Chief of Naval Operations.

19 October 1967 – Chief of Naval Operations forwarded Admiral Russell's report to an extensive list of naval commands, assigned Rear Admiral Edward C. Outlaw to coordinate analysis and implementation of proposed recommendations, and directed subordinate commands to provide comments on the proposed recommendations by 25 November 1967.

1 December 1967 – Admiral Holmes completed his review of Rear Admiral Massey's report.

23 July 1968 – Chief of Naval Operations directed the Chief of Naval Material to provide quarterly updates on the status of *Russell Report* recommendations.

November 1968 – The Naval Air Systems Command established a Carrier Aircraft Support Study (CASS) group

14 January 1969 – Flight deck fire erupted on the aircraft carrier *USS Enterprise* after a Zuni rocket exploded while attached to an F-4 Phantom jet staged on deck. Twenty-seven personnel perished; 344 others were injured (65 seriously).

15 January 1969 – Commander of US Pacific Fleet Naval Air Force appointed Rear Admiral Frederic A. Bardshar to investigate *Enterprise* fire.

February 1969 – Rear Admiral Bardshar completed his report. His report validated the necessity of nearly all of the damage control improvements proposed by Rear Admiral Massey and Admiral Russell. Chief of Naval Operations directed the CASS group to focus on following up lessons learned from Enterprise fire. The status of these recommendations were included in future quarterly progress reports to the Chief of Naval Operations outlining progress on *Russell Report* recommendations.

21 August 1969 – The Chief of Naval Operations returned Rear Admiral Massey's report, with endorsing letters from Vice Admiral Booth and Admiral Holmes, to the Navy's Judge Advocate General for storage.

December 1971 – Carrier Aircraft Support Study (CASS) completed.

28 August 1972 – Chief of Naval Operations directed the Chief of Naval Material to provide semiannual updates (instead of quarterly reports) on the status of *Russell Report* recommendations.

29 October 1972 – Machinery space fire in the aircraft carrier USS Saratoga killed three sailors and injured twelve others. Three days later, the Chief of Naval Operations requested a special report updating him on the status of *Russell Report* recommendations.

18 November 1974 – Periodic status reports on *Russell Report* recommendations discontinued.

APPENDIX C

SUMMARY OF SELECTED *RUSSELL REPORT* RECOMMENDATIONS

Admiral Russell's report was used as the source document for this appendix, which summarizes several of the most significant damage control improvement proposals discussed in the body of the thesis.

Recommendation 1-1: Advanced Flight Deck Fire Fighting System. Proposed features included "remote control, massive and quick response, cooling for ordnance, sufficient redundancy to compensate for derangement of portions of the system…a means for quick drainage or dispersal of large quantities of spilled fuel from the flight deck."

Recommendation 1-6: Marking of Escape Routes. Proposed establishing a "standardized system of marking and lighting emergency escape routes in aircraft carriers" to aid personnel attempting to escape smoke-filled interior compartments.

Recommendation 1-9: Improved Interior Communications. Recommended that all aircraft carriers be surveyed to determine adequacy of the shipboard general announcing system, the "1MC." It also recommended prompt correction of any deficiencies that were discovered.

Recommendation 1-10: Improved Fire Hose. Recommended that the Navy require neoprene wrapped hoses on flight and hangar decks to reduce kinking that commonly occurred with standard cotton-jacketed fire hoses used aboard Navy ships. It also proposed development of quick-disconnect couplings for these hoses.

Recommendation 1-11: Review of Ship Alterations Affecting Safety. Proposed that the Navy review all pending ship alterations and ship repair requests, and that items affecting damage control and firefighting be given high priority during maintenance periods.

Recommendation 1-22: Damage Control Equipage Allowance. Recommended further analysis of fires on the carriers *Oriskany* and *Forrestal* to determine an appropriate allowance for OBAs and their canisters, firefighting foam, fire extinguishers, hoses, and other damage control equipment.

Recommendation 1-23: Funding for Damage Control Equipment. Proposed that the Navy provide ships with dedicated funding for damage control items, to "avoid having safety equipment compete with all other ship upkeep items for the limited funds available."

Recommendation 1-26: Escape Criteria. Proposed changing ship construction criteria to require two exits from berthing compartments and working areas designed for ten or more men. Recommended modifying existing ships to meet these criteria, where feasible.

Recommendation 2-1: Current Mk-V Gas Mask Capabilities. Recommended distributing information to the fleet on the capabilities and limitations of using gas masks as an escape breathing device. The gas mask could be used to filter out airborne particles (protecting the wearer against some contaminants found in smoke), but provided the user with no protection against high levels of carbon monoxide or low oxygen levels.

Recommendation 2-3: Emergency Breathing Apparatus. Proposed development of masks with a small portable oxygen supply to eliminate one of the most serious limitations of using the gas mask as an escape breathing device.

Recommendation 2-6: Flight Deck Personnel Equipment. Proposed development of more effective personnel protective gear, such as fire retardant clothing.

Recommendation 2-7: OBA Improvement. Advocated further development of OBAs to make them smaller, more robust, and simpler to use.

Recommendation 2-8: Improved Proximity Suit. Recommended development of a more effective proximity suit. Also proposed including specialized boots as an integral part of the new suit.

Recommendation 5-1: Air Wing Damage Control / Fire Fighting Training. Recommended that all air wing personnel receive basic damage control and fire fighting training prior to embarking on an aircraft carrier.

Recommendation 5-2: Fleet Damage Control Training Facilities. Recommended expanding these facilities to meet fleet training requirements.

Recommendation 5-5: En Route Damage Control Training for Enlisted Personnel. Proposed mitigating the effect of high personnel turnover by providing training for junior enlisted personnel before they reported to their first ship.

Recommendation 5-7: Increased Emphasis on Damage Control. Recommended stressing the importance of damage control at the Navy’s training commands, including Officer Commissioning School, Naval Reserve Officer Training Corps (NROTC) units, and the Naval Academy.

Recommendation 5-8: Training Aids. Advocated development of more effective and realistic damage control training aids, including a film containing actual footage of the *Forrestal* fire.

GLOSSARY

1 MC. Shipwide general announcing system.

Class Alpha Fire. Involved combustible materials such as bedding, books, and clothing.

Class Bravo Fire. Involved flammable liquids such as oils and paint.

Class Charlie Fire. Occurred in electrical equipment.

Class Delta Fire. Occurred when metals such as magnesium ignited.

Compartment Check-Off List. Posted list of all watertight fittings in a shipboard compartment, or interior subdivision.

Fire Bill. Published list posted on US Navy ships to assign specific duties to crew members in the event of a fire.

Firemain Loop. A continuous line of piping containing firefighting water aboard Navy ships. A diagram of a typical loop is included in Appendix A.

Manual of the Judge Advocate General Investigation. Conducted to determine the cause of an accident, and to identify who should be held responsible for resulting damage.

Material Condition Circle X-Ray. A modification of Material Condition X-Ray. Permitted crew members to open certain pre-designated watertight fittings.

Material Condition Circle Yoke. A modification of Material Condition Yoke. Permitted crew members to open certain pre-designated watertight fittings.

Material Condition Circle Zebra. A modification of Material Condition Zebra. Permitted crew members to open certain pre-designated watertight fittings.

Material Condition X-Ray. The lowest degree of watertight integrity on a US Navy ship. Substantially eases crew access to interior compartments, but was rarely set.

Material Condition Yoke. The intermediate degree of watertight integrity on a US Navy ship. Provided a good balance between convenience for crew and ship safety, and was typically set inport or while ships operated in friendly waters.

Material Condition Zebra. The highest degree of watertight integrity on a US Navy ship. Substantially disrupts crew comfort, and is typically set for training, during emergencies, and prior to expected attack.

Operating Target. Funds allocated to individual ships to purchase items such as paint, damage control equipment, paper, and soap.

Oxygen Breathing Apparatus. Portable oxygen-generating protective gear worn by shipboard firefighters to protect them from toxic gases.

Pilot Landing Aid Television. Camera system that recorded events on aircraft carrier flight decks.

PKP extinguishers. Portable dry chemical fire extinguishers used aboard Navy ships.

Ship Alteration. Approved modification of a vessel to correct an identified deficiency.

William fittings. Shipboard fittings marked with a black letter “W”. These fittings were vital to ship operation, and were normally kept open regardless of which material condition was set.

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MIL-F-24385(NAVY)
21 November 1969
SUPERSEDING
MIL-F-23905B(AS)
25 April 1967

MILITARY SPECIFICATION

FIRE EXTINGUISHING AGENT, AQUEOUS FILM FORMING FOAM (AFFF) LIQUID CONCENTRATE, SIX PERCENT, FOR FRESH AND SEA WATER

This specification has been concurred in by interested commands of the Navy Department and the Marine Corps.

1. SCOPE

1.1 This specification covers the requirements for aqueous film forming foam (AFFF) liquid concentrate fire extinguishing agent consisting of fluorocarbon surfactants and foam stabilizers. The liquid concentrate will be diluted for use in concentrations of six parts concentrate to ninety-four parts fresh or sea water by volume.

2. APPLICABLE DOCUMENTS

2.1 The following documents, of the issue in effect on date of invitation for bids or request for proposal, form a part of the specification to the extent specified herein:

SPECIFICATIONS

FEDERAL
TT-E-489 - Enamel, Alkyd, Gloss (For Exterior and Interior Surfaces).
PPP-D-700 - Drums: Metal, 55-Gallon, (For Acid and Corrosive Liquids).
PPP-D-729 - Drums: Metal, 55-Gallon, (For Shipment of Noncorrosive Material).
PPP-D-1152 - Drum, Steel, 55-Gallon (24-Gage) Reinforced.
PPP-P-704 - Pails, Metal: Shipping Steel, (1 through 12 Gallon).

MILITARY
MIL-P-116 - Preservation, Methods of.
MIL-G-5572 - Gasoline, Aviation, Grades 80/87, 100/130,115/145.

STANDARDS

FEDERAL
FED-STD-595 - Colors.

MILITARY
MIL-STD-105 - Sampling Procedures and Tables for Inspection by Attributes.
MIL-STD-129 - Marking for Shipment and Storage.
MIL-STD-130 - Identification Marking of U.S. Military Property.
MIL-STD-147 - Palletized and Containerized Unit Loads, 40" x 48" Pallets, Skids, Runners, or Pallet-Type Base.

(Copies of specifications, standards, drawings, and publications required by suppliers in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

2.2 Other publications. The following documents form a part of this specification to the extent specified herein. Unless otherwise indicated, the issue in effect on date of invitation for bids or request for proposal shall apply.

AMERICAN SOCIETY FOR TESTING AND MATERIALS
ASTM A279-63 - Total Immersion Corrosion Test of Stainless Steels.
ASTM D445-65 - Test for Viscosity of Transparent and Opaque Liquids (Kinematic Viscosities).
ASTM D1141-52 (1965) - Substitute Ocean Water, Specification for.
ASTM D1298-67 - Test for Specific Gravity of Petroleum Liquids, Hydrometer Method.
ASTM D1331-56 - Tests for Surface and Interfacial Tension of Solutions of Surface Active Agents.

FSC 4210

(Application for copies should be addressed to the American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania 19103.)

(Technical society and technical association specifications and standards are generally available for reference from libraries. They are also distributed among technical groups and using Federal agencies.)

UNIFORM CLASSIFICATION COMMITTEE

Uniform Freight Classification Rules

(Application for copies should be addressed to the Uniform Classification Committee, 202 Union Station, 516 West Jackson Blvd., Chicago, Illinois 60606.)

NATIONAL CLASSIFICATION BOARD

National Motor Freight Classification Rules.

(Application for copies should be addressed to National Motor Freight Traffic Association, Inc., 1616 P Street, N.W., Washington, D.C. 20036.)

NATIONAL FIRE PROTECTION ASSOCIATION (NFPA)
NFPA No. 412 - Suggested Standard Test Procedures for Aircraft Rescue and Fire Fighting Vehicles Utilizing Foam (1969 Edition)

(Application for copies should be addressed to National Fire Protection Association, 60 Batterymarch Street, Boston, Mass. 02110).

3. REQUIREMENTS

3.1 Qualification. Liquid concentrate fire extinguishing agents furnished under this specification shall be products which are qualified for listing on the applicable Qualified Products List at the time set for opening of bids (see 4.3 and 6.3).

3.2 Material. The concentrate shall consist of fluorocarbon surfactants plus other compounds as required to conform to the requirements specified hereinafter. The material shall have no adverse effect on the health of personnel when used for its intended purpose.

3.3 Compatibility. The concentrate of one manufacturer shall be compatible with the concentrate furnished by the other manufacturers listed on the qualified products list for this specification. An admixture shall conform to 3.10, 3.11, and 3.13, when tested as specified in 4.7.7, 4.7.8, and 4.7.12. The percentages of the components in the admixture shall be determined by the testing activity.

3.4 Specific gravity. The specific gravity shall be determined as specified in 4.7.1. Samples tested subsequent to qualification shall deviate not more than 0.01 from the specific gravity value determined during qualification testing.

3.5 Viscosity. The concentrate shall have a maximum kinematic viscosity of 300 centistokes (cs) at 40° ± 0.1°F., when tested as specified in 4.7.2.

3.6 pH value. The concentrate shall have a pH value between 4.0 and 8.0 at 77° ± 1°F., when tested as specified in 4.7.3. Samples tested subsequent to qualification shall deviate not more than 0.5 from the pH value determined during qualification testing, but in no case shall be less than 4.0 or greater than 8.0 at 77° ± 1°F.

3.7 Surface tension. The solution shall have a maximum surface tension of 18 dynes per centimeter at 77° ± 1°F., when tested as specified in 4.7.4.

3.8 Interfacial tension. A 6-percent solution shall have a maximum interfacial tension of 5.0 dynes per centimeter at 77° ± 1°F., when tested as specified in 4.7.5.

3.9 Foamability. The solution of AFFF concentrate in water (six parts concentrate to ninety-four parts water by volume) shall produce a foam possessing an expansion of 7.0 minimum and a 25-percent drainage time of 3 minutes minimum value, when tested as specified in 4.7.6 with both fresh (tap) water and synthetic sea water.

3.10 Film formation and sealability. When tested as specified in 4.7.7, the film produced by the sample shall spread over the surface of the fuel, and shall result in a surface from which no sustained ignition of fuel vapors can be detected.

3.11 Fire performance.

3.11.1 Twenty-eight square-foot test. When tested for fire performance as specified in 4.7.8, the fire shall be completely extinguished with an application density of 0.10 gal/ft ^{2} (84-second application time) or less, and shall exhibit a 25-percent burnback time of at least 240 seconds.

3.11.2 Four-hundred square-foot test. When tested for fire performance as specified in 4.7.9, at least 85 percent of the fire shall be extinguished within 30 seconds and the total of the "percent of fire extinguished" values recorded at 10, 20, 30, and 40 seconds shall be 285 or greater.

3.11.3 Twelve-hundred sixty square-foot test. When tested for fire performance as specified in 4.7.10, at least 85 percent of the fire shall be extinguished within 30 seconds, and the total of the "percent of fire extinguished" values recorded at 10, 20, 30, and 40 seconds shall be 285 or greater.

3.12 Corrosion. When tested as specified in 4.7.11, the corrosion rate of the concentrate shall not exceed 25 milligrams per square decimeter per day (mdd) for cold rolled steel, 0.5 mdd for 6061T6 aluminum alloy, and corrosion-resistant steel (CRES 304). The corrosion rate of a 6-percent sea water solution shall not exceed 10 mdd for cupro-nickel (90 percent Cu-10 percent Ni).

3.13 Stability. The concentrate and solution in fresh water shall be tested as specified in 4.7.12. At the end of the required storage period, the concentrate samples shall show no evidence of precipitation or stratification. The diluted solution samples shall show no evidence of stratification, and precipitate formation shall not exceed 1 percent by volume. In addition, stored samples shall conform to the limits specified herein, except that foam expansion shall be no less than 6.0 (after storage), when tested as specified in 4.7.1, 4.7.5, 4.7.6, and 4.7.7.

3.14 Marking.

3.14.1 Identification marking shall be in accordance with MIL-STD-130. In addition, the marking on the containers (see 5.3) shall be in white characters against a blue background (see 5.1.1.3).

3.14.2 Two identical markings conforming to figure 1 shall be applied to containers so that the markings are located diametrically opposite. The markings shall be applied on the containers in such a manner that water immersion, contact with the contents of the containers, or normal handling will not impair the legibility of the marking. No paper labels shall be used.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for inspection. Unless otherwise specified in the contract or purchase order, the supplier is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified in the contract or order, the supplier may use his own or any other facilities suitable for the performance of the performance of the inspection requirements specified herein, unless disapproved by the Government. The Government reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure supplies and services conform to prescribed requirements.

4.2 Classification of tests. The inspection of the fire extinguishing agent shall be classified as follows:

(a) Qualification tests.
(b) Quality conformance inspection.
    (1) Examination of filled containers.
    (2) Quality conformance tests.
    (3) Production check tests.

4.3 Qualification tests. [1]Qualification tests shall be conducted at a laboratory satisfactory to the Naval Ship Engineering Center. Qualification tests shall consist of examination and qualification tests shown in table I.

4.3.1 Samples for qualification tests. Five filled 5-gallon containers are required for the qualification tests.

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[1] Application for qualification tests shall be made in accordance with "Provisions Governing Qualification SD-6" (see 6.3 and 6.3.1).

THIS END UP

U.S.

AQUEOUS FILM FORMING FOAM (AFFF) LIQUID CONCENTRATE

In accordance with

MILITARY SPECIFICATION MIL-F-24385

THIS FIRE EXTINGUISHING CONCENTRATE IS FOR USE BY DILUTION WITH WATER IN FIXED OR MOBILE SYSTEMS. IT MAY BE USED ALONE OR IN COMBINATION WITH "TWINNED" DRY CHEMICAL EQUIPMENT. THE CONCENTRATE MAY BE DILUTED FOR USE IN FLOW PROPORTIONING EQUIPMENT WITH SEA WATER OR FRESH WATER AT VOLUME PROPORTIONS OF SIX GALLONS CONCENTRATE TO 94 GALLONS WATER. IT MAY ALSO BE DILUTED FOR READY-USE STORAGE AS A SIX-PERCENT PREMIX SOLUTION WITH FRESH WATER ONLY.

FOR READY USE DO NOT STORE BELOW 32°F. AVOID PROLONGED STORAGE ABOVE 120°F.

DO NOT MIX WITH OTHER THAN LIQUID CONCENTRATE APPROVED UNDER SPECIFICATION MIL-F-24385 OR WATER.

MANUFACTURER'S NAME
ADDRESS
BATCH NO.
DATE OF MANUFACTURE.

Figure 1 - Container markings.

4.4 The examination and tests applicable to each classification shall be as shown in table I:

Table I - Categories of inspection

Reference	Title	Qualification	Quality conformance	Production check [2]
4.5.2	Examination of filled containers	X	X	X
3.3, 4.7.7, 4.7.8, 4.7.12	Compatibility	X		
3.4, 4.7.1	Specific gravity	X	X	
3.5, 4.7.2	Viscosity	X	X	
3.6, 4.7.3	pH value	X	X	
3.7, 4.7.4	Surface tension	X	X	
3.8, 4.7.5	Interfacial tension	X	X	
3.9, 4.7.6	Foamability	X	X	
3.10, 4.7.7	Film formation	X	X	
3.11.1, 4.7.8	Fire performance (28 sq. ft.)	X	X	X
3.11.2, 4.7.9	Fire performance (400 sq. ft.)	X	X	
3.113, 4.7.10	Fire performance (1260 sq. ft.)	X	[1]	
3.12, 4.7.11	Corrosion	X		
3.14, 4.7.12	Stability	X		

[1] Either the 400-square foot or 1260-foot fire test may be performed for quality conformance testing at the discretion of the supplier.

[2] Tests of this specification, in addition to the fire performance test, will be performed as necessary to insure that the sample is essentially identical to the product upon which qualification approval has been granted.

4.5 Sampling for quality conformance inspection.

4.5.1 Inspection lot. For purposes of sampling, a lot shall consist of all material manufactured as one batch and transferred from one mixing tank to the shipping container.

4.5.2 Sampling for examination of filled containers. A random sample of filled containers shall be selected in accordance with MIL-STD-105 at inspection level I. The acceptable quality level = 2.5 percent defective to verify compliance with all requirements regarding fill, closure, marking, and other requirements not requiring tests, as specified in 4.6.1, 5.1.1.1, and 5.1.1.2.

4.5.3 Sampling for quality conformance tests. Three filled 5-gallon containers shall be selected at random from each lot and used as one composite sample for the tests specified in 4.6.2, or three 5-gallon containers of the product shall be withdrawn from an agitated mixing tank prior to packaging. The results of the tests required by 4.6.2 shall be submitted to the Naval Ship Engineering Center or the designated Laboratory.

4.5.4 Sampling for production check tests. In addition to the sample selected for quality conformance tests, four additional 5-gallon containers from the first lot offered for delivery under a contract or order, and thereafter from any one lot in each group of ten successive lots shall be selected and forwarded to a laboratory designated by the Naval Ship Engineering Center for the tests specified in 4.6.3.

4.6 Quality conformance inspection.

4.6.1 Examination of filled containers. Each sample filled container shall be examined for defects of construction of the container and the closure, for evidence of leakage, and for unsatisfactory markings. Each filled container shall also be weighed to determine the amount of contents. Any container in the sample having one or more defects or less than required fill, shall not be offered for delivery, and if the number of defective containers in any sample exceeds the acceptance number for the appropriate sampling plan of MIL-STD-105, this shall be cause for rejection of the lot represented by the sample.

4.6.2 Quality conformance tests. The samples selected in accordance with 4.5.3 shall be subjected to the tests of table I, as applicable.

4.6.2.1 Action in case of failure. If the sample tested is found to be not in conformance with any requirement of this specification, the lot represented by the sample shall be rejected.

4.6.3 Production check tests. The samples selected as specified in 4.5.4 shall be composited by the designated testing laboratory, and the composite sample shall be subjected to the fire performance test specified in 4.7.8. In addition, the sample shall be subjected to such other tests of this specification as are necessary to determine that the sample is essentially identical to the product upon which qualification approval has been granted.

4.6.3.1 Action in case of failure. Acceptance of the first lot offered for delivery under a contract or order shall be withheld until a satisfactory report is received on the composite production check test sample. Thenceforth, except as hereinafter specified, acceptance and rejection of lots shall normally be on the basis of the sampling, examination, and tests specified in 4.5, 4.6, and 4.7 and acceptance shall not be withheld pending receipt of test reports on production check test samples. However, upon receipt of an unsatisfactory test report on a production check test sample, additional samples shall be selected from every subsequent lot offered for delivery. The samples so selected shall be submitted to a laboratory designated by the Naval Ship Engineering Center and shall there be subjected to the examination and tests specified in 4.6 and 4.7. Lots shall then be accepted only upon receipt of a satisfactory test report on the samples so selected. Additional testing shall be discontinued and lot acceptance returned to the normal basis when two successive lots have been accepted. The contractor shall not be permitted to submit more than three separate samples for production check tests (see 4.6.3) in the event of failure.

4.7 Test procedures.

(NOTE: Where sea water is required for tests, synthetic sea water in accordance with ASTM D1141-52 shall be used.)

4.7.1 Specific gravity. The specific gravity of the liquid concentrate shall be determined in accordance with ASTM Method D1298-67.

4.7.2 Viscosity. The viscosity of the liquid concentrate shall be determined in accordance with ASTM Method D445-65 using a capillary viscometer of appropriate size number at 40° ± 0.1°F.

4.7.3 pH value. The pH value of the liquid concentrate shall be determined potentiometrically, using a pH meter equipped with a glass electrode and a reference electrode.

4.7.4 Surface tension. The surface tension of a solution of 1 cc of the liquid concentrate in 370 cc of distilled water shall be determined in a Cenco DuNuoy tensiometer, or equal, in accordance with ASTM D1331-56 and until the readings come to an equilibrium (approximately 30 minutes).

4.7.5 Interfacial tension. The interfacial tension between reagent grade cyclohexane and a 6-percent by volume solution of the liquid concentrate in distilled water shall be determined in a Cenco DuNuoy tensiometer, or equal, in accordance with ASTM D1331-56, and until the readings come to an equilibrium.

4.7.6 Foamability. Foam samples for analyses shall be taken from the same equipment as used in the fire performance test specified in 4.7.8 which shall be operated in the same manner. A 6-percent solution shall be 70° ± 2°F. Foam shall be discharged from the nozzle held at hip height and directed onto the collection backboard from a distance of approximately 10 feet. The methods and procedures used shall be as specified in National Fire Protection Association Publication NFPA No. 412.

4.7.7 Film formation and sealability. The test shall determine the ability of a fire-extinguishing agent of the foam-forming type to develop a vapor-sealing film on a hydrocarbon fuel surface. As the foam drains, a small percentage of the liquid drop-out remains surface-borne and spreads to provide protection against reignition of exposed fuel.

4.7.7.1 A corrosion-resisting steel Graduated Measure of 1000 ml capacity (4-1/2 inches in diameter, 5 inches deep) (Cole-Parmer Co., Chicago, Illinois, or similar) shall be fitted at the top edge with two small metal clips protruding 1/8 inch into the opening. They shall serve to restrain an 80-mesh conical screen of corrosion-resisting steel (5 inches in height by 4-3/4 inches in diameter) from floating out of the container during the test. A Waring Automatic Blender, or similar, shall be used as the test foam maker (at 70° ± 5°F.).

4.7.7.2 First, 600 ml of 98-percent cyclohexane shall be placed into the Graduated Measure. One hundred ml of the 6-percent solution to be tested shall be foamed for 10 seconds at low speed in the blender. Two hundred ml of this foam shall be poured onto the fuel surface. The screen shall then be inserted into the measure and clipped firmly into place, and a stopwatch shall be started.

4.7.7.2.1 After 1 minute of elapsed time, a small flame shall be passed six times around the fuel surface at a height of 1/2 inch (± 1/8 inch). A small flash may occur but no sustained ignition shall result if an effective vapor-seal is present. This flame can be readily provided using a hand-held propane tank fitted with a capillary tubing outlet and adjusted with the valve to give about a 1-inch long pilot flame.

4.7.8 Fire performance (28-square-foot test).

4.7.8.1 Test site. The 28-square-foot fire performance test shall be conducted in a level circular pan 6 feet in diameter (28 square feet), fabricated from 1/4-inch thick steel and having sides 5 inches high, resulting in a freeboard of approximately 2-1/2 inches during tests. The pan shall be without leaks so as to contain gasoline on a substrate of water. The water depth shall be held to a minimum, and shall be used only to ensure complete coverage of the pan with fuel.

4.7.8.2 Test equipment. The nozzle used for applying agent shall be of a type available from National Foam System, Inc., West Chester, Pa., or equal, as a laboratory testing item with a flow rate of 2.0 gallons per minute (g.p.m.) at 100 pounds per square inch (p.s.i.) pressure. The outlet shall be modified by a "wing tip" spreader having a 1/8-inch wide circular arc orifice 1-7/8 inches long. (Bernz-o-matic flame spreader TX-1527, slightly pinched down.)

4.7.8.3 Test materials. The 6-percent solution in fresh water and sea water shall be 70° ± 10°F. The charge shall consist of 6-percent ± 0.1 percent concentrate in fresh water and sea water. The fuel shall be 10 gallons of gasoline conforming to MIL-G-5572.

4.7.8.4 Test procedure. No tests shall be conducted with wind speeds in excess of 10 miles per hour. The complete fuel charge shall be dumped into the diked area within a 60-second time period.

4.7.8.4.1 The fuel shall be ignited within 60 seconds after completion of fueling and shall be permitted to burn freely for 15 seconds before the application of the extinguishing agent.

4.7.8.4.2 The fire shall be extinguished as rapidly as possible and in the most effective and expeditious manner. This shall be achieved by maintaining the nozzle 3-1/2 to 4 feet above the ground and angled upward at a distance that permits the closest edge of the foam pattern to fall on the nearest edge of the fire. The nozzle shall be moved slowly from side to side to permit the foam pattern to fall from edge to edge of the fire. The operator shall move forward and around the area as the fire front recedes and shall always maintain the nozzle in the same attitude. When the fire is extinguished, the time-for-extinguishment shall be recorded continuing distribution of the agent over the test area until exactly 3 gallons of premix has been applied. (90-second application time.)

4.7.8.4.3 Burnback. The burnback test shall start within 30 seconds after the 90-second solution application. A weighted 1-foot diameter pan having 2-inch side walls and charged with 1 quart of gasoline shall be placed in the center of the area. (An eyebolt with an 8-inch shaft attached to the center of the pan and a 10-foot pole with a hook on the end will facilitate the placement of the pan.) The fuel in the pan shall be ignited just prior to placement. Burnback time shall commence at the time of this placement and terminate when 25 percent of the fuel area (7 square feet), (36-inch diameter), originally covered with foam is aflame. After the large test pan area will sustain burning, the small pan shall be removed.

4.7.8.4.4 A minimum of three runs each in fresh water and sea water of the 28-square foot test, including burnback, will be required for qualification. One run each in fresh water and sea water will be required for quality conformance and production check tests.

4.7.8.5 Results: The following shall be recorded:

(a) Time for extinguishment (seconds).
(b) Time for 25 percent area burnback (seconds).

The following shall be calculated and reported:

(a) Application density for extinguishment (gals/ft.^{2}) =

$$\frac{2\ \text{gal.}}{\text{min.}} \times \frac{1}{28\ \text{ft.}^2} \times \frac{\text{Extinguishment time (seconds)}}{60}$$

(b) Burnback time (seconds).

The results for each test run shall be reported.

4.7.9 Fire performance (400-square-foot test).

4.7.9.1 Test site. The fire test shall be conducted in a level circular area 22.6 feet in diameter (400 square feet). The base and surrounding dike shall be of material suitable for the containment of fuel on a substrate of water. The water depth shall be the minimum required to ensure complete coverage of the diked area with fuel.

4.7.9.2 Test equipment. The nozzle used for applying the agent shall be a Rockwood FFF nozzle with stream shaper designed to discharge 16 g.p.m. at 100 pounds per square inch (p.s.i.) or equal (available from Bliss-Portland, South Portland, Maine 04106). The test shall be run with the nozzle discharging 16 g.p.m. at 100 p.s.i. pressure at the nozzle (application rate 0.04 g.p.m. per square foot).

4.7.9.3 Test materials. The solutions in fresh water and sea water shall be 70° ± 10°F, and shall contain 6.0 ± 0.1 percent AFFF concentrate. The fuel shall be 150 gallons of gasoline conforming to MIL-G-5572.

4.7.9.4 Test procedure. No tests shall be conducted with wind speeds in excess of 10 miles per hour. The complete fuel charge shall be dumped into the diked area as rapidly as possible. Before fueling for any test run, all extinguishing agent from the previous test runs shall be removed from the diked area.

4.7.9.4.1 The fuel shall be ignited within 60 seconds after completion of fueling, and shall be permitted to burn freely for 15 seconds before the application of the extinguishing agent.

4.7.9.4.2 The fire shall be extinguished as rapidly as possible, and in the most effective and expeditious manner. This shall be achieved by maintaining the nozzle 3-1/2 to 4 feet above the ground and angled upward at a distance that permits the closest edge of the foam pattern to fall on the nearest edge of the fire. The nozzle shall be moved slowly from side to side to permit the foam pattern to fall from edge to edge of the fire. The operator shall move forward and around the area as the fire front recedes, and shall always maintain the nozzle in the same attitude.

4.7.9.4.3 A minimum of three runs each in fresh water and sea water of the 400-square foot fire performance test shall be required for qualification. One run each in fresh water and sea water will be required for quality conformance and production check tests.

4.7.9.5 Results. The "percentage of fire extinguished" at 10-second intervals after beginning application of the extinguishing agent shall be recorded. The values recorded at 10, 20, 30, and 40 seconds shall be summed and reported for each test run.

4.7.10 Fire performance (1260-square-foot test).

4.7.10.1 Test site. The fire test shall be conducted in a level circular area 40 feet in diameter (1260 square feet). The base and surrounding dike shall be of nonporous material for the containment of fuel on a substrate of water. The water depth shall be the minimum required to ensure complete coverage of the diked area with fuel.

4.7.10.2 Test equipment. The nozzle used for applying agent shall be a Rockwood FFF nozzle with double screen designed to discharge 50 g.p.m. at 100 p.s.i. (available from Bliss-Portland, South Portland, Maine 04106) or equal. The test shall be run with the nozzle discharging 50 g.p.m. at 100 p.s.i. pressure at the nozzle.

4.7.10.3 Test materials. The solution in fresh water and sea water shall be 70° ± 10°F., and shall contain 6.0 ± 0.1 percent AFFF concentrate. The fuel shall be 250 gallons of gasoline conforming to MIL-G-5572.

4.7.10.4 Test procedure. No tests shall be conducted with wind speeds in excess of 10 miles per hour. The complete fuel charge shall be dumped into the diked area as rapidly as possible. Before fueling for any test run, all extinguishing agent from the previous test runs shall be removed from the diked area.

4.7.10.4.1 The fuel shall be ignited within 60 seconds after completion of fueling, and shall be permitted to burn freely for 15 seconds before the application of the extinguishing agent.

4.7.10.4.2 The fire shall be extinguished as rapidly as possible, and in the most effective and expeditious manner. This shall be achieved by maintaining the nozzle 3-1/2 to 4 feet above the ground and angled upward at a distance that permits the closest edge of the foam pattern to fall on the nearest edge of the fire. The nozzle shall be moved slowly from side to side to permit the foam pattern to fall from edge to edge of the fire. The operator shall move forward and around the area as the fire front recedes, and shall always maintain the nozzle in the same attitude.

4.7.10.4.3 A minimum of three runs each, in fresh water and sea water, of the 1260-square foot fire performance test shall be required for qualification. One run each in fresh water and sea water will be required for quality conformance and production check tests.

4.7.10.5 Results. The "percentage of fire extinguished" at 10-second intervals after beginning application of the extinguishing agent shall be recorded. The values recorded at 10, 20,30, and 40 seconds shall be summed and reported for each test run.

4.7.11 Corrosion. The corrosion tests shall be conducted with the AFFF concentrate on cold rolled steel, corrosion-resistant steel (CRES 304), 6061T6 aluminum alloy, and with 6-percent solution prepared with synthetic sea water on cupro-nickel alloy consisting of 90 percent copper and 10 percent nickel as specified in ASTM A279-63. The metal coupons shall be approximately 1/16-inch thick and milled to a finished dimension of 1/2 inch by 3 inches. The metal coupons shall be two thirds immersed in the appropriate liquids and held for 38 days at a temperature of 98° ± 2°F. The container shall be capped to prevent evaporation. At the end of the exposure period, the weight loss shall be determined and calculated out on an mdd basis.

4.7.12 Stability. Three samples each of the concentrate and 6-percent solution in fresh water shall be placed in cylindrical glass containers of 1000 ml. capacity (approximately 2 inches in diameter and 19 inches high). The containers shall be stoppered to prevent evaporation and stored in an oven maintained at 135° ± 5°F. for 10 days. Additional samples of both concentrate and dilute solution stored shall be of sufficient quantity to perform the test specified in 4.7.6 after storage.

4.7.12.1 At the end of the exposure period, the concentrate samples shall show no evidence of precipitation or stratification. The diluted solution samples shall show no evidence of stratification, and precipitate formation shall not exceed 1 percent by volume. Precipitation shall be determined visually in the glass storage containers. Stratification shall be determined by visual examination and by subjecting specimens drawn from the top and bottom of the glass storage containers to the tests specified in 4.7.1, 4.7.5, and 4.7.7.

4.8 Inspection for preparation for delivery. Samples items and packages shall be selected in accordance with MIL-P-116 and inspected to verify conformance with the requirements of section 5.

5. PREPARATION FOR DELIVERY

(The preparation for delivery requirements specified herein apply only for direct Government procurements. For the extent of applicability of the preparation for delivery requirements of referenced documents listed in Section 2, see 6.4.).

5.1 Preservation and packaging. Preservation and packaging for levels A and C shall be as specified hereinafter.

5.1.1 The foam-forming liquid shall be furnished in 5-gallon pails or 55-gallon drums as specified (see 6.2).

5.1.1.1 Five-gallon pails. The five-gallon pails shall conform to type I, class 3 of PPP-P-704 and as follows:

(a) The interior of the pails shall have a coating system approved by Naval Ship Engineering Center which has demonstrated satisfactory resistance to the liquid concentrate. The supplier shall furnish appropriate data prior to qualification. Application of the coating shall ensure the packaged product from making contact with any metal part of the container.
(b) Pour openings shall have a minimum diameter of 1-1/4 inches.
(c) Wire handles shall be galvanized or protectively coated to resist corrosion.

5.1.1.2 Fifty-five gallon drums. Fifty-five gallon drums shall conform to type I of PPP-D-729, type I or III of PPP-D-700, or PPP-D-1152 at the option of the supplier.

5.1.1.2.1 Lining. Fifty-five-gallon drums shall be lined on all interior surfaces as specified for pails.

5.1.1.3 Exterior coating. Pails and drums shall have a bright blue exterior coating conforming to TT-E-489, color number 15123 of Federal Standard No. 595.

5.2 Packing. For levels A, B, and C, no further packing required.

5.2.1 Method of shipment shall comply with Uniform Freight or National Motor Freight Classification Rules or Regulations or other carrier rules as applicable to the mode of transportation.

5.2.2 Pallets. When specified (see 6.2), five-gallon pails shall be palletized in accordance with load type III of MIL-STD-147.

5.3 Marking. In addition to the marking specified in 3.14 and any special marking required in the contract or order, containers and palletized unit loads shall be marked in accordance with MIL-STD-129.

6. NOTES

6.1 Intended use. The concentrate is intended for use in mechanical foam generating equipment such as fire-fighting trucks or foam sprinkler systems for extinguishing fires in flammable liquids such as gasoline or fuel oils.

6.2 Ordering data. Procurement documents should specify the following:

(a) Title, number, and date of this specification.
(b) Level of packaging and packing required (5.1 and 5.2).
(c) Size of container required (5.1.1).
(d) Whether palletizing is required (5.2.2).

6.3 With respect to products requiring qualification, awards will be made only for such products as have, prior to the time set for opening of bids, been tested and approved for inclusion in Qualified Products List QPL-24385 whether or not such products have actually been so listed by that date. The attention of the suppliers is called to this requirement, and manufacturers are urged to arrange to have the products that they propose to offer to the Federal Government tested for qualification, in order that they may be eligible to be awarded contracts or orders for the products covered by this specification. The activity responsible for the qualified products list is the Naval Ship Engineering Center, Department of the Navy, Center Building, Prince Georges Center, Hyattsville, Maryland, 20782 and information pertaining to qualification of products may be obtained from that activity. Application for Qualification tests shall be made in accordance with "Provisions Governing Qualification SD-6" (see 6.3.1).

6.3.1 Copies of "Provisions Governing Qualification" may be obtained upon application to Commanding Officer, Naval Publications and Forms Center, 5801 Tabor Avenue, Philadelphia, Pennsylvania 19120.

6.4 Sub-contracted material and parts. The preparation for delivery requirements of referenced documents listed in section 2 do not apply when material and parts are procured by the supplier for incorporation into the equipment and lose their separate identity when the equipment is shipped.

Review activities:
AS

User activities:
OS, YD, MC

Preparing activity:
Navy - SH
(Project 4210-N051)

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The biodegradability of aqueous film-forming foams (AFFF) used for fire fighting was evaluated in laboratory-scale activated sludge and trickling filter reactors at the Air Force Weapons Laboratory (AFWL). Three AFFFs were evaluated: "Light Water" FC-200 from 3M Company; Aerowater 3 percent from National Foam Company; and Aerowater 6 percent, also from National Foam Company. Concentrations not to exceed 100 mg/l of AFFF influent to the biological treatment process could be satisfactorily treated without affecting the performance of the process and with apparent detoxification of the AFFF. More detailed bioassay tests are required. Adsorption of AFFFs onto activated carbon is practical with removals varying from 75 to 100 percent, depending on the AFFF.

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TREATABILITY OF AQUEOUS FILM-FORMING FOAMS USED FOR FIRE FIGHTING

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TECHNICAL REPORT NO. AFWL-TR-73-279

Final Report for Period June 1972 through August 1973

Approved for public release; distribution unlimited.

FOREWORD

The research was prepared under Program Element 63723F, Project 683M.

Inclusive dates of research were June 1972 through August 1973. The report was submitted 26 November 1973 by the Air Force Weapons Laboratory Project Officer, Lieutenant Ronald H. Kroop (DEE).

This technical report has been reviewed and is approved.

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ABSTRACT

(Distribution Limitation Statement A)

The biodegradability of aqueous film-forming foams (AFFF) used for fire fighting was evaluated in laboratory-scale activated sludge and trickling filter reactors at the Air Force Weapons Laboratory (AFWL). Three AFFFs were evaluated: "Light Water" FC-200 from 3M Company; Aerowater 3 percent from National Foam Company; and Aerowater 6 percent, also from National Foam Company. Concentrations not to exceed 100 mg/l of AFFF influent to the biological treatment process could be satisfactorily treated without affecting the performance of the process and with apparent detoxification of the AFFF. More detailed bioassay tests are required. Adsorption of AFFFs onto activated carbon is practical with removals varying from 75 to 100 percent, depending on the AFFF.

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ABBREVIATIONS AND SYMBOLS

AFFF	aqueous film-forming foam
COD	chemical oxygen demand
COD_T	total chemical oxygen demand
COD_F	filtrate chemical oxygen demand
BOD	biochemical oxygen demand
BOD_5	5-day biochemical oxygen demand
SS	suspended solids
MLSS	mixed liquor suspended solids
SVI	sludge volume index

SECTION I

INTRODUCTION

1. BACKGROUND

Aqueous film-forming foams (AFFF), MIL-F-24385, are fire-fighting agents for use on fuel and oil-type fires. Aqueous film-forming foams are concentrates and are, therefore, diluted prior to use. The specified dilution is 6 percent AFFF and 94 percent fresh or sea water. Aqueous film-forming foams have or are currently replacing the protein-type foams as the primary fire-fighting agent at most Air Force installations.

The Military Specification for AFFFs, MIL-F-24385, is a performance specification and, therefore, the composition of the products will vary to some extent. Basically, the AFFFs are fluorocarbon surfactants with foam stabilizers (Ref. 1). The fluorocarbon surfactant is likely to be a sulfonate compound such as sodium fluorocarbon sulfonate where the sulfonate group is soluble in water and the fluorocarbon group soluble in the fuel or oil. The fluorocarbon group is generally in the 8- to 10-carbon chain length. The foam stabilizer is likely to be a polyethylene glycol or glycol ether derivative (Ref. 2).

Three specific AFFFs were investigated by the Air Force Weapons Laboratory (AFWL) to determine the treatability and hazards of disposing of AFFFs. These were Light Water FC-200 manufactured by 3M Company, St Paul, Minnesota, and Aerowater 6 percent and Aerowater 3 percent manufactured by National Foam Company, West Chester, Pennsylvania. FC-200 is on the Qualified Products List (QPL) of the Military Specification, and Aerowater 6 percent is being considered at the time of this report. Aerowater 3 percent cannot satisfy the requirements of the Military Specification; however, hangar deluge systems may use a 3 percent AFFF instead of the 6 percent. FC-200 concentrate has a chemical oxygen demand (COD) of 710,000 mg/l and a pH of 7.4. Aerowater 6 percent concentrate has a COD of 456,000 mg/l and a pH of 7.6. Aerowater 3 percent concentrate has a COD of 495,000 mg/l and a pH of 8.0.

2. PURPOSE OF STUDY

The original purpose of this effort was to solve the specific problem of disposing of AFFFs from the "Crash Rescue Fire-Fighting Training Smoke-Abatement System" at Hill AFB, Utah. Basically, the smoke-abatement system consists of water-spray injection just above the burning fuel. For the system at Hill AFB the water injected into the fire would be collected, retained, and recirculated. Retention would be accomplished in an earthen reservoir. There was concern that the AFFFs used in the fire-fighting training would be solubilized in the spray injection water and through recirculation of this water, the AFFF concentration would increase to the point where the spray injection water would have a detrimental effect on the fire. Therefore, to prevent the AFFF concentration from "building up" in the recirculated water, an attempt was made to determine if microbial growth could be achieved in the reservoir when AFFFs represented the only source of organic matter for the microorganisms (the required nutrients added). If the microorganisms could use the AFFFs as a source of organic matter, the AFFF concentration might be kept low enough to prevent build-up problems.

During the Second Annual Environmental Workshop hosted by the Air Force Weapons Laboratory (AFWL), numerous major Air Command environmental coordinators expressed concern for disposing of AFFFs after use, whether in a real fire or in a training situation. This, coupled with concern voiced by Hq USAF/PRE about the disposal of large volumes of AFFF from proposed warehouse and hangar deluge systems, led AFWL to expand the effort to investigate the disposal of AFFFs in a more general situation. Of prime importance was the determination of the feasibility and the limitations of using existing biological waste treatment processes for achieving biodegradation and detoxification of the AFFFs. Also investigated was the use of activated carbon adsorption with the intent to employ a simple adsorption column at fire-training sites which are remotely located and unable to tie into a sanitary sewer. This would become an integral part of a smoke-abatement system. After treatment with activated carbon, water could then be directly discharged onto the land, into a water course, or possibly recycled into the water source of the smoke-abatement system.

SECTION II

LITERATURE REVIEW

The Environmental Health Laboratory at Kelly AFB, Texas, conducted an investigation on the biodegradability and toxicity of Light Water FC-199 (Ref. 3). On a macroscopic basis FC-199 is different from FC-200 in that the pH of FC-199 concentrate is in the range of 4.5. FC-200 was developed to eliminate the corrosive properties of FC-199.

Lefebre (Ref. 3) demonstrated a toxic effect to microorganisms, as measured by oxygen uptake rates, at an FC-199 concentration of 2500 ppm. Laboratory-scale continuous-flow activated-sludge reactors were operated on a mixture of synthetic sewage and varying concentrations of FC-199. At 250 ppm of FC-199 in the influents and a 12-hour detention time, COD and BOD_5 removals were 91 and 96 percent, respectively. At 500 ppm FC-199, detention time 6 hours, COD and BOD_5 removals were 90 and 96 percent, respectively. At 500 ppm there was significant inhibition of nitrification (Ref. 3).

Systematic bioassays were conducted on untreated FC-199 using fathead minnows. It was determined that the 96-hour LC_{50} (concentration at which 50 percent of the test fish are killed in 96 hours of exposure) was 398 ppm. Further, it was demonstrated that fathead minnows were able to survive during 8 days of testing in the clarified activated sludge reactor effluent when the FC-199 concentration was 250 ppm (Ref. 3).

The 3M Company has conducted some investigations into the disposal of Light Water FC-200, the AFFF product that they now manufacture. They have operated laboratory-scale continuous-flow activated-sludge reactors in which FC-200 was the only source of organic matter available to the microorganisms. At an FC-200 concentration of 250 ppm (COD - 175 mg/l), COD removal averaged 85 percent. At concentrations above 250 ppm, COD removal efficiency decreased. The source of microorganisms for the 3M Company laboratory-scale experiments was from their industrial wastewater-treatment plant activated-sludge reactor which has been receiving wastewater for years from the manufacturing of Light Water and other halogenated hydrocarbons (Ref. 4).

The 3M Company has also evaluated nonbiological methods of disposal. Oxidation with ozone, adsorption with activated carbon, foam fractionation, and incineration were investigated. Ozone oxidation and foam fractionation did not prove to be feasible. Incineration would be applicable only if the AFFF concentration were maintained fairly high, i.e., in the range of 1 to 6 percent. Activated carbon adsorption proved to be quite effective for dilute solutions of AFFF (Ref. 4).

Static bioassays have been conducted by the 3M Company on FC-200 using fathead minnows. It was demonstrated that both before and after biological wastewater treatment, the 96-hour LC_{50} was 80 ppm of FC-200 (Ref. 4).

SECTION III

MATERIALS AND METHODS

1. SCREENING EXPERIMENTS

The initial tests conducted on the three AFFFs consisted of 15-day biochemical oxygen demand (BOD) experiments using the static dilution technique. Biochemical oxygen demand tests for FC-200 were accomplished with both unacclimated and acclimated seed at an FC-200 dilution of 2/100,000. Aerowater 3 percent and Aerowater 6 percent concentrations were evaluated with unacclimated seed at a dilution of 1/100,000.

2. OXIDATION POND EXPERIMENTS

Four laboratory-scale oxidation ponds were operated at different organic loadings using Light Water FC-199 as the only source of organic matter available to the microorganisms. FC-199 was used because FC-200 had not yet been introduced at the time of the oxidation pond experiments. The oxidation ponds consisted of stainless steel water baths 18 inches (0.456 m) wide, 36 inches (0.912 m) long, and operated at a water depth of 10 inches (0.254 m). This yielded a liquid volume of 105 liters. The oxidation ponds were operated outdoors in direct sunlight during the months of May and June 1972. Originally, the oxidation ponds were filled with 103 liters of tap water and 2 liters of seed taken from the oxidation ponds on Kirtland AFB, New Mexico.

The primary purpose of the oxidation pond experiments was to simulate the loadings on the recirculation reservoir of the "Crash Rescue Fire-Fighting Training Smoke-Abatement System" at Hill AFB, Utah. To simulate the training operation which would be 3 to 5 days per month and several fires per day, Light Water was added to the four oxidation ponds in different amounts and at different time frequencies. Oxidation pond 1 (OP1) received 44 ml of Light Water concentrate initially to yield a 0.042 percent solution and a COD of 294 mg/l. For OP1 this was repeated every fifth day to simulate a fixed level of training every 5 days. The 44 ml was added in 4- to 11-ml aliquota every 2 hours for an 8-hour period. OP2 received 44 ml, repeated every tenth day. OP3 and OP4 received three times the amount of Light Water (132 ml) as did OP1 and OP2. This yielded an initial COD of 882 mg/l. Light water was added to OP3 every fifth day and to OP4 every tenth day. Ammonium nitrate and a phosphorous solution was added each time to maintain a COD:N:P ratio of 100:5:2. Evaporation losses were made up daily, and samples were then taken for COD and suspended solids determinations.

3. ACTIVATED SLUDGE EXPERIMENTS

Activated sludge experiments were conducted for each AFFF, using laboratory-scale continuous-flow completely mixed reactors with separate upflow clarification (figure 1). The reactor volume was 8 liters, and the clarifier volume was 3 liters. Retention time in the reactor was 4 hours, taking into account a 25 percent return sludge flow rate. Reactor 1 was the control and received only synthetic wastewater, simulating domestic sewage. The synthetic wastewater consisted of a protein source, nonfat dry milk, and a carbohydrate source (common sugar). The nonfat dry milk represented 220 mg/l of COD, as did the sugar. Ammonium chloride, NH_4Cl, or ammonium sulfate, $(NH_4)_2SO_4$, was added to yield 40 mg/l of NH_3N. A mixture of monobasic and dibasic potassium phosphate, KH_2PO_4 and K_2HPO_4, was added to yield 20 mg/l of P. Reactor 2

Figure 1. Activated Sludge Systems

received the synthetic wastewater and varying concentrations of FC-200. Reactor 3 received synthetic wastewater and Aerowater 3 percent. Reactor 4 received synthetic wastewater and Aerowater 6 percent. The last three reactors were brought to a steady-state condition with the synthetic wastewater before dosing with the AFFF.

Three separate activated sludge tests were conducted. Test 1 consisted of operating the four reactors until significant degradation in effluent quality occurred. Test 2 was conducted only on FC-200 and Aerowater 3 percent because the concentrations of each that yielded poor effluent quality in test 1 appeared too low. Therefore, the purpose of test 2 was to verify the results of test 1. It should be noted that near the end of test 2 reactor 4 was restarted on the synthetic wastewater and Aerowater 6 percent solely to provide an effluent for the toxicity experiments. Test 3 consisted of "slug loading" reactor 2 with 200 mg/l of FC-200 and reactor 4 with 200 mg/l of Aerowater 6 percent to determine the adverse effects, if any, on unacclimated microorganisms. This was done after the reactors were drained, reseeded, and brought to steady state on just the synthetic wastewater.

The AFFF concentration was increased in steps in each reactor for tests 1 and 2 (table I). It was originally intended to increase the AFFF concentration every 3 days; however, after observing the performance of the units, the frequency of increasing the AFFF concentration became variable, depending on the effluent quality. It should be noted that the influent wastewater was made during the late afternoon. Therefore increases in AFFF concentration were first reflected in the next morning's samples.

The performance of each reactor and the effluent quality was judged by analysis for mixed liquor suspended solids (MLSS), sludge volume index (SVI), total effluent COD, filtrate effluent COD, and effluent suspended solids (see analytical procedure for methods of analysis). Mixed liquor suspended solids (MLSS) and SVI were determined once a day in the morning. An attempt was made to maintain the MLSS concentration between 2000 to 3000 mg/l. Effluent samples were taken from a reservoir which contained 24 hours of flow and, therefore, represented composited samples.

Table I

AFFF CONCENTRATIONS IN ACTIVATED SLUDGE EXPERIMENTS

	AFFF concentration (mg/l)		
Day	FC-200	Aerowater 3 percent	Aerowater 6 percent
		Test 1	
1- 4	0	0	0
5- 7	10	10	10
8-11	25	25	25
12-13	50	50	50
14-23	80	80[1]	80
24-26	80[2]		120
27-32			150
33-37			210
38-53			250
		Test 2	
1- 4	0	0	
5- 8	10	10	
9-11	20	20	
12-19	50	50	
20-25	80	80	
26-32	120	120	
33-39	160	160	
40-44	200	200	
45-52	250	250	
53-59	320	320	0[4]
60-66	320[3]	400	75,[5] 125[6]
67-70		600	200[7]
		Test 3	
1- 8	200		200
9-11	0		200

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[1] Day 18 reactor shutdown.
[2] Day 26 reactor shutdown.
[3] Day 62 reactor shutdown.
[4] Reactor started; being brought to steady state.
[5] Reactor begins 75 ppm AFFF on day 63.
[6] Reactor begins 125 ppm AFFF on day 66.
[7] Reactor begins 200 ppm AFFF on day 69.

4. TRICKLING FILTER EXPERIMENTS

A laboratory-scale trickling filter (figure 2) was operated to determine the adverse effects that FC-200 and Aerowater 6 percent would have on the performance of the trickling filter process. The trickling filters consisted of two columns operated independently (in parallel). Both contained 5.5 feet (1.680 m) of polypropylene plastic media (Kock Flexirings* 5/8 inch (0.0175 m) 105 ft^2/ft^3 (348 m^2/m^3)). As illustrated in figure 2, samples could be taken at depths of 18 inches (0.456 m), 36 inches (0.912 m), and 66 inches (1.815 m, full depth). This final discharge entered a small clarification and recirculation basin which was flushed with tap water every 2 to 4 days to remove sloughed biological solids.

Both columns were brought to steady state on the synthetic wastewater as described in the activated sludge experiments. Then column A (the column on the left) received varying concentrations of FC-200, and column B received Aerowater 6 percent. The concentrations received versus time are shown in table II.

Two tests were conducted for the FC-200 and the Aerowater 6 percent. Test 1 was without recycle at a hydraulic loading of 200 gpd/ft^2 (8150 l/day/m^2), and test 2 was with a one-to-one recycle at a hydraulic loading of 200 gpd/ft^2, i.e., 100 gpd/ft^2 of influent and 100 gpd/ft^2 of recycled effluent. Between tests 1 and 2 the trickling filters received only synthetic wastewater for a period of 9 days.

Samples were taken from the two sampling ports of each column and from the final discharge. These samples were grab samples taken in the morning, with COD being the only parameter analyzed. Because the samples contained varying amounts of settleable solids, the samples were allowed to settle, and the supernatent was used for COD analysis.

5. ADSORPTION EXPERIMENTS

Both batch and continuous-flow activated-carbon adsorption experiments were conducted using Calgon Filtersorb 400 granular activated carbon. Only Aerowater 6 percent and FC-200 were evaluated. Solutions were made up to contain approximately 2000 mg/l of each AFFF. It was believed that this would represent

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*Registered trademark.

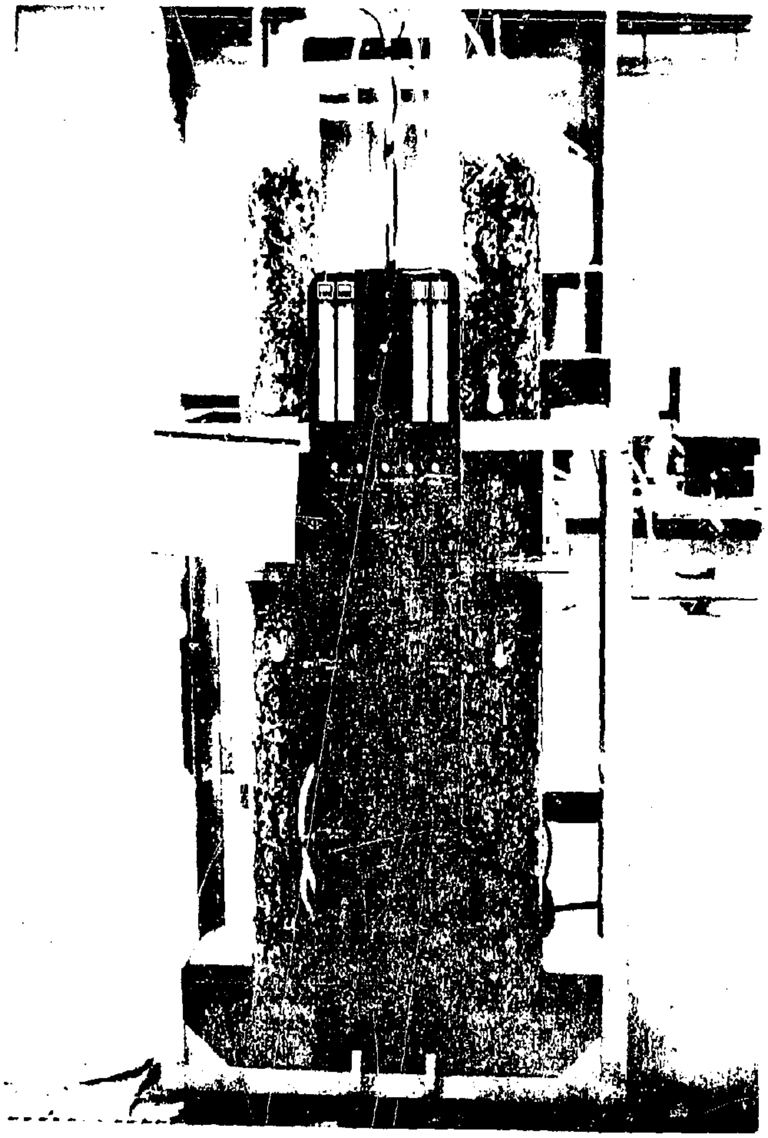

Figure 2. Trickling Filter System

Table II

AFFF CONCENTRATIONS IN TRICKLING FILTER EXPERIMENTS

	AFFF concentration (mg/l)	
Day	FC-200	Aerowater 6 percent
Test 1, No recycle		
1- 2	0	0
3- 6	25	25
7-11	50	50
12-16	80	80
17-20	120	120
21-35	160	160
Test 2, One-to-one recycle		
1	0	0
2- 8	25	25
9-14	50	50
15-21	80	80
22-29	120	120
30-37	160	160
38-45	200	200
46-50	250	250
51-54	300	300

an expected discharge of AFFF from a fire-training facility employing a water spray injection system for smoke abatement. For the batch tests, 4 liters of each AFFF solution were made. To 2 liters of each AFFF solution, 20 mls of JP-4 jet fuel were added, shaken, and allowed to separate. The purpose of adding JP-4 was to determine if certain compounds in the AFFF were preferentially soluble in JP-4 and would thereby be extracted from the aqueous phase. The effect of this extraction, if any, on the adsorption of the AFFF was determined by conducting batch adsorption tests on both the untreated (no JP-4) solutions and the aqueous phase of the JP-4-treated solutions. Five hundred ml erlenmeyer flasks were used, each containing 200 mls of solution and varying amounts of pulverized (-200 mesh) activated carbon. Five flasks were used for each solution, containing 0.1, 0.4, 0.8, 1.2, and 2.0 grams of activated carbon, weighed to four decimal places. The flasks were agitated for 1 hour on a gyratery shaker at 22°C, after which the activated carbon was removed by vacuum filtration, using GFC filter paper.

Continuous-flow experiments were conducted for the 2000-mg/l solutions (not treated with JP-4) of Aerowater 6 percent and FC-200. Small columns were used to achieve breakthrough in a reasonable time frame. The columns used were 1.25 inches (0.318 m) inside diameter and contained 24 inches (0.61 m) of activated carbon. The flow of 23.8 ml/min was set to yield an empty-bed contact time of 20 minutes. The flow was downflow with the discharge restricted to maintain a 2- to 3-inch liquid level above the activated carbon. Sampling ports were provided at 6 and 15 inches of activated carbon depth. Samples were taken periodically for analysis of COD.

6. TOXICITY EXPERIMENTS

To ascertain the detoxification, if any, that the biological wastewater treatment processes were achieving on the AFFFs, rainbow trout (4 to 6 inches in length (0.103 to 0.153 m)) were exposed to the activated sludge effluents (clarified effluent) from each reactor that, at the time, was receiving 200 mg/l of each AFFF. The trout were also exposed to the secondary effluent from the control. In addition, trout were exposed to each of the influents, i.e., synthetic wastewater and 200 mg/l AFFF, and to distilled water plus 200 mg/l AFFF. Four trout were added to each container having approximately 4 liters of liquid. The liquid was maintained at 10°C in an incubator and was aerated to maintain a dissolved oxygen concentration of 6 to 7 mg/l. During the test period (4 days), the liquid was changed once every 24 hours.

7. ANALYTICAL PROCEDURE

Chemical analyses were conducted on collected samples for determination of the desired compound (contaminant), thereby permitting evaluation of the treatment process performance. Chemical oxygen demands were determined in accordance with Standard Methods for the Examination of Water and Wastewater (Ref. 5). Both the standard and dilute technique were used as appropriate. Filtrate COD was determined on samples after filtering through GFC filter paper in accordance with Standard Methods.... For the activated sludge effluents, the effluent suspended solids and filtrate COD were determined from filtering of the same sample. For MLSS and SVI, 100 mls were drawn from the reactor, placed in a 100-ml graduated cylinder, and allowed to settle for 30 minutes, at which time the volume of settled solids was read. The 100 mls were then filtered through GFC filter paper for determineation of the MLSS. The SVI was then calculated from equation (1)

$$\text{SVI} = \text{mls of settled solids} \times 10{,}000/\text{MLSS} \qquad (1)$$

Free fluoride was analyzed for in the activated sludge effluents to determine if the fluorocarbon compound was being biologically metabolized, yielding free fluoride. This analysis was conducted using both the SPADNS method and the free ion electrode method described in reference 5.

Several attempts were made to develop a method of analysis for determining the fate of the fluorocarbon fraction of the AFFF. The first attempt was to measure the absorbance of infrared light energy for the fluorocarbon bond in the infrared region of 7.5- to 10-micron wavelength. Several concentrations of pure AFFF in distilled water were scanned in this wavelength region. IR-Tran cells of various cell thicknesses were used. In the concentration range of interest for the AFFFs, 1 to 300 mg/l, the strong absorbance of the water in the 7.5- to 10-micron wavelength made this technique impractical.

Since extraction of the fluorocarbon fraction from the aqueous phase into a solvent could not be quantified without having the pure fluorocarbon compound by itself, i.e., no method to determine extraction efficiency, an attempt was made to evaporate the sample, then take it up in a polar or nonpolar solvent. The solvents used were benzene, chloroform, carbon tetrachloride, iopropyl ether, hexane, and methanol. Fifty mls of sample were evaporated at 103°C in 100-ml test tubes, then 50 ml of solvent was added and agitated on a vortex mixer. The degree of resolubilization was determined visually. Aerowater 3 percent was the only AFFF that could be completely resolubilized, and this was in benzene. This was true even after 48 hours. However, the background adsorbance from benzene was too strong in the 7.5- to 10-micron wavelength. Thus, this technique was also ineffective for pure solutions.

The 3M Company developed a gas chromatographic technique for analysis of FC-200. However, "ghosting*" was a serious problem and made this method of analysis impractical. Further, it was learned from the 3M Company that the gas chromatographic method was for determination of the foam stabilizer fraction and not the fluorocarbon fraction.

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*Ghosting is subsequent elution of the organic compound when the next sample is injected.

SECTION IV

RESULTS

1. SCREENING EXPERIMENTS

The screening experiments consisted of determining the biological oxygen demand (BOD) uptake over a 15-day period. FC-200 was evaluated using both acclimated and unacclimated seed. The acclimated seed was obtained from the activated sludge reactor receiving FC-200. The two Aerowater AFFFs were only evaluated using unacclimated seed. The results of these experiments are detailed in figures 3 through 5. For FC-200 it is seen that the acclimated seed demonstrated a slightly increased rate of oxygen uptake but not a higher overall total uptake. The 5-day BOD for the concentrated FC-200 is approximately 70,000 mg/l with the ultimate BOD (assuming this to occur at the 15-day point) of approximately 360,000 mg/l. The BOD_5 of Aerowater 3 percent concentrate was approximately 75,000 mg/l with a BOD_{ult} of 315,000 mg/l. Aerowater 6 percent concentrate had a BOD_5 of 40,000 mg/l with the ultimate BOD in excess of 280,000 mg/l.

Because of the tremendous dilution required (2/100,000 and 1/100,000) to determine BODs by the static dilution technique, the "typical" first order curve did not result. This is not to say that the data are invalidated but rather points out the limitation of BOD analysis. The significance to be drawn from the BOD tests performed is that at least some of the compounds in the AFFFs are available for biological metabolism, and further untreated AFFFs discharged into a watercourse would exert a very high oxygen demand.

2. OXIDATION POND EXPERIMENTS

As described in section III, four oxidation ponds were operated to simulate the AFFF loadings on the recirculation reservoir of the "Crash Rescue Fire-Fighting Training Smoke-Abatement System" at Hill AFB, Utah. In a more general sense, the results of the oxidation pond experiments could be related to any oxidation or holding pond where AFFFs represented the only source of organic matter available to the microorganisms. The COD reductions achieved in oxidation ponds (OP) 1 and 2 are shown in figure 6. Reductions from OP3 and OP4 are shown in figure 7. Reiterating, OP1 was loaded with 0.042 percent FC-199

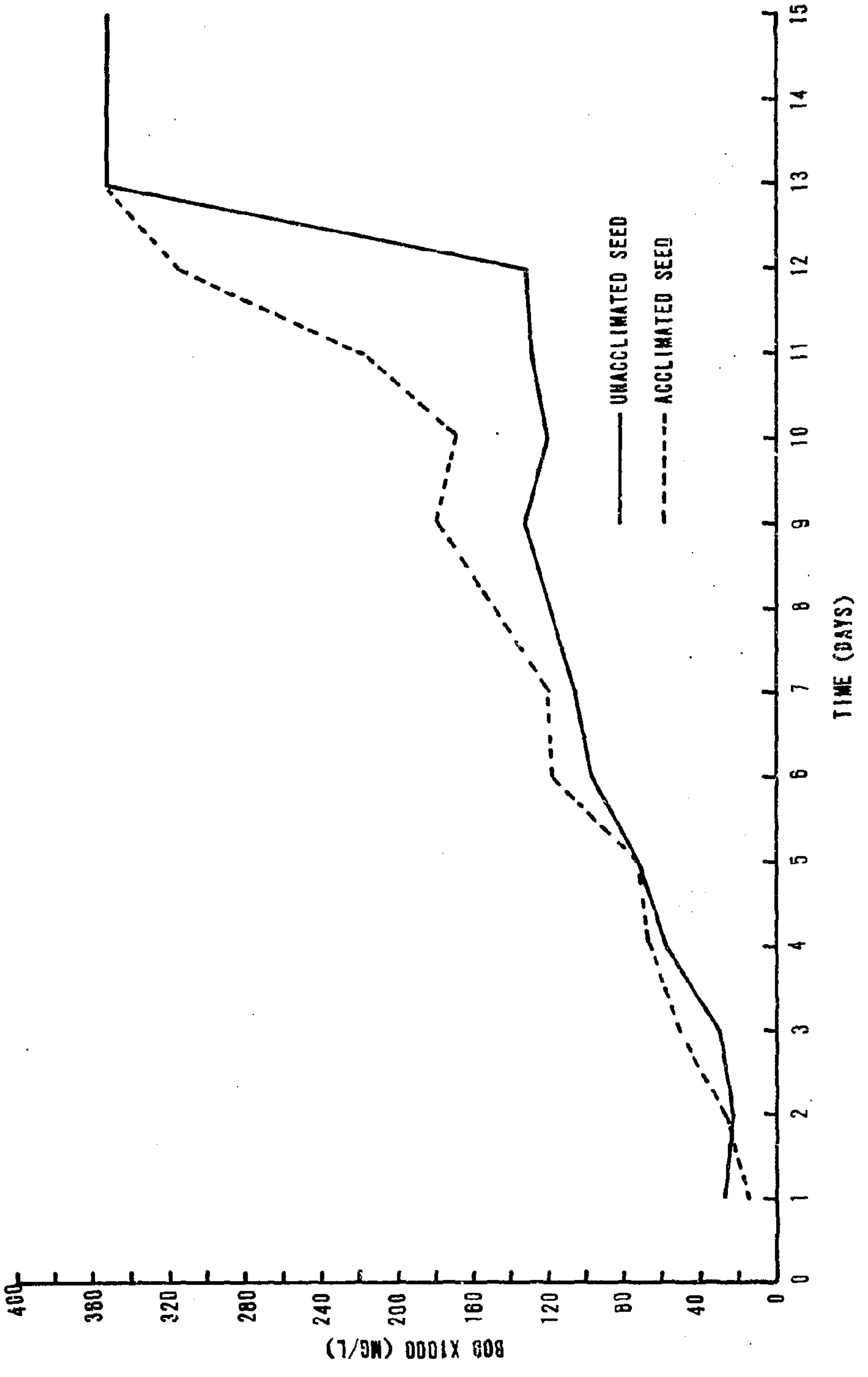

Figure 3. BOD Curve, FC-200

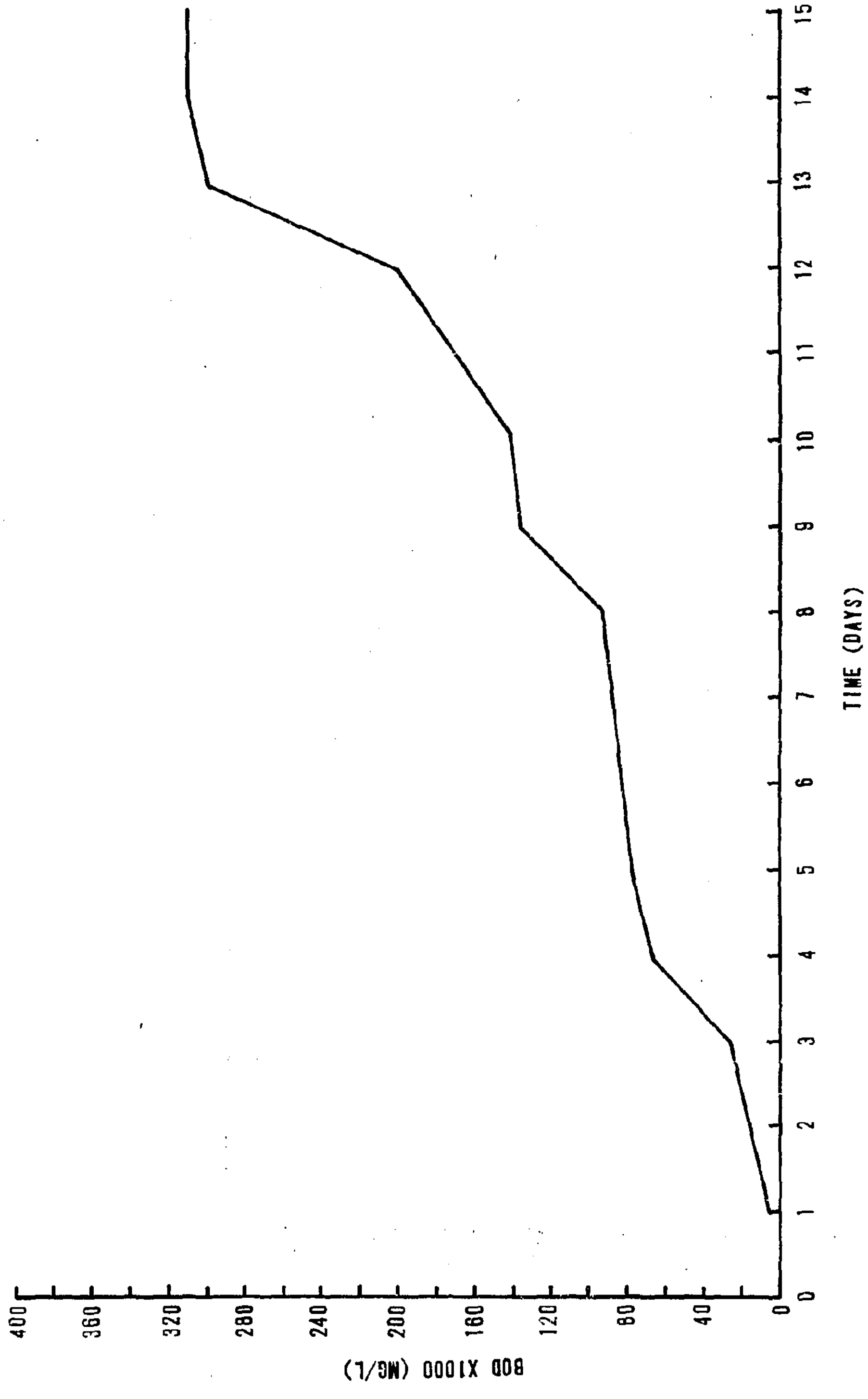

Figure 4. BOD Curve, Aerowater 3 Percent

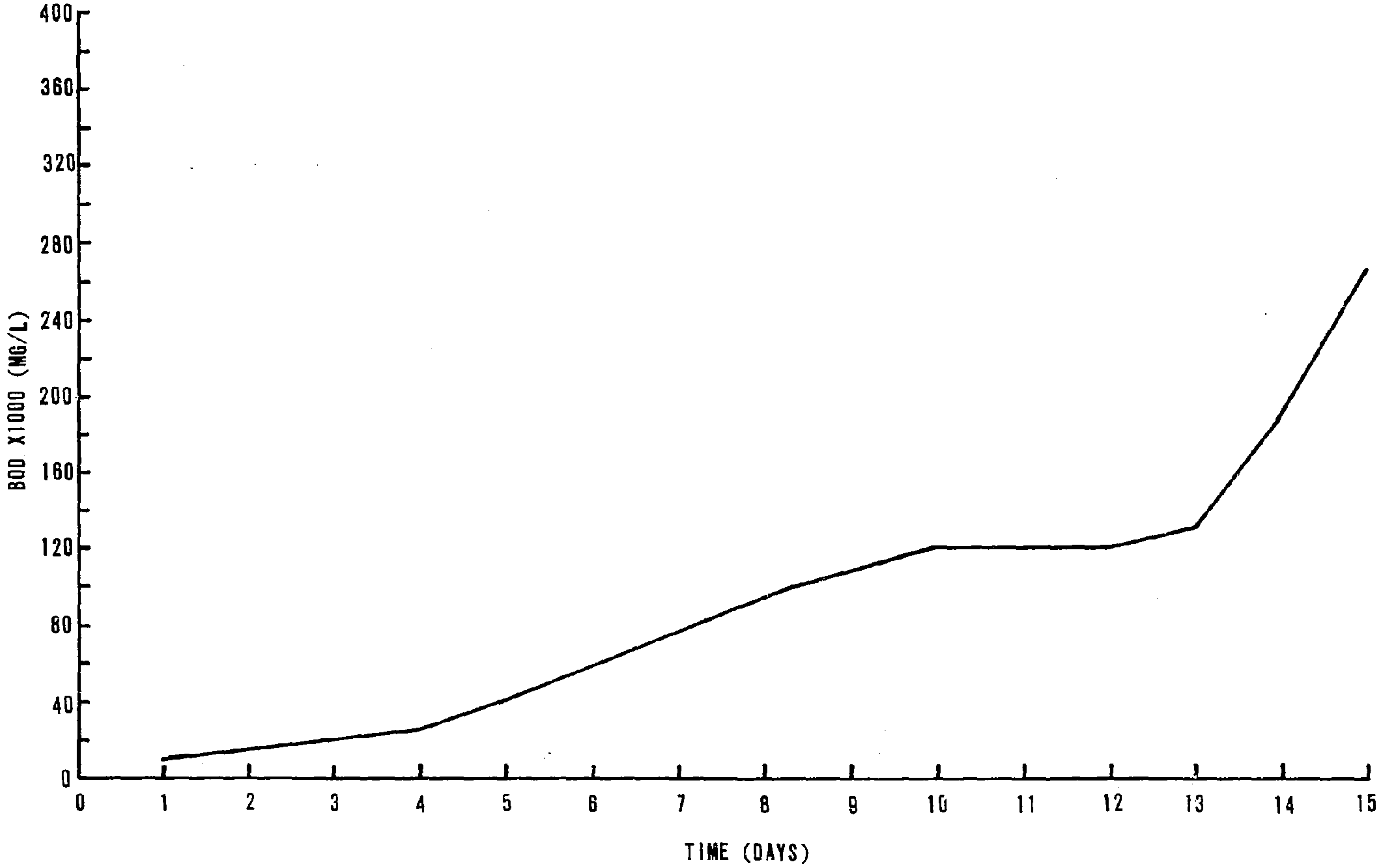

Figure 5. BOD Curve, Aerowater 6 Percent

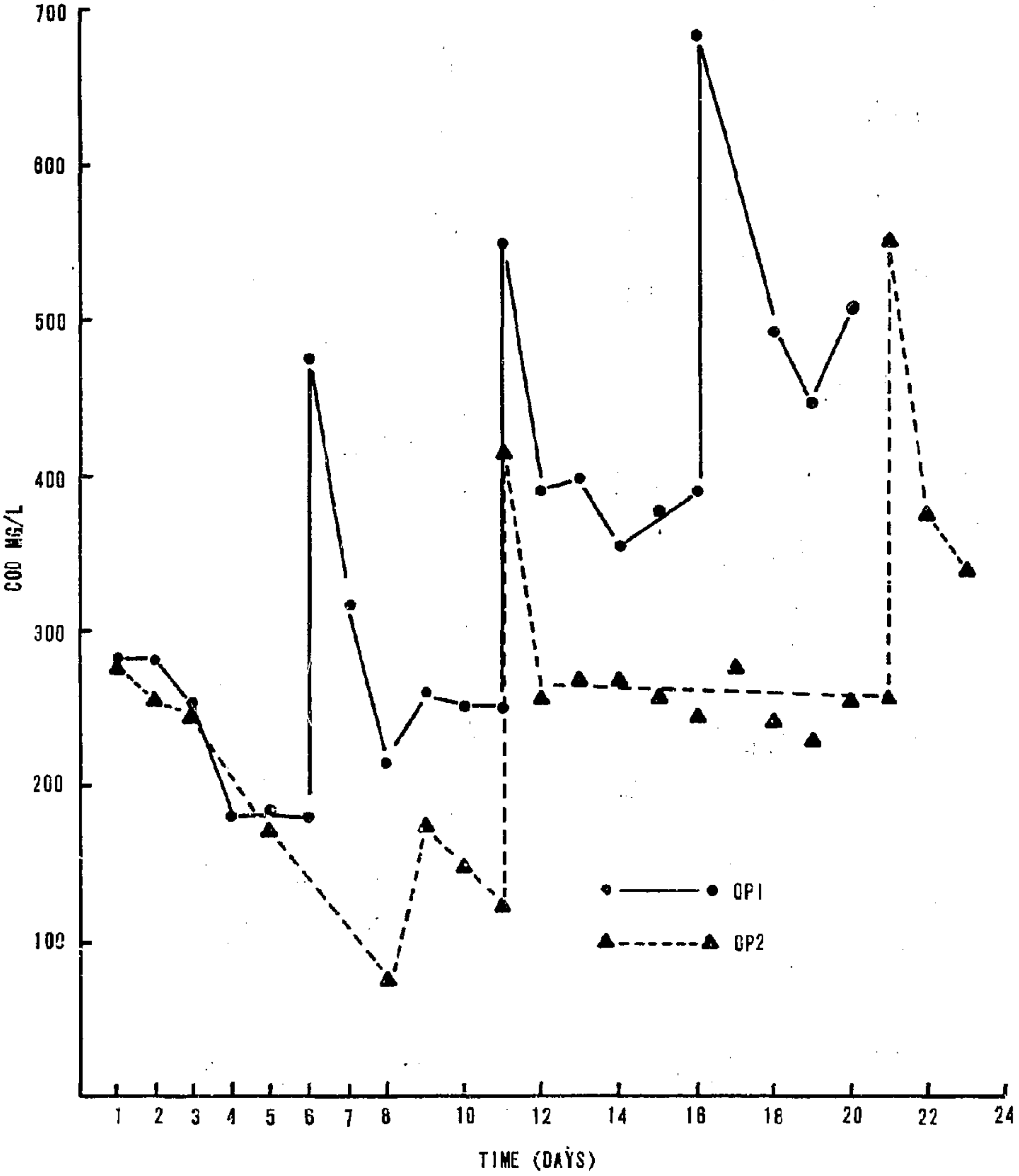

Figure 6. Oxidation Ponds 1 and 2, FC-199

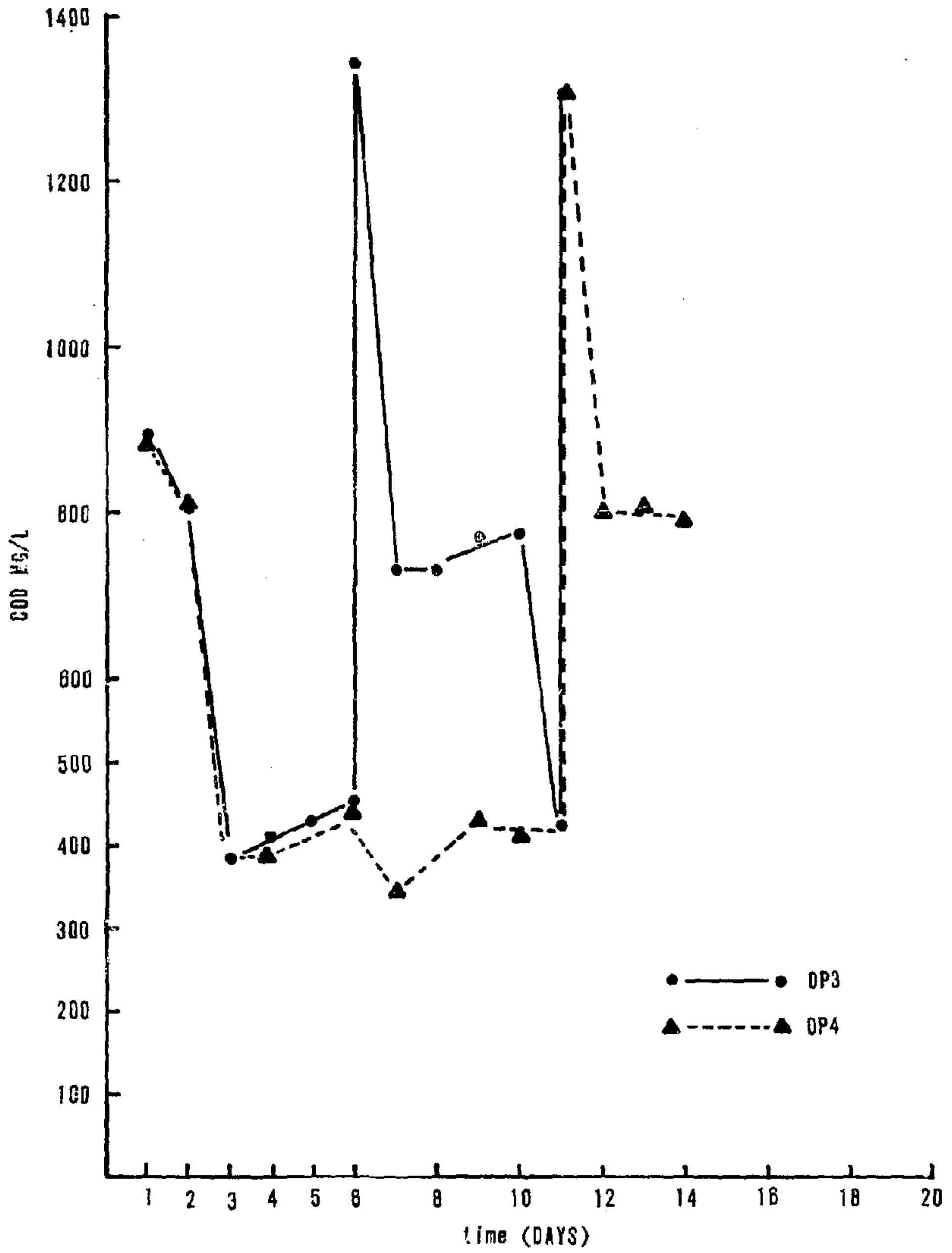

Figure 7. Oxidation Ponds 3 and 4, FC-199

every fifth day (initial COD - 294 mg/l) and OP2 every 10th day. Oxidation pond 3 was loaded with 0.136 percent FC-199 every fifth day (initial COD - 882 mg/l) and OP4 was loaded every 10th day. The results demonstrated a COD reduction occurring after dosing with FC-199 with most of the reduction occurring in the first 2 days after dosing. However, it is seen that there is a general build-up of some substance that is chemically but not biologically oxidizable. This COD reduction is not consistent with the concentration of suspended solids (taken to be biological solids) in the oxidation pond which did not increase with the decreasing COD, but rather followed no ascertainable pattern, varying in concentration between 10 and 70 mg/l for each of the oxidation ponds. If one assumes cell yields of 0.5 mg/l of biological oxidation of domestic wastewater to apply for the oxidation ponds, then biological solids concentrations in excess of 150 mg/l should have been observed.

The COD reduction achieved coupled with the lack of appreciable biological growth led to the assumption that some of the compounds in FC-199 were undergoing photochemical oxidation. Therefore, a fifth oxidation pond was set up but not seeded. The initial COD in this oxidation pond was 296 mg/l. Within the experimental error of the analysis, the COD concentration did not change over a 10-day period. Thus, it was concluded that photochemical oxidation was not the cause of the COD reduction. This leaves unanswered the reason for the observed COD reduction without appreciable biological growth.

3. ACTIVATED SLUDGE EXPERIMENTS

a. Test 1

The data collected for test 1 are listed in table III and are graphically represented in figures 8 through 11. The data show that none of the reactors were achieving proper settling characteristics as measured by sludge volume index and/or effluent suspended solids. This led to occasional use of alum (aluminum sulfate) and/or a cationic polyelectrolyte. Control of MLSS between 2000 to 3000 mg/l was attempted, but much of the time the reactors were outside of this concentration range. The control performance was more erratic than that desired. However, in general, COD removal was in the range of 85 to 90 percent for total effluent COD and consistently in excess of 90 percent removal for filtrate COD.

Table III

ACTIVATED SLUDGE ANALYSES, TEST 1

Day	COD_{INF}	COD_T	COD_F	SS_{EFF}	MLSS	SVI	Remarks
			Control				
1	500	24	24	<10	788	800	
2		44	48	<10	1086		
3		133	71	<10	1294	470	
4	440	55	16	48	1645	480	
5	445	95	103	26	2325	400	
6		82	38	34	2640	363	
7	466	62	25	14	2274	370	
8		24	25	16	2420	334	
9	457	150	34	18	2536		
10	474	68	41	18	2240	313	
11		53	37	25	2693	215	
12		73	49	21	2569	237	
13	434	57	41	15	2384	252	
14		43	31	<10	2262	252	
15		48	28	12	2652	294	
16		64	60	23	1079	639	
17		150	35	70	909	1023	Adding 20 mg/1 alum
18		43	20	14	1217	559	
19		46	23	12	1146	785	Discontinue alum
20		58	35	12	1290	450	
21		16	20	15	1343	707	
22		89	24	37	2383	411	
23	351	101	40	11	2860	339	
24		15	16	10	3625	270	
25		25	23	12	3375	190	
26		34	25	<10	4056	160	
27		17	22	<10	3364	214	
28		24	7	<10	2356	293	
29		8	14	<10	1958	460	
30		74	18	17	2114	426	
31		51	22	38	2319	328	

Table III (cont'd)

Day	COD_{INF}	COD_T	COD_F	SS_{EFF}	MLSS	SVI	Remarks
32		66	31	23	2208	290	
33		35	26	<10	2490	246	
34		40	36	41	2675	202	
35		32	53	43	2686	279	
36		72	14	50	2420	289	
37	351	58	15	44	2396	221	
38		40	27	10	2571	307	
39	454	33	33	20	2430	407	
40		50	21	34	1189	580	
41		74	33	14	1083	553	
42	No sample						
43		53	15	14	1464	410	
44		19	17	13	1453	475	Begin 1 mg/l polyelct. 10 mgl alum
45		182	36	123	1823	521	
46		124	23	114	1444	270	
47		75	18	27	1478	420	
48		89	32	21	1295	386	
49	345	73	38	14	1602	393	
50		59	19	13	1945	396	
51		92	80				
52		87	67	45	2146	261	
				FC-200			
1		81	40	40	774		
2		59	24	10	609		
3		67	86	12	1232	450	
4		59	31	15	1123	490	
5	445	82	40	<10	2240	402	First sample 10 mg/l FC-200
6		90	41	<10	2599	380	
7	404	88	33	13	2516	378	
8		60	38	27	1742	419	First sample 25 mg/l FC-200
9	468	120	73	45	1430		

Table III (cont'd)

Day	COD_{INF}	COD_T	COD_F	SS_{EFF}	MLSS	SVI	Remarks
10	474	155	51	91	914	492	First sample 50 mg/l FC-200
11		122	66	71	795	755	Adding 10 mg/l alum
12		219	93	105	403	695	Adding 20 mg/l alum
13	426	117	73	23	734	926	
14		83	59	16	690	1377	
15		171	60	77	565	1664	First sample 80 mg/l
16		100	72	49	661	1362	
17		77	73	<10	979	981	
18		83	58	18	526	760	
19		---	54	<10	939	958	
20		69	65	<10	1108	560	
21		48	52	<10	1015	887	
22		121	65	44	925	1081	
23		186	61	40	1394	710	
24		149	46	35	1477	670	
25		70	35	26	1288	776	
26		33	32	17	1565	633	
			Aerowater 3 Percent				
1		57	32	16	766	980	
2		48	28	15	421		
3		223	102	<10	1277	220	
4		55	35	18	1199	233	
5	450	198	155	61	2198	237	First sample 10 mg/l 3 percent
6		91	36	<10	2020	356	
7	428	62	25	16	3298	258	
8		48	57	26	2772	238	First sample 25 mg/l 3 percent
9	453	85	54	19	2856		
10	458	131	31	25	2591	208	First sample 50 mg/l 3 percent
11		91	44	33	2687	261	
12		93	53	35	2836	310	

Table III (cont'd)

Day	COD_{INF}	COD_T	COD_F	SS_{EFF}	MLSS	SVI	Remarks
13	481	105	93	37	3680	226	
14		39	31	10	3371	267	First sample 80 mg/l
15		187	44	90	3500	274	
16		300	68	108	2153	246	
17		340	62	393	1889	529	
18		130	38	65	326	552	
Aerowater 6 Percent							
1		73	49	22	501	860	
2		63	55	14	848		
3		180	43	11	1166	450	
4		47	27	12	1184	439	
5	450	77	64	15	2063	339	First sample 10 mg/l 6 percent
6		55	37	31	1300	484	
7	436	59	30	<10	2010	393	
8		44	44	<10	1277	297	First sample 25 mg/l 6 percent
9	485	73	51	15	687		
10	440	55	31	<10	1420	317	First sample 50 mg/l 6 percent
11		67	44	19	1055	351	
12		73	53	19	1998	385	
13	473	65	45	10	1823	521	First sample 80 mg/l 6 percent
14		71	47	<10	2400	417	
15		108	52	40	2434	403	
16		72	56	19	1610	602	
17		88	85	19	2494	401	
18		110	54	43	1469	640	
19		54	50	54	1448	663	
20		69	54	<10	3172	246	
21		40	40	12	2730	231	
22		49	28	<10	3684	166	
23	424	57	50	<10	2776	180	First sample 120 mg/l

Table III (cont'd)

Day	COD_{INF}	COD_{T}	COD_{F}	SS_{EFF}	MLSS	SVI	Remarks
24		45	48	14	3144	305	
25		117	26	32	3365	285	
26		96	65	27	2848	337	
27		73	40	26	3007	326	
28		56	25	29	2854	347	First sample 150 mg/l 6 percent
29		---	48	28	2955	332	
30		68	33	24	2112	459	
31		146	38	82	1914	381	
32		98	42	48	1988	342	
33		43	49	13	1226	285	
34		75	24	40	1600	150	First sample 210 mg/l 6 percent
35		66	33	98	1554	129	
36		59	40	12	1498	207	
37		48	37	10	1962	398	
38	529	89	54	33	2462	223	First sample 250 mg/l 6 percent
39	546	72	57	17	3052	193	
40		70	48	21	2877	247	
41		127	101	---	1636	410	
42		262	211	---	---	---	
43		172	114	33	2380	315	
44		105	80	76	2670	135	
45		162	94	31	1675	567	
46		367	134	147	938	597	
47		277	169	64	755	464	
48		230	153	47	728	1278	
49	456	278	110	95	911	1021	
50		182	112	61	1157	484	
51		158	118	---	---	---	
52		95	89	118	756	529	

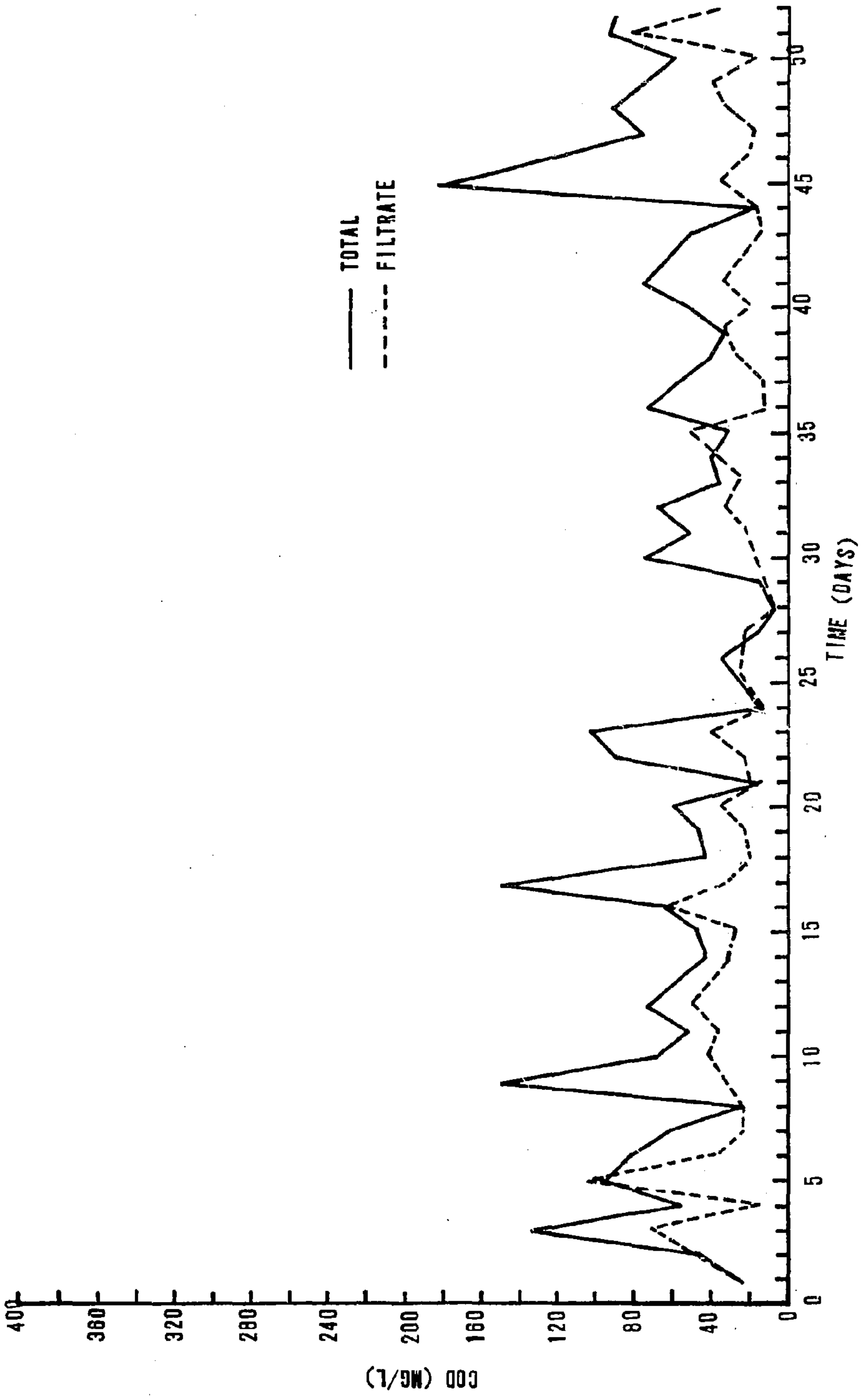

Figure 8. Test 1, Activated Sludge Effluent COD Control

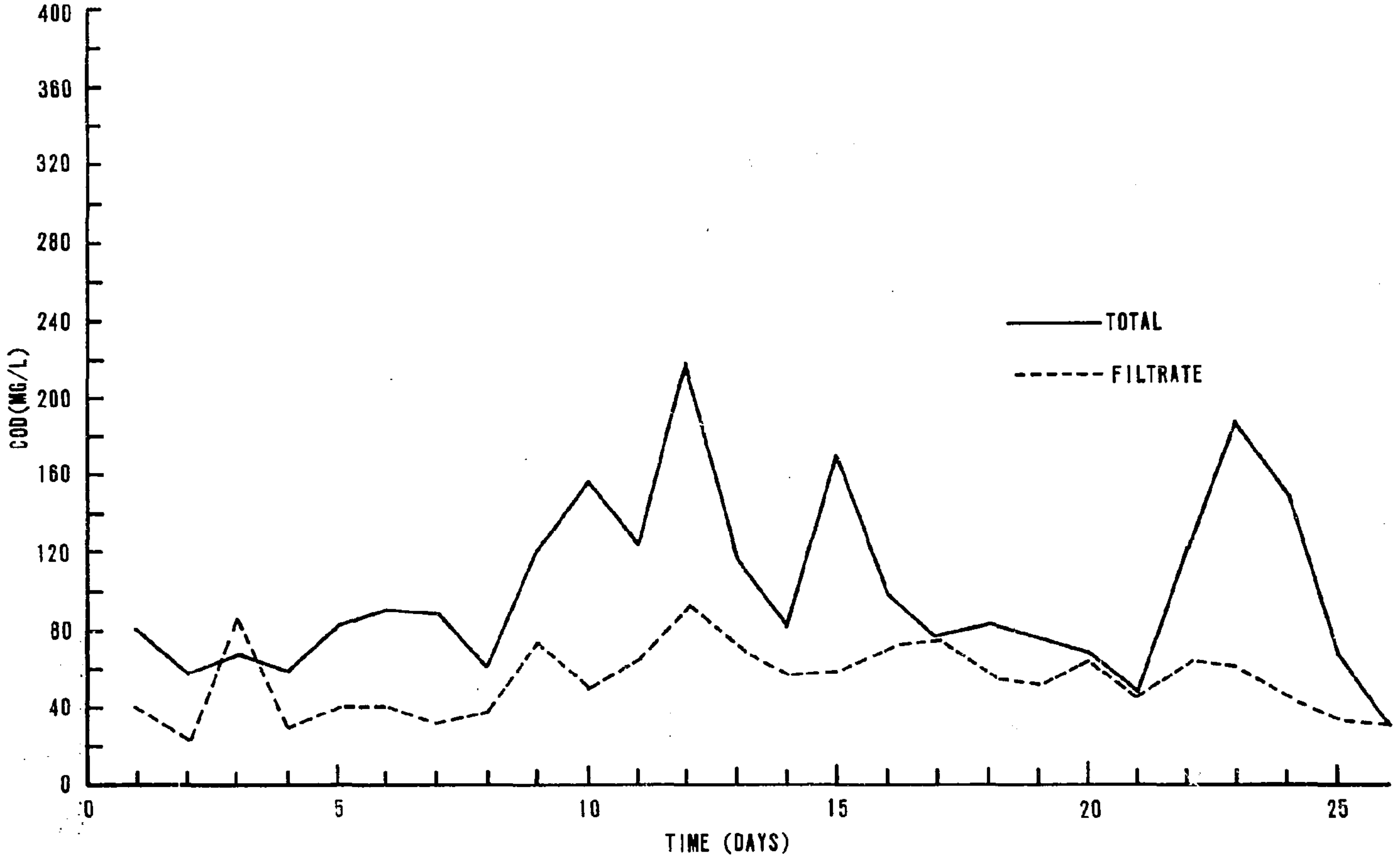

Figure 9. Test 1, Activated Sludge Effluent COD, FC-200

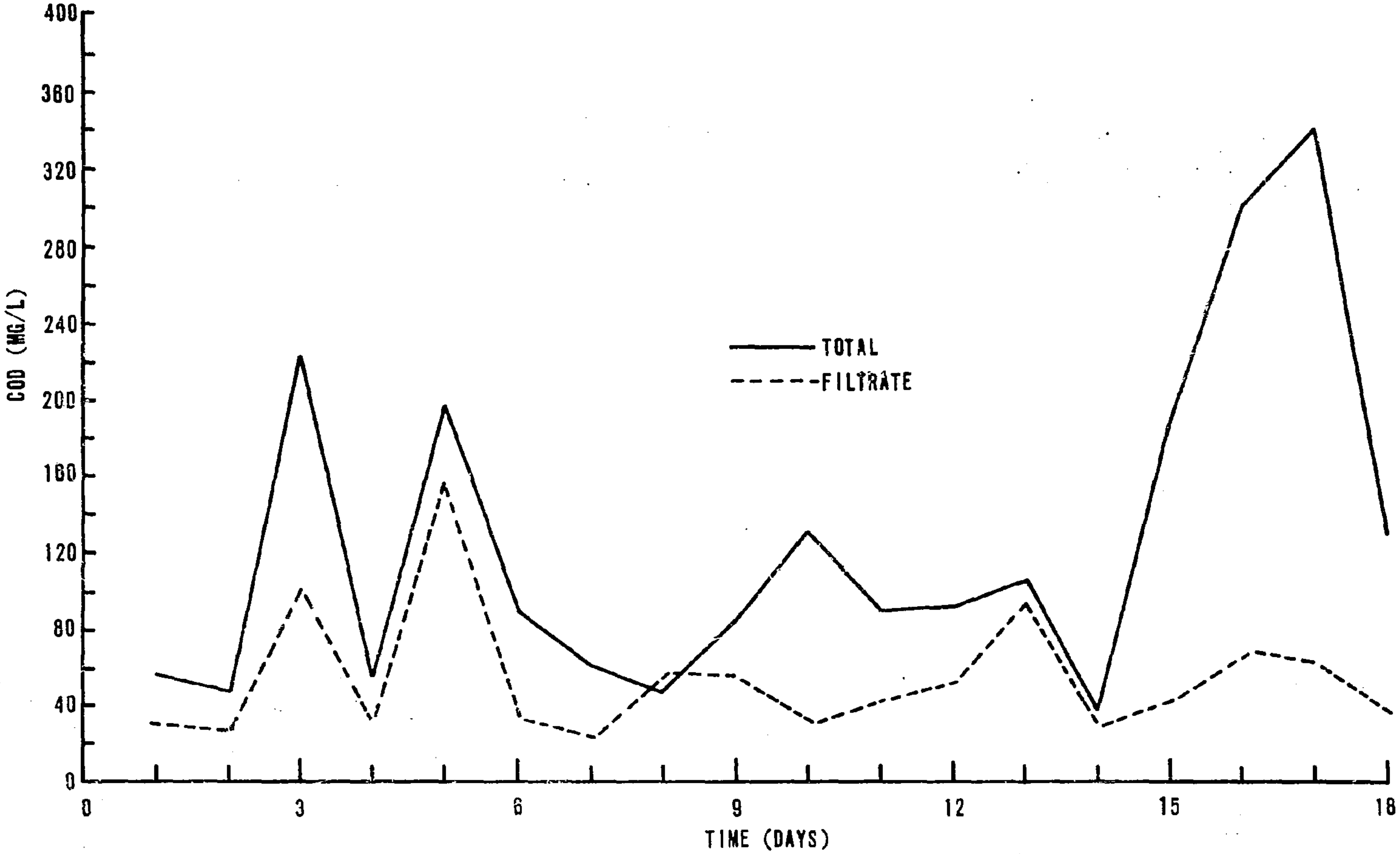

Figure 10. Test 1, Activated Sludge Effluent COD, Aerowater 3 Percent

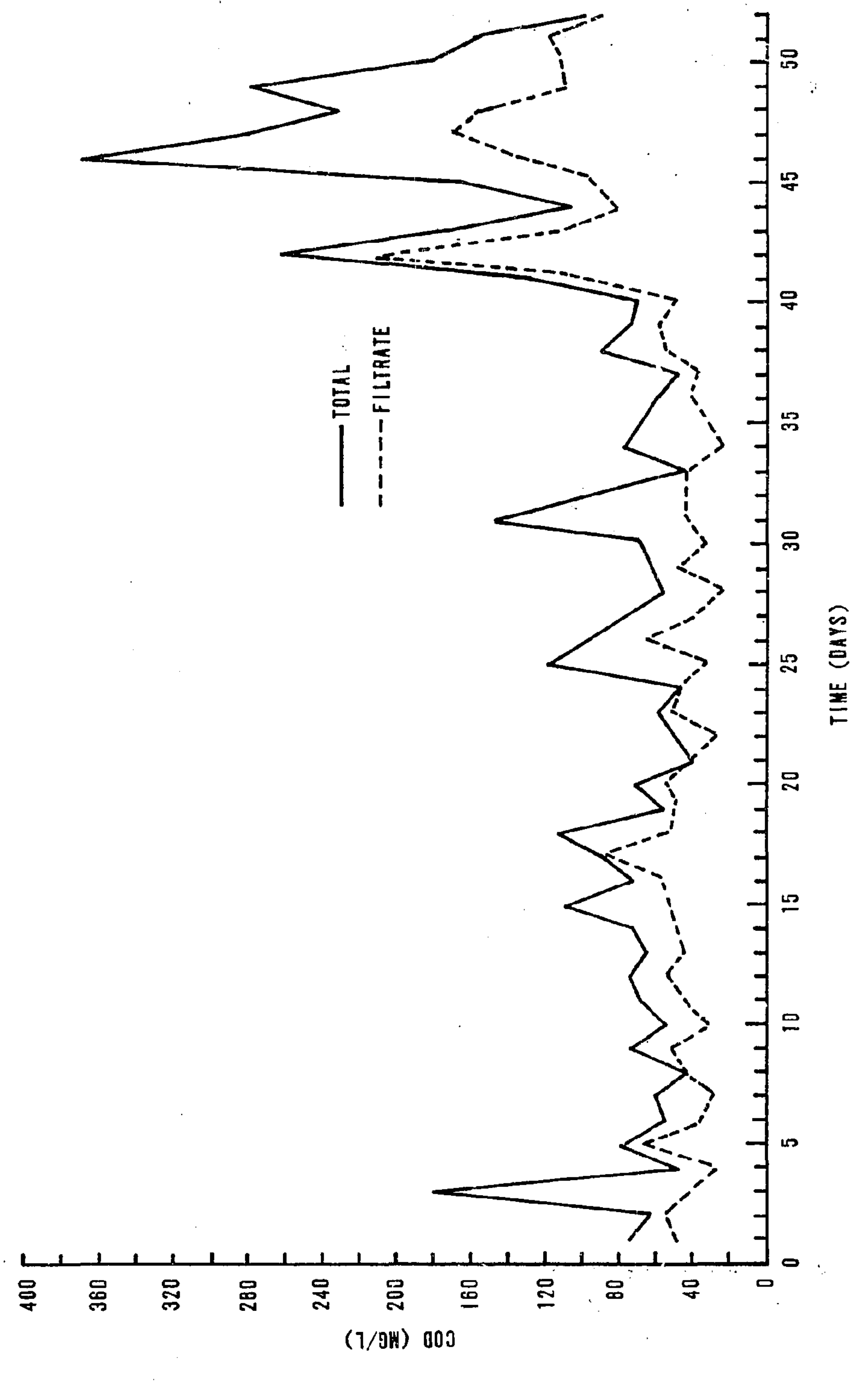

Figure 11. Test 1, Activated Sludge Effluent COD, Aerowater 6 Percent

For reactor 2 table III and figure 9 show that at the time the FC-200 concentration was increased to 50 mg/l, day 10, the MLSS decreased drastically, and the SVI increased roughly twofold. The use of alum to control this condition was only marginally successful. Effluent COD concentrations increased to unacceptable values. Although the FC-200 concentration was increased to 80 mg/l, it was clear that the activated sludge reactor performance had been upset at 50 mg/l of FC-200.

The performance of reactor 3, in which Aerowater 3 percent was used, yielded higher effluent CODs than either the control or the other two reactors up to the time (day 14) the concentration was increased to 80 mg/l. The total effluent COD increased drastically then, primarily because of effluent suspended solids. At day 16 the MLSS began to decrease rapidly, and the reactor was shut down on day 18.

Reactor 4 (Aerowater 6 percent) performance was reasonably consistent and acceptable (see table III and figure 11), although effluent CODs were somewhat higher than that of the control, until the concentration reached 250 mg/l. Shortly after the Aerowater 6 percent concentration was increased to 250 mg/l (day 38), the effluent COD, total and filtrate, increased significantly, the MLSS decreased, and the SVI increased appreciably at this time. It thus appeared that the activated sludge process could not tolerate 250 mg/l of Aerowater 6 percent.

b. Test 2

The results for test 2 are presented in table IV and figures 12 through 15. The primary purpose of test 2 (as stated in section III) was to determine if, in fact, the limiting concentrations of FC-200 and Aerowater 3 percent were valid. It is noted that during test 2, the performance of the reactors with respect to settlability and acceptable MLSS concentrations, effluent CODs, total and to some extent filtrate, were sporadic for the control. There were some mechanical difficulties encountered--the sludge recycle would stop during the night because of the geometry of the sludge hopper causing a clear zone with no sludge. This was corrected for the most part by keeping the volume of sludge in the bottom of the clarifier to a minimum.

The performance of reactor 2 (FC-200, table IV and figure 13) was unsteady during the initial dosing of FC-200, days 4 through 13, but was relatively satisfactory thereafter until day 37 when effluent quality began to

Table IV

ACTIVATED SLUDGE ANALYSES, TEST 2

Day	COD_{INF}	COD_T	COD_F	SS_{EFF}	MLSS	SVI	Remarks
1		69		Control			
1		69	30	26	2123	57	
2		54	38	21	2366	42	
3		52	32	22	2084	48	
4		41	25	<10	2453	45	
5		53	45	16	2557	43	
6	429	61	52	<10	2349	64	
7		71	49	<10	2009	50	
8		44	39	31	1840	54	
9	417	128	101	<10	1834	55	Solids concentration in clarifier
10	386	61	44	18	2353	47	No recycle or sludge
11	402	43	30	<10	1846	54	
12		70	33	38	2866	63	
13	394	218	162	61	3432	52	No sludge recycle
14		63	31	<10	3476	40	
15	No data						
16		46	44	13	3269	58	
17		84	35	42	2945	63	
18		184	39	36	2808	64	No sludge recycle
19		44	41	52	2999	63	
20	402	185	32	45	2866	59	No sludge recycle
21		86	24	15	2764	61	
22		37	35	87	2073	58	
23		62	35	30	2575	43	
24	422	145	40	35	2398	67	
25	414	72	52	17	2148	61	
26		39	34	14	2672	60	
27		36	34	<10	2972	47	
28	409	94	64	16	3710	43	
29		73	63	24	2658	56	
30		48	43	34	2237	63	

Table IV (cont'd)

Day	COD_{INF}	COD_{T}	COD_{F}	SS_{EFF}	MLSS	SVI	Remarks
31		26	21	29	3306	51	
32	382	30	28	53	3034	53	
33		27	20	<10	3217	50	
34		22	19	<10	3426	50	
35		25	25	12	4017	42	
36		24	21	17	3682	43	
37		28	27	35	4169	41	
38		42	30	13	2010	55	Upset; broken line
39	417	39	26	17	1968	61	
40		35	31	25	2148	56	
41		42	35	12	2105	57	
42		62	32	23	2396	71	
43		38	26	15	1819	71	
44	361	31	36	<10	2491	80	
45		37	33	21	1850	76	
46		87	---	23	2021	89	
47		168	42	27	1840	109	
48		50	27	11	1680	101	
49		47	35	23	1673	90	
50		45	37	<10	2451	78	
51		46	30	19	2271	88	
52	404	90	30	34	2204	109	
53	456	16	12	<10	2289	100	
54		30	30	12	2607	84	
55		29	37	<10	2213	90	
56		32	30	12	2015	84	
57		34	48	<10	2254	80	
58		64	70	<10	2216	81	
59	445	57	56	<10	3121	61	
60		44	58	10	3541	56	
61		41	27	<10	3580	50	
62		56	30	12	3733	54	
63		54	49	16	3997	50	

Table IV (cont'd)

Day	COD_{INF}	COD_T	COD_F	SS_{EFF}	MLSS	SVI	Remarks
64	454	112	117	18	3820	47	
65		65	37	22	3916	51	
66	461	52	47	26	3795	50	
67				11	3897	44	
68	414	44	36	14	4319	46	
69				26	3042	49	
				FC-200			
1		34	32	13	1491	67	
2		50	32	39	1770	51	
3		51	33	19	1814	50	
4	345	62	32	32	2083	67	First sample 10 mg/l FC-200
5		44	32	29	2351	51	
6	444	52	39	<10	2698	41	
7		184	66	122	2038	54	
8		153	47	27	2279	57	
9	474	111	94	<10	2260	62	First sample 20 mg/l FC-200
10	339	68	46	24	2100	67	
11	402	43	30	<10	1846	54	
12		104	58	31	1861	65	First sample 50 mg/l FC-200
13		215	162	35	1700	65	
14	375	53	43	20	2111	62	
15	No data						
16		79	46	55	2584	58	
17		71	47	36	2146	65	
18		84	26	44	1756	68	
19		49	44	54	1560	64	
20	480	54	50	92	1231	73	First sample 80 mg/l FC-200
21		56	45	22	1618	68	
22		114	36	81	1354	66	

Table IV (cont'd)

Day	COD_{INF}	COD_{T}	COD_{F}	SS_{EFF}	MLSS	SVI	Remarks
23		40	38	51	1635	27	
24	484	35	27	14	2500	60	
25	471	79	61	20	2430	62	
26		89	36	28	3139	54	First sample 120 mg/l FC-200
27		45	45	11	3100	45	
28	504	61	53	22	3625	50	
29		98	56	24	3266	55	
30		43	43	35	4160	48	
31		61	45	31	4414	41	
32	546	44	39	30	4654	39	First sample 160 mg/l FC-200
33		59	42	10	4175	50	
34		90	41	53	3520	55	
35		58	54	18	3374	50	
36		49	45	19	3386	53	
37		41	39	32	3612	53	
38		48	39	25	3982	50	
39	551	76	67	15	3406	59	First sample 200 mg/l FC-200
40		98	84	33	3808	32	
41		108	108	13	3758	67	
42		139	118	117	3674	63	
43		134	63	63	3209	65	
44	615	72	67	<10	3749	53	First sample 260 mg/l FC-200
45		---	---	44	3470	52	
46		60	50	20	2558	63	
47		139	139	17	2549	59	
48		40	39	<10	2211	59	
49		43	43	23	1872	69	
50	No data; reactor overflowed						
51	No data; reactor overflowed						
52	645	98	71	10	835	96	First sample 320 mg/l
53	537	170	95	25	1414	78	

Table IV (cont'd)

Day	COD_{INF}	COD_T	COD_F	SS_{EFF}	MLSS	SVI	Remarks
54		173	97	39	902	499	
55		180	78	58	962	343	
56		165	77	46	1257	684	
57		86	34	60	2227	292	
58		191	66	46	1433	188	
59	671	176	109	70	1559	603	
60		158	86	83	1474	468	
61		158	110	39	1149	305	
			Aerowater 3 Percent				
1		84	55	37	1509	60	
2		53	37	31	1431	49	
3		33	27	10	1522	53	
4	418	30	25	<10	1825	49	First sample 10 mg/l 3 percent
5		52	41	14	2098	43	
6	421	52	48	<10	2305	52	
7		111	71	32	2013	50	
8		84	57	21	2412	54	First sample 20 mg/l 3 percent
9	472	182	89	<10	2062	49	
10	449	77	41	33	1706	41	
11	425	46	43	<10	1649	67	
12		75	43	24	1904	74	First sample 50 mg/l 3 percent
13	394	261	152	65	1258	70	
14		46	41	86	1615	124	
15	No data						
16		47	47	10	1575	70	
17		54	43	12	1592	85	
18		68	43	19	1761	85	
19		44	44	23	1810	88	
20	457	77	46	36	1522	72	First sample 80 mg/l
21		140	47	112	1662	90	
22		37	36	57	1434	77	

Table IV (cont'd)

Day	COD_{INF}	COD_T	COD_F	SS_{EFF}	MLSS	SVI	Remarks
23		46	29	32	1792	51	
24	465	69	32	43	2310	71	
25	457	76	58	22	2540	71	
26		60	40	33	3330	60	First sample 120 mg/l 3 percent
27		47	42	<10	3166	58	
28	465	91	63	22	3720	48	
29		78	56	23	2847	60	
30		38	33	39	3682	52	
31		51	43	37	3232	56	
32	515	41	35	---	3736	51	First sample 160 mg/l 3 percent
33		44	27	13	3441	55	
34		37	37	<10	3779	53	
35		36	37	13	3880	46	
36		49	41	28	3609	53	
37		45	46	19	3867	52	
38		66	48	15	3626	50	
39	528	57	47	24	3770	53	First sample 200 mg/l 3 percent
40		66	50	35	3974	58	
41		71	56	22	3637	52	
42		77	49	40	3940	53	
43		47	36	13	4048	52	
44	486	54	57	10	4519	51	First sample 260 mg/l 3 percent
45		54	66	15	3896	54	
46		62	22	22	4374	50	
47		101	56	31	4272	56	
48		43	39	<10	4474	51	
49		61	46	14	4556	55	
50		63	55	<10	4949	51	
51		62	45	<10	5418	42	
52	562	63	63	<10	5230	52	First sample 320 mg/l 3 percent
53	458	65	62	<10	6027	50	

Table IV (cont'd)

Day	COD_{INF}	COD_T	COD_F	SS_{EFF}	MLSS	SVI	Remarks
54		58	67	18	5857	51	
55		112	65	11	5830	45	
56		106	73	13	4709	42	
57		75	74	<10	5172	43	
58		103	93	11	5152	37	
59	634	152	105	23	2490	40	First sample* 400 mg/l 3 percent
60		140	100	49	2858	35	
61		121	82	36	2867	35	
62		122	79	37	3374	36	
63		90	92	152	2977	34	
64	530	110	98	21	3456	32	
65		93	90	20	4061	30	
66	722	102	69	35	4026	35	First sample 600 mg/l 3 percent
67		---	---	38	3664	27	
68	659	304	77	100	2654	30	
69		412	98	147	---	---	

---

*Foaming causing bacteria to wash out of reactor

Aerowater 6 Percent

Day	COD_{INF}	COD_T	COD_F	SS_{EFF}	MLSS	SVI	Remarks
1		---	---	---	3051	187	
2		69	49	35	3565	79	
3		48	19	15	3506	80	
4		61	30	31	3451	72	First sample 75 mg/l 6 percent
5		46	51	11	4048	67	
6		155	89	19	4227	62	
7	510	69	50	13	4485	65	First sample 125 mg/l 6 percent
8		41	31	15	4094	66	
9		---	---	<10	3994	60	
10		53	58	13	4636	58	First sample 200 mg/l 6 percent

Table IV (cont'd)

Day	COD_{INF}	COD_T	COD_F	SS_{EFF}	MLSS	SVI	Remarks
11		---	---	29	4590	61	
12		61	58	<10	3190	72	
13		39	40	17	2712	92	

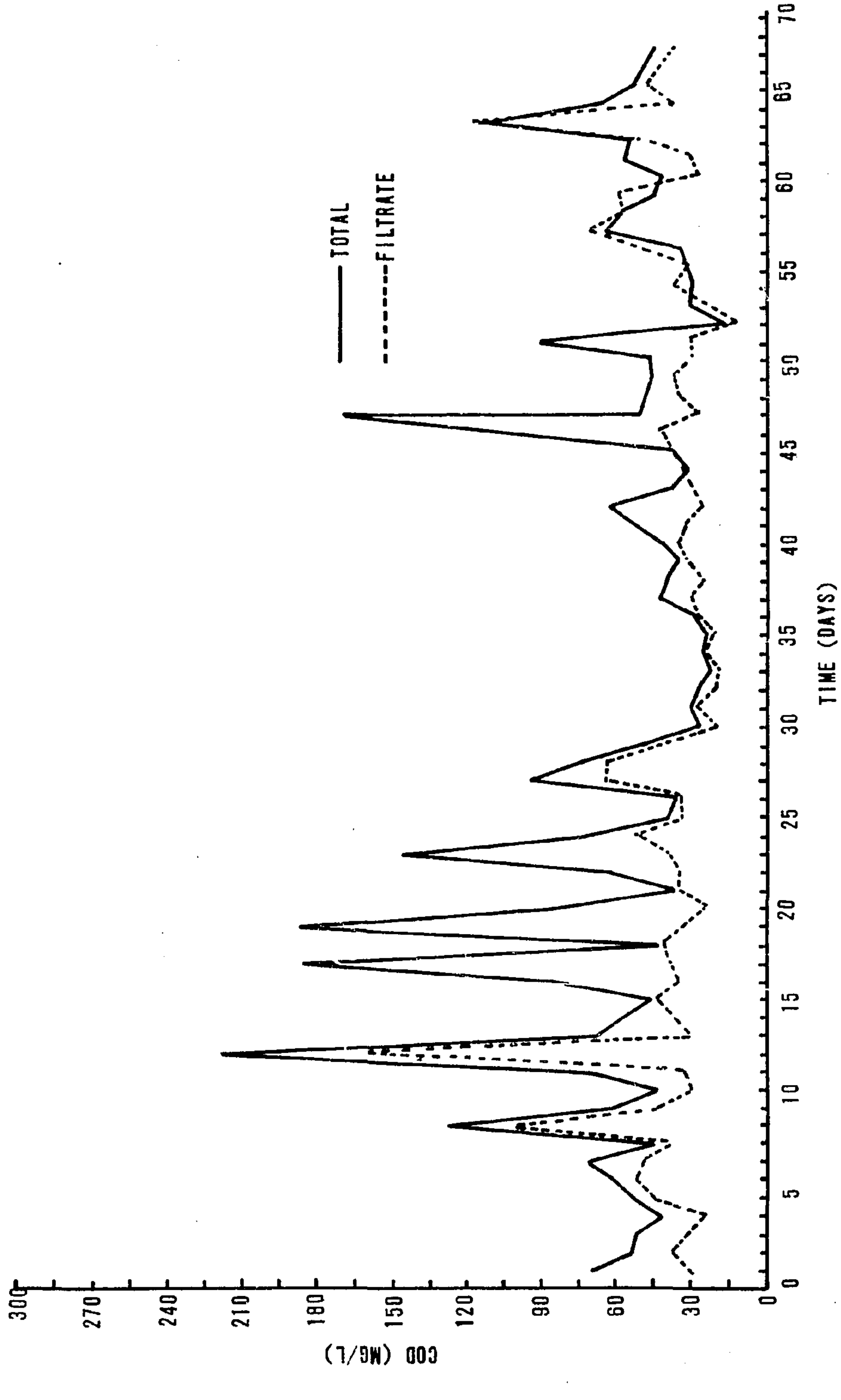

Figure 12. Test 2, Activated Sludge Effluent COD Control

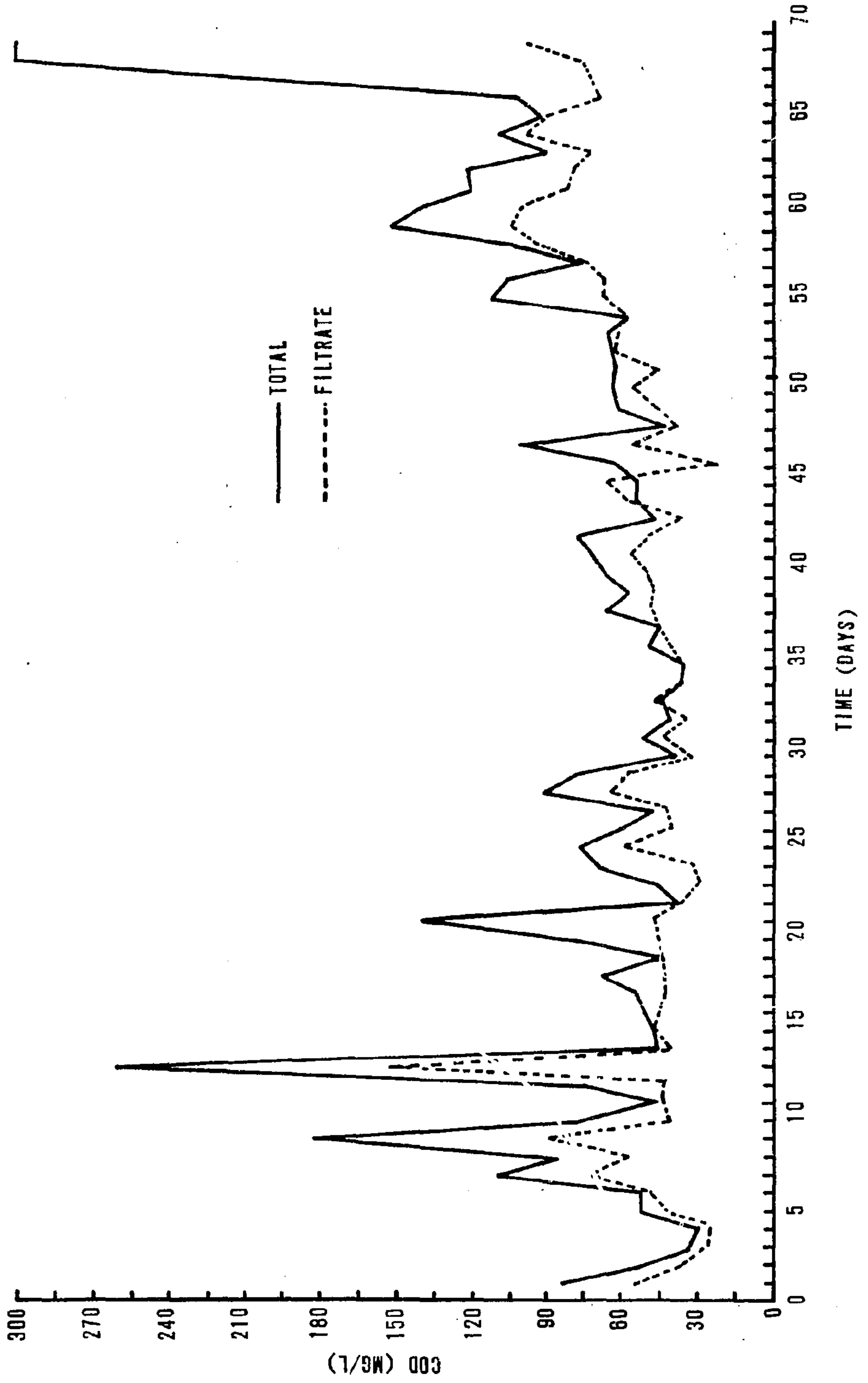

Figure 13. Test 2, Activated Sludge Effluent COD, FC-200

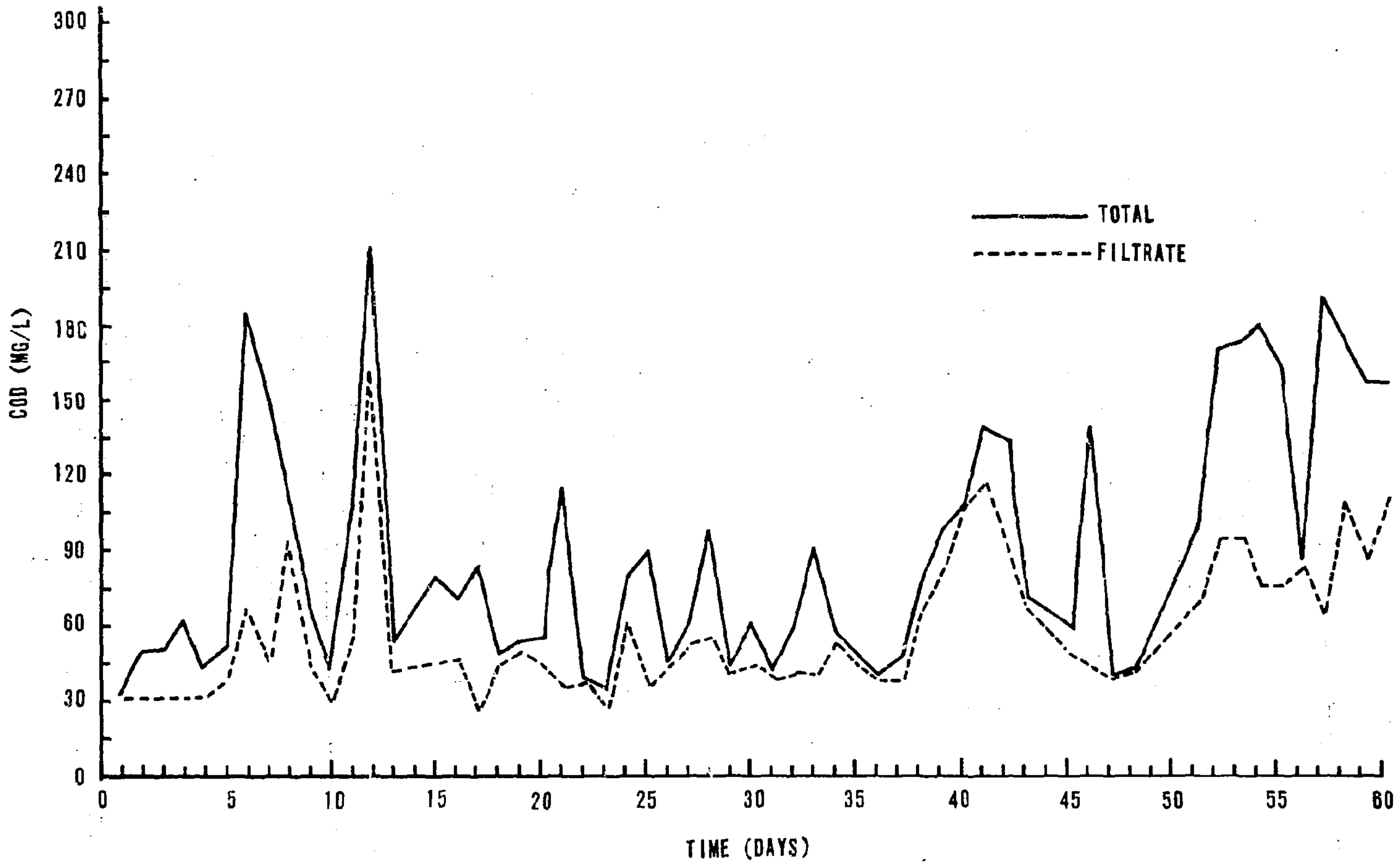

Figure 14. Test 2, Activated Sludge Effluent COD, Aerowater 3 Percent

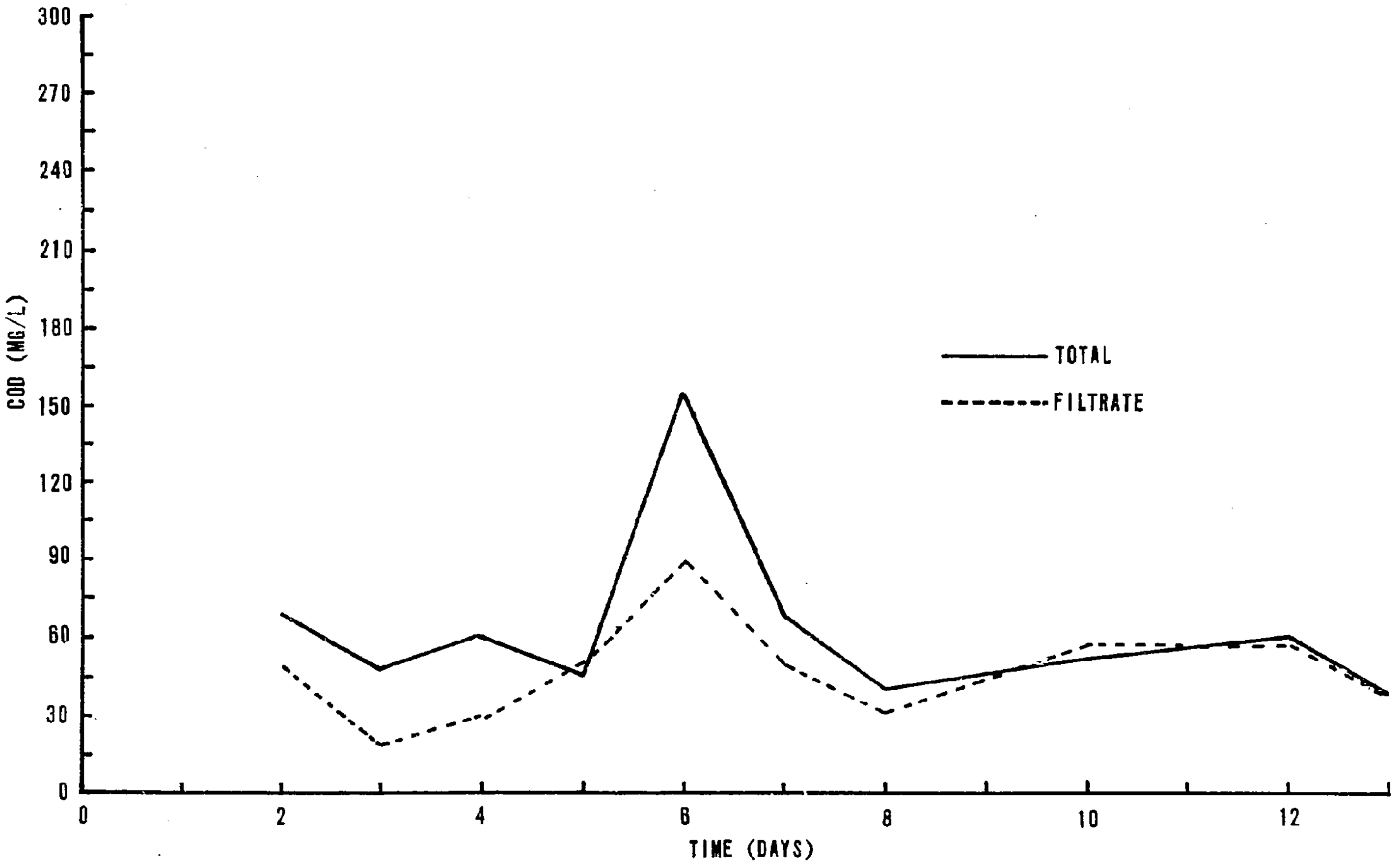

Figure 15. Test 2, Activated Sludge Effluent COD, Aerowater 6 Percent

degrade. This is several days after the reactor had been receiving 160 mg/l of FC-200. On days 50 and 51 the overflow line from the reactor to the clarifier plugged during the night. The reactor spilled over and washed out much of the MLSS. From that point on the reactor was unable to recover, and the effluent quality degraded seriously.

The effect of Aerowater 3 percent on the activated sludge process for test 2 is shown in figure 14. Again, unsteady performance was observed during the dosing of low concentrations of Aerowater 3 percent on days 4 through 14. After day 14 performance evened out, with the exception of day 21 when the effluent contained a high concentration of effluent suspended solids. This appears to have been caused by the increase of the Aerowater 3 percent concentration to 80 mg/l. At about day 35 the total and filtrate effluent COD began to rise gradually, apparently in response to increasing concentrations of Aerowater 3 percent. On day 53 effluent quality degraded rapidly in response to the increase of Aerowater 3 percent concentration to 320 mg/l. This degradation in effluent quality would have occurred sooner except that the MLSS was allowed to rise to over 5000 mg/l.

As stated earlier, reactor 4 was restarted on Aerowater 6 percent primarily to obtain an effluent for the toxicity experiments which were conducted at 200 mg/l of AFFF. Even though the Aerowater 6 percent concentration was increased relatively faster than for the other AFFFs, effluent quality (with the exception of day 6) was consistent and acceptable when measured against the control.

c. Test 3

Recognizing that slug loads of AFFFs would occur at domestic wastewater treatment plants, an attempt was made to determine what impact would result from such undesirable occurrences. Unacclimated activated sludge reactors were slug loaded with 200 mg/l of FC-200 and Aerowater 6 percent, then increased in the case of Aerowater 6 percent to 400 mg/l. The results of these slug loadings are listed in table V and figure 16 for FC-200 and in figure 17 for Aerowater 6 percent.

For FC-200 it was observed that 200 mg/l led to large volumes of foam which encapsulated much of the MLSS, carrying them out of the reactor. Effluent COD increased dramatically on day 7 (FC-200 was added the evening of day 6) and though the effluent COD decreased sharply on day 8, the upset for day 7 was clearly unacceptable.

Table V

ACTIVATED SLUDGE ANALYSES, TEST 3, SLUG LOADING

Day	COD_{INF}	COD_T	COD_F	SS_{EFF}	MLSS	SVI	Remarks
FC-200							
1		112	22	33	1552	64	
2		139	42	77	1692	236	
3	446	95	59	49	1892	476	
4		79	47	34	3120	212	
5	445	85	31	36	3604	72	
6		---	---	37	3526	65	
7	556	420	96	274	2478	77	First sample 200 mg/l FC-200
8		110	110	257	---	---	Uncontrollable foaming
Aerowater 6 Percent							
1		61	58	<10	3190	72	At 200 mg/l 6 percent
2		39	40	17	2712	92	
3	535	31	31	<10	3481	126	
4		64	55	---	---	---	
5	646	175	71	51	3093	259	First sample 400 mg/l 6 percent
6		374	133	120	2755	334	
7		435	135	121	3204	179	
8	628	183	125	47	3779	233	
9		209	134	59	3724	207	
10		194	112	83	4093	230	
11		217	104	69	3995	235	

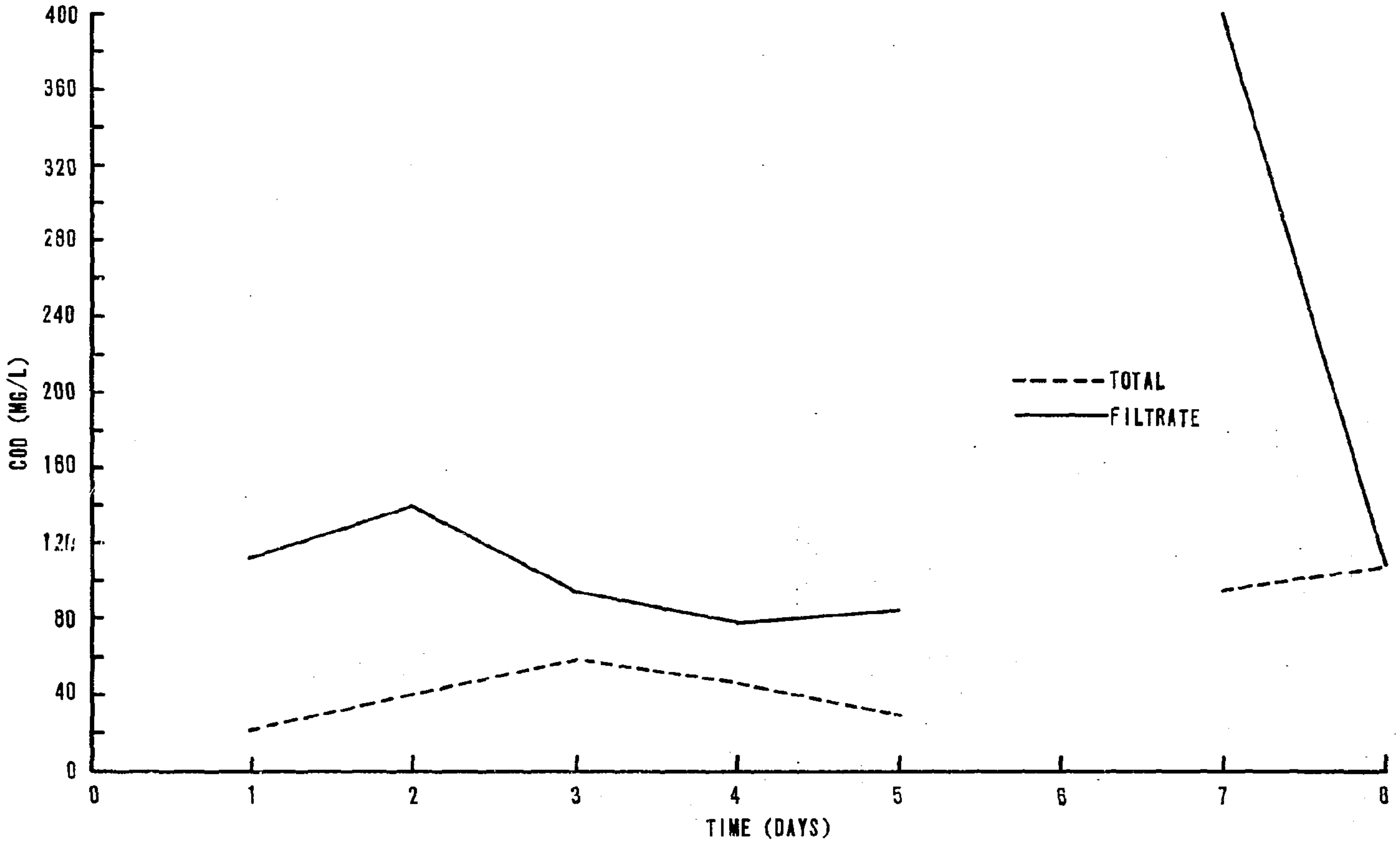

Figure 16. Test 3, Slug Loading, FC-200, Activated Sludge Effluent COD

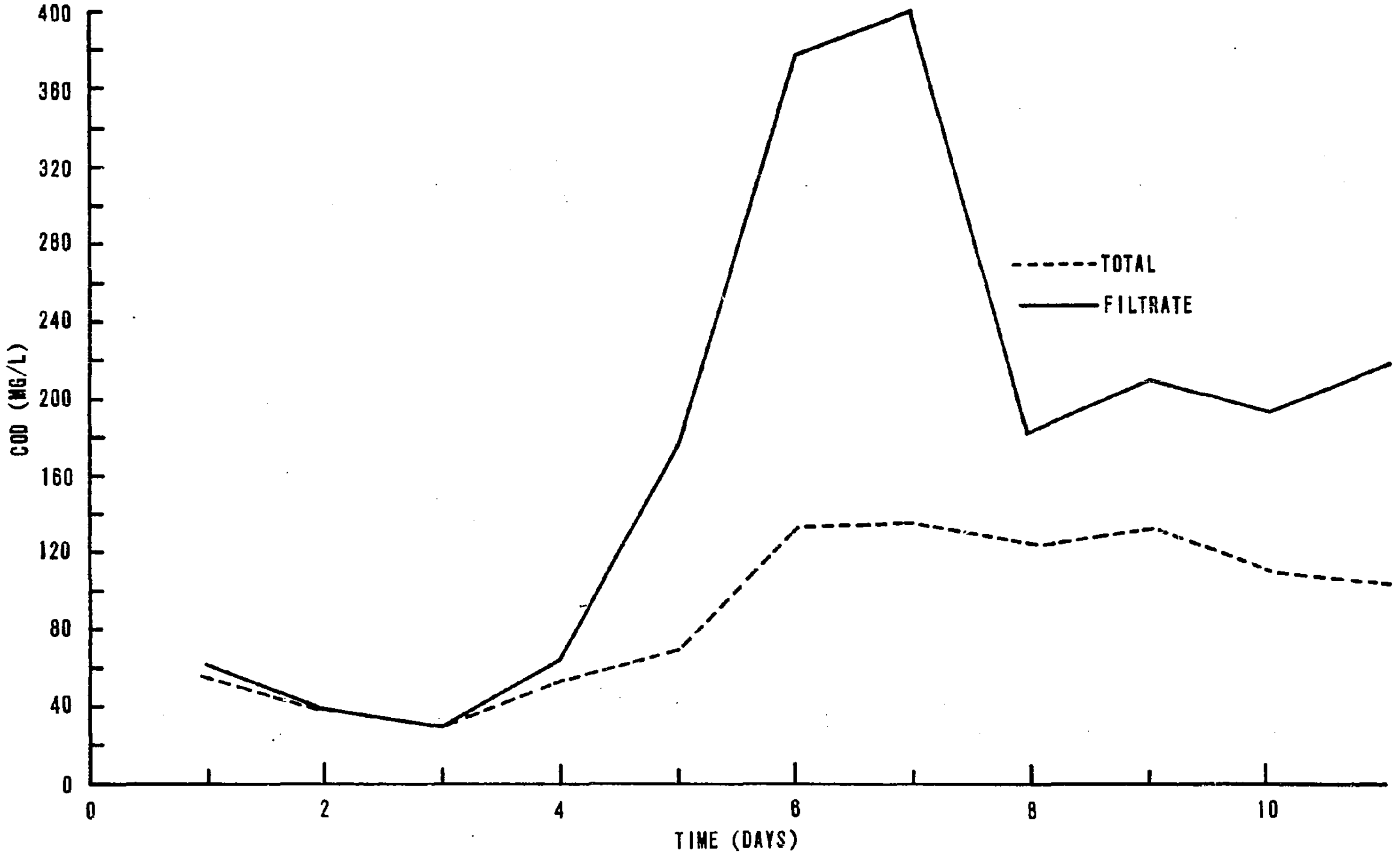

Figure 17. Test 3, Slug Loading, Aerowater 6 Percent, Activated Sludge Effluent COD

The slug load of 200 mg/l of Aerowater 6 percent did not appear to cause any drastic effects on the reactor performance, as shown in figure 17. Therefore, on day 4 the concentration was doubled, after which the total and filtrate effluent COD climbed rapidly, coupled with decreasing settlability. Thus, it appeared that the unacclimated reactor could tolerate a slug load of 200 mg/l but not 400 mg/l.

d. Summary of Activated Sludge Results

Summarizing the results of the activated sludge experiments, average percent COD removal and average effluent COD is plotted against influent AFFF concentration in figures 18 through 20. These figures were constructed by averaging the effluent COD values for a given influent AFFF and then connecting the lines between each point, thus permitting determination of where the effluent quality begins to decrease. Percent COD removal was plotted for both total and filtrate. Effluent COD was plotted for just the total. It must be remembered that increasing the AFFF concentration causes an increase in the influent COD (10 mg/l FC-200 ≅ 7 mg/l COD, 10 mg/l Aerowater 3 percent ≅ 5 mg/l COD, and 10 mg/l Aerowater 6 percent ≅ 4.5 mg/l COD). Therefore, even if the same percent COD removal was obtained after increasing the AFFF concentration, the effluent COD would be higher. For this reason a more practical value is placed on the effluent COD curves.

For FC-200 (figure 18) it is seen that percent COD removal tends to increase and effluent COD tends to decrease up to 160 mg/l. The percent removal increase can be explained by the increasing influent COD attributed to the FC-200. The effluent COD decrease can be attributed to either unsteady performance initially or possibly to an inhibiting effect of the FC-200 on the unacclimated microorganisms. Effluent COD takes a sharp rise between 160 to 200 mg/l; however, at 260 mg/l the effluent COD decreases significantly. Since these are averaged values, these phenomena are not readily explainable.

In figure 19 it is seen that for Aerowater 3 percent the percent COD removal, total and filtrate, shows a gradual decline above an influent concentration of 160 mg/l. However, between 400 and 600 mg/l the percent filtrate COD removal remained constant, while the percent total COD removal dropped significantly. This is explained by the increased effluent suspended solids concentration. For the effluent COD there is a decrease in concentration up to 120 mg/l influent Aerowater 3 percent which, like FC-200, is attributed to

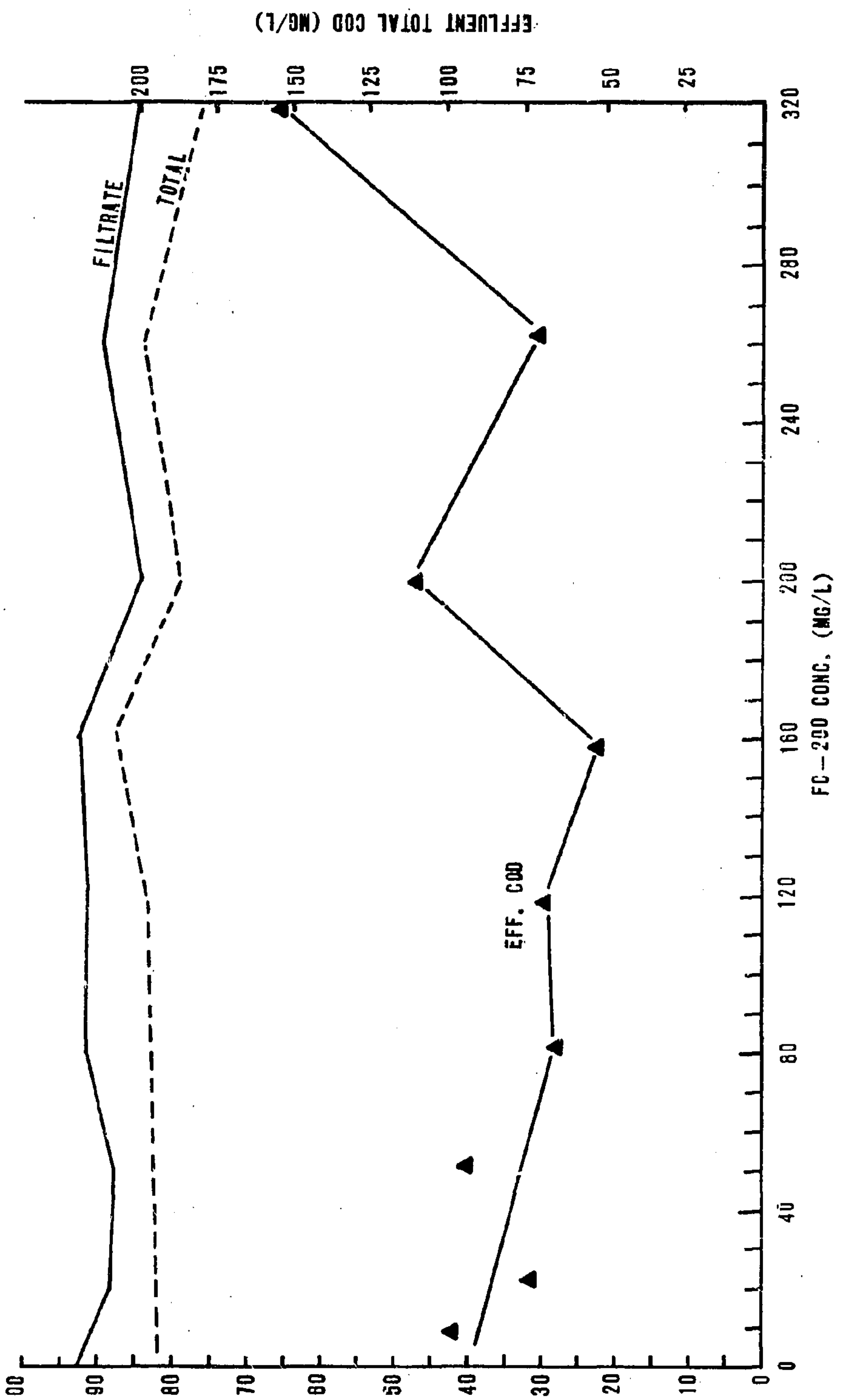

Figure 18. Percent COD Removal and Effluent COD versus Influent Concentration, Activated Sludge, FC-200

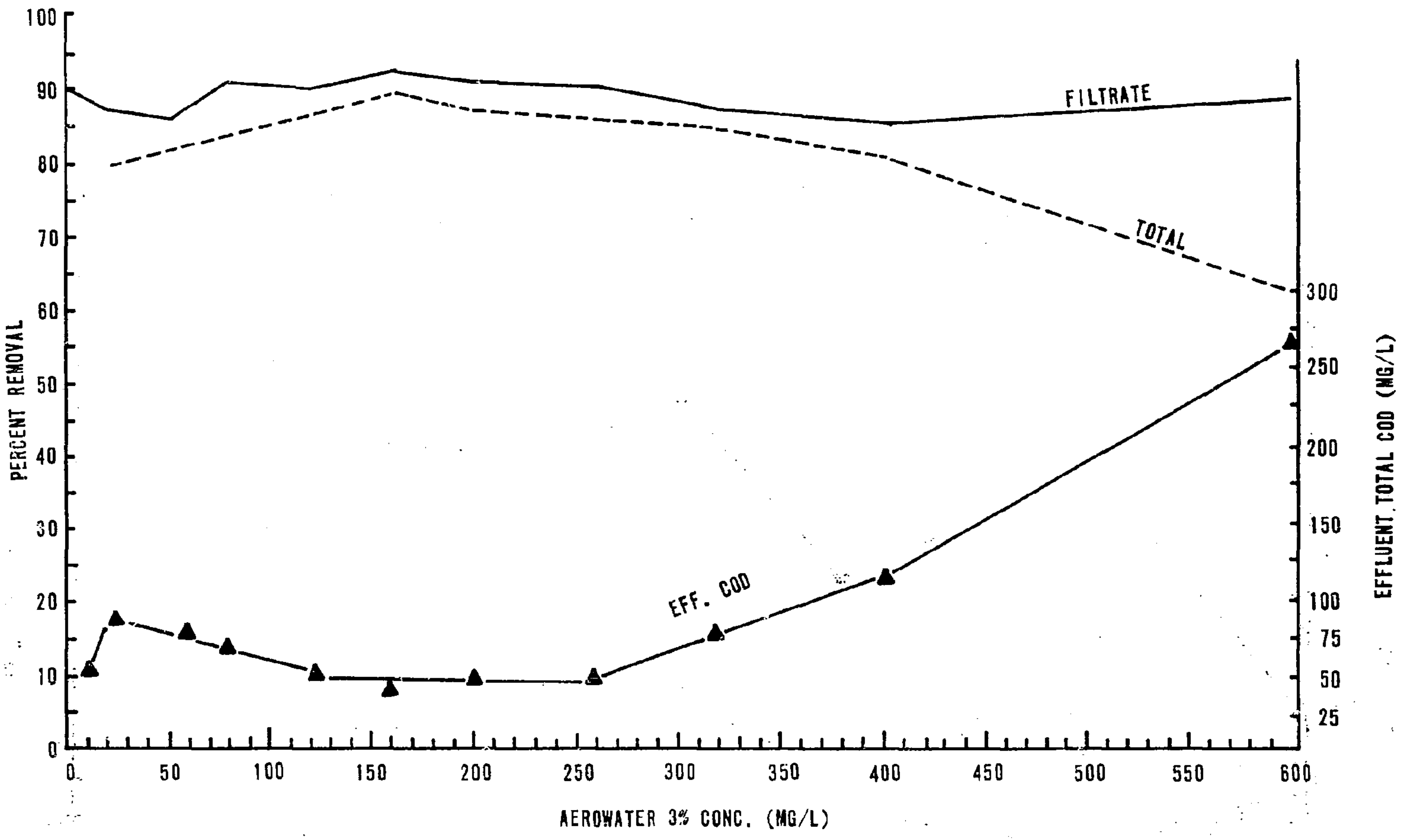

Figure 19. Percent COD Removal and Effluent COD versus Influent Concentration, Activated Sludge, Aerowater 3 Percent

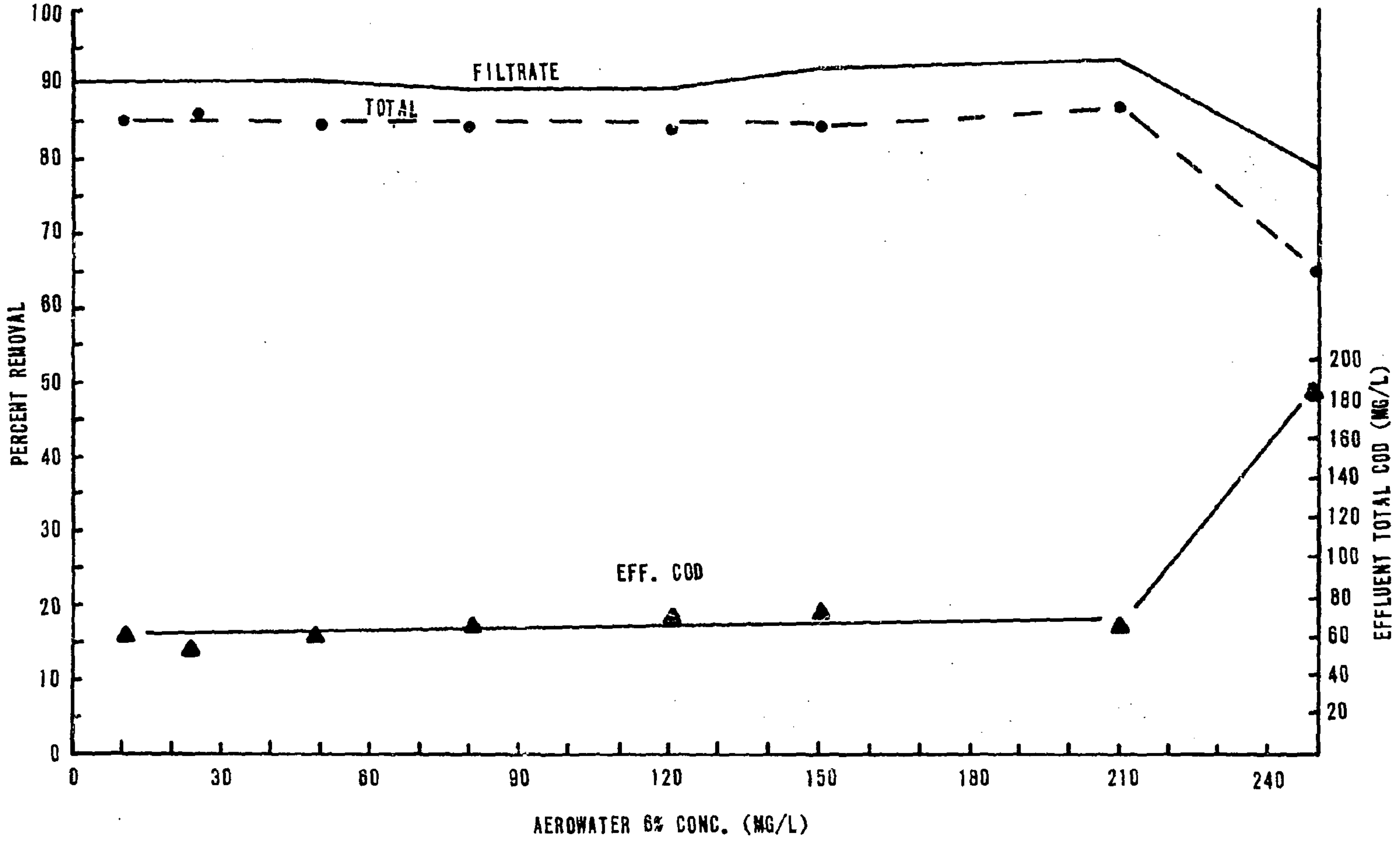

Figure 20. Percent COD Removal and Effluent COD versus Influent Concentration, Activated Sludge, Aerowater 6 Percent

either unsteady performance initially or an initial inhibiting effect. Above 250 mg/l the effluent COD increases to clearly unacceptable levels.

Summarizing the effects of Aerowater 6 percent on the activated sludge process, it is seen from figure 20 that total effluent COD increased quite gradually up to 210 mg/l, above which there was a sharp increase. This is reflected by the percent COD removal curves. Effluent CODs of 60 to 70 mg/l are as expected from a reasonably well-operated activated sludge plant.

4. TRICKLING FILTER EXPERIMENTS

a. Test 1

The data collected for test 1 are demonstrated in table VI and in figures 21 and 22. As stated in section III, test 1 was conducted with no recycle of the effluent. The hydraulic loading was 200 gpd/ft^2. Since both columns were receiving AFFFs and there were no additional columns available, a control was not run concurrently. However, just before the dosing of the AFFF, both columns A and B were achieving 75 to 85 percent COD removal when receiving synthetic wastewater. Samples were taken from the two sampling ports and the final discharge. These data are presented in table VI. Only the final discharge is presented in the figures to avoid cluttering of the illustrations. During Test 1, sloughing of the microorganisms was moderate and observed to be at a relatively constant rate. It is seen from table VI that, in general, for both FC-200 and Aerowater 6 percent, most of the COD removal occurred between sample port 2 and the final discharge. This is contrary to expected performance for standard trickling filters receiving domestic wastewater. This, coupled with the fact that the COD concentrations at sample ports 1 and 2 were frequently the same value with sample port 2 sometimes having higher COD than sample port 1, leads to the assumption that the samples taken at sample ports 1 and 2 were unrepresentative.

From figure 21 for FC-200 it is seen that the effluent CODs from the final discharge were quite erratic but do demonstrate an increasing effluent concentration with time (increasing FC-200 concentration). Essentially, the same observation is made for Aerowater 6 percent in that the effluent CODs were clearly unacceptable by the time 160 mg/l of AFFF was reached; the columns were converted back to receiving only synthetic wastewater on day 25.

Table VI

TRICKLING FILTER ANALYSES, TEST 1, NO RECYCLE
[COD (mg/l)]

Day	Influent	Port 1	Port 2	Final discharge	Remarks
			FC-200		
1		331	331	60	
2		411	359	103	First sample 25 mg/l FC-200
3		350	293	98	
4		208	216	74	
5		296	264	86	
6	373	271	240	95	First sample 50 mg/l FC-200
7		279	256	85	
8		238	234	83	
9		197	205	65	
10		165	213	88	
11		163	202	120	
12	368	182	253	96	First sample 80 mg/l FC-200
13		245	285	111	
14		310	278	94	
15		278	242	88	
16		248	240	106	First sample 120 mg/l FC-200
17		326	294	110	
18		397	413	113	
19		411	340	158	
20	550	387	308	133	First sample 160 mg/l FC-200
21		368	225	186	
22		400	354	300	
23		377	392	285	
24		226	365	201	
25		414	367	176	

Table VI (cont'd)

Day	Influent	Port 1	Port 2	Final discharge	Remarks
			Aerowater 6 Percent		
1		317	314	67	First sample 25 mg/l 6 percent
2		296	348	89	
3		386	337	81	
4		220	252	70	
5		216	304	62	
6	357	136	209	74	First sample 50 mg/l 6 percent
7		120	213	74	
8		155	202	100	
9		110	173	61	
10		189	193	54	
11		83	163	94	
12	364	150	174	152	First sample 80 mg/l 6 percent
13		91	202	146	
14		246	214	146	
15		111	206	122	
16		205	181	80	First sample 120 mg/l 6 percent
17		290	278	115	
18		294	270	95	
19		372	304	126	
20	484	332	324	117	First sample 160 mg/l 6 percent
21		298	306	134	
22		377	300	192	
23		338	269	177	
24		---	274	89	
25		348	270	109	

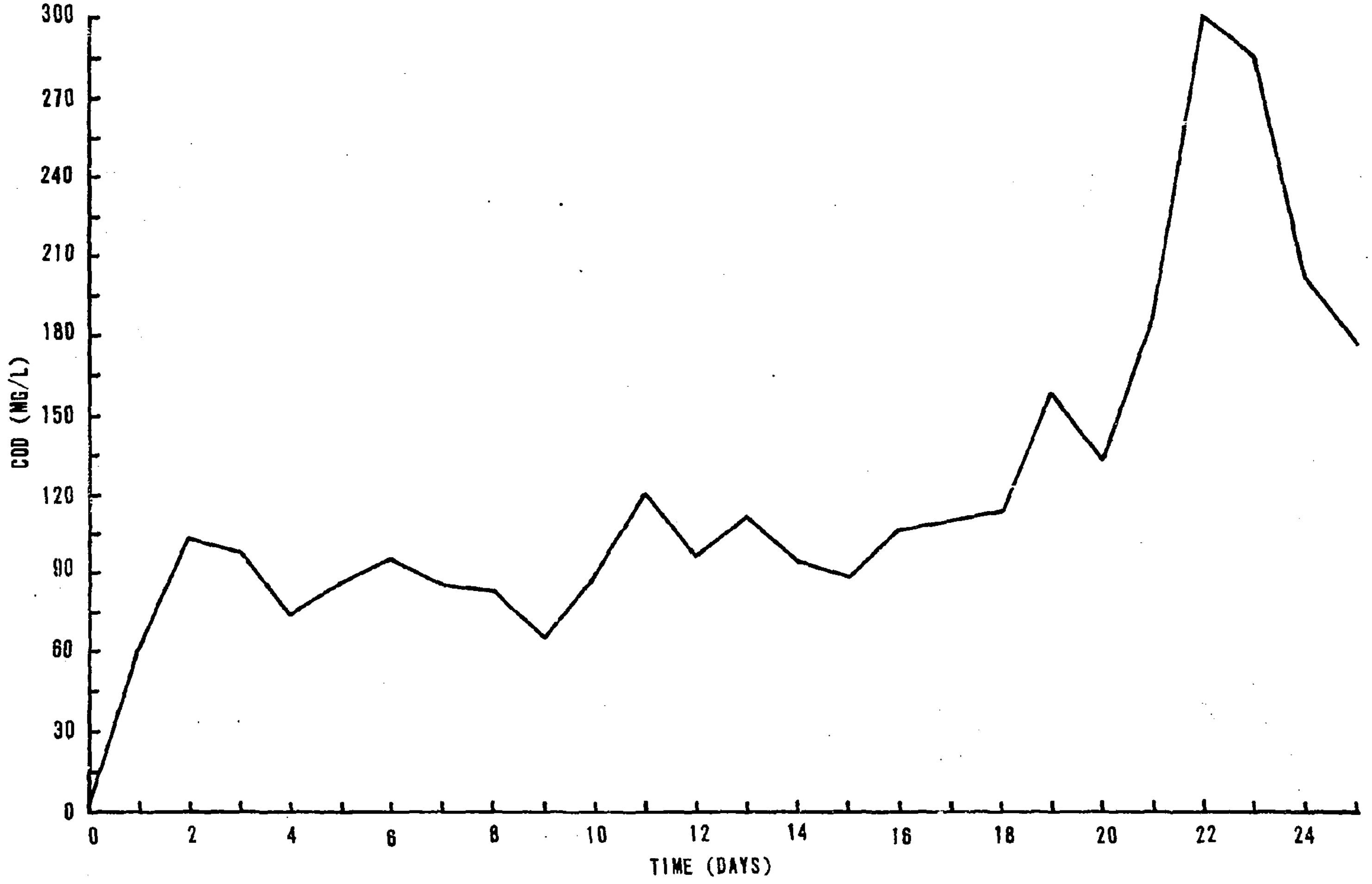

Figure 21. Trickling Filter Effluent COD (No Recycle), FC-200

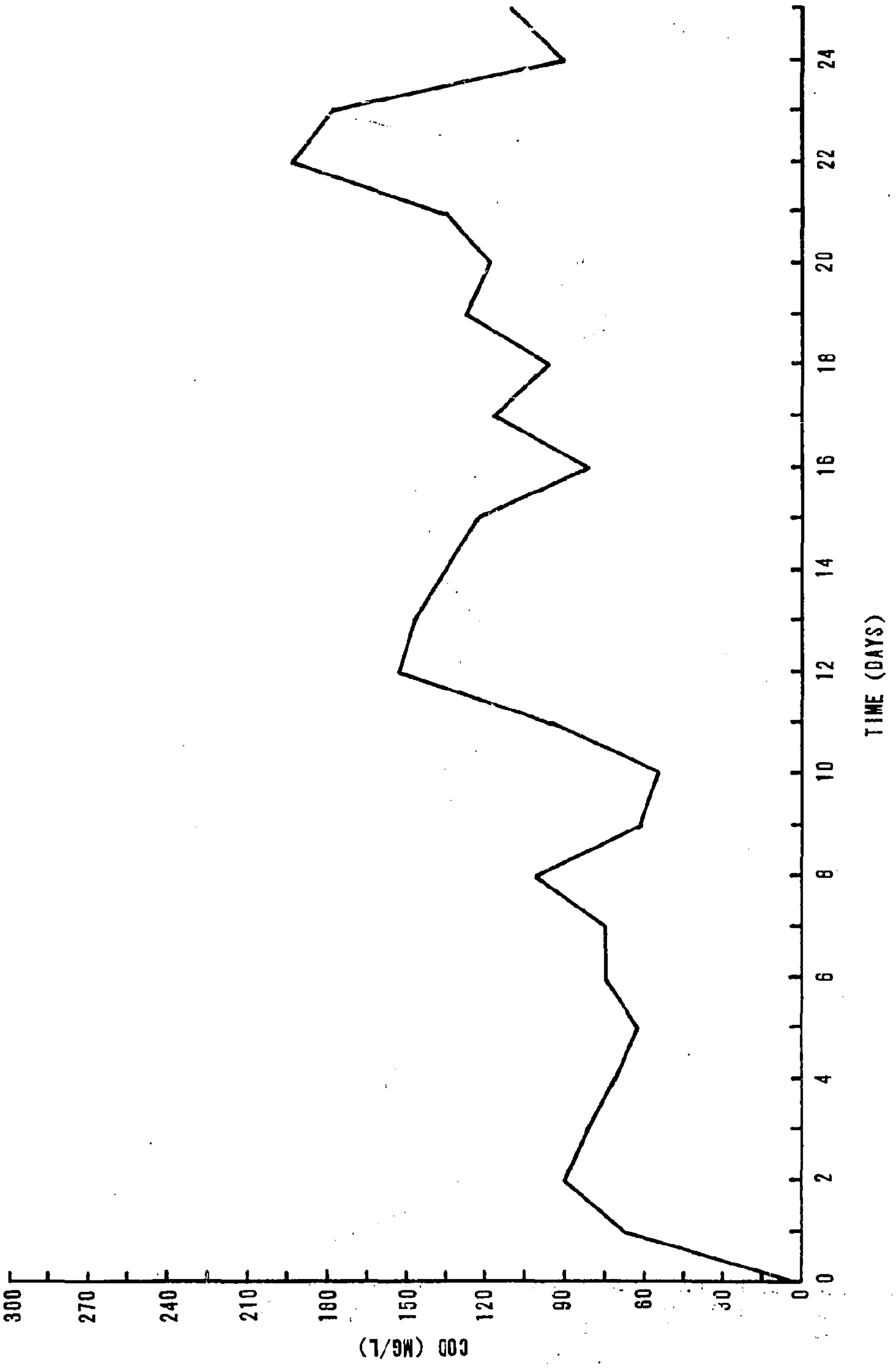

Figure 22. Trickling Filter Effluent COD (No Recycle), Aerowater 6 Percent

b. Test 2

Test 2 consisted of dosing the columns with equal volumes of influent and recycled effluent, i.e., one-to-one recycle. The recycle was taken from the collection basin to which the final discharge entered. As stated in section III, the hydraulic loading was 200 gpd/ft^2 (8150 l/day/m^2) of which 100 gpd/ft^2 was synthetic wastewater plus AFFF and 100 gpd/ft^2 was recycled effluent. After test 1, the columns were dosed with synthetic wastewater for 9 days, at which time it was considered acceptable to begin adding the FC-200 and Aerowater 6 percent. Table VII and figures 23 and 24 represent the results for test 2. It should be noted that the influent listed in table VII is that which was in the feed tank and not that which entered the top of the column. The COD concentration entering the top of the column at any time would equal the feed tank COD plus the recycled effluent COD divided by 2.

From figure 23 it is seen that for the trickling filter column receiving FC-200, no change in performance at the final discharge is observed up to about day 36, at which time the FC-200 concentration was increased to 200 mg/l. However, even up to this point the effluent COD was higher than expected and quite variable. Above 200 mg/l FC-200 effluent quality started to degrade beyond the already less than acceptable quality.

Recycling of effluent is a common practice in the operation of trickling filters to improve effluent quality. For the trickling filter loaded with FC-200, recycling the effluent did not improve performance but rather had some deleterious effects when the data is compared against test 1. However, there is insufficient data to determine if this occurrence is caused by the FC-200.

Figure 24 illustrates the performance of the trickling filter receiving Aerowater 6 percent during test 2. It can be seen that up to 300 mg/l of Aerowater 6 percent, influent to the trickling filter, there was no observed degradation of effluent quality. When compared against the data of test 1 (figure 22), it is seen that recycle of the effluent, which in turn lowers the organic loading, permitted the achievement of higher AFFF loadings than without recycle, while still yielding acceptable effluent quality.

c. Summary of Trickling Filter Results

Summarizing the results of the two trickling filter tests, influent AFFF concentration is plotted against averaged percent COD removal and effluent COD concentration for both no recycle and one-to-one recycle. This is plotted

Table VII

TRICKLING FILTER ANALYSES, TEST 2, ONE-TO-ONE RECYCLE [COD (mg/l)]

Day	Influent	Port 1	Port 2	Final discharge	Remarks
			FC-200		
1		234	191	127	
2		184	160	112	
3		244	220	124	
4		192	200	128	
5		288	264	144	
6		212	248	64	
7		236	216	78	
8		273	301	98	
9		301	294	123	
			Aerowater 6 Percent		
1		---	139	87	
2		96	76	52	
3		100	80	36	
4		80	72	36	
5		164	96	24	
6		156	64	---	
7		100	40	29	
8		203	210	78	
9		231	203	95	
			FC-200		
1	488	321	294	106	First sample 25 mg/l FC-200
2		369	282	121	
3		351	311	164	
4		319	295	129	
5		315	287	126	
6		344	328	147	
7		246	354	210	
8	484	329	298	---	First sample 50 mg/l FC-200

Table VII (cont'd)

Day	Influent	Port 1	Port 2	Final discharge	Remarks
9		341	333	286	
10		333	318	274	
11		372	348	288	
12		335	314	218	
13		242	222	165	
14		256	232	140	
15		320	304	240	First sample 80 mg/l FC-200
16		203	203	147	
17		271	283	195	
18		232	232	192	
19		292	240	224	
20		160	144	128	
21	524	240	176	192	First sample 120 mg/l FC-200
22		320	312	240	
23		202	165	133	
24	No data				
25		218	198	117	
26		292	276	196	
27		140	124	112	
28		176	152	116	
29	584	304	280	192	First sample 160 mg/l FC-200
30		384	360	256	
31		352	304	224	
32		372	368	272	
33		264	220	196	
34		240	232	200	
35		200	152	112	
36	559	269	281	225	
37	618	285	277	245	First sample 200 mg/l FC-200
38		457	394	378	
39		449	201	386	

Table VII (cont'd)

Day	Influent	Port 1	Port 2	Final discharge	Remarks
40		465	457	433	
41		394	386	337	
42		424	424	384	
43	592	424	416	380	
44		432	408	368	
45	587	272	224	192	First sample 250 mg/l FC-200
46		280	216	224	
47		237	213	213	
48		153	145	153	
49		269	277	237	
50	640	308	286	271	First sample 300 mg/l FC-200
51		401	318	303	
52		320	288	268	
53		336	272	216	
54		337	305	265	
			Aerowater 6 Percent		
1	464	194	194	119	First sample 25 mg/l 6 percent
2		---	143	113	
3		223	179	83	
4		147	128	61	
5		150	134	36	
6		214	176	58	
7		103	56	52	
8	468	198	135	75	First sample 50 mg/l 6 percent
9		222	123	87	
10		230	171	75	
11		233	170	83	
12		210	125	133	
13		210	97	113	
14		132	88	32	

Table VII (cont'd)

Day	Influent	Port 1	Port 2	Final discharge	Remarks
15	480	256	176	88	First sample 80 mg/l 6 percent
16		139	84	52	
17		187	120	84	
18		192	84	84	
19		180	120	52	
20		120	88	60	
21	504	272	148	68	First sample 120 mg/l 6 percent
22		120	112	64	
23		---	85	36	
24	No data				
25		80	61	---	
26		244	160	104	
27		200	104	52	
28		156	72	56	
29	528	200	128	96	First sample 160 mg/l 6 percent
30		192	144	104	
31		88	80	64	
32		---	136	56	
33		96	64	32	
34		208	120	40	
35		136	88	64	
36	474	132	48	40	
37	545	165	68	28	First sample 200 mg/l 6 percent
38		236	142	79	
39		465	134	118	
40		442	94	79	
41		187	122	57	
42		240	176	72	
43	560	240	160	96	
44		244	160	96	
45	540	104	136	72	First sample 250 mg/l 6 percent

Table VII (cont'd)

Day	Influent	Port 1	Port 2	Final discharge	Remarks
46		240	160	72	
47		253	173	108	
48		100	64	48	
49		153	76	48	
50	584	211	218	143	First sample 300 mg/l 6 percent
51		303	198	131	
52		240	136	96	
53		225	169	80	
54		273	213	---	

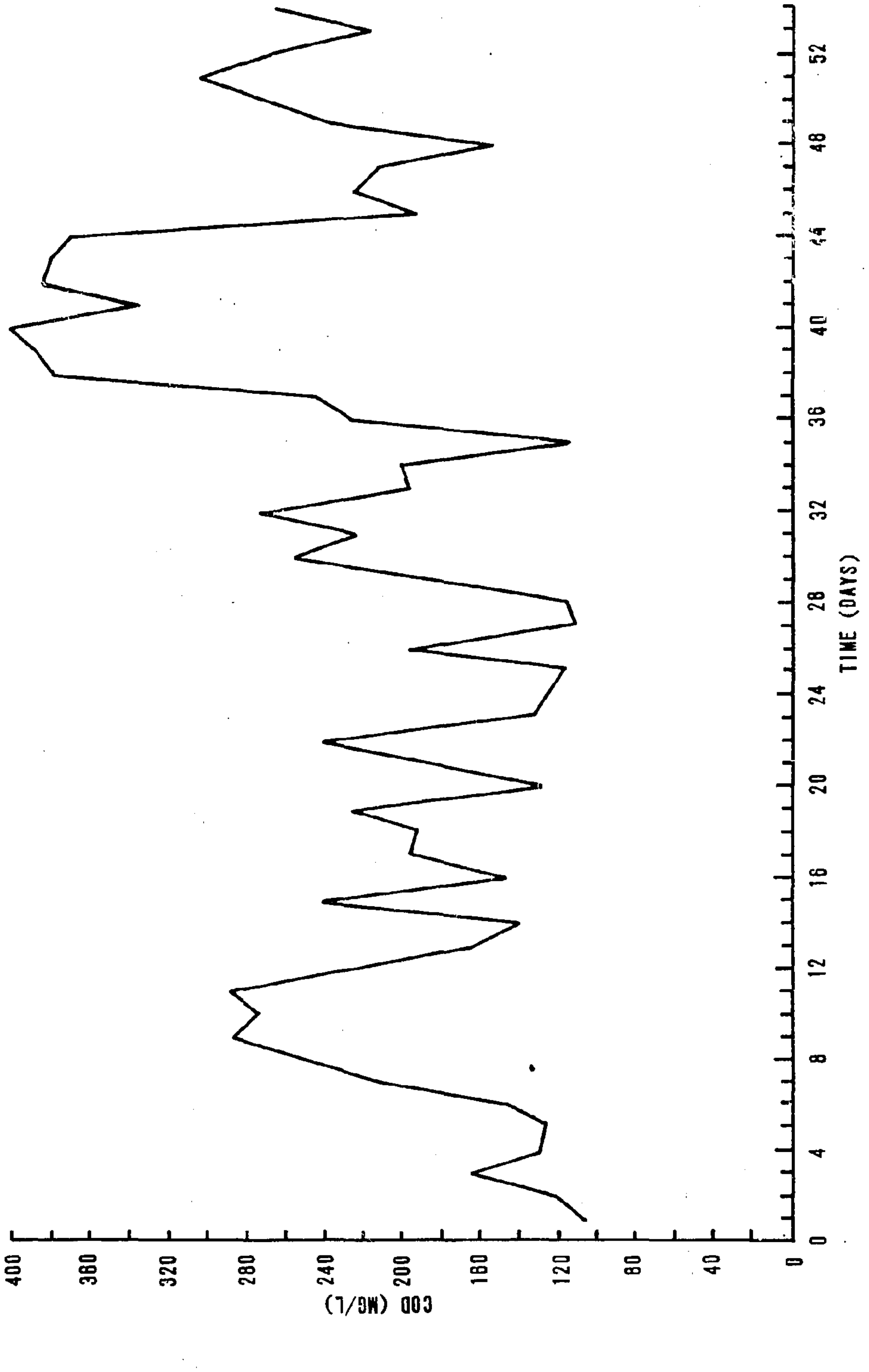

Figure 23. Trickling Filter Effluent COD (One-to-One Recycle), FC-200

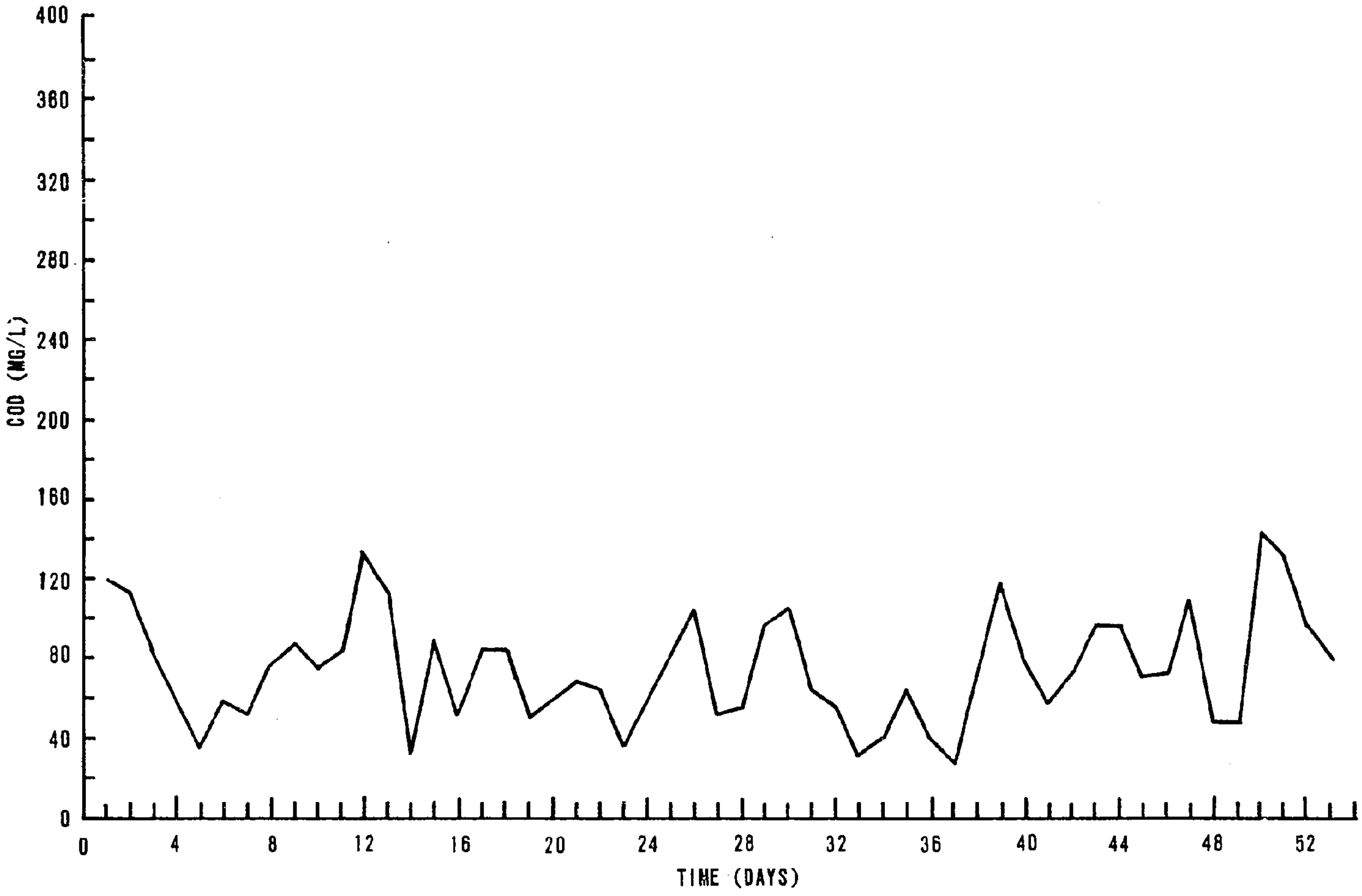

Figure 24. Trickling Filter Effluent COD (One-to-One Recycle), Aerowater 6 Percent

in figure 25 for FC-200 and in figure 26 for Aerowater 6 percent. It must be remembered that increasing AFFF concentrations results in increasing influent COD concentrations and thus affects percent COD removal. For FC-200, as was stated earlier, performance was better with no recycle than with the one-to-one recycle. Percent COD removals and effluent COD concentrations were less than acceptable for all concentrations of FC-200 in both tests. The FC-200 concentration above which the effluent quality starts to degrade beyond a baseline effluent quality (baseline not necessarily taken to be acceptable) appears to be 120 mg/l for both no recycle and one-to-one recycle.

The impact of Aerowater 6 percent on effluent quality is seen in figure 26. It was observed that above 50 mg/l of Aerowater 6 percent, with no recycle, there was a significant increase of effluent COD. On the other hand, for one-to-one recycle, the effluent COD remained nearly constant and of acceptable quality up to 250 mg/l of Aerowater 6 percent.

Why, in the case of FC-200, effluent quality would suffer from recycling of a portion of the effluent and improve in the case of Aerowater 6 percent is not readily explainable. This is a significant observation, but unfortunately, ther are insufficient data to say that this occurrence is a result of the AFFF. It would be difficult to reason that recycling of the effluent containing treated or partially treated FC-200 would cause a decrease in effluent quality from that of no recycle. This is especially true since the overall mass of FC-200 entering the trickling filter from the feed solution during one-to-one recycle is one half of that during no recycle.

5. TOXICITY EXPERIMENTS

The results of the toxicity experiments are given in table VIII. From this table it is seen that for Aerowater 3 percent and Aerowater 6 percent all the rainbow trout were able to survive for 96 hours in the activated sludge effluent. However, for the FC-200 on the first test, all four trout had died within 24 hours. When the test was repeated, two trout died within 48 hours and the remaining two in the next 24 hours. Further, all the trout exposed to the influents and the distilled water containing untreated AFFFs died within 96 hours. That the trout would die in distilled water is not immediately explainable. Potential explanation for this occurrence is the sensitivity of the trout to the change in mineral content of water to which they were acclimated.

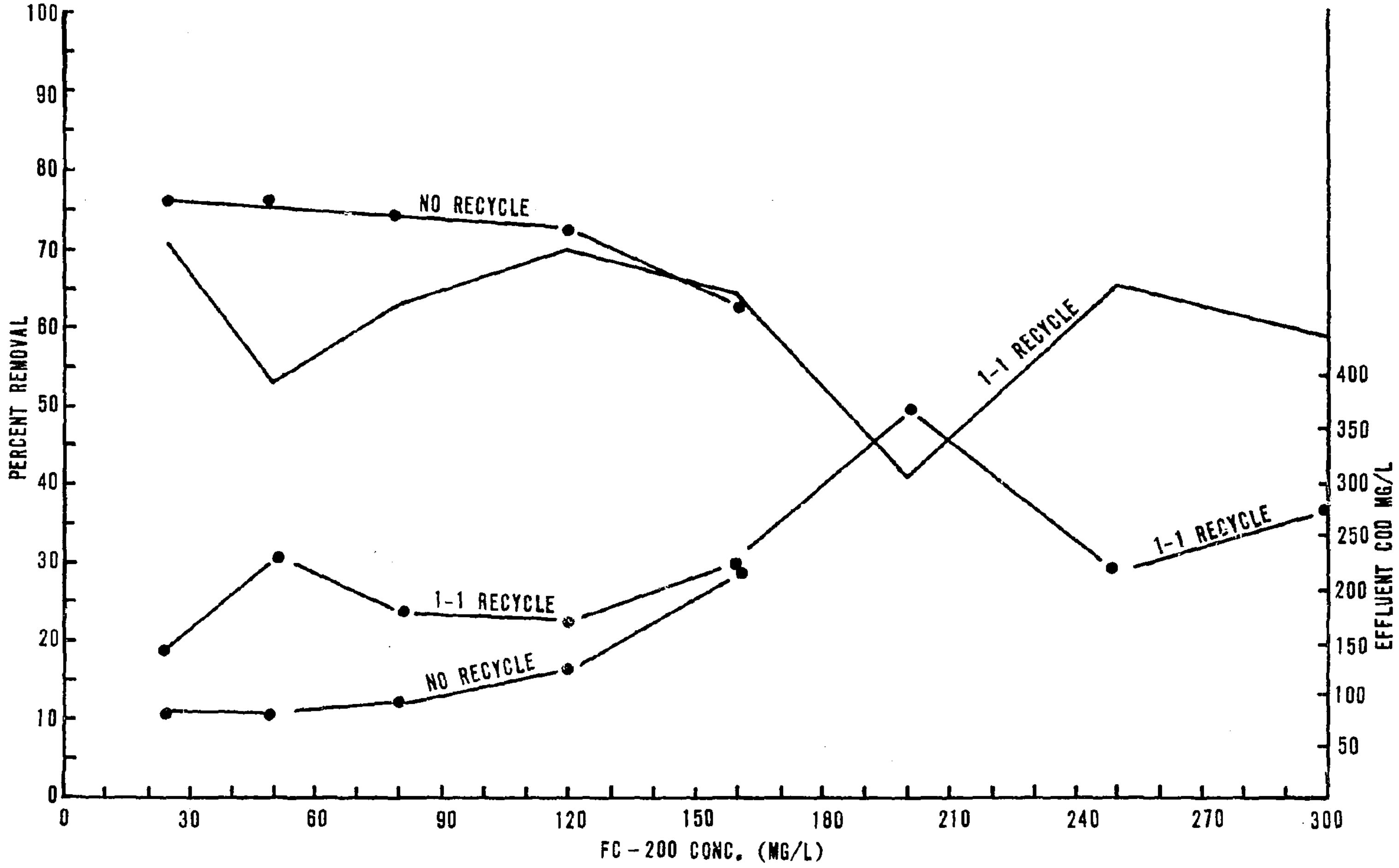

Figure 25. Percent COD Removal and Effluent COD versus Influent FC-200 Concentration, Trickling Filter

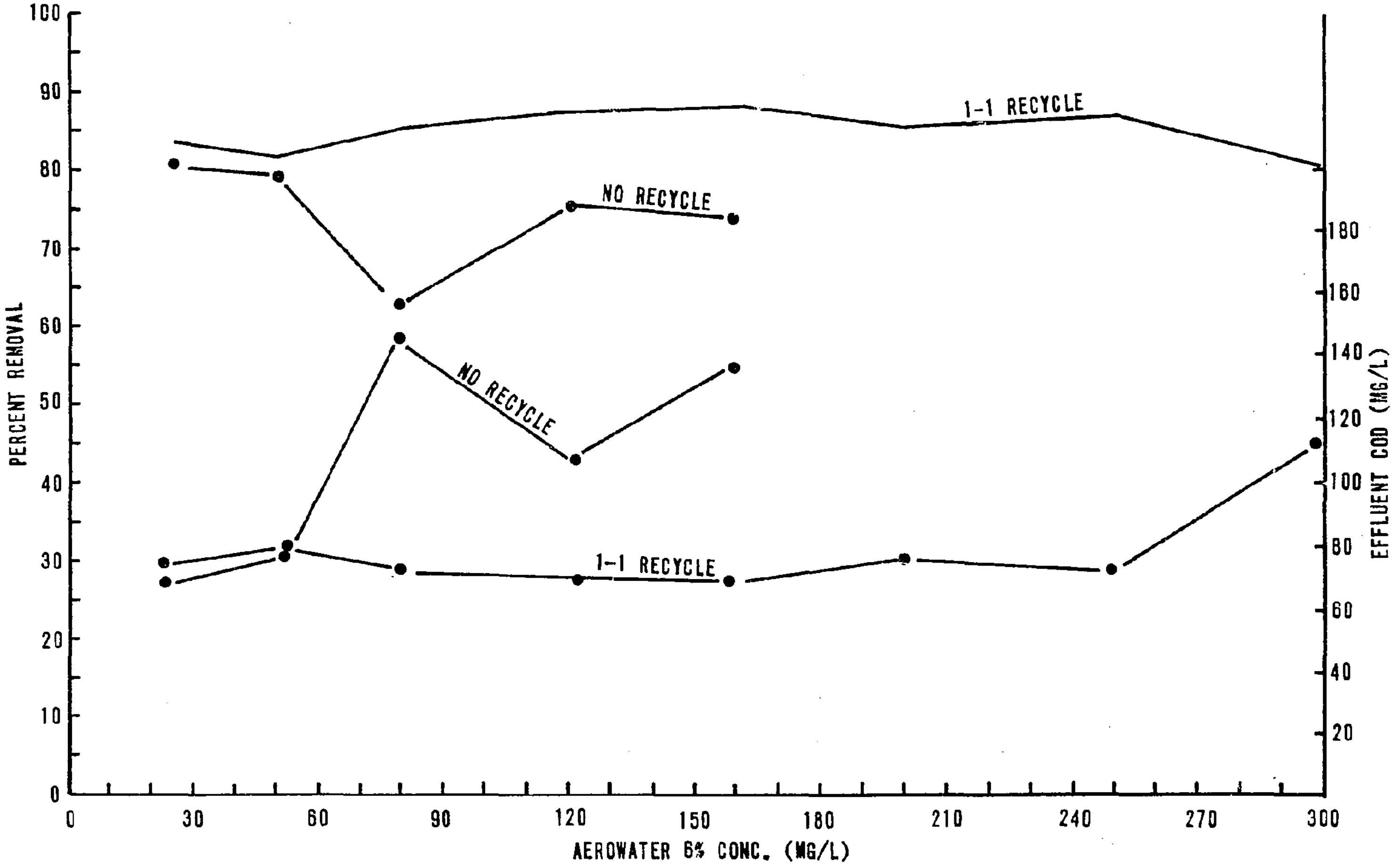

Figure 26. Percent COD Removal and Effluent COD versus Influent Aerowater 6 Percent Concentration, Trickling Filter

Table VIII

TOXICITY OF AFFF TO RAINBOW TROUT*

Condition	Time 24 hr	48 hr	72 hr	96 hr
Effluent control	0	0	0	0
Effluent Aerowater 3 percent	0	0	0	0
Effluent Aerowater 6 percent	0	0	0	0
Effluent FC-200	4	---	---	---
Effluent FC-200 (repeat)	1	2	4	---
Influent control (synthetic wastewater)	2	2	4	---
Influent Aerowater 3 percent	1	4	---	---
Influent Aerowater 6 percent	1	4	---	---
Influent FC-200	1	4	---	---
Distilled water	1	2	2	4
Distilled water and Aerowater 3 percent	1	1	2	4
Distilled water and Aerowater 6 percent	1	2	4	---
Distilled water and FC-200	2	2	4	---

---

*Starting with four trout per tank, number given is the cumulative number dead.

The data show that there is definite detoxification occurring by biological treatment for Aerowater 3 percent and Aerowater 6 percent. For FC-200 biological treatment does not appear to offer significant detoxification. However, one must be cautioned not to accept this as conclusive data since it represents only one test at one AFFF concentration. Further, the concentration of AFFF used is higher than that recommended (see Conclusions, section VI) for discharge into a sanitary sewer.

6. ADSORPTION EXPERIMENTS

The 2000-mg/l solutions of FC-200 and Aerowater 6 percent yielded CODs as indicated below (the average of triplicate analysis):

FC-200	1500 mg/l
FC-200 after JP-4	1433 mg/l
Aerowater 6 percent	944 mg/l
Aerowater 6 percent after JP-4	992 mg/l

JP-4 added to distilled water (20 ml in 2 liters), then separated, yielded a COD of approximately 100 mg/l in the aqueous phase. This indicates that some of the compounds in JP-4 are at least slightly soluble in water. Coupling this fact with the COD data for the four solutions reveals that there was a decrease in COD of the FC-200 solution that was contacted with JP-4, although approximately 100 mg/l of COD was added from the JP-4. This indicates that a significant fraction of FC-200 is extracted into the JP-4 phase. This fraction is estimated to be approximately

$$\frac{1500 + 100 - 1433}{1500 + 100} = 10 \text{ percent}$$

Conversely for Aerowater 6 percent there is a 48-mg/l increase in COD after contact with JP-4. This indicates that a much smaller fraction of Aerowater 6 percent is taken up in the JP-4 phase.

The results of the batch adsorption experiments are given in figures 27 through 30. The notation used is X = wt of COD adsorbed = initial COD concentration C_0 - final COD concentration C_F x volume, M = wt of activated carbon

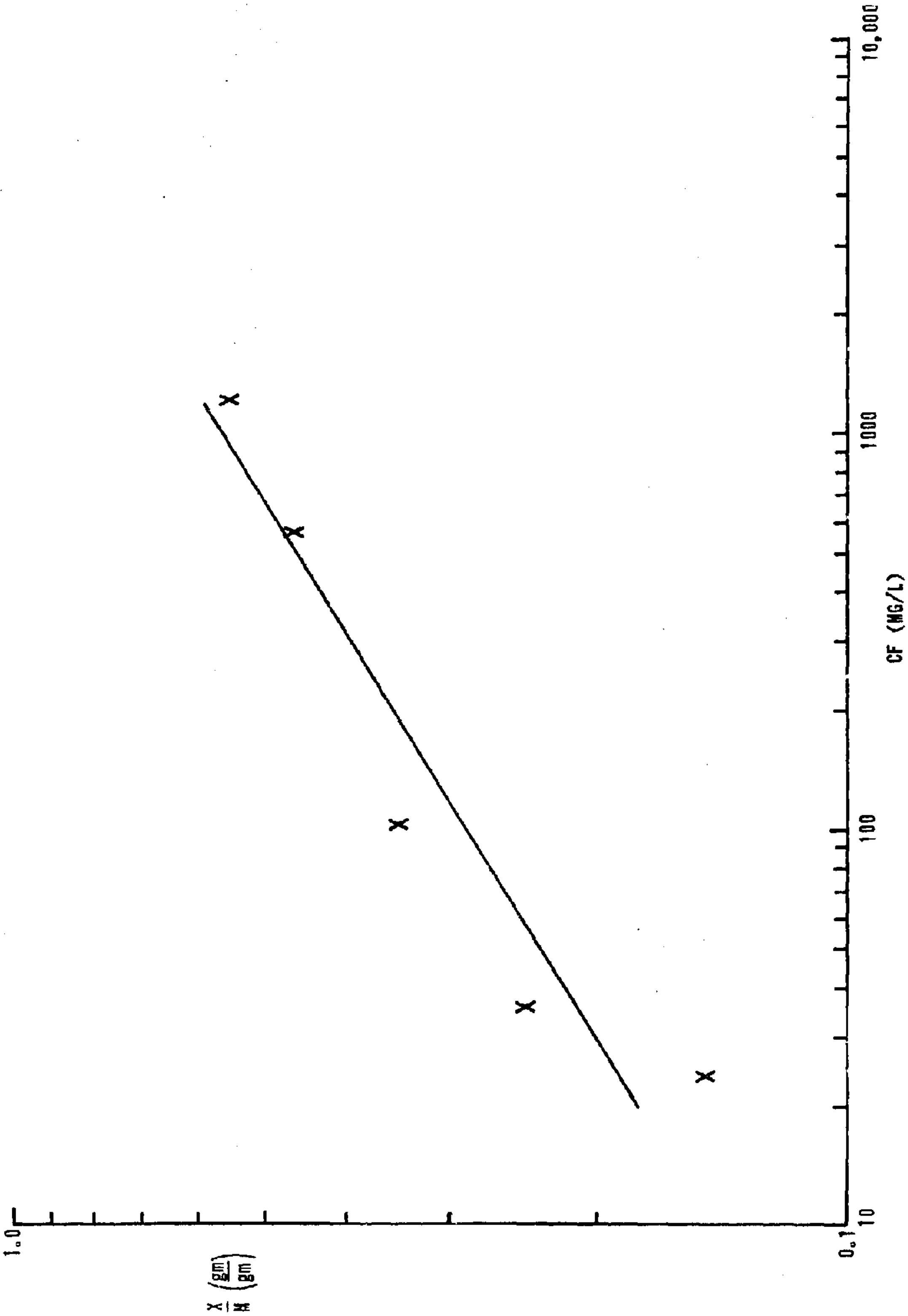

Figure 27. Batch Adsorption Isotherm, FC-200 (No JP-4)

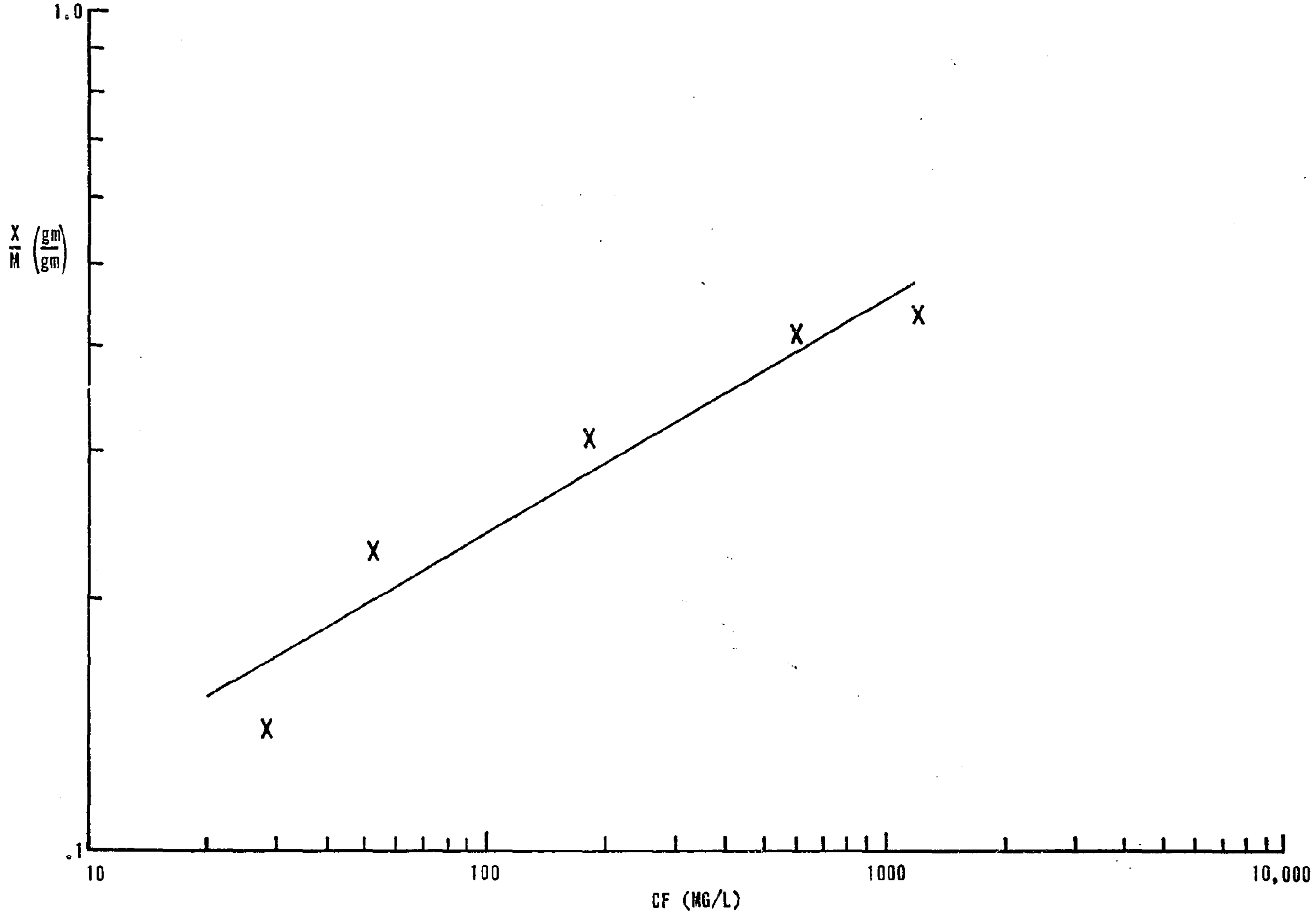

Figure 28. Batch Adsorption Isotherm, FC-200 (After JP-4 Extraction)

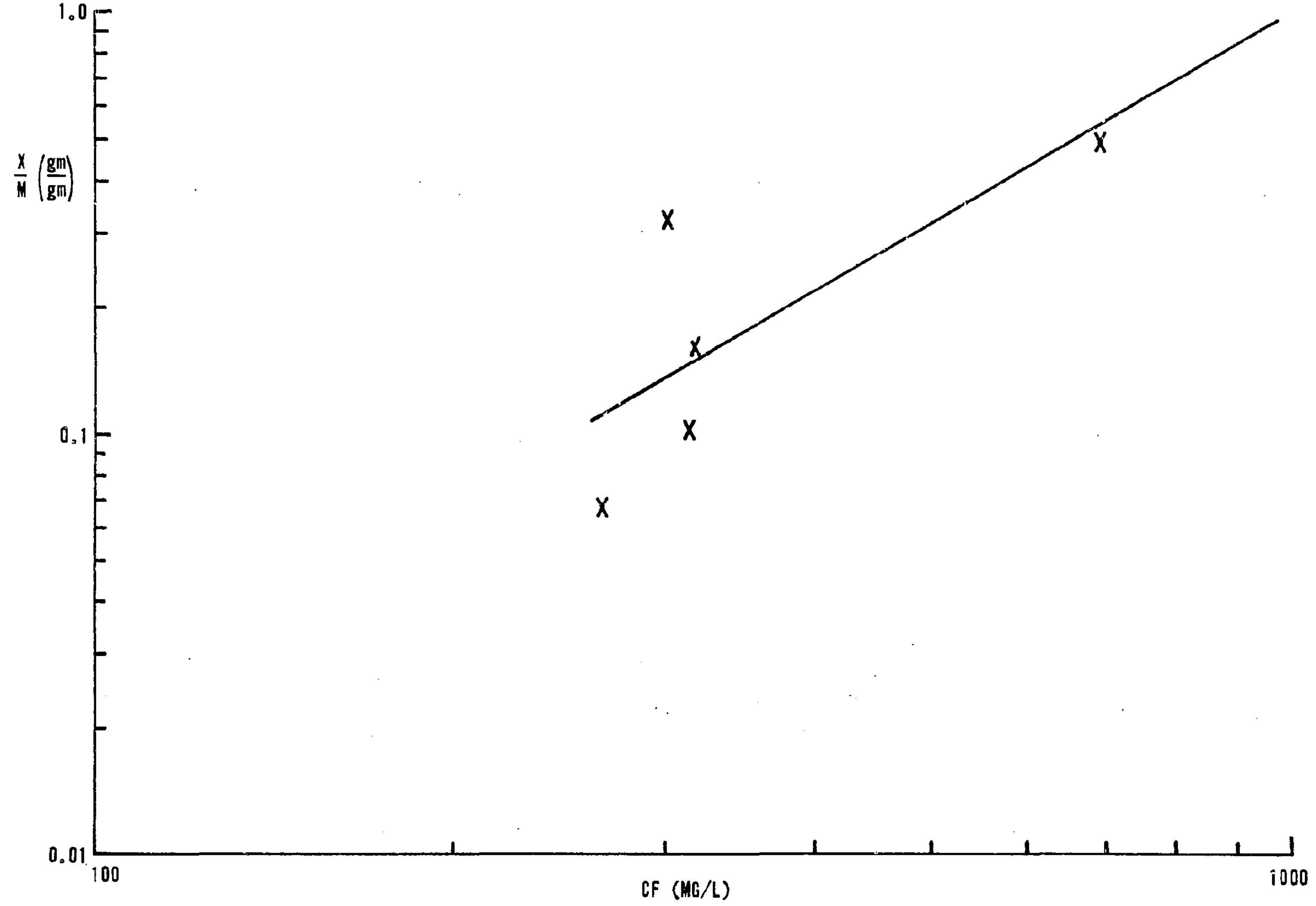

Figure 29. Batch Adsorption Isotherm, Aerowater 6 Percent (No JP-4)

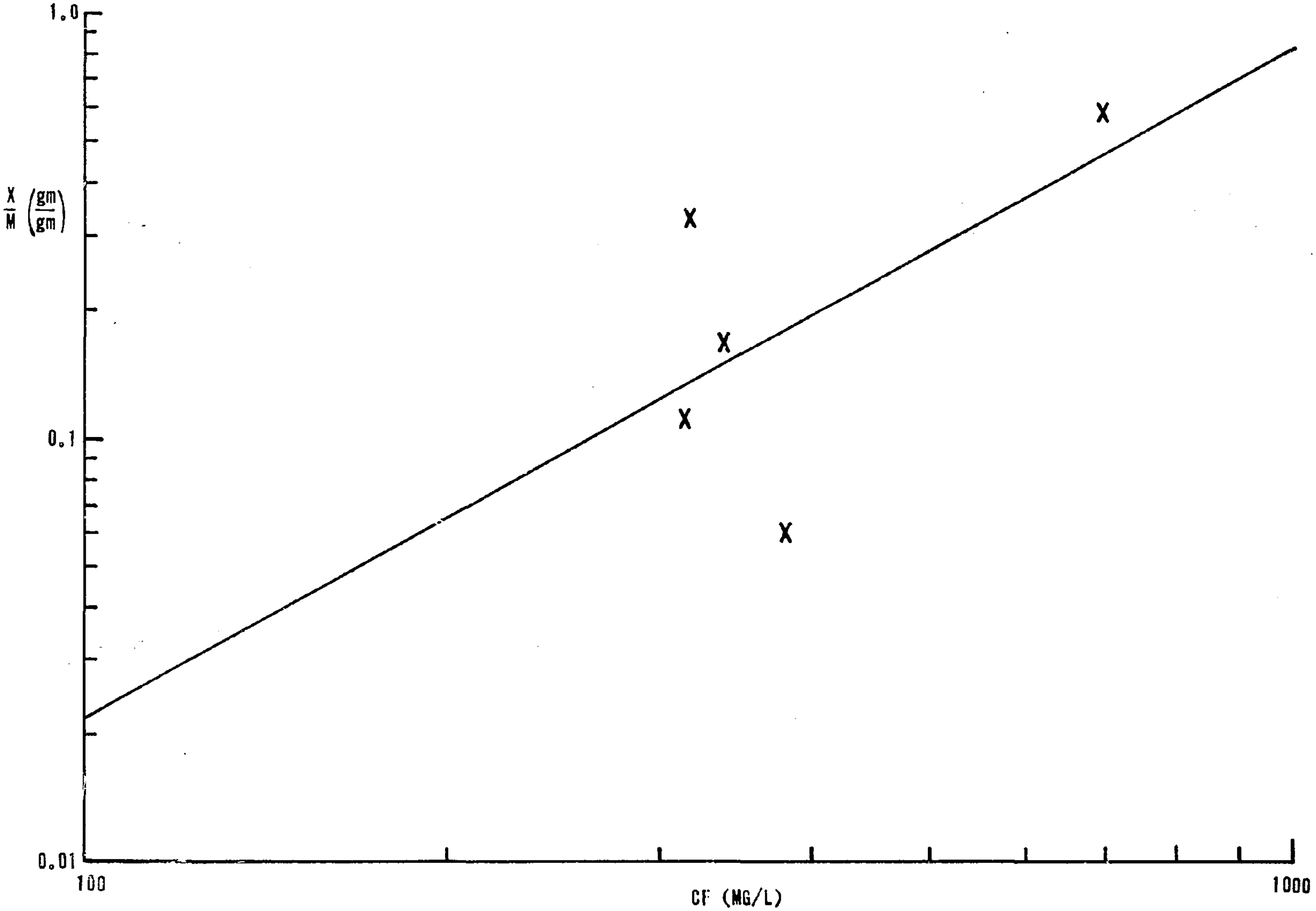

Figure 30. Batch Adsorption Isotherm, Aerowater 6 Percent (After JP-4 Extraction)

used, and C_F = final COD concentration = COD remaining in solution. X/M then becomes the carbon loading, also taken to be a good approximation of the adsorptive capacity.

Comparing figures 27 and 28, it is seen that the carbon loading is slightly lower for the FC-200 solution that was contacted with JP-4. X/M at C_F of 1500 mg/l = 0.6 for the FC-200 solution and equals 0.5 for the FC-200 solution contacted with JP-4. This difference is attributed to the presence of different organic compounds in the solution after JP-4 contact.

For Aerowater 6 percent one cannot make any comparisons because the batch adsorption data did not obey the Freundlich isotherm properties. A straight line is constructed through the data points in figures 29 and 30 using a least-squares fit. However, no validity is placed on this line. The data points do indicate the presence of a nonadsorbable component in the Aerowater 6 percent, comprising approximately 300 mg/l of COD. This is further substantiated in the continuous-flow experiments.

Assuming that some JP-4/water separator would be provided in a fire-training facility and therefore no JP-4 would contact the activated carbon, one can conclude from the batch data (at least for FC-200) that a somewhat reduced carbon loading (adsorptive capacity) will result from the interaction of the AFFF and the JP-4.

The results of the continuous-flow experiments are given in figure 31 for FC-200 and in figure 32 for Aerowater 6 percent. Only the pure solutions were used for the continuous-flow experiments. The breakthrough curves in figure 31 for the two sampling ports and the final discharge are very good with the slope of the breakthrough portion being relatively moderate. With respect to contact time until breakthrough, essentially all the FC-200 has been adsorbed by the time the water reaches the first sampling port (5 minutes contact time).

Being conservative and saying that the activated carbon is completely exhausted at the bottom of the breakthrough curve (approximately 360 minutes for port 1 and 1200 minutes for port 2), the adsorptive capacity for FC-200 is calculated to be 0.34 gm COD removed/gm of activated carbon. In terms of the FC-200, this is equivalent to 0.49 gm FC-200 removed/gm of activated carbon; or in terms of liquid volume, 0.48 ml FC-200 removed/gm of activated carbon (0.058 gal/lb). Expressed another way, for every gallon of FC-200 concentrate used, approximately 17 pounds of activated carbon would be required.

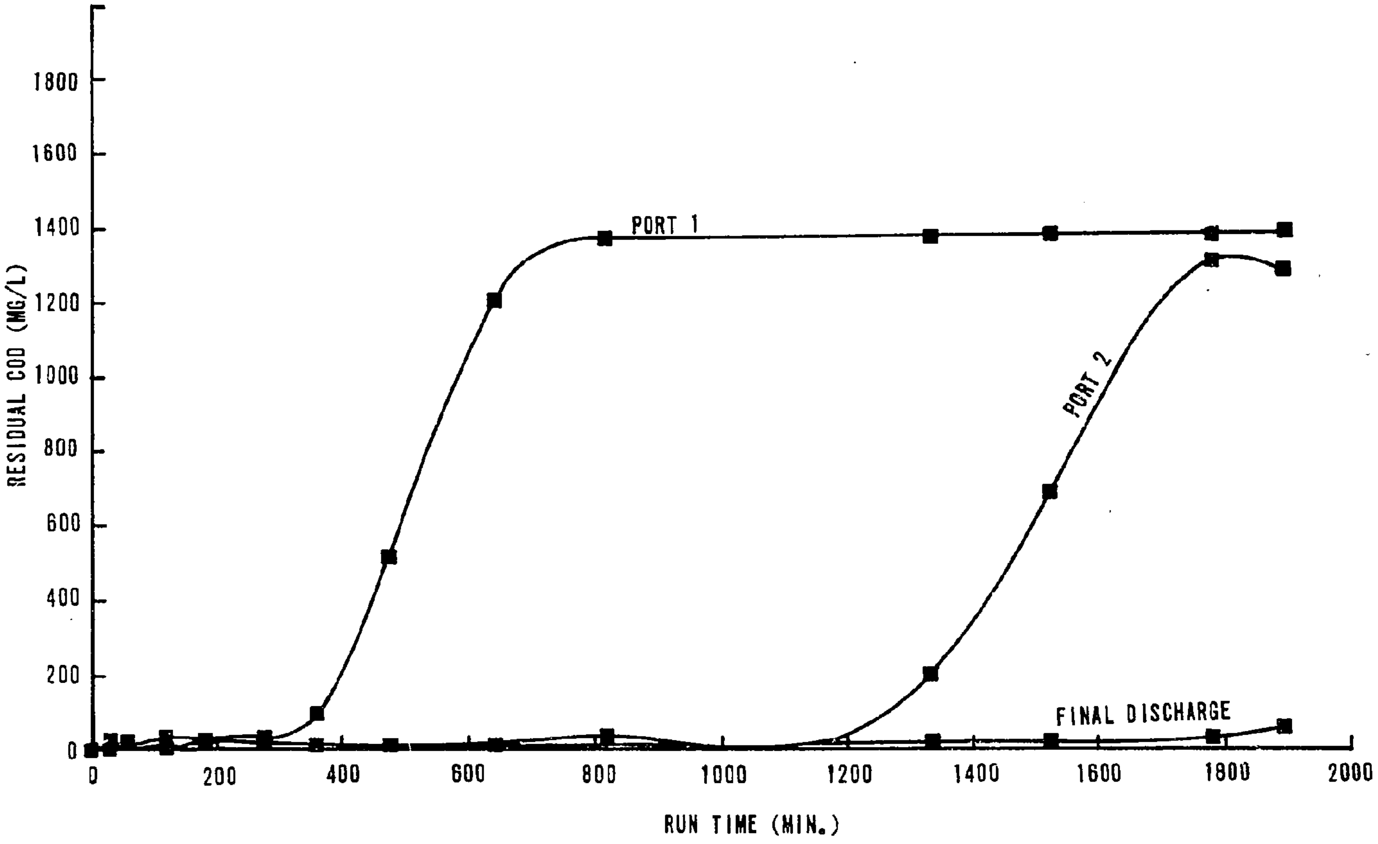

Figure 31. Breakthrough Curves, FC-200

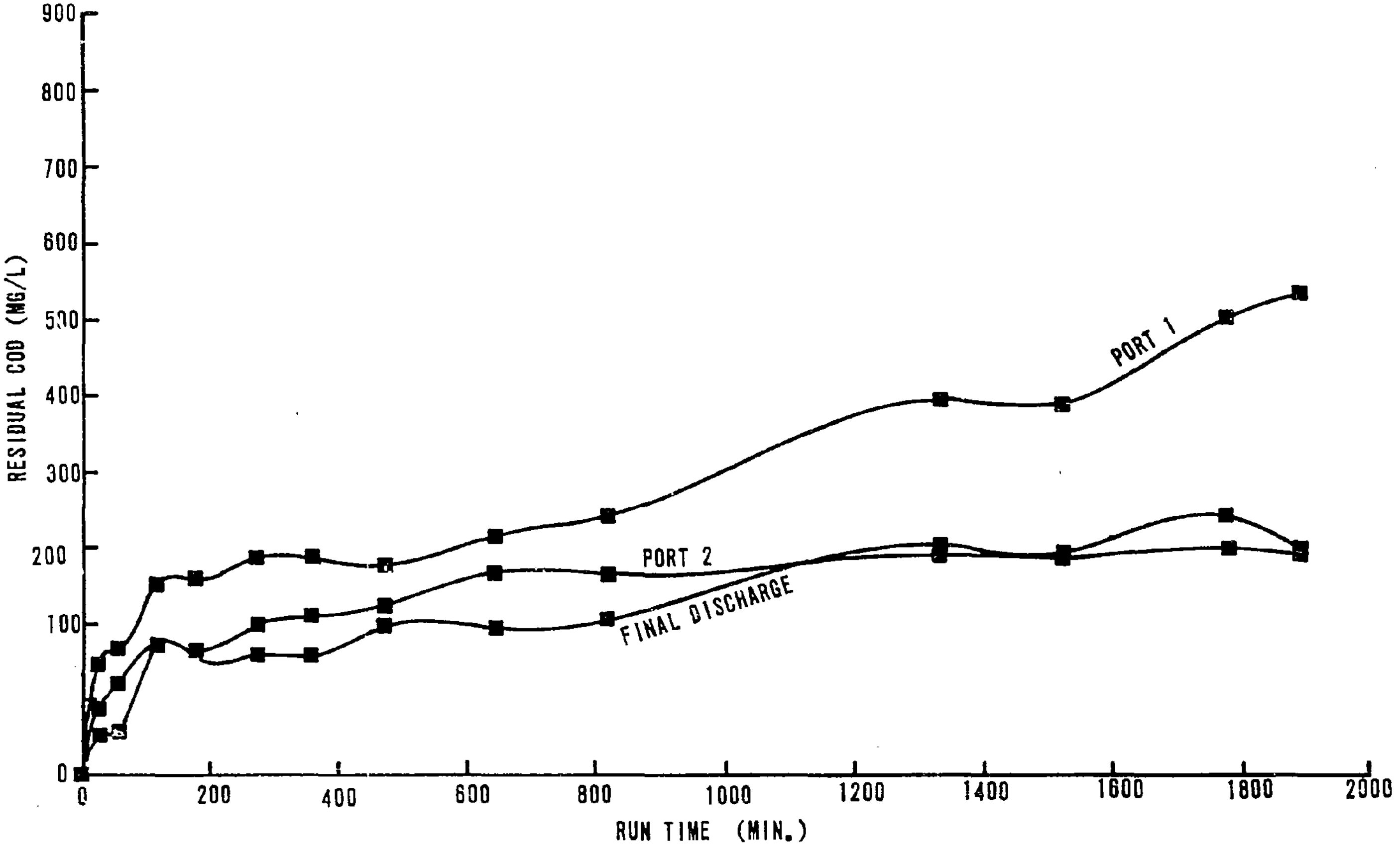

Figure 32. Breakthrough Curves, Aerowater 6 Percent

Recall that this is based on a conservative estimate of the adsorbed capacity and is for a 2000-mg/l solution of FC-200. If a more concentrated solution is processed, generally one can expect a higher adsorptive capacity since higher organic concentrations usually result in the activated carbon being relatively more saturated at exhaustion.

For Aerowater 6 percent it is seen in figure 32 that the breakthrough curves are not typical, and therefore it is not possible to calculate a realistic adsorptive capacity. This is due to a nonadsorbable fraction which accounts for 200 to 300 mg/l of COD. Therefore, virgin activated carbon is capable only of removing approximately 75 percent of the COD. A much longer contact time would further reduce the COD in the discharge, but not significantly, as evidenced by the difference in COD between the sampling ports at any given time. It is assumed that the nonadsorbable fraction is the foam stabilizer since this is likely to be a glycol compound which would be relatively polar and possibly of low molecular weight. Both properties would result in low affinity for being adsorbed or activated carbon. If this assumption is correct, the discharge of the water after activated carbon adsorption would likely be acceptable since glycol-type compounds are generally of low toxicity to aquatic life. On the other hand, the discharge at 200 to 300 mg/l of COD representing glycol compounds would pose a high oxygen demand since the glycol compounds are largely biodegradable.

SECTION V

DISCUSSION

1. BIODEGRADATION AND TOXICITY EXPERIMENTS

The results of the biodegradability experiments yielded much information as summarized below. First, it appears that it would be very difficult to acclimate a biological culture to degrade AFFFs when they represented the only source of organic matter. Second, the three AFFFs tested yielded for practical purposes the same degree of treatability when blended with a synthetic wastewater. Although the data tended to demonstrate that the biological waste treatment processes could assimilate higher concentrations of Aerowater 3 and 6 percent than FC-200, one would have to retest to verify this conclusively. Third, while AFFF dosages as high as 250 mg/l were capable of being treated, this was under laboratory conditions with a constant composition of influent wastewater; therefore a conservative maximum concentration of 80 to 100 mg/l is recommended. Since slug loading to unacclimated bacteria caused excessive foaming and impaired reactor performance, it appears obvious that bleeding in the AFFF at a controlled rate (not to exceed 50 mg/l initially and building up to 100 mg/l maximum) is a necessity. This would obviously require holding capabilities and some means of controlling the release to the sanitary sewer. Knowing the wastewater flow at the sewage treatment plant, one can easily calculate a release rate once the quantity of AFFF used is known.

Concerning the detoxification provided by biological waste treatment, the rudimentary experiments performed tend to indicate detoxification of Aerowater 3 percent and 6 percent, but not for FC-200. However, these experiments were too brief to draw a definite conclusion. It should be remembered that these toxicity experiments were conducted at influent AFFF concentrations of 200 mg/l; whereas it is recommended that the AFFF concentration not exceed 100 mg/l in the influent wastewater.

Since a good analytical method was not developed to follow the biodegradation, if any, of the AFFFs, one can only surmise what is happening to the major components, the fluorocarbon surfactant, and the foam stabilizer. The foam stabilizer, which is assumed to be some type of polyethylene glycol or glycol ether, should be fairly biodegradable and should not pose any problems to either the treatment plant or the receiving stream. The fluorocarbon surfactant, on the other hand, is at best only partially biodegradable. The microorganisms can probably break down the fluorocarbon surfactant into smaller chain-length compounds and potentially oxidize the surfactant portion completely. The fraction of compound containing the fluorocarbon bonds will almost undoubtedly not oxidize. This was substantiated in the beginning of the activated sludge experiments where it was observed that no increase in free fluoride concentration was occurring in the treated effluent. It is possible that if the microorganisms were able to break the original compound to a compound containing only F, C, and H that the solubility in water would be significantly reduced so that it would tend to separate or be readily adsorbed onto a solid surface such as the microorganisms. How these assumptions and hypotheses fit in with detoxification of the AFFFs cannot be answered since the exact composition of each AFFF is not known.

2. ACTIVATED CARBON EXPERIMENTS

The results of the activated carbon adsorption experiments demonstrate a definite affinity of the AFFFs (particularly FC-200) for being adsorbed on activated carbon. Essentially, complete removal of the FC-200, as measured by COD, was achieved within 5 minutes of contact time. For the Aerowater 6 percent only partial removal (70 to 75 percent) of the COD was achieved. Increasing the contact time beyond 20 minutes would not yield appreciable increase in the COD removal. Why FC-200 was completely removed by activated carbon and the Aerowater 6 percent only partially removed is easily explained by the fact that they are different formulations and, although likely to be similar in composition, the differences in the compounds used readily account for adsorption of FC-200 and partial adsorption of Aerowater 6 percent.

The use of activated carbon for treating AFFFs would be preferred for the small-proficiency fire-training facilities where it is not feasible to tie into a sanitary sewer. Assuming a smoke-abatement system would be in use, all that would be required is a small holding facility to allow the JP-4 carryover to separate and a pump to lift the water to the top of an activated carbon column. The column can be constructed of any convenient plastic pipe. Plastic, PVC, polyethylene, etc., is necessary because granular activated carbon is very corrosive. It is envisioned that the column would be about 15 inches in diameter and about 10 feet in height. The actual size would have to be determined for each fire-training facility. The top could be opened to the atmosphere for easy filling and withdrawal of the activated carbon. The bottom should be closed with the discharge regulated to keep the column flooded during operation. Since it is not expected to use more than a few hundred pounds of activated carbon per month, the exhausted activated carbon should be thrown away, accumulated in Remarketing and Distribution for potential resale, or mixed with coal (assuming coal is used on base for heating). By keeping a log on the number of gallons of FC-200 used, one can calculate the frequency of replacing the activated carbon by using the adsorptive capacity which conservatively, for FC-200, is 1 gallon FC-200 adsorbed per 17 pounds of activated carbon.

SECTION VI

CONCLUSIONS AND RECOMMENDATIONS

1. Biodegradation of AFFFs when they represent the only source of organic matter is not practical.

2. Discharge of AFFFs into sanitary sewers where physically practical should be done, but at a controlled rate so as not to exceed 100 mg/l of AFFF influent to the biological treatment plant. It does not appear that either activated sludge or tricking filter processes offer an advance over the other. The discharge rate should be set initially so as not to exceed, say, 50 mg/l of AFFF influent to the biological treatment plant to permit time for acclimation of the microorganisms. Slug loading should definitely be avoided. If practical, it is recommended that the AFFF be continuously discharged, which would result in the lowest concentration in the domestic wastewater.

3. From the aspect of biological treatability one cannot conclude decisively that any of the three AFFFs tested is more amenable to biological treatment than the others. Rather it is concluded that all three can be satisfactorily discharged into a sanitary sewer when the AFFF concentration does not exceed 100 mg/l (see conclusion 4).

4. Detoxification (lack of acute toxicity) of the AFFFs by biological treatment at 200 mg/l of AFFF appears to be achieved for the Aerowater products but not for FC-200. However, because of the rudimentary techniques employed, this cannot be taken as a firm conclusion. Long-term and precise bioassay tests should be conducted on each AFFF.

5. For small fire-training facilities using water spray-injection smoke-abatement systems where it is impractical to tie into a sanitary sewer, activated carbon adsorption should be employed before discharging the water containing AFFF.

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3. Lefebre, E. E., Biodegradability and Toxicity of Light Water, EHL(K)-71-36, USAF Environmental Health Laboratory Report, November 1971.
4. Representatives of 3M Company, St Paul, MN, personal communication.
5. Standard Methods for the Examination of Water and Wastewater, 13th Ed., 1971.

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UNITED STATES AIR FORCE

KELLY AFB, TEXAS 78241

BIODEGRADABILITY AND TOXICITY OF LIGHT WATER® FC206, AQUEOUS FILM FORMING FOAM

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I. SUMMARY

Light Water ®, FC206, is an aqueous film forming foam (AFFF) used for fire fighting. Biodegradability studies show that it can be biologically treated in controlled concentrations up to 200 ul/l in synthetic sewage on a continuous basis. Higher concentration appear amenable to treatment in oxidation ponds over long time periods. Toxicity studies with fathead minnow juveniles and fry indicate that FC206 is less toxic than AFFF's previously tested. The 96-hour LC_{50} for fathead minnow juveniles and fry were 1080 ul/l and 170 ul/l respectively. Using a 0.05 application factor, a concentration unit of 54 ul/l is recommended for discharge to any waters containing aquatic life.

II. INTRODUCTION

This is the fourth report on the biodegradability and toxicity of a commercial aqueous film forming foam used to fight fires by the Air Force. The results of studies of Light Water® (FC206) a product of Minnesota Mining and Manufacturing Co., St Paul, Minn, are presented here. The FC206 is used to make a six percent solution for the fire fighting operations. This study was conducted at the request of Hq USAF/SGPA and Hq USAF/PREE.

III. DISCUSSION

A. Composition

Results of analysis at this laboratory are shown in Table 1. The specific gravity of the concentrate is 1.020 with a pH of 7.8.

Table 1. Composition of FC206.

PARAMETER	QUANTITY
Water	~70%
Diethylene Glycol Monobutyl Ether	~27%
Flurocarbon (Structure not Determined)	~ 2%
Sodium Sulfate	~ 1%
Chemical Oxygen Demand	500,000 mg/l
Total Organic Carbon	96,000 mg/l
Surfactants (MBAS as LAS)	41,000 mg/l
Fluorine	14,000 mg/l

B. Respiration Studies

1. Biochemical Oxygen Demand

The need for measurement of biochemical oxygen demand (BOD) over incubation periods in excess of the standard five days has been pointed out by several investigators and reported previously (5). Additionally, incubation at 25°C rather than the standard 20°C allows determination of the Ultimate BOD in a shorter time period without adverse affects on the micro-organism composition although temperatures in excess of 30°C would alter composition (2). Figure 1 is a curve showing the BOD over a 20-day period as measured with the E/BOD Respirometer as previously reported (13). Table 2 is a summary of these E/BOD measurements.

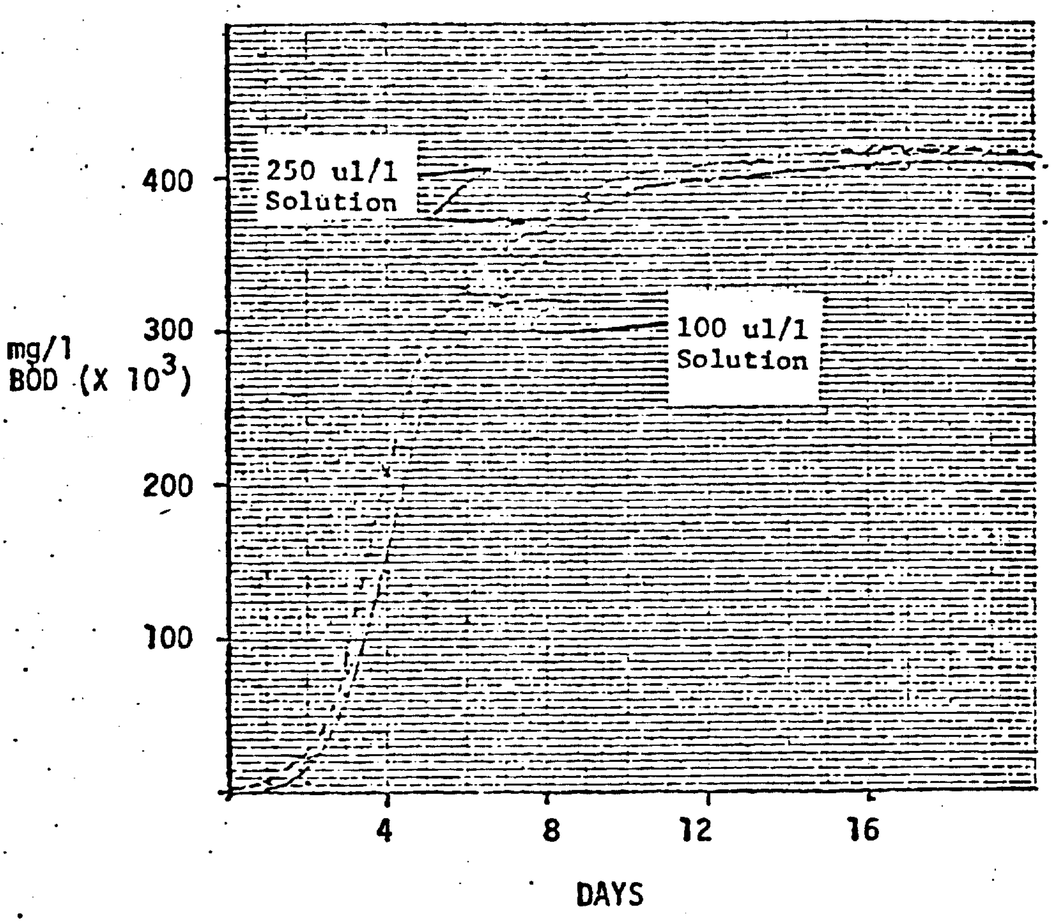

Figure 1. Biological Oxygen Demand as a Function of Time of FC 206 by USAF Environmental Health Laboratory, Kelly AFB TX, 1974.

Table 2. Summary of Data From Measurement of Extended BOD of FC206 at 25°C with the E/BOD Respirometer

	mg/l	Percent of E/BOD_{20}
E/BOD_5	2.68×10^5	65.2
E/BOD_{10}	3.95×10^5	96.1
E/BOD_{15}	4.10×10^5	99.7
E/BOD_{20}	4.11×10^5	

2. Warburg Respirometer Studies

Figure 2 shows the variation in oxygen uptake with respect to concentration of the FC206. Acclimation of the microorganisms can be seen by the increase in oxygen uptake rates at the higher concentrations with respect to time. Since the dilution of FC206 from normal usage is to a six percent solution, oxygen up take was not measured beyond the 10 percent solution.

C. Pilot Plant Studies

1. Two bench-scale activated sludge pilot plants were fed increasing concentrations of FC206 in synthetic sewage of composition shown in Table 3. The plants began to show solids loss at an FC206 concentration of 200 to 225 ul/l. Most of the solids loss appeared to be physical in nature from the foaming action forcing the solids over the side of the reactor. Tables 4 and 5 are summaries of the measured parameters for each plant. Table 6 shows the recovery of solids in the first plant when the FC206 concentration was lowered from 500 ul/l to 200 ul/l.

Table 3. Composition of Synthetic Sewage Used in Biodegradability Studies

Glucose	160	mg/l
Peptone	160	mg/l
Urea	28.6	mg/l
$Na\ HCO_3$	102	mg/l
$KH_2\ PO_4$	32.5	mg/l
Tap Water		

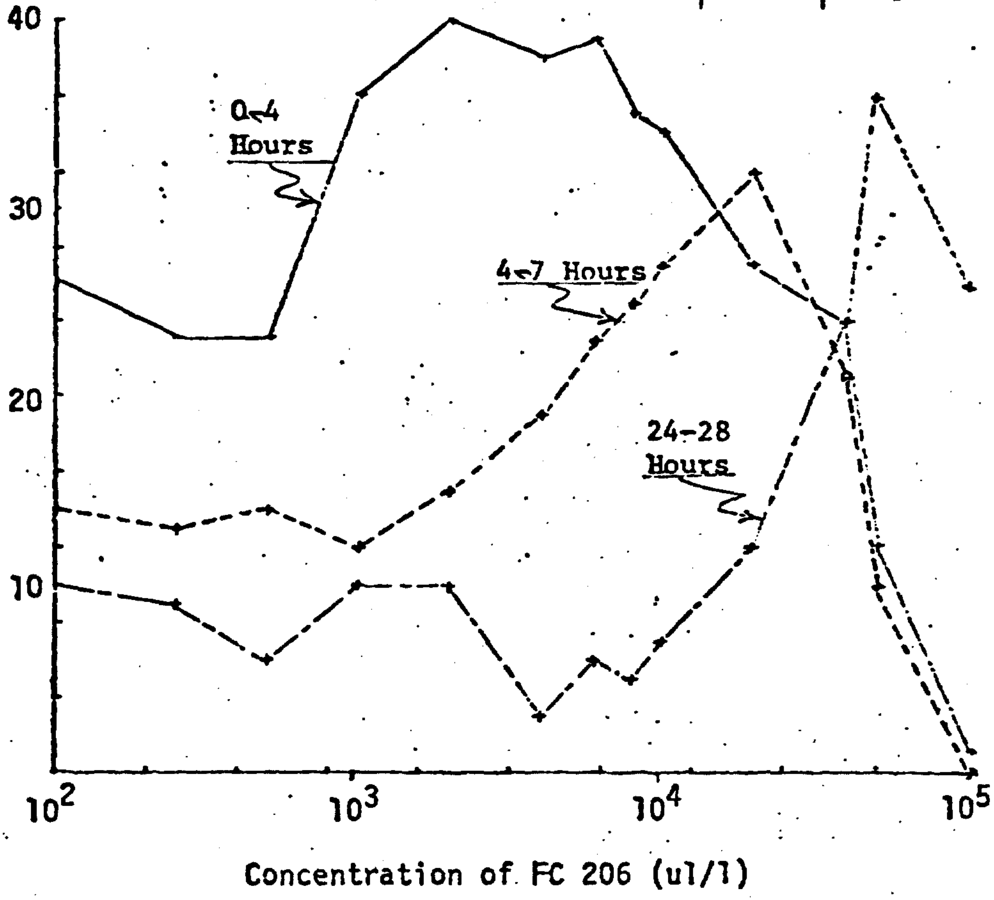

Figure 2. Oxygen Uptake of Varying Concentrations of FC 206 Using the Warburg Respirometer

2. Five Fathead minnows (Pimephales promelas) were placed in each container receiving effluent from each of the plants at the beginning of the study. One fish succumbed in the first plant effluent after 27 days and one in the second plant effluent after 43 days indicating that the effluents were relatively non-toxic. Five giant water fleas (Daphnia magna) were placed in each effluent container on the 36th day and survived to the termination of the study (51 days).

Table 4. Summary of Analysis of Samples From Activated Sludge Pilot Plant No. 1 Receiving FC206 and Synthetic Sewage.

No. of Days	ul/l FC206	mg/l Avg. MLSS	pH Range	D.O. Range mg/l	Percent BOD_5 Removal	Percent TOD Removal
5	50	3045	7.2-7.3	4.0-6.2	97.8	>95.8
3	75	3315	7.1-7.2	4.2-4.4	No Data	>95.4
5	100	3363	7.2-7.3	4.8-5.6	98.9	>95.6
3	200	3587	7.1-7.2	4.0-5.6	98.8	>99
8	300	3016	7.2-7.4	4.0-6.0	92.1	>99
5	400	2685	7.3-7.4	5.8-6.2	97.6	91.5
14	500	1763	7.4-7.8	5.0-7.4	94.8	54.5
1	300	1000	7.7	6.6	17.7	>99
3	200	1513	7.7-8.1	6.0-7.2	85.7	No Data

Table 5. Summary of Analysis of Samples from Activated Sludge Pilot Plant No. 2 Receiving FC206 and Synthetic Sewage.

No. of Days	ul/l FC206	mg/l Avg. MLSS	pH Range	D.O. Range mg/l	Percent BOD_5 Removal	Percent TOD Removal
5	50	2397	7.2-7.5	2.0-6.0	98.0	>96.1
8	75	2648	7.2-7.3	4.8-5.8	98.8	>95.4
3	125	2863	7.3-7.3	4.6-5.6	98.7	>99
8	225	3052	7.2-7.4	4.6-5.4	98.3	>99
5	250	2985	7.0-7.2	4.6-6.0	98.2	>97.9
22	300	2414	7.1-7.4	4.4-7.0	96.5	>98.2

Table 6. Daily Measurement of MLSS in Plant No. 1
From 30th to 51st Days.

Day	ul/1 FC206	mg/1 MLSS
30	500	2810
31	500	2650
32	500	2820
36	500	840
38	500	1020
39	500	1100
43	500	1100
44	300	1000
45	200	1280
46	200	1460
51	200	1800

D. Toxicity Studies

1. METHODS AND MATERIALS

a. Experimental Animals

Toxicity studies used the fathead minnow (Pimephales promelas) to determine the relative toxicity of FC206 solutions -- (Concentrate and pilot plant effluents). Sexually-immature fathead minnows were supplied by the National Fish Hatchery at Uvalde, Texas. The fish were acclimatized to the laboratory conditions and local water for a minimum of 30 days before use. Mean fish weight was 0.913 gm ($\sigma = 0.370$). The fish were fed a commercial fish food*. Immature fathead minnow fry used in static bioassays were reared at EHL/K. Age of fry at time of use was 21 days.

b. Exposure Procedure

(1) Continual flow type bioassays used proportional diluting equipment as developed by Mount and Brungs (7) (8). These diluters supplied logarithmic scaled dilutions of the compound being tested to a flow-through chamber for each concentration in which the experimental animals were held. Studies with fry were static bioassays with three fry per each one-liter test concentration.

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*Tetramin®, Distributor, Tetra Sales Corp. Heyward, CA 94545.

(2) Bioassays were performed in accordance with principles described in Standard Methods (12) and Sprague (9). Test animals were not fasted prior to testing. They were not fed during the actual assay period. Ten fish were used for each concentration and the control. Exposure chambers were plastic rat cages modified to contain 4 liters of diluted toxicant.

(3) Response of the test animals was recorded throughout a 96-hour test period. Probit analysis was performed on the data recorded at 24, 48, 72 and 96 hours of exposure to evaluate quantal response to graded doses. After the first bioassay, a true 96 hour replicate was performed using the same procedures and concentrations as used in the first run. In all these bioassays the test animals were placed into the exposure chambers in a random order by using a table of random numbers. The chambers themselves were positioned in random order. The control chamber contained water from the same water tank as the water that was used as the diluent in the other test chambers. The flow of diluted toxicant into the chamber was adjusted to a retention time of 2 hours. This is equal to a 6 hour, 95% replacement time and insures adequate maintenance of the dissolved oxygen concentration. The quantal response measured was death. A fish was counted as dead when all gill movement ceased. Dissolved oxygen and pH were monitored to insure that the cause of death was not lack of oxygen or changes in pH.

c. Dilution Water

Unchlorinated well water from a deep well was used as the dilution water in these studies. The water was collected in 400 gallon fiberglas trailer-tanks at an on-base well site. The water trailers were hauled to the Laboratory and allowed to sit at least 24 hours before the water was used. Air was bubbled through the water. The water was adjusted by heating or cooling to 24°C before it was run into the proportional diluter. The pH was 7.2 Hardness (EDTA as mg/l $CaCO_3$) was 194. Total alkalinity (as $CaCO_3$) was 160 mg/l.

d. Treatment use of Data

LC_{50}s* or TL_{50}s were determined by the probit analysis method of Litchfield and Wilcoxon. (6) Other statistical treatments such as the $(CHI)^2$ test for "Goodness of Fit" were by standard formulas. (3) To be used in this report and the previous reports on Fire-Fighting foam chemicals, toxicity study results had to fulfill two important criteria. 1) Graded quanted responses had to definitively relate to the logarithms of serial dilutions in each test chamber. 2) the results had to be repli-

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*LC_{50}, or Lethal Concentration 50%, is a concentration value statistically derived from the establishment of a dose-related response of experimental organisms to a toxicant. The LC_{50} represents the best estimation of the dose required to produce death in 50% of the organisms. Note that a more toxic chemical has a smaller LC_{50}. The time period for which the 50% response was derived must also be indicated.

cable. The establishment of dose-effect and time-effect relationships allowed scientifically based predictions of the ecological effects of the tested chemicals on a body of water during use, accidental spillage or disposal. Also the relative toxicity of one material could be compared with another; perhaps with the goal of selecting one that would have the least effect on aquatic biota. Finally, the results could be used to set "allowable" or minimal effect concentrations in bodies of water that may receive these materials as waste.

2. Results of Toxicity Studies

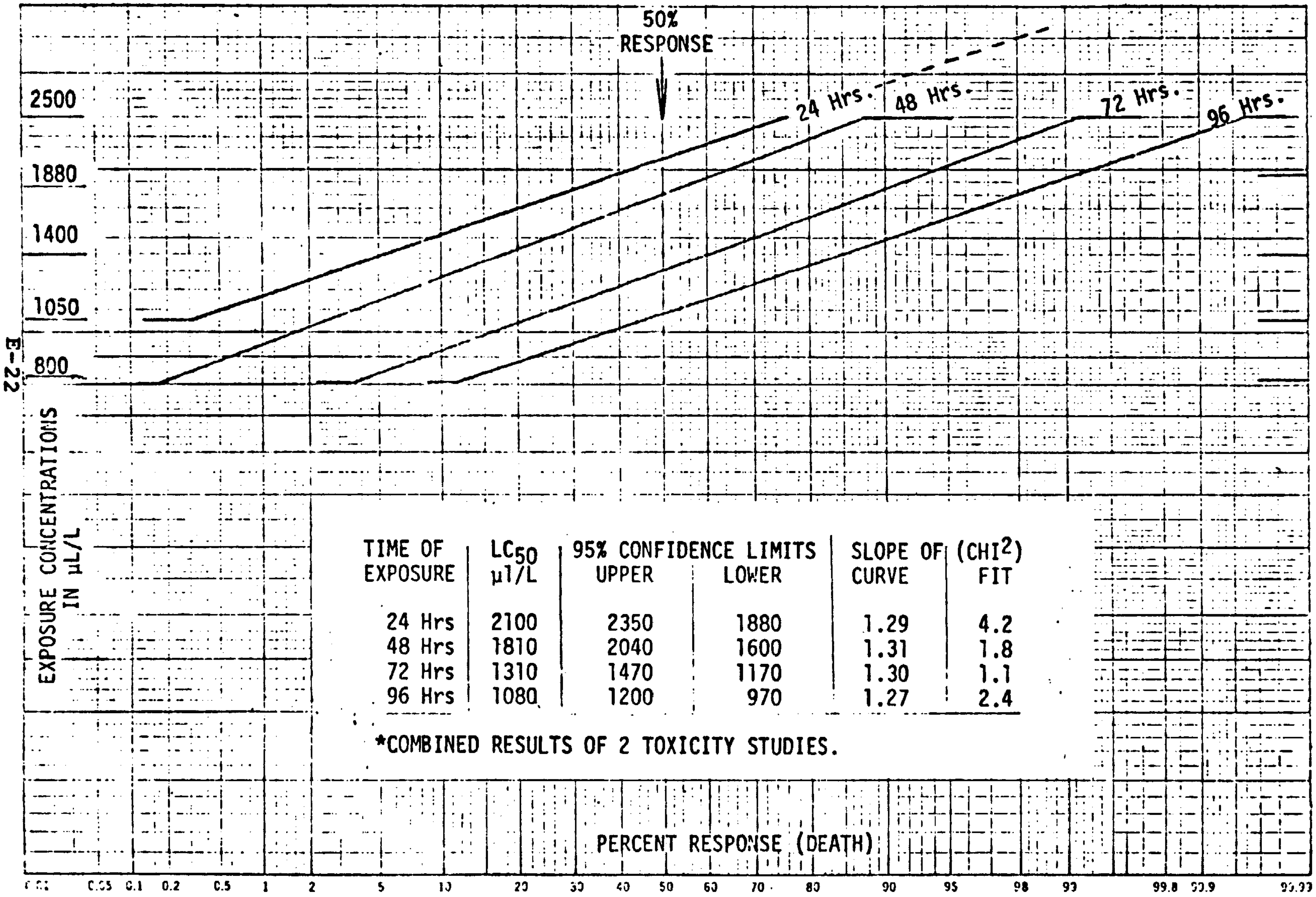
a. The sexually immature minnows were exposed to concentrations of FC206 ranging from 800 ul/l to 2500 ul/l (see Figure 3). At 48, 72 and 96 hours of exposure there was 100 percent death at the 2500 ul/l concentration and no deaths at the 800 ul/l concentration. At 24 hours of exposure there were no deaths in the 1050 ul/l concentration and 75 percent deaths in the 2500 ul/l concentration..

b. Figure 4 illustrates the change in LC_{50} with increasing time of exposure. As the percent of deaths increase with time of exposure (lower LC_{50}s), there is a reduction in the slope of the curve between 72 and 96 hours. The reduction in the slope indicates that the 96 hour value may be approaching the incipient LC_{50} (lethal threshold concentration). Therefore, for FC206, the 96 hour LC_{50} is considered to be an adaquate estimation of the incipient LC_{50} and can be used to set acceptable concentration limits of FC206 for short periods of time.

c. The 96 hour LC_{50} for 3 week old fry was 170 ul/l. The LC_{50} value for fry compared with the 1080 ul/l value for the juvenile fish indicates that the FC206 concentrate is approximately 6 times more toxic to the fry than more mature forms. Thus the increased sensitivity of immature forms indicates that the limits of safety using a 1/10 application factor for short term exposure would provide just adequate protection and that a 1/20 value would be more desirable.

Figure 3

QUANTAL RESPONSE CURVES* OF FISH EXPOSED TO FC 206



TIME OF EXPOSURE	LC_{50} µl/L	95% CONFIDENCE LIMITS UPPER	LOWER	SLOPE OF CURVE	(CHI^2) FIT
24 Hrs	2100	2350	1880	1.29	4.2
48 Hrs	1810	2040	1600	1.31	1.8
72 Hrs	1310	1470	1170	1.30	1.1
96 Hrs	1080	1200	970	1.27	2.4

*COMBINED RESULTS OF 2 TOXICITY STUDIES.

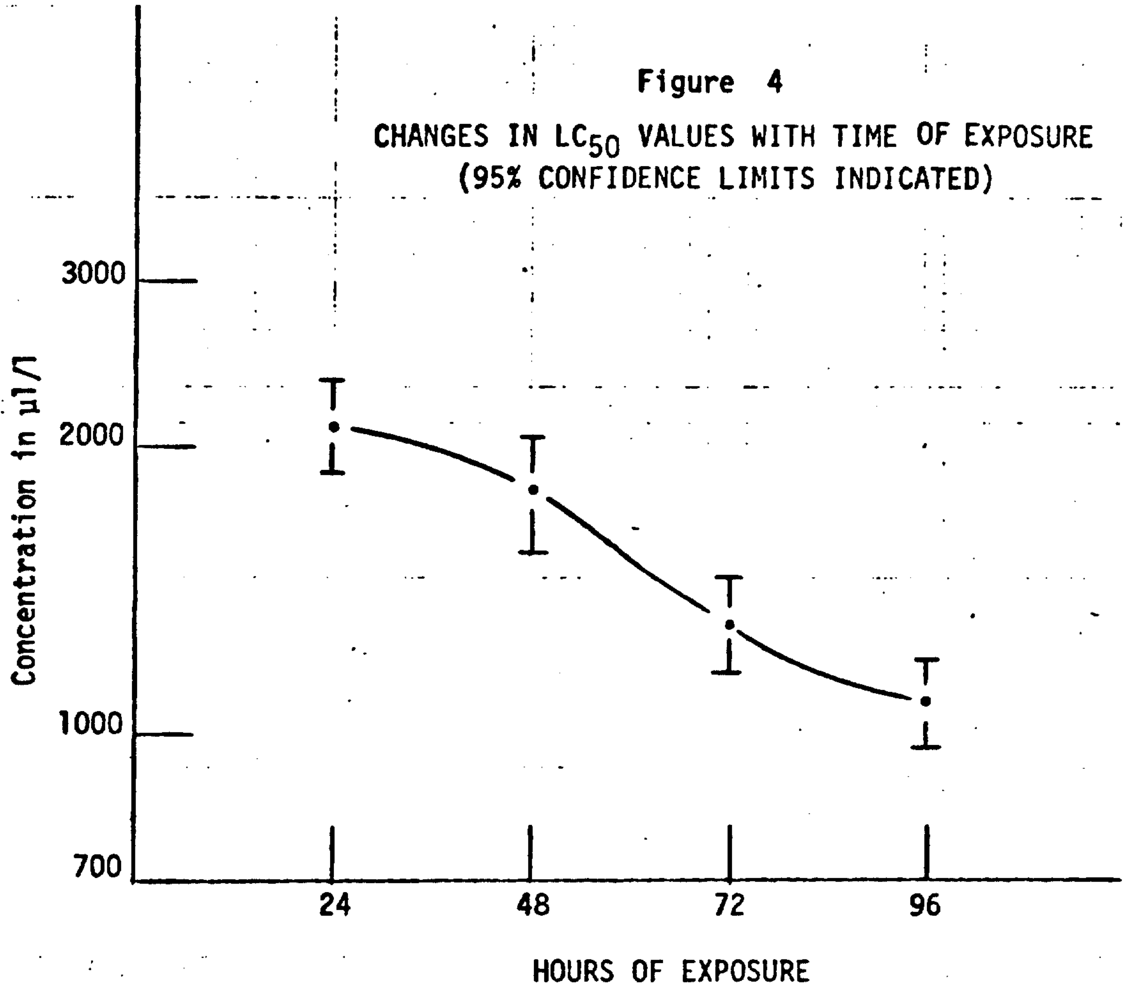


Figure 4

CHANGES IN LC_{50} VALUES WITH TIME OF EXPOSURE
(95% CONFIDENCE LIMITS INDICATED)

E. Comparison with AFFF's Previously Studies

1. Table 7 is a summary of the various parameters measured for each of the AFFF products studied thus far. (4,5,13). The greater percentage of the ultimate BOD being measured in the first five days on the newer products indicates a more rapid degree of biodegradability.

Table 7. Comparison of Various Parameters of AFFF's

	3M - LIGHT WATER			NAT'L FOAM SYSTEMS	
PARAMETER	FC199	FC200	FC206	AOW 3	AOW 6
pH	4.6	7.6	7.8	7.8	7.9
Specific Gravity	1.02	0.989	1.020	1.062	1.031
Water		59%	70%	72%	72%
Diethylene Glycol Monobutyl Ether		39%	27%	10%	10%
COD $(X10^3)$	550 mg/l	730 mg/l	500 mg/l	500 mg/l	350 mg/l
TOC $(X10^3)$		235 mg/l	96 mg/l	130 mg/l	100 mg/l
BOD_u $(X10^3)$	18 mg/l	450 mg/l	411 mg/l	354 mg/l	300 mg/l
BOD_5 (% BOD_u)	37	2	65	45	45

2. Table 8 summarizes the daily changes in LC_{50}'s during 96-hour bioassays for each of the AFFF concentrates previously studied.

Table 8. Changes in Toxicity of AFFF's to Fathead Minnows with increase in time of exposure.

	LC_{50} (Concentrations in µl/l)				
	3M - LIGHT WATER			NAT'L FOAM SYSTEMS	
	FC199	FC200	FC206	AOW 3	AOW 6
24-Hour	650	*	2100	1030	635
48-Hour	588	135	1810	820	255
72-Hour	450	97	1300	630	245
96-Hour	398	97	1080	600	225

*No mortality in 24 hours in one bioassay but 50% in highest concentration (150 µl/l) in duplicate bioassay.

IV. CONCLUSIONS

A. No acute toxicity to activated sludge microorganims was exhibited by FC206 up to 100,000 ul/l of the concentrate in synthetic sewage/activated sludge. Dilution of the concentrate for fire fighting operations is six percent (60,000 ul/l).

B. Respiration studies indicate that acclimation of microorganisms to concentrations up to 100,000 ul/l could occur and would allow successful waste treatment in oxidation ponds.

C. Bench scale - activated sludge treatment plants effectively treated concentrations of 200 ul/l on a continuous feed basis. Above this concentrations, sludge microorganisms were not able to build rapidly. This was probably due primarily to the physical removal of solids through foaming rather than direct toxicity to the microorganisms. Fathead minnows and daphnia lived in effluent from the plant being fed 500 ul/l.

D. In acute toxicity studies in which the test fish (Pimaphales promelas) were exposed to continously replenished concentrations of FC206, the 96 hour LC_{50} was 1080 ul/l (0.11%). The 96 hour value was considered to be an adequate estimation of the incipient LC_{50} (lethal threshold concentration) and suitable for use with application factors to predict "safe levels" for short-term exposure periods.

E. In comparing toxicities, FC206 concentrate was approximately six times more toxic to fry than the larger juvenile Fathead minnows. Also, FC206 concentrate was less toxic to Fathead minnows than previously tested fire fighting foams.

V. RECOMMENDATIONS

A. Wastewater from fire-fighting training operations should be passed through a gravity oil separator. The waste should then be held in a pond for natural oxidation and decomposition or pumped to a secondary sewage treatment facility at a controlled flow rate. Secondary treatment could be provided with the domestic sewage such that the influent to the sewage treatment plant will not contain in excess of 20 ul/l of the FC206. This recommendation is based on training exercises and is not necessarily intended for operational use.

B. Using the 96 hour LC_{50} of 1080 ul/l and an application factor of 0.05, the calculated "safe level" of FC206 concentrate is 54 ul/l for short term exposure. For situations in which the aquatic animals will be exposed more than 4 days, concentration of FC206 should not exceed 20 ul/l in the affected body of water.

VI. REFERENCES

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APPENDIX
Participants in Study

PARTICIPANTS

Biodegradability and Toxicity of Light Water, FC206 Aqueous Film Forming Foam

Biodegradability Studies:

Project Officer:	Maj Edward E. LeFebvre Consultant, Environmental Chemistry
	1Lt Thomas Doane, Consultant, Environmental Chemistry TSgt Samuel A. Britt, Laboratory Techician Mr. Gilbert Valdez, Physical Sciences Aide A1C Gregory Knerl, Laboratory Techician

Bioassays:

Maj. Roger Inman, Veterniary Ecologist Toxicologist
MSgt Melvin Struck, Laboratory Animal Techician
TSgt Jerold Akey, Laboratory Animal Techician

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APPENDIX F

SMALL SCALE AFFF/DYE DISPERSION TEST

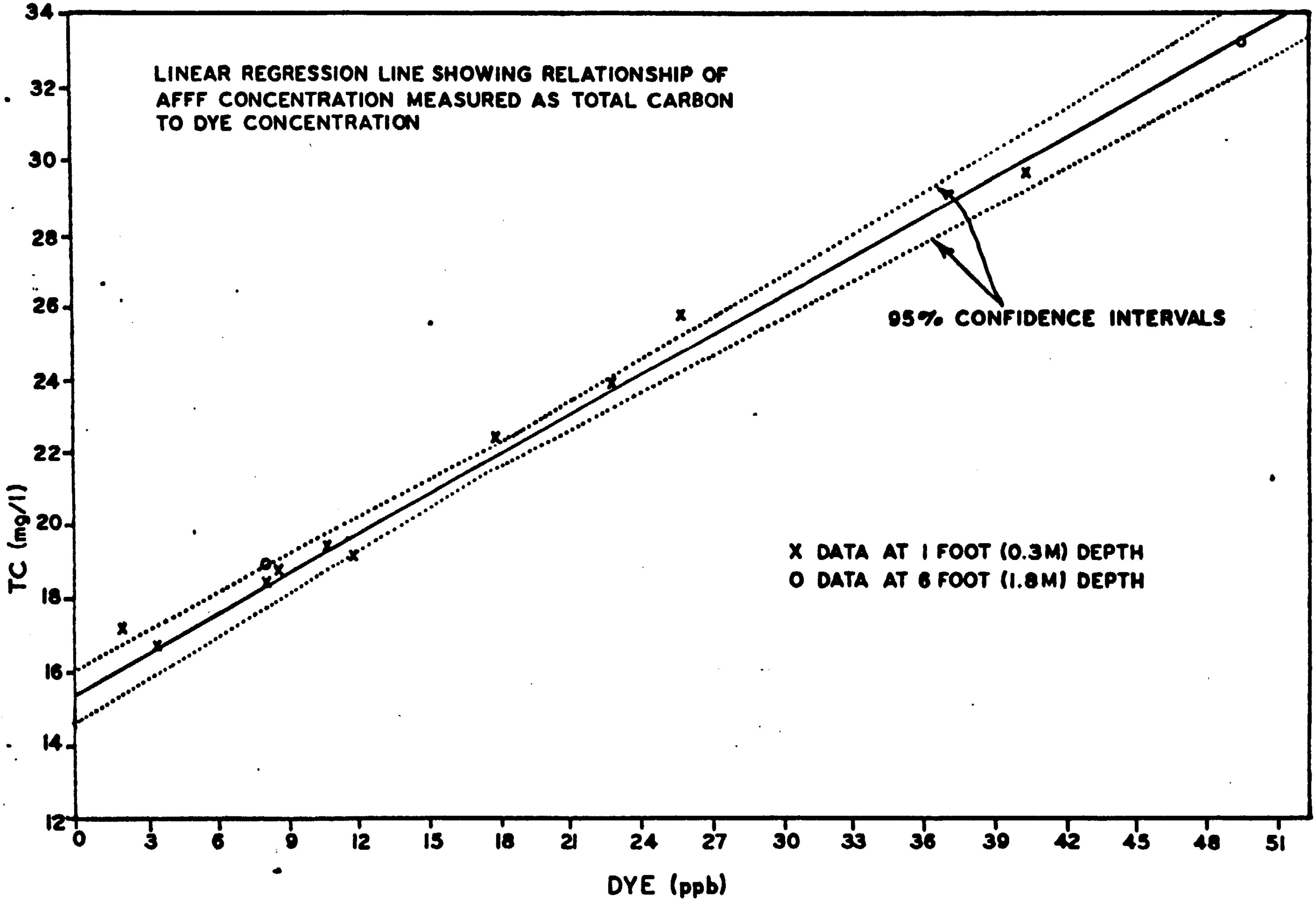
1. A small scale test was conducted in Dungan Basin at the David W. Taylor Naval Ship Research and Development Center, Annapolis Laboratory, on 3 September 1975. Released into the basin was a mixture of 1.2 gal (4.5 ℓ) of AFFF (3M Co. FC-206) and 18.8 gal (71.2 ℓ) of water drawn from the basin. The AFFF/water mixture was dyed to a concentration of 100 ppm (by weight) with rhodamine WT dye. The mixture was poured overboard at 1412 hours from a small boat in the center of the basin. Samples were pumped into collection bottles from depths of one foot (called surface samples, S), six feet, and nine feet from areas within the visible dye patch visually estimated to be those of highest dye concentration. Samples were analyzed for dye concentration, TC, and COD. Results of analyses are contained in table F-1. It was assumed that the increase in TC above background levels was due to the presence of AFFF.

2. Rhodamine dye concentration and TC data for samples collected at the one foot (0.3 m) depth are plotted in figure F-1. The relationship between dye and TC demonstrates that dye can be used to simulate the dispersion of AFFF. Although the rate of change in AFFF and dye was different, the dilution factors remained the same. Therefore, dilution data from an in situ dye dispersion study can be used to develop dilution factors applicable for predicting the decrease in AFFF concentration after release of a known quantity of AFFF under similar conditions in the study area.

Table F-1
Results of Laboratory Analyses of Water Samples from Dungan Basin Before and After the Addition of AFFF and Rhodamine Dye

Time	Depth (ft)	(m)	Dye Concentration (ppb)	TC (mg/ℓ)	COD (mg/ℓ)
Bkgd	1	0.3	<2	15.6	128
Bkgd	1	0.3	<2	13.8	125
Bkgd	6	1.8	<2	14.8	68
Bkgd	6	1.8	<2	13.8	70
1412	-	-	Release dye, 1.0 x 10^5 ppb	-	2.6 x 10^4
1415	1	0.3	8.9	18.6	96
1415	6	1.8	8.3	18.7	80
1417	1	0.3	40.6	29.6	150
1417	6	1.8	49.5	33.2	144
1419	1	0.3	25.7	24.8	160
1419	6	1.8	<2	14.6	84
1420	1	0.3	21.8	23.8	184
1420	6	1.8	<2	14.8	104
1422	1	0.3	17.8	22.4	100
1422	6	1.8	<2	14.8	80
1423	1	0.3	10.9	19.4	68
1423	6	1.8	<2	14.1	148
1424	1	0.3	8.5	18.2	76
1424	6	1.8	<2	15.3	64
1425	1	0.3	3.7	16.6	88
1425	6	1.8	<2	14.1	132
1425	9	2.7	<2	14.1	152
1427	1	0.3	11.9	19.2	100
1427	6	1.8	<2	14.6	68
1427	9	2.7	<2	14.1	188
1430	1	0.3	2.1	17.3	64
1430	6	1.8	<2	13.6	48
1430	9	2.7	<2	14.8	96

FIGURE F-1


LINEAR REGRESSION LINE SHOWING RELATIONSHIP OF AFFF CONCENTRATION MEASURED AS TOTAL CARBON TO DYE CONCENTRATION
95% CONFIDENCE INTERVALS
X DATA AT 1 FOOT (0.3M) DEPTH
O DATA AT 6 FOOT (1.8M) DEPTH
TC (mg/l)
34
32
30
28
26
24
22
20
18
16
14
12
0
3
6
9
12
15
18
21
24
27
30
33
36
39
42
45
48
51
DYE (ppb)

APPENDIX G

TENTATIVE ALLOCATION PLANS AND CONSTRUCTION SCHEDULES FOR SHIP CHT SYSTEMS, SWOBS, AND PIER SEWERS

TABLE G-1
ACTIVITIES WHICH HAVE/PLAN TO HAVE PIERSIDE FACILITIES FOR SHIP-TO-SHORE SEWAGE TRANSFER TOGETHER WITH FACILITY DESCRIPTION AND STATUS*

15 October 1976

LOCATION	MCON NO.	PCR NO.	DESCRIPTION	STATUS
NORFOLK COMPLEX				
NAVSTA	P-807	W289D	PIERS 7,12,20,21,22,23	CONST.COMPL. FACILITY OPERATING
			PIER 24	UNDER CONST. UNTIL 6/78
			PIER 25	UNDER CONST. UNTIL 7/77
NAB LITTLE CREEK	P-206	W131J	PIERS 56,57,58,59	CONST.COMPL. FACILITY OPERATING
NAVSTA	P-911	W289E	PIERS 2,3,4,5,10	UNDER CONST. UNTIL 1/77
NSY PORTSMOUTH	P-177	W164G	WHARFS 1-12,15,23-27,29-33 35,36,38,39,41-45	UNDER CONST. UNTIL 4/77
NAB LITTLE CREEK	P-207	W131K	PIERS 1-8,11-15,16-19	UNDER CONST. UNTIL 3/77
NSY PORTSMOUTH	P-999	W164A	PIER C	UNDER CONST. UNTIL 4/77
SAN DIEGO COMPLEX				
NAVSTA	P-176	W027D	PIER 4	CONST.COMPL. FACILITY OPERATING
NSSF	P-036	W304A	PIERS 5000,5002, DEPERMING PIER	CONST.COMPL. FACILITY OPERATING
NAS NORIA	P-313	W018L	WHARFS I,J,K	CONST.COMPL.(MUNICIPAL CONN. COMPL.) Lift Station Pump Prob.
NAVSTA	P-179	W027F	PIERS 5,6,8	UNDER CONST. UNTIL 5/77; PIER 5 CONST.COMPL.
			SMALL CRAFT BASIN	CONST.COMPL.
			MOLE PIER	CONST.COMPL.
			PIERS 1,2,3	UNDER CONST. UNTIL 1/78
			PIER 9	PLANNED EST.COMPLETION 12/78
	P-191	W032j	PIER 10	PLANNED EST.COMPLETION 12/79
	P-198	- -	PIERS 11,12,13	PLANNED EST.COMPLETION 12/80
NSC	P-022	W209K	BROADWAY PIER	UNDER CONST. UNTIL 12/76
	P-023	W209j	FUEL PIER PT.LOMA	UNDER CONST. UNTIL 12/77
NUC	P-059	W028D	PIERS 1,2 PT. LOMA	PLANNED EST. COMPLETION 6/78
	P-057	W028C	SAN CLEMENTE ISLAND	PLANNED EST. COMPLETION 7/79
NAB CORONADO	P-093	W220C	PIERS 3,8,13	UNDER CONST. UNTIL 12/77

*NCBC letter to CNO, 25A1:WLR:hla, Control No. 610-23, Seria 5054 of 16 November 1976, enclosure (1).

TABLE 1 (cont.)

LOCATION	MCON NO.	PCR NO.	DESCRIPTION	STATUS
CHARLESTON				
NSC	P-903	W305A	PIER A	UNDER CONST. UNTIL 6/77
NSY			PIERS C,D,F,G,H,J,K,L,M	UNDER CONST. UNTIL 6/77
NAVSTA			PIERS N,P,Q,R,S,T,U	UNDER CONST. UNTIL 6/77
NWS	P-901	W119H	WHARF A, PIERS B,C,	UNDER CONST. UNTIL 11/76
MAYPORT				
NAVSTA	P-964	W049K	WHARFS B,C,D,A	CONST.COMPL. FACILITY OPERATING
PEARL HARBOR COMPLEX				
NSB	P-119	W057G	PIERS S1-S5,S8,S9	CONST.COMPL. (awaiting sewage transfer hose)
NAVSTA	P-991	W165G	PIERS B1-B26,	UNDER CONST. UNTIL 2/77
NSY			B1-B21,GD1-GD5,	UNDER CONST. UNTIL 2/77
			O2, MR NO. 2	UNDER CONST. UNTIL 2/77
NAVSTA	P-991A	W165H	PIERS M1-M4,	UNDER CONST. UNTIL 2/77
NSC			H1-H4,	UNDER CONST. UNTIL 2/77
NSB			S10-S14,S20,S21	UNDER CONST. UNTIL 2/77
NAVSTA	P-179	W165I	A1-A7,S15-S19,F1-F5	UNDER CONST. UNTIL 10/77
NSC			V1-V4,K3-K11	UNDER CONST. UNTIL 10/77
NAVSTA	P-179A	W165J	F12,F13	UNDER DESIGN, EST.COMPL. 7/78
NAVMAG	P-179B	W165J	W1-W5	UNDER DESIGN, EST.COMPL. 3/79
SAN FRANCISCO				
NAS ALAMEDA	P-100	W007M	PIER 3	CONST.COMPL. FACILITY OPERATING
	P-133	W007N	PIERS 1,2	CONST.COMPL. FACILITY OPERATING
NWS CONCORD	P-153	W008F	PIER 2	PLANNED, EST.COMPLETION 6/80
NSY VALLEJO	P-203	W031F	WHARFS 2-20,24	PLANNED, EST.COMPLETION 5/78
			PIERS 21-23	PLANNED, EST.COMPLETION 5/78
NSC OAKLAND	P-002,3,4	W019F	- - - - -	PLANNED, EST.COMPLETION 12/79
PUGET SOUND				
NTS KEYPORT	P-190	W146j	WHARF	UNDER CONST. UNTIL 1/77
NSY BREMERTON	P-166	W144K	PIERS 3-8	PLANNED, EST. COMPLETION 1/80
NSC BREMERTON	P-038	W147N	FUEL PIER	PLANNED, EST. COMPLETION 5/77

TABLE G-1 (cont.)

LOCATION	MCON NO.	PCR NO.	DESCRIPTION	STATUS
LONG BEACH				
NAVSTA	P-131	W014F	PIERS 9,11,15	CONST.COMPL.
NSY	P-172	W015I	PIERS 1,2,3,6,E	CONST.COMPL.
NAVSTA	P-133	W014G	PIER 7	UNDER CONST. UNTIL 1/77
NWS SEAL BEACH	P-096	W035C	WHARF	PLANNED, EST. COMPLETION 7/78
GROTON/NEW LONDON				
NSB NEW LONDON	P-157	W040D	PIERS 1-4,6,8-10,12,13,15,17,31	CONST.COMPL.(awaiting sewage transfer hose)
NUSC	P-116	W332A	PIER 7	PLANNED EST. COMPLETION 9/79
PENSACOLA				
NAS	P-999	W051K	PIERS 302,302	CONST.COMPL.(awaiting sewage transfer hose)
WASHINGTON D.C.				
NAVSTA	P-194	W042j	PIERS 1,4	CONST.COMPL. FACILITY OPERATING
PORTSMOUTH N.H.				
NSY	- - -	- - -	PIERS 1,2,3	CONST.COMPL. FACILITY OPERATING
ADAK				
NAVSTA	P-834	W002I	PIER 3	PLANNED, EST. COMPLETION 12/79
EARLE				
NWS	P-771	W190A	PIERS 2,3	PLANNED, EST. COMPLETION 6/77
NEW ORLEANS				
NSA	P-047	W063C	PIER 1	PLANNED, EST. COMPLETION 8/79
PANAMA CITY				
NSCL	P-999	W266B	SOUTH DOCK, EAST DOCK	CONST.COMPL (awaiting sewage transfer hose)

TABLE G-1 (cont.)

LOCATION	MCON NO.	PCR NO.	DESCRIPTION	STATUS
PORT HUENEME				
CBC	P-332	W023K	WHARFS 2-6,A	PLANNED, EST. COMPLETION 9/79
YORKTOWN				
NWS	P-336	W136C	PIER 2	UNDER CONST. UNTIL 1/77
PHILADELPHIA				
NSY	P-451	W106D	PIERS 1,2,4	UNDER CONST. UNTIL 11/76
	P-443	W106B	PIERS 5,6	CONST.COMPL.(awaiting sewage transfer hose)
ROOSEVELT ROADS				
NAVSTA	P-997	W111H	PIERS 1,2,3	UNDER CONST. UNTIL 4/77
GUAM				
NAVSTA	P-094	W064K	A,B & V	UNDER CONST. UNTIL 11/76
NAVSHIPREPFAC			L,M,N,& O	UNDER CONST. UNTIL 11/76
NSD			R,S,T, & U	UNDER CONST. UNTIL 11/76
NAVMAG			H	UNDER CONST. UNTIL 11/76
NAVSTA	P-107	W064R	X	PLANNED, EST. COMPLETION 12/79
PORTLAND, OR				
NAVRESCTR	O&MN	W258C	PIERSEWER	AWAITING AWARD OF CONST.CONTRACT (EST.COMPL. OF CONST. 4/77)
TACOMA, WA				
NAVRESCTR	O&MN	W151C	PIERSEWER	AWAITING AWARD OF CONST.CONTRACT (EST.COMPL. OF CONST. 4/77)
EVERETT, WA				
NAVRESCTR	O&MN		PIERSEWER	UNDER CONST. UNTIL 1/77

TABLE G-1 (cont.)

LOCATION	MCON NO.	PCR NO.	DESCRIPTION	STATUS
GALVESTON, TX NAVRESCTR	MCNR P-032	W322A	PIERSEWER STRUCT. #11	PLANNED, EST. COMPLETION 7/77
ST. PETERSBURG, FL NAVRESCTR	MCNR P-241	W329A	PIERSEWER STRUCT. #6	PLANNED, EST. COMPLETION 7/77
BRONX, NY (Fort Schyler) NAVRESCTR	MCNR P-315	W324A	PIERSEWER	PLANNED, EST. COMPLETION 1/78
PERTH AMBOY NAVRESCTR	MCNR P-346	W338A	PIERSEWER	PLANNED, EST. COMPLETION 12/78
PORTLAND, ME NAVRESCTR	MCNR P-343	W340A	PIERSEWER	PLANNED, EST. COMPLETION 10/78
BALTIMORE, MD NAVRESCTR	MCNR P-243	W072A	PIERSEWER	PLANNED, EST. COMPLETION 10/77
JACKSONVILLE, FL			NO PIERSEWER PLANNED	
BOSTON, MA			NO PIERSEWER PLANNED	
NEWPORT, RI (NETC) NAVSTA	P-208	W116N	PIERSEWER PLANNED	

TABLE G-1 (cont.)

LOCATION	MCON NO.	PCR NO.	DESCRIPTION	STATUS
GREAT LAKES, IL			NO PIERSEWER PLANNED	
YOKOSUKA, JAPAN				
LA MADDALENA, IT				
HOLY LOCH, SC			WILL USE SWOB	
ROTA, SPAIN			WILL USE SWOB	
BAHRAIN				
GAETA				
NAPLES				
BROOKLYN, NY (Floyd Bennett Field) NAVRESCTR	MCNR P-319	W337B	PIERSEWER PLANNED	

TABLE G-2
SHIPS WASTE OFFLOAD BARGE (SWOB) ALLOCATION PLAN AND DELIVERY SCHEDULE*

	FY74 PROCUREMENT (OIL)		FY75 PROCUREMENT (OIL)			FY76 PROCUREMENT (OIL & SEWAGE)		TOTAL ALLOCATED	
	ALLOCATED	DELIVERED	ALLOCATED	DELIVERED	TO BE DELIVERED	ALLOCATED (OIL)	ALLOCATED (SEWAGE)	OIL	SEWAGE
NAVSHIPYD Portsmouth	0	0	0	0	1	0	0	1	0
WPNSTA Earle	0	0	2	0	1 (Note 1)	1	0	2	0
NAVSHIPYD Philadelphia	0	0	0	0	0	2	0	2	0
WPNSTA Yorktown	1	1	0	0	0	0	0	1	0
NAVSTA Norfolk	3	3	3	3	0	0	2	6	2
NAVPHIBASE Little Creek	1	1	1	1	0	0	1	2	1
NAVSHIPYD Norfolk	1	1	0	0	0	1	0	2	0
NAVSTA Charleston	2	2	0	0	0	1	0	3	0
NAVSHIPYD Charleston	0	0	0	0	0	0	1	0	1
NAVSHIPYD Puget Sound	2	2	3	3	0	0	0	5	0
NAVSHIPYD Mare Island	1	1	0	0	0	0	0	1	0
NAVFUELDEP Point Molate	0	0	1	0	1-Jan '77	0	1	1	1
NSC Oakland	1	1	0	0	0	0	0	1	0
NAVSHIPYD Long Beach	2	2	0	0	0	0	1	2	1
NAVSTA San Diego	3	3	0	0	0	0	2	3	2
NAS North Island	2	2	0	0	0	0	0	2	0
NAVSHIPYD Pearl Harbor	1	1	0	0	0	0	0	1	0
NAVSTA Pearl Harbor	2	2	1	0	1 (Note 2)	0	3	3	3
NAVSTA Guam	0	0	1	0	1 (Note 2)	0	1	1	1
NAVSTA Subic Bay	0	0	1	0	1 (Note 2)	0	0	1	0
FLEACT Yokosuka	0	0	2	0	2 (Note 3)	0	0	2	0
NAVSTA Rota	0	0	1	0	1 (Note 4)	0	1	1	1
NAVSUPPO La Maddalena	0	0	1	0	1 (Note 4)	0	0	1	0
NAVSTA Roosevelt Roads	0	0	2	0	2-Jan '77	0	0	2	0
NAVSTA Guantanamo Bay	0	0	1	0	1-Jan '77	0	0	1	0
TOTALS	22	22	20	7	13	5	13	47	13

*Information provided by Naval Facilities Engineering Command (NAVFAC 104), 10 January 1977.

Notes:
1. One barge delivered by contractor stored at NAVSHIPYD Puget Sound to be delivered by contractor to final destination.
2. Three barges delivered by contractor in July 1976 to NAVSHIPYD Long Beach to await a Navy tow of opportunity to final destinations.
3. Two barges delivered by contractor in September 1976 to NAVSHIPYD Long Beach to await a Navy tow of opportunity to final destinations.
4. Three barges delivered by contractor in July 1976 to INACTSHIPPAC Portsmouth to await a Navy tow of opportunity to final destinations.

TA[illegible] G-3

CHT COMPL[illegible]N SCHEDULE*

1 SEPT'76

FY-73	FY-74	FY-75	FY-76-7T	FY-77	FY-78	FY-79	FY-80	FY-81
COMP. CG-11 - - - - AS-11 AS-16 AS-31 AS-32 AS-37 ASR-8 (4) ASR-9 ASR-14 - - - - LPH-3 - - - - **PART.** LPD-6 (* in 7T) LSD-32 (* in 7T) LSD-34 (* in 77) **INCR.** CV-60(6)(8)	**COMPLETES** CG-10 CG-17 CG-27 DD-945 DDG-11 DDG-33 DDG-37 DDG-46 FF-1049 FF-1053 FF-1054 FFG-1 - - - - AD-18 AD-37 AE-21 AE-22 AFS-6 AO-98 AO-147 AOR-1 AR-7 AS-12 ATF-100 ATF-101 ATF-161 - - - - LPD-7 LST-1179 LST-1182 - - - - **PARTIALS** CG-26 (* in '78) CG-28 (* in '76) CGN-35 (* in '76 DD-835 Note (5) DD-839 (* in '78) DD-862 (* in '78) DD-863 Note (5) DD-895 Note (5) DD-886 (* in '78) DDG-7 (* in '77) FF-1056 (* in '78) FF-1057 (* in '7) FF-1058 (* in '78) FF-1060 (* in '7) FFG-2 (* in '79) - - - - AE-27 (* in '76) AO-149 (* in '79) ARS-8 (* in '76) ARS-23 (* in '76) ARS-24 Note (5) ARS-25 (* in '76) ASR-13 (* in '78) ASR-15 (* in '78) ATF-96 (* in '76) ATF-106 (* in '76) ATF-110 (* in '76) ASR-16 Note (4) - - - - LKA-113 (* in '78) LPD-8 (* in '79) LPD-13 (* in '78) LSD-28 (* in '79) LST-1183(* in '78) LST-1184(* in '76) **INCREMENTALS** CV-67 (8)	**COMPLETES** CG-29 CG-36 CGN-25 DD-937 DD-938 DD-941 DD-948 DD-950 DD-763 DD-754 DD-927 DDG-31 DDG-36 DDG-45 FF-1041 FF-1059 FF-1066 FF-1077 FFG-5 FFG-6 - - - - AD-38 AFS-2 AFS-7 AG-153 AO-99 AOR-2 ARS-38 ARS-40 ARS-42 - - - - LKA-116 LPD-1 LPD-10 LPD-11 LPH-7 LPH-10 LSD-37 LST-1180 LST-1185 LST-1186 LST-1187 LST-1191 - - - - **PARTIALS** LCC-20 (* in '78) **INCREMENTALS** CV-64 (8) CV-66 (8)	**COMPLETES** CG-18 CG-22 DD-931 DD-933 DD-940 DD-943 DD-946 DDG-4 DDG-9 DDG-10 DDG-19 DDG-22 DDG-23 DDG-32 AGFF-1 FF-1065 FF-1037 FF-1050 FF-1051 FF-1052 FF-1062 FF-1063 FF-1068 FF-1071 FF-1072 FF-1075 FF-1078 FF-1079 FF-1091 FFG-3 - - - - AD-19 AE-28 AE-26 AE-29 AFS-4 AGF-3 AOE-1 AOE-4 AOR-3 AOR-6 ARS-41 AS-34 ATS-1 ATS-2 ATF-103 ATF-105 ATF-113 ATF-162 AR-5 - - - - LCC-19 LKA-112 LPA-248 LPA-249 LPD-3 LPD-9 LPD-12 LPD-14 LPH-9 LPH-11 LPH-12 LSD-29 LSD-35 LSD-38 LSD-39 LST-1181 LST-1188 LST-1189 LST-1195 **COMPLETIONS OF PARTIALS** CG-28 CGN-35 - - - - AE-27 ARS-8 ARS-23 ARS-25 ATF-96 ATF-106 ATF-110 - - - - LPD-6 LSD-32 **INCREMENTALS** CV-63(8)	**COMPLETES** CV-67(6)(7) - - - - CG-20 CG-23 CG-24 CG-30 CG-32 DDG-15 DDG-35 DDG-38 DDG-40 FF-1055 FF-1061 FF-1070 FF-1073 FF-1074 FF-1076 FF-1080 FF-1082 FF-1083 FF-1084 FF-1085 FF-1086 FF-1087 FF-1089 - - - - AD-15 AE-23 AE-24 AE-32 AE-34 AE-35 AFS-1 AO-51 AOE-2 AOR-5 AR-8 ARS-43 AS-33 AS-36 ATF-160 - - - - LPD-15 LST-1193 **COMPLETIONS OF PARTIALS** DDG-7 - - - - - - - - LSD-34 - - - - **INCREMENTALS** CV-59 (8) CV-61 (8)	**COMPLETES** CVT-16(6)(7)(8) CV-63 (6)(7)(8) - - - - CG-21 CG-33 DDG-5 DDG-6 DDG-8 DDG-16 DDG-18 DDG-20 DDG-36 DDG-43 DDG-44 DD-951 FF-1047 FF-1048 FF-1069 FF-1088 FF-1090 FF-1091 FF-1092 FF-1093 FF-1094 FF-1095 FF-1096 DD-962 (NRT) - - - - AE-25 AE-33 AFS-5 AR-6 AS-19 AS-18 - - - - LSD-33 LSD-36 LKA-115 **COMPLETIONS OF PARTIALS** CG-26 DD-886 FF-1056 FF-1057 FF-1058 FF-1060 FFG-2 DD-839 DD-862 - - - - ASR-13 ASR-15 - - - - LCC-20 LKA-113 LPD-13 LST-1183 LST-1184 **INCREMENTALS** CV-61(6) CV-60(8) CV-62(6)(8) CV-63(6) CV-64(6) CV-66(7)	**COMPLETES** CV-60 (7) CV-62 (7) CV-64 (7) CVN-65(6)(7)(8) CV-66 (6) - - - - CG-31 DDG-2 DDG-13 DDG-14 DDG-17 DDG-24 DDG-39 DDG-42 DDG-46 FF-1066 FF-1067 FF-1097 FF-1098 - - - - AFS-3 AGM-6 ASR-21 ASR-22 AGDS-2 - - - - LKA-117 LSD-30 LSD-31 **COMPLETIONS OF PARTIALS** AO-148 - - - - LPD-8 LSD-28 **INCREMENTALS** CV-41(7) CV-39(6)	**COMP.** CV-39(7) - - - - CG-5 DDG-3 DDG-41 - - - - AOE-3 **INCR.** CV-61(8)	**COMP.** CV-41(8) CV-61(7) CV-63(7) - - - - CG-16 CG-19 DD-944 DDG-12 DDG-21 FFG-4 FF-1040 FF-1043 [illegible] [illegible] - - - - ATS-3 ARS-39 - - - - LKA-114 LPD-2 LPD-4 LPH-2 LSD-40 LST-1190 LST-1192 LST-1194 LST-1196 LST-1197 LST-1199

TOTAL COMPLETIONS (1)

FY	COMP.	COMP. OF PART.	TOT
'73	10		10
'74	28		28
'75	41		41
'76-'7T	68	11	79
'77	41	2	43
'78	35	16	51
'79	26	3	29
'80	5		5
'81	26		26
		GRAND TOTAL	312

Notes:
- * - Indicates completion to be accomplished in year specified.
- (1)- Total completions include completes, completions of partials and completions of incrementals.
- (2)- CHT system to be installed, however, not in current overhaul schedules through FY-'81.
- (3)- Partial installation - completion undetermined.
- (4)- To be stricken in FY-'77.
- (5)- Scheduled for decommissioning.
- (6)- Fwd. piping portion.
- (7)- Aft piping portion.
- (8)- Tank portion.

FOR OFFICIAL USE ONLY

*CHT Ship/Shore Interface Information Book, Hydronautics Technical Report 7607.1 prepared for NAVSEC 6159, October 1976.

NAVAL RESEARCH LABORATORY
WASHINGTON, D.C. 20375

IN REPLY REFER TO:
6180-525:HBP:pij
Prob. No. 61C05-19D
29 Oct 76

From: Commanding Officer, Naval Research Laboratory
Washington, D. C. 20375
To : Commander, Aeronautical Systems Division (ASD/AEG)
Wright Patterson Air Force Base, Ohio 45433

Subj: R&D Final Report on DOD-AGFSRS-76-10 (MIRP FY 7615-76-05064) Improved Environmental Impact Properties for AFFF Materials; forwarding of

Encl: (1) Two copies of subject report

1. Enclosure (1) is forwarded herewith for your information and retention.

6180-525A:HBP:pij
21 October 1976

Subj: R&D Final Report on DOD-AGFSRS-76-10 (MIPR FY 7615-76-05063) Improved Environmental Impact Properties for AFFF Materials

Encl: (1) Work Statement from NRL Contract N00173-76-C-0295
(2) NSRDC/A ltr 2853:AMM 3160 dated 16 July 1976

1. A contract was signed, effective 29 June 1976, with the Ansul Co. to perform experimental work pertaining to the environmental characteristics of AFFF formulations and components thereof. A detailed statement covering the program is given in enclosure (1). A copy of Ansul's final report will be forwarded upon receipt at NRL. This is scheduled for December 1976.

2. Under separate contract with DTNSRDC/Annapolis, studies were completed on the recently qualified AFFF concentrate made by the Ansul Co. These results are given in enclosure (2).

3. This is a final report on the subject contract. The remaining work to be done at NRL after completion of the Ansul contract will be carried out under the sponsorship of the Air Force Civil Engineering Center.

H.B Peterson ED

Henry B. Peterson
Head - Fire Suppression Section
Chemical Dynamics Branch
Code 6180 - Chemistry Division

Encl (1) to NRL ltr
6180-525:HBP:pij
NRL Prob C05-19D

SECTION F - DESCRIPTION/SPECIFICITIONS

CONTRACTOR'S PROPOSAL

F-1. PROPOSAL OBJECTIVE

a) The purpose of this work is to explore the development of experimental AFFF formulations that would exhibit reduced impact on the environment while retaining certin fire suppression characteristics. In particular it is proposed to examine the effect of the AFFF formulation components on the biological oxygen demand of the concentrate. In light of results previously obtained with available concentrates, fish toxicity is not considered to be a problem and therefore will not be investigated.

b) It is furthermore proposed that the requirements of the MIL-F-24385 Amendment 8 and the proposed revision thereto will not apply to the present investigation. There will in all probability be a trade off between biological impact and physiochemical characteristics. Fire performance and corrosion characteristics are of primary importance whereas refractive index, pH, viscosity, foam expansion ratio, and surface interfacial tension are of lesser importance.

c) The generally accepted method for determining proportioned or premixed solution composition is to measure the refractive index of the solution. In order to get acceptable accuracy and precision with field type refractometers, solvent levels of 15-20% are currently used in commercial products. It is assumed that these levels are deleterious from a biological aspect. Some effort will be expended in evaluating alternate analytical techniques for the measurement of AFFF solution concentration.

1.2 PROGRAM STEPS

a) Raw Material BOD_{20}

Twenty day BOD studies will be conducted on typical fluorocarbon surfactants, hydrocarbon surfactants and solvents. The purpose will be to determine the effect of chemical composition on BOD_{20}.

SECTION F - (Cont'd)

b) BOD$_{20}$ Design Experiment

Investigate the effect of component concentration and type on BOD$_{20}$. Candidate formulations will be selected based on this investigation.

c) Formulation Design Experiment

Formulations will be selected based on the BOD$_{20}$ investigation and screened for fire performance and physiochemical properties. This will include corrosion characteristics, concentrate stability in addition to fire performance.

d) Analytical Methods Evaluation

An investigation of alternate analytical methods for determining solution concentration will be conducted to determine if a simple method for use in the field is feasible.

STATEMENT OF WORK (NRL's)

ENVIRONMENTALLY IMPROVED AQUEOUS FILM FORMING FOAM (AFFF)

F-2. INTRODUCTION

The present formulations with respect to fire suppression are highly effective. However, improvements are desired in the environmental area; i.e., development of compositions that have a reduced impact on the environment without loss of fire suppression effectiveness.

2.1 TECHNICAL TASKS

a) The Contractor shall explore the development of experimental AFFF formulations that would exhibit a reduced impact on the environment while retaining fire effectiveness.

b) The proposed study will examine the effect of AFFF formulation components on the biological oxygen demand (BOD), chemical oxygen demand (COD), biodegradability, toxicity toward sewage bacteria, fish toxicity, effect of component concentration on selected environmental/biological parameters, formulation design experiments, and analytical methods evaluation.

SECTION F - (Cont'd)

2.1.1 TASK I - Raw Material BOD_{20} and COD

Twenty-day BOD studies shall be conducted on typical fluorocarbon surfactants, hydrocarbon surfactants and solvents. The purpose will be to determine the effect of chemical composition on BOD_{20}. Chemical oxygen demand (COD) measurements, toxicity toward sewage bacteria, and fish toxicity (kill fish) will also be made on the above materials.

2.1.2 TASK II - Biodegradability and BOD_{20} Design Experiment

Investigate the effect of component concentration on biodegradability and BOD_{20}. Candidate formulations will be selected based on this investigation.

2.1.3 TASK III - Formulation Design Experiment

Formulations shall be selected based on the BOD_{20} biodegradability investigation and screened for fire performance and physiochemical properties. This will include corrosion characteristics, concentrate stability in addition to fire performance.

In the event that a more highly concentrated material (to be used in less than a 6% solution) is desired, all environmental properties shall be adjusted to a 6% datum base.

2.1.4 TASK IV - Analytical Methods Evaluation

An investigation of alternate analytical methods for determining solution concentration shall be conducted to determine if a simple method for use in the field is feasible.

3. PERFORMANCE FIRE MEASUREMENTS

3.1 Compare fire performance of the new formulation with that of formulation currently manufactured and employed in the field - by the same test methods. Fire performance test procedures shall conform to Paragraph 4.7, Mil-F-24385 (NAVY) Amendment 8, as applicable.

SECTION F - (Cont'd)

4. RECORDS

4.1 Processing, formulations, method of preparation, aging, stabilization, and other pertinent parameters shall be maintained so that your process and materials can be later accurately duplicated, so that future programs may be coordinated or compared to the results and conclusions of your current study. These records shall be available for perusal by NRL Scientific Officer for a period of 1 year following completion of the work.

5. DELIVERABLES

5.1 1. The contractor shall provide NRL a final summary report on all tasks and sub-tasks of this study. It shall consist of summaries of all studies and experiments along with theoretical or experimental based conclusions or recommendations.

2. 100 gallons of experimental concentrate of the final selected formulation.

SECTION G - PRESERVATION/PACKAGING AND PACKING

1 Material shall be crated in accordance with best domestic commercial practices to assure safe delivery to the Naval Research Laboratory.

2 Marking: Receiving Officer, Naval Research Laboratory, Washington, D. C., 20375, Contract Number N00173-76-C-0295.

3 The Contractor shall mark all shipments under this contract in accordance with the edition of MIL-STD-129 "Marking for Shipments and Storage", in effect on the date of the contract.

4 The Contractor shall comply with FED STD 313 (Symbols for Packages and Containers for Hazardous Industrial Chemical and Materials) to the extent applicable.

DEPARTMENT OF THE NAVY
NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER
HEADQUARTERS
BETHESDA, MARYLAND 20034

ANNAPOLIS LABORATORY
ANNAPOLIS, MD 21402
CARDEROCK LABORATORY
BETHESDA, MD 20034

IN REPLY REFER TO:
2853:AMM
3160

16 JUL 1976

From: Commander, David W. Taylor Naval Ship R&D Center
To: Director, Naval Research Laboratory, Code 6180

Subj: Ansul, AFFF, Ansul Co., Marinette, Wisconsin 54143, 6% concentrate, DOT Formulation No. A-71108, Bioassay of

Ref: (a) Work Request No. N00173-76-WR-60166

Encl: (1) Report TM-28-76-29, "DTNSRDC Standard Static Marine Bioassay Procedure for Shipboard Chemicals"

1. In compliance with reference (a), listed below are the results of the bioassay tests of Ansul:

A.	Fundulus sp. Killifish	LC_{50} = 4,287 ppm in 96 hrs
B.	Artemia salina Brine Shrimp	LC_{50} = 3,937 ppm in 72 hrs
C.	Pseudomonas nigrifaciens Bacterial Species	Bactericidal = 50,000 ppm in 96 hrs Bacteriostatic = 40,000 ppm in 96 hrs
D.	Thalassiorira pseudonana	LC = <4000 ppm in 96 hrs

2. The results of the Biochemical Oxidation Demand (BOD) and the Chemical Oxidation Demand (COD) tests along with a comparison of the BOD test in saline and non-saline waters are listed on page 2. These tests were performed by Code 2860 according to the 13th Edition, 1971 of "Standard Methods for the Examination of Water and Waste-Water."

Encl (2) to NRL LTR RPT
6180-525A:HBP:pij

2853:AMM
3160

Subj: Ansul, AFFF, Ansul Co., Marinette, Wisconsin 54143, 6% concentrate, DOT Formulation No. A-71108, Bioassay of

RESULTS OF BIOCHEMICAL OXYGEN DEMAND (BOD) AND CHEMICAL OXIDATION DEMAND (COD) STUDY OF ANSUL

TEST DURATION (DAYS)	DILUTION	BOD (mg./l.) With NaCl	BOD (mg./l.) Without NaCl
5	1:30,000	1.8 5.4×10^4	1.4 4.2×10^4
	1:100,000	1.2 1.2×10^5	0.9 0.9×10^4
10	1:30,000	1.4 4.2×10^4	oxygen depleted
	1:100,000	1.9 1.9×10^5	4.3 4.3×10^5

COD = 4.09×10^5 mg./l.

3. The results of the "In Vivo" tests indicate that Ansul has a relatively low level of toxicity and the BOD and COD test results indicate a reasonably high level of biodegradability.

A. L. [illegible]
By direction

Copy to:
NAVSEC (SEC 6101)

CANDIDATE ENVIRONMENTAL
IMPACT STATEMENT

DISCHARGING AQUEOUS FILM FORMING FOAM (AFFF) TO HARBOR WATERS DURING TESTS OF MACHINERY SPACE FIRE-FIGHTING FOAM SYSTEMS ABOARD U.S. NAVY SHIPS

JANUARY 1978

DEPARTMENT OF THE NAVY
NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER
HEADQUARTERS
BETHESDA, MARYLAND 20034

ANNAPOLIS LABORATORY
ANNAPOLIS, MD 21402
CARDEROCK LABORATORY
BETHESDA, MD 20034

IN REPLY REFER TO:
286:CSA
9593
2863-515
15 OCT 1976

From: Commander, David W. Taylor Naval Ship R&D Center
To: Commander, Naval Ship Engineering Center (SEC 6159)

Subj: Candidate Environmental Impact Statement (Draft) on Discharging Firefighting System Aqueous Film Forming Foam (AFFF) into Harbors; Status and Synopsis of

Ref: (a) DTNSRDC RDT&E Work Unit Summary 2863-514, AFFF Harbor Dispersion Study, of 1 June 1975

1. Preparation of a draft Candidate Environmental Impact Statement (CEIS) on the discharge of AFFF from naval ships testing their machinery space firefighting foam generating systems in port (the proposed action) will be completed by 30 October 1976. Difficulties obtaining adequate information for the preparation of the CEIS have been encountered. These include the lack of information on components of 3M Company FC206 AFFF concentrate (which is proprietary), the unavailability of data on the quantities of AFFF generated both aboard ships during system testing and in each port facility and the frequency of such generation, the wide variation in the environmental conditions at naval port facilities which makes generalization of existing site characteristics very difficult, and the limited data available for predicting the rates of dispersion and assimilation of AFFF discharges into the harbors.

2. The above problems have been solved on the basis of information obtained from the sources listed below, and of the stated assumptions.

a. As stated, the 3M Company has not provided any useful information about the components of FC206. However, estimates of composition have been made by the U. S. Air Force, and results of various tests indicate that FC206 is nearly 100% biodegradable. Waste streams containing FC206 have also been successfully treated by conventional activated sludge techniques in concentrations of 200 to 1000 mg/l with sewage although foaming problems were not considered.

b. The quantities of AFFF that could be generated in Navy ports were estimated on the basis of operational experience of the Fire Fighting Assistance Team (FFAT), known equipment characteristics, and ship location information. The numbers and types of ships in each Navy homeport were listed. Using the number of AFFF machinery space systems aboard each ship and the conclusion that one-sixth of all system tests are conducted in port, the quantity of AFFF that could be generated per year for each port was calculated. Twelve Navy ports discharge 90% of the potential yearly total (the remaining ports discharge less than 30 gallons of AFFF concentrate per year).

c. The U. S. Navy Hydrographic Office (now NAVOCEANO) from 1959 through 1963 conducted studies of the relative flushing capabilities of eighteen harbors. Nine of these harbors are included in the 12 Navy ports with the highest potential AFFF discharge volume. It was possible to construct hypothetical examples of the worst case AFFF discharge for 9 ports and predict the rate of decrease of AFFF concentration in the discharge area based upon existing data. (Use of these data reduced the estimated project cost from $125K to $60K.)

3. Alternatives to the proposed action were investigated. These included utilization of an alternative nontoxic concentrate for tests; revising or refining test procedures to reduce the volume of discharge; rescheduling tests for discharge to pierside sewers, collection barges or open sea; performing tests with AFFF discharge contained as part of a closed system; redesigning shipboard maintenance plans to eliminate flow test; and enhancement of system component reliability to eliminate requirements for flow test. The alternatives as well as the proposed action were evaluated to determine the operationally and environmentally most acceptable alternatives.

4. A CEIS does not give specific conclusions or recommendations concerning a proposed action. It details the effects on the human environment of an action and of its alternatives. In a draft statement, an alternative may be favored. Also discussed are considerations that offset the adverse environmental effects of the proposed action.

5. The content of the CEIS can be summarized as follows. The preferred approach in the statement in preparation is continuation of current practice: discharging minimum quantities of AFFF into the waters of those harbors where collection and treatment or disposal of test effluent is not now practiced. Procedures are now available and are often used that both minimize the quantity of effluent generated and eliminate foaming of the discharge. Some Navy port facilities, on their own initiative, are evaluating procedures for collecting AFFF discharges in shipboard wastewater collection, holding and transfer (CHT) systems for transfer to pierside sanitary sewers or waste collection barges. A recommended

—049 - Paul Smith

minor modification of test procedures and effluent collection equipment, if coinciding with the Ship-to-Shore Sewage Transfer Program, could potentially eliminate AFFF discharges to harbor waters in major ports by calendar year 1981.

H. H. SINGERMAN
By direction

Copy to:
NAVSEA (SEA 0492P) ←

CANDIDATE ENVIRONMENTAL
IMPACT STATEMENT

DISCHARGING AQUEOUS FILM FORMING FOAM (AFFF) TO HARBOR WATERS DURING TESTS OF MACHINERY SPACE FIRE-FIGHTING FOAM SYSTEMS ABOARD U.S. NAVY SHIPS

January 1978

Prepared by the David W. Taylor Naval Ship Research and Development Center for the Naval Sea Systems Command in accordance with OPNAVINST 6240.3D in compliance with Section 102(2)(c) of the National Environmental Policy Act of 1969

LIST OF APPENDICES

Appendix A - NAVSEA message 191523Z Feb 1975, AFFF Testing (unclassified)

Appendix B - Comparisons of the Various Parameters of AFFF's

Appendix C - FP-180 Water Motor Proportioner

Appendix D - AFFF System Test and Waste Disposal Procedures

Appendix E - Biodegradability and Toxicity of FC-206

Appendix F - Small Scale AFFF/Dye Dispersion Test

Appendix G - Tentative Allocation Plans and Construction Schedules for Ship CHT Systems, SWOB's, and Pier Sewers

LIST OF ABBREVIATIONS AND SYMBOLS

AFFF - aqueous film forming foam
ASAP - as soon as possible
AvGas - aviation gasoline
BOD - biochemical oxygen demand
BOD$_5$ - five-day biochemical oxygen demand
BOD$_u$ - ultimate biochemical oxygen demand
°C - degree Celsius
CEIS - candidate environmental impact statement
CHT - collection, holding and transfer (tanks aboard ship)
cm^3 - cubic centimetre
CNM - Chief of Naval Material
COD - chemical oxygen demand
DO - dissolved oxygen
FC-200 - type of "Light water" AFFF, 3M Company
FC-206 - type of "Light water" AFFF, 3M Company
FFAT - fire-fighting assistance team
FP-180 - water motor proportioner for mixing fire fighting foam concentrate with sea water
ft - foot
FWPCA - Federal Water Pollution Control Act
g - gram
gal - gallon
gpm - gallon per minute
HCFF - high capacity fog foam

JP-4	- Navy aircraft fuel
JP-5	- Navy aircraft fuel
ℓ	- litre
LC_{50}	- concentration of a toxic substance that will kill 50 percent of test organisms within a specified time period
ℓ/s	- litre per second
m	- metre
m^3	- cubic metre
mg	- milligram
mg/ℓ	- milligram per litre
NAVFAC	- Naval Facilities Engineering Command
NAVFACWESTDIV	- Naval Facilities Engineering Command, Western Division
NAVOCEANO	- Naval Oceanographic Office
NAVSEA	- Naval Sea Systems Command
NAVSEC	- Naval Ship Engineering Center
NCBC	- Naval Construction Battalion Center
NFPA	- National Fire Protection Association
NPDES	- National Pollution Discharge Elimination System
NRL	- Naval Research Laboratory
NSC	- Naval Safety Center, Norfolk, Virginia
pH	- negative logarithm of the hydrogen ion concentration
PKP	- potassium bicarbonate powder
PMS	- preventive maintenance schedule

ppb - part per billion (1 x 10^{-9})

ppm - part per million (1 x 10^{-6})

SHIPALT - ship alteration

SWOB - ship waste off-load barge

TC - total carbon

TDS - total dissolved solids

TSS - total suspended solids

3M - Minnesota Mining and Manufacturing Company

μℓ/ℓ - microlitres per litre

CEIS PREPARATION COST ESTIMATES

The following estimate of preparation costs for this document against the catagories identified below are listed in accordance with OPNAVINST 6240.3D, paragraph 4302b.

1. Salaries of military and civilian personnel. $30K.

2. Associated travel costs. None.

3. Directly associated research costs. $4.4K.

4. Contract and consultant costs directly related. $22.3K.

5. Indirect but related costs. $1.3K.

6. Administrative costs. $2K.

7. Costs of public hearings. None.

SECTION 1

SUMMARY

1. This is a Candidate Environmental Impact Statement (CEIS).

2. Title: Discharging Aqueous Film Forming Foam (AFFF) to Harbor Waters During Tests of Machinery Space Fire-Fighting Foam Systems Aboard U.S. Navy Ships.

Action: Administrative.

3. Action Description: Regular in situ testing of AFFF fire-fighting systems aboard ship is imperative in the interest of personnel safety and material protection. Each test of a machinery space system generates approximately 90 gal (0.34 m^3) of AFFF at a concentration of 3.5 to 6 percent in sea water. Containment and disposal of AFFF test mixtures is difficult due to design configuration, foaming, or the unavailability of containment vessels. Therefore, AFFF is discharged overboard as it is produced.

a. All AFFF fire-fighting equipment that is newly installed, repaired, altered or converted from protein foam by an industrial activity is tested to insure proper operation and required output.

b. All AFFF fire-fighting equipment is tested on a six-month PMS.

Location: AFFF fire-fighting equipment is tested aboard naval ships located in 33 ports in the continental United States and Hawaii and in 6 naval shipyards servicing surface ships. Approximately 90 percent of the AFFF discharged is produced at naval installations in the following 10 locations.

San Diego, California
Norfolk (Naval Base), Virginia
Charleston, South Carolina
Honolulu (Pearl Harbor), Hawaii
Philadelphia, Pennsylvania
Mayport, Florida
Norfolk (Little Creek Amphibious Base), Virginia
Long Beach, California
Bremerton (Puget Sound), Washington
Alameda, California

4. Environmental Impact:

a. Air - no impact.

b. Navigable waters.

(1) Physical, chemical, biological.

(a) Discharge into harbors with inadequate natural mixing may result in localized areas of chemicals concentration - initial dilution and dispersion rapidly reduce chemicals concentration.

(b) Chemicals interaction with other contaminants already in the harbor is unknown - the possible effects of AFFF are reduced by discharging limited quantities and by rapid dilution.

(c) Certain concentrations of AFFF are toxic to marine organisms - the toxicity of AFFF has been determined, and the concentration of AFFF in harbor waters after discharge is well below acute toxic levels.

(d) The BOD of AFFF is very high - the BOD and COD of AFFF are nearly equal, indicating that the substance is nearly 100% biodegradable.

c. Socioeconomic - Port areas are normally associated with industrial activity and are not used for commercial fishing or recreation. The discharge of limited quantities of AFFF will have no socioeconomic affect on the port area.

d. Aesthetic - Testing with the recommended non-foaming nozzles will eliminate unsightly foam on the water surface previously associated with AFFF discharges.

5. Alternatives:

a. Test with substitute concentrate material.

b. Redefine test procedures to reduce discharge volume.

c. Adjust test schedules for discharge only when collection, treatment, and disposal facilities are available.

d. Perform tests with discharge contained as part of a closed system.

e. Eliminate shipboard flow test by redesigning maintenance plan.

f. Eliminate shipboard flow test by enhancing system component performance reliability.

g. Preferred Approach - Discharge minimum quantities of AFFF into harbors where collection and treatment or alternate disposal of test effluent is not now practiced. Gradually eliminate discharge by utilizing collection, treatment, and disposal facilities now being constructed as they become available for service.

6. Environmental Significance

a. This statement concludes that the impact of the proposed action on the environment will not be environmentally significant. Given the low volumes of AFFF discharged, the infrequency of the discharge, and the rapid dilution that takes place in the receiving water, the proposed action should not be environmentally controversial when considered with the criticality of the fire protection function aboard ship. The environmental impact will be further reduced as adequate facilities for collection, treatment, and disposal of AFFF test effluents become available for service.

SECTION 2

INTRODUCTION

1. Project Description

Proposed Action: Discharge Aqueous Film Forming Foam (AFFF) to Harbor Waters During Tests of Machinery Space Fire-Fighting Foam Generation Systems Aboard U.S. Navy Ships.

a. Each surface ship of the Navy is equipped with a fire-fighting system with a capacity and state-of-readiness to combat and extinguish fires within the range of severity which could occur as a result of normal day-to-day operations or offensive or defensive combat incidents.

b. Criticality of the fire protection function dictates that equipment and fire-fighting crews be exercised on a regular basis as part of the maintenance program. A naval message from Commander, NAVSEA 0945D, appendix A, requires, "All AFFF fire-fighting equipment that is newly installed, repaired, altered or converted from protein foam by an industrial activity shall be tested to insure proper operation and required output." The message states that the following procedures be observed when testing AFFF hoses.

(1) The minimum acceptable concentration of AFFF in the output mixture of the system is 3.5 percent.

(2) The foam should be generated for one minute before sampling. After the sample has been taken, the system should be secured ASAP to avoid excessive use of AFFF concentrate.

(3) If the only work done on a system was on the foam generator (proportioner or pump), then only one hose shall be tested with AFFF to verify foam generator performance. One and one-half inch variable flow nozzles shall be tested at 95 gpm (6 ℓ/s) in machinery spaces and 125 gpm (7.9 ℓ/s) in hangar bays or flight decks. Two and one-half inch variable flow nozzles should be tested at 250 gpm (15.8 ℓ/s).

(4) The above requirements apply, and the systems shall be tested and certified in port prior to ship trial runs, for testing of the machinery space AFFF fire-fighting system aboard active ships and new construction.

c. Critical areas of greatest fire potential (such as machinery spaces, hangar and flight decks, weapons elevators, and helicopter landing areas) are protected by fire-fighting foam generation equipment that employ AFFF as the extinguishing agent.

2. Background

a. Many fire-fighting formulations have been evaluated for efficiency and safety. Because oil floats on water, the application of water on an oil fire could spread the flaming oil, but by generating and applying a foam, an oil fire could be extinguished by smothering the flames. A protein-based "mechanical foam" was developed that, when mixed with water and air, would spread over the surface of an oil fire and prevent the vapors from escaping, mixing with air and burning. However, protein foam has the disadvantage of being fragile. If the foam blanket is disturbed and broken, volatile vapors could escape and a flashback could occur. In a congested machinery space, it is likely that with the movement of firefighters and their equipment, this could occur.[1]

b. AFFF was developed in the mid-1960's. It has the advantage of producing a more rugged vapor sealing blanket than protein foam. It can be vigorously sprayed on a fire and a vapor barrier would remain intact in foot traffic. The active ingredient in AFFF is fluorocarbon surfactant. Fluorocarbon surfactants function as effective vapor securing agents based upon their outstanding effect in reducing the surface tension of water and of their controllable oleophobic and hydrophilic properties, and on their chemical stability. Thus, the physical properties of water can be controlled so that it can foam, float, spread across and remain on the surface of a hydrocarbon fuel even though water itself is denser than the fuel. The term "light water" was based upon those properties. "Light water" appeared in several early military specifications defining the properties of this class of agents. The NFPA later adopted the term "aqueous film forming foam" to refer to fluorocarbon surfactant-based fire-fighting agents. The term "light water" has become associated with the fire-fighting products of the 3M Company.[1]

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[1] Superscripts refer to similarly numbered entries in Section 10, References.

c. To improve shipboard protection against fires, the Navy is converting all protein foam generating fire-fighting equipment aboard ship to AFFF.[2] The AFFF concentrate specified for use in testing fire-fighting systems must conform to MIL-F-24385 (Military Specification Fire Extinguishing Agent, Aqueous Film Forming Foam (AFFF) Liquid Concentrate, Six Percent, for Fresh and Sea Water, Amendment 2, 25 June 1970). Approved AFFF concentrate (Light Water® FC-206, manufactured by 3M Company) is obtained from the Federal Supply under NSN-9C-4210-00-087-4742 for 5 gal (19 ℓ) containers and NSN-9C-4210-00-087-4750 for 50 gal (190 ℓ) drums.

d. A common type of AFFF currently used aboard naval ships is Light Water FC-200 manufactured by 3M Company. The stocks of FC-200 are gradually being replaced by FC-206. A comparison of various parameters of AFFF's are contained in appendix B. The constituents of the AFFF formulas are trade secrets and have not been disclosed to the Navy.

e. By design, the fire-fighting mixture should consist of 94% firemain water and 6% AFFF concentrate. However, acceptance test criteria allow for a mixture to contain, as a minimum, 3 1/2% AFFF concentrate. Considering the test use of a 1 1/2 inch nozzle at 90 gpm (5.7 ℓ/s), an output of from 3.15 gal (11.9 ℓ) to 5.4 gal (20.4 ℓ) of the AFFF concentrate could be discharged overboard during each minute of the test. Since the ship would not be moving at the time of

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effluent discharge, its dispersion would be totally dependent upon the initial dilution of the discharge and diffusion due to local tidal movements, current flow, etc.

f. The foam proportioning equipment installed aboard Navy ships for machinery space fire control in most cases is the FP-180 foam proportioner. A description of the FP-180 and a diagram of a typical permanent installation in contained in appendix C.

g. The FP-1000 foam proportioner and the AFFF Two Speed Injection Pump are often installed in ship hanger bays and on flight decks. These highflow systems are not installed in machinery spaces and will not be tested in port (see section 3.a.(2)). Therefore, they will not be discussed further.

3. Site Characteristics

a. Obligatory in-port testing of AFFF fire-fighting systems is required after work on the system and during regular PMS testing:

(1) The message in appendix A states, "All AFFF fire-fighting equipment that is newly installed, repaired, altered or converted from protein foam by an industrial activity shall be tested to insure proper operation and required output." For the purpose of this statement an "industrial activity" is defined as a facility at which the construction, conversion, or repair of ships is accomplished. Most industrial activity aboard Navy surface ships is done at the six naval shipyards listed below:

Activity		City State
Naval Shipyard:	Philadelphia	Philadelphia, PA
Naval Shipyard:	Norfolk	Portsmouth, VA
Naval Shipyard:	Charleston	Charleston, SC
Naval Shipyard:	Long Beach	Long Beach, CA
Naval Shipyard:	Puget Sound	Bremerton, WA
Naval Shipyard:	Pearl Harbor	Honolulu, HI

(2) All AFFF fire-fighting equipment is also tested on a six-month PMS. For the purpose of this CEIS, it is assumed that regular PMS testing of non-machinery room AFFF system can be delayed until the earliest opportunity when a ship is underway in unrestricted waters. AFFF generated by these system tests can then be discharged directly overboard. However, the criticality of machinery room AFFF systems for personnel safety and material protection makes it imperative that these systems be tested at regular intervals (according to ship PMS) even though a ship may be in port. AFFF generated during in-port PMS testing is discharged overboard. Generation rates are based upon unclassified information about U.S. Navy commissioned surface ship inventories on a homport basis.[3] The relative locations of U.S. Navy homeports are shown in figure 2-1. Estimates of the quantity of AFFF discharged overboard in each Navy port are given in table 4-4. The ports are ranked based upon the estimated quantity of AFFF discharged during in-port testing. Estimates of newly installed, repaired, altered or converted AFFF systems

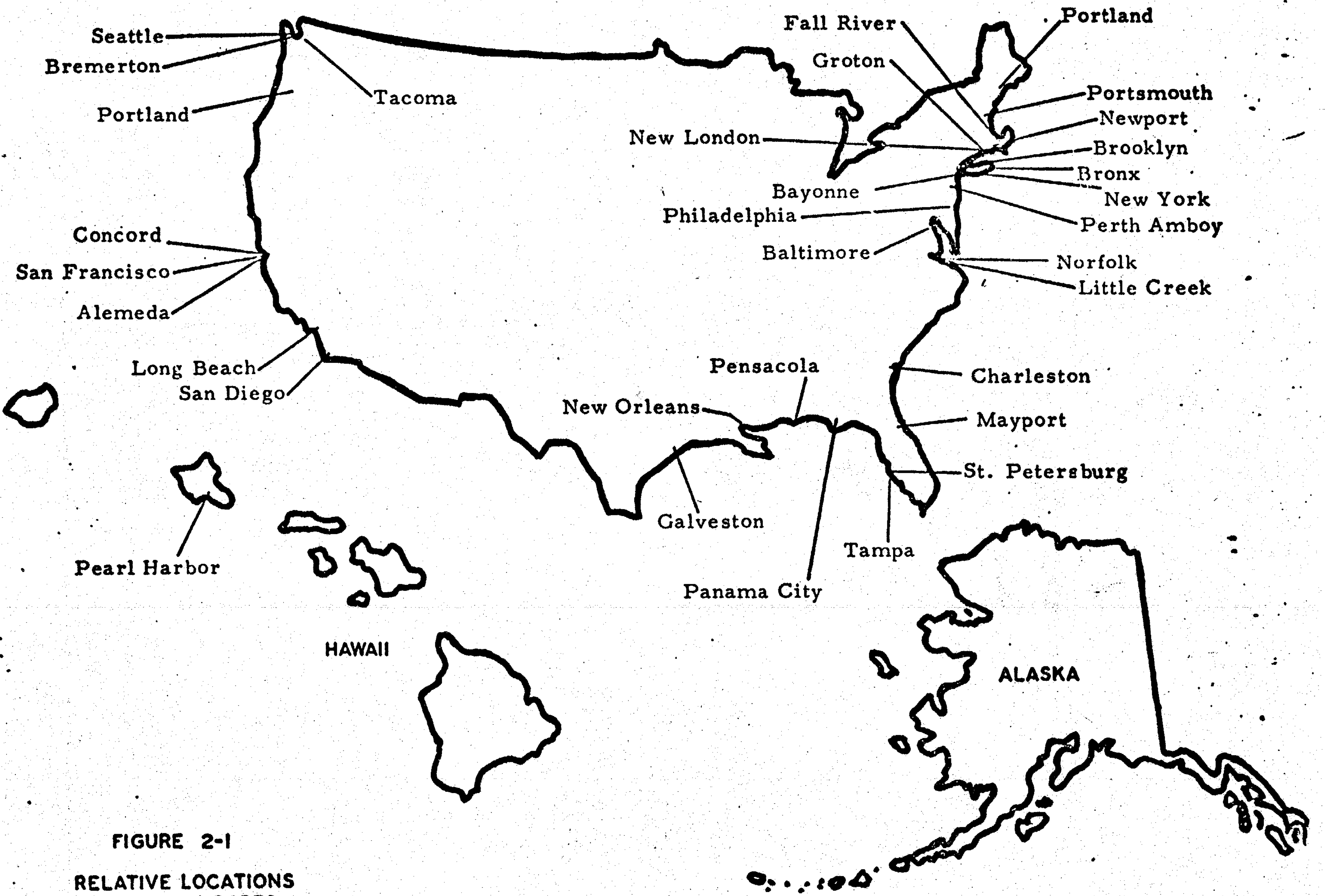


FIGURE 2-1

RELATIVE LOCATIONS
OF U.S. NAVY PORTS

are added onto port totals for PMS testing only when alternatives to direct discharge disposal procedures are not practiced (see table 4-2). Approximately 90 percent of the AFFF discharged is generated in the ten ports listed in table 2-1. The annual discharges in each of the remaining ports are estimated at less than 32 gal (0.12 m^3) of AFFF concentrate per year. These quantities can be considered negligible.

Table 2-1
Summary of Estimated Volumes of AFFF
Discharged Overboard in Navy Ports Per Year
During Testing of Machinery Space Fire-Fighting Systems

Port Location	6% AFFF gal (m^3)	Concentrate AFFF gal (m^3)
San Diego, CA	9480 (35.88)	568.8 (2.12)
Norfolk (Naval Station), VA(a)	7770 (29.41)	466.2 (1.76)
Charleston, SC(a)	3690 (13.84)	221.4 (0.84)
Honolulu (Pearl Harbor), HI(b)	3360 (12.72)	201.6 (0.76)
Philadelphia, PA (b)	2760 (10.45)	165.6 (0.63)
Mayport, FL	2640 (9.90)	158.4 (0.60)
Little Creek, Norfolk, VA	1950 (7.31)	117 (0.44)
Long Beach, CA(a)	1560 (5.85)	93.6 (0.35)
Bremerton (Puget Sound), WA(b)	940 (3.56)	56.4 (0.21)
Alameda, CA	660 (2.47)	40 (0.15)
Other Navy Homeports	4163.3 (15.77)	249.8 (0.95)

(a) Excluding shipyard tests.
(b) Including shipyard tests.

b. The information contained in table 2-2 was supplied by the Navy Environmental Support Office, NCBC, Port Hueneme, California. It tabulates the water quality classifications and parameters for which water quality standards have been adopted for each harbor area listed in table 2-1.

Table 2-2
WATER QUALITY REFERENCES FOR SELECTED NAVY PORTS

Harbor Area	Beneficial or Protected Use Classification		Applicable Standards/Objectives		Water Quality References	Interstate/State/Local Water Quality Management Agencies
	Code	Description(a)	Code	Parameter(b)		
San Diego Bay San Diego, CA	Coastal	IND NAV REC-1 REC-2 COMM SAL RARE MAR MIGR SHELL	N/A	COLOR TASTE & ODOR FLOATING SOLIDS TSS SETTLEABLE SOLIDS OIL & GREASE TURBIDITY pH DO BACTERIA TEMP TOXICITY General non-quantified limitations on waste from vessels	• "*Comprehensive Water Quality Control Plan for the San Diego Basin (Abstract), July 1975*" Source: San Diego Regional Water Quality Control Bd. 6154 Mission Gorge Rd. San Diego, CA	• California Water Quality Control Bd., San Diego Region (303 planning(c)) • Comprehensive Planning Organization of the San Diego Region (208 planning(d))
Long Beach Harbor Long Beach, CA	Coastal	NAV REC-2 COMM RARE MAR SHELL	N/A	COLOR TASTE & ODOR FLOATING MATERIAL TSS SETTLEABLE SOLIDS OIL & GREASE BIOSTIMULANTS TURBIDITY pH DO BACTERIA TEMP TOXICITY PESTICIDES	• "*Water Quality Control Plan for the Los Angeles River Basin, Mar 1975*" Source: Los Angeles Regional Water Quality Control Board 107 S. Broadway, Suite 4027 Los Angeles, CA 90012	• California Water Quality Control Board, Los Angeles Region (303 planning)
San Francisco Bay Alameda, CA		REC-1 REC-2 NAV MAR RARE WILD COMM IND SHELL	N/A	COLOR TASTE & ODOR FLOATING MATERIAL TSS SETTLEABLE SOLIDS OIL & GREASE BIOSTIMULANTS TURBIDITY pH DO BACTERIA TEMP TOXICITY PESTICIDES	• "*Water Quality Control Plan for the San Francisco Bay Basin, July 1975*" Source: Bay Area Regional Water Quality Control Bd. 111 Jackson St. Oakland, CA 94607	• California Water Quality Control Board, Bay Area Region (303 planning) • Association of Bay Area Governments (208 planning) • Bay Conservation District Commission (coastal zone management)

(Continued)

Table 2-2

WATER QUALITY REFERENCES FOR SELECTED NAVY PORTS (CONTINUED)

	Beneficial or Protected Use Classification		Applicable Standards/Objectives		Water Quality References	Interstate/State/Local Water Quality Management Agencies
	Code	Description(a)	Code	Parameter(b)		
Willoughby Bay Norfolk, VA	IIBa	ESTUARINE MUN REC-1 MAR	II	DO pH TEMP	• *"Small Coastal Basins Water Quality Data Report, Oct 76"* Source: Virginia Institute Marine Science Attn: Dr. Bruce Neilson Gloucester Point, VA • *Virginia Water Quality Standards*, amended Nov 74 • *"Water Quality Inventory 305(b) Report, Apr 1976"* • *"Lower James River Basin 303(e) Report (Planning Bulletin 217(3), July 1974"* Source: Virginia Water Control Board P.O. Box 11143 2111 N. Hamilton St. Richmond, VA 23230	• Virginia Water Control Board (303 planning) • Hampton Roads Water Quality Agency (208 planning) • Bureau of Shellfish Sanitation
Little Creek Virginia Beach, VA	IIIB	FREE FLOW STR. MUN REC-1 MAR	III B All Class	DO pH TEMP BACTERIA General non-quantified limitations on floating... toxic, and deleterious substances.		
Cooper River Charleston, SC	SC	TIDAL REC-2 COMM MAR	SC	FLOAT. SOLIDS DO BACTERIA pH General non-quantified limitations on toxic and deleterious substances	• *Stream Classifications for State of South Carolina amended 9/1/72* • *Water Classifications Standards System, amended 1974* • *"Santee-Cooper River Basin Water Quality Management Plan, 1975"* Source: SC Dept of Health and Environmental Control	• South Carolina Dept. Health and Environmental Control (303 planning) • Berkely-Charleston-Dorchester Planning Council (208 planning) • South Carolina Wildlife and Marine Resources Center (coastal zone management)
St. John's River Mayport, FL	III	REC-1 REC-2 MAR WILD		pH DO BACTERIA TURBIDITY TDS FLUORIDES CHLORIDES GROSS BETA CYANIDE COPPER ZINC CHROMIUM PHENOLS LEAD DETERGENTS MERCURY TEMP General non-quantified limitations on toxic and deleterious substances	• *"St. John's River Basin Plan"* Source: Florida Dept. of Environmental Regulations Tallahassee, FL	• Florida Dept. of Environmental Regulation (303 and 208 planning) • Bureau of Coastal Zone Management, Department of Natural Resources (coastal zone management)

(Continued)

Table 2-2

WATER QUALITY REFERENCES FOR SELECTED NAVY PORTS (CONTINUED)

Harbor Area	Beneficial or Protected Use Classification		Applicable Standards/Objectives		Water Quality References	Interstate/State/Local Water Quality Management Agencies
	Code	Description(a)	Code	Parameter(b)		
Sinclair Inlet Bremerton, WA	A	MIGR WILD REC-1 REC-2 IND NAV COMM SHELL	A	BACTERIA DO TEMP TOTAL DISSOLVED GAS pH TURBIDITY General non-quantified limitations on toxic and deleterious substances	None available	• State Department of Ecology (303 and 208 planning, coastal zone management)
Delaware estuary (Zone 01.020) Philadelphia, PA	1.2	WARM	a_2	pH	• 25 PA Code Chapter 93, *Water Quality Criteria, amended 6/20/74.* • USGS Report *"Water Resources Data for Pennsylvania - Part II Water Quality Records"* Source: District Chief, Water Resources Division Federal Building P.O. Box 1107 Harrisburg, PA 17108	• PA Dept of Environmental Resources (303 planning) • Delaware River Basin Commission (303 coordinator, coastal zone management). • Delaware Valley Regional Planning Commission (208 planning)
	1.3	MIGR	b_4	DO		
	2.2	IND	d_7	TEMP		
	2.4	WILD	d_9	TEMP		
	3.1	REC-2 boating	e_4	TDS		
	3.2	REC-2 fishing	f_4	BACTERIA		
	4.1	POW	g_2	TURBIDITY		
	4.2	NAV	i_2	ALKALINITY		
	4.3	WASTE	j_2	MBAS		
			q_2	PHENOL		
			w_1	RADIOACTIVITY		
			h	TOX(e)		

(a) The abbreviated descriptions are modeled after the designations used by the Regional Water Quality Control Boards of California. The following description for each abbreviated designation is intended to provide a generalized concept rather than the specific definition offered by each locale.

IND - Includes uses which do not depend primarily on water quality such as mining, cooling water supply, hydraulic conveyance, gravel washing, fire protection, and oil well repressurization.

NAV - Includes commercial and naval shipping.

POW - Uses for hydropower generation.

REC-1 - Includes all recreational uses involving actual body contact with water, such as swimming, wading, waterskiing, skin diving, surfing, sport fishing, uses in therapeutic spas, and other uses where ingestion of water is reasonably possible.

REC-2 - Recreational uses which involve the presence of water but do not require contact with water, such as picnicking, sunbathing, hiking beachcombing, camping, pleasure boating, tidepool and marine life study, hunting, and aesthetic enjoyment in conjunction with the above activities as well as sightseeing.

COMM - The commercial collection of various types of fish and shellfish, including those taken for bait purposes, and sport fishing in ocean, bays, estuaries and similar non-freshwater areas.

(Continued)

WARM - Provides a warmwater habitat to sustain aquatic resources associated with a warmwater environment.

SAL - Provides an inland saline water habitat for aquatic and wildlife resources.

WILD - Provides a water supply and vegetative habitat for the maintenance of wildlife.

MAR - Provides for the preservation of the marine ecosystem including the propagation and sustenance of fish, shellfish, marine mammals, waterfowl, and vegetation such as kelp.

MIGR - Provides a migration route and temporary aquatic environment for anadromous and other fish species.

RARE - Provides an aquatic habitat necessary, at least in part, for the survival of certain species established as being rare and endangered species.

SHELL - The collection of shellfish such as clams, oysters, abalone, shrimp, crab, and lobster for either commercial or sport purposes.

MUN - Includes usual uses in community or military water systems and domestic uses from individual water supply systems.

WASTE - A receiving body for treated waste water effluent reflecting levels of treatment necessary to preserve all designated beneficial use categories.

(b)Specific quantified or non-quantified limitations are identified for each parameter in the appropriate area water quality documents.

(c)Planning pursuant to Section 303, PL92-500.

(d)Planning pursuant to Section 208, PL92-500.

(e)Threshold Odor Number.

SECTION 3

RELATIONSHIP OF PROPOSED ACTION TO LAND USE PLANS, POLICIES AND CONTROLS FOR THE AFFECTED AREAS

1. The proposed action relates to the marine environment. There is no direct impingement upon land use plans, policies or controls. A possible indirect effect caused by the implementation of the proposed action would be increased levels of BOD in a localized portion of the harbor water immediately after receiving an AFFF discharge. When considered in combination with the existing (or projected) levels of contamination in the water, the action, if it occurs frequently enough, might prohibit a new land use which would generate a pollution level in excess of allowable limits established for the site by local or federal standards and regulations. However, the limited quantity of AFFF and the infrequency of testing causes an insignificant contribution to water quality degradation in comparison to the highly developed industrialized land uses already associated with surrounding shorelines.

2. The Navy has committed itself to assure that the operation of naval complexes has been reconciled with local land/water use plans, policies and controls.[4] Navy-wide programs to improve ship-to-shore waste collection, handling and disposal will continue to reduce the environmental impact on areas surrounding naval bases and shipyards. The eventual disposal

of shipboard generated AFFF test solution will be incorporated into current environmental enhancement programs for which their relationship to land use plans, policies, and controls has been assessed.

SECTION 4

PROBABLE IMPACT OF THE PROPOSED ACTION ON THE ENVIRONMENT

1. Introduction

a. It is essential that newly installed and modified AFFF fire-fighting systems be tested prior to ship departure for sea trials. U.S. Navy ships are presently having their protein foam generating fire-fighting equipment aboard surface ships converted to AFFF. The first systems converted were aircraft carrier hangar deck and flight deck equipment. SHIPALT's have been issued to convert aircraft carrier protein foam equipment to AFFF in the HCFF stations, hangar sprinkling systems, machinery spaces, fixed flight deck fire-fighting washdown systems, and hard hoses for hangar space and flight deck. Machinery space protein foam equipment for all other types of surface ships is also being converted by SHIPALT to AFFF use and combined ("twinned") with PKP. PKP is an effective fire-fighting agent for oil fires when the oil is in spray form and burning in space.[5] Figure 4-1 is a diagram of a twin agent (AFFF and PKP) fire extinguishing system. The AFFF system can be operated independently of the PKP units for testing or fire fighting.

b. There are two circumstances when machinery space AFFF systems need to be operated to test the FP-180 foam proportioner:

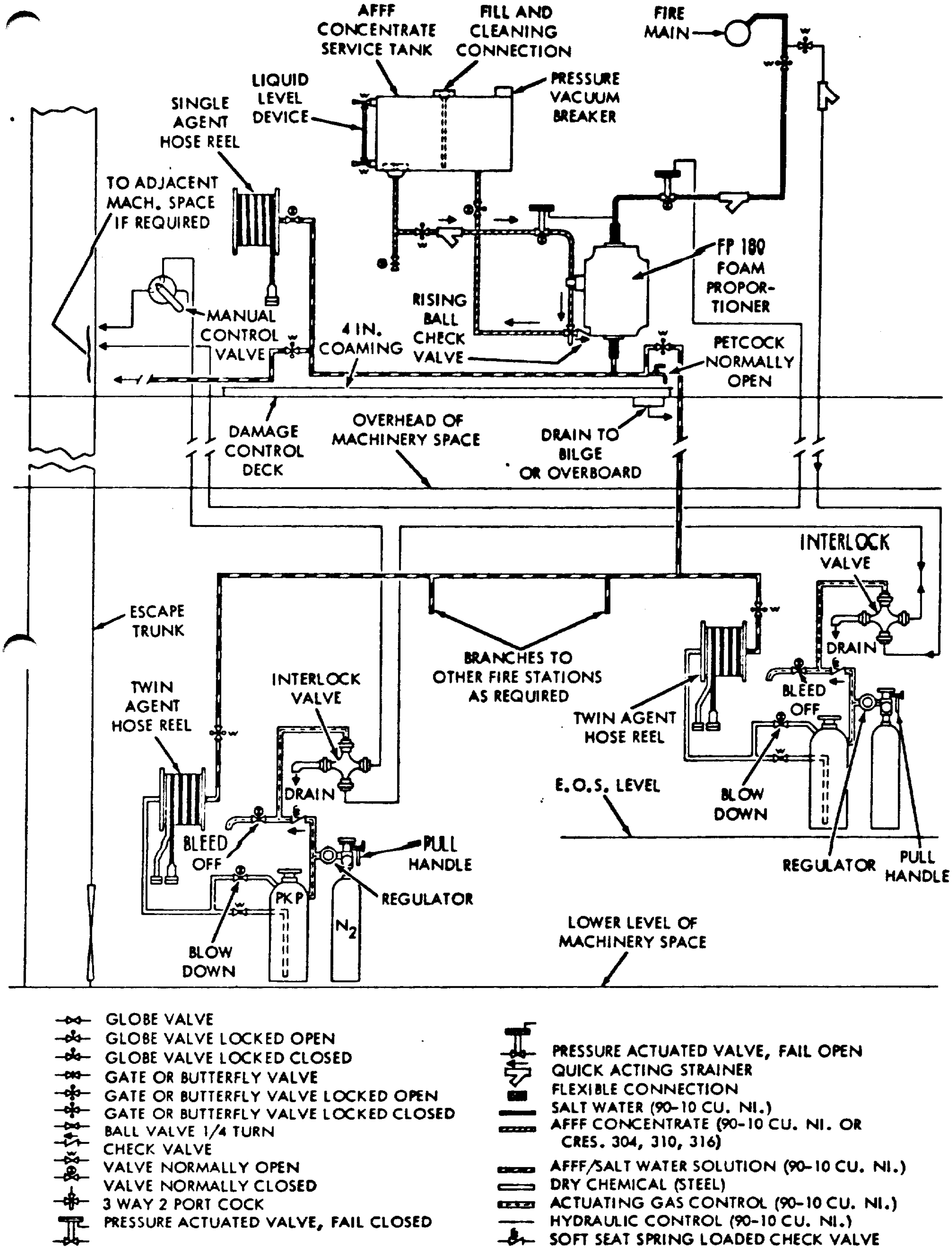


Figure 4-1
Twin Agent (AFFF and PKP) Fire Extinguishing System[5]

the first is after equipment is newly installed, repaired, altered or converted by an industrial activity; the second is scheduled preventive maintenance. NAVSEA 0993-LP-023-6010 technical manual requires preventive maintenance semiannually or more frequently if conditions warrant it.[5] Appendix D contains a copy of the Long Beach Naval Shipyard procedures for testing AFFF/PKP fire-fighting systems. These procedures are representative of those used in other shipyards.

c. The environmental assessment parameters which relate to the proposed action and the appraisals of the magnitude of the resulting impacts are given in table 4-1. There are no apparent air quality impacts of the proposed action.

2. Navigable Waters Impact. The ecological effect of any chemical introduced into a given environment for the first time is a function of many factors. Its physical and chemical structure will determine what physiological influences it could exert on life forms with which it may come into contact. However, its concentration at any point in time is a measure of the probability of such effects occurring. Therefore, an assessment of maximum concentration expected and the speed with which the chemical is purged from the environment are essential elements in the formulation of impact estimates. Since these evaluations must precede a proposed action, direct measurements are not possible. Therefore, the best indirect evidence available has to be applied to the construction of a

Table 4-1
Appraisal of the Proposed Action's Impact Upon the Environmental Assessment Parameters

Assessment Parameter	Effect of the Proposed Action	Data or Observations for Evaluation of Parameter Impact
Physical/ Chemical/ Biological		
Flow Variations, (concentration - time factors)	The discharge of a quantity of AFFF into harbor waters with inadequate natural mixing capability may result in localized areas of chemical concentration.	Information with regard to tidal, current and wind movements has been acquired in order to calculate the flushing capability of the receiving waters.
Associated Chemical Contaminants	The physical-chemical interaction of AFFF with other major chemical contaminants normally found in a particular harbor could result in altered dispersion, degradation, and toxicological properties of some of the reactants. This could influence the "self purification" capability of the harbor.	Qualitative and quantitative data regarding the major types of contaminants normally found in a particular harbor would determine the degree of chemical interaction with AFFF. Natural mixing in receiving waters and the extremely low concentration of chemicals and AFFF will minimize environmental effects.
Toxicological Properties of AFFF	It is possible that finite concentrations of any chemical will have a detrimental effect on some biological entity in a particular environment. Therefore, the nature of this influence, the spectrum of biological life affected, and the concentration constraints imposed within a particular environment will determine if AFFF and its anticipated usage will constitute an ecological hazard.	The influence of AFFF on marine life in a harbor and contiguous waters must be determined. These effects should be evaluated within the practical range of chemical concentrations anticipated if the proposed action is implemented and should include short-range (acute and sub-acute) and long-range (chronic) toxicity testing. Data currently available (appendix E) supplies the requisite information.

Table 4-1 (cont'd)

Assessment Parameter	Effect of the Proposed Action	Data or Observations for Evaluation of Parameter Impact
pH of AFFF Effluents	The pH of the AFFF product in question, FC-206, is identified at approximately the neutral point, 7.8, in appendix B; therefore, there should be minimal impact on the pH of the harbor waters.	The applicable procurement specification, MIL-F-24385, for the AFFF allows as acceptable a range of pH from 4 to 8. The specification should be changed to conform more closely to the reported control value of pH 7 to 8.
AFFF Pollution Loading Potential	The BOD and COD of FC-206 are very high (appendices B and E). This means that high chemical concentrations could temporarily deplete the DO content of the receiving waters if discharged in large quantities.	The fact that BOD and COD values for FC-206 are relatively the same is indicative that this material is highly biodegradable. The fact that the BOD_5 is 65% of the BOD_u indicates the material is rapidly biodegradable.
<u>Socioeconomic</u>		
Fishing (commercial and recreational) Water Skiing and Swimming	The discharge of AFFF is not expected to affect commercial fishing or recreational use. Harbor areas associated with shipyards are centers of industrial activity and are not used for recreation.	Rapid dilution and biochemical degradation of AFFF within the industrial harbor areas should reduce concentrations to within acceptable limits while within the harbor whereby normal fish feeding or recreational water uses outside harbor areas are not affected.
<u>Aesthetic</u>		
Water Surface	The surfactant and film forming characteristics of the AFFF mixture could result in an unsightly film on the harbor surface.	AFFF testing can be conducted with nonfoaming nozzles. When discharged overboard the AFFF disperses beneath the surface (appendix F).

hypothetical case. Before constructing such a case, the following information must be obtained: (a) the quantity and frequency of potential AFFF discharges; (b) the dilution of a discharge and natural mixing within the harbor; and (c) the rate of removal of the discharge from the receiving waters by natural flushing and by decomposition.

a. While specific data on the generation rates of AFFF from machinery space system testing are not available, it is possible to estimate the quantity of AFFF solution generated per system test and the frequency of those tests using data and information obtained from naval shipyards and experience gained by the FFAT.

(1) Quantities of AFFF generated at naval shipyards as a result of machinery room FP-180 testing are contained in table 4-2. These have been provided by the shipyards cited. They were derived by multiplying the number of ships having their fire-fighting foam systems converted from protein to AFFF by the quantity of foam generated while testing each system. No data are available on the generation rates of AFFF from semiannual PMS maintenance aboard ships in port; however, experience of the FFAT has shown that approximately 90 gal (0.34 m^3) of 6% AFFF solution are generated per test and that ships' operating schedules usually obligate in-port PMS testing at a frequency of about once every three years. Other PMS testing is conducted at sea. The above estimates

are reasonable compared with data in a report on handling ship industrial wastes in San Diego, California. The report is being prepared by contract for NAVFACWESTDIV. The monthly generation rate of AFFF was compiled based on NAVSEC (SEC 6159) survey data from 1972 and on contacts with cognizant commands in the area. Typical AFFF waste generation rates were reported at 530 gal (2.0 m^3) for 40 ships at the Naval Station, 660 gal (2.5 m^3) for 5 ships at North Island, and 30 gal (0.1 m^3) for 4 ships at the Submarine Support Facility.[6] The report estimates include some non-machinery space AFFF equipment testing.

Table 4-2
Quantity of AFFF Generated During In-Port Fire-Fighting Foam System Testing at Naval Shipyards (NSY)*

Activity	Number of Ships	AFFF		Period (years)	Disposal Procedure
		(gal)	(m^3)		
Portsmouth NSY		**	**		
Philadelphia NSY	11	1500	5.7	1	None
Norfolk NSY	-	8000	30.3	1.5	Yes
Charleston NSY	3	225	0.9	1	Yes
Long Beach NSY	9	1100	4.2	1	Yes
Mare Island NSY		**	**		
Puget Sound NSY	1	400	1.5	1	None
Pearl Harbor NSY		***	***		

*Calendar year 1975 estimates.
**No surface ships serviced during CY75.
***Data not available.

(2) The numbers of machinery spaces and proportioners aboard ships with fire-fighting foam systems are given in table 4-3. The quantity of 6% AFFF that could be generated aboard ship per year is estimated for each significant Navy port in table 4-4. Estimates were obtained by multiplying the output

per proportioner by the total number of FP-180 proportioners aboard the ships in the group. The experiences of the FFAT indicate that approximately 90 gal (0.34 m^3) of AFFF are generated during a single test. For in-port PMS testing once every three years, the total quantity of AFFF concentrate generated per port per year is also estimated in table 4-4 assuming maximum generating conditions of 90 gal (0.34 m^3) AFFF solution at 6%.

Table 4-3
FP-180 Proportioners in Machinery Room Spaces
Aboard U.S. Navy Ships by Class Grouping

Group	Number FP-180 Proportioners	Ship Classes in Group
1	1	AE, ASR, ARS
2	2	AD, AFS, AG, AO, AOE, AOG, AOR, AR, AS, ATF, FFG, LCC, LKA, LPD, LPH, LPA, LSD, ATS, MSC, MSO, LHA, AF
3	4	CG (DLG), DD, DDG, FF, LST, CGN
4	6	CV, CVN

(3) The AFFF generation estimates from the shipyards given in table 4-2 are included in table 4-4. When a shipyard is in the same harbor area as a homeport (i.e., Norfolk, VA), the shipyard generation rates were combined with those estimates of PMS testing. Shipyards not associated with homeports (i.e., Long Beach, CA) are listed and ranked with those ports in table 4-4.

Table 4-4
Estimated Yearly Quantity of AFFF Generated Aboard Ships In Port Based Upon 90 Gal (0.34 m^3) of 6% Mixture Per Test Once Every Three Years and CY75 Shipyard Generation Estimates

U.S. Navy Port Listing(a)	Rank (b)	Number of Ships in Group — Group 1	2	3	4	Total Number of Proportioners In Port	Estimated Gal (m^3) of 6% AFFF Generated — Port	Shipyard	Estimated Total Gal (m^3) of AFFF Concentrate Discharged Per Year
Alameda, CA	10		2		3	22	660 (2.47)		40 (0.15)
Baltimore, MD				1		4	120 (0.45)		7.2 (0.03)
Bayonne, NJ				1		4	120 (0.45)		7.2 (0.03)
Bronx, NY				1		4	120 (0.45)		7.2 (0.03)
Bremerton, WA	9		2	2	1	18	540 (2.02)	400 (1.51)	56.4 (0.21)(c)
Brooklyn, NY				1		4	120 (0.45)		7.2 (0.03)
Charleston, SC	3	3	10	25		123	3690 (13.84)	225 (0.85)	221.4 (0.84)(d)
Concord, CA		8				8	240 (0.90)		14 (0.05)
Groton, CT		1				1	30 (0.11)		1.8 (0.01)
Fall River, MA			1			2	60 (0.22)		3.6 (0.02)
Galveston, TX				1		4	120 (0.45)		7.2 (0.03)
Pensacola, FL					1	6	180 (0.67)		11 (0.04)
Portland, ME			2			4	120 (0.45)		7.2 (0.03)
Little Creek, VA	7	3	11	10		65	1950 (7.31)		117.0 (0.44)
Long Beach, CA	8		3	10	1	52	1560 (5.85)	1100 (4.16)	93.6 (0.35)(d)
Mayport, FL	6	2	7	15	2	88	2640 (9.90)		158.4 (0.60)
New London, CT			1	1		6	180 (0.67)		10.8 (0.04)
New Orleans, LA				1		4	120 (0.45)		7.2 (0.03)
New York, NY				2		8	240 (0.91)		14 (0.05)
Newport, RI			1	4		18	540 (2.04)		32 (0.12)
Norfolk, VA	2	3	29	42	5	259	7770 (29.41)	8000 (30.28)	466.2 (1.76)(d)
Panama City, FL			1			2	60 (0.23)		3.6 (0.01)
Pearl Harbor, HI	4	8	13	20		112	3360 (12.72)		201.6 (0.76)(d)
Perth Amboy, NJ			2			4	120 (0.45)		7.2 (0.03)
Philadelphia, PA	5		1	10		42	1260 (4.77)	1500 (5.68)	165.6 (0.63)(c)
Portland, OR			1	2		10	300 (1.14)		18 (0.07)
Portsmouth, NH			1			2	60 (0.23)		3.6 (0.02)
Tampa, FL				1		4	120 (0.45)		7.2 (0.03)
San Diego, CA	1	2	41	55	2	316	9480 (35.88)		568.8 (2.12)
San Francisco, CA			7	2		18	540 (2.04)		32 (0.12)
Seattle, WA				3		12	360 (1.36)		22 (0.08)
St. Petersburg, FL			2			4	120 (0.45)		7.2 (0.03)
Tacoma, WA			1	1		6	180 (0.68)		11 (0.04)

(a) U.S. homeports for naval surface ships.[3]
(b) Ranked by estimated quantity of AFFF generated per year during testing.
(c) Includes AFFF generated by shipyard tests; no alternate disposal procedure.
(d) Excludes AFFF generated by shipyard tests; alternate disposal procedure practiced.

b. The long-range effect of a contaminant on the harbor environment is dependent on the contaminant's rate of removal. Theoretical analyses of the dilution and flushing capabilities for each of 18 harbors were made by the U.S. Navy Hydrographic Office (now NAVOCEANO) from 1959 through 1963. The analyses were based on available measurements of the physical and dynamic characteristics of the site. The results of each theoretical analysis were reported separately for each port, and the dilution and flushing capabilities of each port were compared in a summary report.[7] The summary report states: "...The major factors, not necessarily in order of importance, which determine the reduction of concentration of an introduced contaminant are: (1) volume of water available for dilution, (2) rate at which the contaminant is dispersed throughout this volume, and (3) rate of advection (i.e., movement by currents)."[7] The methods of investigation and the conclusions of the report are summarized in the following paragraphs.

(1) The Hydrographic Office report states that the volume of water available for dilution is not actually a criterion of flushing capability, although it is of obvious importance since a harbor with poor flushing characteristics still might be safe from contamination if great dilution takes place; a harbor with a small dilution volume and a relatively high rate of flushing might retain a high amount of contamination for a relatively long period of time.

Examples are Long Beach, California which has a large dilution volume and Mare Island Strait, San Francisco, California which has a high flushing rate as shown in figure 4-2.

(2) The amount of turbulence within a water area will determine the rate at which a contaminant is dispersed throughout the dilution volume. For the most part, tidal currents are the source of turbulence. However, horizontal or vertical motion induced through seiches, waves, winds, etc. may serve as a mixing agent. The distribution of conservative physical properties indicates the relative degrees of mixing.

(3) Figure 4-2, Comparison of Dilution Volumes and Flushing Capability of 18 Harbors, taken from this report, was based upon the following assumptions and conclusions.[7]

(a) The initial dilution volume was taken to be the volume of water defined by the length of a flood tidal excursion and the width and depth of the body of water through which the tidal excursion is measured. Where possible this volume was calculated, however where current speed data were not available and the embayment was considered sufficiently small, the volume of the embayment was taken as the dilution volume.

(b) Flushing also affects the concentration of contaminant within a harbor. A contaminant will be removed from an area either by net flow from it or by mixing of the harbor water and the currents passing the entrance of the harbor. These factors were reflected in the exchange ratio

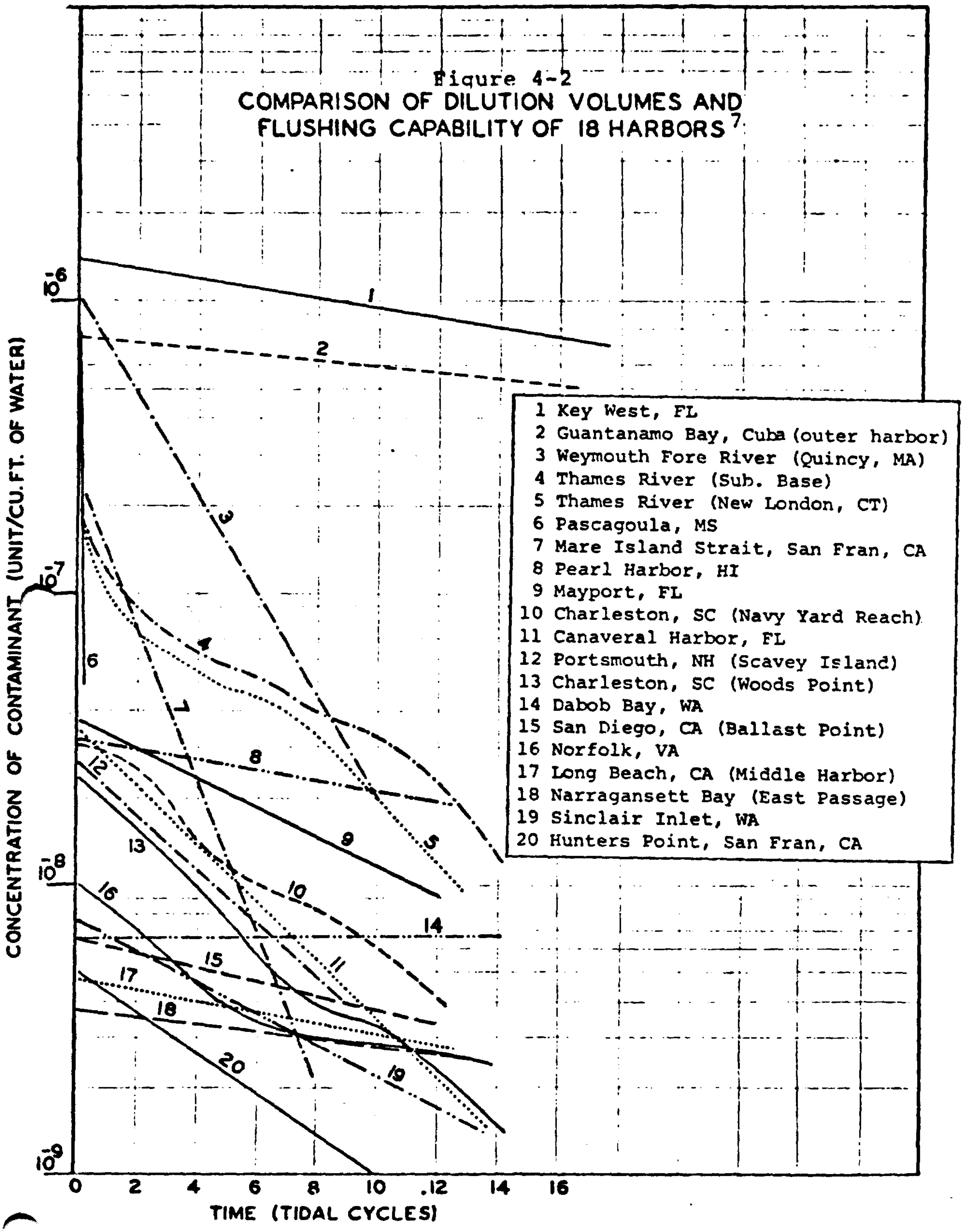


Figure 4-2
COMPARISON OF DILUTION VOLUMES AND FLUSHING CAPABILITY OF 18 HARBORS[7]

for each of these harbors, and this ratio was adjusted to account for the fraction of the tidal prism that is lost during each tidal cycle. It was further assumed that a volume of new uncontaminated water replaces the lost fraction of the tidal prism. These considerations were applied to nonestuarine embayments and to harbors in estuarine embayments in which the point source of contamination was not more than one flood tidal excursion from the entrance. (Flood excursion is defined in the study as the distance traveled by a "particle" of water or of contaminant between one slack before flood and the succeeding slack before ebb.) If the point source was located more than one flood tidal excursion from the harbor entrance, and the harbor was estuarine, the distribution of the contaminant between the point source and the harbor entrance was calculated. It was assumed that the contaminant contained in a segment at a given time was uniformly distributed throughout the high tide volume of that segment. The concentration within the segment was calculated, and the highest concentration found within the estuary at a given time was plotted in figure 4-2. The curves show the rate of decrease of peak concentration within a harbor over 14 tidal cycles. Their relative slopes afford a comparison of the rates of contaminant decrease among the harbors. The position of the curve at time = 0 reflects the amount of dilution that the contaminant would undergo within the first tidal cycle after introduction (assuming that 100 units of contaminant are introduced and the dilution volume is the volume of water defined by the length of a flood tidal excursion and the width and depth of the body of water through which the tidal excursion is measured).

(4) Advection is the true flushing agent as other processes mentioned tend only to reduce the concentration of a contaminant; they do not remove it from the area. Currents immediately offshore from the harbor serve as a mode of transport to oceanic areas where dilution volumes are virtually unlimited.

(5) For analyzing the relative flushing capabilities of the harbors, the data available were inadequate for examining many of the probabilities involved in the event of contamination. In some locations stratification of water results from density differences, and the net inflow in the bottom layer of this type of estuary would be upstream rather than seaward. Should the bottom layer of this type of estuary become contaminated, the flushing time would be prolonged greatly.

(6) The Hydrographic Office summary report cautioned that in light of their information, the flushing analysis for each harbor is believed to be valid insofar as the data available at the time would allow. The limitations imposed by data deficiencies are pointed out in each of the 18 reports for the individual harbors.

c. To verify the results of the theoretical flushing analyses, the Hydrographic Office conducted actual dye tracer field tests for a group of harbors representing the types of harbors studied for their relative flushing capabilities (dye being a conservative substance during the periods observed). The dilution factors measured during five field tests conducted at large Navy ports are summarized in table 4-5. The peak concentration of any conservative contaminant at a time after release can be predicted by multiplying the total amount of contaminant released (concentration x volume) by the dilution factors in the table for that time.

(1) The field test procedures consisted of releasing a quantity of dissolved tracer dye (rhodamine-B, or fluorescein) and monitoring its dilution and dispersion until dye concentrations had decreased below the detection limit of the analytical equipment (two parts of dye per hundred billion parts of water) or until the dye had been transported out of the harbor. Field measurements of the test areas included collection of water samples for analysis of dye concentration and salinity, current and temperature measurements and aerial photographs.

(2) A comparison of the results of the flushing analyses and field tests indicates the usefulness and the limitations of the tidal prism method. One of the basic assumptions of the tidal prism theory is that the contaminating material must be distributed uniformly both horizontally and vertically throughout

Table 4-5
Dilution Factors for Five Navy Harbors Determined from Field Measurements of Dye Dilution and Dispersion

Time After Release		Dilution Factor (per litre)				
Hrs.	Min.	Mayport Basin[8]	Pearl Harbor[9] (Southeast Loch)	San Diego[10] (Ballast Point)	San Francisco[11] (Mare Island Strait)	Norfolk[12] (Hampton Roads)
0	10			6.6E-7*		2.2E-7
0	30			6.6E-9	1.8E-7	7.1E-8
1	0	2.2E-9		9.2E-10	1.2E-7	1.1E-8
2	0	1.2E-9			9.5E-8	
3	0	5.5E-10		1.0E-10	5.7E-8	1.3E-10
4	0		1.2E-7		3.3E-8	
5	0	4.9E-10	1.0E-7		1.6E-8	
6	0		8.0E-8	2.6E-11		2.4E-11
8	0		6.2E-8			
10	0	3.3E-10	4.8E-8			
12	0		4.4E-8	1.3E-11		7.7E-12
15	0	2.2E-10				
24	0	1.1E-10	2.6E-8			2.6E-12
48	0	1.1E-11	9.7E-9			1.5E-12
72	0	3.3E-12	6.6E-9			
96	0		4.4E-9			
120	0		3.2E-9			
240	0		2.9E-9			

Superscripts 8-12 refer to references, Section 10.
*FORTRAN exponent form: 6.6E-7 = 6.6×10^{-7}

the harbor. Thus, valid comparison of the predicted decreasing peak concentration curve and the observed curve cannot be made until the dye is uniformly distributed throughout the basin. For the Mayport Basin field test this occurred within six hours.[8] Application of the tidal prism method to the entire volume of Pearl Harbor failed to give realistic estimates of the decreasing concentration of a contaminant released within the harbor; however, concentration decreases within the Southeast Loch where the shipyard and naval station are located can be estimated fairly accurately after mixing of the dye within the loch is complete at 48 hours after release.[9] A comparison of the other field tests with the theoretical analyses indicated that the predicted reductions in peak contaminant concentrations as shown in figure 4-2 are valid for predicting the flushing rate of a contaminant from a harbor.

(3) In all cases field tested by the Hydrographic Office, the initial dilution rate as seen from peak concentration curves is very rapid. This fact has also been borne out by other dye dispersion studies.[13]

(4) To confirm that a 6% AFFF solution will disperse in a manner similar to that of a dye release, a small scale test was conducted in Dungan Basin at the David W. Taylor Naval Ship Research and Development Center, Annapolis Laboratory. The experiment involved the release of 20 gal (75.7 ℓ) of 6% AFFF mixture composed of 1.2 gal (4.5 ℓ) of AFFF concentrate

mixed with 18.8 gal (71.2 ℓ) of dilution water and dyed with rhodamine WT dye to an initial concentration of 100 ppm by weight. The experiment proved the applicability of using dye to obtain dilution factors applicable for AFFF. (The experimental procedure and results are contained in appendix F.)

d. The dilution factors contained in the Hydrographic Office field reports can be used to estimate the maximum concentration of AFFF within a harbor after a discharge and to estimate the rates of removal from the harbor by flushing.

(1) Based upon the Hydrographic Office dilution factors and the estimated quantity and frequency of potential AFFF discharges, hypothetical cases for an AFFF release can be developed. Each case is hypothetical in the sense that the discharge from a single ship (point source) is used in the calculations whereas it is possible that discharges from additional ships could enter the harbor at the same time. Furthermore, it is assumed that the ship will discharge its AFFF in a harbor location where there is good mixing; it is possible that AFFF would sometimes be discharged in less desirable areas such as those sheltered from the diluting effects of tidal flows. To offset these possibilities, the worst case conditions are assumed: the maximum quantity of AFFF would be discharged per ship and biological decomposition of the AFFF would not occur.

(2) Theoretical peak AFFF concentrations have been calculated in table 4-6 based upon the dilution factors given in table 4-5. Sample calculations for five ports are based on the hypothetical discharge of AFFF from the largest ship likely to be berthed at those locations since it would emit the largest volume of AFFF and would thus provide a more rigorous test. It is recognized that all systems would not be checked simultaneously but would probably be exercised over a period of a few hours. Each test could involve the generation of about 90 gal (0.34 m^3) of maximum 6% concentration AFFF. The system will be secured as soon as possible after sample collection. In order to evaluate the worst possible case, calculations are based on the unlikely assumption that all machinery space FP-180 proportioners are tested simultaneously and the ship represents a single point source.

(3) A sample calculation for determining peak AFFF concentration following testing aboard an AS-type ship berthed at the Submarine Support Facility, Ballast Point, San Diego, follows.

(a) AFFF generated during testing of two FP-180 machinery space proportioners aboard an AS-type ship is 180 gal (0.68 m^3) of 6% solution containing 10.8 gal (40.9 ℓ) of concentrate.

(b) The dilution factor (DF) in San Diego ten minutes after release is 6.6×10^{-7}/litre.[10]

Table 4-6
Peak AFFF Concentrations in Four Navy Harbors at Intervals After Discharge of 6% AFFF Test Mixture

Time After Discharge		Peak AFFF Concentration in mg/ℓ				
		Mayport Basin*	Pearl Harbor* (Southeast Loch)	San Diego** (Ballast Point)	San Francisco* (Mare Island Strait)	Norfolk* (Hampton Roads)
Hrs.	Min.					
0	10			28.0		27.0
0	30			0.28	23.0	8.8
1	0	0.27		0.04	15.0	1.4
2	0	0.15			12.0	
3	0	0.07		<0.01	7.1	0.02
4	0		15.0		4.1	
5	0		12.0		2.0	
6	0		10.0			<0.01
8	0		7.8			
10	0	0.06	6.0			
12	0		5.5			
15	0	0.03				
24	0	0.02	3.3			
48	0	<0.01	1.2			
72	0		0.8			

*CV-type ship, six FP-180's tested, 540 gal 6% AFFF (32.4 gal concentrate).
**AS-type ship, two FP-180's tested, 180 gal 6% AFFF (10.8 gal concentrate).

(c) Therefore, the AFFF concentration at that time can be calculated.

$$(40.9 \text{ litre AFFF}) \frac{(10^3 \text{cm}^3)}{\text{litre}} \frac{(1.02 \text{ g AFFF})}{\text{cm}^3} = 4.2 \times 10^4 \text{g AFFF}$$

$$(4.2 \times 10^4 \text{g AFFF}) \frac{(6.6 \times 10^{-7} \text{DF})}{\text{litre}} \frac{(10^3 \text{mg})}{\text{g}} = 28 \text{ mg AFFF per litre}$$

Using the same procedure, the predicted AFFF concentration after one hour is further reduced to 0.04 mg/ℓ.

e. Based upon the results of the Hydrographic Office studies as shown in figure 4-2, it is apparent that there is considerable variability between harbors with regard to the dispersion of substances within harbors and the rate substances will be flushed from harbors. This is due to differences in harbor volumes, tidal flow volumes, eddies, currents, etc. Therefore, it was impractical to experimentally measure actual peak AFFF concentrations in Navy harbors after shipboard AFFF system test effluent discharges. However, from the information presented thusfar on the limited quantity and frequency of AFFF discharges, on the rapid dilution of a discharge, and on the rate of removal of AFFF from a harbor by natural flushing, it is possible to predict concentrations of AFFF after discharge, and the following conclusions can be drawn.

(1) Immediate Effect of an AFFF Discharge. The initial dilution (determined by measuring peak dye concentration immediately after completion of the release) of the dye released during the Hydrographic Office dye dispersal field test for

Key West was approximately 1000 times.[14] Key West had the lowest dilution predicted for the 18 harbors studied, as shown in figure 4-2. During coastal dye dispersion studies using 5000 gal (18.9 m^3) of a seawater-sewage-dye mixture, initial dilutions of 1000 to 2000 times were measured at the point of discharge.[13] The small scale AFFF/dye discharge into Dungan Basin discussed in appendix F indicated initial dilutions of 3200 times. Thus, the initial concentration of AFFF (60,000 ppm maximum) can be expected to be reduced to no more than 60 ppm very soon after impact with the receiving waters. This concentration is only 5% of the 40-hour LC_{50} concentration found toxic to brine shrimp during bioassay tests conducted at the David W. Taylor Naval Ship Research and Development Center. Therefore, the immediate effect of the proposed action, discharging AFFF to harbor waters during in-port testing of machinery space fire-fighting systems, on the environment is considered negligible based upon the dilutions expected during the discharge. Appendix E contains toxicity data on six other representative saltwater organisms tested by the Center as well as tests on additional fresh and saltwater organisms conducted by other laboratories.

(2) Long-Term Effect of AFFF Discharges. The chronic effects of AFFF have not been evaluated and total quantities of chemical discharged during the simultaneous testing of fire-fighting equipment from several ships have not been measured

(although based upon the assumed in-port testing frequency and the relatively small number of machinery space proportioners, the likelihood of multiple tests being conducted at the same time and location is remote). However, it can be concluded from the concentration data in table 4-6 and the toxicity data in appendix E that the dosage of AFFF required to kill 50% of the organisms after 96 hours of exposure (LC_{50}) was considerably higher than the residual AFFF concentration calculated to persist in any of the five selected harbors at the end of that period of time. In fact, for even the largest theoretical AFFF discharge given in table 4-6, the concentration of AFFF in the marine environment will be reduced in minutes to levels well below those acutely toxic to marine organisms. Furthermore, biodegradation data for FC-206 (appendices B and E) indicate that within the accuracy of the BOD and COD tests, AFFF FC-206 is virtually wholly biodegradable.

SECTION 5

ALTERNATIVES TO PROPOSED ACTION

1. **The U. S. Navy is committed to providing adequate fire** protection for the prevention, containment, and extinguishment of fires. Testing is necessary to verify the readiness of fire-fighting equipment to effectively respond, as called upon, to combat fires. Confidence in both equipment and personnel is achieved by exercising the fire-fighting stations on a regular basis and verifying system performance after alterations or repairs.

a. The need for maintaining a fast, effective system for shipboard fire fighting has been repeatedly demonstrated. Since 1969 alone, over 1100 shipboard fires have been reported to the Naval Safety Center. Major losses in that period of time include the USS KENNEDY/USS BELKNAP collision and fire in 1975 (now estimated at $213M, 8 deaths), USS NEWPORT NEWS in 1972 ($6.5M, 21 deaths), USS FORCE in 1973 (total loss), USS KITTYHAWK in 1973 ($1M, 6 deaths), USS FORRESTAL in 1972 ($20M) and in 1967 ($20M, 133 deaths), USS ENTERPRISE in 1969 ($5M, 27 deaths) and USS ORISKANY ($10M, 43 deaths). NSC reports 106 property damage accidents involving fires in machinery spaces aboard surface ships from July 1974 to January 1977, totalling $5.8M in material damage and 36 casualties.

b. As ships and ships' systems become more sophisticated and the use of aluminum and composite structural materials increases, the vulnerability to fire also increases. To keep pace with the need for more sophisticated fire-fighting strategy, methods for the prevention, containment, and extinguishment of fires have been improving. One such improvement was the development of AFFF in the mid-1960's to replace protein foam.[15]

c. Tests by NRL demonstrated that "light water" was two to three times as effective as protein foam in extinguishing bilge fires and recommended that a dual discharge system of "light water" and PKP be adopted for rapid, improved extinguishment of fuel fires in shipboard engine room spaces.[16] Further testing by NRL, NAVSEC, and NAVSEA continued to demonstrate the superiority of AFFF over protein foam for extinguishing fires involving AvGas, JP-4, and JP-5.[17]

d. The objective of Navy fire protection strategy is to markedly reduce the vulnerability of ships, aircraft, facilities, and personnel to the hazards and damages of fire from both hostile and peacetime action.[15] AFFF systems are an integral part of a ship's fire-fighting capability. The following proposed action and alternatives are analyzed with that objective in mind as well as the environmental impact of AFFF system testing.

2. <u>Proposed Action</u>: Overboard Discharge of Foam. The objective of the proposed action is to dispose of effluent produced by machinery space AFFF fire-fighting foam system testing. The current approach to testing AFFF systems is to generate foam through one nozzle on each proportioner, to quickly sample the discharge for determination of AFFF

concentration in the mixture, and to secure the system as soon as possible to prevent excessive use of AFFF concentrate. The foam is usually discharged directly overboard due to the unavailability of collection and/or treatment facilities.

3. There are six basically different alternative approaches to the proposed action. They are summarized as follows.

a. Alternative (A). Test with Substitute Concentrate Material. Direct research and development efforts toward obtaining a substitute material for fire equipment test use which is more acceptable environmentally and which is functional as AFFF.

b. Alternative (B). Refine Procedures to Reduce Discharge Volume. Refine the test procedures to reduce the volume of the AFFF mixture produced.

c. Alternative (C). Adjust Test Schedules for Discharge Only When Collection, Treatment and Disposal Facilities are Available. Establish that tests only be conducted when the AFFF discharge can be handled in an environmentally acceptable manner. This includes discharge to pier sewers, collection barges or on the open sea while underway.

d. Alternative (D). Perform Tests with Discharge Contained as Part of a Closed System. Provide, as ancillary shipboard equipment, a dedicated holding tank capability to support the AFFF flow test and cause minimal scheduling interference. The AFFF mixture test effluent could be disposed of in accordance with the plan of alternative (C).

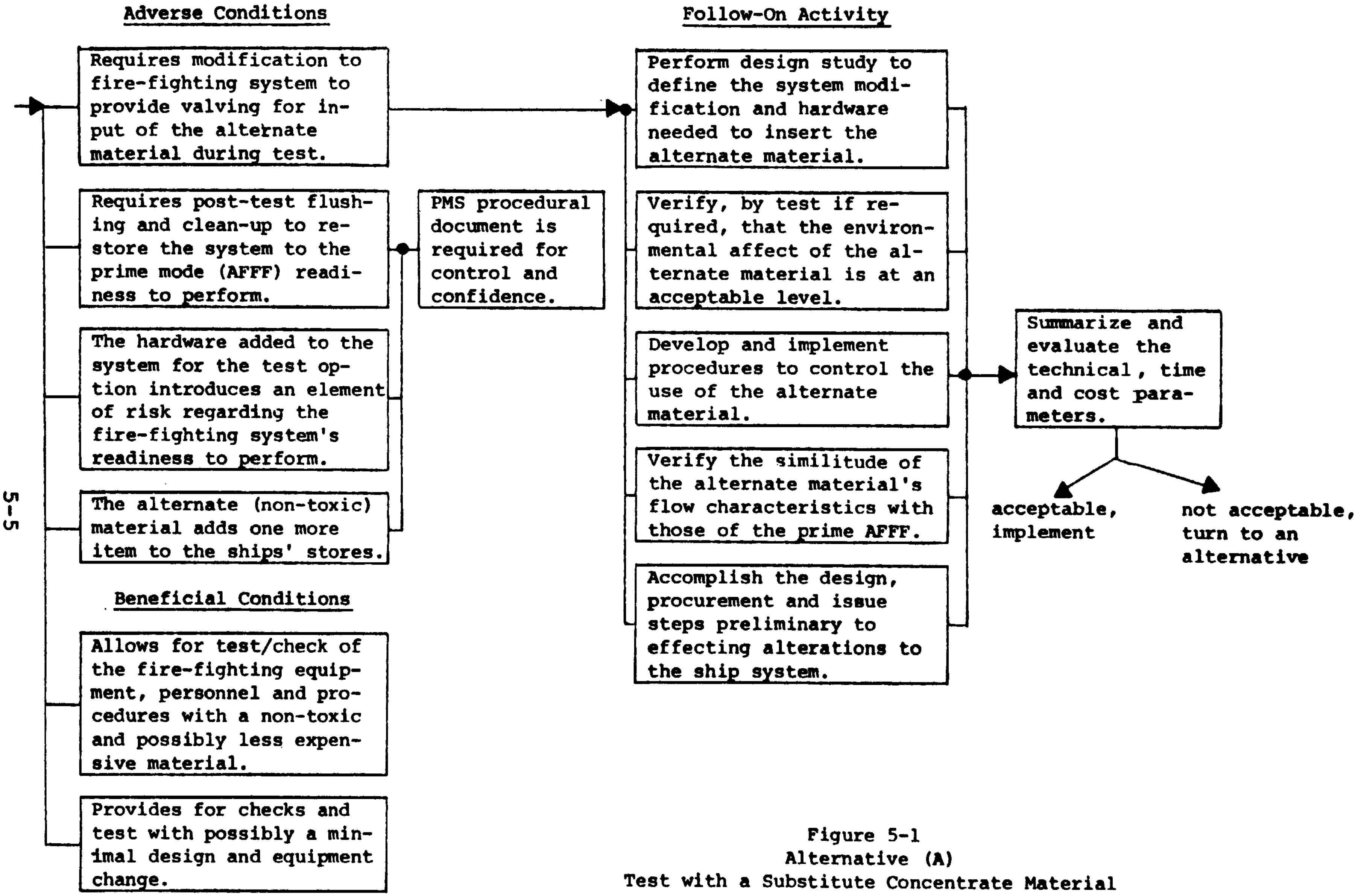
The implementation of alternative (B) would improve the feasibility of the portable tankage alternative by reducing the volume to be handled.

e. <u>Alternative (E)</u>. <u>Eliminate Shipboard Flow Test by Redesigning Maintenance Plan</u>. Redesign the plan of maintenance for the fire-fighting equipment to eliminate the shipboard flow test requirements.

f. <u>Alternative (F)</u>. <u>Eliminate Shipboard Flow Test by Enhancing System Component Performance Reliability</u>. Enhance system reliability by modifying equipment to increase confidence of system performance to an acceptable level without regular flow testing using AFFF.

4. Figures 5-1 through 5-6 summarize the adverse and beneficial effects (including those with cost and risk elements) in flow chart form, and develop the follow-on technical and administrative actions necessary for the conclusive acceptance or rejection of each alternative.

5. When the objective of alternative (A), test with a substitute concentrate material, is considered with regard to the environmental assessment parameters in table 4-1, it is concluded that by the nature of the change to a less harmful material, the potential for harmful impact is measurably reduced.



Adverse Conditions

Requires modification to fire-fighting system to provide valving for input of the alternate material during test.

Requires post-test flushing and clean-up to restore the system to the prime mode (AFFF) readiness to perform.

The hardware added to the system for the test option introduces an element of risk regarding the fire-fighting system's readiness to perform.

The alternate (non-toxic) material adds one more item to the ships' stores.

Beneficial Conditions

Allows for test/check of the fire-fighting equipment, personnel and procedures with a non-toxic and possibly less expensive material.

Provides for checks and test with possibly a minimal design and equipment change.

PMS procedural document is required for control and confidence.

Follow-On Activity

Perform design study to define the system modification and hardware needed to insert the alternate material.

Verify, by test if required, that the environmental affect of the alternate material is at an acceptable level.

Develop and implement procedures to control the use of the alternate material.

Verify the similitude of the alternate material's flow characteristics with those of the prime AFFF.

Accomplish the design, procurement and issue steps preliminary to effecting alterations to the ship system.

Summarize and evaluate the technical, time and cost parameters.

Figure 5-1
Alternative (A)
Test with a Substitute Concentrate Material
Flow Chart

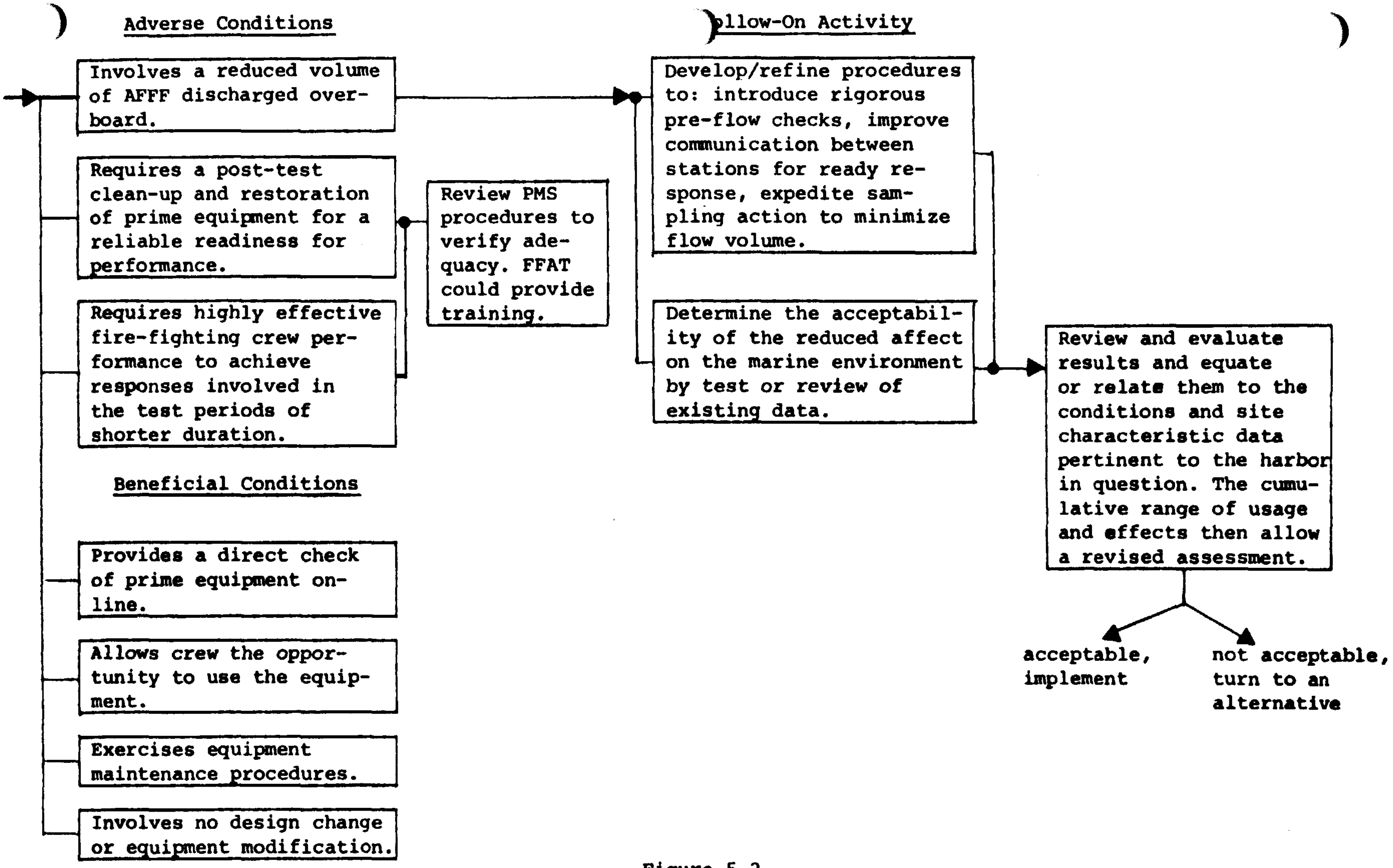


Figure 5-2
Alternative (B)
Refine Procedures to Reduce Discharge Volume
Flow Chart

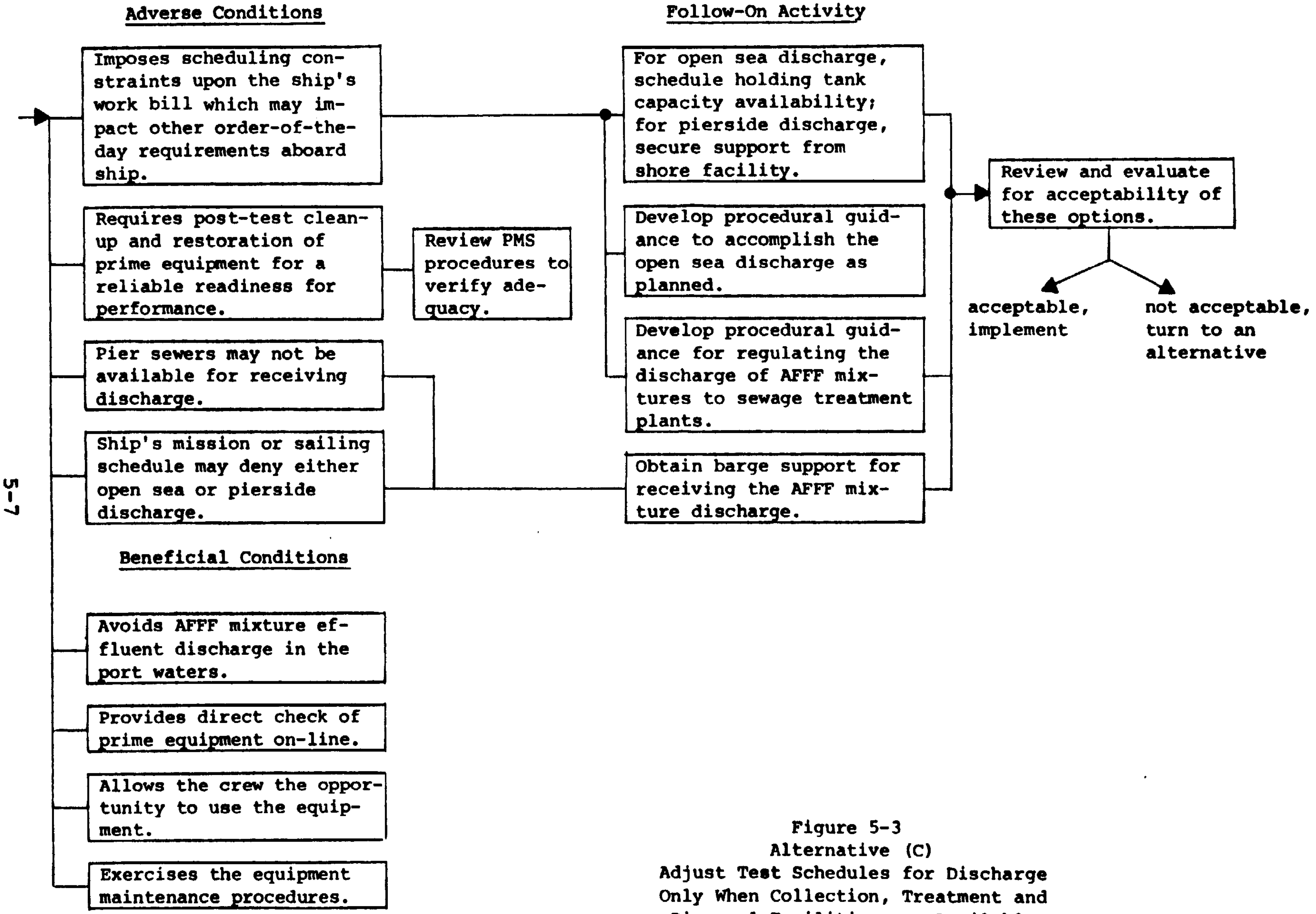


Figure 5-3
Alternative (C)
Adjust Test Schedules for Discharge
Only When Collection, Treatment and
Disposal Facilities are Available
Flow Chart

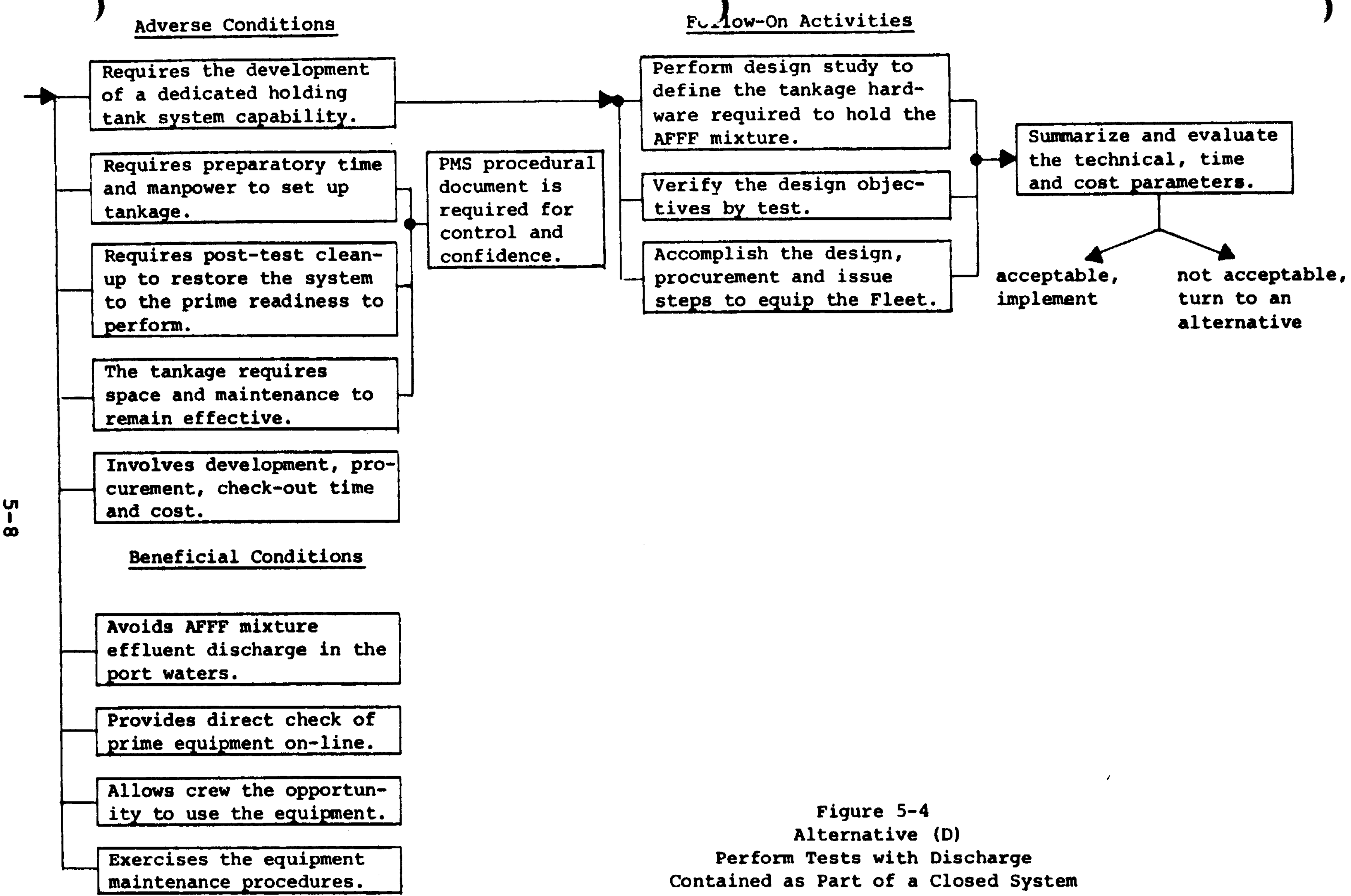
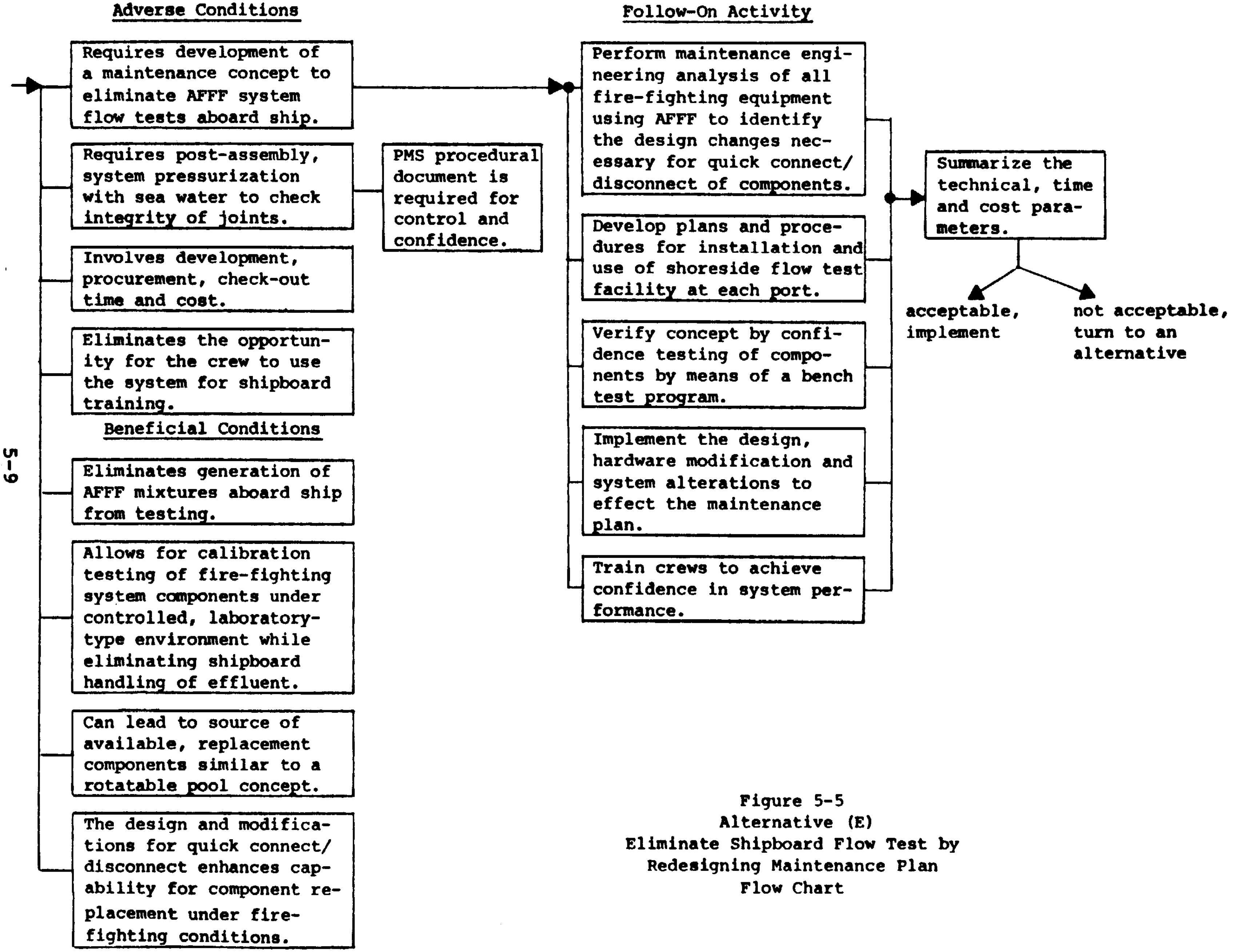


Figure 5-4
Alternative (D)
Perform Tests with Discharge
Contained as Part of a Closed System
Flow Chart



Adverse Conditions

Requires development of a maintenance concept to eliminate AFFF system flow tests aboard ship.

Requires post-assembly, system pressurization with sea water to check integrity of joints.

Involves development, procurement, check-out time and cost.

Eliminates the opportunity for the crew to use the system for shipboard training.

Beneficial Conditions

Eliminates generation of AFFF mixtures aboard ship from testing.

Allows for calibration testing of fire-fighting system components under controlled, laboratory-type environment while eliminating shipboard handling of effluent.

Can lead to source of available, replacement components similar to a rotatable pool concept.

The design and modifications for quick connect/disconnect enhances capability for component replacement under fire-fighting conditions.

PMS procedural document is required for control and confidence.

Follow-On Activity

Perform maintenance engineering analysis of all fire-fighting equipment using AFFF to identify the design changes necessary for quick connect/disconnect of components.

Develop plans and procedures for installation and use of shoreside flow test facility at each port.

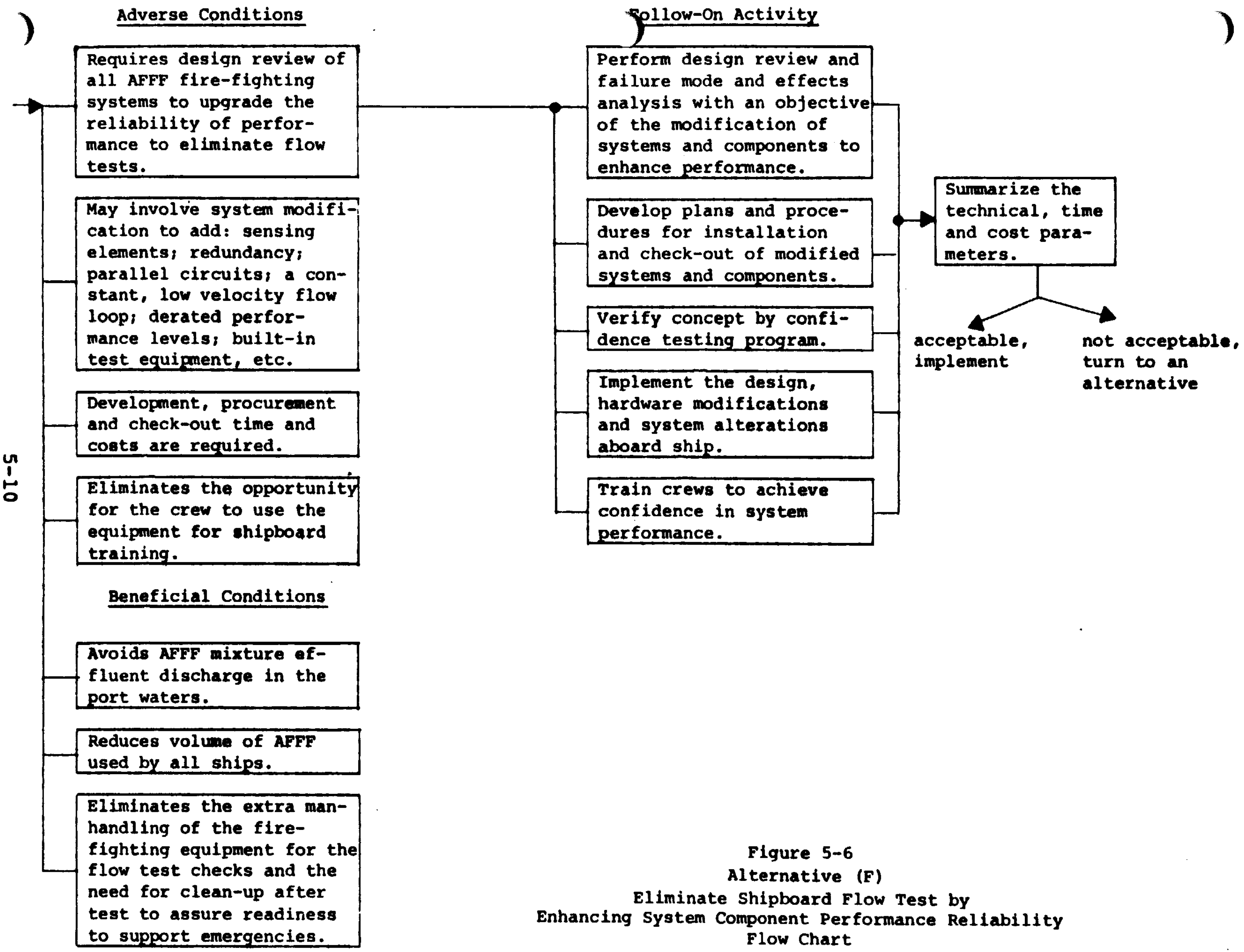
Verify concept by confidence testing of components by means of a bench test program.

Implement the design, hardware modification and system alterations to effect the maintenance plan.

Train crews to achieve confidence in system performance.

Summarize the technical, time and cost parameters.

Figure 5-5
Alternative (E)
Eliminate Shipboard Flow Test by
Redesigning Maintenance Plan
Flow Chart



Adverse Conditions

Requires design review of all AFFF fire-fighting systems to upgrade the reliability of performance to eliminate flow tests.

May involve system modification to add: sensing elements; redundancy; parallel circuits; a constant, low velocity flow loop; derated performance levels; built-in test equipment, etc.

Development, procurement and check-out time and costs are required.

Eliminates the opportunity for the crew to use the equipment for shipboard training.

Beneficial Conditions

Avoids AFFF mixture effluent discharge in the port waters.

Reduces volume of AFFF used by all ships.

Eliminates the extra manhandling of the fire-fighting equipment for the flow test checks and the need for clean-up after test to assure readiness to support emergencies.

Follow-On Activity

Perform design review and failure mode and effects analysis with an objective of the modification of systems and components to enhance performance.

Develop plans and procedures for installation and check-out of modified systems and components.

Verify concept by confidence testing program.

Implement the design, hardware modifications and system alterations aboard ship.

Train crews to achieve confidence in system performance.

Summarize the technical, time and cost parameters.

acceptable, implement

not acceptable, turn to an alternative

Figure 5-6
Alternative (F)
Eliminate Shipboard Flow Test by
Enhancing System Component Performance Reliability
Flow Chart

a. This alternative has already been investigated by NRL.[18] The NRL report considered several test materials which duplicated AFFF concentrate in viscosity and had a suitable refractive index for analysis using the hand-held refractometer presently used. Glycerin was one of the materials found to give the desired performance, was readily available and was low in cost, and it was therefore evaluated. The NRL study concluded, "It is feasible to simulate AFFF concentrates for proportioner testing by adding appropriate agents to water to give it the proper viscosity and refractive index."[18] However, the use of a substitute material was not recommended. The report further stated, "It is believed that the logistical problem of having a simulated concentrate in the supply system, the operation of change-over from real concentrate to simulant and then back to real concentrate for each test, and the increased potential for introducing errors and confusion would not be justified on the basis of the differential costs per gallon of the simulated and real concentrates."[18]

b. NAVSEC considered glycerin as an AFFF substitute for testing but found it unacceptable from an operational standpoint although glycerin has a lower toxicity than FC-206 (appendix E). They stated the following.

> "Because glycerin might react with AFFF substances and make AFFF substances ineffective, use of glycerin for testing of foaming stations would require that the tanks be washed out following use of glycerin and refilled with AFFF. The chance of contamination of AFFF tanks by glycerin, which might make AFFF tanks inoperable or reduce the AFFF concentration to unacceptable limits, makes the use of glycerin for testing proportioning pumps less advisable.
>
> In addition, the use of glycerin for testing could allow operational mistakes that affect foam unit performance to occur. If a foam station was accidently left filled with glycerin, the foam unit could be totally ineffective. If a second tank and valving were added, valves could be left set in the wrong position after testing. Any of these occurrences could turn a small fire into a major casualty if the foam unit malfunctioned. The subsequent possible loss of lives therefore makes this alternative unacceptable."[19]

c. AFFF is a highly developed fire-fighting substance. It is unlikely that a substitute substance could be found that is compatible with AFFF such that operational effectiveness is not degraded and a substance that is also environmentally more acceptable for discharge.

d. Therefore, alternative (A), test with substitute concentrate material, has been rejected.

6. When the objective of alternative (B), refine procedures to reduce discharge volume, is considered with regard to the environmental assessment parameters of table 4-1, it is concluded that, by the nature of the change to reduce the volume of the discharge, the potential for harmful impact is reduced.

a. Current testing time is now approximately one minute. Shorter times may be acceptable providing foam is being delivered from the nozzle in a uniform spray pattern and the hose has been previously flushed with salt water to verify that the hose is not clogged. However, if new in-line test devices (as described in section 9) are adopted, observation of nozzle spray pattern will be impossible. Also, even though the test operating time could theoretically be reduced, there is no assurance that the test team could or would minimize generation times. An AFFF discharge would still result.

b. Alternative (B), refine procedures to reduce discharge volume, is rejected.

7. Alternatives (C) and (D) have as an objective, the elimination of untreated AFFF discharges in port while still permitting system testing as currently practiced; therefore, the potential for damaging the environment is eliminated if adequate treatment is provided.

a. Alternative (C), adjust test schedules for discharge only when collection, treatment and disposal facilities are available, relies on direct discharge to waste collection systems other than those specifically for AFFF containment. These waste collection systems include shipboard wastewater CHT systems, SWOB's, donuts and tank trucks. Also included in alternative (C) is discharge to open sea in unrestricted waters directly from AFFF systems undergoing tests or indirectly through CHT systems. Such an alternative is not considered viable, however, as ship safety requires that machinery space AFFF fire fighting systems be tested prior to getting underway.

(1) CHT systems are being installed on ships as part of the Navy program to eliminate the discharge of shipboard sanitary wastes into navigable waters.

(a) CHT systems provide for the collection and transfer of sewage from waste drains as well as soil drains. Waste drains collect wastewater from hotel services such as showers, lavatories, laundries, galleys, sculleries, sinks, etc. Soil drains collect sanitary sewage from water closets and urinals. Separate soil and waste drains transport waste to collection headers for diversion overboard or to the holding tank. The holding tank contains sensing elements to control sewage pumps, a flushing system, and may contain an aeration system. Waste is transferred from the holding tank by sewage pumps, through discharge piping overboard either to the sea or through deck discharge fittings and hose to shore.[20]

(b) The major advantage of utilizing CHT systems for collection of shipboard generated AFFF is that the waste handling system is already aboard, and therefore extensive installation and alteration of a specific AFFF waste handling system is avoided. A lesser advantage from an AFFF waste handling standpoint is the initial dilution with other waste streams that the AFFF will have in the tank prior to pump-out. The degree of dilution will vary from ship class to class based upon the normal working capacity of the tank. Any dilution of AFFF waste prior to handling or treatment will lessen the possible waste handling problems due to foaming and lessen the possible waste treatment problems due to high BOD loading. A tentative installation schedule for CHT's is provided in appendix G.

(2) SWOB's were originally conceived for the collection of oily waste from aircraft carriers, ships at anchor, and ships berthed at remote locations. The SWOB's procured in FY74 and FY75 were outfitted to handle only oily waste. Eighteen will be constructed with FY76 funds; thirteen will handle sewage, five oily waste. A sewage retrofit package developed in FY76 can be used at the discretion of the user activity to convert an oily waste barge to a sewage barge.

(a) SWOB's scheduled for procurement in FY76 are 75,000 gal (284 m^3) barges intended for the collection of sewage from ships at anchor, or berthed at locations where pier sewers are not planned because of high construction costs. The barges would transport the waste collected to available pier sewers or some other discharge location for adequate treatment and disposal. A tentative allocation plan for SWOB's is provided in appendix G.

(b) The advantages of utilizing SWOB's for collection and transport of AFFF wastes are the same as those for CHT systems.

(3) Waste oil rafts, or "donuts" as they are called, are for the collection and transport of oily waste from ships berthed at piers without oily waste collection facilities and from ships at anchor.

(a) A donut is a circular or elliptical cylinder with a flotation collar at the upper open end. The lower end of the cylinder extends several feet beneath the harbor water surface. The bottom is usually closed by baffles (older systems have open bottoms). Waste oil or waste oil-water mixture is discharged from a ship into the top of the donut displacing water within the donut. The water and oil separate gravimetrically within the donut. The floating oil is confined within the donut and any water added flows out of the donut and mixes with the harbor water. A donut can be towed from ship to ship until full, and then it is pumped out to an oil disposal or reclamation facility.

(b) A donut is an unsatisfactory means of collection and transportation for AFFF discharges. The specific gravity of sea water (1.02 - 1.03 at 4°C) and the specific gravity of AFFF (FC-206, 1.020 at 4°C) are nearly identical. Furthermore, they are fully miscible. Therefore, AFFF and sea water will not separate gravimetrically and a donut will have no separation or confining effect.

(4) Liquid wastes are often removed from naval installations by contractors utilizing tank trucks. Wastes can be collected in shoreside tanks which are emptied by a contractor or discharged directly into waiting trucks.

(a) Disposal of AFFF waste discharges by contractor is an acceptable alternative that is practiced in some locations (i.e., Long Beach Naval Shipyard, appendix D). However, disposal by contractor involves additional coordination between ship, shore facility, and contractor, and therefore it involves additional expense and possibly delays.

(b) Collection of AFFF in tanks could be an acceptable alternative until other more efficient alternatives become available.

b. Alternative (D), perform tests with discharge contained as part of a closed system, relies on a designated shipboard holding tank for containing AFFF wastes. Alternative (D) differs from alternative (C) in that specific ancillary shipboard equipment would have to be provided for alternative (D).

(1) Allocating additional space and equipment aboard ship for handling only wastes from AFFF testing is not attractive. A closed test system would only be used during infrequent in-port testing (estimated as once every three years). It would have to be fabricated of materials compatible with AFFF and cleaned and serviced after use. The added benefit derived from dilution with other shipboard waste streams (in CHT system collection alternative (C)) prior to disposal would also be lost. Strict shipboard size and weight limitations would make location of an AFFF collection system difficult. Therefore, the operational and physical disadvantages of providing a separate, closed AFFF test system makes alternative (D) much less attractive than utilizing existing waste handling systems, alternative (C).

(2) Alternative (D), perform tests with AFFF discharge contained as part of a closed system, is rejected.

8. Alternative (E), eliminate shipboard flow test by redesigning maintenance plan, has as an objective the elimination of shipboard flow testing with AFFF and thus the generation of the waste aboard ship.

a. This option recognizes that the fire-fighting systems are comprised of electro/mechanical/hydraulic components connected electrically and/or hydraulically aboard ship. System evaluation could identify the key components requiring AFFF flow test for operational confidence. With some design change, the critical components could be given quick connect/disconnect capability to allow the scene of confidence checks of the components to shift from the ship to shore side where the AFFF discharge could be more easily disposed of without contamination of harbor waters. An overall shipboard fire-fighting system pressure/flow confidence check could be performed using sea water. A program of design, procurement, training and installation is involved. The implementation of this alternative accrues a dividend by increasing the effectiveness of maintenance capabilities.

b. Although alternative (E) eliminates shipboard testing, implementation of a maintenance plan would require time. Shipboard testing would have to continue in the interim period. Alternative (E) is rejected.

9. Alternative (F), eliminate shipboard flow test by enhancing system component performance reliability, has as an objective the elimination of shipboard flow testing with AFFF.

a. A systems analysis could be performed with the objective of changing equipment design to maximize the operational reliability and thereby, by performance, assure confidence in the system without regular flow tests using AFFF. Consideration of the classic paths to increased reliability such as: redundancy, added sensing circuits or parallel circuits, derated performance requirements, built-in test equipment, etc. are warranted.

b. Alternative (F), like alternative (E), also eliminates shipboard testing. However, also like alternative (E), alternative (F) would require time to implement. Thus, alternative (F) is rejected.

10. Table 5-1 summarizes the advantages and disadvantages of the six alternative actions considered. The alternatives are rated satisfactory or unsatisfactory based upon evaluation criteria under the environmental and operational objectives. Each alternative was evaluated based upon the same criteria in table 5-1. Implementation of any of the alternatives would reduce the navigable waters impact of the proposed action; however, alternatives (A), (D), (E), and (F) all have operational disadvantages and were therefore rejected. Alternatives (B) and (C) have been rated most satisfactory based upon the operational objective and are therefore most desirable. However, neither alternative (B) nor (C) can be implemented immediately. Therefore, due to the firm safety requirement for continuing AFFF system testing, the following approach is preferred.

11. Preferred Approach. Considering the proposed action and the alternative actions with a high regard for safety as well as the environment, the preferred approach to testing AFFF fire-fighting systems is continuation of current practice: in port, discharge minimum quantities of AFFF into the waters of those harbors where collection and treatment or alternate disposal of test effluent is not now practiced, and at sea, conduct as many of the necessary tests as possible while a ship is underway in unrestricted waters.

Table 5-1
Comparative Summary of the Affects of the Alternative Actions

Evaluation Criteria	Alternatives					
	(A)	(B)	(C)	(D)	(E)	(F)
Environmental Objective: Reduce Environmental Impact						
1. Navigable waters impact reduction.	S	S	S	S	S	S
2. Lead time to begin implementation of alternative.	U	U	U	U	U	U
Operational Objective: Reliable, Efficient, Simple Operation						
Maximize;						
1. Crew confidence by direct check of equipment on-line.	S	S	S	S	U	U
2. Crew experience through actual equipment use.	S	S	S	S	U	U
Minimize;						
1. AFFF system complexity.	U	S	S	U	S	U
2. AFFF equipment redesign or modification.	S	S	S	S	U	U
3. Ancillary equipment not otherwise available.	U	S	S	U	S	U
4. Logistical support.	U	S	S	U	U	U
5. Maintenance (manpower) requirement.	U	S	U	S	U	S
6. Additional training requirement.	U	U	S	U	S	S
7. Imposition of test scheduling restraints.	S	S	U	S	S	S
S - satisfactory TOTAL S	5	9	8	6	5	4
U - unsatisfactory TOTAL U	6	2	3	5	6	7

a. AFFF system test procedures can be used that both minimize the quantity of effluent generated and eliminate the foaming of the discharge on the harbor surface. Some Navy port facilities, on their own initiative, have implemented procedures for collecting AFFF discharges in portable tanks, pierside sanitary sewers, waste collection barges, or tank trucks (Norfolk Naval Shipyard, Charleston Naval Shipyard, Mayport Naval Station, San Diego Naval Station, and Long Beach Naval Shipyard). Appendix D includes disposal procedures used by Long Beach Naval Shipyard (an example of tank truck disposal) and Norfolk Naval Shipyard (an example of disposal in a sanitary sewer). Until adequate collection and disposal procedures are tested and implemented at other port facilities, direct overboard disposal of AFFF test effluents will be necessary. Adoption of test procedures using the in-line test device recommended by the FFAT, and further development of more environmentally acceptable AFFF formulations would continue to reduce the impact of overboard discharges (see section 9).

b. Table 5-2 shows the capabilities for treating AFFF discharged to the sanitary sewer system at the ten major naval port facilities listed in table 2-1. Estimates of the daily sewage flows from the naval installations and the operating capacities of the listed sewage treatment plants have been

Table 5-2

Treatment Capabilities for AFFF at Major Naval Port Facilities

Naval Port Facility						
Location	Approximate Daily Flow in Millions gal (m^3)	Plant Name	Type	Operating Daily Flow in Millions gal (m^3)	Tank Truck Pumpout Rate for 200 µℓ/ℓ Port Facility Discharge gpm (ℓ/m)	Sewage Treatment Plant Influent AFFF Concentration with 200 µℓ/ℓ Port Facility Discharge µℓ/ℓ
San Diego, CA: Naval Station, North Island, Point Loma	 1.0 (0.004) 1.5 (0.006) 0.2 (0.001)	City of San Diego Metropolitan Sewage Treatment Plant, Point Loma	Primary	100 (0.378)	 0.14 (0.53) 0.21 (0.79) 0.03 (0.10)	2.0
Norfolk, VA	4.0 (0.015)	Hampton Roads Sanitary District, Army Base Plant	Primary (E.1979)	16 (0.060)	0.56 (2.1)	50
Charleston, SC	1.4 (0.005)	North Charleston Sewer District Plant	Primary (E.1980)*	11 (0.042)	0.19 (0.74)	25
Pearl Harbor, HI	5.5 (0.021)	Fort Kamehameha Tri-services Treatment Plant	Secondary	5.5 (0.021)	0.76 (2.89)	200
Philadelphia, PA	1.0 (0.004)	City of Philadelphia South East Water Pollution Control Plant	Primary (E.1980)	136 (0.515)	0.14 (0.53)	1.4
Mayport, FL	0.6 (0.002)	Mayport Naval Station Treatment Plant	Secondary	0.6 (0.002)	0.08 (0.32)	200
Little Creek, VA	1.0 (0.004)	Hampton Roads Sanitary District, Elizabeth River Plant	Secondary	16 (0.060)	0.14 (0.53)	12
Long Beach, CA	1.0 (0.004)	Port of Long Beach, City of Los Angeles, Terminal Island Treatment Plant	Secondary	11 (0.042)	0.14 (0.53)	18
Bremerton, WA	0.6 (0.002)	Charleston Treatment Plant	Primary (E.1980)*	6 (0.023)	0.08 (0.32)	20
Alameda, CA	1.1 (0.004)	East Bay Municipal Utilities District Treatment Plant	Primary (E.1977)	80 (0.303)	0.15 (0.58)	2.8

*Estimated completion date of secondary treatment plant.

obtained from the Navy Environmental Support Office (Code 25), Port Hueneme, California, and NAVFAC Engineering Field Divisions. A maximum target AFFF concentration of 200 μℓ/ℓ in the port facility has been selected to minimize foaming in the municipal sewer system. Based upon findings of a USAF study (appendix E), operational problems due to foaming occurred in a bench scale-activated sludge sewage treatment plant at concentrations above 200 μℓ/ℓ. The USAF study concludes that FC-206 can be successfully treated at concentrations of 200 μℓ/ℓ on a continuous basis. Tests reported by the 3M Company (appendix E) showed no microbial inhibition at concentrations less than 1000 mg/ℓ. Therefore, it appears that the degree of foaming and not the treatability of AFFF effluents will determine acceptable discharge concentrations.

c. Dilution of an AFFF test effluent within the port facility will occur in two stages: first, initial dilution in the CHT tank; second, dilution in the port facility sewer system. Figure 5-7 illustrates the initial dilution required in a CHT tank such that, when combined with the dilution in the sewer system, the AFFF concentration leaving the facility does not exceed 200 μℓ/ℓ. Figure 5-7 assumes collection of 90 gal (0.34 m^3) of 6% AFFF solution (5.4 gal [20.4 ℓ] AFFF) per CHT tank discharge. Pumping rates of 100 gpm (6.3 ℓ/s) and 150 gpm (9.5 ℓ/s) are most common; exceptions are 400 gpm (25 ℓ/s) pumps aboard two NIMITZ class ships, 800 gpm (50 ℓ/s) pumps aboard five TARAWA class ships, and 20 gpm (1.3 ℓ/s) pumps aboard one ALBANY class ship.[21] Ships with a combination CHT tank capacity and pumping rate that plots below their facility location line in figure 5-7 would have to find alternative disposal or dilution procedures (i.e., separate holding tank, SWOB barge, etc.).

d. Thus, completion of shipboard CHT tank installation, pier sewer construction, and SWOB delivery could eliminate AFFF system test effluent discharges to harbor waters by calendar year 1981.

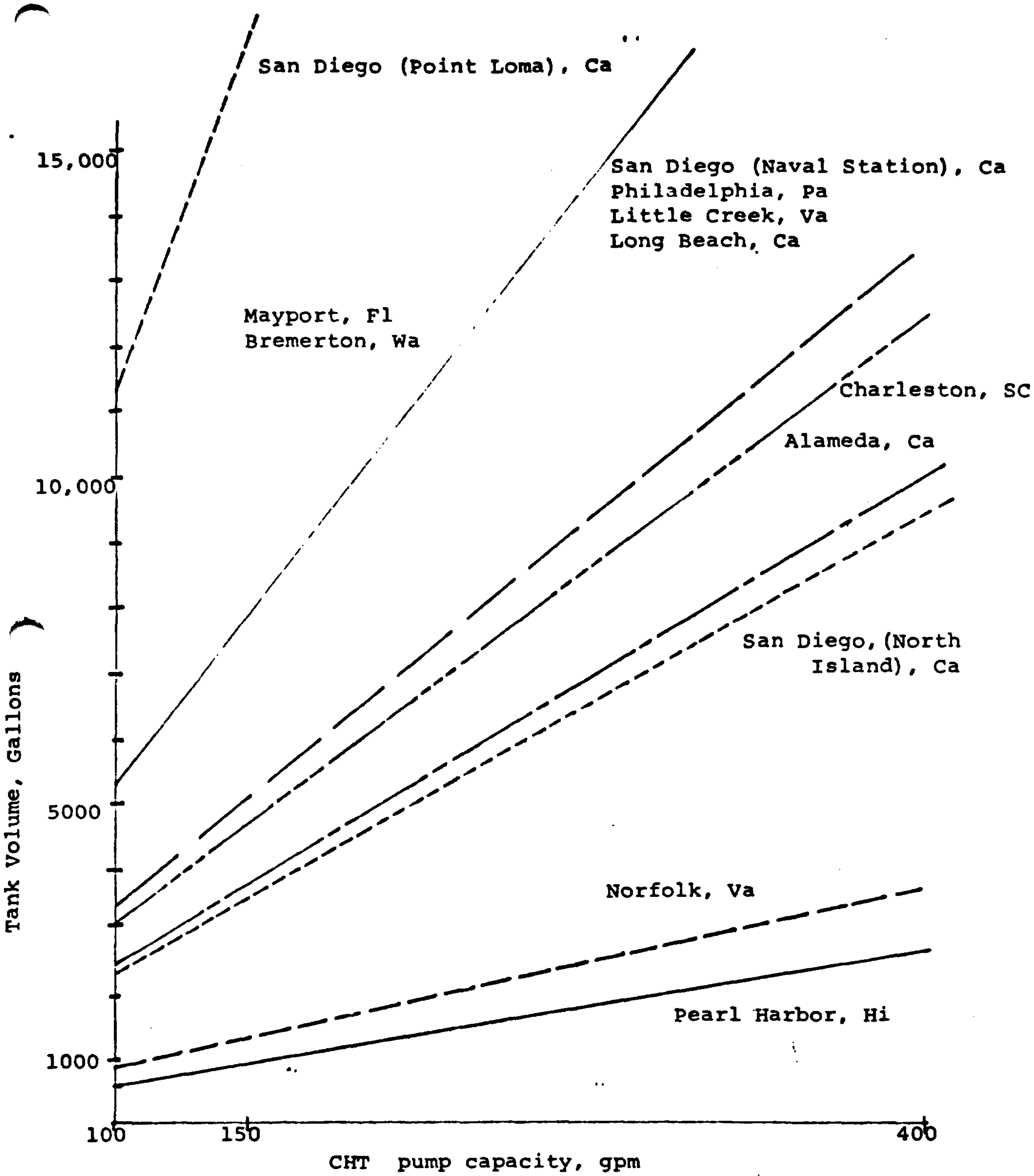


Figure 5-7. CHT Tank Dilution Volumes Required to Maintain AFFF Concentrations at or Below 200 ul/l in the Port Facility Discharge.

SECTION 6

PROBABLE ADVERSE ENVIRONMENTAL EFFECTS WHICH CANNOT BE AVOIDED SHOULD THE PROPOSAL BE IMPLEMENTED

1. Although the quantities of 6% AFFF mixtures that will be discharged are very small compared to other wastes discharged in and around harbor areas, a single assessment of the environmental effects of an action which occurs in many varied locations and under differing circumstances is difficult. Regularly scheduled testing of AFFF fire-fighting systems will occur aboard less than 500 Navy ships scattered in not less than 33 ports.

2. The chronic effects of AFFF chemicals on marine life are as yet unknown. Potential toxicities of residual chemical forms and the possible bioaccumulation of AFFF chemicals in plants or animals has not yet been determined. However, existing evidence on the high degree of biodegradability of AFFF and the treatability of AFFF mixtures by conventional biological treatment plants, provides supportive evidence that AFFF can be assimilated into the environment with little if any harmful effect (appendix E).

SECTION 7

THE RELATIONSHIP BETWEEN LOCAL SHORT-TERM USE OF MAN'S ENVIRONMENT AND THE MAINTENANCE AND ENHANCEMENT OF LONG-TERM PRODUCTIVITY

1. The current discharge of AFFF test effluents into harbor waters for disposal should have no immediate or short-term effect upon the use of a harbor area for industrial purposes. It is unlikely that the industrialized uses of port facilities will change in the near future because commerical aquatic or recreational uses of the environment are not currently compatible with an industrialized area. Therefore, long-term productivity of the harbor area as currently defined will not be affected.

SECTION 8

ANY IRREVERSIBLE AND IRRETRIEVABLE COMMITMENTS OF RESOURCES THAT WOULD BE INVOLVED IN THE PROPOSED ACTION SHOULD IT BE IMPLEMENTED

1. The tests and bioassays reported in appendix E are all of a comparatively short-term duration. The long-range impact resulting from the continued use and discharge of AFFF mixtures is not known. It has been recognized that persistent contamination at low levels of toxicity may be more harmful to marine life than sporadic occurrences of higher concentrations.[22] Discharges of AFFF test mixtures into harbors are only avoidable in those ports in which facilities for collection and transfer of liquid waste from ship to shore are operational. Preceding implementation of preferred alternative solutions identified in section 5, water quality in the immediate vicinity of an AFFF discharging vessel will be adversely affected for a short time. There are no corroborating data from long-term tests at low levels of AFFF concentration. The level of any irreversible or irretrievable commitment of natural resources by implementation of the proposed action, if it were to continue unchanged, is not known.

SECTION 9

CONSIDERATIONS THAT OFFSET THE ADVERSE ENVIRONMENTAL EFFECTS

1. The CNM/NAVSEA FFAT has found that many shipboard installed fire-fighting systems and foam proportioners were unreliable for a variety of reasons (i.e., proportioners worn, valving faulty and/or misaligned, electrical circuitry incomplete or otherwise inoperative and piping integrity severely degraded). One of the principal reasons for the conditions found has been attributed to the lack of adequate testing of proportioners and associated systems due to environmental considerations. Because of such considerations, current in-port test procedures require that foam discharges must be collected on board in a tank or discharged to a suitable containment vessel. At-sea test procedures specify that a ship must be underway at 10 knots and be outside the 12-mile limit prior to conducting tests that discharge foam solutions overboard. As a result, when the foregoing requirements cannot be met, many foam proportioners and associated systems are not properly tested prior to a ship getting underway. In event of a shipboard fire such lack of testing presents an undue hazard to the ship as well as to personnel aboard. Together with routine PMS testing requirements, tests are particularly needed after completion of alterations, repairs, or installation of AFFF systems during ship overhauls or after construction. A firm requirement exists to conduct tests in port prior to sea trials.

AFFF discharge from some systems cannot be easily contained due to necessary design configurations and the amount of foam produced. The problem of containment is further complicated in some instances because suitable collection vessels are not readily available, and ship's bilges, tanks and/or barges usually contain small amounts of oil making them unsatisfactory for receiving AFFF mixtures. Disposal of mixtures of oil and AFFF solutions is extremely difficult from a practical standpoint in that AFFF renders the oil unsuitable for disposal by conventional means. It is therefore imperative, in the interest of personnel safety and material protection, that fully operable and reliable fire-fighting systems be maintained aboard ship. This requires regularly scheduled operational PMS testing and operational testing after equipment is newly installed, repaired, altered or converted. Until practical means of collection and alternate means of disposal are developed, it will be necessary to discharge AFFF mixtures overboard.

2. The following actions are currently being undertaken and will directly or indirectly either reduce the volumes of AFFF discharged or lessen the environmental impact of those discharges.

a. In view of the chronological improvement in the toxicological character of AFFF formulations as supported by evidence contained in appendix E, it is reasonable to assume that variants could ultimately become available that would be environmentally even more acceptable than currently available AFFF's. A study has begun to develop new formulations of AFFF material to improve environmental characteristics (Contract No. N00173-76-R-B-039). The development of experimental AFFF formulations that would exhibit a reduced impact on the environment while retaining fire-fighting effectiveness will be explored. The study will examine the effect of AFFF formulation components on the BOD, COD, biodegradability, toxicity toward sewage bacteria, fish toxicity, effect of component concentration on selected environmental/biological parameters, formulation design experiments, and analytical methods evaluation. New AFFF formulas will be selected and screened for fire-fighting performance and physiochemical properties. Alternate analytical methods for determining solution concentration shall be conducted to determine if a simpler method for use in the field is feasible.

b. The Navy has embarked on a program to eliminate the discharge of shipboard sanitary wastes into navigable waters in accordance with PL 92-500, its implementing standards and regulations. To accomplish this program, pier sewers are being constructed to collect ship CHT system discharge for shoreside treatment. Pier sewer construction began in FY73 and is scheduled for completion in FY81. Pier sewers will provide an environmentally acceptable means for disposal of shipboard generated AFFF testing mixtures to sewage treatment plants. The construction schedule for major port wastewater collection facilities ashore as of 15 October 1976 is contained in appendix G.

c. The discharge into a harbor of AFFF solutions through an aeration nozzle has, in the past, produced unsightly expanses of foam floating on the harbor surface. Through the adoption of an in-line foam testing device developed by the FFAT, the aeration nozzle is no longer required for testing and the foaming problem is being eliminated. The device consists of a standard nozzle gauge adapter now required for foam testing, a small drain valve for sample collection, and a selection of interchangeable orifice plates for obtaining desired flow rate. The open end of the hose run from the device may be inserted directly into a tank top or held beneath the surface of a receiving body of water. It prevents the normal 5 to 1 expansion of foam that causes a collecting tank to fill and overflow rapidly or that causes the unsightly foam layer floating on a harbor surface.

SECTION 10

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APPENDIX A

EXCERPT FROM

NAVSEA MESSAGE 191523Z FEB 1975

AFFF TESTING

FM COMNAVSEASYSCOM WASHINGTON DC

TO (SHIPYARDS)

A. COMNAVSHIPSYSCOM WASHINGTON DC 230053Z FEB 74 (NOTAL)

B. COMNAVSHIPSYSCOM WASHINGTON DC 010005Z NOV 74 (NOTAL)

1. The requirements of ref A are superseded by this message. Naval industrial activities must test each shipboard AFFF fire fighting system that has been newly installed, modified or repaired by the activity prior to ship departure. The tests shall be conducted using only approved AFFF concentrate solutions and results certified to the ship's commanding officer. If the test solutions must be collected, they shall be clearly identified and disposed of in accordance with local regulations. End of summary.

2. All AFFF fire fighting equipment that is newly installed, repaired, altered or converted from protein foam by an industrial activity shall be tested to insure proper operation and required output. It is recommended that ship's force verify proper lineup and operational integrity of all other fire fighting systems not included in the foregoing. The following shall be observed when testing AFFF hoses:

a. The minimum acceptable concentration of AFFF in the output mixture of the system is 3.5 percent.

b. Allow foam to be generated for one minute before taking a sample. After the sample has been taken the system should be secured ASAP to avoid excessive use of AFFF concentrate.

c. If the only work done on a system was on the foam generator, (proportioner or pump), then only one hose shall be tested with AFFF to verify the foam generator performance. It is recommended, however, that all other hose lines be tested by use of salt water to verify system line up.

d. All systems shall be tested with the installed nozzle at maximum trigger depression or maximum handle throw. 1 and 1/2 inch variable flow nozzles shall be set at 95 gallons per minute, (gpm), in machinery spaces, and 125 gpm in hangar bays or flight decks. Set 2 and 1/2 inch var. flow nozzles at 250 gpm.

e. Output concentration shall be determined by refractometer analysis, using American Optical Inst. Co. Refractometer No. 10402 or 10430 or equal, NSN 1H 6650-00-107-8509, estimated unit price is $83.00. Samples for refractometer analysis shall be taken at the discharge of the nozzle and analyzed IAW MRC 13 C33R or 24 D82U within two hours after collection. Results of refractometer analysis shall be certified in writing from the industrial activity to the ship commanding officer prior to ship departure.

3. After extensive investigation and tests, it has been determined that AFFF fire fighting systems must be tested with AFFF concentrate to confirm specified system operation and concentration output. No substitute testing liquid is acceptable. The AFFF concentrate shall conform to MIL-F-24385 as identified

in ref B. Approved AFFF concentrate is available in the supply system under NSN 9C-4210-00-087-4742 for 5 gal. containers and NSN 90-4210-00-087-4750 for 50 gal. drums. Direct proprietary purchase of AFFF from any other source rather than the Navy Supply System shall not be made without prior approval of NAVSEA. Some previous 3-M products not on the qualified products list (QPL) that may be found aboard ship are still acceptable for Navy shipboard use. These formulations are the 3-M Co. formulations FC 195 and FC 199. These formulations are compatible with currently stocked QPL concentrates. 3-M formulation FC 196 should not be used due to its high free chlorine ion content which promotes pitting and corrosion of stainless steel.

4. For testing of the machinery space AFFF fire fighting systems the following requirements are applicable for active ships and new construction:

a. The requirements of paras 2 and 3 apply.

b. The systems shall be tested and certified in port prior to ship trial runs.

c. When testing in port AFFF/water foam shall not be discharged into harbor water since such discharge may be harmful to marine life. The AFFF/water foam can be either collected and contained in drums, tanks, tank trucks, sludge barges, closed bottom donuts, YO's or other suitable containers, or the foam can be discharged into the machinery space bilge.

If the AFFF/water foam is tested by discharging into the bilge, then bilge discharging shall be deferred until the ship is outside the 50-mile limit.

d. The AFFF/water foam should not be commingled with reclaimable waste oil products.

e. In port disposal of collected foam shall be governed by local regulations. Guidance information for in port disposal is available from the Environmental Branch of the cognizant NAVFAC Engineering Field Divisions.

5. For testing of AFFF fire fighting systems other than machinery space AFFF fire fighting system, the following requirements are applicable for active and new construction ships:

a. The requirements of paras 2 and 3 apply.

b. The required tests may be conducted while ship is at dockside, when the ship is outside the 3 mile limit and underway at a speed of at least ten knots or when the ship is outside the 12 mile limit, whichever is the most practical.

c. If the tests are conducted at dockside, the requirements of paragraph 4.c to 4.f apply.

d. If conducted while ship is outside the 3 mile limit and underway at ten knots or when ship is outside the 12 mile limit the AFFF/water foam may be discharged overboard as they are discharged from the system.

e. Aircraft carrier flight deck washdown systems (flush deck and deck edge nozzles) shall be tested outside the 12 mile limit. It is recommended that prior to AFFF/water foam testing the flight deck washdown system be thoroughly flushed with salt water to remove any oil and dirt that may have drained through the nozzles into the system.

6. NAVSEA is to be notified in the event that local authority prohibitions or other circumstances preclude testing and certification of shipboard AFFF systems as required by this msg. The point of contact at NAVSEA is Mr. P. Hans, SEA 0495D, Autovon 222-8504.

7. This msg does not authorize the expenditure of customer funds nor does it authorize change orders without prior NAVSEA or TYCOM approval.

APPENDIX B

COMPARISONS OF THE VARIOUS PARAMETERS OF AFFF'S

Comparison of Various Parameters of AFFF's*

Parameter	3M - Light Water			National Foam Systems	
	FC199	FC200	FC206	AOW 3	AOW 6
pH	4.6	7.6	7.8	7.8	7.9
Specific Gravity	1.02	0.989	1.020	1.062	1.031
Water		59%	70%	72%	72%
Diethylene Glycol Monobutyl Ether		39%	27%	10%	10%
COD $(X10^3)$	550 mg/ℓ	730 mg/ℓ	500 mg/ℓ	500 mg/ℓ	350 mg/ℓ
TOC $(X10^3)$		235 mg/ℓ	96 mg/ℓ	130 mg/ℓ	100 mg/ℓ
BOD_u $(X10^3)$	18 mg/ℓ	450 mg/ℓ	411 mg/ℓ	354 mg/ℓ	300 mg/ℓ
BOD_5 (% BOD_u)	37	2	65	45	45

*USAF EHL(K) Rept. 74-26, November 1974. (FOUO)

APPENDIX C

FP-180 WATER MOTOR PROPORTIONER

Naval Ships Technical Manual, Chapter 9930, Fire Fighting - Ship, Articles 9930.120 to 9930.123, September 1967 edition. (FOUO)

9930.120 FP-180 WATER MOTOR PROPORTIONER

1. The FP-180 water motor proportioner has 2½-inch connections at both the inlet and outlet sides and two ½-inch foam pickup tubes. It is a positive displacement foam liquid pump driven by a positive displacement water motor. Flow through the water motor causes the foam pump to inject a metered amount of foam into the fire stream, depending on the position of the foam valve. (See figure 9930-39.) (61)

2. The foam valve has 3 positions, 1 for each of the 2 ½ pickup tubes and an "off" position. A plexi-glass sight tube enables the operator to determine when to shift from 1 pickup tube to the other as a foam can becomes empty, thus ensuring a continuous supply of foam. In the "off" position, with flow through the fire line, water is delivered through the foam pump under pressure, and both water-motor and pump "float" on the line making the fire line available for conventional fire fighting.

3. The FP-180 may be permanently installed for some applications. In this case flexible couplings must be attached to the water motor inlet and outlet and a fixed pipe leading from an installed foam tank will be attached to one pickup tube inlet and the other inlet will be plugged. The foam valve is placed in one position only.

4. The water motor proportioner is designed to proportion 6 percent foam liquid into the fire lines at inlet pressures of 75 to 175 psi and with flows of 60 to 180 g.p.m.

5. Foam can be dispensed by any of the four following combinations:

a. One 1½-inch line equipped with foam nozzle and proportioner supplied by either a 1½- or 2½-inch hose line.

b. Two 1½-inch lines wyed off from the 2½-inch outlet. Both lines equipped with foam nozzles.

c. Three 1½-inch lines with foam nozzles.

d. One 2½-inch line equipped with foam nozzle.

9930.121 OPERATION OF THE PORTABLE FP-180 PROPORTIONER

1. Connect inlet to 2½-inch hose line and connect discharge lines, within capacity of proportioner and as needed. (On ships having 1½-inch fireplugs single 1½-inch inlet and outlet lines can be used.)

2. Set foam valve to "off" position. Foam valve should always be in "off" position except when actually drafting foam.

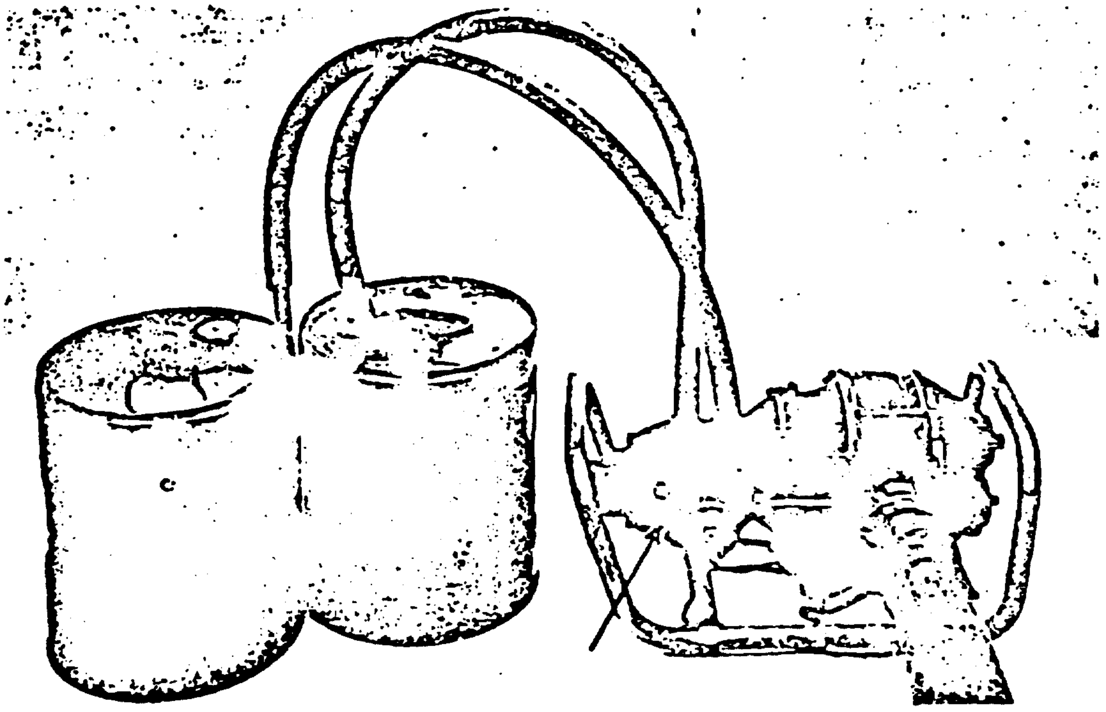


Figure 9930-39. Incoming, or upstream side, arrow points to handle in a foam position.

3. Insert each pickup tube in full foam can.

4. Actuate hose line. To start proportioning foam, shift to "foam" position. The valve is so designed that, in intermediate positions, a jet of water flows through the pickup tube, purging air and ensuring an immediate prime of the foam pump. No noticeable dwell at intermediate positions is necessary to complete the action. If foam liquid color does not show in the plexiglass tube within a few seconds, shift to the other foam position and check for a blocked pickup tube or an air leak in the line.

(1,2)

5. When a foam can is almost empty, shift to other "foam" position and replace empty can.

6. After proportioning foam, always flush the foam pump by running the proportioner two or three minutes in the "off" position, then work the valves two or three times when the unit is running. Return valve handle to "off" position when finished.

9930.122 OPERATION OF PERMANENTLY INSTALLED FP-180 FOAM PROPORTIONER

1. Installed FP-180 foam stations are arranged the same on all ships but may differ in type of controls used to actuate the system. Controls may consist of local manual control valves or remote hydraulic control valves.

2. The station will be composed of an FP-180, 50-gallon foam tank and associated piping and valves. The foam tank is arranged for quick filling from 5-gallon cans. Fitted with a vent, drain connection gage glass and access plates for cleaning.

3. The stations are installed to supply foam for machinery spaces and helicopter landing platforms. Proportioners for landing platforms are arranged for local manual control at the station. Those for machinery spaces may be arranged emote control from the foam hose outlets in the ma- ery and/or local manual control at the station. Figure 9930-40 shows the latest machinery space foam installation. The system is activated by turning the control cock to "drain", relieving pressure on value 1 which opens admitting seawater. Valve 2 is then opened by firemain pressure admitting foam liquid to the proportioner. This type system fails open, that is. any breech of control lines actuates the foam proportioner. The foam outlet valves still have to be opened to supply the hose lines.

4. On older installations, valve 1 is similar to valve 2 and is opened by turning the control cock to a position which admits firemain pressure to the valve bonnet, opening the valve. This type system fails closed when the control lines are breeched.

5. On still older installations the foam outlets are located outside the space on damage control deck with the foam station. In this case, one must leave the space to obtain the hose line and activate the station

9930.123 CARE AND MAINTENANCE OF THE FP-180 WATER-MOTOR PROPORTIONER

1. Foam liquid dries into a hard-surfaced sticky film that may prevent operation of the proportioner. It is therefore important that the pump and water motor be carefully flushed after each use. The unit should be thoroughly drained after flushing. Stand the unit on the water motor discharge and turn the extended shaft clockwise with a wrench applied to the milled flats on the end of the shaft.

2. After draining, a few ounces of light lubricating oil should be squirted into the motor through the suction and discharge openings. Oil should also be squirted into the foam valve and foam pump. To get oil into the foam pump, place the foam valve in a "foam" position and pour oil into the corresponding pickup tube opening. Turn the extended shaft several revolutions by hand to distribute the oil within the proportioner.

3. The proportioner should periodically be checked for free turning. Always replace the cover over the extended motor shaft to prevent oil leakage or entrance of foreign matter.

4. If the unit fails to turn freely and there are no foreign objects in the water motor visible through inlet or outlet connections, look for dried foam liquid or foreign matter in the foam pump. Have the foam valve in one of the "foam" positions. Pour water through the corresponding inlet connection and turn the rotors first one way then the other. Hot water dissolves caked foam liquid deposits faster than cold water. Never use gasoline or any solvent to wash out dried foam liquid. It may be necessary to remove the foam valve and accessory piping from the pump and pour water directly into the pump ports. At any time that this is done, it is well to clean all foam-carrying accessories before they are replaced on the unit.

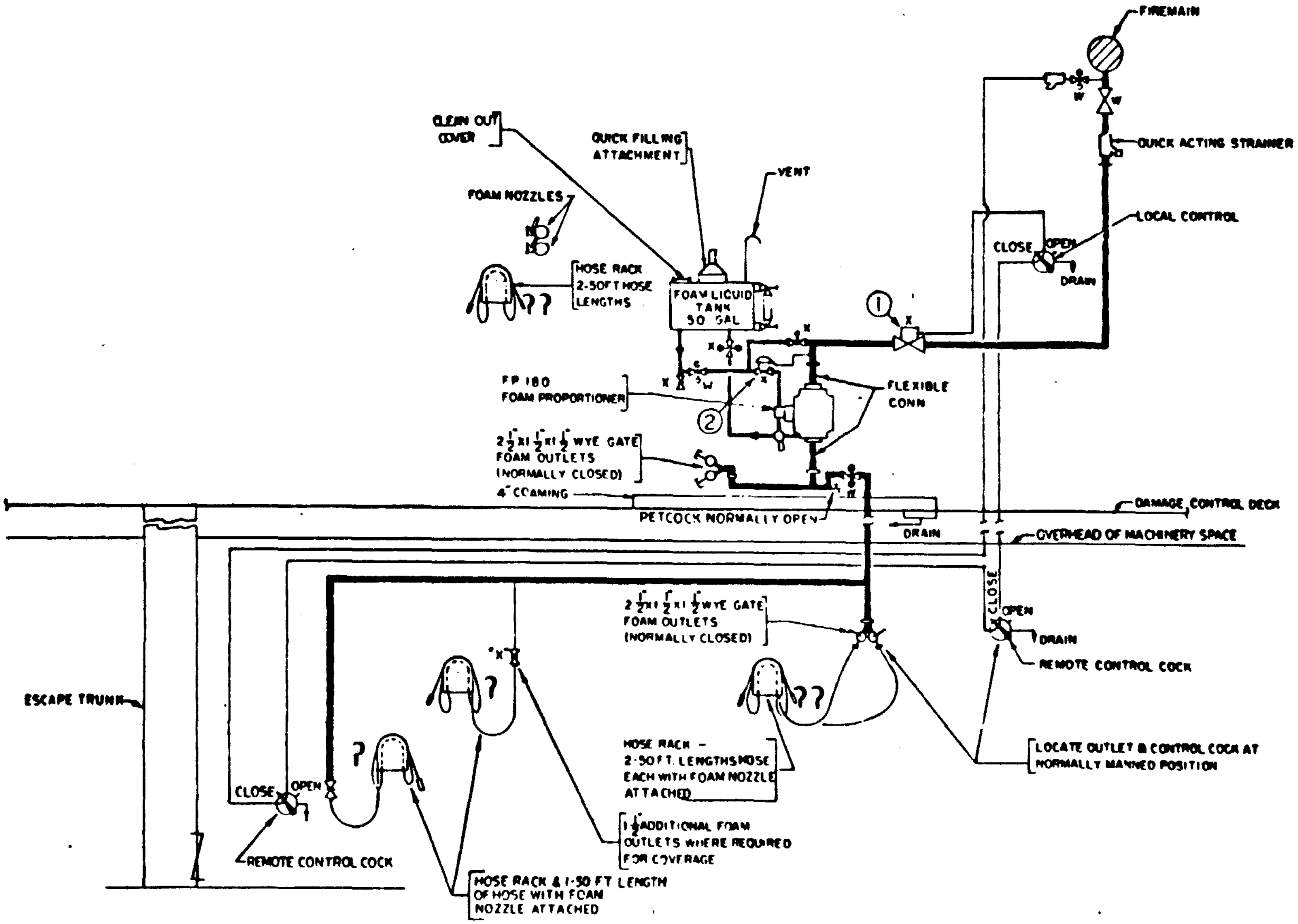


Figure 9930-40. Diagrammatic arrangement of foam hose system.

APPENDIX D

AFFF SYSTEM TEST AND WASTE DISPOSAL PROCEDURES

1. AFFF/PKP Fire-Fighting System Test Procedures for Long Beach Naval Shipyard (18 pages)
2. Hazardous Waste Disposal Procedure No. 10 from Norfolk Naval Shipyard (1 page)
3. "Disposal of Aqueous Film Forming Foam (AFFF) Wastes," Pollution Solution, Naval Environmental Protection Support Service, PS-003A, 18 September 1975 (4 pages)

WRP:nn(303)
2 April 1976

MEMORANDUM

From: W. R. Prince, Operational Safety Advisor, LBNS

To: Craig Alig, Code 2863, Naval Ship R. and D. Center

Subj: Disposal of AFFF

1. Craig, below is the information you requested:

a. Based on nine regular overhauls per year, we dispose of approximately 1100 gallons of AFFF per year.

b. It is off loaded into a 2500 gallon sludge tank, transported to a holding area, picked up by an outside contractor, and dumped in a Class I Sanitation dump.

2. Hope this information will be of some benifit to you.

Bill Prince
Bill Prince

STATUS OF SHEETS	REV			
	SHEET	1	2	3
REV.				
SHEET				

SHIP	PLAN REV.	BY DESIGN CODE	P & E NO.	SHIPALT	P & E LEAD CODE	APPROVED	DATE

PLAN ISSUED FOR

LONG BEACH NAVAL SHIPYARD

LONG BEACH, CALIFORNIA 90801

AFFF/PKP FIRE FIGHTING SYSTEM
TEST PROCEDURES

AFFF/PKP TEST PROCEDURES

EXAMINED	
OFFICIAL	NAME
CHIEF ENGR.	
ASST. CH. ENGR.	
BRANCH HD.	
SECTION HD.	
REVIEWED	
DRAWN	

APPD. DATE

DATE

SIZE	CODE IDENT. NO.	NAVSEA DRAWING NO.	REV.
A	89219 D-2		
SCALE		SHEET OF	

AFFF SYSTEM
TEST PROCEDURE

1.0 PURPOSE:

To verify and determine strength and tightness of newly installed twin agent fire extinguishing system and to demonstrate satisfactory operation of system.

2.0 REFERENCES:

2.1 OPNAV INST 6240.3C of 20 Apr 1973

2.2 NAVSEA Notice 9930 of 13 Sep 1973

2.3 NAVSEA MESG R 2300537 Feb 74

2.4 NAVSEA Technical Manual 0993-023-6010 Fire Extinguishing System Twin Agent (AFFF and PKP)

2.5 Type-507-450663 - C1 FP180 - Foam Liquid Proportioner Modifications

2.6 Type-507-4506918 - Operating Diagram Machinery Spaces Fire Fighting System

SIZE	CODE IDENT. NO.	NAVSEA DRAWING NO.	REV.
A	89219		
SCALE		SHEET	

3.0 PREREQUISITES

PIPING

3.1 All existing piping not removed by conversion shall be inspected for presence of protein foam deposits, if found, clean as follows:

3.2 (a) One flushing with hot water for period of 15 minutes.

(b) One flushing with solution of hot water and 10% AFFF.

PROPORTIONER

3.3 The existing FP180 proportioner/s (total to be tested ( )) shall be tested for proper operation.

3.4 Proper operation of the proportioner is determined by color-comparison analysis of the protein-salt water mixture with known admixtures of 2, 4, 6, and 8 percent or by measurement of the mixture using a refractometer. Five percent protein in the mixture is the minimum allowed and indicates proper proportioner operation. For operation of the refractometer, see Maintenance Requirement Cards (MRC) 92 B58V Q for the procedure of AFFF systems in machinery space of MRC 13 C33R A for AFFF/HCFF Stations.

3.5 Proportioners failing to pass the refractometer test shall be replaced with new FP180 proportioners.

3.6 Proportioners which pass refractometer test shall be flushed in accordance with paragraph 3.2.(a) and 3.2.(b).

4.0 TEST EQUIPMENT

4.1 Supply of small containers

4.2 1-1/2" firehose (sufficient length)

5.0 SERVICES REQUIRED

5.1 Salt water services

SIZE	CODE IDENT. NO.	NAVSEA DRAWING NO.			REV.
A	89219				
SCALE			SHEET		

7.0 PRECAUTIONS

7.1 In compliance with the environmental protection policies of reference (2.1), Aqueous Film Forming Foam (AFFF) may be harmful to marine life and shall not be discharged into navigable waters. Despite this restriction, it is essential that newly installed and modified AFFF fire fighting systems be tested prior to ship departure for sea trials as specified in reference (2.3).

7.2 Therefore, all AFFF fire fighting equipment newly installed, repaired, altered, or converted from protein foam, by industrial activites, shall be tested to insure design operability and output. These tests shall be conducted and the results returned to Design Code 260.15 for written certification to the commanding officer prior to trials or departure.

7.3 Test requirements shall include verification that the system output contains a minimum AFFF concentration of 3.5 percent as specified in reference (2.2). Output concentration shall be determined by refractometer in accordance with applicable MRC cards. Samples for refractometer analysis shall be taken at the discharge of a hose nozzle and analyzed within 2 hours after collection.

7.4 An exception is granted for sample testing of aircraft carrier flight deck washdown fire fighting systems while in port. Verification of output concentration of these systems may be deferred for performance beyond the 12-mile limit because of the impracticability of collecting AFFF foam discharge from slush deck nozzles. All other washdown systems tests shall be conducted prior to getting under way.

7.5 Mixtures containing AFFF, produced by these tests, must be contained in drums, tanks, sludge barges or closed bottom donuts as required for oil disposal in reference (2.1). However, AFFF should not be co-mingled with reclaimable waste oil products. The mixture shall not be discharged into harbor waters since AFFF could produce concentrations affecting marine life. Disposal, including introduction into municipal sewer systems, shall be governed by local regulations.

7.6 Report immediately to the Ship's Superintendent any defects which may delay completion of test.

7.7 List the locations of blanks, etc., used during the conduct of tightness test on Sheet No.

7.8 Observe normal safe working practices in accordance with LBNSY Instruction 5100.27C.

SIZE	CODE IDENT. NO.	NAVSEA DRAWING NO.	REV.
A	89219		
SCALE		SHEET	

8.0 SHIP/SYSTEM/PLANT CONDITIONS:

8.1 Ship - dockside

8.2 System - modifications complete and ready for testing.

9.0 TEST PROCEDURE/TEST SPECIFICATIONS:

9.1 PRELIMINARY VISUAL INSPECTION - PHASE I

9.1.1 Inspect the entire installation for satisfactory workmanship and agreement with references.

9.1.2 Ascertain instruction and label plates are properly located and correctly inscribed.

9.1.3 Determine that foam liquid tank has been tested for tightness prior to installation.

9.1.4 Check that foam proportioners have been filled to the proper level with correct grade of new oil.

9.1.5 Ascertain that 100 ft. of 1-1/2" hose and an AFFF nozzle are provided with each new hose reel on the

9.1.6 Ascertain that 50 ft. of 3/4" hose, 50 ft. of 1-1/2" hose and twin agent nozzle are provided with each new hose reel in the machinery spaces.

9.1.7 Remove cover over the extended motor shaft and check each proportioner for free turning. Replace cover.

9.1.8 Record data as required on Sheets

9.1.9 REPORT

The twin agent fire extinguishing system was visually inspected and found satisfactory on the date indicated.

C/260.15 Test Engr./Tech. ________________ Date __________

SIZE	CODE IDENT. NO.	NAVSEA DRAWING NO.	REV.
A	89219		
SCALE		SHEET	

9.2 HYDROSTATIC TEST - PHASE II

9.2.1 At each foam station with the foam proportioner and AFFF tank isolated, test new firemain and foam concentrate piping hydrostatically to 150 PSIG.

9.2.2 At each foam station with the dry chemical and nitrogen tanks and the dry chemical portion of the machinery space hose reels isolated, test PKP supply piping to hose reels hydrostatically to 330 PSIG for 30 minutes minimum and examine piping, valves, and fittings for tightness. After satisfactory completion of this test, drain water from piping and thoroughly dry out by blowing through with warm, dry air.

9.2.3 At each foam station with the new nitrogen piping between the 3-way hytrol valve and nitrogen-PKP tank assembly isolated, test this piping hydrostatically to 330 PSIG. After satisfactory completion of this test, drain water from piping and thoroughly dry out by blowing through with warm, dry air.

9.2.4 REPORT

The AFFF piping system was given a hydrostatic test and was found satisfactory on the date indicated.

C/260.15 Test Engr/Tech ____________________ Date ______________

Shop Personnel _____________________________ Date ______________

Ship's Representative ______________________ Date ______________

9.3 PRE-OPERATIONAL TEST - PHASE III (PKP SYSTEM ONLY)

9.3.1 Make sure all nozzles are closed.

9.3.2 Close black ball valve.

9.3.3 Remove the safety clip from the nitrogen cylinder valve and pull the quick opening "pull" handle.

9.3.4 Observe the opening of the powertrol and hytrol valves and the flow of AFFF solution from the normally open petcock.

9.3.5 Close the nitrogen cylinder valve, and install the safety clip and lead and wire seal.

9.3.6 Open the blue ball valve.

SIZE	CODE IDENT. NO.	NAVSEA DRAWING NO.	REV.
A	89219		
SCALE		SHEET	

9.3.7 Open the dry chemical nozzle and hold open until evidence of flow ceases.

9.3.8 Close blue ball valve and replace pin and lead and wire seal.

9.3.9 Open green ball valve. Powertrol and hytrol valves should close immediately and flow from the petcock should gradually decrease to zero.

9.3.10 Wait 5 minutes. Close green ball valve.

NOTE: If powertrol and hytrol valves close before green ball valve is opened probable cause is faulty check valve.

9.3.11 Open black ball valve.

9.3.12 Check nitrogen cylinder pressure. If over 1500 PSI, system is ready for use. If under 1500 PSI,replace with spare cylinder.

9.3.13 Repeat steps 9.3.1 through 9.3.12 for remaining PKP units.

9.3.14 Return to each PKP unit in the previous order and open and close green ball valves to check for pressure build-up.

NOTE: When shutting down the system after test or use leave the green ball valve open for 5 minutes to insure that N_2 pressure is relieved.

9.3.15 REPORT

The PKP units were pre-operated and where found satisfactory on the date indicated.

C/260.15 Test Engr/Tech ____________________ Date __________

Ship's Representative ______________________ Date __________

9.4 OPERATIONAL TEST - PHASE IV

9.4.1 Fill the AFFF supply tank with fresh water.

9.4.2 From each foam station operate the AFFF system using the local control valve as per operating chart of reference (2.6), discharging overboard through hose station on DC deck and using additional 1-1/2" fire hose as required.

	SIZE	CODE IDENT. NO.	NAVSEA DRAWING NO.			REV.
	A	89219				
	SCALE			SHEET		

9.4.3 Observe that the water level in the AFFF tank falls at a normal rate. (Approximately 5 GPM when discharging through a 1-1/2" nozzle).

9.4.4 Demonstrate foam recirculation using the FP180 test procedure on operating chart of reference (2.6).

9.4.5 Perform the following operational test on the dry chemical extinguisher set:

(1) Remove safety clip from nitrogen cylinder valve and pull lever.

(2) Check that sea water and AFFF concentrate valves are in open position.

(3) Close cylinder valve and replace safety clip.

(4) Seal cylinder valve with lead and wire seals.

(5) Open and close dry chemical nozzles quickly and observe discharge of "Purple-K" dry chemical.

(6) Open and close AFFF nozzles in the machinery space hose reels quickly and observe discharge.

(7) Close black dry chemical valve.

(8) Open blue hose clean out valve.

(9) Open dry chemical nozzle to clear all dry chemical from hose line and relieve all pressure from tank.

(10) Close blue hose clean out valve.

(11) Replace ring pin and seal with lead and wire seal.

(12) Open black dry chemical valve.

(13) Open green vent valve and check that sea water and AFFF concentrate valves close.

(14) Close green vent valve.

(15) Remove fill cap and replace "Purple-K" which was used, approximately 15 pounds.

(16) Replace fill cap, hand tighten.

(17) Replace nitrogen cylinder if pressure is less than 1500 PSI at 70°F.

(18) Replace any missing lead and wires.

9.4.6 During the operation of AFFF system, take one (1) sample of the foam solution and submit to the lab, Code 134.1, for refractometer analysis.

NOTE: After completion of the refractometer analysis, the lab should submit results to Code 260.15.

9.5 REFRACTOMETER ANALYSIS - PHASE V (Lab only)

9.5.1 A refractometer analysis shall be accomplished by the Industrial Lab to determine the AFFF concentration of the AFFF solution.

NOTE: This procedure has been incorporated into the Maintenance Requirement Cards (MRC) for the AFFF system for machinery spaces (performed every six months) and the AFFF high capacity fog foam (AFFF/HCFF) stations (performed annually) to ensure an adequate as well as an efficient amount of concentrate (3.5 to 6 percent) is available.

During test operation of a foam-proportioning system, the pollution-control requirement must be adhered to; that is, foam generating tests of foam equipment must be conducted when the foam generated is retained in a tank or barge.

9.5.2 To perform the refractomer analysis, the following equipment is required:

12-inch ruler
Data sheet and graph paper
Eye dropper
Light water (AFFF concentrate)
Clean bucket
100-ml beaker
50-ml beaker
Sample bottles
Lens tissue, 100 sheets
100-cc volumetric flasks (3), marked 2%, 4%, and 6% and glass flask stoppers
Funnel
1.3330-1.3700 angstrom optical refractometer, American Optical Instrument Company No. 10420 or 0-30 scale AOIC No. 10430 or equal, No. 10430 is available from SPCC under FSN No. 1H6650-600-6154
10-ml measuring pipette

-3-

9.5.3 PREPARATION OF CALIBRATION CURVE

9.5.3.1 Since the concentration of sea water varies depending on the area or region where the ship is operating, a new calibration curve must be developed for each refractometer analysis. Obtain about 50-ml of AFFF concentrate from the storage tank; this can be drawn from the gauge glass drain. To ensure that no sediment is drawn out, drain and refill the gauge glass before taking the test sample. Next obtain from the firemain about a gallon of sea water. First, clean and dry three 100-cc volumetric flasks and designate 2, 4, and 6 percent respectively. Then fill these flasks approximately 3/4 full with the sea water; into the flask marked 2 percent, pipette 2-cc of the collected AFFF concentrate; into the flask marked 4 percent, pipette 4-cc of AFFF concentrate; into the flask marked 6 percent, pipette 6-cc of concentrate. Next fill the volumetric flasks up to the 100-cc line with water, insert the glass stopper, and invert each flask several times to mix thoroughly. The next step is determining the refractive index of the sea water sample and the 2-, 4-, and 6-percent samples. With the aid of an eye dropper, place a few drops of the sea water sample on the glass surface of the refractometer. Make sure all air bubbles are expelled when the top prism plate is moved into its closed position against the bottom glass surface. Best readings are obtained when the refractometer is held level, pointed toward an overhead light source and a slight finger pressure is applied on the upper prism. Read the number from the left-hand scale where the horizontal line appears between the dark and light fields and record the value of the data sheet (See Table I). This value is the refractive index of the sea water sample and will be the concentration "0 percent" value. Special care should be observed in cleaning the glass surface of the prism. The fluid should be removed by lightly blotting and wiping with lens tissue. A dry lens tissue should then be dipped in clean fresh water and the glass surface should be lightly wiped with the wet tissue and then dried with a dry lens tissue. Using the same method as for "0 percent" concentration, obtain refractive index values for the 2, 4, and 6 percent standard solutions and record the readings on the data sheet. Special care should be taken to clean the refractometer's glass surface and rinse out the eye dropper with fresh water after each reading. A calibration curve can now be plotted using the refractive index as the vertical values and horizontal values increasing from 0 to 10 percent (See Table 2).

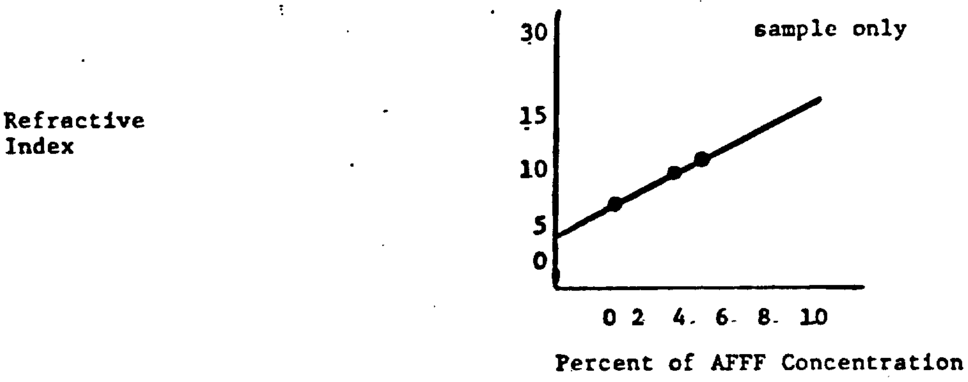
9.5.3.2 Plot the values from Table 1 for the "0 percent" water sample and the 2, 4, and 6 percent standard solutions on the graph paper and draw a straight line through the four points; this will be the calibration curve for the particular station where the concentration sample was taken. If a straight line is not obtained, discard the samples and start again with fresh samples. This completes the preparation for analysis of the test samples.

SIZE	CODE IDENT. NO.	NAVSEA DRAWING NO.	REV.
A	89219		
SCALE		SHEET	

Table 1

Concentration		
% Concentrate	% Water	Refractive index from scale readings
1.0	100 (Water sample)	1.
2.2	98 (Standard solution)	2.
3.4	96 (Standard solution)	3.
4.6	94 (Standard solution)	4.
5.-	--- (System test sample)	5.

Table 2



SIZE	CODE IDENT. NO.	NAVSHIPS DRAWING NO.	REV.
A	89219		
SCALE		SHEET	

9.5.4 FOAM SOLUTION TEST

9.5.4.1 Samples of foam solution may be collected wherever it can be certain that the sample is a true representation of the system output. After allowing sufficient time to elapse after start up to ensure that the system has come to equilibrium (about one minute), a sample may be obtained by holding a container with a handle into the edge of the handline stream (or from a pan set on the deck to catch some of the foam discharge from a flight deck fire fighting system flush deck nozzle.)

9.5.4.2 Now place a few drops of foam solution from the system test sample on the refractometer and obtain its refractive index (samples should be analyzed within two hours after the system test run). Using the refractive index, the concentration of the sample can be obtained from the calibration curve. Record the concentration on the data sheet. If the test samples read less than 3.5 percent, attempt the following corrections and retest the system: Inspect foam concentrate tank supply lines to AFFF/HCFF FP1000 proportioner of AFFF injection pump for obstructions and closed valves; clean the AFFF supply line strainer; inspect foam or flight deck flush deck nozzles for obstructions; increase firemain pressure, inspect FP1000 proportioner foam pump for seizure or binding; check proportioner foam pump rotor clearances; using one and two hoselines respectively, compare the proportioner RPM with that in the proportioner manual. If RPM is not up to specification, the proportioner should be repaired. If unable to obtain 3.5 to 6 percent station operating concentration, report deficiency to D.C. Central, and retain data sheets and graphs for comparison against future tests.

REPORT

	AFFF STATION	AFFF/PKP STATION	AFFF/PKP STATION	AFFF/PKP STATION	AFFF/PKP STATION
1. Workmanship					
2. Agreement with ref. dwgs.					
3. Instruction and label plates					
4. Tightness of foam liquid tank		NA	NA	NA	NA
5. Proportioner oil level		NA	NA	NA	NA
6. Were the following provided at foam outlet on D.C. deck?					
(a) 1 foam nozzle		NA	NA	NA	NA
(b) 125' of 1-1/2 hose		NA	NA	NA	NA
7. Were the following provided at each hose outlet in the machinery space?					
(a) 50' length 1-1/2" hose	NA				
(b) 50' length 3/4 hose	NA				
(c) 1 twin agent nozzle	NA				
8. Hydrostatic Test					
(a) 150 PSI held for 30 minutes for SW piping		NA	NA	NA	NA
(b) 330 PSI held for 30 minutes for nitrogen piping	NA				

SIZE	CODE IDENT. NO.	NAVSEA DRAWING NO.	REV.
A	89219		
SCALE		SHEET	

REPORT

	AFFF STATION	AFF/PKP STATION	AFFF/PKP STATION	AFFF/PKP STATION	AFFF/PKP STATION
(c) 330 PSI held for 30 minutes for PKP supply piping	NA				
9. Operational Test performed					
10. Was dry chemical nozzle opened to clear all dry chemical from hose line and relieve all pressure from tank?	NA				
11. Were green vent valve and blue valve closed at end of test on dry chemical extinguisher set?	NA				
12. Was black valve open at end of test on dry chemical extinguishing set?	NA				
13. Was "Purple-K" which was used replaced?	NA				
14. Was foam pump flushed and drained?		NA	NA	NA	NA
15. Refractometer tests results		NA	NA	NA	NA

SIZE	CODE IDENT. NO.	NAVSEA DRAWING NO.	REV.
A	89219		
SCALE		SHEET	

REPORT

	AFFF STATION	AFFF/PKP STATION	AFFF/PKP STATION	AFFF/PKP STATION	AFFF/PKP STATION
1. Workmanship					
2. Agreement with ref. dwgs.					
3. Instruction and label plates					
4. Tightness of foam liquid tank		NA	NA	NA	NA
5. Proportioner oil level		NA	NA	NA	NA
6. Were the following provided at foam outlet on D.C. deck?					
(a) 1 foam nozzle		NA	NA	NA	NA
(b) 125' of 1½ hose		NA	NA	NA	NA
7. Were the following provided at each hose outlet in the machinery space?					
(a) 50' length	NA				
(b) 50' length 3/4 hose	NA				
(c) 1 twin agent nozzle	NA				
8. Hydrostatic Test					
(a) 150 PSI held for 30 minutes for SW piping		NA	NA	NA	NA
(b) 330 PSI held for 30 minutes for nitrogen piping	NA				

SIZE	CODE IDENT. NO.	NAVSEA DRAWING NO.	REV.
A	89219		
SCALE		SHEET	

REPORT

	AFFF STATION	AFFF/PKP STATION	AFFF/PKP STATION	AFFF/PKP STATION	AFFF/PKP STATION
(c) 330 PSI held for 30 minutes for PKP supply piping	NA				
9. Operational Test performed					
10. Was dry chemical nozzle opened to clear all dry chemical from hose line and relieve all pressure from tank?	NA				
11. Were green vent valve and blue valve closed at end of test on dry chemical extinguisher set?	NA				
12. Was black valve open at end of test on dry chemical extinguishing set?	NA				
13. Was "Purple-K" which was used replaced?	NA				
14. Was foam pump flushed and drained		NA	NA	NA	NA
15. Refractometer test results		NA	NA	NA	NA

SIZE	CODE IDENT. NO.	NAVSEA DRAWING NO.	REV.
A	89219		
SCALE		SHEET	

11ND-NSYLB-9673/66 (4-73)

TEST EQUIPMENT CALIBRATION VERIFICATION TABLE

THE TABLE BELOW IS TO BE FILLED IN BY THE SHOP REPRESENTATIVE TO SUBSTANTIATE THAT THE STATUS OF TEST EQUIPMENT UTILIZED IN CONJUNCTION WITH THIS TEST MEMO IS PROPERLY CALIBRATED. IF TEST EQUIPMENT IS NOT OF REQUIRED CURRENT CALIBRATION, DISCONTINUE TEST UNTIL PROPERLY CALIBRATED EQUIPMENT IS AVAILABLE.

TYPE OF EQUIPMENT	MANUFACTURER	LBNS SER. NO.	DATE CALIB	EXPIRATION DATE	REPRESENTATIVE
13330-1.3700 angstrom optical refractometer, American Optical Instrument Company No. 10420 or 0-30 scale AOIC No. 10430 or equal, No. 10430 is available from SPCC under FSN. No. 1H6650-600-6154.					

T________________

SHEET ________ OF ________

PWINST 11350.1 CH 2
Code 403
23 April 1975

HAZARDOUS WASTE DISPOSAL PROCEDURE NO. 10

DATE ISSUED: 11 APR 1975

HAZARDOUS MATERIAL COVERED: Aqueous Film Forming Foam (AFFF) Wastes

FSN 4210-00-087-4742 FSN 4210-00-087-4750

SPECIAL HANDLING INSTRUCTIONS: Collect AFFF wastes in containers of suitable size to permit easy handling. Containers may be flushed and reused.

DISPOSAL INSTRUCTIONS: Discharge to the Yard sanitary sewerage system at a controlled rate not to exceed 10 gallons of undiluted AFFF per hour.

Prepared by: Lt. C. V. Cecil, CEC, USN, Code 403

Concurrence: Code 730 William J. Marr

POLLUTION
SOLUTION

PS-003A
(Rev. 18 Sep 1975)

NAVAL
ENVIRONMENTAL
PROTECTION
SUPPORT
SERVICE

NEPSS

NAVY ENVIRONMENTAL SUPPORT OFFICE
Naval Construction Battalion Center, Port Hueneme, California 93043

DISPOSAL OF AQUEOUS FILMFORMING FOAM (AFFF) WASTES

I PROBLEM

AFFF products are fluorocarbon surfactants used for fire fighting. AFFF wastes from firefighting system tests and training exercises must be disposed of in accordance with local and federal guidelines.

More Details of the Problem: Naval industrial activities must test each shipboard AFFF firefighting system that has been installed, modified, or repaired to ensure that the minimum concentration of AFFF in the output mixture is 3.5% (the optimum is 6%). The foam is generated for one minute at flow rates of 95 to 250 gpm before the sample is taken to measure AFFF concentration.

In-port and under certain circumstances at sea, the effluent containing AFFF must be collected and clearly identified for other than direct disposal to the ocean.

AFFF wastewaters containing petroleum are produced from training operations at firefighting schools. For additional guidance in handling these wastes, see Reference 2.

II SOLUTIONS

The acceptable procedures for shore disposal of AFFF wastes are summarized from References 2 and 3 as follows:

A. Discharge Wastes to Sewage Treatment Plant: AFFF wastes free from oil can be discharged to free flowing sanitary sewers at controlled rates. Safe discharge concentrations to a secondary sewage treatment plant (STP) depend upon the specific AFFF used and the average flow rate of the plant. If the AFFF is identified, the safe discharge concentration listed in the table below can be used to determine the discharge rate. It is advisable to discharge at the recommended concentration or at a concentration which will allow acclimation until it is certain that the plant is adapted to this type of waste. Conditions in some localities might allow discharge up to or exceeding the maximum.

If the AFFF concentrate in the waste cannot be identified but is known to be on the AFFF specifications[3] qualified products list, the lowest discharge limit should be assumed (10 μl/l recommended to 100 μl/l maximum).

TABLE 1
COMPARISON OF CONCENTRATIONS OF AFFF IN SYNTHETIC SEWAGE AMENABLE TO BIOLOGICAL TREATMENT
(Data from Table 8, Reference 4)

Manufacturer's AFFF Concentrate Label	Recommended[a] for Treatment μl/l (ppm)	Maximum to[b] Sewage Treatment Plant μl/l (ppm)
	(gal per million gal of secondary STP flow)	
FC-199	25	250
FC-200	10	10
FC-206	20	200
Aer-O-Water 3	150	1700
Aer-O-Water 6	150	1700
K74-100	25	250

[a] Based on reactions to microorganisms, aquatic life, and safety factors

[b] Based on activated sludge pilot plant studies using a synthetic sewage consisting of glucose (160 mg/ℓ), peptone (160 mg/ℓ), urea (28.6 mg/ℓ), sodium bicarbonate (102 mg/ℓ), potassium phosphate (32.5 mg/ℓ), and tap water

B. Discharge Wastes to Receiving Body of Water

Wastes can be discharged to a stream containing aquatic life within the following limits:

RECOMMENDED MAXIMUM CONCENTRATION OF AFFF FOR DIRECT DISCHARGE TO STREAM
(From Reference 4)

AFFF CONCENTRATE	MAXIMUM CONCENTRATION μl/l (ppm)
FC-199	20
FC-200	5
FC-206	54
Aer-O-Water 3	60
Aer-O-Water 6	22
K74-100	55

C. Filter Waste Through Activated Carbon: AFFF products can be adsorbed on carbon[5]. The efficiency depends upon the particular AFFF concentrate, e.g., 100 percent removal of FC-200 and 70-75 percent removal of Aer-O-Water 6 within 5 minutes of contact time. The effluent may be suitable for discharge to a stream or it can be discharged into a sanitary sewer at an appropriate rate. Pending development of techniques for recovering the adsorbed chemicals, the used carbon can be disposed of in incinerators, mixed with coal for coal-burning furnaces, or disposed of in landfill sites which accept household wastes.

D. The attached flow diagram, Figure 1, can be used to determine the options and restrictions of disposal methods, including disposal at sea.

III RECOMMENDATIONS

The preferred method for disposal of AFFF wastes is discharging to a biological sewage treatment plant under controlled conditions.

IV BENEFITS

Disposal by controlled rate of discharge to a biological treatment plant is a simple and safe procedure which can be accomplished at most naval activities. This method reduces the possibility of environmental damage and eliminates costs of storage and special handling.

V CONTACT

Additional details regarding these disposal methods may be obtained from NAVFAC, Code 0451E, or by contacting NESO, Code 2522, Autovon 360-5071.

VI REFERENCES

1. Naval Message 191523Z Feb 75 COMNAVSEASYSCOM, Washington, D.C.

2. NAVFACENGCOM letter 1042/WEG of 13 May 1975, to: NCBC Port Hueneme, Subj: Aqueous Filmforming Foam; revised disposal guidance.

3. Military Specifications, MIL-F-24385 (NAVY), 21 Nov 1969.

4. E. E. Lefebvre and R. C. Inman, "Biodegradability and Toxicity of Ansul K74-100, Aqueous Film Forming Foam," U.S.A.F. Environmental Health Laboratory, EHL (k) 75-3, Jan 1975.

5. R. K. Kroop and J. E. Martin, Treatability of Aqueous Film-Forming Foams Used for Fire Fighting, Air Force Weapons Laboratory, Kirkland Air Force Base, AFWL-TR, 73-279, February, 1974.

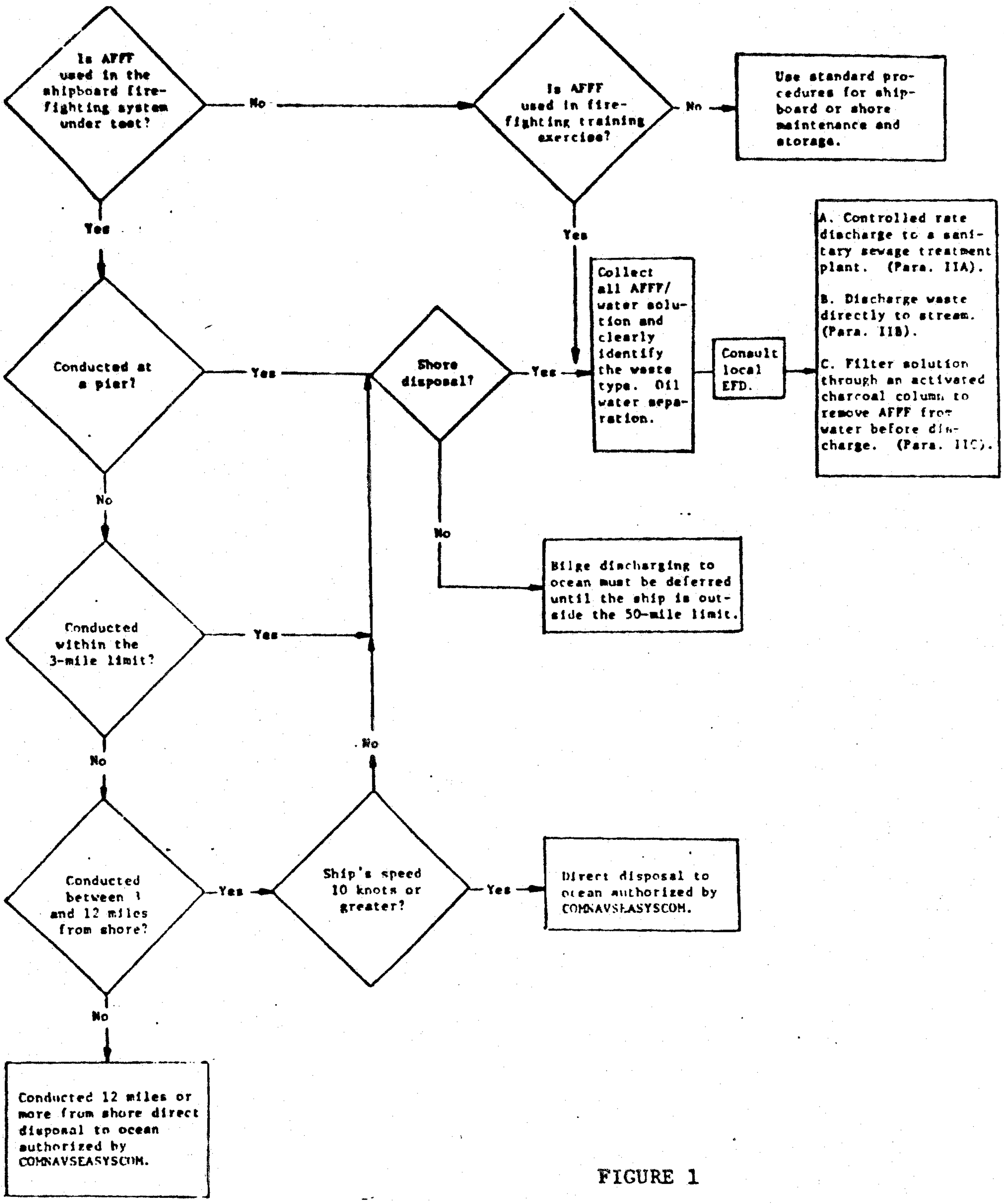


FIGURE 1

Flow Diagram for Disposal of Waste From AFFF Firefighting Tests

APPENDIX E

BIODEGRADABILITY AND TOXICITY OF FC-206

1. 3M Company letter to Mr. C. Alig, Subject: FC-206, dtd 25 June 1976 (3 pages)
2. NAVSEC letter to NAVSEA, 6159C/SD, 9360/ 593.344, ETA 4088025, Ser 270, dtd 3 July 1974, enclosure (1), Bioassay Data (excerpt) (5 pages)
3. USAF Environmental Health Laboratory Report EHL(K) 74-26, November 1974 (21 pages)

3M

GENERAL OFFICES • 3M CENTER • SAINT PAUL, MINNESOTA 55101 • TEL. (612) 733-1110

ENVIRONMENTAL ENGINEERING AND POLLUTION CONTROL
3M COMPANY
P.O. BOX 33331 • 900 BUSH AVENUE • SAINT PAUL, MINNESOTA 55133
TEL. (612) 733-6033

June 25, 1976

Subject: FC-206

Mr. Craig Alig
Naval Ship R & D
Code 2863
Annapolis, MD 21402

Dear Mr. Alig:

This is in response to your request regarding the environmental effects of "LIGHT WATER" Brand Aqueous Film Forming Foam Concentrate FC-206.

The 3M Company is conducting an ongoing program to evaluate and assess the environmental impact of its new and existing products. In accordance with this program, FC-206 has been subjected to a testing schedule designed to evaluate the product's overall environmental impact. Where possible, this product has been tested utilizing those existing methods and procedures which are outlined in "Standard Methods for the Examination of Water and Wastewater," 13th Edition, 1971.

Due to the basic nature and function of FC-206, the wastewater discharge from its use in either an actual or simulated situation, is most likely to find its way to an aquatic ecosystem, usually being first conveyed to a wastewater treatment system. For this reason, the information presented in this letter will be directed toward the aquatic toxicity and biological treatability characteristics of FC-206.

The freshwater aquatic toxicity studies which have been conducted on FC-206 have utilized a warm water and cold water fish (Pimephales promelas and Salmo gairdneri). The results of the studies on the concentrate as sold are as follows:

Species Fish	96-Hr. LC_{50}
Fathead minnow (Pimephales promelas)	3000 mg/l Continuous Flow Test
Rainbow trout (Salmo gairdneri)	1800 mg/l Static Test

MINNESOTA MINING AND MANUFACTURING COMPANY

Invertebrate aquatic toxicity studies have been conducted on FC-206. The species tested and their toxicity responses are as follows:

Species	48-Hr. LC_{50}
Water flea (Daphnia Magna)	5850 mg/l
Scud (Gammarus fasciatus)	5170 mg/l

Marine aquatic toxicity studies have been conducted on FC-206. The species tested and their toxicity responses are as follows:

Species	96-Hr. LC_{50}
Mummichog (Fundulus heteroclitus)	1820 mg/l Static Test
Grass shrimp (Palaemonetes vulgaris)	280 mg/l Static Test
Fiddler crab (Uca pugilator)	3260 mg/l Static Test
	48-Hr. LC_{50}
Atlantic oyster larvae (Crassostrea virginica)	>100 <240 mg/l

The ability of an FC-206 wastewater discharge to be stabilized in a biological wastewater treatment system has been evaluated in accordance with parameters such as the biochemical and chemical oxygen uptake rate which are normally used in treatability studies. The biochemical and chemical oxygen demand test results are as follows:

BOD_5	210,000 mg/l
BOD_{ult}	420,000 mg/l
COD	420,000 mg/l

The oxygen uptake tests by the dissolved oxygen probe method have shown that no microbial inhibition will occur at FC-206 concentrations less than 1000 mg/l. This concentration level has also been confirmed through tests which measure activity of microorganisms by the TTC* reduction in an activated sludge biological population.

*TTC (2,3,5-Triphenyltetrazolium Chloride) Re: "Dehydrogenase Enzyme as a Parameter of Activated Sludge Activities," Ford, et al. Proceedings of the 21st Industrial Waste Conference, Purdue, May 3, 4, and 5, 1966.

In addition, a conventional activated sludge pilot plant was successfully operated using a feed source which consisted of a mixture of settled domestic sewage and FC-206. At an FC-206 concentration of 1000 mg/l, the average reductions in COD and BOD levels were 73% and 86%, respectively. When operating at an FC-206 level of 1000 mg/l, the average BOD_5 concentration in the effluent from the pilot plant was 18 mg/l.

In general, it is advisable to treat FC-206 wastewater discharges in combination with either domestic or industrial wastewater in a biological or physiochemical wastewater treatment system. A combined raw wastewater discharge providing a maximum concentration of 1000 mg/l FC-206 concentrate would permit satisfactory treatment.

All statements, technical information and recommendations contained herein are of a general nature and are based on laboratory tests we believe to be reliable, but the accuracy, completeness or applicability to particular circumstances is not guaranteed. No express warranties are created herein, and implied warranties of merchantability and fitness for a particular purpose are disclaimed.

A more complete evaluation of your specific situation should be based on the particular circumstances and factors involved, including consultation with the appropriate pollution control agencies.

We hope this information will be of value to you. If we can be of further assistance, please contact Mr. D.L. Bacon on (612) 733-5453.

Very truly yours,

R L Bohon

Robert L. Bohon, Manager
Environmental Laboratory

RLB/mab

BIOASSAY DATA EXCERPTED FROM ENCLOSURE (1), NAVSEC LETTER TO NAVSEA, 6159C/SD, 9630/593.344, ETA 4088025, SER 270, DATED 3 JULY 1974.

FC-200 AFFF and FC-206 AFFF toxicities were determined by performing bioassays on seven representative saltwater organisms at the Naval Ship Research and Development Center, Annapolis Division. The seven saltwater organisms tested were carefully selected as representatives of the water column. Bioassays were also performed on two other commercial alternative AFFF substances (Aerowater Number 3 and Aerowater Number 6), (manufactured by the National Foam Corporation) and on glycerine, a substance that was considered as a possible alternative to AFFF for use for pierside testing of foam station units.

The organisms tested are listed in table 1. Because it is a representative marine fish species and can be raised in the laboratory, 2 to 3 inch length Killifish (Fundulus majalus) were used for testing. The two bottom organisms that were used were the common Atlantic Oyster (Crassostrea virginia) and the Ribbed Bay Mussel (Modiolus modiolus). The barnacle used was the common white acorn species (Balanus eburneau). The brine shrimp (Artemia salina) tested was the San Francisco Bay strain. Although it is not found in brackish waters, its inclusion in a bioassay procedure has many advantages: (a) it is a standard bioassay organism used by many biology laboratories; (b) it is a reference organism used by EPA; (c) its life cycle, maintenance and culture conditions are very well documented; and (d) its response to a host of chemicals is known. Cyclotella nanna is a brown centric diatom, fully oceanic, but often found in brackish water. Pseudomonas nigrificans (American Type Cultural Collection No. 19375) is a marine bacteria belonging to that vast group of bacteria (Pseudomonas) which is found in almost all the salt waters of the world. Bacteria are the common denominator in water, so their inclusion in a bioassay is absolutely necessary. These organisms were selected and placed in test tanks or flasks. The desired amounts of the chemicals were added volumetrically, and at the end of 96 hours the LC_{50} (concentration of the chemical which is lethal to 50% of the test organisms) was recorded. (For brine shrimp, a 40 hour LC_{50} was determined.) Table 2 shows the actual number of organisms used for testing of each concentration of any one chemical.

The LC_{50} for these chemicals are listed in table 3. Table 3 shows that the least toxic AFFF compound is FC-206, although glycerine is less toxic than FC-206.

Table 1

BIOASSAY ORGANISMS

Name	Type	Stage	Habitat
Killi Fish (Fundulus majalus)	Fish Vertebrate	Young Adult 2-3" long	Estuarine Water Columns
Bay Mussel (Modiolus modiolus)	Mollusc Shelled	Adult 1-2" long	Brackish Bottom
Brine Shrimp (Artemia salina)	Bronchiopod Crustacean	Adult (2 weeks old)	Standard Bioassay
Barnacle (Balanus eburneus)	Cirriped Crustacean	Adult 3/4-1½" base	Brackish Littoral
Oyster (Crassostrea virginia)	Mollusc Shelled	Adult 2" - 4"	Brackish Bottom
Diatom (Cyclotella nana)	Algae Brown Green	1-2 x 10^6 cells/cc	Oceanic
Marine Bacteria (Pseudomonas Nigrificans)	Bacteria	2 x 10^7 cells/cc	Oceanic to Brackish

Table 2

NUMBER OF ORGANISMS AND CHEMICAL CONCENTRATIONS

Organism	Number of Organisms/ Test Concentration	No. of Concentrations	Total No. of Organisms
Killi Fish	6	(Control & 9) x 3	180
Bay Mussel	6	(Control & 9) x 3	180
Brine Shrimp	20	(Control & 9) x 3	600
Barnacle	10	(Control & 9) x 3	300
Oyster	6	(Control & 9) x 3	180
Algae	2 test tubes each with 10^3 to 10^6 cells/cc	(Control & 9) x 3	60 tubes
Bacteria	2 test tubes each with 10^7 cells/cc	(Control & 9) x 3	60 tubes

Table 3

96 HOUR LC_{50} (40 hour LC_{50} for brine shrimp)

FC-200 AFFF (3M Company)

Organism	96 Hr. LC_{50}
Fish	76 ppm
Brine Shrimp	80 ppm
Oyster	Greater than 60,000 ppm
Mussel	26,530 ppm
Barnacle	283 ppm
Algae	110 ppm
Bacteria	1,000 ppm

FC-206 AFFF (3M Company)

Organism	96 Hr. LC_{50}
Fish	2,679 ppm
Brine Shrimp	1,187 ppm
Oyster	Greater than 60,000 ppm
Mussel	10,000 ppm
Barnacle	10,000 ppm
Algae	1,560 ppm
Bacteria	10,000 ppm

Glycerine

Organism	96 Hr. LC_{50}
Fish	51,870 ppm
Brine Shrimp	17,275 ppm
Oyster	Greater than 60,000 ppm
Mussel	35,660 ppm
Barnacle	45,000 ppm
Algae	33,500 ppm
Bacteria	Greater than 100,000 ppm

National Foam Aerowater Number 3
(National Foam Corporation)

Organism	96 Hr. TC 50
Fish	850 ppm
Brine Shrimp	727 ppm
Oyster	Greater than 60,000 ppm
Mussel	150 ppm
Barnacle	155 ppm
Algae	574 ppm
Bacteria	20,000 ppm

National Foam Aerowater Number 6
(National Foam Corporation)

Organism	96 Hr. TC 50
Fish	900 ppm
Brine Shrimp	8,567 ppm
Oyster	35,000 ppm
Mussel	80 ppm
Barnacle	427 ppm
gae	980 ppm
Bacteria	20,000 ppm

USAF ENVIRONMENTAL HEALTH LABORATORY (AFLC)

UNITED STATES AIR FORCE

KELLY AFB, TEXAS 78241

BIODEGRADABILITY AND TOXICITY OF LIGHT WATER® FC206, AQUEOUS FILM FORMING FOAM

November 1974

EHL(K) 74-26

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N O T I C E

TABLE OF CONTENTS

TABLE OF CONTENTS

I. SUMMARY

Light Water ®, FC206, is an aqueous film forming foam (AFFF) used for fire fighting. Biodegradability studies show that it can be biologically treated in controlled concentrations up to 200 ul/l in synthetic sewage on a continuous basis. Higher concentration appear amenable to treatment in oxidation ponds over long time periods. Toxicity studies with fathead minnow juveniles and fry indicate that FC206 is less toxic than AFFF's previously tested. The 96-hour LC_{50} for fathead minnow juveniles and fry were 1080 ul/l and 170 ul/l respectively. Using a 0.05 application factor, a concentration unit of 54 ul/l is recommended for discharge to any waters containing aquatic life.

II. INTRODUCTION

This is the fourth report on the biodegradability and toxicity of a commercial aqueous film forming foam used to fight fires by the Air Force. The results of studies of Light Water® (FC206) a product of Minnesota Mining and Manufacturing Co., St Paul, Minn, are presented here. The FC206 is used to make a six percent solution for the fire fighting operations. This study was conducted at the request of Hq USAF/SGPA and Hq USAF/PREE.

III. DISCUSSION

A. Composition

Results of analysis at this laboratory are shown in Table 1. The specific gravity of the concentrate is 1.020 with a pH of 7.8.

Table 1. Composition of FC206.

PARAMETER	QUANTITY
Water	~70%
Diethylene Glycol Monobutyl Ether	~27%
Flurocarbon (Structure not Determined)	~ 2%
Sodium Sulfate	~ 1%
Chemical Oxygen Demand	500,000 mg/l
Total Organic Carbon	96,000 mg/l
Surfactants (MBAS as LAS)	41,000 mg/l
Fluorine	14,000 mg/l

B. Respiration Studies

1. Biochemical Oxygen Demand

The need for measurement of biochemical oxygen demand (BOD) over incubation periods in excess of the standard five days has been pointed out by several investigators and reported previously (5). Additionally, incubation at 25°C rather than the standard 20°C allows determination of the Ultimate BOD in a shorter time period without adverse affects on the micro-organism composition although temperatures in excess of 30°C would alter composition (2). Figure 1 is a curve showing the BOD over a 20-day period as measured with the E/BOD Respirometer as previously reported (13). Table 2 is a summary of these E/BOD measurements.

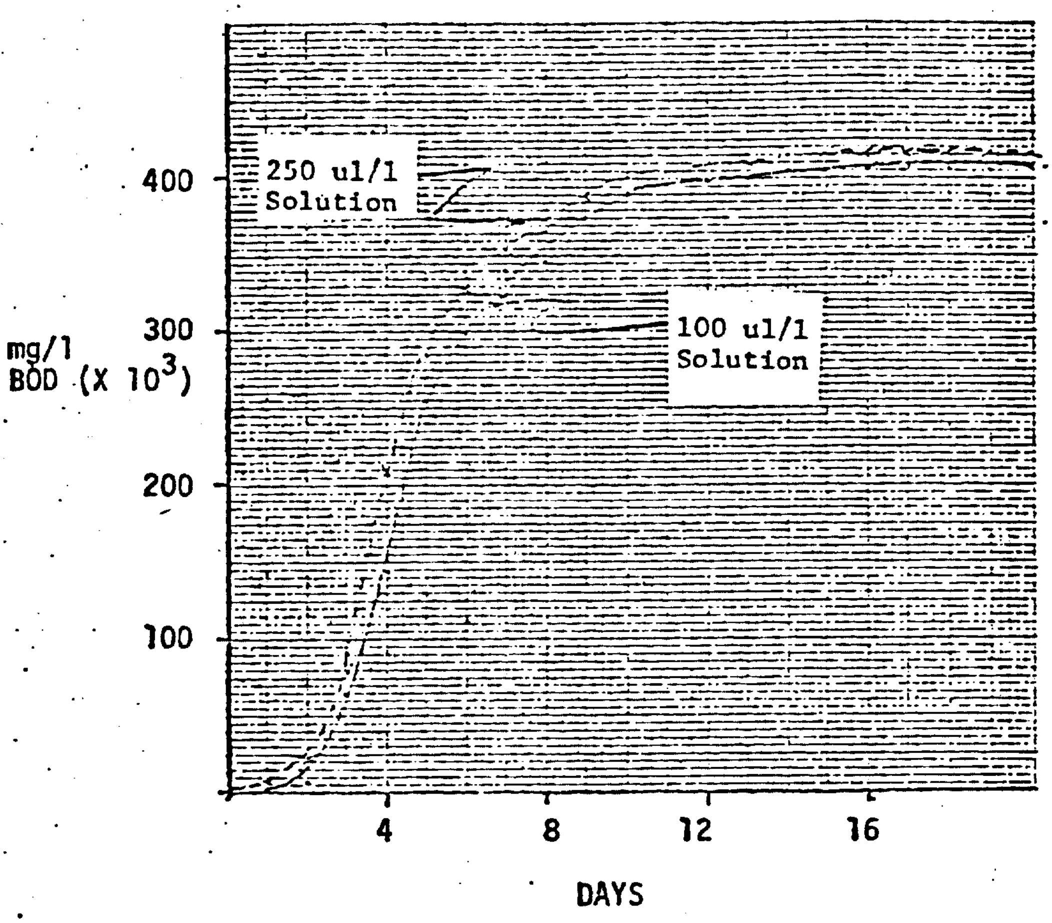

Figure 1. Biological Oxygen Demand as a Function of Time of FC 206 by USAF Environmental Health Laboratory, Kelly AFB TX, 1974.

Table 2. Summary of Data From Measurement of Extended BOD of FC206 at 25°C with the E/BOD Respirometer

	mg/l	Percent of E/BOD_{20}
E/BOD_5	2.68×10^5	65.2
E/BOD_{10}	3.95×10^5	96.1
E/BOD_{15}	4.10×10^5	99.7
E/BOD_{20}	4.11×10^5	

2. Warburg Respirometer Studies

Figure 2 shows the variation in oxygen uptake with respect to concentration of the FC206. Acclimation of the microorganisms can be seen by the increase in oxygen uptake rates at the higher concentrations with respect to time. Since the dilution of FC206 from normal usage is to a six percent solution, oxygen up take was not measured beyond the 10 percent solution.

C. Pilot Plant Studies

1. Two bench-scale activated sludge pilot plants were fed increasing concentrations of FC206 in synthetic sewage of composition shown in Table 3. The plants began to show solids loss at an FC206 concentration of 200 to 225 ul/l. Most of the solids loss appeared to be physical in nature from the foaming action forcing the solids over the side of the reactor. Tables 4 and 5 are summaries of the measured parameters for each plant. Table 6 shows the recovery of solids in the first plant when the FC206 concentration was lowered from 500 ul/l to 200 ul/l.

Table 3. Composition of Synthetic Sewage Used in Biodegradability Studies

Glucose	160	mg/l
Peptone	160	mg/l
Urea	28.6	mg/l
$NaHCO_3$	102	mg/l
KH_2PO_4	32.5	mg/l
Tap Water		

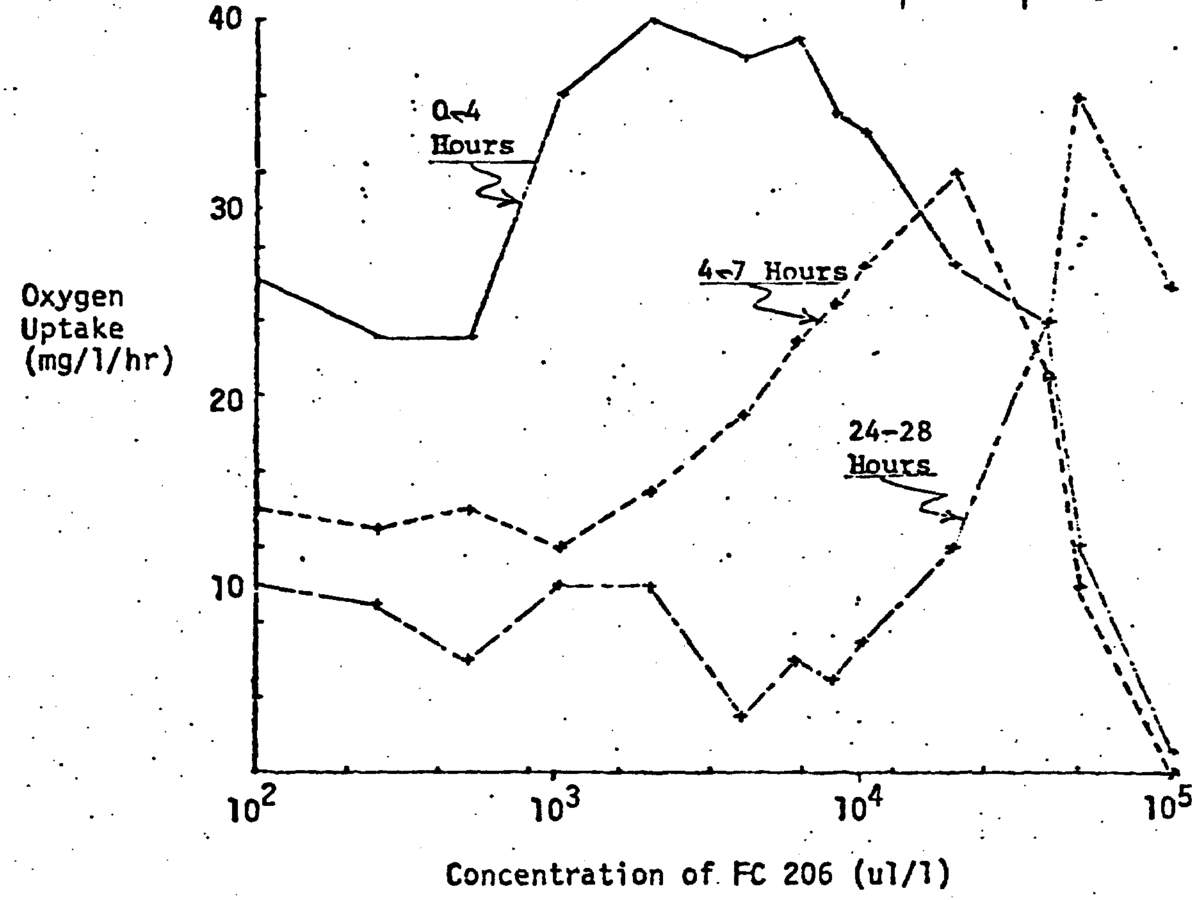

Figure 2. Oxygen Uptake of Varying Concentrations of FC 206 Using the Warburg Respirometer

2. Five Fathead minnows (Pimephales promelas) were placed in each container receiving effluent from each of the plants at the beginning of the study. One fish succumbed in the first plant effluent after 27 days and one in the second plant effluent after 43 days indicating that the effluents were relatively non-toxic. Five giant water fleas (Daphnia magna) were placed in each effluent container on the 36th day and survived to the termination of the study (51 days).

Table 4. Summary of Analysis of Samples From Activated Sludge Pilot Plant No. 1 Receiving FC206 and Synthetic Sewage.

No. of Days	ul/l FC206	mg/l Avg. MLSS	pH Range	D.O. Range mg/l	Percent BOD_5 Removal	Percent TOD Removal
5	50	3045	7.2-7.3	4.0-6.2	97.8	>95.8
3	75	3315	7.1-7.2	4.2-4.4	No Data	>95.4
5	100	3363	7.2-7.3	4.8-5.6	98.9	>95.6
3	200	3587	7.1-7.2	4.0-5.6	98.8	>99
8	300	3016	7.2-7.4	4.0-6.0	92.1	>99
5	400	2685	7.3-7.4	5.8-6.2	97.6	91.5
14	500	1763	7.4-7.8	5.0-7.4	94.8	54.5
1	300	1000	7.7	6.6	17.7	>99
3	200	1513	7.7-8.1	6.0-7.2	85.7	No Data

Table 5. Summary of Analysis of Samples from Activated Sludge Pilot Plant No. 2 Receiving FC206 and Synthetic Sewage.

No. of Days	ul/l FC206	mg/l Avg. MLSS	pH Range	D.O. Range mg/l	Percent BOD_5 Removal	Percent TOD Removal
5	50	2397	7.2-7.5	2.0-6.0	98.0	>96.1
8	75	2648	7.2-7.3	4.8-5.8	98.8	>95.4
3	125	2863	7.3-7.3	4.6-5.6	98.7	>99
8	225	3052	7.2-7.4	4.6-5.4	98.3	>99
5	250	2985	7.0-7.2	4.6-6.0	98.2	>97.9
22	300	2414	7.1-7.4	4.4-7.0	96.5	>98.2

Table 6. Daily Measurement of MLSS in Plant No. 1
From 30th to 51st Days.

Day	ul/l FC206	mg/l MLSS
30	500	2810
31	500	2650
32	500	2820
36	500	840
38	500	1020
39	500	1100
43	500	1100
44	300	1000
45	200	1280
46	200	1460
51	200	1800

D. Toxicity Studies

1. METHODS AND MATERIALS

a. Experimental Animals

Toxicity studies used the fathead minnow (Pimephales promelas) to determine the relative toxicity of FC206 solutions -- (Concentrate and pilot plant effluents). Sexually-immature fathead minnows were supplied by the National Fish Hatchery at Uvalde, Texas. The fish were acclimatized to the laboratory conditions and local water for a minimum of 30 days before use. Mean fish weight was 0.913 gm ($\sigma = 0.370$). The fish were fed a commercial fish food*. Immature fathead minnow fry used in static bioassays were reared at EHL/K. Age of fry at time of use was 21 days.

b. Exposure Procedure

(1) Continual flow type bioassays used proportional diluting equipment as developed by Mount and Brungs (7) (8). These diluters supplied logarithmic scaled dilutions of the compound being tested to a flow-through chamber for each concentration in which the experimental animals were held. Studies with fry were static bioassays with three fry per each one-liter test concentration.

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*Tetramin®, Distributor, Tetra Sales Corp. Heyward, CA 94545.

(2) Bioassays were performed in accordance with principles described in Standard Methods (12) and Sprague (9). Test animals were not fasted prior to testing. They were not fed during the actual assay period. Ten fish were used for each concentration and the control. Exposure chambers were plastic rat cages modified to contain 4 liters of diluted toxicant.

(3) Response of the test animals was recorded throughout a 96-hour test period. Probit analysis was performed on the data recorded at 24, 48, 72 and 96 hours of exposure to evaluate quantal response to graded doses. After the first bioassay, a true 96 hour replicate was performed using the same procedures and concentrations as used in the first run. In all these bioassays the test animals were placed into the exposure chambers in a random order by using a table of random numbers. The chambers themselves were positioned in random order. The control chamber contained water from the same water tank as the water that was used as the diluent in the other test chambers. The flow of diluted toxicant into the chamber was adjusted to a retention time of 2 hours. This is equal to a 6 hour, 95% replacement time and insures adequate maintenance of the dissolved oxygen concentration. The quantal response measured was death. A fish was counted as dead when all gill movement ceased. Dissolved oxygen and pH were monitored to insure that the cause of death was not lack of oxygen or changes in pH.

c. Dilution Water

Unchlorinated well water from a deep well was used as the dilution water in these studies. The water was collected in 400 gallon fiberglas trailer-tanks at an on-base well site. The water trailers were hauled to the Laboratory and allowed to sit at least 24 hours before the water was used. Air was bubbled through the water. The water was adjusted by heating or cooling to 24°C before it was run into the proportional diluter. The pH was 7.2 Hardness (EDTA as mg/l $CaCO_3$) was 194. Total alkalinity (as $CaCO_3$) was 160 mg/l.

d. Treatment use of Data

LC_{50}s* or TL_{50}s were determined by the probit analysis method of Litchfield and Wilcoxon. (6) Other statistical treatments such as the $(CHI)^2$ test for "Goodness of Fit" were by standard formulas. (3) To be used in this report and the previous reports on Fire-Fighting foam chemicals, toxicity study results had to fulfill two important criteria. 1) Graded quanted responses had to definitively relate to the logarithms of serial dilutions in each test chamber. 2) the results had to be repli-

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*LC_{50}, or Lethal Concentration 50%, is a concentration value statistically derived from the establishment of a dose-related response of experimental organisms to a toxicant. The LC_{50} represents the best estimation of the dose required to produce death in 50% of the organisms. Note that a more toxic chemical has a smaller LC_{50}. The time period for which the 50% response was derived must also be indicated.

cable. The establishment of dose-effect and time-effect relationships allowed scientifically based predictions of the ecological effects of the tested chemicals on a body of water during use, accidental spillage or disposal. Also the relative toxicity of one material could be compared with another; perhaps with the goal of selecting one that would have the least effect on aquatic biota. Finally, the results could be used to set "allowable" or minimal effect concentrations in bodies of water that may receive these materials as waste.

2. Results of Toxicity Studies

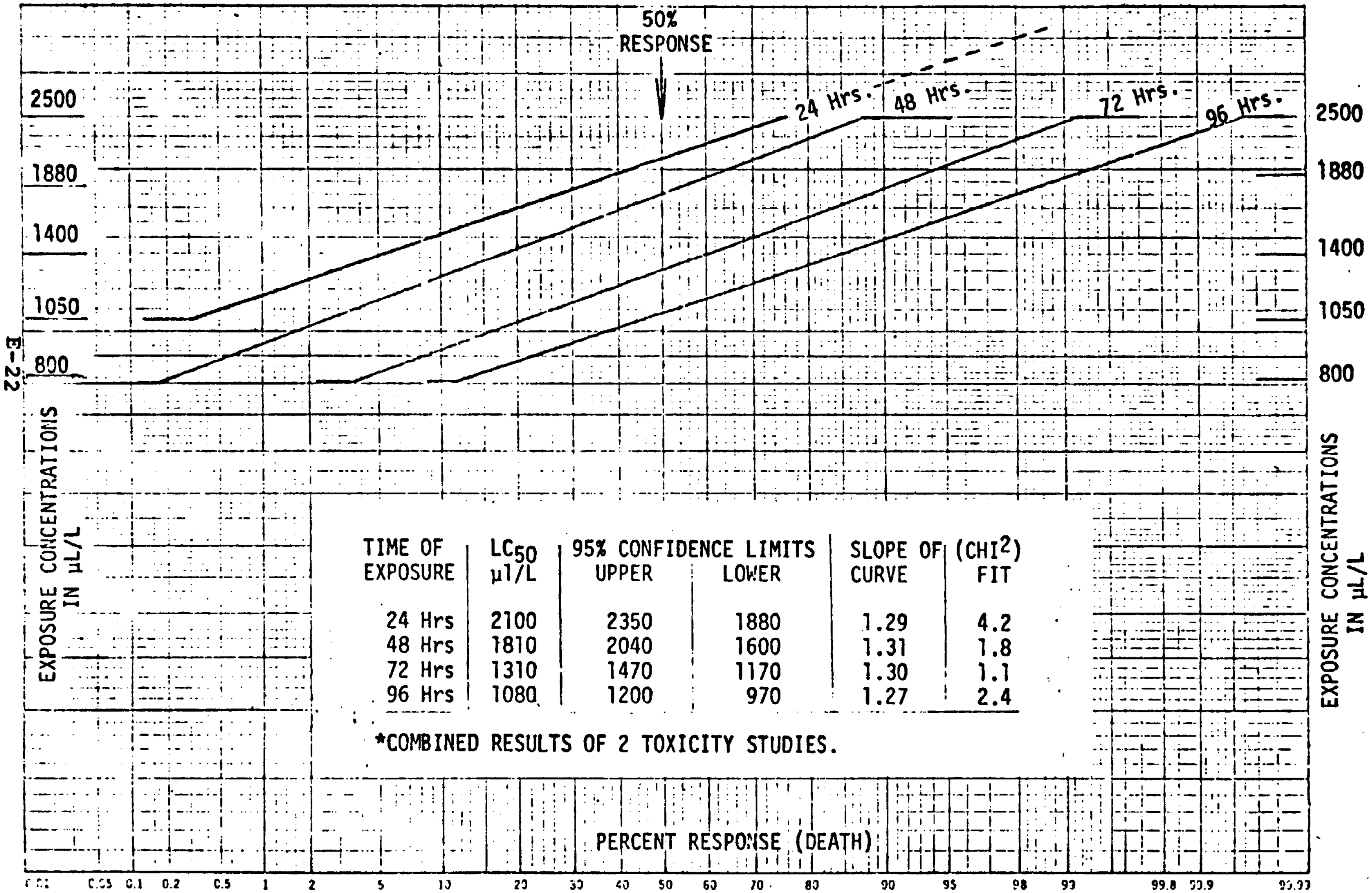
a. The sexually immature minnows were exposed to concentrations of FC206 ranging from 800 ul/l to 2500 ul/l (see Figure 3). At 48, 72 and 96 hours of exposure there was 100 percent death at the 2500 ul/l concentration and no deaths at the 800 ul/l concentration. At 24 hours of exposure there were no deaths in the 1050 ul/l concentration and 75 percent deaths in the 2500 ul/l concentration..

b. Figure 4 illustrates the change in LC_{50} with increasing time of exposure. As the percent of deaths increase with time of exposure (lower LC_{50}s), there is a reduction in the slope of the curve between 72 and 96 hours. The reduction in the slope indicates that the 96 hour value may be approaching the incipient LC_{50} (lethal threshold concentration). Therefore, for FC206, the 96 hour LC_{50} is considered to be an adaquate estimation of the incipient LC_{50} and can be used to set acceptable concentration limits of FC206 for short periods of time.

c. The 96 hour LC_{50} for 3 week old fry was 170 ul/l. The LC_{50} value for fry compared with the 1080 ul/l value for the juvenile fish indicates that the FC206 concentrate is approximately 6 times more toxic to the fry than more mature forms. Thus the increased sensitivity of immature forms indicates that the limits of safety using a 1/10 application factor for short term exposure would provide just adequate protection and that a 1/20 value would be more desirable.

Figure 3

QUANTAL RESPONSE CURVES* OF FISH EXPOSED TO FC 206

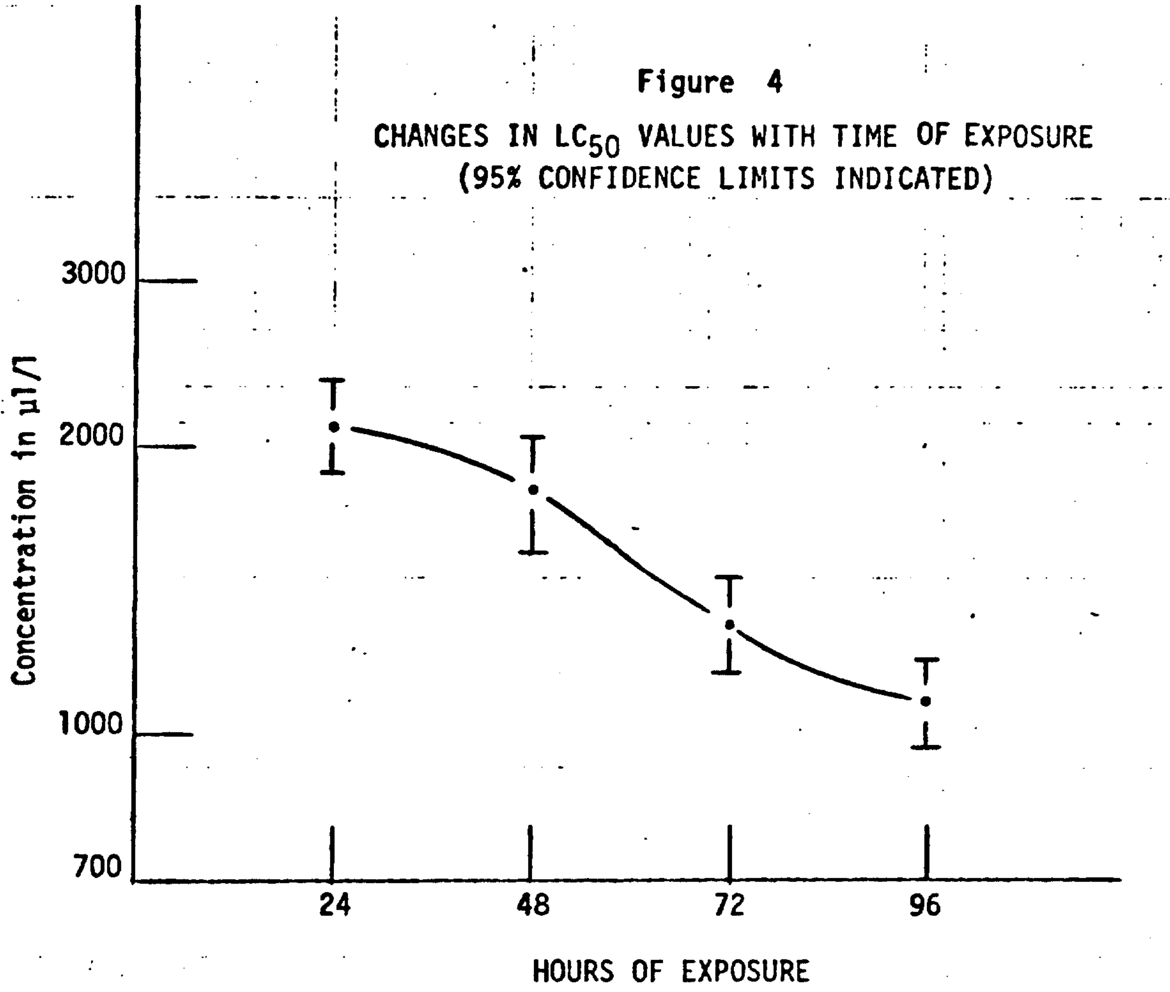


TIME OF EXPOSURE	LC_{50} µl/L	95% CONFIDENCE LIMITS UPPER	95% CONFIDENCE LIMITS LOWER	SLOPE OF CURVE	(CHI^2) FIT
24 Hrs	2100	2350	1880	1.29	4.2
48 Hrs	1810	2040	1600	1.31	1.8
72 Hrs	1310	1470	1170	1.30	1.1
96 Hrs	1080	1200	970	1.27	2.4

*COMBINED RESULTS OF 2 TOXICITY STUDIES.

Figure 4

CHANGES IN LC_{50} VALUES WITH TIME OF EXPOSURE
(95% CONFIDENCE LIMITS INDICATED)



E. Comparison with AFFF's Previously Studies

1. Table 7 is a summary of the various parameters measured for each of the AFFF products studied thus far. (4,5,13). The greater percentage of the ultimate BOD being measured in the first five days on the newer products indicates a more rapid degree of biodegradability.

Table 7. Comparison of Various Parameters of AFFF's

	3M - LIGHT WATER			NAT'L FOAM SYSTEMS	
PARAMETER	FC199	FC200	FC206	AOW 3	AOW 6
pH	4.6	7.6	7.8	7.8	7.9
Specific Gravity	1.02	0.989	1.020	1.062	1.031
Water		59%	70%	72%	72%
Diethylene Glycol Monobutyl Ether		39%	27%	10%	10%
COD $(X10^3)$	550 mg/l	730 mg/l	500 mg/l	500 mg/l	350 mg/l
TOC $(X10^3)$		235 mg/l	96 mg/l	130 mg/l	100 mg/l
BOD_u $(X10^3)$	18 mg/l	450 mg/l	411 mg/l	354 mg/l	300 mg/l
BOD_5 (% BOD_u)	37	2	65	45	45

2. Table 8 summarizes the daily changes in LC_{50}'s during 96-hour bioassays for each of the AFFF concentrates previously studied.

Table 8. Changes in Toxicity of AFFF's to Fathead Minnows with increase in time of exposure.

	LC_{50} (Concentrations in µl/l)				
	3M - LIGHT WATER			NAT'L FOAM SYSTEMS	
	FC199	FC200	FC206	AOW 3	AOW 6
24-Hour	650	*	2100	1030	635
48-Hour	588	135	1810	820	255
72-Hour	450	97	1300	630	245
96-Hour	398	97	1080	600	225

*No mortality in 24 hours in one bioassay but 50% in highest concentration (150 µl/l) in duplicate bioassay.

IV. CONCLUSIONS

A. No acute toxicity to activated sludge microorganims was exhibited by FC206 up to 100,000 ul/l of the concentrate in synthetic sewage/activated sludge. Dilution of the concentrate for fire fighting operations is six percent (60,000 ul/l).

B. Respiration studies indicate that acclimation of microorganisms to concentrations up to 100,000 ul/l could occur and would allow successful waste treatment in oxidation ponds.

C. Bench scale - activated sludge treatment plants effectively treated concentrations of 200 ul/l on a continuous feed basis. Above this concentrations, sludge microorganisms were not able to build rapidly. This was probably due primarily to the physical removal of solids through foaming rather than direct toxicity to the microorganisms. Fathead minnows and daphnia lived in effluent from the plant being fed 500 ul/l.

D. In acute toxicity studies in which the test fish (Pimaphales promelas) were exposed to continously replenished concentrations of FC206, the 96 hour LC_{50} was 1080 ul/l (0.11%). The 96 hour value was considered to be an adequate estimation of the incipient LC_{50} (lethal threshold concentration) and suitable for use with application factors to predict "safe levels" for short-term exposure periods.

E. In comparing toxicities, FC206 concentrate was approximately six times more toxic to fry than the larger juvenile Fathead minnows. Also, FC206 concentrate was less toxic to Fathead minnows than previously tested fire fighting foams.

V. RECOMMENDATIONS

A. Wastewater from fire-fighting training operations should be passed through a gravity oil separator. The waste should then be held in a pond for natural oxidation and decomposition or pumped to a secondary sewage treatment facility at a controlled flow rate. Secondary treatment could be provided with the domestic sewage such that the influent to the sewage treatment plant will not contain in excess of 20 ul/l of the FC206. This recommendation is based on training exercises and is not necessarily intended for operational use.

B. Using the 96 hour LC_{50} of 1080 ul/l and an application factor of 0.05, the calculated "safe level" of FC206 concentrate is 54 ul/l for short term exposure. For situations in which the aquatic animals will be exposed more than 4 days, concentration of FC206 should not exceed 20 ul/l in the affected body of water.

VI. REFERENCES

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APPENDIX

Participants in Study

PARTICIPANTS

Biodegradability and Toxicity of Light Water, FC206 Aqueous Film Forming Foam

Biodegradability Studies:

Project Officer:	Maj Edward E. LeFebvre Consultant, Environmental Chemistry

1Lt Thomas Doane, Consultant, Environmental Chemistry
TSgt Samuel A. Britt, Laboratory Techician
Mr. Gilbert Valdez, Physical Sciences Aide
A1C Gregory Knerl, Laboratory Techician

Bioassays:

Maj. Roger Inman, Veterniary Ecologist Toxicologist
MSgt Melvin Struck, Laboratory Animal Techician
TSgt Jerold Akey, Laboratory Animal Techician

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APPENDIX F

SMALL SCALE AFFF/DYE DISPERSION TEST

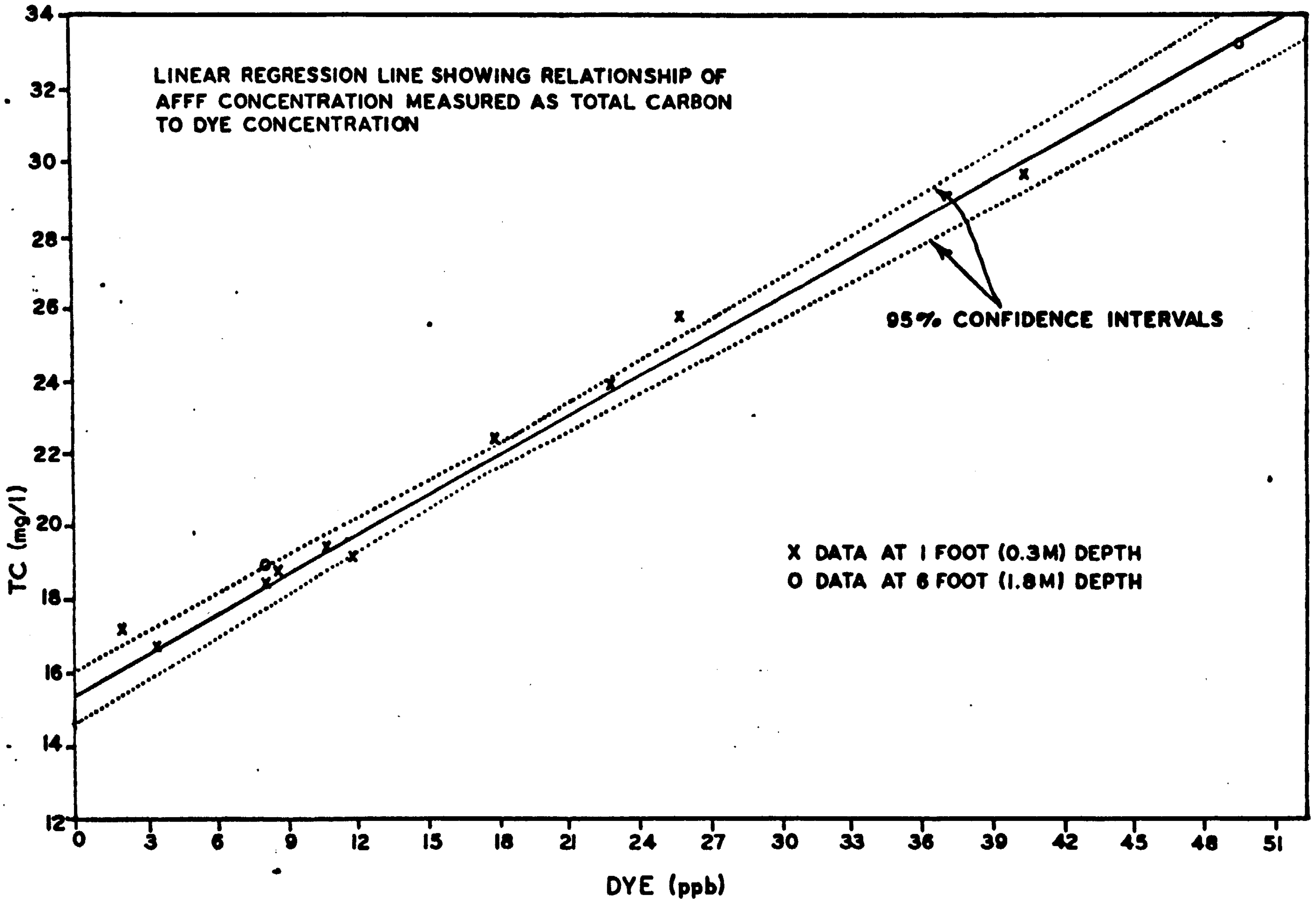
1. A small scale test was conducted in Dungan Basin at the David W. Taylor Naval Ship Research and Development Center, Annapolis Laboratory, on 3 September 1975. Released into the basin was a mixture of 1.2 gal (4.5 ℓ) of AFFF (3M Co. FC-206) and 18.8 gal (71.2 ℓ) of water drawn from the basin. The AFFF/water mixture was dyed to a concentration of 100 ppm (by weight) with rhodamine WT dye. The mixture was poured overboard at 1412 hours from a small boat in the center of the basin. Samples were pumped into collection bottles from depths of one foot (called surface samples, S), six feet, and nine feet from areas within the visible dye patch visually estimated to be those of highest dye concentration. Samples were analyzed for dye concentration, TC, and COD. Results of analyses are contained in table F-1. It was assumed that the increase in TC above background levels was due to the presence of AFFF.

2. Rhodamine dye concentration and TC data for samples collected at the one foot (0.3 m) depth are plotted in figure F-1. The relationship between dye and TC demonstrates that dye can be used to simulate the dispersion of AFFF. Although the rate of change in AFFF and dye was different, the dilution factors remained the same. Therefore, dilution data from an in situ dye dispersion study can be used to develop dilution factors applicable for predicting the decrease in AFFF concentration after release of a known quantity of AFFF under similar conditions in the study area.

Table F-1
Results of Laboratory Analyses of Water Samples from Dungan Basin Before and After the Addition of AFFF and Rhodamine Dye

Time	Depth		Dye Concentration	TC	COD
	(ft)	(m)	(ppb)	(mg/ℓ)	(mg/ℓ)
Bkgd	1	0.3	<2	15.6	128
Bkgd	1	0.3	<2	13.8	125
Bkgd	6	1.8	<2	14.8	68
Bkgd	6	1.8	<2	13.8	70
1412	-	-	Release dye, 1.0×10^5 ppb	-	2.6×10^4
1415	1	0.3	8.9	18.6	96
1415	6	1.8	8.3	18.7	80
1417	1	0.3	40.6	29.6	150
1417	6	1.8	49.5	33.2	144
1419	1	0.3	25.7	24.8	160
1419	6	1.8	<2	14.6	84
1420	1	0.3	21.8	23.8	184
1420	6	1.8	<2	14.8	104
1422	1	0.3	17.8	22.4	100
1422	6	1.8	<2	14.8	80
1423	1	0.3	10.9	19.4	68
1423	6	1.8	<2	14.1	148
1424	1	0.3	8.5	18.2	76
1424	6	1.8	<2	15.3	64
1425	1	0.3	3.7	16.6	88
1425	6	1.8	<2	14.1	132
1425	9	2.7	<2	14.1	152
1427	1	0.3	11.9	19.2	100
1427	6	1.8	<2	14.6	68
1427	9	2.7	<2	14.1	188
1430	1	0.3	2.1	17.3	64
1430	6	1.8	<2	13.6	48
1430	9	2.7	<2	14.8	96

FIGURE F-I



LINEAR REGRESSION LINE SHOWING RELATIONSHIP OF AFFF CONCENTRATION MEASURED AS TOTAL CARBON TO DYE CONCENTRATION

APPENDIX G

TENTATIVE ALLOCATION PLANS AND CONSTRUCTION SCHEDULES FOR SHIP CHT SYSTEMS, SWOBS, AND PIER SEWERS

TABLE G-1
ACTIVITIES WHICH HAVE/PLAN TO HAVE PIERSIDE FACILITIES FOR SHIP-TO-SHORE SEWAGE TRANSFER TOGETHER WITH FACILITY DESCRIPTION AND STATUS*

15 October 1976

LOCATION	MCON NO.	PCR NO.	DESCRIPTION	STATUS
NORFOLK COMPLEX				
NAVSTA	P-807	W289D	PIERS 7,12,20,21,22,23	CONST.COMPL. FACILITY OPERATING
			PIER 24	UNDER CONST. UNTIL 6/78
			PIER 25	UNDER CONST. UNTIL 7/77
NAB LITTLE CREEK	P-206	W131J	PIERS 56,57,58,59	CONST.COMPL. FACILITY OPERATING
NAVSTA	P-911	W289E	PIERS 2,3,4,5,10	UNDER CONST. UNTIL 1/77
NSY PORTSMOUTH	P-177	W164G	WHARFS 1-12,15,23-27,29-33 35,36,38,39,41-45	UNDER CONST. UNTIL 4/77
NAB LITTLE CREEK	P-207	W131K	PIERS 1-8,11-15,16-19	UNDER CONST. UNTIL 3/77
NSY PORTSMOUTH	P-999	W164A	PIER C	UNDER CONST. UNTIL 4/77
SAN DIEGO COMPLEX				
NAVSTA	P-176	W027D	PIER 4	CONST.COMPL. FACILITY OPERATING
NSSF	P-036	W304A	PIERS 5000,5002, DEPERMING PIER	CONST.COMPL. FACILITY OPERATING
NAS NORIA	P-313	W018L	WHARFS I,J,K	CONST.COMPL.(MUNICIPAL CONN. COMPL.) Lift Station Pump Prob.
NAVSTA	P-179	W027F	PIERS 5,6,8	UNDER CONST. UNTIL 5/77; PIER 5 CONST.COMPL.
			SMALL CRAFT BASIN	CONST.COMPL.
			MOLE PIER	CONST.COMPL.
			PIERS 1,2,3	UNDER CONST. UNTIL 1/78
			PIER 9	PLANNED EST.COMPLETION 12/78
	P-191	W032j	PIER 10	PLANNED EST.COMPLETION 12/79
	P-198	- -	PIERS 11,12,13	PLANNED EST.COMPLETION 12/80
NSC	P-022	W209K	BROADWAY PIER	UNDER CONST. UNTIL 12/76
	P-023	W209j	FUEL PIER PT.LOMA	UNDER CONST. UNTIL 12/77
NUC	P-059	W028D	PIERS 1,2 PT. LOMA	PLANNED EST. COMPLETION 6/78
	P-057	W028C	SAN CLEMENTE ISLAND	PLANNED EST. COMPLETION 7/79
NAB CORONADO	P-093	W220C	PIERS 3,8,13	UNDER CONST. UNTIL 12/77

*NCBC letter to CNO, 25A1:WLR:hla, Control No. 610-23, Seria 5054 of 16 November 1976, enclosure (1).

TABLE 1 (cont.)

LOCATION	MCON NO.	PCR NO.	DESCRIPTION	STATUS
CHARLESTON				
NSC	P-903	W305A	PIER A	UNDER CONST. UNTIL 6/77
NSY			PIERS C,D,F,G,H,J,K,L,M	UNDER CONST. UNTIL 6/77
NAVSTA			PIERS N,P,Q,R,S,T,U	UNDER CONST. UNTIL 6/77
NWS	P-901	W119H	WHARF A, PIERS B,C,	UNDER CONST. UNTIL 11/76
MAYPORT				
NAVSTA	P-964	W049K	WHARFS B,C,D,A	CONST.COMPL. FACILITY OPERATING
PEARL HARBOR COMPLEX				
NSB	P-119	W057G	PIERS S1-S5,S8,S9	CONST.COMPL. (awaiting sewage transfer hose)
NAVSTA	P-991	W165G	PIERS B1-B26,	UNDER CONST. UNTIL 2/77
NSY			B1-B21,GD1-GD5,	UNDER CONST. UNTIL 2/77
			O2, MR NO. 2	UNDER CONST. UNTIL 2/77
NAVSTA	P-991A	W165H	PIERS M1-M4,	UNDER CONST. UNTIL 2/77
NSC			H1-H4,	UNDER CONST. UNTIL 2/77
NSB			S10-S14,S20,S21	UNDER CONST. UNTIL 2/77
NAVSTA	P-179	W165I	A1-A7,S15-S19,F1-F5	UNDER CONST. UNTIL 10/77
NSC			V1-V4,K3-K11	UNDER CONST. UNTIL 10/77
NAVSTA	P-179A	W165J	F12,F13	UNDER DESIGN, EST.COMPL. 7/78
NAVMAG	P-179B	W165J	W1-W5	UNDER DESIGN, EST.COMPL. 3/79
SAN FRANCISCO				
NAS ALAMEDA	P-100	W007M	PIER 3	CONST.COMPL. FACILITY OPERATING
	P-133	W007N	PIERS 1,2	CONST.COMPL. FACILITY OPERATING
NWS CONCORD	P-153	W008F	PIER 2	PLANNED, EST.COMPLETION 6/80
NSY VALLEJO	P-203	W031F	WHARFS 2-20,24	PLANNED, EST.COMPLETION 5/78
			PIERS 21-23	PLANNED, EST.COMPLETION 5/78
NSC OAKLAND	P-002,3,4	W019F	- - - - -	PLANNED, EST.COMPLETION 12/79
PUGET SOUND				
NTS KEYPORT	P-190	W146J	WHARF	UNDER CONST. UNTIL 1/77
NSY BREMERTON	P-166	W144K	PIERS 3-8	PLANNED, EST. COMPLETION 1/80
NSC BREMERTON	P-038	W147N	FUEL PIER	PLANNED, EST. COMPLETION 5/77

TABLE G-1 (cont.)

LOCATION	MCON NO.	PCR NO.	DESCRIPTION	STATUS
LONG BEACH				
NAVSTA	P-131	W014F	PIERS 9,11,15	CONST.COMPL.
NSY	P-172	W015I	PIERS 1,2,3,6,E	CONST.COMPL.
NAVSTA	P-133	W014G	PIER 7	UNDER CONST. UNTIL 1/77
NWS SEAL BEACH	P-096	W035C	WHARF	PLANNED, EST. COMPLETION 7/78
GROTON/NEW LONDON				
NSB NEW LONDON	P-157	W040D	PIERS 1-4,6,8-10,12,13,15,17,31	CONST.COMPL.(awaiting sewage transfer hose)
NUSC	P-116	W332A	PIER 7	PLANNED EST. COMPLETION 9/79
PENSACOLA				
NAS	P-999	W051K	PIERS 302,302	CONST.COMPL.(awaiting sewage transfer hose)
WASHINGTON D.C.				
NAVSTA	P-194	W042j	PIERS 1,4	CONST.COMPL. FACILITY OPERATING
PORTSMOUTH N.H.				
NSY	- - -	- - -	PIERS 1,2,3	CONST.COMPL. FACILITY OPERATING
ADAK				
NAVSTA	P-834	W002I	PIER 3	PLANNED, EST. COMPLETION 12/79
EARLE				
NWS	P-771	W190A	PIERS 2,3	PLANNED, EST. COMPLETION 6/77
NEW ORLEANS				
NSA	P-047	W063C	PIER 1	PLANNED, EST. COMPLETION 8/79
PANAMA CITY				
NSCL	P-999	W266B	SOUTH DOCK, EAST DOCK	CONST.COMPL (awaiting sewage transfer hose)

TABLE G-1 (cont.)

LOCATION	MCON NO.	PCR NO.	DESCRIPTION	STATUS
PORT HUENEME				
CBC	P-332	W023K	WHARFS 2-6,A	PLANNED, EST. COMPLETION 9/79
YORKTOWN				
NWS	P-336	W136C	PIER 2	UNDER CONST. UNTIL 1/77
PHILADELPHIA				
NSY	P-451	W106D	PIERS 1,2,4	UNDER CONST. UNTIL 11/76
	P-443	W106B	PIERS 5,6	CONST.COMPL.(awaiting sewage transfer hose)
ROOSEVELT ROADS				
NAVSTA	P-997	W111H	PIERS 1,2,3	UNDER CONST. UNTIL 4/77
GUAM				
NAVSTA	P-094	W064K	A,B & V	UNDER CONST. UNTIL 11/76
NAVSHIPREPFAC			L,M,N,& O	UNDER CONST. UNTIL 11/76
NSD			R,S,T, & U	UNDER CONST. UNTIL 11/76
NAVMAG			H	UNDER CONST. UNTIL 11/76
NAVSTA	P-107	W064R	X	PLANNED, EST. COMPLETION 12/79
PORTLAND, OR				
NAVRESCTR	O&MN	W258C	PIERSEWER	AWAITING AWARD OF CONST.CONTRACT (EST.COMPL. OF CONST. 4/77)
TACOMA, WA				
NAVRESCTR	O&MN	W151C	PIERSEWER	AWAITING AWARD OF CONST.CONTRACT (EST.COMPL. OF CONST. 4/77)
EVERETT, WA				
NAVRESCTR	O&MN		PIERSEWER	UNDER CONST. UNTIL 1/77

TABLE G-1 (cont.)

LOCATION	MCON NO.	PCR NO.	DESCRIPTION	STATUS
GALVESTON, TX NAVRESCTR	MCNR P-032	W322A	PIERSEWER STRUCT. #11	PLANNED, EST. COMPLETION 7/77
ST. PETERSBURG, FL NAVRESCTR	MCNR P-241	W329A	PIERSEWER STRUCT. #6	PLANNED, EST. COMPLETION 7/77
BRONX, NY (Fort Schyler) NAVRESCTR	MCNR P-315	W324A	PIERSEWER	PLANNED, EST. COMPLETION 1/78
PERTH AMBOY NAVRESCTR	MCNR P-346	W338A	PIERSEWER	PLANNED, EST. COMPLETION 12/78
PORTLAND, ME NAVRESCTR	MCNR P-343	W340A	PIERSEWER	PLANNED, EST. COMPLETION 10/78
BALTIMORE, MD NAVRESCTR	MCNR P-243	W072A	PIERSEWER	PLANNED, EST. COMPLETION 10/77
JACKSONVILLE, FL			NO PIERSEWER PLANNED	
BOSTON, MA			NO PIERSEWER PLANNED	
NEWPORT, RI (NETC) NAVSTA	P-208	W116N	PIERSEWER PLANNED	

TABLE G-1 (cont.)

LOCATION	MCON NO.	PCR NO.	DESCRIPTION	STATUS
GREAT LAKES, IL			NO PIERSEWER PLANNED	
YOKOSUKA, JAPAN				
LA MADDALENA, IT				
HOLY LOCH, SC			WILL USE SWOB	
ROTA, SPAIN			WILL USE SWOB	
BAHRAIN				
GAETA				
NAPLES				
BROOKLYN, NY (Floyd Bennett Field) NAVRESCTR	MCNR P-319	W337B	PIERSEWER PLANNED	

TABLE G-2
SHIPS WASTE OFFLOAD BARGE (SWOB) ALLOCATION PLAN AND DELIVERY SCHEDULE*

	FY74 PROCUREMENT (OIL)		FY75 PROCUREMENT (OIL)			FY76 PROCUREMENT (OIL & SEWAGE)		TOTAL ALLOCATED	
	ALLOCATED	DELIVERED	ALLOCATED	DELIVERED	TO BE DELIVERED	ALLOCATED (OIL)	ALLOCATED (SEWAGE)	OIL	SEWAGE
NAVSHIPYD Portsmouth	0	0	0	0	1	0	0	1	0
WPNSTA Earle	0	0	2	0	1 (Note 1)	1	0	2	0
NAVSHIPYD Phildadelphia	0	0	0	0	0	2	0	2	0
WPNSTA Yorktown	1	1	0	0	0	0	0	1	0
NAVSTA Norfolk	3	3	3	3	0	0	2	6	2
NAVPHIBASE Little Creek	1	1	1	1	0	0	1	2	1
NAVSHIPYD Norfolk	1	1	0	0	0	1	0	2	0
NAVSTA Charleston	2	2	0	0	0	1	0	3	0
NAVSHIPYD Charleston	0	0	0	0	0	0	1	0	1
NAVSHIPYD Puget Sound	2	2	3	3	0	0	0	5	0
NAVSHIPYD Mare Island	1	1	0	0	0	0	0	1	0
NAVFUELDEP Point Molate	0	0	1	0	1-Jan '77	0	1	1	1
NSC Oakland	1	1	0	0	0	0	0	1	0
NAVSHIPYD Long Beach	2	2	0	0	0	0	1	2	1
NAVSTA San Diego	3	3	0	0	0	0	2	3	2
NAS North Island	2	2	0	0	0	0	0	2	0
NAVSHIPYD Pearl Harbor	1	1	0	0	0	0	0	1	0
NAVSTA Pearl Harbor	2	2	1	0	1 (Note 2)	0	3	3	3
NAVSTA Guam	0	0	1	0	1 (Note 2)	0	1	1	1
NAVSTA Subic Bay	0	0	1	0	1 (Note 2)	0	0	1	0
FLEACT Yokosuka	0	0	2	0	2 (Note 3)	0	0	2	0
NAVSTA Rota	0	0	1	0	1 (Note 4)	0	1	1	1
NAVSUPPO La Maddalena	0	0	1	0	1 (Note 4)	0	0	1	0
NAVSTA Roosevelt Roads	0	0	2	0	2-Jan '77	0	0	2	0
NAVSTA Guantanamo Bay	0	0	1	0	1-Jan '77	0	0	1	0
TOTALS	22	22	20	7	13	5	13	47	13

*Information provided by Naval Facilities Engineering Command (NAVFAC 104), 10 January 1977.

Notes:
1. One barge delivered by contractor stored at NAVSHIPYD Puget Sound to be delivered by contractor to final destination.
2. Three barges delivered by contractor in July 1976 to NAVSHIPYD Long Beach to await a Navy tow of opportunity to final destinations.
3. Two barges delivered by contractor in September 1976 to NAVSHIPYD Long Beach to await a Navy tow of opportunity to final destinations.
4. Three barges delivered by contractor in July 1976 to INACTSHIPPAC Portsmouth to await a Navy tow of opportunity to final destinations.

TA[illegible]E G-3
CHT COMPL[illegible]ON SCHEDULE*

1 SEPT'76

FY-73	FY-74	FY-75	FY-76-7T	FY-77	FY-78	FY-79	FY-80	FY-81
COMP. CG-11 - - - - AS-11 AS-16 AS-31 AS-32 AS-37 ASR-8 (4) ASR-9 ASR-14 - - - - LPH-3 - - - - **PART.** LPD-6 (* in 7T) LSD-32 (* in 7T) LSD-34 (* in 77) **INCR.** CV-60(6)(8)	**COMPLETES** CG-10 DDG-37 CG-17 DDG-46 CG-27 FF-1049 DD-945 FF-1053 DDG-11 FF-1054 DDG-33 FFG-1 - - - - AD-18 AR-7 AD-37 AS-12 AE-21 ATF-100 AE-22 ATF-101 AFS-6 ATF-161 AO-98 AO-147 AOR-1 - - - - LPD-7 LST-1179 LST-1182 - - - - **PARTIALS** CG-26 (* in '78) CG-28 (* in '76) CGN-35 (* in '76 DD-835 Note (5) DD-839 (* in '78) DD-862 (* in '78) DD-963 Note (5) DD-895 Note (5) DD-836 (* in '78) DDG-7 (* in '77) FF-1056 (* in '78) FF-1057 (* in '7) FF-1058 (* in '78) FF-1060 (* in '7) FFG-2 (* in '79) - - - - AE-27 (* in '76) AO-149 (* in '79) ARS-8 (* in '76) ARS-23 (* in '76) ARS-24 Note (5) ARS-25 (* in '76) ASR-13 (* in '78) ASR-15 (* in '78) ATF-96 (* in '76) ATF-100 (* in '76) ATF-110 (* in '76) ASR-16 Note (4) - - - - LKA-113 (* in '78) LPD-8 (* in '79) LPD-13 (* in '78) LSD-28 (* in '79) LST-1183(* in '78) LST-1184(* in '76) **INCREMENTALS** CV-67 (8)	**COMPLETES** CG-29 DDG-31 CG-36 DDG-36 CGN-25 DDG-45 DD-937 FF-1041 DD-938 FF-1059 DD-941 FF-1066 DD-948 FF-1077 DD-950 FFG-5 DD-763 FFG-6 DD-756 DD-927 - - - - AD-38 ARS-38 AFS-2 ARS-40 AFS-7 ARS-42 AC-153 AO-99 AOR-2 - - - - LKA-116 LSD-37 LPD-1 LST-1180 LPD-10 LST-1185 LPD-11 LST-1186 LPH-7 LST-1187 LPH-10 LST-1191 - - - - **PARTIALS** LCC-20 (* in '78) **INCREMENTALS** CV-64 (8) CV-66 (8)	**COMPLETES** CG-18 FF-1065 CG-22 FF-1037 DD-931 FF-1050 DD-933 FF-1051 DD-940 FF-1052 DD-943 FF-1062 DD-946 FF-1063 DDG-4 FF-1069 DDG-9 FF-1071 DDG-10 FF-1072 DDG-19 FF-1075 DDG-22 FF-1078 DDG-23 FF-1079 DDG-32 FF-1098 AGFF-1 FFG-3 - - - - AD-19 ARS-41 AE-26 AS-34 AE-28 ATS-1 AE-29 ATS-2 AFS-4 ATF-103 AGF-3 ATF-105 AOE-1 ATF-113 AOE-4 ATF-162 AOR-3 AOR-6 AR-5 - - - - LCC-19 LSD-29 LKA-112 LSD-35 LPA-248 LSD-38 LPA-249 LSD-39 LPD-5 LST-1181 LPD-9 LST-1188 LPD-12 LST-1189 LPD-14 LST-1195 LPH-9 LPH-11 LPH-12 **COMPLETIONS OF PARTIALS** CG-28 CGN-35 - - - - AE-27 ATF-96 ARS-8 ATF-100 ARS-23 ATF-110 ARS-25 - - - - LPD-6 LSD-32 **INCREMENTALS** CV-63(8)	**COMPLETES** CV-67(6)(7) CG-20 FF-1076 CG-23 FF-1080 CG-26 FF-1082 CG-30 FF-1083 CG-32 FF-1084 DDG-15 FF-1085 DDG-35 FF-1086 DDG-38 FF-1087 DDG-40 FF-1089 FF-1055 FF-1061 FF-1070 FF-1073 FF-1074 - - - - AD-15 ARS-43 AE-23 AS-33 AE-26 AS-36 AE-32 ATF-160 AE-34 AE-35 AFS-1 AO-51 AOE-2 AOR-5 AR-8 - - - - LPD-15 LST-1193 **COMPLETIONS OF PARTIALS** DDG-7 - - - - - - - - LSD-34 - - - - **INCREMENTALS** CV-59 (8) CV-61 (8)	**COMPLETES** CVT-16(6)(7)(9) CV-63 (6)(7)(9) - - - - CG-21 FF-1047 CG-33 FF-1049 FF-1067 DDG-5 FF-1088 DDG-6 FF-1090 DDG-9 FF-1091 DDG-16 FF-1092 DDG-18 FF-1093 DDG-20 FF-1094 DDG-36 FF-1095 DDG-43 FF-1096 DDG-44 DD-962 DD-951 (NRT) - - - - AE-25 AR-6 AE-33 AS-19 AFS-5 AS-18 - - - - LSD-33 LKA-115 LSD-36 **COMPLETIONS OF PARTIALS** CG-26 FF-1058 DD-836 FF-1060 FF-1056 FFG-2 FF-1057 DD-839 DD-862 - - - - ASR-13 ASR-15 - - - - LCC-20 LST-1183 LKA-113 LST-1184 LPD-13 **INCREMENTALS** CV-61(6) CV-60(8) CV-62(6)(8) CV-63(6) CV-64(6) CV-66(7)	**COMPLETES** CV-60 (7) CV-62 (7) CV-64 (7) CVN-65(6)(7)(8) CV-66 (6) - - - - CG-31 DDG-46 DDG-2 FF-1066 DDG-13 FF-1067 DDG-14 DDG-17 FF-1097 DDG-24 FF-1098 DDG-39 DDG-42 - - - - AFS-3 AGDS-2 AOR-4 ASR-21 ASR-22 - - - - LKA-117 LSD-30 LSD-31 **COMPLETIONS OF PARTIALS** AO-149 - - - - LPD-8 LSD-28 **INCREMENTALS** CV-61(7) CV-59(6)	**COMP.** CV-59(7) - - - - CG-5 DDG-3 DDG-41 - - - - AOE-3 **INCR.** CV-61(8)	**COMP.** CV-41(8) CV-61(7) CV-63(7) - - - - CG-16 CG-19 DD-944 DDG-12 DDG-21 FFG-4 FF-1048 FF-1043 [illegible] [illegible] - - - - ATS-3 ARS-39 - - - - LKA-114 LPD-2 LPD-4 LPH-2 LSD-40 LST-1190 LST-1192 LST-1194 LST-1196 LST-1197 LST-1179

TOTAL COMPLETIONS (1)

FY	COMP.	COMP. OF PART.	TOT
'73	10		10
'74	28		28
'75	41		41
'76-'7T	68	11	79
'77	41	2	43
'78	35	16	51
'79	26	3	29
'80	5		5
'81	26		26
		GRAND TOTAL	312

Notes: * - Indicates completion to be accomplished in year specified.
(1)- Total completions include completes, completions of partials and completions of incrementals.
(2)- CHT system to be installed, however, no. in current overhaul schedules through FY-'81.
(3)- Partial installation - completion undetermined.
(4)- To be stricken in FY-'77.
(5)- Scheduled for decommissioning.
(6)- Fwd. piping portion.
(7)- Aft piping portion.
(8)- Tank portion.

FOR OFFICIAL USE ONLY

*CHT Ship/Shore Interface Information Book, Hydronautics Technical Report 7607.1 prepared for NAVSEC 6159, October 1976.

Tech File: Fire Fighting Foams

AFAMRL-TR-82-50

ADA 127354

Selection

THE TOXICITY OF PERFLUORO-N-DECANOIC ACID AND 2,3,7,8-TETRACHLORODIBENZO-P-DIOXIN IN L5178Y MOUSE LYMPHOMA CELLS

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MARCH 1983

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TECHNICAL REVIEW AND APPROVAL

AFAMRL-TR-82-50

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

Roger C. Inman

ROGER C. INMAN, Colonel, USAF
Chief
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Air Force Aerospace Medical Research Laboratory

SECURITY CLASSIFICATION OF THIS PAGE (*When Data Entered*)

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9. PERFORMING ORGANIZATION NAME AND ADDRESS AFAMRL, Toxic Hazards Division, AMD, AFSC, Wright-Patterson AFB, Ohio 45433		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 61102F, 2312, V1, 18
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16. DISTRIBUTION STATEMENT (*of this Report*)

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17. DISTRIBUTION STATEMENT (*of the abstract entered in Block 20, if different from Report*)

18. SUPPLEMENTARY NOTES

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19. KEY WORDS (*Continue on reverse side if necessary and identify by block number*)

Perfluoro-n-decanoic Acid	2,3,7,8-Tetrachlorodibenzo-p-dioxin
Toxicology	Polyfluorinated acids
L5178Y Mouse Lymphoma Cells	
Cell Culture	
Erythrocyte Fragility	

20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

Perfluoro-n-decanoic acid (PFDA) causes toxic sequelae in vivo very similar to those caused by 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD). The toxicity of these two compounds, several other polyfluorinated fatty acids, and corresponding hydrogenated fatty acids have been studied in vitro in L5178Y mouse lymphoma cells. Below concentrations which cause cell lysis (⩾500 μg/ml), PFDA did not affect suspension growth. After 24 hr treatment with concentrations between 1 and 100 μg/ml treated cells no longer grew into clones when plated in semi-soft agar. This impairment of clone-forming ability was reversible after growth of

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treated cells in fresh medium for 36 hr. Perfluoro-n-octanoic acid did not impair clone-forming ability at any concentration; and neither did the straight-chain hydrogenated fatty acid analogs. All polyfluorinated acids tested (either perfluorinated or ω-hydro-analogs) with chain length 9 or greater caused impairment of clone-forming ability after treatment with concentrations that were non-toxic in suspension. TCDD (highest dose, 0.5 μg/ml) had no effect on growth in suspension. After 48 hr treatment with TCDD concentrations of 0.01 μg/ml or greater, plated cells formed clones with altered morphology. These clones were less discrete, lacking a clearly defined boundary. The effect on clone morphology required 36 hr treatment of cells with TCDD in suspension and was reversible following 48 hr growth in fresh medium. Cell division time in suspension was 10-12 hrs and was unaffected by PFDA or TCDD. In vivo PFDA treatment altered erythrocyte fragility in rats. It is suggested that the toxicity of PFDA and TCDD in vivo and in L5178Y cells in vitro may be due to an ability of these chemicals to interfere with normal structure and/or function of biological membranes.

PREFACE

This research was performed in the Biochemical Toxicology Branch, Toxic Hazards Division, Air Force Aerospace Medical Research Laboratory from January 1980 through December 1981. It was performed in support of Task 2312V1, "Toxicological Mechanisms of Air Force Chemicals and Materials;" Work Unit 2312V118, "Effects of Air Force Propellants and Chemicals on Metabolic Mechanisms." Portions of this work were presented at the 21st Annual Meeting of the Society of Toxicology, Boston, Massachusetts, 22-26 February 1982.

INTRODUCTION

Perfluorinated fatty acids, perfluorinated sulfonic acids, and appropriate derivatives are used commercially in numerous applications which take advantage of their exceptional surfactant properties and extreme chemical and thermal stability (Guenthner and Victor, 1962). Most commercially important derivatives are based on perfluoroalkyl chain lengths of 5 to 7. The acute and subchronic toxicity of ammonium perfluoro-n-octanoate (PFOA) has been described in detail in both rats and rhesus monkeys (Griffith and Long, 1980). Less is known of the toxicity of longer chain analogs.

In an abstract Andersen et al. (1981) described the acute toxicity of perfluoro-n-decanoic acid (PFDA; nonadecafluoro-n-decanoic acid; $C_{10}F_{19}O_2H$) in a variety of rodent species. This acid was significantly more toxic than PFOA and its toxicity differed both quantitatively and qualitatively from that of the shorter chain analog. Toxic signs and target organs for PFDA were similar to those seen with 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD). The single dose oral LD_{50} - 30 days of PFDA in male rats was about 50 mg/kg and rats intubated with 90 mg/kg lost nearly 50% of their initial body weight before dying two to three weeks after intubation. As does TCDD, PFDA caused severe thymic atrophy.

As part of a comparison of the biological effects of PFDA and TCDD, we have evaluated the toxicity of these chemicals in several isolated cell systems. In part, this paper describes effects of various polyfluorinated fatty acids, hydrogenated fatty acids, and TCDD on growth characteristics of L5178Y mouse lymphoma cells, a T-cell derived lymphoma (Muller et al., 1981), which grows both in suspension and in semi-soft agar. A T-cell lymphoma was used because T-lymphocytes appear to be targets of PFDA and TCDD toxicity in rodents. This conclusion was based on the marked thymic cortical atrophy noted in animals treated with either of these chemicals. L5178Y cells are commonly used for mutagenicity testing and the mutagenic potential of these chemicals in L5178Y cells is reported elsewhere (Rogers et al., 1982). In addition, limited results of osmotic fragility studies of erythrocytes from rats treated with PFDA are described in an attempt to relate altered osmotic fragilities to the effects of PFDA on L5178Y cells.

MATERIALS AND METHODS

L5178Y Mouse Lymphoma Cells: L5178Y cells were originally obtained from Dr. C. F. Arlett, MRC, Cell Mutation Unit, Brighton, England. They were routinely screened for mycoplasma contamination. The routine methods for maintenance of L5178Y cells and the soft agar cloning technique were as described elsewhere (Cole and Arlett, 1976), except that McCoy's 5A medium (supplemented with penicillin, streptomycin, sodium pyruvate, and 10% horse serum) was used instead of Fischer's medium. For toxicity experiments, L5178Y cells were treated for 24 hrs with doses of PFDA ranging from 0.01 µg/ml to 1 mg/ml, or for 48 hrs with doses of TCDD ranging from 0.001 µg/ml to 0.50 µg/ml. At the end of the treatment period, cells were centrifuged, washed in McCoy's 5A medium and resuspended in McCoy's 5A containing 20% horse serum. Cells were plated for growth in soft agar, and plates were examined for clones after 9-10 days incubation in a humidified CO_2

incubator. Horse serum was obtained from Gibco-Biocult. Penicillin, streptomycin, and sodium pyruvate were obtained from Sigma.

Chemicals: Fatty acids (all > 99% pure)[1], perfluoro-n-decanoic acid (>98%)[1], perfluoro-n-octanoic acid (>96%)[1], 11-H eicosafluoro-n-undecanoic acid (97-99%)[2], and 9-H hexadecafluoro-n-nonanoic acid[3] were obtained commercially. The latter two compounds contain a single hydrogen at the omega position. Perfluoro-n-dodecanoic acid[4] (71% $C_{11}F_{23}CO_2H$; 3% $C_{10}F_{21}CO_2H$; 2% $C_9F_{19}CO_2H$; remainder unidentified, nonfunctional fluorocarbon) and TCDD were gifts[5]. For L5178Y studies, TCDD was dissolved in acetone and the fatty acids and fluorinated analogs were dissolved in dimethylsulfoxide except perfluorinated dodecanoic was also dissolved in acetone.

Osmotic Fragility: Male Fischer 344 rats (200-300 g) were treated ip with 50 mg PFDA/kg. Propylene glycol:water (50:50 v/v) was used as diluent with a final dosing volume of 2 ml/kg. Treated and diluent control rats in groups of four to five were killed at various times after injection. Blood was drawn from the inferior vena cava after opening the abdomen of anesthetized rats and erythrocytes harvested by centrifugation. Osmotic fragility was determined as described in Dacie and Lewis (1963). Curves were constructed for hemolysis at 10 saline concentrations between 0.25 and 0.85%. Data presented are percent hemolysis at a single intermediate saline concentration, 0.4%.

RESULTS

Fatty Acids: PFDA had little effect on L5178Y suspension growth at concentrations below 100 μg/ml (Fig. 1). At concentrations of 500 μg/ml or above, cells were dissolved by the surfactant action of the acid and neither cells nor debris were visible in suspensions at these concentrations. In comparison to the dose-response curve for suspension growth, the curve for clone-forming ability was shifted some 2.5 log units to the left: the ED_{50}-24 hr for impairing clone-forming ability was approximately 3×10^{-1} μg/ml. To our knowledge, this ability - dissociating the markers of suspension growth and clone-forming ability in these transformed cells - has not been reported for any other chemical. Perfluorinated-n-dodecanoic and 11-H-eicosafluoro-n-undecanoic acid caused a similar displacement of the two dose response curves (Table 1). On the other hand, PFOA which was slightly less toxic to cells in suspension than was PFDA did not show the differential toxicity with respect to suspension and clonal growth. The ω-H-hexadecafluoro-n-nonanoic acid displaced the dose response curves for suspension and clone forming ability, but the displacement was less than that seen with PFDA (Table 1). With hydrogenated fatty acid analogs from C_8 to C_{11}, toxicity was equal both in suspension and in agar (Table 2).

[1] Aldrich Chemical Company, Milwaukee, WI 53233.

[2] PCR Research Chemicals, Inc., Gainesville, FL 32602.

[3] Alfred Bader Library of Rare Chemicals, Division of Aldrich Chemical Company, Milwaukee, WI 53233.

[4] Commercial Chemicals Division 3M, 3M Center, St Paul, MN 55144.

[5] Dow Chemical USA, Midland, MI 46460.

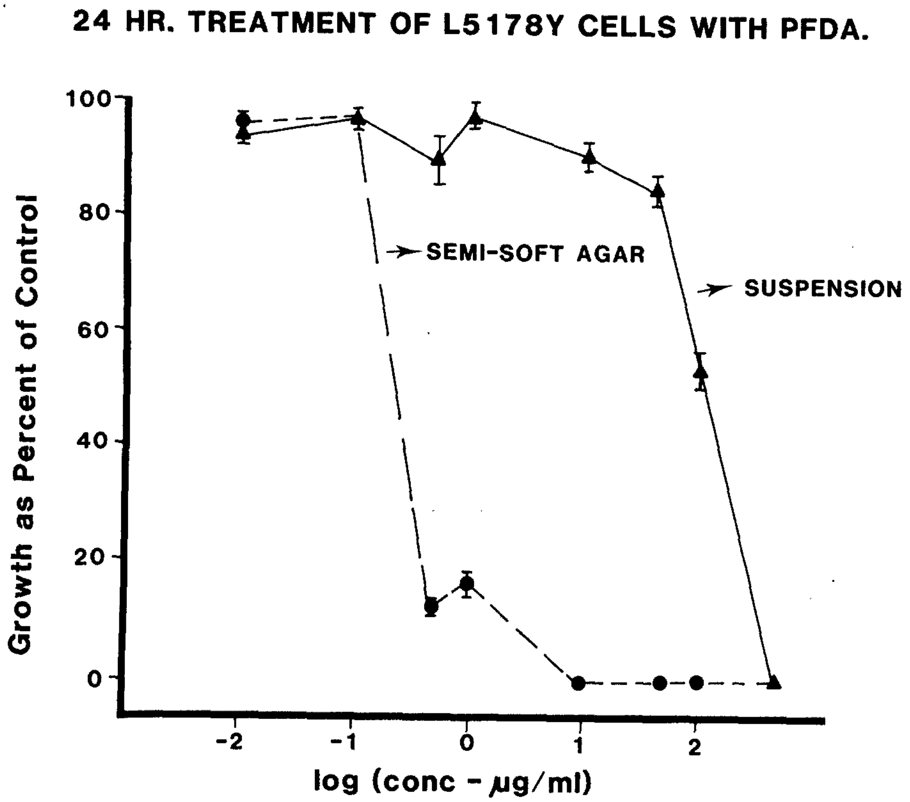


Figure 1. Toxicity of PFDA in L5178Y Cells. L5178Y cells were grown for 24 hr in the presence of varying amounts of PFDA (x-axis). Triangles are total growth in suspension as percent of control growth in the absence of PFDA. Aliquots of the cells treated with different concentrations were plated and grown for 8 to 10 days on semi-soft agar. Circles are percent of plated cells which gave rise to clones relative to similar values for control cells. Data points are mean and standard errors (n = 3-7).

Table 1

The Effects of Various Polyfluorinated Fatty Acids on Growth of L5178Y Mouse Lymphoma Cells in Suspension and on their Clone Forming Ability in Semi-Soft Agar

	Perfluoro-n-octanoic Acid		9-H Hexadecafluoro-n-nonanoic Acid		Perfluoro-n-decanoic Acid		11-H Eicosafluoro-n-undecanoic Acid		Perfluoro-n-dodecanoic Acid	
Dose	Suspension	Agar	Suspension	Agar	Suspension	Agar	Suspension	Agar	Suspension	Agar
(µg/ml)	(% Control)		(% Control)		(% Control)		(% Control)		(% Control)	
0.01	94[a]	98	94	97	94 ± 2[b]	96	96	100	87	97
0.1	100	96	83	95	97 ± 1.4[c]	97 ± 0.7	78	90	78	87
0.5					89 ± 4.7[b]	12 ± 1.1				
1	89	98	94	95	97 ± 1.1[b]	16 ± 1.9	75	11	91	25
10	89	98	94	89	90 ± 2.2[b]	0	82	0	72	0
50	76	90	92	89	84 ± 2.3[b]	0	82	0	75	0
100	76	90	83	0	53 ± 3.6[b]	0	82	0	72	0
500	21	21	--[d]	--	---[d]	--	--[d]	--	--[d]	--
1000	--[d]	--	--[d]	--	---[d]	--	--[d]	--	--[d]	--

[a] Result of single experiment. Numbers in each column are growth as percent of growth of control cells.
[b] Mean ± standard error (n = 3).
[c] Mean ± standard error (n = 7).
[d] These concentrations dissolved cells in suspension.

Table 2

The Effect of Various Fatty Acids on Growth of L5178Y Mouse Lymphoma Cells in Suspension and on their Clone Forming Ability in Semi-Soft Agar

Dose	Nonanoic Acid		Decanoic Acid		Undecanoic Acid	
	Suspension	Agar	Suspension	Agar	Suspension	Agar
(μg/ml)	(% Control)		(% Control)		(% Control)	
0.01	85[a]	98	106	96	95	96
0.1	82	98	94	94	85	93
1	92	98	100	93	75	96
10	90	94	84	90	82	93
50	85	98	75	82	82	86
100	72	88	63	63	42	44
500	33	26	--[b]	--	--[b]	--
1000	--[b]	--	--[b]	--	--[b]	--

[a] Numbers in both columns are growth as percent of growth of control cells.
[b] These concentrations dissolved cells in suspension.

Time to Effect and Reversibility: Cell division time for L5178Y cells in suspension under growth conditions used in this study was 10 to 12 hours. An experiment was performed to see if cells required a period of treatment with PFDA before diminished clone-forming ability could be observed. Cells were grown in suspension containing 0.5 μg PFDA/ml and removed at various times for plating to observe loss of clone-forming ability (Fig. 2a). There was a lag of 8 hr before any appreciable effect was observed and the time of treatment required to reduce plating efficiency to 50% of control was about 12 hr, i.e., one cell generation.

Cells were also grown for 24 hr in the presence of 0.5 μg of PFDA/ml harvested by centrifugation and washed in fresh growth medium. These treated cells were resuspended for growth in fresh, uncontaminated medium and aliquots withdrawn after various times for plating (Fig. 2b). The decreased plating efficiency was reversible, but recovery was more prolonged than the time required to induce the diminished clone-forming ability. The time of growth in fresh medium necessary to restore 50% plating efficiency was nearly 36 hr, or about three cell generations. Cell division time of L5178Y cells in suspension was unaffected by pretreatment with 0.5 μg PFDA/ml.

Dioxin: In L5178Y cells TCDD did not dissociate growth in suspension from growth in soft agar at any concentration tested, up to 0.5 μg/ml. However, the morphology of the clones obtained after treating cells in suspension with concentrations of TCDD between 0.01 and 0.5 μg/ml, was markedly different from controls (Fig. 3). Instead of the well-circumscribed, circular clusters of control clones, those clones formed after dioxin-treatment were less-discrete and lacked a well-defined border. After growing cells in suspension for 46 hr in the presence of 0.005 μg TCDD/ml,

TIME TO RESPONSE/TIME TO RECOVERY OF L5178Y CELLS TREATED WITH PFDA.

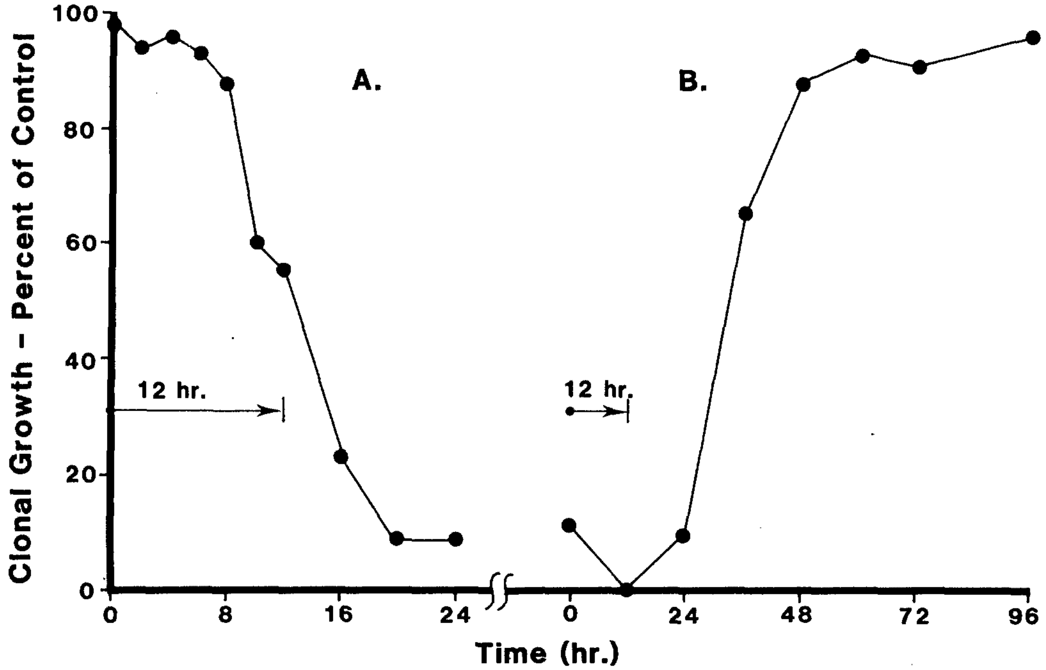
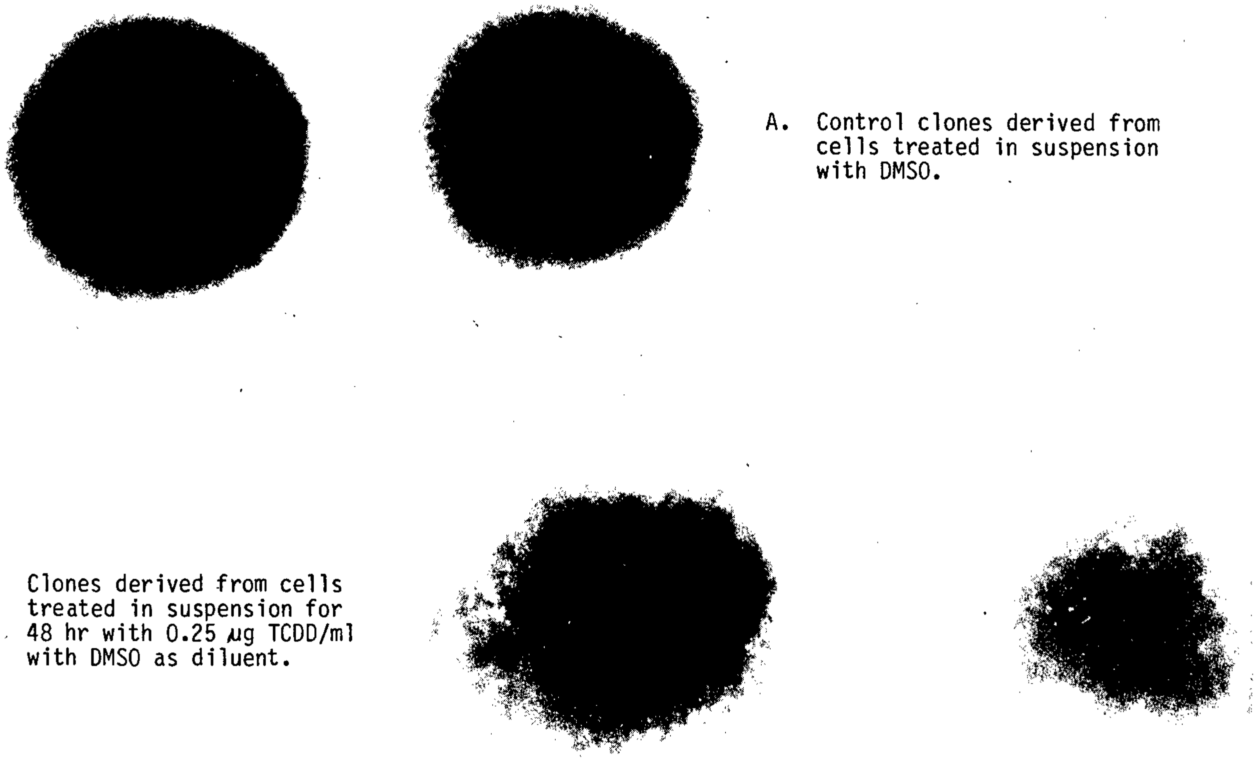


Figure 2. Time course of impairment and recovery of cloning ability in L5178Y cells treated with PFDA in suspension. A: Time to effect: cells were grown for various lengths of time (x-axis) in suspension in a medium containing 0.5 µg PFDA/ml and plated in semi-soft agar. Growth is expressed as percent of plated cells forming clones after treatment relative to percent of untreated cells which give rise to clones. B: Time to recovery: cells were treated in suspension with 0.5 µg PFDA/ml for 24 hr, and harvested by centrifugation. Aliquots were removed and grown in fresh, uncontaminated medium for various lengths of time (x-axis). Cells were then plated to observe recovery of the ability to form clones.

all clones formed after plating were normal; at 0.01 µg/ml, most clones formed were abnormal; and by 0.5 µg/ml, all clones had altered morphology. By inspection of the plates, the ED_{50}, that is the concentration of dioxin required to produce alterations affecting 50% of the formed clones when cells were initially maintained in suspension with dioxin for 48 hr before plating, was about 0.01 µg/ml, i.e., about 3×10^{-8}M.

In time-course experiments analogous to those in Fig. 2, but conducted with 0.01 µg dioxin/ml, the time of treatment in suspension required to produce 50% of maximum response in altering clone morphology was about 36 hr. A time to recovery of normal growth characteristics was also estimated for cells grown initially for 48 hr in the presence of 0.01 µg TCDD/ml. The time of growth in fresh medium required to give a 50% return to normal clonal morphology was about 48 hr. As noted with PFDA, effects on clone growth were reversible, but recovery and expression times for the effects were longer with TCDD than with PFDA.

Red Blood Cell Fragility: Rat red blood cells were obtained from rats killed at various times after ip injection of 50 mg PFDA/kg. There was increased resistance to hemolysis after treatment with PFDA (Fig. 4) and the time course of decreased fragility was similar to the time course of weight loss in treated rats (Andersen et al., 1981).



A. Control clones derived from cells treated in suspension with DMSO.

B. Clones derived from cells treated in suspension for 48 hr with 0.25 µg TCDD/ml with DMSO as diluent.

Figure 3. Altered clone morphology after treating L5178Y cells in suspension with TCDD.

DISCUSSION

Knutson and Poland (1980) studied the effects of TCDD on 23 cultured cell types and found no toxicity in any of these mammalian cell lines at treatment concentrations of up to 10^{-7}M and contact times of up to two weeks. Markers for toxicity included (1) alterations in the morphology of cells or the cell cultures, (2) percentage viable cells, and (3) growth rate. Among the 23 cell lines were five lymphoid cell types derived from thymic cortex - three were murine and two were virally transformed human leukocytes. All these cell types were tested for growth in suspension and cell viability by trypan blue exclusion. Beatty et al. (1975) found that TCDD had no effect on growth or morphology of normal human lymphocytes in suspension. Our results are similar to the extent that TCDD did not affect growth or cell viability of L5178Y cells in suspension. The altered growth characteristics observed in this paper are more subtle and only apparent when cells are grown in semi-soft agar, where they are constrained to grow in close proximity to each other. The concentration dependence of the effect with TCDD is such that a 48 hr treatment with 0.01 μg/ml (i.e., about 3 x 10^{-8}M TCDD) causes the effect in most of the treated cells. This concentration is reasonable for physiological significance since the mouse LD$_{50}$ is about 300 μg TCDD/kg, or about 1 μmoles/kg (McConnell et al., 1978).

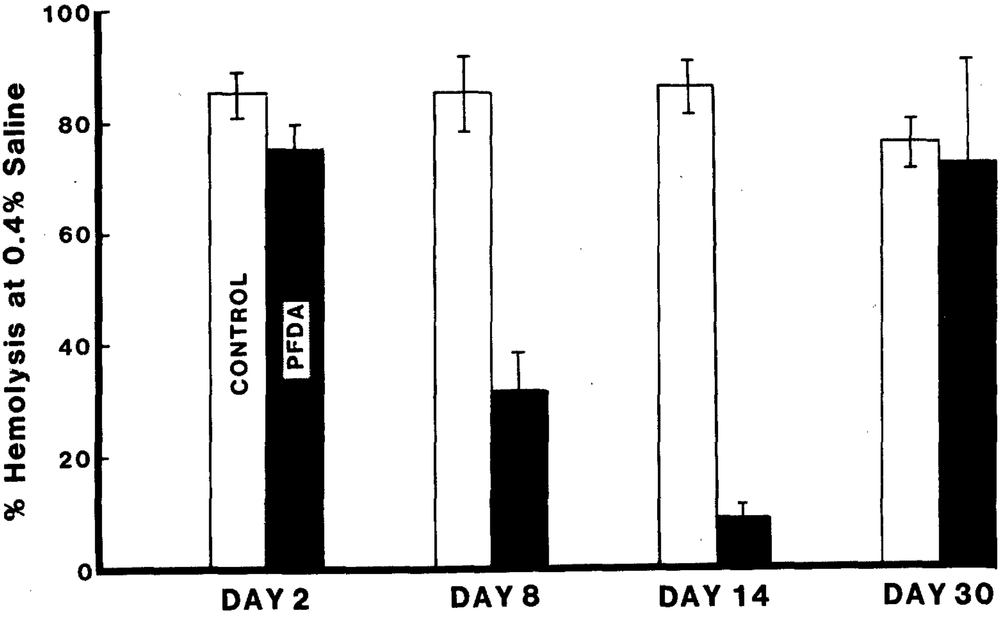


Figure 4. Relative osmotic fragilities of red blood cells from rats injected ip with 50 mg PFDA/kg and killed at various times after injection. Data are mean and standard deviation (n = 4-5). From the overall curves with 10 salt concentrations, the concentration at which 50% hemolysis occurred was 0.43, 0.38, 0.34, and 0.43%, respectively, in treated rats at 2, 8, 16, and 30 days. Control groups at these sampling times had 50% hemolysis at 0.45, 0.44, 0.45, and 0.43%, respectively.

Alterations in clone morphology seen after TCDD are striking, but estimations of concentration dependence are essentially qualitative, i.e., the percentage of abnormal clones is estimated by inspection and making a distinction between normal and slightly abnormal clones is difficult. We have maintained a restrictive definition of what constitutes an abnormal clone and scoring was done solely by Dr. A. M. Rogers. For these reasons, the estimated ED_{50} for the effects with TCDD are probably high. More quantitative determinations of these TCDD dose response curves await determination of the biochemical basis of the altered morphology and methods to unequivocally identify altered clonal units.

With PFDA, results are readily quantified since treated cells no longer proliferate in semi-soft agar. The ED_{50} - 24 hr for the loss of clone-forming ability was 0.3 µg/ml (i.e., about 6 x 10^{-7}M); this contrasts to a single dose LD_{50} in mice of about 100-150 mg PFDA/kg or 0.2-0.3 mmoles/kg (Andersen et al., 1981; Van Rafelghem and Andersen, unpublished experiments, 1981).

With the polyfluorinated acids examined, this toxicity is present with acids of chain length greater than 8. The differences in single cell toxicity between the fluorinated octanoic and decanoic acids are striking, but consistent with the different acute toxicity reported for these two acids in rats. The hydrogenated fatty acids are without differential effect on clone-forming ability of L5178Y cells. In terms of cell lysis, expressed as toxicity in suspension, hydrogenated and polyfluorinated fatty acids were about equipotent (Tables 1 and 2).

The molecular basis of the impairment of clone-forming ability is unknown. Subtle changes may have occurred in cell membranes to inhibit growth of cells when maintained in close contact. In this regard, the osmotic fragility results suggest a biological membrane more resistant to hypoosmotic insult. Increased resistance can be due to a variety of causes, one of which is altered membrane composition (Kuiper et al., 1971). Preliminary studies in our laboratory have now shown that erythrocytes from PFDA-treated animals also show increased membrane fluidity (M. George and M. E. Andersen, unpublished studies, 1982), and that the total fatty acid composition of the liver lipid pool in these rats shows a dramatic shift toward increasing unsaturation, especially in the stearic to oleic acid ratio (Olson et al., 1982). While indirect, these results suggest compositional and functional alterations in membranes subsequent to PFDA exposure in the rat in vivo.

There is no unifying hypothesis explaining the toxicity of TCDD and materials causing similar toxic effects, i.e., certain polyhalogenated biphenyls (Sleight et al., 1981; Biocca et al., 1981) and long-chain perfluorinated fatty acids of chain length 9 or above (Andersen et al., 1981). It may be that these various chemicals, including PFDA and TCDD, are toxic due to effects on cell membranes resulting in interference with cell-cell or cell-mediator interactions. These effects could either be direct or mediated by interference with some endogenous hormonal control of membrane composition/function. Toxicity would not be a result of cell necrosis or grossly visible organellar alterations, but from more subtle structural alterations of biomembranes and attendant disturbances in intercellular communication. This hypothesis is under active investigation in our laboratory.

The cell line used for this research was so-called TK $^{+/+}$ with regard to the gene locus for the enzyme thymidine kinase (TK). Our stock of these cells, brought to Dayton from England by Dr. Rogers, was destroyed during a malfunction of the deep freeze storage unit. We have not observed differential effects on suspension and clonal growth with L5178Y TK$^{+/-}$ cells - a cell line more commonly used in mutation research and, therefore, much more readily available. It appears that future work on this phenomenon will have to be restricted to the TK$^{+/+}$ cells.

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TOXICITY OF AQUEOUS FILMFORMING FOAMS TO MARINE ORGANISMS: LITERATURE REVIEW AND BIOLOGICAL ASSESSMENT

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This document summarizes information from literature regarding the toxicity of aqueous filmforming foams (AFFF) and presents results of supplementary toxicity tests using AFFF and appropriate marine organisms.

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INTRODUCTION

Aqueous filmforming foams (AFFF) are used regularly by the Air Force and Navy in training exercises at fire-fighting schools and, when necessary, for fuel/oil fire control aboard ship. These AFFF agents work by producing a flame-quenching blanket that floats on the surface of fuel and/or water. This blanketing results in complete surface vapor-proofing, cooling the fuel, and preventing reflash or reburning of the extinguished surface. These agents are also effective on unburned fuels, rendering them fireproof to future ignition.

The AFFFs are a combination of fluorocarbons, surfactants, and solubilizers. They have an exceptional resistance to thermal, chemical, electrical, and biological attack ~~(Chan, 1982)~~. The AFFF agents a oduced by only a few different manufacturers under the guidelines and spec ications given in MIL-F-24385C (Military Specification, 1981). Approximately million gallons of AFFF are produced for Naval and Air Force use annually. Depending on the formulation being used, the concentrate is diluted to either an optimum 3- or 6-percent solution with freshwater, seawater, or bilge water before using in fire-fighting systems. Wastewater resulting from training exercises generally contains less than half the original AFFF concentration. About 200 million gallons of AFFF wastewater are being generated annually by the Navy and the Air Force.

The usage of AFFF and the disposal of AFFF-laden wastewater have the potential for an adverse impact on the environment. These foams are potentially toxic due to the fluorocarbons and surfactants. Additionally, the wastewater contains other contaminants such as residual fuel and combustion products, which could add to the toxicity. The use of seawater or bilge water as the dilutor yields other potentially toxic contaminants from the high concentrations of chlorides and sulfides (Chan, 1982).

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The possible adverse effects of AFFF and AFFF-laden wastewater are divided into two categories: (1) the toxic effects to the aquatic/marine environment and (2) the effects on biological processes in sewage treatment plants. There is a potential for adverse effects on sewage treatment organisms if these wastewaters are discharged directly into the sewage system. Possible impacts are (1) inhibition of microbial oxygen uptake, (2) toxicity to microbial organisms, (3) foaming in aeration basins, and (4) development of sludge settling problems in clarifiers.

The toxicity of AFFF to various freshwater and marine organisms has been assessed. The 3-M Company (manufacturer of several "Lightwater" AFFF agents) has tested each of its products for toxicity to freshwater and/or marine organisms. Product Environmental Data Sheets prepared by the 3-M Company are presented in Appendix A. These reports provide information on the toxicity of AFFF agents to freshwater and marine organisms as well as information regarding possible effects on conventional biological treatment facilities. The USAF Environmental Health Laboratory, Kelly AFB, Texas, performed assays on AFFF agents manufactured by Ansul Company (Ansul K74-100); National Foam Systems, Inc. (Aer-O-Water 3 and Aer-O-Water 6); and 3-M Company (Lightwater FC-199, FC-200, and FC-206). Their toxicity data along with information regarding recommended levels to sewage treatment facilities and direct stream discharge are presented in Appendix B. A compilation of toxicity data from the available literature has been assembled and is presented as Table 1.

A-1

Table 1. Data available from the literature on the toxicity of AFFF agents to freshwater and marine organisms.

Agent/Species Assessed	(Freshwater/Marine)	Results of Study	Source
FC-199:			
Fathead Minnow (*Pimephales promelas*)	(FW)	96 hr LC_{50} = 398 mg/l	LeFebvre & Thomas, 1973
FC-200:			
Fathead Minnow (*Pimephales promelas*)	(FW)	96 hr LC_{50} = 97 mg/l	LeFebvre & Thomas, 1973
FC-203:			
Fathead Minnow (*Pimephales promelas*)	(FW)	96 hr LC_{50} = 750 mg/l	3M Co., 1980a
Rainbow Trout (*Salmo gairdneri*)	(FW)	96 hr LC_{50} = 1300 mg/l	3M Co., 1980a
Water Flea (*Daphnia magna*)	(FW)	48 hr LC_{50} = 1600 mg/l	3M Co., 1980a
Scud (*Gammarus fasciatus*)	(FW)	48 hr LC_{50} = 1100 mg/l	3M Co., 1980a
Green Algae (*Chlorella pyrenoidosa*)	(FW)	No growth inhibition @ 1000 mg/l	3M Co., 1980a
Blue-green Algae (*Phormidium inundatum*)	(FW)	No growth inhibition @ 1000 mg/l	3M Co., 1980a
Oyster larvae (*Crassostrea virginica*)	(M)	48 hr LC_{50} = 47 mg/l	3M Co., 1980a
Killifish (*Fundulus heteroclitus*)	(M)*	95 hr LC_{50} = 2500 mg/l	3M Co., 1980a
Grass Shrimp (*Palaemonetes pugio*)	(M)	96 hr LC_{50} = 510 mg/l	3M Co., 1980a
FC-203A:			
Fathead Minnow (*Pimephales promelas*)	(FW)	96 hr LC_{50} = 300 mg/l	3M Co., 1980a
FC-203C:			
Killifish (*Fundulus heteroclitus*)	(M)*	96 hr LC_{50} = 1400 mg/l	3M Co., 1982a
Fathead Minnow (*Pimephales promelas*)	(FW)	96 hr LC_{50} > 2000 mg/l	3M Co., 1982a
Green Algae (*Selenastrum capricornatum*)	(FW)	96 hr LC_{50} = 408 mg/l	3M Co., 1982a
FC-206:			
Fathead Minnow (*Pimephales promelas*)	(FW)	96 hr LC_{50} = 3000 mg/l	3M Co., 1980b
Fathead Minnow (*P. promelas*) juveniles	(FW)	96 hr LC_{50} = 1080 μl/l	LeFebvre & Inman, 1974
Fathead Minnow (*P. promelas*) fry	(FW)	96 hr LC_{50} = 170 μl/l	LeFebvre & Inman, 1974
Rainbow Trout (*Salmo gairdneri*)	(FW)	96 hr LC_{50} = 1800 mg/l	3M Co., 1980b
Killifish (*Fundulus heteroclitus*)	(M)*	96 hr LC_{50} = 1820 mg/l	3M Co., 1980b
Grass Shrimp (*Palaemonetes vulgaris*)	(M)	96 hr LC_{50} = 280 mg/l	3M Co., 1980b

* Found in brackish to saltwater environments.

Table 1. Data available from the literature on the toxicity of AFFF agents to freshwater and marine organisms (continued).

Agent/Species Assessed	(Freshwater/Marine)	Results of Study	Source
FC-206 (Continued):			
Fidler Crab (Uca pugilator)	(M)	96 hr LC$_{50}$ = 3260 mg/l	3M Co., 1980b
Oyster Larvae (Crassostrea virginica)	(M)	48 hr LC$_{50}$ = > 100 < 240 mg/l	3M Co., 1980b
Water Flea (Daphnia magna)	(FW)	48 hr LC$_{50}$ = 5850 mg/l	3M Co., 1980b
Scud (Gammarus fasciatus)	(FW)	48 hr LC$_{50}$ = 5170 mg/l	3M Co., 1980b
Green Algae (Chlorella pyrenoidosa)	(FW)	Growth inhibited at 1:1000 dilution	Chan 1982
Blue-green Algae (Phormidium inundatum)	(FW)	Growth inhibited at 1:1000 dilution	Chan, 1982
FC-206A:			
Bluegill Sunfish (Lepomis macrochirus)	(FW)	96 hr LC$_{50}$ = 1200 mg/l	3M Co., 1980c
Fathead Minnow (Pimephales promelas)	(FW)	96 hr LC$_{50}$ > 3000 mg/l	3M Co., 1980c
Water Flea (Daphnia magna)	(FW)	48 hr LC$_{50}$ = 2300 mg/l	3M Co., 1980c
FC-206C:			
Killifish (Fundulus heteroclitus)	(M)*	96 hr LC$_{50}$ > 2000 mg/l	3M Co., 1982b
Fathead Minnow (Pimephales promelas)	(FW)	96 hr LC$_{50}$ > 2000 mg/l	3M Co., 1982b
Green Algae (Selenastrum capricornutum)	(FW)	96 hr LC$_{50}$ = 345 mg/l	3M Co., 1982b
FC-780:			
Killifish (Fundulus heteroclitus)	(M)*	96 hr LC$_{50}$ > 5000 mg/l	3M Co., 1982c
FC-780B:			
Bluegill Sunfish (Lepomis machrochirus)	(FW)	96 hr LC$_{50}$ = 1600 mg/l	3M Co., 1981
Killifish (Fundulus heteroclitus)	(M)*	96 hr LC$_{50}$ = 3900 mg/l	3M Co., 1981
AOW-3:			
Fathead Minnow (Pimephales promelas)	(FW)	96 hr LC$_{50}$ = 600 mg/l	LeFebvre & Thomas, 1973
AOW-6:			
Fathead Minnow (Pimephales promelas)	(FW)	96 hr LC$_{50}$ = 225 mg/l	LeFebvre & Thomas, 1973
ANSUL K74-100:			
Fathead Minnow (Pimephales promelas)	(FW)	96 hr LC$_{50}$ = 1100 mg/l	LeFebvre & Inman, 1975

These earlier studies demonstrated that a wide range of toxic concentrations exist for a variety of organisms. Larvae of the Eastern oyster (Crassostrea virginica) were the most sensitive organisms tested, with a 48-hour EC_{50} of 47 mg/liter to the FC-203 formulation (manufactured by the 3-M Company). All species of fish tested showed a high tolerance to the various AFFF agents tested with an average LC_{50} near 1500 mg/liter. In general, these data suggest the available AFFF formulations are mildly toxic or nontoxic.

The second area of concern is the impact of AFFF on sewage treatment organisms. The 3-M Company has performed biodegradation tests, microbial respiration inhibition tests, and activated sludge pilot plant studies on many of its AFFF products. These results, along with the recommended treatment concentrations, are summarized in Table 2. Information for AFFF agents produced by the Ansul Company and the National Foam Systems Company are also included in this table. These data suggest that there is little potential for toxicity from AFFF introduced to the sewage treatment facilities. There is a potential problem, however, with excessive foaming for some of the agents. The recommended treatment concentrations reflect these precautions.

The vast majority of the available toxicity data has come from studies performed on freshwater organisms. Since there is a high potential for dispersion of AFFF in the marine environment and this is a prime Navy operating area, more studies on the toxicity to marine organisms should be conducted before a final assessment can be made. The purpose of this study was to collect information from the literature regarding the toxicity of AFFF and conduct supplementary toxicity tests using AFFF and appropriate marine organisms. This work was performed during October 1982 at the Naval Ocean Systems Center by personnel in the Marine Sciences Division with funding from the Naval Facilities Engineering Command.

METHODS

The FC-780B AFFF agent manufactured by the 3-M Company is the formulation currently being used by the Navy. It is routinely diluted to a 6-percent solution for fire-fighting purposes. It was assessed for toxicity to marine phytoplankton and crustaceans. The 96-hour definitive toxicity tests were preceded with a series of range-finding tests to identify the approximate toxic concentration. Conditions and procedures were the same for both range-finding and definitive toxicity tests. The species selected for these tests are routinely used for bioassays and toxicity testing.

TOXICITY TO PHYTOPLANKTON

The toxicity of this AFFF agent to marine phytoplankton was determined by monitoring in vivo fluorescence (IVF) and 3-(3,4-dichlorophenyl)-1, 1-dimethylurea (DCMU)-induced fluorescence (DCMU-F). The IVF measurements were used to estimate growth rates according to the procedures given in Lockheed (1979), with minor modifications. The ratios of DCMU-F to IVF were calculated for phytoplankton under the various test conditions and used as a measure of photosynthetic efficiency (Roy & Legendre, 1979, 1980).

Table 2. Effects of various AFFF agents on sewage treatment facilities. Information collected from data reported in the literature.

AFFF Agent/ 20 Day BOD (mg/l)	Effects on Microbial Respiration	Effects on Microbial Activity	Activated Sludge Pilot Plant Studies	Recommended Treatment Concentration/Source
FC-200: 339,000	N/A	N/A	N/A	5 µl/l Thomas & LeFebvre, 1974
FC-203: 1,060,000	No inhibition @ conc. up to 1000 mg/l	No inhibition @ conc. up to 1000 mg/l	N/A	N/A 3M Co., 1980a
FC-203A: 427,000	N/A	N/A	N/A	N/A 3M Co., 1980a
FC-203C: 580,000	No inhibition @ conc. up to 1000 mg/l.	N/A	N/A	25 mg/l 3M Co., 1982a
FC-206: 210,000	No inhibition @ conc. up to 1000 mg/l.	No inhibition @ conc. up to 1000 mg/l.	Acceptable treatability below 1000 mg/l; 1000 mg/l does cause foaming.	100 mg/l 3M Co., 1980b
FC-206A: 330,000	No inhibition @ conc. up to 1000 mg/l.	No inhibition @ conc. up to 1000 mg/l.	No foaming or sludge settling problems during testing.	N/A 3M Co., 1980c
FC-206C: 330,000	No inhibition @ conc. up to 1000 mg/l.	N/A	N/A	50/mg/l 3M Co., 1982b
FC-780B: 372,000	N/A	N/A	N/A	100 mg/l 3M Co., 1981
AOW-3: 338,000	N/A	N/A	N/A	60 µl/l LeFebvre & Thomas, 1973
AOW-6: 287,000	N/A	N/A	N/A	22.5 µl/l LeFebvre & Thomas, 1973
ANSUL K74-100: 154,000	N/A	N/A	N/A	55 µ/l LeFebvre & Inman, 1975

NA = Not applicable

The phytoplankton Dunaliella sp. (Division Chlorophyta) was selected as the test species for this study. Stock cultures of Dunaliella were maintained in exponential-phase growth on Guillard's F/2 medium (Guillard & Ryther, 1962) at constant temperature (18 °C) and illumination (1.9 milliwatts/cm^2).

Determination of Test Concentrations

Two range-finding tests were done prior to the definitive toxicity test with Dunaliella. In the first range-finding test, FC-780B AFFF concentrations of 0.01, 0.10, and 1.00 gm/liter were assessed over a 96-hour period. No deleterious effects were observed in phytoplankton at these concentrations of this AFFF agent. The second range-finding test, a 72-hour assay, resulted in no effect at either a 1.0- or a 2.0-gm/liter exposure. Complete cessation of growth and death of cells were observed at the 10.0-gm/liter exposure after 72 hours. A concentration of 60.0-gm/liter (equal to the 6-percent dilution) resulted in immediate death of the exposed phytoplankton. The AFFF concentrations used in the definitive toxicity test, 2.0, 4.0, 8.0, and 10.0 gm/liter plus controls, were selected from the results obtained in the second range-finding test.

Test Procedures

For all toxicity tests, 1.5 liters of culture media were inoculated with stock phytoplankton 5 days prior to the start of the test. After this 5-day period, the cells had entered exponential-phase growth. Cell density was approximately 6.0 times 10^4 cells/ml. Test solutions were prepared by adding 100 ml of this culture to 100 ml of each AFFF test solution. A final cell density of 3 times 10^4 cells/ml was achieved. Control samples were prepared by combining 100 ml of the phytoplankton culture with 100 ml of filtered seawater.

The AFFF test solutions were prepared by weighing aliquots of AFFF concentrate to the nearest 0.001 gm. These known amounts of concentrate were diluted with appropriate volumes of 0.45-μ filtered seawater to achieve the desired AFFF concentrations.

Twenty replicates were prepared for the controls and for each FC-780B AFFF concentration assessed. A 6.5-ml aliquot of phytoplankton/AFFF solution was delivered to the test containers. Ten-ml (13 by 100 mm) glass-stoppered KIMAS glass tubes were used for the test containers. These tubes fit directly into the fluorometer.

All tubes were cleaned and conditioned in the following manner. They were first soaked for 24 hours in RBS-35 biological cleaning solution. This solution was decanted, and the tubes were rinsed six times in hot tap water followed by six rinses with deionized water. A 24-hour soak in filtered seawater followed the washing regime. The seawater soak was decanted just prior to the start of the test.

Immediately after combining algae and AFFF, the tubes were filled with the test solutions and IVF measurements were made on all replicates. Fluorescence measurements were made with a Turner Designs model 10-000R fluorometer. Following these IVF measurements, DCMU-F measurements were made on three replicates selected randomly from each treatment condition. DCMU-F measurements were made approximately 1 minute after adding 50 µl deionized water saturated with DCMU to the phytoplankton samples. The samples containing DCMU were discarded after measurement; remaining samples were maintained in a constant temperature incubator (18 °C) under constant illumination (1.9 milliwatts/cm^2). Tubes were held in a wire mesh rack suspended approximately 18 cm above eight "Cool White" fluorescent bulbs.

The IVF and DCMU-F measurements were made at 24-hour intervals over a 96-hour period. All samples were placed on a Vortex mixer for 15 seconds prior to measurement to assure sample homogeneity.

Data Analysis

The data obtained over the 96-hour period were used to assess differences in growth rates and photosynthetic efficiencies in phytoplankton. Growth rates were determined from the IVF data. Using the IVF data as the dependent variable and time as the independent variable, linear regression equations were generated for phytoplankton grown under each condition. Since growth rate is approximated by the slope of the regression line, similar slopes indicate similar growth rates. An analysis of covariance on these linear regression equations was used to compare growth rates (slopes) of controls and treatments. The data were also displayed graphically to depict subtle changes in IVF over time, since the regression equations and the statistical analyses did not show where such changes occurred.

The productivity efficiency of phytoplankton was computed as the ratio of DCMU-F to IVF. These values were determined for each 24-hour period over the 96 hours. As with the IVF data, the productivity efficiency data were plotted against time to depict subtle trends. The Kruskal-Wallis test was used to determine if differences existed among treatments at each sampling period. This statistical test compares each sample with all remaining samples to maximize the number of possible comparisons. If a significant difference was detected by the Kruskal-Wallis test, the nonparametric multiple range test (Zar, 1974) was used to determine where differences occurred. Control versus "Treatment" comparisons are reported here. All statistical tests were performed at the 95-percent confidence level.

TOXICITY TO BRINE SHRIMP

The second species selected for AFFF toxicity testing was Artemia salina, commonly known as brine shrimp. Toxicity to brine shrimp was determined by calculating the percent survival after a 96-hour exposure period. Ten-day-old larvae were used in this series of tests.

Larvae were obtained by hatching brine shrimp eggs in the laboratory. San Francisco Bay brand eggs were mixed with seawater and aerated to assure continual mixing of the solution. The brine shrimp hatched 48-72 hours later. At this time, larvae were separated from egg cases and maintained on the green alga Dunaliella for 10 days. Brine shrimp were held in the constant temperature (18 °C) and illumination (1.9 milliwatts/cm^2) incubator during the rearing phase and toxicity testing.

Determination of Test Concentrations

Previous experiments in this laboratory with brine shrimp have indicated their tolerance to toxic materials to be equal to or greater than that demonstrated by Dunaliella. For this reason, the first range-finding test with brine shrimp assessed AFFF concentrations of 0.10, 0.50, and 1.0 gm/liter. After 72 hours, survival was 100 percent for the controls and 88 percent for shrimp exposed to the highest concentration of AFFF (1.0 gm/liter). Since this test demonstrated no toxicity, a second test was run in which AFFF concentrations of 1.0, 3.0, and 9.0 gm/liter were assessed. One-hundred-percent mortality was observed at the highest concentration after 96 hours. Survival at 1.0 and 3.0 gm/liter was 86 and 52 percent, respectively. Survival for the control organisms was 80 percent after 96 hours. Because of this low control survival, these test results could not be used in determining LC$_{50}$ values for brine shrimp exposed to AFFF. However, apparently AFFF concentrations ranging from 1.0 to 9.0 gm/liter should bracket the LC$_{50}$. Therefore, these same concentrations were used in the definitive toxicity test.

Test Procedures

Test solutions of the desired concentrations were prepared by adding known amounts of AFFF concentrate to appropriate volumes of 0.45 μ filtered seawater. Five replicates per concentration were prepared, each consisting of 40 ml. Five controls were also prepared, each containing 40 ml of 0.45 μ filtered seawater. The test containers used were 50-ml glass test tubes, cleaned and conditioned as previously described for glassware used in the phytoplankton tests. After the tubes were filled with test solutions, 10 larval brine shrimp were fed Dunaliella (approximately 4 times 10^5 cells/shrimp/day). The samples were maintained for 96 hours in the incubator. The number of live shrimp per replicate was recorded at 24-hour intervals.

Data Analysis

The survival data for each treatment were plotted against time to examine trends. The 96-hour survival data were compared statistically with the Kruskall-Wallis test to determine if differences existed among treatments. If differences were detected, the nonparametric multiple range test was used to identify where these differences existed. The data were evaluated at the 95-percent confidence level.

RESULTS

PHYTOPLANKTON

Growth curves were generated from the IVF data for the control algae and for algae exposed to various concentrations of AFFF (Figure 1). Changes in IVF over time are quite similar for the controls and the 2.0-gm/liter exposure. Dunaliella at the 2.0-gm/liter exposure had a slightly higher IVF output than the controls. With 4.0-gm/liter AFFF, IVF was lower than the controls only during the first 48 hours. After 48 hours this treatment series demonstrated increased IVF. This suggests that the cells were only affected initially and later recovered. There was no change in IVF for Dunaliella at the 8.0-gm/liter exposure over the first 72 hours. A very short increase in IVF was seen with the 96-hour measurement. There was essentially no change in IVF over time for Dunaliella at the 10.0-gm/liter exposure.

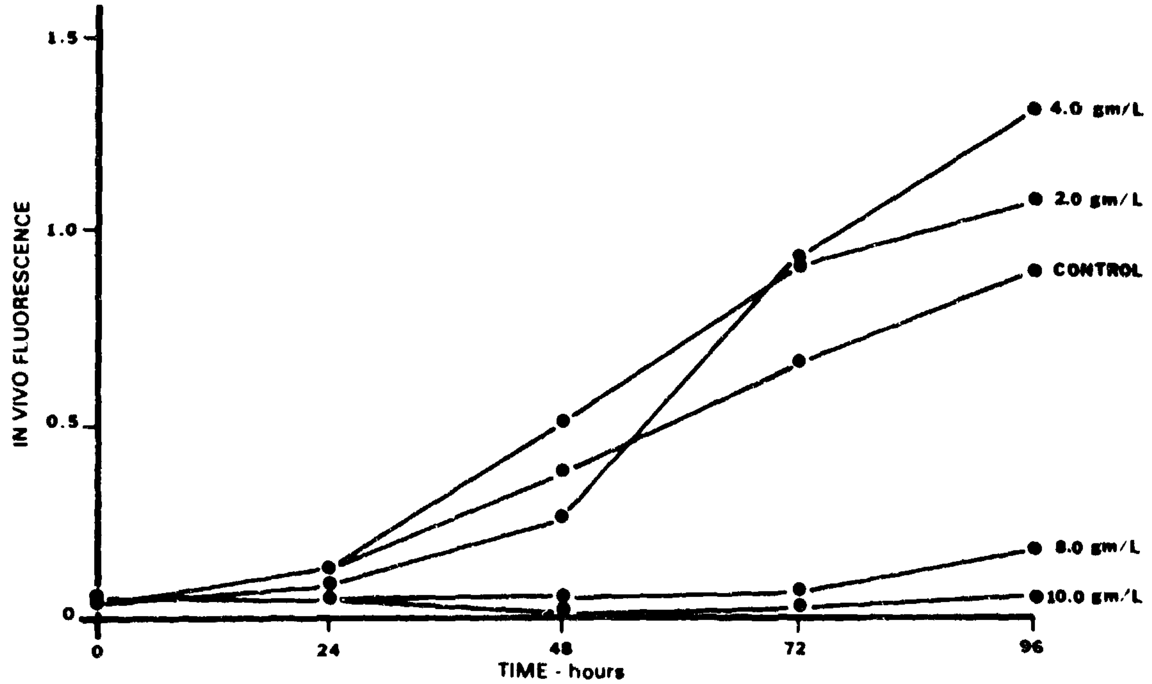

Figure 1. Effects of AFFF on the in vivo fluorescence of *Dunaliella* during the 96-hour exposure period.

These growth curves were analyzed with a linear regression analysis and an analysis of covariance (Table 3). The results of these statistical tests indicated significant differences in slopes between the controls and both the 2.0-gm/liter and the 4.0-gm/liter treatments. In both cases, the growth rates for exposed phytoplankton were significantly higher than the growth rate for the controls. This suggests there was possible growth stimulation in Dunaliella due to AFFF exposure.

Table 3. Linear regression equations generated from the in vivo fluorescence data and the results of statistical analyses on these data. Data evaluated at the 95-percent confidence level.

	Linear Regression Equation	r^2
Control	$Y = 0.0098X - 0.030$	0.9606
2.0 gm/liter	$Y = 0.0120X - 0.0382$	0.9604
4.0 gm/liter	$Y = 0.0140X - 0.1401$	0.8905
8.0 gm/liter	$Y = 0.0013X - 0.0133$	0.4280
10.0 gm/liter	$Y = 0.000067X - 0.0377$	0.0140

Analysis of Covariance Test Results

$F_{calc} = 14.31$

$F_{crit} = 3.09$

Yes, there is a significant difference among slopes.

Multiple Comparison Test Results

	Q_{calc}	Q_{crit}	Conclusion
Control vs 2.0	5.99	2.00	Significant difference
Control vs 4.0	6.76	3.35	Significant difference
2.0 vs 4.0	3.16	2.80	Significant difference
Control vs 8.0	--	--	Significant difference*
Control vs 10.0	--	--	Significant difference*

* Significant difference determined by visual examination of data and resulting linear regression equations.

When compared to the controls, both the 8.0- and 10.0-gm/liter AFFF treatments had significantly lower growth rates (Figure 1). These differences are obvious from the graphical data. The data from these treatments were not analyzed statistically because they did not meet the necessary criteria of significant regressions. Regression equations for these two data sets had slopes of essentially zero. Both data sets had negative growth rates for the first 2 days of the experiment. Low levels of IVF exhibited by the 8.0- and 10.0-gm/liter exposures indicate that growth in Dunaliella was inhibited at these AFFF concentrations.

The ratios of DCMU-F/IVF obtained for the controls and Dunaliella exposed to four concentrations of the FC-780B AFFF over the 96-hour period are shown in Figure 2. The relationships observed in the IVF data between controls and AFFF-exposed phytoplankton are also present in these ratios. First, the ratios for the 2.0-gm/liter exposure parallel the control values throughout the test, with the values for the treatments being slightly lower than the controls. The 4.0-gm/liter exposure resulted in decreasing ratios over the first 72 hours and increasing ratios over the next 48 hours. After 96 hours, the ratios were quite similar to the controls. This increase may be an indication of recovery by Dunaliella. Exposure of Dunaliella to 8.0- and 10.0-gm/liter AFFF resulted in ratios that declined from 2.0 to approximately 1.0 during the first 48 hours. A ratio of 1.0 is characteristic of dead or near-dead cultures. A slight increase in the DCMU-F/IVF ratio was observed during the last 24 hours for phytoplankton as the 8.0-gm/liter exposure. Phytoplankton exposed to 10.0-gm/liter AFFF did not show signs of recovery over the entire test period.

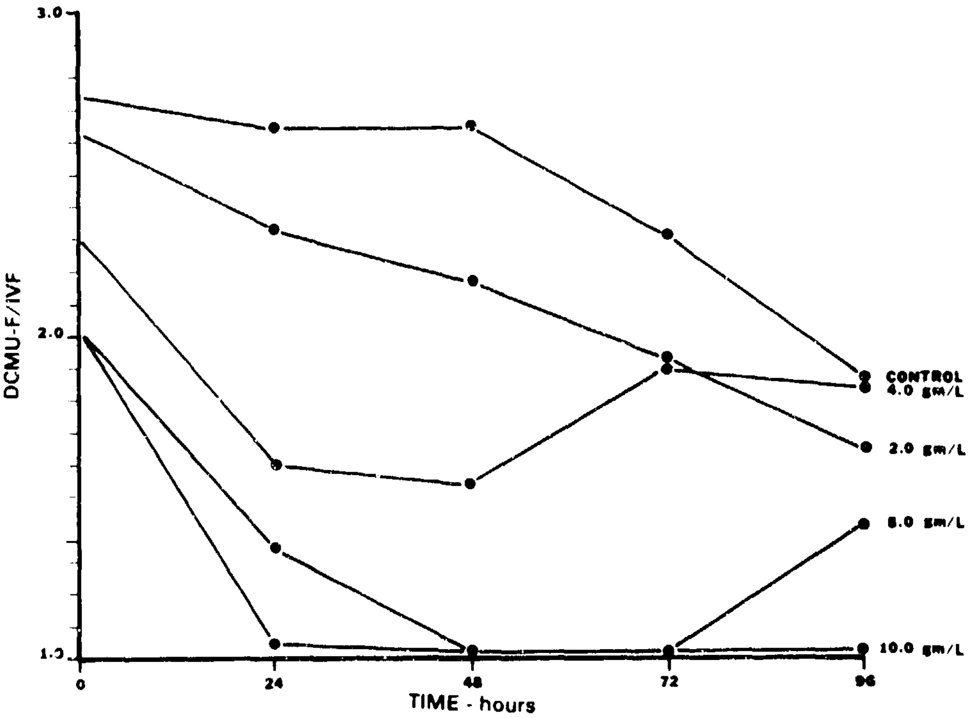

Figure 2. Effects of the FC-780B AFFF on the ratio of DCMU-fluorescence to in vivo fluorescence for *Dunaliella* during the 96-hour exposure period.

The Kruskal-Wallis tests applied to the DCMU-F/IVF ratios resulted in significant intergroup differences at each sampling period. Multiple range tests (Table 4) indicated the ratios for phytoplankton at the 2.0-gm/liter exposure were similar to those of the control phytoplankton throughout the 96 hours. The ratios for phytoplankton at the 8.0- and 10.0-gm/liter exposures were significantly different from the control values over the same period. Significant differences in ratios between the controls and phytoplankton at the 4.0-gm/liter exposure were found to exist at the 24- and 48-hour sampling periods.

Table 4. Results of the nonparametric multiple comparisons performed on productivity efficiency data. All evaluations were made at the 95-percent confidence level.

Nonparametric Multiple Comparison Test Results

Time of Measurement	Significantly Similar	Significantly Different
Initial - T_o	Control = 2.0 gm/l Control = 4.0	Control ≠ 8.0 gm/l Control ≠ 10.0
24 Hours	Control = 2.0 gm/l	Control ≠ 4.0 gm/l Control ≠ 8.0 Control ≠ 10.0
48 Hours	Control = 2.0 gm/l	Control ≠ 4.0 gm/l Control ≠ 8.0 Control ≠ 10.0
72 Hours	Control = 2.0 gm/l Control = 4.0	Control ≠ 8.0 gm/l Control ≠ 10.0
96 Hours	Control = 2.0 gm/l Control = 4.0	Control ≠ 8.0 gm/l Control ≠ 10.0

The phytoplankton were examined for cellular abnormalities, activity, and general appearance at the end of the test. A Zeiss light microscope was used. Algal cells from the controls and the 2.0-gm/liter treatment appeared active with normal shapes and sizes. Very little detrital material was present. Cells from the 4.0-gm/liter exposure were also active and of normal shape and size, but the density was slightly depressed. The 8.0-gm/liter exposure resulted in both suppressed densities and activity. Surviving cells were of the normal shape and size; however, much detrital material was observed. Very few live cells were found in the 10.0-gm/liter exposure. The sample media for this treatment contained a high level of particulates.

BRINE SHRIMP

The survival data obtained for 10-day-old larval brine shrimp are given in Figure 3. Control survival was 98 percent after 96 hours. Treatment survival after 96 hours for the 1.0- and 3.0-gm/liter AFFF exposures were 92 and 96 percent, respectively. No significant differences were found between controls and treatments. The results suggest 9.0-gm/liter AFFF is toxic to these organisms. Survival was 46 percent at 48 hours, 10 percent at 72 hours, and 0 percent at 96 hours.

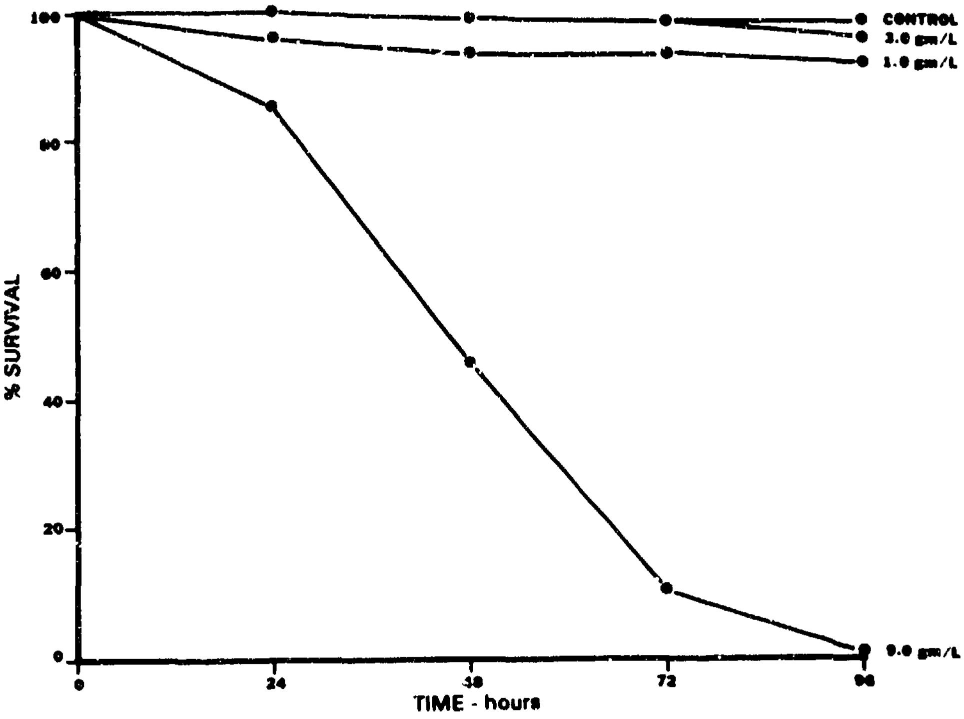

Figure 3. Effects of the FC-780B AFFF on the survival rate of *Artemia salina* during the 96-hour exposure period.

The brine shrimp were actively swimming throughout the test in the controls, 1.0-, and 3.0-gm/liter exposures. Phytoplankton added as the food source increased slightly in density over time for the same three conditions. Brine shrimp in the 9.0-gm/liter exposure were inactive after the first 24 hours with the majority laying on the bottom of the test tubes. Phytoplankton supplied to these samples did not increase in density over time. These samples turned slightly cloudy after 48 hours.

DISCUSSION

FC-780B AFFF was not toxic to the marine alga Dunaliella at concentrations up to 4.0-gm/liter (40,000 ppm). Based on data from this study, the 96-hour EC_{50} for Dunaliella for FC-780B AFFF is between 4.0- and 8.0-gm/liter. It is not clear whether the actual EC_{50} is closer to 4.0- or 8.0-gm/liter, but based on the fact that 4.0-gm/liter did have a slight effect at 48 hours and the 8.0-gm/liter killed almost everything, it is likely that the actual EC_{50} is closer to 4.0-gm/liter.

Similarly, there was no significant toxicity to brine shrimp nauplii (Artemia salina) at concentrations of 3.0-gm/liter (30,000 ppm). There was a significant difference in survival between the 3.0-gm/liter exposure and the

9.0-gm/liter exposure. The estimated 96-hour LC_{50} is between 4.0 and 6.0-gm/liter. The 96-hour LC_{50} estimated for brine shrimp is in the range of those reported by the 3-M Company (1981) for Bluegill sunfish (1.6 gm/liter) and Killifish (3.9 gm/liter).

From the available literature, the 96-hour LC_{50} concentrations for the majority of organisms appear to be equal to or slightly greater than 1.0 gm/liter. The results obtained in this and previous studies show that the various AFFF agents can be considered mildly toxic to marine life at concentrations near 6.0 gm/liter. This is within a factor of 10 from concentrations actually used in fire-fighting operations (60 gm/liter). Between 3.0 and 4.0 gm/liters there may be a sublethal effect, but both Dunaliella and A. salina appear to recover from these effects. AFFF concentrations below 1.0 gm/liter are not toxic to the marine organisms tested here.

The increase in phytoplankton density upon exposure to the lower concentrations of AFFF suggests algal blooms may result from dumping this material into seawater. The reason for enhanced growth is unclear at this time. However, they may not be a significant problem since concentrated AFFF will not remain in the water column very long. Tidal cycles, wave activity, and currents will aid in dispersing and diluting the AFFF.

The recovery capability of phytoplankton after exposure to AFFF concentrations approaching the EC_{50} is an indication of the organisms' ability to avoid significant environmental impacts. This recovery was observed in both cell density and productivity efficiency for Dunaliella exposed to AFFF concentrations of 4.0 gm/liter. As the concentration decreases due to initial mixing in the water column, exposed phytoplankton have the capability of recovering from the initial shock and reproducing normally.

The potential problems in sewage treatment facilities have not been addressed in depth in this study. The 3-M Company suggests diluting the FC-780B AFFF formulation at a rate of 1 gallon per 10,000 gallons sewage (see the Product Environmental Data Sheet for the FC-780B AFFF agent, Appendix A). This dilution rate prevents serious foaming in aeration basins as well as settling problems in the clarifiers. The data reported in the available literature show that the problems of disposal and introduction into sewage treatment systems have been adequately covered.

In addition to the retention times and treatment procedures in disposal operations being worked out for several AFFF agents, an alternative method of disposal has been investigated. The Naval Civil Engineering Laboratory (NCEL) has developed an oil/water separation system based on ultrafiltration and reverse osmosis processes. This system is capable of separating unburned oil and AFFF from the wastewater (Chan, 1982). Both oil and AFFF are reclaimed and used again rather than being dumped into the sewage system or seawater. Only after complete separation is the wastewater dumped. NCEL tested the system at the San Diego Navy Firefighting School during 1979. The results of these studies were very promising. It is a very feasible method of reclaiming fuel and AFFF as well as eliminating potential adverse environmental impacts resulting from ocean or sewage system disposal.

CONCLUSIONS

Cont'd

The results of this study suggest that the dispersion of AFFF agents in the marine environment should not have a significant impact on marine life. Dilution of the 6-percent solution used for fire-fighting operations by wave and tidal activity results in concentrations that can be considered mildly toxic or nontoxic to marine life. The FC-780B AFFF is not toxic to the marine alga Dunaliella at concentrations up to 4.0 gm/liter. The estimated 96-hour LC_{50} for brine shrimp, Artemia salina, is between 4.0 and 6.0 gm/liter. These LC_{50} concentrations are in the range of those reported for other marine and freshwater organisms.

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APPENDIX A

3-M PRODUCT

ENVIRONMENTAL DATA SHEETS

Product Environmental Data

Environmental Laboratory
Environmental Engineering and Pollution Control
900 Bush Avenue
PO Box 33331
St. Paul, MN 55133
612/778 5104

COMMERCIAL CHEMICALS DIVISION
"LIGHT WATER" BRAND AQUEOUS FILM FORMING FOAM CONCENTRATES
FC-203 AND FC-203A

DESCRIPTION: Water-miscible fire extinguishing agents.

APPEARANCE: Clear, amber liquids.

USAGE: Foams, containing 3% FC-203 or FC-203A in water, cover and thus extinguish hydrocarbon liquid-based fires. For more detailed usage information, see your technical service representative.

WASTE DISCHARGE: Facilities which use "LIGHT WATER" Brand AFFF agents in actual or simulated firefighting activities usually direct the resulting wastes to wastewater treatment systems. Whenever possible, 3M recommends disposing of FC-203 and FC-203A wastes in this manner. However, aquatic and soil environments sometimes receive these wastes untreated.

AQUATIC TOXICITY DATA:

Freshwater Organisms Fish	Static 96-Hr. LC_{50}	
	FC-203	FC-203A
Fathead minnow (*Pimephales promelas*)	750 mg/l	300 mg/l
Rainbow trout (*Salmo gairdneri*)	1300 mg/l	--
Invertebrates	Static 48-Hr. LC_{50}	
Water flea (*Daphnia magna*)	1600 mg/l (1300-2100 mg/l)*	
Scud (*Gammarus fasciatus*)	1100 mg/l (840-1300 mg/l)*	

Algae - FC-203 concentrations $\leq$1000 mg/l did not prevent the growth of *Chlorella pyrenoidosa* and *Phormidium inundatum*.

Date: 7/29/80 (Supersedes 3/4/80) Page 1 of 3

Environmental Laboratory
Environmental Engineering and Pollution Control
900 Bush Avenue
PO Box 33331
St Paul, MN 55133
612/778 5104

COMMERCIAL CHEMICALS DIVISION
"LIGHT WATER" BRAND AQUEOUS FILM
FORMING FOAM CONCENTRATES
FC-203 AND FC-203A

(continued)

AQUATIC TOXICITY DATA (continued)

Marine Organisms

Species	48-Hr. EC_{50}** (FC-203)
Eastern Oyster embryo-larvae (*Crassostrea virginica*)	47 mg/l (10-234 mg/l)*
	96-Hr. LC_{50} (FC-203)
Common mummichog (*Fundulus heteroclitus*)	2500 mg/l (1700-3600 mg/l)*
Grass shrimp (*Palaemonetes pugio*)	510 mg/l (360-710 mg/l)*

Low DO could have contributed to the toxicity of FC-203 to shrimp.

* 95% confidence limits
** The effect measured was the reduction of the number of embryo-larvae developing to the straight-hinged veliger stage.

TOTAL ORGANIC CARBON (TOC): 264,000 mg/l

BIODEGRADATION AND TREATABILITY DATA:

Biodegradation	FC-203	FC-203A
BOD_5	560,000 mg/l	72,000 mg/l
BOD_{20}	1,060,000 mg/l	427,000 mg/l
COD	1,070,000 mg/l	648,000 mg/l

Product Environmental Data

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COMMERCIAL CHEMICALS DIVISION
"LIGHT WATER" BRAND AQUEOUS FILM
FORMING FOAM CONCENTRATES
FC-203 AND FC-203A

(continued)

Effect on Microbial Respiration

Dissolved oxygen concentration measurements, performed by placing a dissolved oxygen probe in activated sludge mixed liquor and ceasing aeration, showed no inhibition of microbial oxygen uptake rates at FC-203 concentrations up to 1000 mg/l.

Effect on Microbial Activity

The TTC* test, which measures microbial toxicity by assaying dehydrogenase enzyme activity in microbial cultures, showed no enzyme inhibition at FC-203 concentrations up to 1000 mg/l. This indicates an absence of microbial toxicity at this concentration.

*TTC (2,3,5-Triphenyltetrazolium Chloride) Re: "Dehydrogenase Enzyme as a Parameter of Activated Sludge Activities," Ford, et al. Proceedings of the 21st Industrial Waste Conference, Purdue, May 3, 4, and 5, 1966.

When possible, tests were performed in accordance with Standard Methods for the Examination of Water and Wastewater, American Public Health Association, 1740 Broadway, New York, 10019.

Date: 7/29/80 (Supersedes 3/4/80) Page 3 of 3

Product Environmental Data

3M

Environmental Laboratory
Environmental Engineering and Pollution Control
900 Bush Avenue
PO Box 33331
St. Paul, MN 55133
612/778 5104

COMMERCIAL CHEMICALS DIVISION
"LIGHT WATER" BRAND AQUEOUS FILM FORMING FOAM CONCENTRATE
FC-206

DESCRIPTION: Water-miscible fire extinguishing agent.

APPEARANCE: Clear, amber liquid.

USAGE: Foams, containing 6% FC-206 in water, cover and thus extinguish hydrocarbon liquid-based fires. For more detailed usage information, see your technical service representative.

WASTE DISCHARGE: Facilities which use FC-206 in actual or simulated firefighting activities usually direct the resulting wastes to wastewater treatment systems. Whenever possible, 3M recommends disposing of FC-206 wastes in this manner. However, aquatic and soil environments sometimes receive these wastes untreated.

AQUATIC TOXICITY DATA:

Freshwater Organisms

Species

Invertebrates	48-Hr. LC_{50}
Water flea (*Daphnia magna*)	5850 mg/l
Scud (*Gammarus fasciatus*)	5170 mg/l

Fish	96-Hr. LC_{50}
Fathead minnow (*Pimephales promelas*)	3000 mg/l Continuous Flow Test 1500 mg/l Static Test
Rainbow trout (*Salmo gairdneri*)	1800 mg/l Static Test

Marine Organisms	96-Hr. LC_{50}
Mummichog (*Fundulus heteroclitus*)	1820 mg/l Static Test
Grass shrimp (*Palaemonetes vulgaris*)	280 mg/l Static Test
Fiddler Crab (*Uca pugilator*)	3260 mg/l Static Test

Date: 12/11/80 (Supersedes 4/4/79) Page 1 of 4

Product
Environmental Data

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612/778 5104

COMMERCIAL CHEMICALS DIVISION
"LIGHT WATER" BRAND AQUEOUS FILM
FORMING FOAM CONCENTRATE
FC-206

(continued)

AQUATIC TOXICITY DATA (continued)

Marine Organisms	48-Hr. EC_{50}
Atlantic oyster larvae (Crassostrea virginica)	>100 <240 mg/l

SOIL SORPTION STUDIES:

Effect of Soil on Toxicity

Soil contact with FC-206 solutions reduces their aquatic toxicity. In the absence of soil, only 60% of fathead minnows (Pimephales promelas) survived 48-hr. static exposure to 2500 mg/l of FC-206. None survived for 72 hours. Mixing 10 g/l of 2% organic soil containing 56% sand, 21% silt, and 23% clay into the same FC-206 solution increased fish survival to 100% at 48 hours and 50% at 72 hours. Suspended soil components in natural waters are expected to similarly reduce FC-206 toxicity.

Soil COD Removal

Shaking 100-ml aqueous solutions of FC-206 for 24 hours with 100 g of soil reduced the soluble COD. The soil used was 57% sand, 36% silt, and 7% clay. It had a 2.5% organic matter content and a cation exchange capacity of 15.3 meq/100 g. The results summarized in the following table suggest that at low concentrations of FC-206, soil contact may also reduce the COD of wastewater.

Concentration of FC-206 in Initial Aqueous Solution (mg/l)	% of COD Removed From Aqueous Phase
600	30
6,000	7
60,000	3

Date:
12/11/80 (Supersedes 4/4/79) Page 2 of 4

COMMERCIAL CHEMICALS DIVISION
"LIGHT WATER" BRAND AQUEOUS FILM
FORMING FOAM CONCENTRATE
FC-206

(continued)

BIODEGRADATION AND TREATABILITY DATA:

5-Day Biochemical Oxygen Demand (BOD_5)	210,000 mg/l
20-Day Biochemical Oxygen Demand (BOD_{20})	420,000 mg/l
Chemical Oxygen Demand (COD)	420,000 mg/l
Total Organic Carbon (TOC)	94,000 mg/kg

OECD Biodegradation Test

The "Modified OECD Screening Test with DOC Analysis" and supplemental parallel sterile controls conclusively demonstrated the extensive biodegradability of FC-206. In 14 days, the dissolved organic carbon (DOC) levels of FC-206 degraded by 90%. The parallel sterile controls proved that this DOC loss was not due to chemical or physical processes such as adsorption, volatilization, or precipitation of the parent material.

Effect on Microbial Respiration

Dissolved oxygen concentration measurements, performed by placing a dissolved oxygen probe in activated sludge mixed liquor and ceasing aeration, showed no inhibition of microbial oxygen uptake rates at FC-206 concentrations up to 1000 mg/l.

Effect on Microbial Activity

The TTC* test, which measures microbial toxicity by assaying dehydrogenase enzyme activity in microbial cultures, showed no enzyme inhibition at FC-206 concentrations up to 1000 mg/l. This indicates an absence of microbial toxicity at this concentration.

*TTC (2,3,5-Triphenyltetrazolium Chloride) Re: "Dehydrogenase Enzyme as a Parameter of Activated Sludge Activities," Ford, et al. Proceedings of the 21st Industrial Waste Conference, Purdue, May 3, 4, and 5, 1966.

Date: 12/11/80 (Supersedes 4/4/79)

COMMERCIAL CHEMICALS DIVISION
"LIGHT WATER" BRAND AQUEOUS FILM
FORMING FOAM CONCENTRATE
FC-206

(continued)

Activated Sludge Pilot Plant Studies

Operation of a conventional activated sludge pilot plant demonstrated the biological treatability of FC-206-containing wastes at concentrations below 1000 mg/l. This system, when operated on a mixture of settled domestic sewage and 1000 mg/l of FC-206, gave average BOD and COD reduction of 86% and 73%, respectively. The average BOD_5 in the effluent was 18 mg/l.

Although not toxic, treating wastes containing 1000 mg/l of FC-206 per liter is not recommended because of foaming. Laboratory tests have shown that foaming is reduced at concentrations below 100 mg/l and eliminated at 10 mg/l.

When possible, tests were performed in accordance with Standard Methods for the Examination of Water and Wastewater, American Public Health Association, 1740 Broadway, New York, 10019.

Product Environmental Data

Environmental Laboratory
Environmental Engineering and Pollution Control
900 Bush Avenue
PO Box 33331
St. Paul, MN 55133
612/778 5104

COMMERCIAL CHEMICALS DIVISION

"LIGHT WATER" BRAND AQUEOUS FILM FORMING FOAM CONCENTRATE, FC-206A

DESCRIPTION: Water-miscible fire extinguishing agent.

APPEARANCE: Light yellow liquid.

USAGE: Foams containing 6% FC-206A in water cover and thus extinguish hydrocarbon liquid-based fires. For more detailed usage information, see your technical service representative.

AQUATIC TOXICITY DATA:

Test Organisms	Conditions	96-Hr. LC_{50}
Bluegill sunfish (*Lepomis macrochirus*)	(Static)	1.2 g/l (1.1 - 1.3 g/l)*
Fathead minnow (*Pimephales promelas*)	(Continuous flow)	>3.0 g/l
		48 Hr. EC_{50}
Water flea (*Daphnia magna*)	(Static)	2.3 g/l (1.9 - 2.9 g/l)*

Effect on Microbial Respiration

Dissolved oxygen concentration measurements, performed by placing a dissolved oxygen probe in activated sludge mixed liquor and ceasing aeration, showed no inhibition of microbial oxygen uptake rates at FC-206A concentrations up to 1000 mg/l.

* 95% confidence limit.

Date: 1/4/80

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Product Environmental Data

3M

Environmental Laboratory
Environmental Engineering and Pollution Control
900 Bush Avenue
PO Box 33331
St. Paul, MN 55133
612/778 5104

COMMERCIAL CHEMICALS DIVISION

"LIGHT WATER" BRAND AQUEOUS FILM FORMING
FOAM CONCENTRATE, FC-206A

(continued)

Effect on Microbial Activity

The TTC** test, which measures microbial toxicity by assaying dehydrogenase enzyme activity in microbial cultures, showed no enzyme inhibition at FC-206A concentrations up to 10,000 mg/l. This indicates an absence of microbial toxicity at this concentration

BIODEGRADATION:

Chemical Oxygen Demand (COD)	451,000 mg/l
Biochemical Oxygen Demand (BOD)	
BOD_5	200,000 mg/l
BOD_{20}	330,000 mg/l

WASTE DISCHARGE:

Facilities which use FC-206A in actual or simulated firefighting activities usually direct the resulting wastes to wastewater treatment systems. Whenever possible. 3M recommends disposing of FC-206A wastes in this manner. However, aquatic and soil environments sometimes receive these wastes untreated.

DISPOSAL: May be bled to wastewater system with a treatment plant in accordance with local regulations.

**TTC (2,3,5-Triphenyltetrazolium Chloride) Re: "Dehydrogenase Enzyme as a Parameter of Activated Sludge Activities," Ford, et al. Proceedings of the 21st Industrial Waste Conference, Purdue, May 3, 4, and 5, 1966.

Date 1/4/80 Page 2 of 2

Product Environmental Data

Environmental Laboratory
Environmental Engineering and Pollution Control
900 Bush Avenue
PO Box 33331
St. Paul, MN 55133
612/778 5104

COMMERCIAL CHEMICALS DIVISION
MILITARY SPEC. TYPE AFFF 6% CONCENTRATE
FC-780B

DESCRIPTION: Fire extinguishing agent.

APPEARANCE: Clear amber liquid.

COMPOSITION:	Wt. %
Water	75
Butyl Carbitol	15
Synthetic Detergents	<5
Fluoroalkyl Surfactants	<5
Urea	5

USAGE: FC-780B is employed at a 6% level (i.e., 94 parts water to 6 parts FC-780B) to extinguish fires involving liquid fuels and other liquid organic compounds.

WASTE DISCHARGE: Facilities which use FC-780B in actual or simulated firefighting activities usually direct the resulting wastes to wastewater treatment systems. Whenever possible, 3M recommends disposing of FC-780B wastes in this manner. However, aquatic and soil environments sometimes receive these wastes untreated.

DISPOSAL: Bleed to wastewater treatment system in accordance with local regulations. Diluting 1 gallon of FC-780B in $\geq$10,000 gallons of sewage prevents the product from causing serious foaming in aeration basins and prevents it from causing sludge settling problems in clarifiers. USEPA Hazardous Waste Number: None.

AQUATIC TOXICITY:

Test Organism	96-Hr. LC_{50}	95% C.I.
[redacted] (*Lepomis macrochirus*)	[redacted]	(1,300-1,800 mg/1)
[redacted] (*Fundulus heteroclitus*)	[redacted]	(3,400-4,600 mg/1)

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Date:

Product Environmental Data

3M

Environmental Laboratory
Environmental Engineering and Pollution Control
900 Bush Avenue
PO Box 33331
St. Paul, MN 55133
612/778 5104

COMMERCIAL CHEMICALS DIVISION
MILITARY SPEC. TYPE AFFF 6% CONCENTRATE
FC-780B

(continued)

TREATABILITY:	Neither foaming nor sludge settling problems developed as a result of aeration in laboratory scale activated sludge reactors containing 100 mg/l of FC-780B. Based on these results, no serious foaming or settling problems are anticipated in waste treatment systems containing less than 100 mg/l of FC-780B.

BIODEGRADATION: **

Chemical Oxygen Demand (COD)	387,000 mg/l
Ratio of Twenty-Day Biochemical Oxygen Demand to Chemical Oxygen Demand (BOD_{20}/COD)	0.96

* 95% confidence interval.

** As reported by the Naval Research Laboratory, Fire Suppression Section, Washington, DC.

Date: 2/9/81 (Supersedes 1/8/80)

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Form 14705-C PWO

Product Environmental Data

Environmental Laboratory
Environmental Engineering and Pollution Control
900 Bush Avenue
PO Box 33331
St. Paul, MN 55133
612/778 5104

COMMERCIAL CHEMICALS DIVISION

"LIGHT WATER"® BRAND AQUEOUS FILM FORMING FOAM CONCENTRATE, FC-203C

DESCRIPTION: Water-miscible fire control agent.

APPEARANCE: Clear, amber colored liquid.

USAGE: Foams containing 3% FC-203C in water cover and thus extinguish hydrocarbon liquid-based fires. For more detailed usage information, see your technical service representative.

AQUATIC TOXICITY DATA:

Test Organisms	Conditions	96-Hr. LC_{50}
Killifish (Fundulus heteroclitus)	(continuous flow)	1,400 mg/l (1,000-2,000 mg/l)*
Fathead minnow (Pimephales promelas)	(Continuous flow)	>2,000 mg/l
		96-Hr. EC_{50}**
Single cell green algae (Selenastrum capricornatum)		408 mg/l (156-995 mg/l)*

*95% confidence limits.
**Concentration inhibiting growth (measured as cell dry weight) by 50%.

Effect on Microbial Respiration

Dissolved oxygen concentration measurements, performed by placing a dissolved oxygen probe in activated sludge mixed liquor containing 1,000 mg/l of FC-203C and ceasing aeration, showed an increased oxygen uptake rate. This indicates an absence of acute microbial toxicity at this concentration and suggests that biodegradable portions of this product are utilized by nonacclimated microbial populations.

Date: 5/26/82

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Product
Environmental Data

3M

Environmental Laboratory
Environmental Engineering and Pollution Control
900 Bush Avenue
PO Box 33331
St. Paul, MN 55133
612/778 5104

COMMERCIAL CHEMICALS DIVISION

"LIGHT WATER"® BRAND AQUEOUS FILM FORMING FOAM CONCENTRATE, FC-203C

(continued)

BIODEGRADATION:

Chemical Oxygen Demand (COD)	0.78 g/g
20-Day Biochemical Oxygen Demand (BOD)	0.58 g/g
20-Day Carbonaceous Biochemical Oxygen Demand	0.59 g/g

DISPOSAL OF FIREFIGHTING WASTES:

If possible, 3M recommends handling wastes resulting from actual or simulated firefighting activities by pretreating in an oil-water separator followed by bleeding to a wastewater treatment system. Serious foaming can be prevented by adjusting the discharge rate so that the FC-203C concentration reaching the aeration basin will be ≤25 mg/l (1 gallon of FC-203C concentrate in ≥40,000 gallons of sewage).

DISPOSAL OF PRODUCT:

Bleed to a wastewater treatment system in accordance with local regulations. Adjusting discharge rates as described in the section above should reduce serious foaming problems in the receiving treatment system.

Date: 5/26/82

Product Environmental Data

3M

Environmental Laboratory
Environmental Engineering and Pollution Control
900 Bush Avenue
PO Box 33331
St Paul, MN 55133
612/778 5104

COMMERCIAL CHEMICALS DIVISION

"LIGHT WATER"® BRAND AQUEOUS FILM FORMING FOAM CONCENTRATE, FC-206C

DESCRIPTION: Water-miscible fire control agent.

APPEARANCE: Clear, amber colored liquid.

USAGE: Foams containing 6% FC-206C in water cover and thus extinguish hydrocarbon liquid-based fires. For more detailed usage information, see your technical service representative.

AQUATIC TOXICITY DATA:

Test Organisms	Conditions	96-Hr. LC$_{50}$
Killifish (*Fundulus heteroclitus*)	(continuous flow)	>2,000 mg/l
Fathead minnow (*Pimephales promelas*)	(Continuous flow)	>2,000 mg/l
		96-Hr. EC$_{50}$**
Single cell green algae (*Selenastrum capricornatum*)		345 mg/l (34-1630)*

*95% confidence limits.
**Concentration inhibiting growth (measured as cell dry weight) by 50%.

Effect on Microbial Respiration

Dissolved oxygen concentration measurements, performed by placing a dissolved oxygen probe in activated sludge mixed liquor containing 1,000 mg/l of FC-206C and ceasing aeration, showed an increased oxygen uptake rate. This indicates an absence of acute microbial toxicity at this concentration and suggests that biodegradable portions of this product are utilized by nonacclimated microbial populations.

Date: 5/26/82

Product Environmental Data

Environmental Laboratory
Environmental Engineering and Pollution Control
900 Bush Avenue
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612/778 5104

COMMERCIAL CHEMICALS DIVISION

"LIGHT WATER"® BRAND AQUEOUS FILM FORMING FOAM CONCENTRATE, FC-206C

(continued)

BIODEGRADATION:

Chemical Oxygen Demand (COD)	0.40 g/g
20-Day Biochemical Oxygen Demand (BOD)	0.33 g/g
20-Day Carbonaceous Biochemical Oxygen Demand	0.34 g/g

DISPOSAL OF FIREFIGHTING WASTES:

If possible, 3M recommends handling wastes resulting from actual or simulated firefighting activities by pretreating in an oil-water separator followed by bleeding to a wastewater treatment system. Serious foaming can be prevented by adjusting the discharge rate so that the FC-206C concentration reaching the aeration basin will be $\leq$50 mg/l (1 gallon of FC-206C concentrate in $\geq$20,000 gallons of sewage).

DISPOSAL OF PRODUCT:

Bleed to a wastewater treatment system in accordance with local regulations. Adjusting discharge rates as described in the section above should reduce serious foaming problems in the receiving treatment system.

Date: 5/26/82

Product Environmental Data

Environmental Laboratory
Environmental Engineering and Pollution Control
900 Bush Avenue
PO Box 33331
St. Paul, MN 55133
612/778 5104

COMMERCIAL CHEMICALS DIVISION

3M BRAND COMMERCIAL GRADE AFFF 6% CONCENTRATE
FC-780

DESCRIPTION: Fire extinguishing agent.

APPEARANCE: Clear amber liquid.

COMPOSITION:

	Percent by Weight
Diethylene glycol monobutyl ether (Butyl Carbitol®)	14
Water	77
Fluoroaliphatic surfactants	<5
Organic surfactants	<5
Urea	6

USAGE: FC-780 is employed at a 6% level (e.g., 94 parts water to 6 parts FC-780) to extinguish fires involving liquid fuels and other liquid organic compounds.

AQUATIC TOXICITY:

Test Organism	96-Hr. LC_{50} FC-780
[redacted] (*Fundulus heteroclitus*)	[redacted]

BIODEGRADATION: *

Chemical Oxygen Demand (COD)	0.32 g/g
Ratio of Twenty-Day Biochemical Oxygen Demand to Chemical Oxygen Demand (BOD_{20}/COD)	0.98

* As reported by the Naval Research Laboratory, Fire Suppression Section, Washington, DC.

Date: 6/11/82 (Supersedes 1/8/80)

APPENDIX B

AFFF ASSAY DATA

Data taken from: D.B. Chan, 1982. Draft initial feasibility
report on AFFF-laden wastewater treatment/
recovery. Technical Memo 54-82-06.

D. Biological Treatment

The Air Force performed four biodegradability and toxicity studies respectively for AER-O-Water (AOW) 3 and 6 (Ref 3), FC-200 (Ref 2), FC-206 (Ref 4), and ANSUL K74-100 (Ref 5) AFFF. Results from these studies are summarized in Table 3.

Table 3. Biological Treatment of AFFF

AFFF Agent	Operation Parameters		Organic Removal, %		Remarks
	Detention Time	Influent Feed	COD	BOD	
1. AOW-3	7.6 hrs.	50-2400 ppm (V/V)	94 down to 66 in 94 days Continuous Experiment	97 down to 66 in 94 days	Ethylene Glycol not biodegradable. Plant did not recover after 1,700 ppm feed
2. AOW-6	7.5 hrs.	50-2400 ppm (V/V)	86 down to 50 in 94 days	96 down to 74 in 94 days	Plant did not recover after 1,700 ppm feed
3. FC-200	6-8 hrs.	50-250 ppm	89 down to 45 in 53 days	Maintained at 96 in 53 days	Efficiency degraded after 100 ppm feed
4. FC-206	6-8 hrs.	50-300 ppm (V/V)	Maintained 96 - 98	98 down to 96.5 in 51 days	Efficiency degraded after 250 ppm feed
5. ANSUL K74-	6-8 hrs.	50-3500 ppm (V/V)		98 down to 75 in 98 days	Efficiency degraded after 250 ppm feed

All experiments were conducted under the following conditions:

a. Using bench-scale, continuous feed activated sludge process

b. Employing pure AFFF concentrate and synthetic sewage as feeding substrate

c. Acclimating activated sludge with synthetic sewage before AFFF was gradually (dosage increased with time) fed to the process

Table 1. Changes in toxicity of AFFF's to Fathead Minnows with increase in time of exposure (From LeFebvre and Inman, 1975).

LC_{50} Concentration (µl/l)

	3M - Light Water			Nat'l Foam Systems		ANSUL Co.
	FC-199	FC-200	FC-206	AOW3	AOW6	K74-100
24 Hours	650	*	2100	1030	635	1725
48 Hours	588	135	1810	820	255	1425
72 Hours	450	97	1300	630	245	1150
96 Hours	398	97	1080	600	225	1100

*No mortality in 24 hours in one bioassay but 50% in highest concentration (150 µl/l) in duplicate bioassay.

Table 5. Comparison of concentrations of AFFF in synthetic sewage amenable to biological treatment (From LeFebvre and Inman, 1975).

	3M - LIGHT WATER			NAT'L FOAM SYSTEMS		ANSUL
	FC199	FC200	FC206	AOW3	AOW6	K74-100
Maximum to Sewage Treatment Plant	250 µl/l	10 µl/l	200 µl/l	1700 µl/l	1700 µl/l	250 µl/l
Recommended for Treatment	25 µl/l	10 µl/l	20 µl/l	150 µl/l	150 µl/l	25 µl/l

Table 6. Recommended maximum concentration of AFF for direct discharge to stream containing aquatic life. (From LeFebvre and Inman, 1975).

3M - LIGHT WATER			NAT'L FOAM SYSTEMS		ANSUL
FC199	FC200	FC206	AOW3	AOW6	K74-100
20 µl/l	5 µl/l	54 µl/l	60 µl/l	22.5 µl/l	55 µl/l

②

AFOEHL REPORT 89-129EQ0063LEA

Biological Analysis of Three Ponds at Peterson AFB, Colorado Springs CO

GREGORY ZAGURSKY
WILLIAM H. JEFFERSON III
ROBERT D. BINOVI, Lt Col, USAF, BSC

November 1989

Final Report

Distribution is unlimited; approved for public release

AF Occupational and Environmental Health Laboratory (AFSC)
Human Systems Division
Brooks Air Force Base, Texas 78235-5501

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A series of three man-made ponds on the golf course at Peterson AFB, Colorado Springs CO were analyzed to determine their current ecological status and future potential for recreational fishing. Biological analysis consisted of collection, enumeration and identification of organisms from the water column and sediment from three sampling sites at each pond. The ponds were evaluated on the basis of species diversity and the types of species present. Chemical analysis of water and sediments for toxicants was also performed.

The results indicated that ponds 1 and 2 are in excellent ecological condition and should be able to maintain stocked game fish which are safe for human consumption. Pond 3 cannot be recommended for stocking with fish in its current condition. Low species diversity suggests that this pond is being stressed by an unknown pollutant. The most likely source is a storm drain which may be a chronic source of pollutants for this pond. Keywords:

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We wish to extend our personal thanks to some specific individuals at AFOEHL who made this research effort rewarding and enjoyable. Lt Col Bob Binovi provided leadership, support, encouragement and some funny stories. The assistance of Lt Becky Bartine and Sgts Rolon and Hernandez was invaluable in solving many problems. A special thanks and salute to Sgt Carol Wilson who worked and put up with us on a day-to-day basis. She was an unending source of assistance, support and supplies. Thanks also to the Biology Department at the Air Force Academy and the Colorado Fish and Game Department for their timely response to our needs for equipment when our shipment from AFOEHL became lost.

Contents

Illustrations

Figure

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I. INTRODUCTION

A series of three man-made, 1- to 2-acre ponds at Peterson AFB in Colorado Springs CO have been impacted by the introduction of pollutants from the flightline area through the storm drainage system resulting in fish kills and an apparent decrease in the invertebrate and plant populations in one of the ponds, designated pond 3. The remaining two ponds (ponds 1 and 2) have been impacted to a lesser extent because of pumping of water from pond 3 into these two ponds. Base personnel were particularly concerned about the ecological health of pond 3 because they would like to utilize the pond as a recreational fishing pond and as a source of water for the base golf course. USAF Clinic/SGPB requested AFOEHL conduct a survey of the ponds in June 1989. The survey was conducted by Gregory Zagursky, William (Jeff) Jefferson, University of South Carolina, Lt Col Robert D. Binovi, 2Lt Rebecca Bartine, and SSgt Carole Wilson.

The objectives of this survey were to (1) determine the physical factors or toxicant responsible for the original biological impact, (2) determine if the ponds are now capable of maintaining a fish population and (3) determine if fish taken from these ponds are and will be safe for human consumption. Also from a long-term perspective, findings of this survey could suggest preventive measures that will maintain the water quality of the ponds for game fish stocking and golf course irrigation and suggest ways to restore the ponds to a natural ecological state with a self-sustaining population of game fish.

II. DISCUSSION

A. Sampling Strategy

The initial approach to accomplish the objectives was wide-ranging because of the unknown nature of the toxicants. The fire suppressant material, Ansulite Aqueous Film Forming Foam (AFFF), which was accidentally spilled into pond 3 shortly before the first fish kill, was initially suspected as the toxicant. Unfortunately, it could not be proven for certain that the chemical was the source of the problem because AFFF would not persist very long in the environment and yet a subsequent restocking resulted in a second fish kill, and pond 3 receives drainage from areas on base subject to spills and discharges of other potentially toxic chemicals, complicating the problem of targeting for a specific toxicant.

All sampling was conducted during the period 6-8 June 1989. Three sampling sites were established in each pond: station C was near the deepest point of each pond; station B was located where the water depth equaled the depth of the photic zone; station A was approximately 1 meter from the shoreline. The biological health of all three ponds was evaluated at the population level (Warren, 1971) by qualitatively and quantitatively sampling the water column and the benthos (bottom sediment) for invertebrates, vertebrates and plants. The water column was sampled for plants and animals with plankton nets, seines and water bottles. Benthic samples were taken along transects with grab samplers for macrobenthos and cores for meiobenthos and the infauna preserved in the field. Since there is a gradient to the impact, with pond 2 being slightly impacted and pond 1 apparently not having been impacted at all, pond 1 was used as a control for comparing species position. The usual set of physical measurements (temperature, pH, secchi disk depth, nutrient levels) was taken at each pond.

In order to determine possible toxic chemical levels in [illegible] 3 ponds, both water and sediment samples were analyzed for a series of possible toxicants (hydrocarbons, heavy metals, pesticides, herbicides). Fish tissue was similarly evaluated for toxic chemicals to determine if it was safe for human consumption.

B. Physical Characteristics

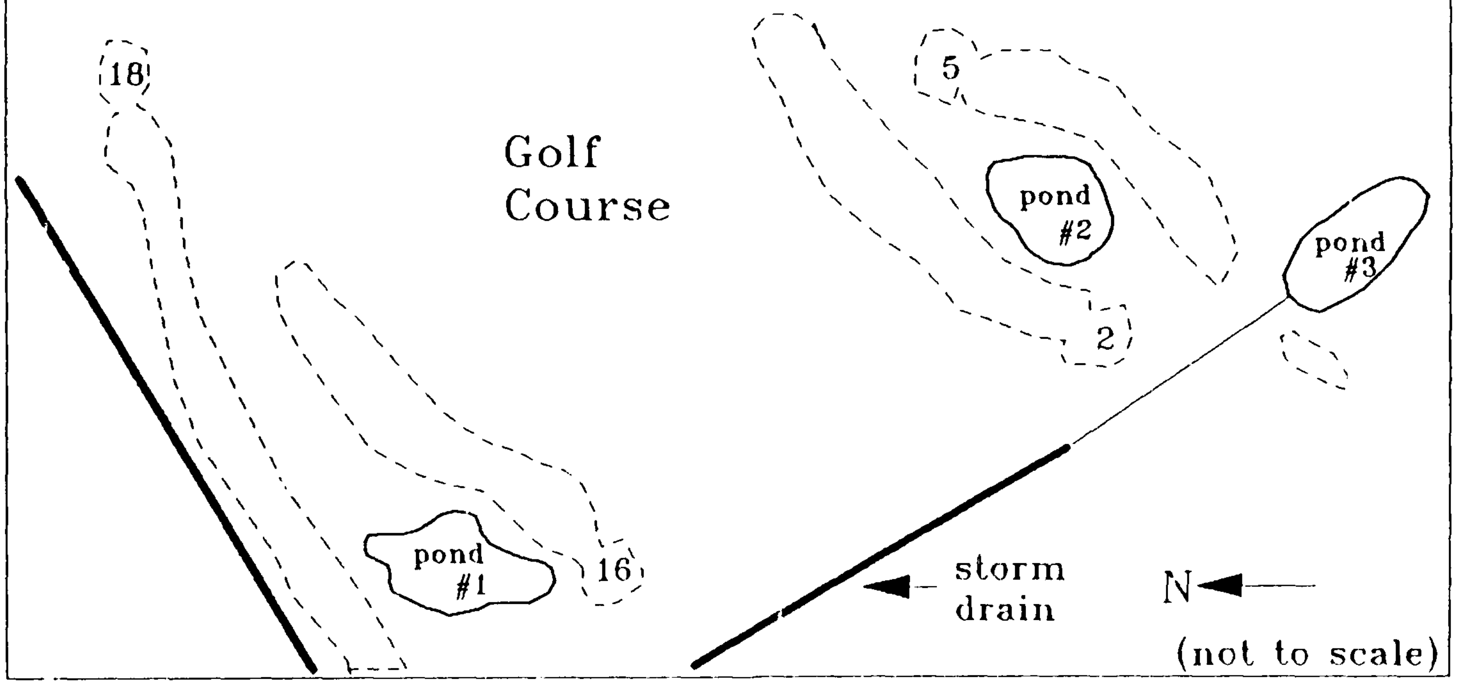
All three ponds were located on the golf course at Peterson AFB, Colorado Springs CO. Figure 1 shows the relative locations of the three ponds and photos of each. The circumference of each pond was measured with a tape and the volumes computed. The pH, temperature and dissolved oxygen levels were measured at various locations and depths with probes. The depth was measured by using a weighted rope and the photic zone (depth of light penetration) measured by using a white, water sampling bottle. The results are summarized in Table 1.

TABLE 1 - PHYSICAL CHARACTERISTICS OF 3 PONDS

	POND 1	POND 2	POND 3
TEMPERATURE (C)	14	14	15
pH (range)	7.8-8.2	7.1-7.6	6.2-6.5
Dissolved Oxygen (surface/depth)	9.0/9.7	9.6/10.0	6.7/6.9
Circumference (m)	384.6	303.9	360.0
Deepest Point (m)	3.9	1.8	1.65
Depth of Photic Zone (m)	1.35	0.67	0.90
Estimated Shoreline Plant Cover (%)	80	70	0

Ponds 1 and 2 had mechanical aerators in operation at the time of sampling and water was being pumped into each. Ponds 1 and 2 also had moderate amounts of vascular plant detritus (mainly tree leaves) along the shoreline. The general water quality of ponds 1 and 2 appeared to be good to excellent. Pond 3 had no aerator and was receiving an inflow of 242,000 gallons/day from an open channel storm drain as measured by an ISCO 2780 flow meter (Lt Col Binovi, pers. comm.). The decaying, floating bodies of 30-50 Necturus sp. (mudpuppies) were observed along the shoreline of pond 3. Also, pond 3 had no observable submerged aquatic vegetation and no aquatic shoreline macrophytes. General water quality of pond 3 was poor.

FIG. 1 RELATIVE LOCATION OF THE THREE STUDY PONDS PETERSON AFB, COLORADO SPRINGS, CO



Pond 1

Pond 2

Pond [illegible]

Figure 1 cont'd

C. Phytoplankton Composition

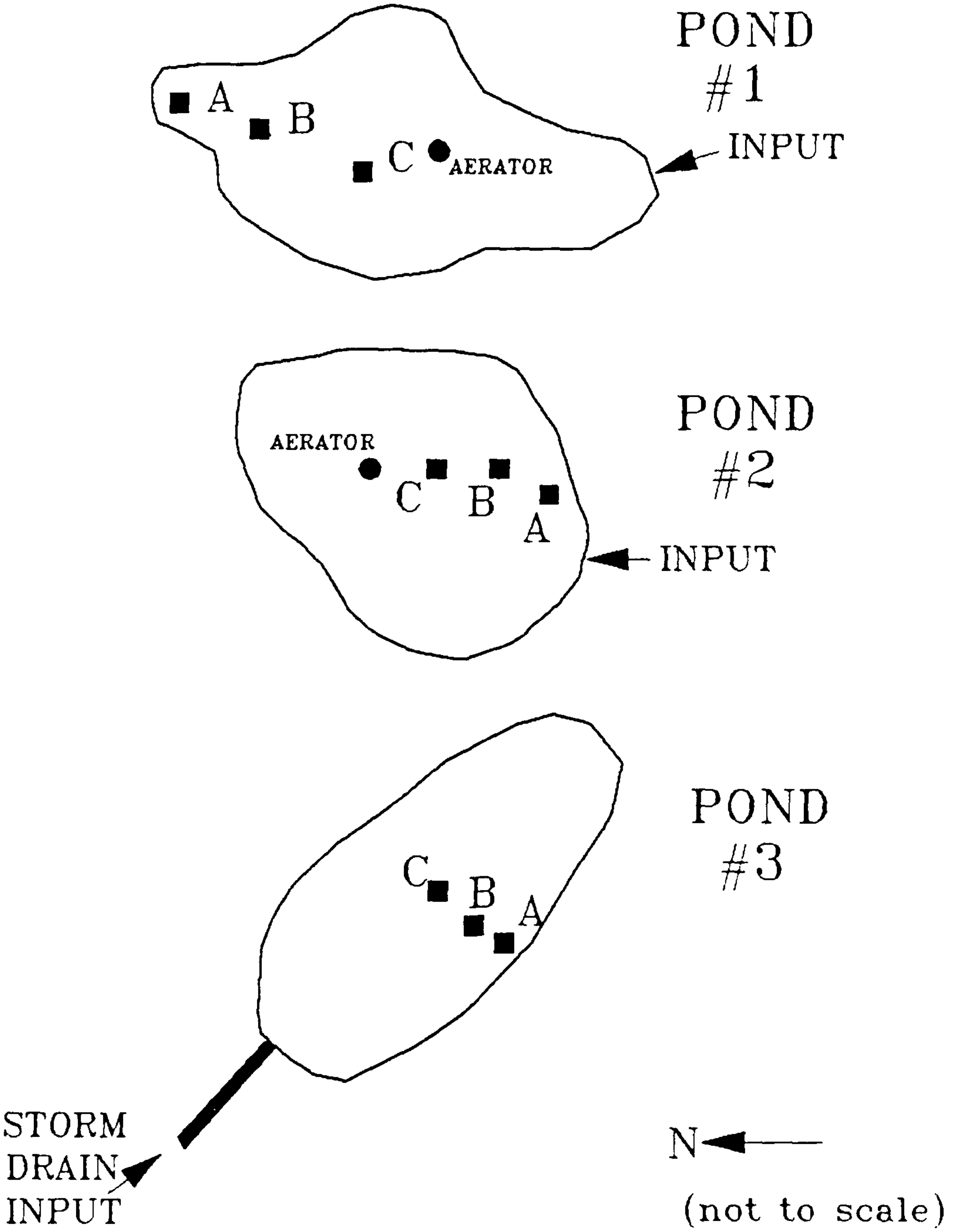
Replicate phytoplankton samples were collected at stations C and B in all ponds by filling a 2-liter bottle with water, 0.5 meters under the water surface. Figure 2 locates the sampling sites. The samples were immediately preserved with Lugol's fixative (Wetzel and Likens, 1979). Three 1 ml subsamples were counted from each sample using a Sedgwick-Rafter counting cell under 100X magnification. The phytoplankton were identified to the genus level and the results summarized in Table 2. The diversity of species at each station in each pond was calculated by using the Shannon-Wiener species diversity index (H') (Shannon and Wiener, 1963).

This data clearly indicates that pond 3 was unable to support a phytoplankton community. This lack of primary producers is strong evidence that this pond was stressed. Comparison of the Shannon-Wiener diversity indices also indicates that ponds 1 and 2 have healthy, diverse and large phytoplankton communities which probably result in a fairly high primary productivity which can support higher trophic levels. The differences in species composition between ponds 1 and 2 may be due in part because of the greater depth of pond 1 and the deeper photic zone. The generally reduced numbers of organisms collected at station C can be attributed to the aerators which probably reduced the number of delicate species.

Table 2 - Phytoplankton Species Composition
(mean number/ml)

	POND 1		POND 2		POND 3	
Genus	Sta. B	Sta. C	Sta. B	Sta. C	Sta. B.	Sta. C
Anacystis	4.5	0.25	11.25	3.5	0.0	0.0
Acanthocystis	4.4	1.5	1.24	0.75	0.0	0.0
Asterionella	4.7	0.75	21.5	12.0	0.0	0.0
Ceratium	0.25	0.5	1.0	1.0	0.0	0.0
Closterium	0.25	0.0	0.25	0.0	0.0	0.0
Cocconeis	19.4	11.25	16.5	5.25	0.0	0.0
Coelastrum	0.25	12.88	14.5	20.25	0.0	0.0
Cosmarium	1.5	5.0	69.5	69.0	0.0	0.0
Cymbella	31.0	9.0	39.63	4.75	0.0	0.0
Dictyosphaerium	147.5	78.8	419.75	337.5	0.0	0.0
Fragilaria	355.4	195.0	525.25	416.75	1.25	1.75
Gloeobotrys	12.0	7.0	24.75	20.5	0.0	0.0
Nephrocytium	69.75	18.5	287.0	379.25	1.25	0.25
Oocystis	6.0	2.0	7.0	9.75	0.0	0.0
Pediastrum	36.75	6.0	116.75	84.25	0.0	0.0
Scenedesmus	168.25	83.25	177.5	149.25	0.0	0.0
Sphaerocystis	58.75	125.25	119.75	190.75	0.0	0.25
Staurastrum	341.75	341.75	276.5	239.5	1.0	0.75
Synedra	32.75	56.25	6.75	0.5	0.0	0.0
Unknown diatoms	254.75	63.0	54.25	17.3	1.5	1.75
Shannon-Wiener Diversity Index	2.12	2.07	2.21	2.12	1.37	0.67

FIG. 2 SAMPLING SITES



D. Zooplankton Composition

Replicate zooplankton samples were collected at stations C and B in all ponds (Fig 2) by taking vertical tows from the pond bottom to the pond surface using a 153-micron mesh, 0.5-m diameter plankton net. Since a flow meter was not available, these samples are not quantitative and species composition can only be compared on a relative basis. The samples were fixed with 5% buffered formalin and then stained with rose bengal to facilitate sample enumeration. A Hansen-Stempel pipet was used to withdraw three 1-ml subsamples from each replicate sample. The animals in the sample were enumerated using a dissecting microscope under 100X magnification. Identification was to the lowest taxonomic group using Pennack (1953) for species keys. Since these samples were qualitative, it was not possible to calculate a species diversity index.

These results (Table 3) show a similar trend to those seen in the phytoplankton composition table. Ponds 1 and 2 have a relatively greater species diversity than pond 3. The rotifer species are almost nonexistent in pond 3, probably because these species are sensitive to poor quality water conditions. The low diversity of species in pond 3 is typical of systems which are under stress from either physical conditions or pollutants. There is a shift in species dominance between ponds 1 and 2, but the relative diversity of species remains the same. The shift may be due to the decreased depth of pond 2 which results in a decrease in feeding area and increased competition amongst species.

Table 3 - Zooplankton Species Composition (mean percentage of total)

	POND 1		POND 2		POND 3	
Organism Name	Sta. B	Sta. C	Sta. B	Sta. C	Sta. B	Sta. C
CRUSTACEA:						
Bosmina coregoni	4.6	3.3	22.4	25.9	0.0	0.0
Bosmina longirostris	4.4	4.3	8.2	9.5	0.29	0.5
copepidites	4.4	3.8	2.4	1.4	1.2	1.4
Cyclops sp.	7.2	7.6	13.8	12.6	2.3	3.5
Daphnia pulex	10.4	10.0	7.1	6.3	18.6	17.3
Diaptomus sp.	0.23	0.11	0.0	0.3	0.0	0.0
nauplii	29.4	31.3	16.8	17.3	77.2	77.1
ROTIFERA:						
Brachionus plicatilis	0.06	0.05	0.0	0.15	0.0	0.0
Keratella cochlearis	35.2	37.0	28.7	24.4	0.15	0.25
Keratella	3.9	2.8	1.3	1.9	0.29	0.0

Note: Totals do not equal 100 because of rounding.

E. Benthos Composition

Replicate benthic samples were collected at stations A, B and C in all ponds (Fig 2). Meiobenthic infauna (defined as larger than 64 microns and smaller than 125 microns) were collected by taking 5.07 cm^2 cores of the sediment. Macrobenthic infauna were collected by taking a composite sample of three 5.07 cm^2 cores. All of these samples were preserved with 5% formalin and later stained with rose bengal to facilitate the counting of organisms. Before identification and enumeration, the meiofauna samples were sieved through a 125- and 64-micron sieve and the material retained on the 64-micron sieve was examined. Macrobenthic samples were only sieved through a 125-micron sieve. Organisms were identified to the lowest possible taxonomic group by use of a dissecting microscope with a magnification of 100X. Since these samples were quantitative, the diversity of species at each station in each pond was calculated by using the Shannon-Wiener species diversity index (H'). The results for the meiofauna are summarized in Tables 4, 5 and 6.

The Shannon-Wiener species diversity index for the meiofauna populations of ponds 1, 2 and 3 is 1.5, 1.4 and 1.1 respectively. Once again pond 3 has a lower species diversity, but the difference is not as great. This is somewhat expected since the sediment is a more stable environment and benthic populations are buffered against any rapid physical changes in the water column. The greatest difference in ponds is seen at station C where pond 3 has a sharply reduced number of organisms. Observations in the field indicated that the sediment at this site was almost completely anaerobic. The species composition and dominant species vary widely between the ponds. This again can be attributed to the relatively stable environment of the benthos which leads to the establishment of relatively constant biological communities with patchy distribution.

Table 4 - Meiofauna Composition of Sampling Station A (mean number/core)

Organism Name	POND 1	POND 2	POND 3
Tobrillus sp. (nematode)	38.5	18.5	14.2
Stauroneis sp. (benthic diatom)	22.6	0.0	0.0
Nitzchia sp. (benthic diatom)	4.5	52.6	0.0
Contracted Rotifera	16.8	11.1	20.0
Desmids (green algae)	5.9	58.2	38.4
Planaria sp. (flatworm)	4.8	2.3	4.3
Crustacea nauplii	7.7	6.2	3.8
Chaetonotus sp. (gastrotrich)	0.0	2.9	0.0

Table 5 - Meiofauna Composition of Sampling Station B (mean number/core)

Organism Name	POND 1	POND 2	POND 3
Tobrillus sp.	74.3	21.6	18.0
Stauroneis sp. (benthic diatom)	283.4	0.0	0.0
Contracted Rotifera	15.8	16.9	13.6
Desmids	4.8	3.3	17.3
Bdelloidae rotifer	0.0	1.2	3.5
Planaria sp.	1.7	10.9	0.8

Table 6 - Meiofauna Composition of Sampling Station C (mean number/core)

Organism Name	POND 1	POND 2	POND 3
Tobrillus sp. (nematode)	12.6	110.4	5.9
Stauroneis sp. (benthic diatom)		48.7	0.0
Nitzchia sp. (benthic diatom)	5.8	62.1	0.0
Contracted Rotifera	3.0	3.5	1.6
Desmids (green algae)	0.0	0.0	6.2
Nematoda - unidentified	8.1	19.0	4.5
Chaetonotus sp. (gastrotrich)	21.8	24.7	2.9
Tardigrada	5.2	17.3	2.1

The data collected for macrobenthic populations is summarized in Tables 7, 8 and 9. The Shannon-Wiener species diversity index for the macrobenthic populations of ponds 1, 2 and 3 is 1.75, 1.9 and 1.4

Table 7 - Macrofauna Composition of Sampling Station A (mean number/core)

Organism Name	POND 1	POND 2	POND 3
Actinolaiminiae sp. (nematode)	13.4	8.5	1.3
Tobrillus sp. (nematode)	42.3	20.7	11.5
Naidium breviseta (oligochaete)	14.3	0.0	0.0
Metriocnemus knobi (insect larva)	14.6	12.8	0.0
Chironomus tentans (insect larva)	0.0	0.0	5.5
Macrocyclops albidus (crustacean)	2.3	2.9	6.6
Pleuroxus aduncus (crustacean)	0.0	0.0	43.1
Musculium sp. (bivalve)	1.2	3.2	0.0
Candona sp. (ostracod)	6.9	10.3	0.0
Planaria sp. (flatworm)	4.0	11.1	1.5
Harpacticoid copepods	0.0	0.0	6.2
nauplii	0.7	2.1	5.4
Desmids (green algae)	1.6	24.6	2.3

Table 8 - Macrofauna Composition of Sampling Station B
(mean number/core)

Organism Name	POND 1	POND 2	POND 3
Actinolaiminiae sp. (nematode)	3.4	1.8	0.0
Tobrillus sp. (nematode)	29.4	18.3	45.8
Naidium breviseta (oligochaete)	8.9	9.1	0.0
Lumbriculus inconstans (oligochaete)	0.0	0.0	44.9
Metriocnemus knobi (insect larva)	4.1	8.9	0.0
Chironomus tentans (insect larva)	0.0	0.0	11.5
Macrocyclops albidus (crustacean)	0.0	0.0	4.1
Musculium sp. (bivalve)	2.7	3.2	0.0
Candona sp. (ostracod)	3.6	2.9	0.0
Planaria sp. (flatworm)	1.9	21.2	3.2
Attheyella sp. (crustacea)	1.6	1.1	0.0
Desmids (green algae)	0.0	2.6	3.5

Table 9 - Macrofauna Composition of Sampling Station C
(mean number/core)

Organism Name	POND 1	POND 2	POND 3
Actinolaiminiae sp. (nematode)	6.6	2.3	0.0
Tobrillus sp. (nematode)	78.9	98.2	49.1
Naidium breviseta (oligochaete)	16.5	8.4	0.0
Lumbriculus inconstans (oligochaete)	0.0	0.0	29.6
Metriocnemus knobi (insect larva)	0.0	3.7	0.0
Chironomus tentans (insect larva)	0.0	0.0	4.7
Macrocyclops albidus (crustacean)	0.0	0.0	6.4
Musculium sp. (bivalve)	1.2	2.3	0.0
Nematode - unidentified	16.8	3.8	4.3

Once again the species diversity of pond 3 is the lowest, indicating that the conditions of this pond are not as good as those of ponds 1 and 2. N. breviseta, M. knobi and Musculium are all organisms which occur only in well oxygenated, high quality aquatic systems. They are absent from pond 3 and replaced by low oxygen tolerant species (L. inconstans and C. tentans) which occupy the same niche.

F. Fish Composition

The fish and macroinvertebrate populations of the shoreline waters of all three ponds were sampled by pulling a 10-foot long, 0.5-inch mesh seine along the banks. The only fish caught by this method were Pimephales promelas (fathead minnows) from ponds 1 and 2; no fish were caught in pond 3. A total of 636 minnows were measured for their standard length and minnows from both ponds had similar length frequency distributions and mean standard length of 38.7 mm.

Also caught in ponds 1 and 2 were Cambarus bartoni (crayfish) which had a mean carapace length of 44.5 mm. The only organisms seined from pond 3 were leeches (Class: Hirundinea), snails and a large aquatic beetle (Hydrophilus sp.)

G. Chemical Analysis

Both water and sediment samples were taken from each pond and the storm drain input to pond 3 for chemical analysis by AFOEHL/SA for total organic carbon (TOC), nitrates, orthophosphates, oil and grease, and MBAS surfactants. An additional group analysis referred to as E.P. Toxicity was done on water and sediment samples for each pond. E.P. Toxicity analyzes for pesticides and a group of biologically active heavy metals. Also, trout (sampled by volunteers using long line sampling methods) and fathead minnows were analyzed for mercury and PCBs as recommended by the EPA. For the sake of brevity, only the significant results are reported.

The only analysis to produce detectable results in the fish flesh was for the PCB Aroclor 1254 which was present in 0.07 and 0.11 μg/gram concentrations in both the minnow and trout from pond 2. The E.P. Toxicity analysis of the sediments from pond 3 indicated the metals barium, cadmium, lead and selenium were all present in higher concentrations than ponds 1 and 2. While none of these levels are currently dangerous, there should be concern as to finding the source for these toxicants. The results of these analyses are given in Table 10.

III. CONCLUSIONS

The ecological conditions of ponds 1 and 2 appear to be excellent based on these findings and they should continue to provide an excellent area to stock with game fish. Pond 3 should not be used for recreational fishing in its current condition. Its ecological condition is questionable as indicated by its low species diversity levels and the presence of pollution indicator species. The primary problem with utilizing pond 3 as a game fishing area is the continuous introduction of stormwater from the storm drain. The presence of the drain means that there is the constant potential for an ecological disaster on a small scale. The drain is a constant source of water of unknown quality. If any pollutant is accidentally spilled anywhere on the base, it has a good chance of entering this drain and pond 3. Also, the storm drain is a source of chronic pollution which may take years to manifest itself. Pesticides applied on the golf course or other areas of the base shortly before a downpour could affect acute toxicity in pond 3. Other chemicals which could conceivably cause acute toxicity problems would be fuels and oil spills, AFFF, and large solvent spills.

Applications of fertilizers anywhere along the storm drainage system would cuase chronic low oxygen conditions by stimulating algal bloom. The fact that low levels of some PCBs are detected in fish and the sediments have higher levels of some biologically active metals should cause concern. While these levels are not currently dangerous, the sources of these pollutants need to be determined and minimized before a problem arises.

One caveat of this study is that all of the samples analyzed (both chemical and biological) were collected over a 2-day period and may not reflect year round conditions. This study should be continued with periodic sampling so that any temporal variability can be observed. This is particularly true of any pollution study in which there may be a chronic, low-level addition of pollutants.

TABLE 10 - E.P. TOXOCITY ANALYSIS FOR METALS
mean (std. dev.) in mg/l; n=2

METAL	POND 1 WATER	POND 1 SEDIMENT	POND 2 WATER	POND 2 SEDIMENT	POND 3 WATER	POND 3 SEDIMENT	STORM DRAIN INPUT
ARSENIC	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
BARIUM	0.0245(0.0035)	0.445(0.106)	0.032(0.0) #1	0.32(0.057)	0.32(0.057)	0.78(.071) #2	0.04(0.0028) #4
CADMIUM	<0.010	<0.010	<0.010	<0.010	<0.010	0.0125(0.0021)	<0.010
CHROMIUM	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
LEAD	<0.050	<0.050	<0.050	<0.050	<0.050	0.0895(0.043)	<0.050
MERCURY	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
SELENIUM	<0.050	<0.050	<0.050	<0.050	<0.050	0.11(0.0) #3	<0.050
SILVER	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010

#1 significantly different from pond 3 (t-test alpha=0.05)
#2 significantly different from pond 2 (t-test alpha=0.05)
#3 significantly different from ponds 1 and 2 (t-test alpha=0.05)
#4 significantly different from ponds 1 and 3 (t-test alpha=0.05)

IV. RECOMMENDATIONS

1. Pond 3 would benefit from mechanical aeration, as do ponds 1 and 2. Recommend capability to maintain a minimum of 5 mg/L during nighttime operation be provided to prevent stess to game fish population.

2. The current practice of using water from pond 3 to fill ponds 1 and 2 should also be curtailed in order to keep these ponds in top condition.

3. In order to utilize pond 3 for fishing, the storm drain should be diverted to some other area before the pond can be prepared to accept fish.

4. Prevent unweathered AFFF from entering the storm drainage system. Hangar fire suppressant systems should be provided with a holding pond to capture the release of AFFF and retain it sufficiently to affect its biodegradation before release into the stormwater system.

5. Aircraft washing, paint stripping, and other corrosion control activities should not be performed at locations such as the ramps where the rinsewater would enter the storm drainage system even after exiting an oil/water separator.

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January 1991

(2)

Hazardous Waste Minimization Assessment: Fort Carson, CO

by
Seshasayi Dharmavaram
Douglas A. Knowlton
Bernard A. Donahue

On November 8, 1984, the U.S. Congress signed into public law the Hazardous and Solid Waste Amendments (HSWA) act establishing a national policy on waste minimization. Regulations created to support the HSWA require hazardous waste generators to develop and follow a hazardous waste minimization program. Moreover, the Department of Defense has established a goal of 50 percent reduction in hazardous waste generation by 1992 (compared to 1985 generation data).

After surveying hazardous material procurement; hazardous waste generation; and current methods of treatment, storage, and disposal, researchers conducted feasibility and economic analyses of minimization options and prepared a hazardous waste minimization (HAZMIN) plan for Fort Carson, CO.

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On November 8, 1984, the U.S. Congress signed into public law the Hazardous and Solid Waste Amendments (HSWA) act establishing a national policy on waste minimization. Regulations created to support the HSWA require hazardous waste generators to develop and follow a hazardous waste minimization program. Moreover, the Department of Defense has established a goal of 50 percent reduction in hazardous waste generation by 1992 (compared to 1985 generation data).

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FOREWORD

This work was performed for Headquarters, U.S. Army Forces Command (HQ, FORSCOM), under an interagency reimburseable order IAO 3788, dated 25 July 1988. The FORSCOM technical monitor was Rudy Stine.

The work was done by the Environmental Engineering Team of the Environmental Division (EN), U.S Army Construction Engineering Research Laboratory (USACERL). Mr. Bernard Donahue is the Acting Team Leader and Mr. Walter Mikucki is the Team Leader. Dr. Edward W. Novak is the Acting Chief of EN Division. The technical editor was Gloria J. Wienke, USACERL Information Management Office.

The contributions made by Ms. Sharon McClellan (FORSCOM); and Mr. Chittaranjan Ray and Mr. Richard Stanbaugh (both of USACERL), in the completion of this project are acknowledged.

COL Everett R. Thomas is Commander and Director of USACERL and Dr. L.R. Shaffer is Technical Director.

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HAZARDOUS WASTE MINIMIZATION ASSESSMENT: FORT CARSON, CO

1 INTRODUCTION

Background

Waste minimization is the process of reducing the net outflow of hazardous solid, liquid, and gaseous effluents from a given source or generating process. It involves reducing air emissions, contamination of surface and ground water, and land disposal by means of source reduction, recycling processes, and treatment leading to complete destruction. Transferring pollutants from one medium to another (e.g., from water to air) by treatment processes is not waste minimization.

On November 8, 1984, the U.S. Congress signed into public law[1] the Hazardous and Solid Waste Amendments (HSWA) act establishing a national policy on waste minimization. HSWA required the U.S. Environmental Protection Agency (USEPA) to issue regulations that began the process of implementing the 1984 amendments to the Resource Conservation and Recovery Act (RCRA).[2] Among the Federal regulations is a requirement that every generator of hazardous wastes (HW) producing in excess of 2205 pounds (lb)* per month certify, when hazardous wastes are manifested (listed on a tracking document), that a hazardous waste minimization program is in operation.[3] Generators are required to submit biennial reports to the USEPA that describe efforts taken to reduce the volume and toxicity of waste generated during the year. Federal regulations issued in October 1986 clarify the status of small quantity (220 to 2205 lb/month) generators (SQG) of hazardous waste.[4] SQGs are required to make a "good faith" effort to minimize hazardous waste generation and implement the best available treatment, storage, or disposal alternative economically feasible.

The more restrictive regulations, high treatment/disposal expenses, and increased liability costs prompted private industry and several government agencies to critically examine means that will lead to prevention of pollution as opposed to end-of-pipe treatment methods. Waste minimization is economically beneficial to Army installations. Some of the cost savings realized by minimizing wastes result from: reduced transportation and disposal costs for offsite disposal; reduced compliance costs for permits, monitoring, and enforcement; reduced onsite treatment costs; reduced onsite storage and handling costs; lower risk of spills, accidents, and emergencies; lower long term liability and insurance costs; reduced raw materials costs; reduced waste generation fees; reduced effluent costs and assessments from local sewage treatment plants; reduced production costs through better management and efficiency; and, reduced operation and maintenance costs.

In fiscal year (FY) 1987, the Army directly paid (through a centrally funded process) the Defense Logistics Agency (DLA) $17.5 million for disposal of only 15 percent of the total wastes generated

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[1] Public Law 98-616, *Hazardous and Solid Waste Amendments* (1984).

[2] Public Law 94-480, *Resource Conservation and Recovery Act* (1976).

* Regardless of the units of measure used in source documents, all measurements have been converted to English units. Metric conversions are on p 157.

[3] 40 CFR 261, *Identification and Listing of Hazardous Waste*, and 40 CFR 262, *Standards Applicable to Generators of Hazardous Wastes* (1985).

[4] Federal Register, Vol 51, No. 190 (October 1986), pp 35190-35194.

by Army installations.[5] The DLA, through its Defense Reutilization and Marketing Offices (DRMOs) located in several regions, was responsible for disposal of most categories of hazardous waste generated by the installations. The installations do not have a separate funding account for waste disposal and therefore do not realize the responsibility for waste generation and the cost of disposal. Beginning in FY 1990, the accounting process for waste disposal will be decentralized to provide a strong economic incentive to reduce waste generation.[6] The installations will have to pay the waste disposal costs from their operation and maintenance budget.

In December 1985, the Joint Logistics Commanders (JLC) established the following Department of Defense (DOD) policy:[7]

> The generation of hazardous waste (HW) at Department of Defense activities is a short- and long-term liability in terms of cost, environmental damage, and mission performance. A HW minimization program shall be developed by each service and shall contain the basic concepts in this directive.

Recognizing the liabilities of improper disposal and the advantages of waste minimization, JLC set a DOD-wide goal of 50 percent reduction in hazardous waste generation by 1992, based on the baseline generation in 1985. The Department of the Army is following this DOD goal and has established a policy[8] applicable to all Active Army, Reserve, and National Guard installations.

Army installations are like small cities with a variety of activities that generate pollution within their boundaries. Unlike civilian cities, where there are many SQGs, each installation as a whole (and its Commander) is a generator held responsible for complying with regulations and reducing pollution from all the activities within its boundaries. Environmental protection must be made a primary concern of every employee on an installation. Everyone must make an effort to protect our air, water, and land from industrial and chemical contaminants. Pollution prevention pays not only in terms of complying with regulations, saving in disposal/treatment costs, reducing liability and improving public image, but also in maintaining the good health and welfare of all people.

Each installation is responsible for implementing a hazardous waste minimization (HAZMIN) plan and each employee, military and civilian, is responsible for following the plan. To comply with both the letter and the spirit of the law, the U.S. Army Forces Command (FORSCOM) contracted the U.S. Army Construction Engineering Research laboratory (USACERL) to prepare HAZMIN plans for five FORSCOM installations. This report is the first of the plans and provides a framework for surveying similar installations and developing their HAZMIN plan.

Objective

The objective of this research was to develop a hazardous waste minimization plan for Fort Carson, CO to include the actions necessary to accomplish reduction in volume and toxicity of hazardous wastes generated.

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[5] V.J. Ciccone and Associates, Inc., *Program Status Report: Department of the Army Hazardous Waste Minimization*, (U.S. Army Environmental Office, August 1988), p 43.

[6] Office of the Assistant Chief of Engineers, "Hazardous Waste Disposal Funding," DAEN-ZCP-B Memorandum (Department of the Army, 28 October 1988).

[7] Joint Logistics Commanders, "Hazardous Waste Minimization Program," Memorandum to the Deputy Secretary of Defense (12 December 1985).

[8] *Hazardous Waste Minimization (HAZMIN) Policy* (Department of the Army, 1989).

Approach

The following approach was used to develop the plan:

1. Prepare a study strategy that included development of a protocol for conducting a HW inspection/survey. The inspection/survey protocol was developed from literature reviews and previous HW surveys performed by the U.S. Army Environmental Hygiene Agency (USAEHA), and the U.S. Army Construction Engineering Research Laboratory (USACERL).

2. Conduct a survey of all possible waste generated at Fort Carson from 22 through 25 January 1989, 5 through 24 March 1989; and 27 August through 2 September 1989.

3. Compile data on hazardous materials procurement by different users on the installation.

4. Compile data on hazardous waste generation for each possible generator on the installation.

5. Compile information on each waste stream including: waste characterization; waste source; baseline generation; current method of treatment, storage, and disposal and the associated costs; and past/present minimization efforts and associated costs.

6. Prioritize waste streams by criteria such as: composition, quantity, degree of hazard, method and cost of disposal, compliance status, liability, and potential to minimize.

7. Identify and prioritize minimization options for major waste streams.

8. Conduct feasibility and economic analyses of minimization options.

9. Prepare the final plan.

Scope

Although an attempt was made to quantify all the hazardous materials procured by and hazardous wastes generated at Fort Carson, a study of the mass balance of chemicals entering and wastes leaving the installation (which allows development of strategies for waste minimization) could not be completed because of lack of data.

Some of the tables prepared for this report contain blanks. The blanks do not represent zero waste generation, but rather that the data was not available. Fort Carson should make every effort to locate the data and update the tables. Proper inventory control will generate data for future use.

Mode of Technology Transfer

The HAZMIN plan (Appendix A) will be presented to Fort Carson for implementation. The recommendations that have been made should be incorporated in the installation policies and regulations.

2 HAZARDOUS WASTE MINIMIZATION

The HSWA requires generators of hazardous wastes to certify that they have a waste minimization program. Every waste shipment manifest (or tracking document) is accompanied by the following declaration, in compliance with Section 3002(b) of HSWA:

> The generator of the hazardous waste has a program in place to reduce the volume and toxicity of such waste to the degree determined by the generator to be economically practicable; . . .

HSWA Section 3002(a) requires the generators of hazardous wastes to submit a biennial report, including their efforts to reduce the volume and toxicity of wastes generated. HSWA Section 3005(h) requires facilities that treat, store, or dispose of hazardous wastes to submit annual reports accompanied by similar declarations on waste minimization.

The HSWA also established a national land disposal restriction program by developing a schedule for banning all hazardous wastes from land disposal by May 1990. In November 1986, USEPA issued the first set of restrictions regarding land disposal of hazardous wastes.[9] These restrictions prohibited land disposal of untreated and concentrated spent solvents. Deadlines for banning land disposal were extended for other solvent wastes because it was felt that sufficient nationwide capacity for treatment did not then exist. It may well be that in a few years commercial land disposal will be available only to hazardous waste residues from treatment processes. In addition, generators must realize that they may be held liable for environmental contamination. Therefore, alternatives to land disposal are necessary.

Minimization includes any reduction in hazardous waste generation and any activities that result in either a reduction in the total volume or quantity of hazardous wastes, or a reduction in the toxicity of hazardous wastes produced, or both, as long as the activities are consistent with the national goal minimizing present and future threats to the environment.[10] By this definition, treatment options such as incineration are considered HAZMIN techniques. HAZMIN, therefore, can be achieved by:

1. Source Reduction: reducing or eliminating waste generation at the source, usually within a process or by an action taken to reduce the amount of waste leaving a process,

2. Recycling Onsite/Offsite: using a waste as an effective substitute for a commercial product, or as an ingredient or feedstock in a process. Recycling also implies reclaiming useful constituent fractions from a waste or removing contaminants, allowing the waste to be reused, or

3. Treatment: eliminating the hazardous characteristics of a waste to make it nonhazardous to human health and the environment.

The hierarchy that should be used in a waste minimization process is shown in Figure 1.* The small amount of residue (e.g., ash) from the process will require "ultimate" disposal (e.g., landfill burial). Various waste minimization techniques, discussed in detail below, are shown in Figure 2.

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[9] Federal Register, Vol 51, No. 190.

[10] *Minimization of Hazardous Waste. Executive Summary and Fact Sheet*, EPA/530/SW-86/033A (U.S. Environmental Protection Agency [EPA], Office of Solid Waste, 1986).

*Figures and tables are located at the end of each chapter.

These techniques can be divided into three HAZMIN categories. Maximum waste reduction is usually achieved by using the best combination of suitable techniques from all three categories.

Source Reduction

Source reduction is at the top of the hierarchy and is the "ideal" solution to the problem of hazardous wastes. All wastes have some potential to be minimized by using better operating practices, product/material substitution, and process changes. Source reduction eliminates the need for storage, transportation, treatment, and residue disposal, and the associated liabilities.

Better Operating Practices

Better operating practices include the simplest source reduction measures such as reducing spillage and leaks, inventory control, employee education/training and control, and better materials/wastes handling practices (e.g., segregation). Experience has shown that education and training programs in safety and hazardous materials/wastes management can be very effective. One approach to good housekeeping is to automate or computerize continuous processes, thereby decreasing human involvement and errors. Waste segregation is an extremely important housekeeping practice that should be incorporated into the work standard. For example, mixing a minute quantity of hazardous waste with a large quantity of nonhazardous waste generates a large quantity of hazardous waste that has to be reported and properly disposed of. Therefore, wastes should never be mixed (e.g., solvents and oils, trash and solvents/oils, gasoline and solvents, etc.). Also, the purity of the waste determines its recyclability (discussed below). Combining dissimilar wastes reduces the chance of recovering either one of them. By using waste segregation and improved handling, most generators could considerably reduce the quantities of wastes generated.

Inventory control is perhaps the most critical and effective better operating practice for HAZMIN. It is a low-cost and easily implementable method that is popularly used in many industries.[11] The quantities of wastes generated can be minimized by reducing the amount of excess material in stock and the amount used in any process or operation. Controlling the purchase of raw materials is the first step in inventory control. Standard operating procedures that allow local or Federal supply system purchase of only approved materials should be established. New materials must be approved before purchase. A tracking system should be established to ensure that all the materials purchased are used properly. Such a materials "manifest" system is a tool that is useful not only in minimizing waste generation but also in complying with the Community "Right-To-Know" law.[12]

Product/Material Substitution

Product/material substitution is a major category of source reduction. Most hazardous wastes are so categorized because they result from processes that use hazardous materials as input or in an intermediate step. Product substitutions are necessary to minimize the environmental impacts of some products (e.g., pesticides such as DDT, 2,4,5-T etc.) and associated wastes. Use of nonhazardous or less hazardous products as substitutes is therefore recommended. An example of product substitution is replacing cadmium plated products with zinc or aluminum plated products in metal finishing operations.

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[11] G.E. Hunt and R.N. Schecter, "Minimization of Hazardous-Waste Generation," in *Standard Handbook of Hazardous Waste Treatment and Disposal*, H.M. Freeman Ed. (McGraw Hill, New York, NY, 1989), pp 5.3-5.27; D. Huisingh, *Profits of Pollution Prevention: A Compendium of North Carolina Case Studies* (North Carolina Board of Science and Technology, Raleigh, NC, 1985).

[12] Public Law 99-499 Title III, *Superfund Amendments and Reauthorization Act* (1986).

Material substitution can also be viewed as a change in a process that involves using nonhazardous or less hazardous input or raw material, or a material with few impurities. Less hazardous materials with fewer impurities can reduce the likelihood of generating high volumes of hazardous wastes. Some examples of material substitution are:[13] replacing chlorinated solvents (e.g., trichloroethylene [TCE], 1,1,1-trichloroethane) with hot caustic solutions or detergents in degreasing operations; using noncadmium pigments in ink manufacture; and replacing cyanide formulations with noncyanide formulations in cadmium electroplating baths.

One major form of product/material substitution is "aqueous" substitution; the use of water-based materials as inputs or products in a process. Many aqueous alternatives have been developed by the chemical industries. Some examples of aqueous substitution are:[14] replacing organic liquids (e.g., TCE, Stoddard solvent, xylene, toluene, etc.) with water-based products (e.g., Citrikleen, Histoclear, etc.) in metal cleaning and degreasing operations; replacing petroleum-based fluids with water-based fluids in metalworking and machining operations; substituting solvent-based ink with water-based ink in the printing processes; and using a water-based developing system instead of a solvent-based system in the manufacture of printed circuit boards.

Process Changes

Some generators will have to consider either improvements in the manufacturing process or even major changes in the technological processes to achieve waste reduction. Process change is a category of source reduction and includes source control. Source control implies examination and reevaluation of the processes that generate hazardous waste. Process optimization and increased efficiency were terms commonly used in source control projects to obtain the best quality product. Not much attention was paid to the waste. The concept of source control, therefore, is not new. Optimizing a process or increasing its efficiency also reduces the quantities of wastes generated. Process change or source control can further be divided into: process/equipment modifications, improved controls, and energy/water conservation.

Process/equipment modifications will require that operating/manufacturing processes and equipment used for waste minimization be redesigned. Some examples of process modifications are:[15] using dry plastic media blasting instead of wet chemical stripping (with methylene chloride, hot caustics, etc.) to remove paint from metallic substrates, replacing cocurrent rinsing with countercurrent rinsing in metal plating and surface finishing operations, and retrofitting the existing chrome-plating processes with equipment that reduces the discharge of rinsewater to almost zero.

Improved controls could also be included under "better operating practices." It implies proper control of processes or equipment to reduce emissions and waste generation. Conserving energy/water by controlling the heat input and reducing the amount of rinse/process water used can reduce emissions, solid wastes, and wastewater.

Recycling Onsite/Offsite

After all source reduction techniques have been examined for a particular waste stream, recycling options, both onsite and offsite, should be considered. Three types of onsite recycling operations are

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[13] *Alternative Technology for Recycling and Treatment of Hazardous Wastes*, Third Biennial Report (California Department of Health Services, Alternative Technology and Policy Development Section, 1986).

[14] *Alternative Technology for Recycling and Treatment of Hazardous Wastes*.

[15] *Alternative Technology for Recycling and Treatment of Hazardous Wastes*.

available:[16] (1) reuse of waste in the same process (e.g., continuous recycling of rinsewaters in plating/finishing operations, recycling of tetrachloroethylene in dry cleaning operations), (2) use of the waste in a different process (e.g., using waste battery acid as a neutralizing agent in an industrial wastewater treatment plant), and (3) processing the waste to produce a reusable product (e.g., distilling solvents, burning used oil for heat content, etc.). Offsite recycling includes methods used to process the waste to produce a usable product (e.g., re-refining waste oil, reclaiming lead from lead-acid batteries, recovering silver from fixing bath solutions, incinerating hazardous wastes for heat content, etc.).

Recycling of hazardous wastes is encouraged by the Federal and State governments. Hazardous waste generators must explore all recycling opportunities for wastes whether or not the generation is reduced. Industrial recyclers are available for a number of wastes. Recyclable wastes include:[17] unused commercial chemical products, halogenated solvents, oxygenated solvents, hydrocarbon solvents, petroleum products (including oils and hydraulic fluids), pickling liquor, unspent acids and alkalis, and selected empty containers. Some offsite programs recycle batteries, mercury, and drums. Offsite recycling is also a major part of the program called "solvent leasing." In this program, a generator will lease process equipment. The equipment owner provides clean solvent and is responsible for removing and recycling used solvent.

An offsite recycling method that needs to be evaluated by DLA and DRMOs is the use of waste exchanges to recycle wastes. Waste exchanges are operations that engage or assist in transferring wastes and information concerning wastes. They help generators develop effective waste minimization programs and comply with legislative and regulatory requirements. A list of waste exchanges operating in North America is provided in Table 1. Some of these organizations are waste information "clearinghouses" and others are waste material exchanges. The information exchanges are usually nonprofit organizations that provide information about the availability and demand of waste materials. Material exchanges act as agents or brokers, and usually take the waste materials, process them, and market them for profit.

Treatment

Treatment of hazardous wastes should be the last minimization choice; after source reduction and recycling, but before "ultimate" disposal. Treatment alternatives must be considered only if source reduction and recycling are not feasible or economically practical. A treatment process: (1) destroys or detoxifies a hazardous waste to a material safe for disposal, (2) concentrates or reduces the volume of wastes for safer handling and disposal, or (3) immobilizes the hazardous components to keep them from the environment. Generators of large amounts of hazardous wastes usually treat the wastes onsite; generators of small amounts of hazardous wastes use offsite treatment facilities. With the increased availability of commercially packaged treatment units, generators may opt to treat wastes onsite. A hazardous residue requiring "ultimate" disposal may still be generated. Treatment processes include neutralization, filtration, evaporation, incineration, and precipitation. Acids, bases, and plating wastes are some of the waste streams that can be treated readily.

Four broad categories of treatment technologies (physical, chemical, biological, and thermal) are applicable to all waste streams. Physical treatment techniques, generally involving phase separation (e.g., solids from liquids), include:[18] separation techniques such as centrifugation, clarification,

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[16] *Alternative Technology for Recycling and Treatment of Hazardous Wastes.*
[17] *Alternative Technology for Recycling and Treatment of Hazardous Wastes.*
[18] *Alternative Technology for Recycling and Treatment of Hazardous Wastes.*

coagulation, decantation, encapsulation, filtration, flocculation, flotation, foaming, sedimentation, thickening, and ultrafiltration; and specific component removal techniques such as adsorption, blending, catalysis, crystallization, dialysis, distillation, electrodialysis, evaporation, magnetic separation, leaching, ion exchange, liquid-liquid extraction, reverse osmosis, stripping, and sand filtration. Some of the physical treatment techniques can be readily used as pretreatment steps (e.g., filtration, sedimentation, etc.) before onsite recycling of wastes and also as a part of better housekeeping practices.

Chemical treatment techniques that use the differences in chemical properties of substances, include:[19] mound adsorption, fixation, oxidation, precipitation, reduction, chlorination, chlorinolysis, cyanide destruction, degradation, detoxification, ion exchange, neutralization, ozonation, and photolysis. Biological treatment techniques include:[20] activated sludge digestion, aerobic processes, composting, trickling filtration, and waste stabilization. Biological treatment processes rely on microorganisms (bacteria, fungi, etc.) to decompose and/or bioaccumulate the contaminants in wastes.

As a HAZMIN technique, treatment, unlike source reduction or recycling, has legal (or RCRA) implications. A permit has to be obtained for treatment of hazardous wastes. Only elementary neutralization (e.g., laboratory acids/bases neutralization) and "enclosed" wastewater and other treatment units are exempt from permitting requirements.[21]

HAZMIN Assessment

The HAZMIN assessment procedure and development of the plan (Appendix A) was based on the methods described in *EPA (Environmental Protection Agency) Manual for Waste Minimization Opportunity Assessments*[22], and other references.[23] The assessment protocol and survey forms are attached in Appendix B.

Development of a successful HAZMIN program contains four critical phases: planning and organization, assessment, feasibility analysis, and implementation (see Figure 3). Figure 4 indicates the two phases that CERL was involved in. FORSCOM recognized the need for the development of a HAMZMIN program and did the initial planning and organization.

The first task in the assessment phase is to gather all the available information pertaining to hazardous materials procurement, waste generation, and operating procedures. Second, the waste streams are prioritized and selected for assessment. Team members are selected and a survey agenda is organized. The next step is the actual survey that includes: interviewing supervisors, foremen, and operators; observing housekeeping practices; inquiring about standard operating procedures; and gathering information about levels of administrative controls. Waste minimization options are then evaluated. The most promising options are selected for detailed evaluation.

In the feasibility analysis phase, the technical and economic feasibility of selected minimization options is evaluated. This phase includes the installation information (Chapter 3) and data gathered

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[19] *Alternative Technology for Recycling and Treatment of Hazardous Wastes.*

[20] *Alternative Technology for Recycling and Treatment of Hazardous Wastes.*

[21] 40 CFR 260, *Hazardous Waste Management System: General* (1985).

[22] *EPA (Environmental Protection Agency) Manual for Waste Minimization Opportunity Assessments*, EPA/600/2-88-025 (USEPA, Hazardous Waste Engineering Research Laboratory, 1988).

[23] R.H. Hemstreet,"How to Conduct your Waste Minimization Audit," in *Waste Minimization Manual*, (Government Institutes, Inc., Rockville, MD, 1987), pp 61-75; M.E. Resch, "Hazardous Waste Minimization Audits using a Two-Tiered Approach," *Environmental Progress*, Vol 7 (1988), pp 162-166; M. Drabkin, C. Fromm, and H. M. Freeman, "Development of Options for Minimizing Hazardous Waste Generation," *Environmental Progress*, Vol 7 (1988), pp 167-173.

(Chapter 4), waste minimization techniques for the various types of sources and wastes (Chapters 5 to 11), and economic analysis of minimization options for select waste streams (Chapter 12).

Fort Carson should implement the HAZMIN plan according to methodology presented in Chapter 13. Successful implementation of the plan will require command support and commitment. Continuance of the HAZMIN program in the future will require constant evaluation of the goals, reassessment of generators, and developing newer/better procedures for minimizing wastes.

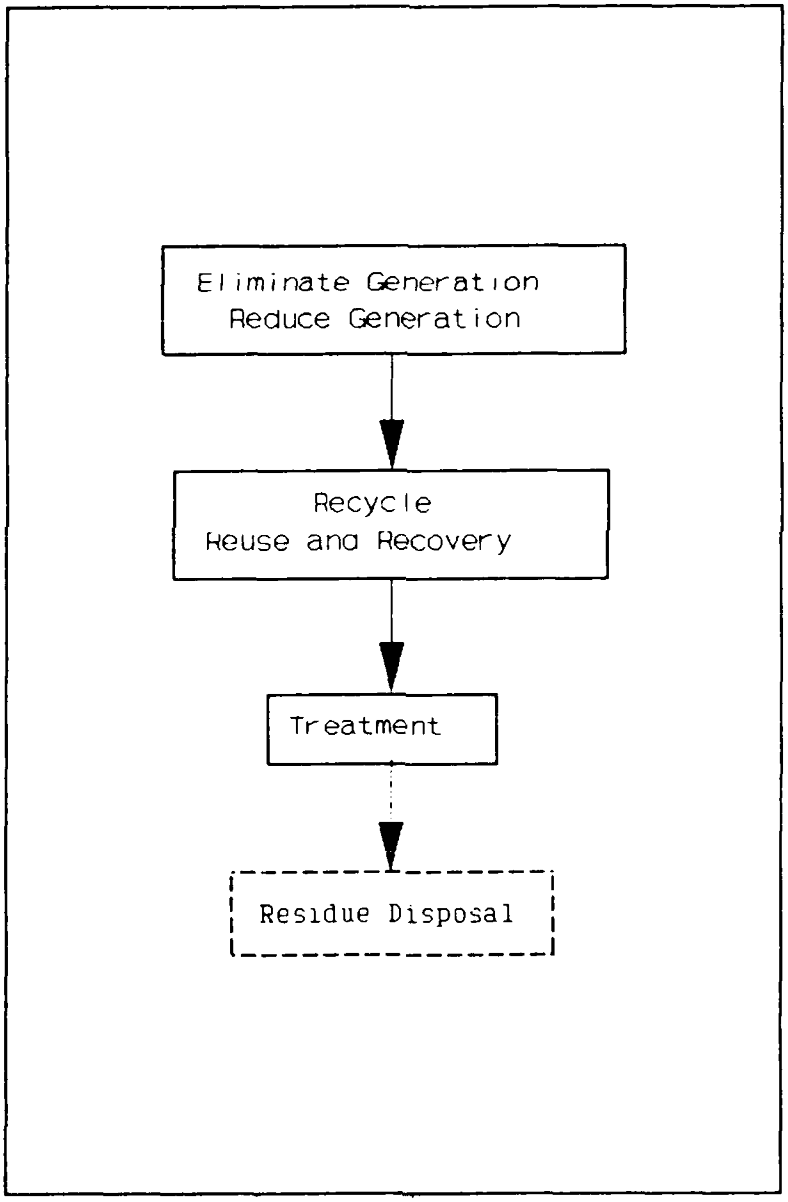

Figure 1. Waste minimization hierarchy.

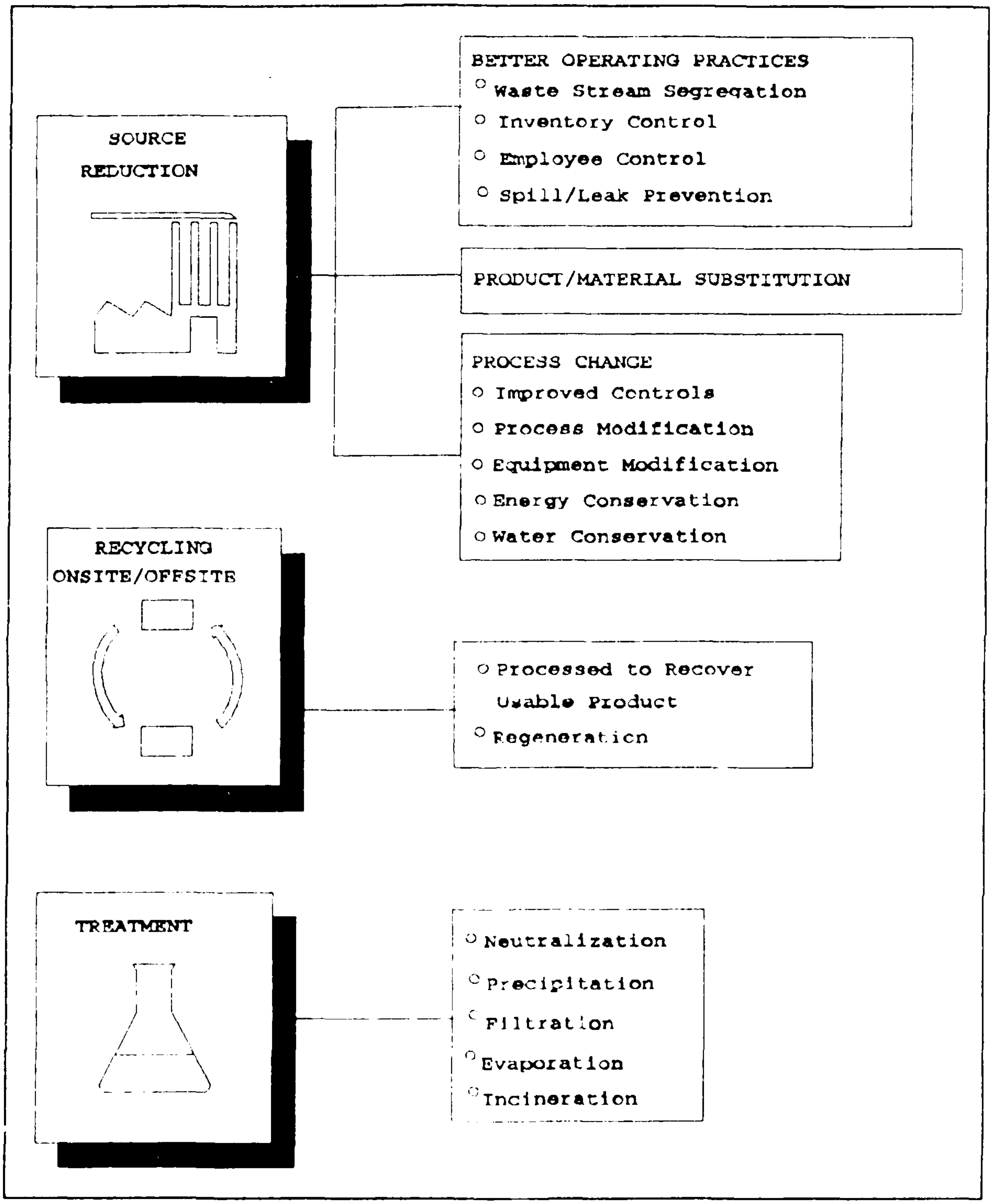

Figure 2. Waste minimization techniques.

Table 1

List of Waste Exchanges

Alberta Waste Materials Exchange
4th Floor Terrace Plaza
4445 Calgary Trail South
Edmonton, Alberta
CANADA T6H 5R7
(403) 450-5461

California Waste Exchange
Department of Health Services
Toxic Substances Control Division
714 P Street
Sacramento, CA 95814
(916) 324-1807

Canadian Inventory Exchange*
900 Blondin
Ste-Adele, Quebec
CANADA J0R 1L0
(514) 229-6511

Canadian Waste Materials Exchange
Ontario Research Foundation
Sheridan Park Research Community
Mississauga, Ontario
CANADA L5K 1B3
(416) 822-4111

Enkam Research Corporation*
P.O. Box 590
Albany, NY 12202
(518) 436-9684

Georgia Waste Exchange*
c/o America Resource Recovery
P.O. Box 7178, Station A
Marietta, GA 30065
(404) 363-3022

Great Lakes Regional Waste Exchange
470 Market Street, S.W.
Suite 100-A
Grand Rapids, MI 49503
(616) 451-8992

Indiana Waste Exchange
P.O. Box 1220
Indianapolis, IN 46206
(317) 634-2142

Industrial Materials Exchange Service
2200 Churchill Road
IUSEPA/SLPC-24
Springfield, IL 62706
(217) 782-0450

Industrial Waste Information Exchange
New Jersey Chamber of Commerce
5 Commerce Street
Newark, NJ 07102
(201) 623-7070

Manitoba Waste Exchange
c/o Biomass Energy Institute, Inc.,
1329 Niakwa Road
Winnipeg, Manitoba
CANADA R2J 3T4
(204) 257-3891

Montana Industrial Waste Exchange
Montana Chamber of Commerce
P.O. Box 1730
Helena, MT 59624
(406) 442-2405

Northeast Industrial Waste Exchange
90 Presidential Plaza, Suite 122
Syracuse, NY 13202
(315) 422-2405

Resource Recovery of America**
P.O. Box 75283
Tampa, FL 33675-0283
(813) 248-9000

South Waste Exchange
Urban Institute
UNCC Station
Charlotte, NC 28223
(704) 547-2307

Southern Waste Information Exchange
P.O. Box 6487
Tallahassee, FL 32313
(904) 644-5516

Tennessee Waste Exchange
Tennessee Manufacturers and Taxpayers Association
226 Capitol Blvd., Suite 800
Nashville, TN 37219
(615) 256-5141

Wastelink, Division of Tenecon Associates*
P.O. Box 12
Cincinnati, OH 45174
(513) 248-0012

Western Waste Exchange
ASU Center for Environmental Studies
Krause Hall
Tempe, AZ 85287
(602) 965-1858

Zero Waste Systems**
2928 Poplar Street
Oakland, CA 94608
(415) 893-8261

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*For-profit information exchange.
**Material waste exchange.

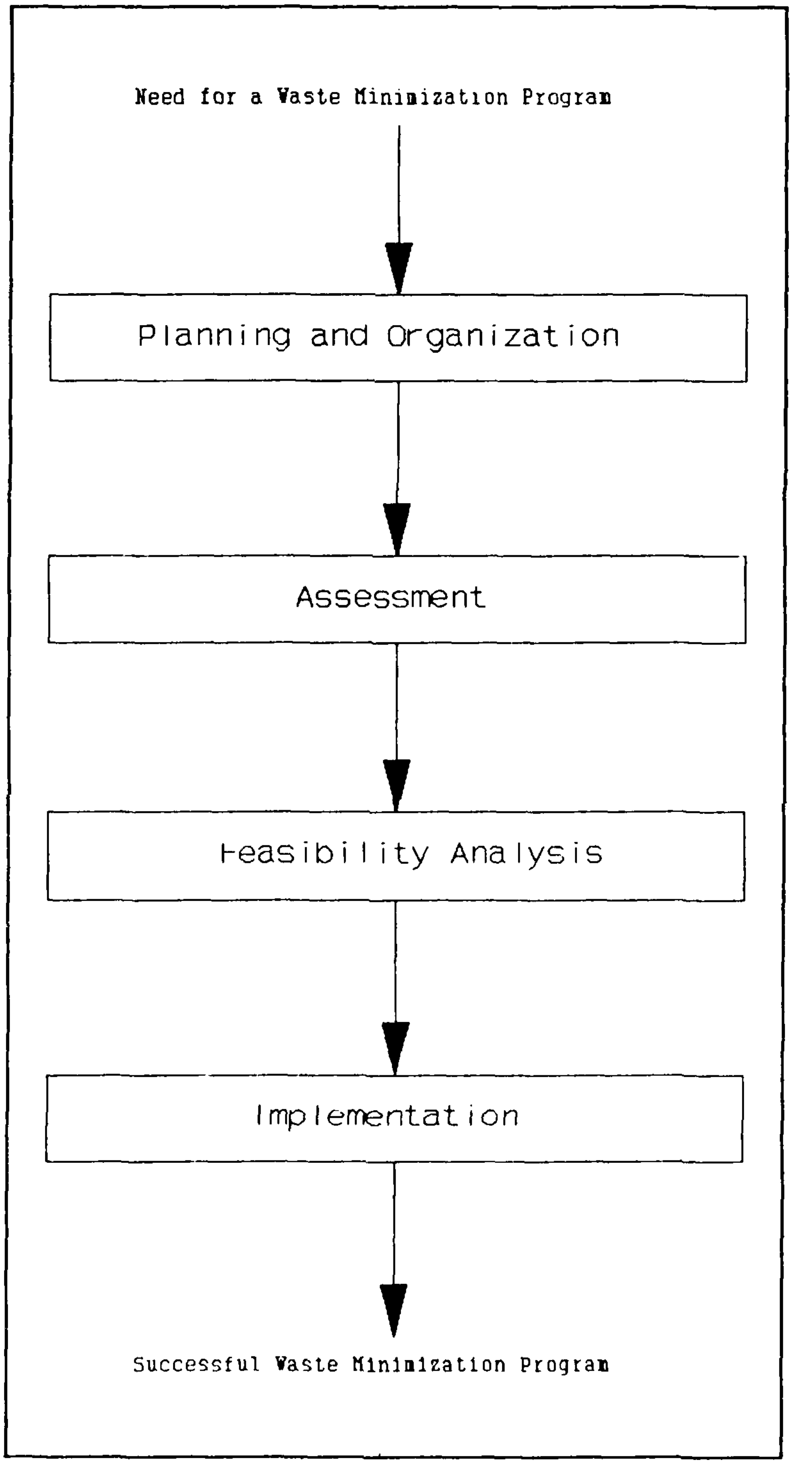

Figure 3. Hazardous waste minimization program development procedure.

ASSESSMENT

- Prioritize and Select Assessment Targets
- Select and Interview Personnel
- Collect HM Procurement and HW Generation Data
- Survey Site and Review Data
- Prioritize Waste Streams and Generate Options
- Screen and Select Options for Further Evaluation

FEASIBILITY ANALYSIS

- Technical Evaluation
- Economic Evaluation
- Select Options for Implementation

Figure 4. Hazardous waste minimization assessment and feasibility analysis procedure.

3 FORT CARSON

History/Geography

Fort Carson, named in honor of Brigadier General Christopher "Kit" Carson, a former frontiersman, is home of the 4th Infantry Division (Mechanized). It is located in eastern Colorado, near Colorado Springs, on rolling plains that border the Rocky Mountains. Military commanders and officials in Washington, DC, chose Colorado Springs as the site of an Army camp on January 6, 1942. The original camp consisted of 60,048 acres of land. Colorado Springs donated 5533 acres, 29,676 acres were purchased from private owners, and 262 acres were purchased from the Department of Interior. The State of Colorado leased 24,577 acres to the Army.

More land was deemed necessary to train a mechanized division. Therefore, an additional 78,741 acres of land was acquired south of the original reservation in 1965 and 1966 from private owners, the State of Colorado, the Colorado School of Mines, and the Department of Interior. With those additions, the total area amounted to the current size of 138,789 acres.

Because of the immediate need for a place to train soldiers, round-the-clock construction at Camp Carson began in early 1942. To avoid grading, the camp was built to conform to the shape of the land, thus providing it with a "banana" belt look. Facilities were built for 35,173 enlisted men, 1818 officers, and 592 nurses. A semipermanent hospital with space for 1726 beds, a prisoner of war internment camp, and barns to house horses and mules were also built.

During World War II (WW II), about 104,165 soldiers were trained at Camp Carson. Three infantry divisions (71st, 104th, and 10th Mountain) and more than 125 other units were activated. Additionally, more than 100 units were transferred from other installations to train at this mountain post. Use of mules in the Army stopped in 1956 and the associated Field Artillery Batallion (pack) was deactivated when helicopters arrived. The 10th Mountain Division was formed and trained at Camp Hale (20 miles west of Leadville, CO) to move weapons over mountainous terrain in any kind of weather. This division was deactivated in 1946 and a Mountain Cold Weather Training Detachment was created and then transferred to Fort Greeley, Alaska, in 1957. In 1965, the Army traded Camp Hale to acquire land on Fort Carson's southern border.

A prisoner of war internment camp was opened in 1943; approximately 9000 German, Italian, and Japanese prisoners of war were interned. These prisoners were repatriated following the end of the war.

The strength of the post after WW II dropped drastically, to only 600 personnel and 320 patients by April 4, 1946. Many units were deactivated and Camp Carson was ready for closure. However, with the advent of military activity in Korea, many reserve units were called for active duty. A Camp Carson Separation Center was established in 1951 to separate Korean Conflict veterans from the service; approximately 100,000 soldiers were processed there. Camp Carson became Fort Carson in 1954. The Cuban Missile Crisis and the Berlin Blockade lead to the activation of the 5th Infantry Division at Fort Carson.

During the Vietnam Conflict (1965 to 1968), approximately 29,000 soldiers in 61 units were trained at Fort Carson and transferred to Vietnam. By July 1967, the number of military personnel and civilians rose to 24,735 and 2445, respectively. Following the conflict, cutbacks were ordered and the number of military personnel dropped to 20,400 while civilian strength rose to 2860 and has remained relatively stable since 1973. The 4th Infantry Division was ordered to locate at Fort Carson in 1970.

In 1974, an additional 245,000 acres of land was acquired at Piñon Canyon, 100 miles southeast of Fort Carson. The Pinon Canyon Maneuver Site was opened for training in 1985. Each brigade of the 4th Infantry Division trains at Piñon Canyon before training at the National Training Center at Fort Irwin, CA. A number of permanent buildings (including the Evans U.S. Army Community Hospital) were constructed at Fort Carson to replace the WW II structures.

Since deployment of the 4th Infantry Division at Fort Carson, it was reorganized into its current form of a mechanized infantry division with the nickname "The Ironhorse Division." It has three maneuver brigades, a combat aviation brigade, four field artillery battalions, and many combat support and combat service support units. This "Ivy" division, as it is also known, has a long history of successful participation in several wars. It is a training division that is a combat-ready "fire brigade" ready to quell aggression wherever and whenever required.

Tenants

The tenants at Fort Carson that generate, handle, or dispose of hazardous materials/waste are:

1. U.S. Army Medical Department Activity (MEDDAC),

2. U.S. Army Dental Activity (DENTAC), and

3. Defense Reutilization and Marketing Office.

Other tenants also located at Fort Carson are: 902nd Military Intelligence (MI) group, Logistics Assistance Office (LAO), U.S. Army Criminal Investigation Command (USACIC), U.S. Army Legal Service Agency, Maintenance Assistance and Instruction Team (MAIT) No. 20, Air Force Air Weather Service Unit, U.S. Army Commissary, U.S. Army Calibration, U.S. Army Audit Agency, U.S. Army Reserve 3rd Battalion 87th Infantry, and Naval Reserve Center.

Environmental Programs

This section provides a description of the status of environmental quality as affected by the number of pollution sources at Fort Carson. The information has been extracted from an *Environmental Operations Review*[24] conducted by AEHA, other assessments,[25] discussion with the Environment, Energy, and Natural (EENR) Office personnel, and the survey conducted during the course of this study.

Air Pollution Control

Fort Carson is required to comply with Federal Clean Air Act Amendments of 1977 and Colorado Air Quality Control Act regulations. These regulations are enforced by the Air Pollution

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[24] *Environmental Operations Review - 4th Infantry Division (Mechanized) and Fort Carson, Colorado Springs, CO*, Study No. 37-26-1385-87, (U.S. Army Enviromental Hygiene Agency, August 1986).

[25] B.N. McMaster, J.D. Bonds, L.C. Carter, W.G. Fraser, J.B. Holly, E.A. Knauft, J.B. Sosebee, J.H. Wiese, and K.A. Civitarese, *Installation Assessment of the Headquarters, Fort Carson and 4th Infantry Division (Mechanized), Fort Carson, Colo., and its Subinstallations Headquarters, Fort Douglas and U.S. Army Support Detachment, Fort Douglas, Utah, and Headquarters, Fort Missoula, Fort Missoula, Mont.*, Report No. DRXTH-AS-IA-82330 (Prepared for the Commander, Headquarters, Fort Carson and 4th Infantry Divsion (Mechanized), Fort Carson, CO, and U.S. Army Toxic and Hazardous Materials Agency, Aberdeen Proving Ground, MD, 1983); *Multimedia Inspection Nov. 30 - Dec. 7 1987; Fort Carson, Colorado; Final Inspection Report* (U.S. Environmental Protection Agency, Region VIII, Denver, Colorado, 1988).

Control Division (APCD) of the Colorado Department of Health and the El Paso County Health Department. Fort Carson and Piñon Canyon are located in the San Isabel Intrastate Air Quality Control Region (AQCR) (Colorado AQCR Nos. 4 and 7). AQCR 4, which encompasses most of Fort Carson, has been classified as "better than National Ambient Air Quality Standard (NAAQS)" for sulfur dioxide (SO_2), "cannot be classified or better than NAAQS" for ozone (O_3) and nitrogen oxide (NO_2), and "does not meet primary NAAQS" for carbon monoxide (CO), total suspended particulates (TSP), and particulate matter less than 10 microns (PM10). AQCR 7, which includes the southern portion of Fort Carson and Piñon Canyon has been classified as "better than NAAQS" for SO_2, TSP, and PM10; and "cannot be classified or better than NAAQS" for O_3, CO, and NO_2.

The EENR at Fort Carson maintains a listing of all the air pollution sources. Stationary sources of air pollution include: boilers/minor combustion sources, incinerators, open burning/open detonation (OB/OD), fuel storage/dispensing, painting, metal cleaning, and miscellaneous (woodworking, building demolition, training exercises, construction/land development projects, etc.) operations. In addition, there are a number of mobile sources (tactical and nontactical vehicles, aircraft, etc.) of emissions that are maintained in compliance through an inspection and maintenance program, a transportation control plan, and a smoking vehicle program.

A majority of Fort Carson's boilers/minor combustion sources, located throughout the post, are exempt from Colorado permitting requirements based on size and/or date of installation. They have all been in compliance with Colorado standards for visible emissions. The permits required have been obtained and updated for installation and modification of boilers in buildings 1860, 6290, 633, 635, and 636; the industrial wastewater treatment plant (IWTP) steam sludge heater; boilers at some of the vehicle and aircraft maintenance facilities; and several boilers at Piñon Canyon.

Only "specification used oil" is occasionally burned in one of the three natural gas/No. 6 fuel oil-fired, high temperature boilers at the Central High Temperature Hot Water Plant (Bldg 1860). The current air emissions permit for these boilers limits the quantities of fuel oil burned annually to 137,000 lb and the sulfur content of the backup fuel to 0.5 percent. The visible emissions must be limited to 0.5 percent. Burning of used or waste oil is not addressed in the permit (although the boiler may qualify as a utility boiler), and may be illegal.

Three stationary engine test cells located in the DOL industrial maintenance shop (Bldg 8000) are used to test engines from wheeled and tracked vehicles. Emissions of less than 5 tons/yr from these cells are exhausted to the atmosphere. Although exempt from permit requirements, filing of an APEN is probably required.

A new pathological incinerator (Consumat Model C-75P rated at 200 lb/hr) was purchased in 1986 to replace the old one (Shenandoah Model G-71/JTC) located in the veterinary clinic (Bldg 6000). Its operation is in compliance with the APCD regulations. In the past, solvents were illegally burned at a firefighter training pit at the Butts Army Air Field. That practice has been stopped and a RCRA (Part B) permit has been obtained for open burning/open detonation of ordnance at Ranges 1, 1A, 121, and 123. A permit is required for open burning of building structures at Piñon Canyon.

The vehicle paint booth in Bldg 8000 was modified in the mid-1980's to accommodate Chemical Agent Resistant Coating (CARC) painting operations. CARC paints contain hexamethylene diisocyanate (HDI) and a number of other methyl isocyanates that are moderately to highly toxic air pollutants. Two other paint booths are located in the autocraft shop (Bldg 2427) and a fourth one is located at the training aids fabrication center (Bldg 6054). The potential of toxic emissions exists from all these booths.

A number of large fuel storage tanks are located throughout Fort Carson. Most of them require permits. However, none of them are regulated as sources of volatile organic carbon (VOC) emissions. A major source of VOC emissions is the vapor degreaser, in Bldg 8000, which is exempt from permitting requirements based on the date of installation. Degreasers containing 1,1,1-trichloroethane are specifically exempt from Colorado VOC regulations since 1,1,1-trichloroethane is considered a "low toxicity air contaminant," and because Fort Carson is in an O_3 attainment area.

Woodworking operations (Bldg 2426 and 210) generate very small quantities of emissions and therefore do not require a permit. There are, however, a number of sources of fugitive dust (e.g., unpaved roads, coal piles, etc.) for which permits have been obtained and a particulate control plan has been developed.

Fort Carson has a number of WW II era buildings that have asbestos insulation. Friable asbestos is being removed or encapsulated in all the buildings that are in use or in the ones that are burned. A proper asbestos management plan has been developed and implemented.[26]

Emissions testing, instrumentation, and mechanic certification are commonly conducted at the Adjustment, Inspection, and Realignment stations. Vehicles built before 1968 and all emergency response vehicles are routinely tested for emissions. Emissions testing may also be required for privately owned vehicles in the future.

Fort Carson does not have an air pollution emergency episode plan. However, it has an excellent ambient air quality monitoring network for both the main post and Piñon Canyon which must be fully developed and maintained. A comprehensive review of all the sources of toxic emissions should also be conducted to comply with the forthcoming ammendments to the Clean Air Act and changes in the State of Colorado VOC and air pollution regulations.

Water Pollution Control

Fort Carson purchases water from the city of Colorado Springs. No contingency/emergency plan exists to cope with a possible shortage of potable water. Although the water distribution system dates back to the early 1940's, no significant problems have been noted. A regular monitoring, inspection, and maintenance program, however, is lacking. The back-flow prevention and cathodic protection systems must be inspected and maintained.

A sanitary wastewater treatment plant (WWTP) at Fort Carson, that was designed in the 1940's and slightly modified in the 1980's, has a capacity of 3 to 4 million gallons per day (MGD). In addition to the municipal wastewaters, the sewer system receives influent from the industrial wastewater treatment plant (IWTP) and from the laundry, photographic shop, painting shops, boiler plants, vehicle wash racks with oil/water separators, and other minor industrial sources. The capacity is exceeded every other day and flows of 6 to 7 MGD are generated at the head of the plant when there are major storms. An increase in waste load, cold weather over an extended period of time, and more stringent discharge standards may cause a noncompliance with the National Pollutant Discharge Elimination System (NPDES) permit.

An IWTP was designed in 1981 as an integral part of the centralized vehicle washrack and consisted of sedimentation, oil skimming, biological (aerobic) treatment, chemical addition, flocculation, and multimedia filtration. Because of problems with filtration system capacity, operation of the facility

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[26] *Fort Carson Asbestos Control Program - Asbestos Management Plan*, Draft Report (Directorate of Engineering and Housing, Fort Carson, Colorado Springs, CO, 16 February 1989).

was halted. A system redesign has not yet been completed. In the meantime, wastewater from the collection system (lift stations and gravity flow sewers) and the "birdbaths" flows into an equalization pond and is then pumped to the two surface aerated biological ponds. The overflow bypasses the remaining IWTP and flows into the WWTP.

Both the Spill Prevention Control and Countermeasures Plan (SPCCP) and the Installation Spill Contingency Plan (ISCP) are currently being updated.

Solid Waste Management

Fort Carson has more than 600 dumpsters located throughout the post for collection of solid waste. A contractor collects the trash from all the dumpsters and transports it to a landfill onpost. No waste is transported offpost. The major generators are the mess and dining facilities, and the commissary; followed by the billeting and family housing areas. The dumpsters are not washed regularly.

Only one landfill (260 acres) is currently active and being operated by General Electric (GE) contractor personnel. It has been in operation since 1978 and is regulated by the Colorado Department of Health and the El Paso County Health Department according to the Colorado Solid Waste Regulations. The landfill has 5 water quality monitoring wells to record the depth and condition of the groundwater around the landfill. Groundwater is monitored for leaching of pollutants.

Although a standing operating procedure (SOP) exists and the landfill is inspected monthly by EENR personnel, several violations have been noted in previous studies. Access to the landfill is not limited and illegal dumping is prevalent. A barrier must be built to secure the facility.

A grit/oil pit is located in a 1/2-acre lagoon near the active landfill. This pit contains grit from the installation's oil/water separators and grit interceptors. In the Environmental Operations Review (EOR) study,[27] a number of other wastes such as aerosol cans, empty drums, and typical vehicle maintenance wastes were also observed in the pit. Presence of HW (e.g., solvents) in the pit makes it an illegal HW disposal facility and Fort Carson is most probably in violation of HW regulations. Additionally, the site has a very high potential for groundwater contamination.

The inactive landfills (No. 2, 5, and 6) are also potential sources of groundwater contamination. Monitoring of groundwater beneath these landfills is also necessary. AEHA conducted a hydrogeologic investigation of these sites in 1988 and recommended expansion of the existing landfill (No. 1) by 114 acres. Some of the corrective actions required for the other landfills include: improving the landfill cover, revegetation of the surfaces, and cleanup of groundwater when required.

A solid waste recycling program has been developed and is successful in segregating paper products, brass, and other metallic products. Aluminum is not recycled.

Hazardous Materials and Waste Management

The USEPA has authorized the State of Colorado to operate its own HW management program. Therefore, HW generators such as Fort Carson are regulated by Colorado HW regulations 5 CCR, parts 2, 99, 100, and 260 through 267,[28] which are very similar to Federal HW regulations.[29] Fort Carson

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[27] *Environmental Operations Review.*

[28] *Title 5, Code of Colorado Regulations (CCR)*, Parts 2, 99, 100, 260-267, 1985.

is classified as a "generator," and as owner and operator of a HW Treatment, Storage, or Disposal Facility (TSDF).

A HW storage facility (Building 9248) is currently authorized to operate under interim status regulations, awaiting approval of a Part B permit. It was originally an ammunition storage bunker that has been refurbished to accommodate different types of wastes (ignitable, corrosive, reactive, toxic, etc.). The facility is in compliance with all the general facility standards and specific requirements for the use and management of containers.

At one time, there were 4 OB/OD sites (Ranges 1, 1A, 121, and 123) used for burning and detonation of small arms ammunition and other reactive wastes. An application has been made to include Ranges 1 and 121 on the Fort Carson's Part A HW TSDF permit to maintain compliance with specific standards for thermal treatment facilities. The other two ranges have been closed. AEHA has conducted a detailed study[30] of the OB/OD ranges and made detailed recommendations for proper operation and compliance with regulatory requirements.

Use of the grit/oil pit, next to Landfill 1, for disposal of the wastes from the oil-water separators is not a good practice. It is also used for illegal dumping by some of the troop units. When tested in 1987, the waste was found to be nonhazardous. The disposal practice continues, while awaiting the construction of a drying bed. The construction was requested in 1987 and has yet to begin.

The open burning of solvents and oils mixed with contaminated fuel at the Butts Army Airfield's Fire Training Pit used to be commonplace. Such a practice would constitute illegal hazardous waste treatment. However, only contaminated fuel is used for fire training and it is constantly monitored for halogen content.

The Commander has the overall responsibility for proper maintenance and operation of the HW management program and is the "owner" of the above TSDF. DRMO, an installation tenant, operates the HW storage facility. The EENR office is assigned the responsibility of maintaining the HW management program and, therefore, shares some of the responsibility for proper operation of the storage facility.

Fort Carson is in complete compliance with generator requirements such as obtaining an EPA identification number (#CO 2210020150); establishing a sampling and analysis program; providing for accummulation, packaging, labeling, and marking; placarding of vehicles used for transportation; submission of annual reports and exception reports; and recordkeeping.

Fort Carson has a good HW management program. An HW inventory was developed in accordance with Army Regulation (AR) 420-47; however, it is not comprehensive and should be updated. A training program was established, in 1988 by EENR to train personnel from each unit. It concentrates on petroleum, oils, and lubricants (POL) management and should be updated to include proper HW management (including packaging, labeling, storage, transport, etc.) and minimization. An HW management plan was written in early 1980 and revised in 1984. It includes forming a hazardous waste management board (HWMB) from the original Environmental Quality Control Committee that used to discuss all forms of environment protection. It also identifies all individual generators, and

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[29] *Title 40, Code of Federal Regulations (CFR)*, Parts 260-266, 270-271, 1985; 40 CFR, Part 761, 1986; 49 CFR, Part 171-173, 178-179, 1985.

[30] *Investigation of Soil Contamination at the Open-Burning/Open-Detonation Grounds*, Hazardous Waste Study No. 37-26-0552-86 (U.S. Army Environmental Hygiene Agency, Aberdeen Proving Ground, Maryland, 1986).

provides guidance for handling, management, and proper disposal of HW. A contractor is revising the plan.

Fort Carson needs to establish a detailed inventory of wastes generated by all the units (including generation rates) and a tracking program for all the major HWs. The management of hazardous materials (HM) always has a direct impact on generation and management of HWs. A proper HM management program should be established. This program should include flagging of incoming materials, tracking of materials to their users, proper inventory of materials used, and their use rates. HMs must not be stored in unlabeled drums, and unused materials must be turned in for resale or disposal.

A number of underground storage tanks (USTs) are located throughout Fort Carson. All of them have been located. USEPA has been notified. A program of leak testing and remediation of leaking underground storage tanks is currently underway.

Some of the specific HWs and their management practices at the unit level will be discussed below. Additional discussion of wastes generated and materials used at Fort Carson is in Chapter 4. Used oil, unserviceable lead-acid batteries/battery acid, painting wastes, oil analysis wastes, vehicle radiator cleaning wastes, engine coolant, and PCB transformers/oils are the major wastes at Fort Carson.

Used/Waste Oil. Used oil is generated in a large quantity by all the vehicle and aircraft maintenance activities. Fort Carson has a used oil treatment (energy recovery) program. A contractor collects the used oil from all the above ground and underground storage tanks and transports it to a tank farm located near Building 1860 where it is burned in one of the boilers. Only "specification" used oil can be burned in the boiler.

A major problem with the used oil at Fort Carson is that it becomes a HW because of poor management practices. Used solvents and other HW are mixed with the used oil at many of the activities. This practice creates large quantities of "hazardous" waste oil. Proper segregation of the wastes can alleviate this problem. Because there are stringent regulatory requirements concerning types of boilers, generators, and burners of HW fuel, proper testing is required before burning. A monitoring program, using colorimetric CLOR-D-TECT[31] kits, has been established to test used oil for chlorinated solvents. Used oil that tests positive for halogenated contamination with the use of CLOR-D-TECT kits are sent to a private laboratory for complete analysis of flashpoint, halogens, heavy metals, and sulfur content. Complete laboratory analyses are also performed prior to the transfer of used oil from oil-water separators at Building 1399 to 40,000 gallon storage tanks at Building 1860.

Segregation and proper management of used oil definitely reduces the quantity of hazardous waste generated. It can result in a major savings in disposal costs and would result in used oil suitable for offsite recycling, sale, or disposal to oil recyclers/rerefiners or any other commercial TSDF.

Lead-Acid Batteries/Electrolyte. Vehicle maintenance activities generate a large number of unserviceable lead-acid batteries. At one time, there were three battery neutralization shops (Bldgs 8000, 8030, and 8142) at Fort Carson. Currently, all batteries are drained and the acid neutralized at the DOL Battery Shop (Bldg 8000). The neutralized acid is released into the industrial waste treatment system; the drained batteries are strapped to wooden pallets and turned in to DRMO. The battery casings are sent to the Department of Energy, Idaho Falls, ID, office for recycling.

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[31] CLOR-D-TECT is a trade mark of the Dexsil Corporation [1 Hamden Park Drive, Hamden, CT 06517; (203) 288-3509]. CLOR-D-TECT 1000 is a go-no-go kit for determining if used oil is contaminated with chlorinated solvents. CLOR-D-TECT Q4000 is a quantitative test for determination of chloride (0 to 4000 ppm) in used oil.

A number of operational problems were discovered at the shops; some have yet to be corrected. In Bldg 8000, the air exchange rate in the battery charging area has been increased and the pH meter repaired. However, the battery shop in Bldg 8030 (belonging to 204th Maint. Bn.) has been shut down with work orders pending for repairs. It is currently only a turn-in point. The battery shop in Bldg 8142, which is part of 183rd Maint. Co., was shut down because of plumbing problems with the neutralization sump, poor air exchange rate, and other ventilation problems. While a work order for repairs is pending, the electrolyte is drained and collected in 55-gal drums and transported to Bldg 8000 for neutralization. Once the repairs are completed, neutralization might resume at the two shops.

The acid is likely to be EP toxic for lead (which must be verified by testing). Therefore, the practice of neutralization and draining into the sewer may be illegal. This practice should be stopped and a proper treatment permit obtained before continuing to neutralize. The sump sediment (consisting of gravel and sludge) must also be tested frequently.

According to Federal and State Regulations, used lead-acid batteries (wet or dry) which are reclaimed are exempt from classification as a HW and, therefore, from requirements for storage, manifesting, and notification. Fort Carson does not have to include the weight of batteries in HW generation rate calculations. Not draining the batteries is the best alternative to current practice which generates a corrosive waste.

Painting Wastes. Two large painting booths in the DOL Consolidated Maintenance Building (Bldg 8000) are used for vehicle painting operations. Smaller paint booths are located in two other buildings, and small-scale painting operations are conducted throughout Fort Carson. Spent paint thinners, paint-contaminated coveralls, empty paint cans, partially full cans of paint, paint booth filters, and grinding residue from paint removal wastes are accumulated and turned in to DRMO for disposal as HW. Empty paint cans and grinding residue with dried paint can be treated as a solid waste and disposed of in the Fort Carson landfill. The filters must be turned in to DRMO if they contain heavy-metal-based paint particles. If not, they can also be treated as solid waste.

Hand sanding and grinding operations are commonly conducted in Bldg 8000. Large quantities of sanding/grinding residue accumulate on the walls and other surfaces. This residue is collected and disposed of as solid waste. Occasionally, it is tested to determine the heavy metal content. The recent installation of a new centralized sand-vacuum system, and the eventual installation of a grind-vacuum system, will alleviate the waste generation problem, reduce air pollution, and hasten the residue collection/disposal.

Oil Analysis Wastes. An oil analysis laboratory in Bldg 8000 is operated by a contractor for analysis of used engine oil under the Army Oil Analysis Program (AOAP). A single mixed waste stream, consisting of heptane, 2,2-butyliminodiethanol, isopropanol, 1,1,1-trichloroethane, and oil was continuously generated in the laboratory. This mixture was then poured into the large underground storage tank containing used oil from other vehicle maintenance operations in Bldg 8000 creating "hazardous" waste oil. Further mixing of this oil with the rest of the installation's used oil generated very large quantities of waste oil which had to be disposed of at a very high price. Segregating the oil analysis wastes into: (1) unused oil samples - which can be mixed with other used oil; (2) oil mixed with heptane, 2,2-butyliminodiethanol - that may be "hazardous" because of ignitability; and (3) oil mixed with 1,1,1-trichloroethane - a listed (F001) HW; is a key to minimizing the amount of waste oil generated.

Radiator Cleaning Wastes. A large hot caustic wash tank for cleaning radiators is located in the DOL Radiator Repair Shop (Bldg 8000). A solution of sodium hydroxide and water is used. This solution is periodically discharged into the sewer system. A testing and monitoring program must be established to comply with regulations. The wastewater could be corrosive and EP toxic for heavy metals. If EP toxic, it has to be handled as a HW.

A second tank in Bldg 250 belongs to the DPCA's Auto Crafts shop but has never been used.

Used Engine Coolant. The vehicle maintenance activities generate large quantities of used engine coolant. This antifreeze solution (50 percent mixture of ethylene glycol and water) is not a hazardous waste. It could be, and some of it is, discharged into the sewer. However, it is a good practice to collect it and recycle it onsite or through an offsite recycling contractor because of the increase in price ($4 to $8/gal) of new antifreeze.

<u>PCB Management</u>: GE's Exterior Electric Shop has compiled a comprehensive inventory of PCB transformers on Fort Carson. Included in the inventory are PCB concentrations for all the transformers in service. PCB transformers (> 50 parts per billion [ppb] and < 60,000 parts per million [ppm] of PCB) are inspected at least once a year and allowed to continue in operation till they fail. When they cannot be used anymore, they are disposed of as a HW. The oil is drained out of the out-of-service non-PCB transformers and the metal sold as scrap.

A rudimentary HAZMIN program has been started as part of the Used Solvent Elimination (USE) program at Fort Carson. A closed-loop contract recycling service (Safety-Kleen) is used to supply cleaning solvent (petroleum naptha) to most of the vehicle maintenance facilities. However, a hazardous (ignitable) solvent (flash point 105 °F) is being used. It should be replaced with a less hazardous solvent (flash point > 140 °F). The following HAZMIN elements were identified in the 1986 EOR:[32] (1) comprehensive HW inventory; (2) accurate HW identification; (3) segregation of HW and nonhazardous waste; (4) USE and HAZMIN program interface; (5) substitution of nonhazardous materials for hazardous materials; (6) inventory control of hazardous materials purchased; and (7) onsite treatment only under the elementary neutralization permitting[33] exclusion.

The above AEHA recommendations are further emphasized throughout this report. Other recommendations are made in Chapter 13 and in the HAZMIN plan (Appendix A).

Pesticide/Pest Management

Fort Carson has a good comprehensive pest management program and a plan for pesticide management has been prepared. Additional details and recommendations are available in the EOR.

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[32] *Environmental Operations Review.*

[33] 40 CFR 260, *Hazardous Waste Management System: General*, 1985.

4 SOURCES OF WASTE GENERATION AND TYPES OF WASTES

FORSCOM Installations

FORSCOM installations are generally administrative, hospital/medical, or active troop installations. Various quantities of hazardous wastes are generated at these installations depending on their respective missions. For comparison, Table 2 shows the quantities of hazardous waste generated at 22 installations.[34] Fort Carson generated 41, 32, and 31 tons in 1985, 1986 and 1987, respectively, as reported in the survey and in their annual *Defense Environmental Status Reports*. These are wastes that were turned in to the DRMO for proper disposal; the numbers do not reflect quantities of: waste oil that is being recycled for heat recovery; acid drained and neutralized from lead-acid batteries; burning of gasoline, aviation fuel, at the fire training area; contaminated water treated at the wastewater treatment plant; hazardous air emissions; etc.

Table 2 does not show the actual quantities of wastes generated at Fort Carson. The data presented in this chapter were obtained from a survey of the various generators, offsite shipping manifests, and IDMS[35] data. An analysis of the data indicates that the average waste (including hazardous and nonhazardous) generation rate is 3,233,467 lb/yr (1621 tons/yr) not including PCB-contaminated equipment. Almost half of it consists of lead-acid battery casings, medical infectious waste, and boiler blowdown. Only 441 metric tons/yr of hazardous or "potentially" hazardous wastes are generated.

Source Types

Many different source types generate hazardous wastes. It is necessary to understand each of the source types and the wastes generated before attempting to minimize the total quantities generated.

Fort Carson is an active troop installation with few tenants. There are a number of major waste streams and small quantities of many different types of miscellaneous wastes. The approach of assessing each generator of wastes was used in the development of the HAZMIN plan. The first step, therefore, was to identify and prioritize all the generators on the installation. Next, each generator was considered in order of decreasing importance for characterization of waste streams generated. The most important waste streams were then studied to determine the minimization options and their technical feasibility.

Three different criteria were used to determine the ranking of the different types of sources. The first is the number of such sources on an installation, which can vary depending on the installation's mission. The second is the numbers and quantities of waste streams generated at each type of source, which is generally known or can be estimated. And the third is the minimization potential (including provision for cost of managing wastes) for the wastes for each type of source, which is important in developing a feasible waste minimization plan. Based on the above criteria, each source type was scored on a scale of 1 to 5. The ranking of sources, shown in Table 3, is in decreasing order of the total scores. Each source type is discussed in the same order below.

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[34] V.J. Ciccone & Associates, Inc., p C-4.

[35] IDMS Database, Defense Reutilization and Marketing Service, Defense Logistics Agency, Battle Creek, Michigan.

Motor Pools and Vehicle Maintenance Facilities (MPVM)

FORSCOM installations typically have a variety of motor pools and vehicle maintenance facilities for tactical and nontactical vehicles. Nontactical vehicle motor pools are used to service and maintain all the administrative vehicles (e.g., cars, vans, trucks, etc.), engineering maintenance vehicles (e.g., trucks, bulldozers, forklifts, etc.) and grounds maintenance vehicles (e.g., tractors, mowers, etc.) on the installation. Servicing and maintenance of tactical vehicles is performed at various troop and tactical vehicle motor pools. Tactical vehicles can be divided into track-laying vehicles (e.g., self-propelled howitzers, guns, mortars, armored personnel carriers, etc.) and wheeled vehicles (e.g., cargo trucks, ambulances, truck tractors, wreckers, etc.). Fort Carson has a number of motor pools and vehicle maintenance (MVPM) facilities as shown in Table 4.

Various levels of services are performed on the vehicles at each of the motor pools and vehicle maintenance facilities. Included in the services are: periodic maintenance (e.g., fluids change, tuneup, etc.), transmission maintenance, engine repair, brake servicing, battery repair/servicing, front-end alignment, and unique repairs (as required, for different tactical vehicles). The typical repair operations that use hazardous materials and generate hazardous wastes are: oil and grease removal, engine parts and equipment cleaning, solution replacement, and paint stripping and painting (discussed later under *Paint Shops*). Among the equipment commonly used at motor pools and vehicle maintenance facilities are: solvent sinks (parts cleaning), hot tanks (for engine and radiator cleaning), and spray equipment.

Some general categories of hazardous materials used at motor pools and vehicle maintenance facilities are: batteries, oils, petroleum distillates, mineral spirits, varsol, halogenated solvents, aromatic hydrocarbons, oxygenated hydrocarbons, mixtures, acids, and alkalis. A variety of nonhazardous materials (e.g., sorbent, rags, etc.) are used in conjunction with these hazardous materials and also generate hazardous wastes.

Each motor pool generates different quantities of wastes (Table 5). For comparison, some of the hazardous and nonhazardous materials used that lead to the generation of wastes are listed in Table 6. The blanks in these tables (and similar tables throughout this report) do not represent zero generation, but rather that the data was not available.

MPVM #9 [2nd Battalion 77th Armor (HHC, A, B, C, and D Companies), Bldg 2492] is the largest volume generator of the MPVMs on Fort Carson. Ninety two-track and 78 wheeled vehicles are repaired and maintained there. It has 5 Safety Kleen solvent tanks and generates 100,800 lb/yr of used oil, which accounts for 73 percent of its wastes. This amount is 16 percent of the total used oil (635,507 lb/yr) generated throughout the fort. MPVMs #12 and #13 [5th Bn 29th Field Artillery (HHB, A, B, C, and Service Batteries), Bldg 1682 and 1368; and 3rd Bn 29 Field Artillery (HB, A, B, C, and Service Batteries), Bldg 1392] are attached to Division Artillery (DIVARTY). They are the second and third largest generators, respectively. Antifreeze solution is generated in the largest quantities (73,920 lb/yr or 63 percent) and (68,640 lb/yr or 59 percent), respectively, followed by other wastes. They have 3 and 5 solvent tanks each. Approximately 200 vehicles (70 tracked and 130 wheeled) are serviced at MPVM #12. Four waste and 1 POL storage areas are located at the MPVM. Some operational problems concerning recycling and oil segregation have been reported. Used lead-acid batteries are directly exchanged for new ones at this and most other MPVMs. MPVM #5 [2nd Bn 8th Inf (HC, A, B, C, D, and E Companies), Bldg 1982] is the fourth largest generator that also has 5 solvent tanks. Used oil accounts for 49 percent (49,000 lb/yr), lead-acid batteries, 15 percent (15,000 lb/yr), and sorbent wastes, 13 percent (13,000 lb/yr) of the wastes.

MPVM #26 [4th Engineering Bn (HC, A, B, C, D, and E Companies), Bldg 9072] is ranked fifth among MPVMs. It has 4 solvent tanks. Approximately 43 percent (41,250 lb/yr) and 33 percent (31,500 lb/yr) of its wastes consist of batteries and used oil, respectively. The 204th and 704th Support Bns (both direct support Command [DISCOM] units) are the direct support units for MPVM #26. Many engineering and construction vehicles (e.g., combat engineering vehicle, armored vehicle launcher bridge, etc.) are maintained here. There are two 800-gal underground storage tanks, located outside the maintenance bays, for storage of waste oil. Small scale painting activities (brush painting) are also conducted at this MPVM. CARC and architectural paints are used. No significant wastes are generated from the painting activities.

MPVM #6 [4th Bn 68th Armor (HHC, A, B, C, and D Companies), Bldg 1882] is the sixth largest generator. It has 5 solvent tanks and generates 25,200 lb/yr (33 percent) of used oil, 18,000 lb/yr (23 percent) of batteries, and 10,560 lb/yr (14 percent) of caustic wash. It is one of the newer motor pools where 100 tracked and 60 wheeled vehicles are maintained. Many different types of chemical coatings are applied on vehicles.

MPVMs #5 and #6 are attached to the 2nd Brigade. The 2nd Brigade was deactivated on December 31, 1989, but the facilities could be used by other units.

With used oil and batteries generation rates of 42,000 lb/yr (57 percent) and 18,750 (25 percent), MPVM #3 [3rd Bn 68th Armor (HC, A, B, C, and D companies), Bldg 3092] is the seventh largest generator. Oil is stored in two above ground pods of 600-gal capacity each. Eighty tracked and 100 wheeled vehicles are maintained here. MPVMs #24 [52nd Engineering Bn (HSC, A, and B Companies), Bldg 3292], #1 [1st Bn 10th Inf (HC, A, B, C, D, and E Companies), Bldg 2992], and #2 [1st Bn 12th Inf, Bldg 2792] are ranked eighth, ninth, and tenth, respectively. Used oil is generated at a rate of 42,000 lb/yr (67 percent), 48,650 lb/yr (81 percent), and 14,000 lb/yr (25 percent), at the three MPVMs. MPVM #24 has 4 solvent tanks that are used for cleaning parts. MPVM #1 repairs and maintains 113 tracked and 60 wheeled vehicles and has 5 solvent tanks. If a part does not fit into the tank, it is cleaned on the ground with MOGAS. The MPVMs have had a number of waste disposal problems including: intercompany theft of drip pans; lack of space for 55-gal barrels and full pods; nonavailablility of funnels for waste oil barrels; spill and slop; and no connection to an oil-water separator. About 37,268 lb/yr of antifreeze is used at MPVM #1. MPVM #2 also has 5 solvent tanks and 2 oil pods with locking oil/water separator. In addition to used oil, MPVM #2 also generates large amounts of antifreeze (17,600 lb/yr), and sorbent (10,000 lb/yr).

Ten other MPVMs (#28, #10, #20, #7, #19, #46, #47, #23, #31, and #11) generate between 35,000 and 55,000 lb/yr. Six MPVMs (#22, #32, #17, #14, #30, and #4) generate between 10,000 and 35,000 lb/yr. The remaining 18 MPVMs (#44, #8, #18, #38, #27, #41, #16, #15, #43, #45, #37, #21, #33, #40, #34, #36, #29, #35, and #39) generate less than 10,000 lb/yr.

MPVM #19 [64th Support Bn (HHC, A, and C Companies), Bldg T-1001] is under the command of the Division Support Command (DISCOM), and generates approximately 40,802 lb/yr. Fifty-eight wheeled and 3 tracked (M113 Armored) vehicles are maintained.

MPVM #46 is the maintenance section (number 1) in the DOL consolidated maintenance building (Bldg 8000). Combat (e.g., M60, M88, M113, M578, vehicles) and engineering construction equipment (e.g., bulldozers, cranes, forklifts, graders, etc.) are repaired and maintained here.

MPVM #23 (183rd Maintenance Company, Bldg 8142) is under the command of the 43rd Support Group. It has 4 solvent tanks and generates 35,647 lb/yr of wastes. This MPVM is a division direct support unit that houses a number of activities including: fuel/electrical repair, battery service/recovery, communication/electrical repair, engineering equipment repair, vehicle maintenance (organizational support), small arms cleaning, and supply warehouse. The battery service and repair shop is no longer functional because of its small size and poor ventilation. Battery acid used to be neutralized in a sump that was not connected to the sanitary sewer system. Repairs are underway to remedy the problem before resuming the neutralization practice. Currently, battery acid is drained and collected in 55-gal drums that are transported to the DOL consolidated maintenance facility (Bldg 8000) where the acid is neutralized.

MPVM #22 (DPCA Auto Skills Shop, Bldg 2427) is a relatively new MPVM that became operational in 1986. Although it has modern equipment, very little of it is used and only a small quantity of waste is generated. This MPVM is used by all the military and some civilian employees for maintenance of their privately owned vehicles (POVs). Some of the available equipment, such as hot caustic tank, radiator leak testing tank, etc., have never been used since installation. A discussion of the painting activities is in the *Paint Shops* section.

MPVM #4 is the Headquarters Company motor pool and MPVM #7 is attached to the 2nd Brigade. After deactivation of the 2nd Brigade, on December 31, 1989, the motor pool could be used by some other unit.

No information, other than the number of solvent recycling machines used, was available from MPVMs #8 [1st Bn 8th Inf, Bldg 2392] attached to 3rd Brigade, #21 [68th Transportation Bn, Bldg 8152] under the command of 43rd Support Group, #25 [19th MP Bn, Bldg 2840], attached to the 4th Inf Div HQ Command, and #27 [4th Bn 61st Air Defense Artillery, Bldg 639] attached to the 4th Inf Div Command.

Of the total wastes (1,546,200 lb/yr) generated, used oil is the largest volume (635,507 lb/yr), followed by antifreeze solution (247,501 lb/yr), lead-acid batteries (201,850 lb/yr), spent solvent (managed through Safety Kleen, 190,103 lb/yr), spent sorbent (120,680 lb/yr), and others (150,559 lb/yr).

Industrial Maintenance, Small Arms Shops (IMSS)

The DOL and DEH are usually responsible for the major IMSS on a FORSCOM installation. The DOL and DEH industrial operations shops repair and maintain everything from office machines and furniture to small arms and nuclear weapons. Tenant units may also have industrial operations shops conducting maintenance and repair on a small scale. Table 7 lists all the IMSS located at Fort Carson.

Industrial shops typically use vapor degreasers for degreasing operations, caustic dip tanks for cleaning iron and aluminum parts, battery recharging and neutralization tanks for battery repair/replacement, painting and paint-stripping equipment (see *Paint Shops* section), and phosphoric/chromic acid tanks for small arms refinishing. These operations use hazardous materials and generate hazardous wastes. Table 8 shows a list of wastes that may be generated from the industrial shops.

Many different kinds of hazardous materials are used at these IMSSs, including halogenated solvents (TCE, 1,1,1-trichloroethane), paint thinners (xylene, toluene, etc.), corrosive chemicals (alkalis, acids, etc.), and radioactive materials. Most of the hazardous and nonhazardous materials used are listed in Table 9.

All of the IMSS listed in Table 7 are located in the DOL Consolidated Maintenance Building (Bldg 8000), which has five sections. IMSS #6 [Battery Service and Repair Shop], operated by C Company of the 704th Maintenance Bn (which is under the command of the 64th Support Group), is located in Section III of the building. It is the largest waste generator; 300,000 lb/yr of lead casings and 90,000 lb/yr of battery acid. Almost all the used lead-acid batteries generated at Fort Carson are brought to IMSS #6 for draining. Some of the battery acid from DISCOM units is brought here in 55-gal drums. All the batteries (open- and closed-cell) are drained. Puncturing closed-cell batteries with a hammer prevents the recycler/ distributor, at the supply warehouse, from reissuing batteries to the units.

A sump is located in IMSS #6 for neutralization of the spent acid. The batteries are drained on the floor. The acid flows into the floor drains which are connected to the sump. All the cells are rinsed with distilled water which also flows into the sump. Sodium bicarbonate (purchased in 100-lb bags) is thrown into the sump untill the liquid stops effervescing. The neutralized liquid from the sump is flushed into the industrial sewer system. Approximately 200 lb of sodium bicarbonate are required to neutralize acid from 16 batteries in about 30 minutes. A recently repaired electronic pH probe connected to the sump effluent will sound an alarm when the pH drops below 6. The drained batteries are accumulated, strapped on pallets, and sent to DRMO for recycling. The spent acid (which may be EP toxic) and the neutralized water are not tested for heavy metals.

IMSS #1 (Tactical and Heavy Equipment Repair, and Steam Rack, Section II), is operated by personnel from the DOL's Maintenance Operations Branch (MOB). Approximately 92,328 lb/yr of wastes are generated. Contaminated fuel comprises almost half (46 percent) of the total wastes, followed by used oil (21 percent), spent solvent (14 percent), antifreeze (6 percent), and others (13 percent). IMSS #2 (Unit Overhaul, Fuel and Electrical Systems Repair, and Special Support, Section III) is also operated by MOB personnel. This IMSS is a large industrial-type operation consisting of a vapor degreaser, engine dynamo testing facility, etc. Used oil is the largest quantity waste, followed by spent cold-cleaning solvent, antifreeze, and spent TCA and TCA degreaser sludge. Table 9 shows that nearly 30,000 lb/year of TCA is used in the degreasing operations. Approximately 22,000 lb/yr is lost because of its volatility and poor operating practices. The degreaser (manufactured by DETREX Corp) is a large machine used to clean oversized (e.g., large engine blocks, barrels, turrets, etc.) and small parts. It was installed in late 1970's; because of its age, it is exempt from State of Colorado regulations for volatile organic carbon emissions. Three people, wearing respirators and other safety equipment, are required to clean the machine and replace the solvent, which is done for 2 days every 3 months.

Large quantities of other wastes, such as used oil (42,000 lb/yr), cleaning solvent (13,351 lb/yr), and antifreeze solution (11,440 lb/yr), are generated at IMSS #2. Several "hot tanks" are used to contain used oil generated throughout Bldg 8000. In the past, chlorinated motor oil and other solvent wastes were also mixed in this tank.

The next largest waste generator is IMSS #5 (Army Oil Analysis Program Laboratory) which is operated by a private contractor (Trowell, Inc.). An unknown amount of TCA and other halogenated solvents are used in chemical analysis of the used oil samples. A large quantity of used oil (12,580 lb/yr) and some chlorinated oil (1,600 lb/yr) is generated. In the past, all the oil and solvents were mixed to form a hazardous waste. Now the three types of wastes are segregated. IMSS #4 (Radiator Service and Machine Shop, Section V) has a hot caustic tank (257 gal) and a leak testing tank (350 gal) for cleaning and repair of radiators. The hot tank contains full strength sodium hydroxide (pH - 12 to 13) and is operated at 190 °F. It is gas-heated and has a lid to prevent evaporation. An automatic rack is used to lower radiators into the tank for approximately 1 hour. This tank is cleaned once a year and the waste sludge is drummed and disposed of as a hazardous waste. The leak detection tank contains water and a rust inhibitor. It is operated at room temperature and emptied once a year. The wastewater is drained into the sanitary sewer. About 2,500 lb/yr of caustic waste and 3,080 lb/yr of antifreeze waste is generated at this IMSS. The waste solution from the hot caustic tank is drained periodically into the sanitary sewer without testing for pH or heavy metals.

In addition to the wastes from the radiator shop, a very small amount of water-soluble cutting oil waste is generated at the machine shop. The cutting oil is mixed with water and applied through jet nozzles on the work that is being machined. It serves to cool the cutting tool and the work piece. As it drips from the machined area, the coolant is captured in a drip reservoir, filtered, and reused. Each machine is emptied once a year and the cutting oil disposed of in a hot tank in Section III. IMSS #3 (Communication and Electronic Equipment Repair, Section IV) is the smallest of all the IMSS. A solvent tank is located in the shop for cleaning electrical and electronic parts. Small numbers of other batteries (lithium, nickel-cadmium) are discarded here.

Lead-acid battery casings (300,000 lb/yr) and spent acid (90,000 lb/yr) drained from the batteries are the largest quantity wastes generated at the IMSS. The casings, and the acid if contained within them, are not a hazardous waste because they are recycled and are exempt from regulatory requirements. However, the acid that is drained is a hazardous waste because of corrosivity and, possibly, EP toxicity for lead. Elementary neutralization of corrosive wastes only is exempt from permitting requirements. A Part B treatment permit has to be obtained for treating wastes that are both corrosive and EP toxic. Other significant wastes generated at the IMSS are: used oil (73,590 lb/yr); contaminated fuel (42,700 lb/yr); spent cleaning solvent (29,057 lb/yr); antifreeze solution (20,416 lb/yr); spent TCA and tank bottom sludge (12,980 lb/yr); and others (16,666 lb/yr).

Aviation Maintenance Facilities (AMF)

Most FORSCOM installations have aviation maintenance facilities for helicopters and airplanes. Various levels of services are performed on the aircraft at each of the facilities. Included in the services are: periodic maintenance (e.g., fluids change, tune-up, etc.), engine repair, brake servicing, battery repair/servicing, and unique repairs (if required, for different aircraft). There are six AMF at Fort Carson as shown in Table 10.

The typical repair operations that use hazardous materials and generate hazardous wastes are: oil and grease removal, engine parts and equipment cleaning, solution replacement, paint stripping, and painting (discussed later under *Paint Shops*). AMF commonly use: solvent sinks (parts cleaning), hot tanks (for engine cleaning), and spraying equipment. Table 11 lists the wastes generated at the AMF. The last column in the table contains data obtained from the IDMS data base and is provided for comparison with the numbers reported by individual AMF.

Some general categories of hazardous materials used at AMF are batteries, oils, petroleum distillates, mineral spirits, varsol, halogenated solvents, aromatic hydrocarbons, oxygenated hydrocarbons, mixtures, acids, and alkalis. A variety of nonhazardous materials (e.g., sorbent, rags, etc.) are used in conjunction with hazardous materials and also generate hazardous wastes. The hazardous and nonhazardous materials used at the AMF are listed in Table 12.

AMF #1 [1st Bn 4th Aviation Regiment (HC, A, B, C, and D Companies); Bldgs 9604, 9620, 9621, 9623, 9624, and 9628] generates more wastes (6,335 lb/yr) than any other AMF. Spent solvent accounts for half of this amount and used oil accounts for 22 percent. Spent solvent, contaminated JP-4, and oil are the major wastes generated at AMF #2 [A Co 2-158 Avn Regiment, Bldg 9620] which is under the command of the 4th Aviation Brigade. AMF #5 [E Co 4th Avn Bde, Bldg 9604] and AMF #3 [F Co 4th Avn Bde, Bldg 9604] are the third and fourth largest generators. The aircraft maintenance bay belonging to DOL (AMF #6) and AMF #4 [Task Force, 4th Avn Bde] generate lesser amounts of wastes than all the other AMFs.

Paint Shops (PS)

A FORSCOM installation has painting operations ranging from spray painting with cans to painting large vehicles. DEH paint shops have the responsibility of painting buildings, preparing signs, and painting the fleet of grounds maintenance and other vehicles. DOL paint shops have large paint booths for painting tactical and nontactical vehicles. The only hazardous waste generated by spray painting with cans, which is common place throughout the installation, is the empty cans with wet/dried paint residue. Paint thinners used in large painting operations result in generation of large quantities of hazardous waste.

There are two major paint shops at Fort Carson as listed in Table 13. The quantities of wastes generated and materials procured are shown in Table 14 and 15, respectively. PS #1 [Body and Paint Shop, Bldg 8000] is operated by DOL personnel. Two large, cross-draft, dry-filter, paint booths are operated for use in enamel and CARC painting of large tactical vehicles. Of the 7650 lb/yr of wastes generated, 56 percent of it consists of paint thinner. Small amounts of other wastes are generated.

PS #2 [Auto Skills Shop] operated by DPCA personnel is a relatively small quantity generator. Two smaller, dry-filter, cross-draft paint booths are located here. The operators are dissatisfied with one of the booths. Accumulation of large quantities of overspray and inadequate air flow were noticed during the survey conducted for this study.

An old paint booth is also located at the DPTM Devices Section (Bldg 6054). There are no air filters connected to the exhaust to capture the solvent and paint aerosol; it is vented directly to the ambient air. However, it is used rarely (6 h/week/yr) and approximately 15 lb/yr of thinner waste is generated. A new paint booth, procured in 1985, is located outside the building. It was never installed because the dimensions of the new booth exceed the internal dimensions of the room. Unsuccessful efforts have been made over the past 4 years to increase the room size.

Paint thinner is the largest quantity (4720 lb/yr) waste generated from the two shops. The last column in Table 14 lists the 1987 IDMS data for comparison. The amount of paint thinner waste disposed of through the DRMO was 7040 lb. Also 19,679 lb of wet paint wastes were generated.

Photography, Printing, and Arts/Crafts Shops (PPAS)

FORSCOM installations have photography and print shops that conduct a wide range of printing operations including standard forms, brochures, pamphlets, newsletters, and circulars. The shops perform image and plate processing. Image processing is a method for preparing artwork that includes typesetting and photoprocessing. The photographic process produces a negative with the light portions of the photographed object filled with deposits of silver. Among the steps involved in a photographic process are: developing, fixing, washing, and reducing/intensifying. Wastes produced by the photographic processes include: chemical wastes, bath dumps, and wastewaters containing photoprocessing chemicals, silver, etc.

The printing process requires an image carrier (manual, mechanical, electrostatic, or photomechanical) that takes the ink from a roller and transfers it to a rubber blanket. The image is then transferred from the rubber blanket to a paper. Wastes produced from the printing process include: waste inks, trash, used plates, used ink containers, damaged or worn rubber blankets, waste press oils (lubricating oils), cleanup solvents, and rags.

There are six PPAS at Fort Carson (Table 16). Four of them belong to DPTM and the other two are operated by DOIM and the Directorate of Personnel and Community Affairs (DPCA). PPAS #1 (DPTM, Photography Section, Bldg 6010) generates the most wastes consisting primarily of bleach, activator, developer, cleaner, and fixer. Silver is recovered, as part of a precious metal recovery program, from all the silver-containing waste solutions. DPTM's Training and Audiovisual Center, Production Shop (PPAS #4) is the second largest generator. Wastes from printing (solvent, inks, etc.) and photography are generated here.

The DPCA Photography Skill Center (PPAS #6) is the third largest generator of photographic wastes (film/paper developers, bleach/fix solutions, and other solutions). Solutions containing recoverable silver are turned in to the Evans Army Hospital for recovery and disposal. The remaining PPAS are smaller than the three discussed above.

Small quantities of a number of different wastes are generated by the PPAS. Developer and fixer solutions are generated in the largest quantities. Fixer solutions are recycled for silver recovery. The 1987 IDMS data (last column, Table 17) indicates that a large amount of toner is also generated. Other significant wastes are: bleach, uralite, electrostatic ink and solution, and adhesive. Table 18 lists the quantities of materials procured.

Hospitals, Clinics, and Laboratories (HCL)

A typical FORSCOM installation has at least one hospital (or medical center) providing full medical and dental services for active duty and retired military personnel and dependents on the installation. Each hospital has many clinics supporting different medical departments (anesthesiology, dermatology, internal medicine, obstetrics and gynecology, pathology, radiology, surgery, urology, etc.). Each department has laboratories that use hazardous materials and generate hazardous wastes. An installation may have teaching facilities (e.g., Institute for Dental Research) and laboratories for training personnel belonging to other medical activities in the military services. Other dental and veterinary clinics and facilities may also be located on the installation. The HCL on Fort Carson are listed in Table 19.

The preventive medicine department of the hospital is primarily responsible for the safety and security of medical staff and patients that may be exposed to hazardous materials/wastes and emissions. Many hazardous chemicals and radioactive materials are used in hospitals, clinics and laboratories. The wastes include: chemical waste, infectious solid waste, noninfectious waste, pharmaceutical waste, and radioactive waste. The wastes generated and materials used by the HCLs are listed in Tables 20 and 21, respectively.

The Evans Army Community Hospital (HCL #1), located at Building 7500, generates nearly 360,000 lb/yr of infectious wastes. Other infectious wastes are generated by the dental clinics (HCL #2). Most of the pathological wastes are generated and incinerated at the veterinary hospital (HCL #3).

A double chamber, natural gas-fired pathological incinerator (100 lb/hr) is located at HCL #3. This incinerator is permitted under the State of Colorado air quality regulations. Some of the equipment operation criteria are: (1) visible emissions should not exceed 20 percent opacity, (2) particulate emissions should not exceed 0.10 grains per dry standard cubic foot corrected at 12 percent CO2, (3) summarized monthly records of daily burning rates and hours of operation must be maintained, (4) preheating of the secondary zone is required before charging and operating the unit, (5) both the primary and secondary burners must be operated at design rate, (6) charging rate should not exceed 100 lb/hr, and (7) operation and maintenance should be performed according to the procedure prescribed by the manufacturer (Incinerator International Inc.).

HCL #1 has a silver recovery unit used to recover silver from fixer solution from throughout Fort Carson. Other precious metal wastes (e.g., gold fillings) from DENTAC are recycled through the precious metal recovery program. A number of chemicals such as xylene, formalin, etc. are used at all the HCLs. The survey data (wastes generated and materials used) were inadequate. However, the 1987 IDMS data (last column, Table 20) show the generation of various chemical wastes.

Other Source Types

Other source types at a typical FORSCOM installation include: heating and cooling plants, laundry and drycleaning facilities, sanitary landfills, wastewater treatment plants, troop units, industrial wastewater treatment plants, fire departments, hazardous waste storage facilities, POL storage yards, golf courses, grounds maintenance/garden shops, entomology shops, electrical maintenance shops, storage warehouses, water treatment plants, and other miscellaneous sources unique to each installation.

Table 22 lists the heating and cooling plants at Fort Carson. The main boiler facility (Bldg 1860) (HCP #1) is used to burn waste oil (183,890 lb/yr), which is generated throughout the fort. Table 23 and 24 list the wastes generated (boiler blowdown) and materials used, respectively. Some spent cleaning solvent is also generated at HCP #2 (Bldg 403). The amount of fuel oil and natural gas used is 289,485 and 336,167 lb/yr, respectively. A number of other chemicals (cyclohexyl, caustic soda, tripolyphosphate, tannin, sodium sulfite, and morpholine) are used in day-to-day operations as shown in Table 24.

The laundry facility at Fort Carson is located in Bldg 1510. It is a pickup point for a contracted operation. All the clothes are laundered and drycleaned offsite at the contractor's (New Method Dry Cleaning & Laundry, Inc.) shop in Canyon City, CO.

Currently, there is only one active solid waste landfill located at Fort Carson. A 1/2-acre unlined pit near the landfill is used for disposal of grit from the oil/water separators located throughout the installation. This pit contains water, oil, oily sludge, solvents, aerosol cans, empty drums, etc. Because of the solvents and heavy metal contaminants likely to be present, this pit is probably an illegal facility in violation of regulations. Additionally, the site has a very high potential for groundwater contamination. An alternate method must be developed for minimization, treatment, or disposal of the oily grit.

A wastewater analysis laboratory is located in Bldg 3387 at the wastewater treatment plant. Water is analyzed for fecal coliform bacteria, residual chlorine, 5-day biochemical oxygen demand (BOD_5), suspended solids (SS), chemical oxygen demand (COD), and alkalinity. Used reagents are discarded into the sanitary sewer system. Many nonreagent chemicals such as hexane, acetone, 1,1,2-trichloro-1,2,2-trifluoroethane (freon) etc. are also stored in the laboratory.

Pesticides are stored and used by the GE entomology section, DPCA golf course, field sanitation teams, school district, and the post exchange to prevent pest-related problems in: household, structural, health-related, and nuisance insect and rodent control programs; weed control programs; and programs involving turf areas (e.g., golf courses), trees, and shrubs. The section stores insecticides and rodenticides in Bldg 212. Herbicides and algicides are stored in Bldg T-204. Mixing of these pesticides is conducted outside the building. The empty containers are triple rinsed and buried in the landfill. The rinseate is reused as a diluent in the mixing operations. A contractor applies herbicides for broadleaf control, algicides in the ponds, and fungicides on the greens of the golf course.

PCBs are found in capacitors and transformers. All the online transformers containing PCBs have been identified by the GE exterior electrical repair shop. They are inspected periodically and the out-of-service transformers are replaced with non-PCB transformers.

The 94th Explosive Ordnance Disposal (EOD) Detachment performs OB/OD of small ammunition in the EOD ranges. Fort Carson has applied to include two ranges (1 and 121) on the RCRA Part A TSDF permit. The ammunition destroyed at these ranges includes: small arms (cartridges), artillery/mortar, grenades, rockets, pyrotechnics, and other hazardous explosive/demolition materials. Hazardous items are typically destroyed at the rate of one to two items per month by surface detonation after being covered by high explosives (e.g., C-4, TNT, etc). Some of the trenches at these ranges are used for burning excess powder bags. These propellant items are directly handled by troops and not the EOD detachment. Soil residue at these ranges must be tested for its toxic/hazardous nature.

The DRMO maintains two areas for storage of hazardous wastes/materials. A yard located to the west of Bldg 318 is used to store materials that can be stored outside such as epoxies, hydraulic fluid, and flammables. Bldg 9248, which was originally an ammunition storage bunker, is a permitted (interim status) hazardous waste management facility used to store toxic, corrosive, ignitable, reactive, and miscellaneous hazardous wastes (e.g., PCB transformers) before disposal. No wastes are actually generated here.

A miscellaneous generator at Fort Carson is the multicrafts skill development center (Bldg 2200). Very small amounts of wastes (metal plating solution, stained glass petina, ceramic slip, paint thinner, saw dust, etc.) are generated during the skill training activities.

Wastes Selected for Technical/Economic Analysis

Table 25 summarizes the data presented in the previous section that were obtained during the HAZMIN survey. Also included are the totals according to waste disposal data obtained from manifests and the IDMS data base. It is difficult to allocate the IDMS waste disposal information to each of the individual generators. However, the totals (5th column) indicate the quantities that were disposed of in 1987. The fourth column in the table presents the totals according to the survey. The suggested generation rate as determined from all the available information is provided in column 6. The 13 different waste categories considered are listed on the last page of Table 25. Table 26 presents the total wastes generation rate according to each of the waste categories and waste types. PCB-contaminated equipment has not been included in the above summaries.

Table 26 shows that motor pools and vehicle maintenance facilities generate the largest quantity (1,701,968 lb/yr) of wastes consisting primarily of used oil (635,507 lb/yr), antifreeze (247,501 lb/yr), lead-acid batteries (201,850 lb/yr), cleaning solvents (191,861 lb/yr), spent sorbent (120,680 lb/yr), and contaminated soil (105,000 lb/yr). The industrial shops (Bldg 8000) generate the next highest quantity (585,409 lb/yr). Most of it is drained lead-acid batteries (300,000 lb/yr) and the battery acid (90,000 lb/yr) which is neutralized. The other wastes of concern are used oil (73,590 lb/yr), cleaning solvent (29,057 lb/yr), antifreeze (20,146 lb/yr), and 1,1,1 trichloroethane (7700 lb/yr), and degreaser tank-bottom sludge (5280 lb/yr). The hospital, veterinary, and dental clinics generate the next largest quantity (515,563 lb/yr), with medical infectious waste accounting for 99 percent of it. The remaining 1 percent consists of spent solvents (e.g., xylene), many other chemicals (e.g., mercury, formalin), and photographic wastes.

Boiler plants are a major generator (267,000 lb/yr) because of the boiler blowdown reported (265,600 lb/yr). This blowdown is discharged into the sanitary sewer. Occasional discharge of blowdown may not adversely affect the wastewater quality; it may still be within NPDES limits, but this can only be determined by proper testing. Aviation maintenance facilities are the next largest generator (52,809 lb/yr) of typical aircraft maintenance wastes such as spent solvent, synthetic oil, spent NICAD batteries, contaminated aircraft fuel, etc. Troop units are next, generating small quantities of expired or spoiled decontaminating agents (e.g., DS-2, STB), and batteries (e.g., lithium, mercury).

The seventh largest type of waste generator is paint shops that generate paint related materials (29,521 lb/yr) such as thinner, and unused paint. Printing, photography, and arts/crafts shops are next. They generate acids/bases, halogenated solvents, and spent photographic and printing chemicals. Some of the shops belonging to GE. Other miscellaneous sources are the smallest quantity waste generators.

In terms of total waste generation, used oil is the largest volume (797,399 lb/yr). It is followed by spent batteries (535,534 lb/yr), spent acids/bases (373,973 lb/yr), spent antifreeze solution (267,917 lb/yr), spent nonhalogenated solvents (237,071 lb/yr), contaminated fuels (77,630 lb/yr), paint related material (38,957 lb/yr), decontaminating agents (18,626 lb/yr), spent halogenated solvents (11,362 lb/yr), photographic/printing chemicals (6587 lb/yr), used alcohols (5646 lb/yr), pharmaceutical wastes (90 lb/yr), and miscellaneous wastes (862,655 lb/yr).

The wastes selected for technical and economic analysis are used oils (797,399 lb/yr), spent antifreeze solution (267,917 lb/yr), spent cleaning solvent (235,309 lb/yr), battery acid (93,744 lb/yr), TCA and TCA sludge (7700 and 5280 lb/yr), and paint thinner (7040 lb/yr).

Table 2

Hazardous Waste Generation at FORSCOM Installations[36]

Installation	Quantity of Waste Generated (metric tons)			Quantity of Waste Generated Onsite (metric tons)			Quantity of Waste Generated Offsite (metric tons)		
	1985	*1986*	*1987*	*1985*	*1986*	*1987*	*1985*	*1986*	*1987*
A.P. Hill	n/a	0.6	810.7	n/a	0.6	810.7	0.0	0.0	0.0
Bragg	94.5	246.9	258.2	94.5	236.3	242.3	0.0	10.6	15.9
Buchanan	-	-	-	-	-	-	-	-	-
Campbell	181.1	42.3	83.7	181.1	42.3	83.7	0.0	0.0	0.0
Carson	37.5	29.1	28.9	37.5	29.1	28.9	0.0	0.0	0.0
Devens	1142.6	359.4	412.4	1142.6	359.4	412.4	0.0	0.0	0.0
Drum	18.4	89.0	0.7	18.4	89.0	0.7	0.0	0.0	0.0
Hood	46.5	238.5	129.8	46.5	223.0	129.6	0.0	15.5	0.3
Irwin	2090.4	1019.6	1224.1	2090.4	1019.6	1224.1	0.0	0.0	0.0
Lewis	n/a	214.3	668.3	n/a	187.3	649.3	n/a	27.0	19.0
McCoy	62.6	35.1	64.0	23.9	23.5	26.2	38.7	11.6	37.8
McPhearson	0.1	2.4	n/a	0.1	2.4	n/a	0.0	0.0	n/a
Meade	n/a	3.1	3.5	n/a	3.1	3.5	n/a	0.0	0.0
Ord	190.9	293.9	n/a	190.9	290.8	n/a	0.0	3.1	n/a
Polk	0.1	20.7	11.5	0.1	20.7	11.5	0.0	0.0	0.0
Presidio, SF	-	-	-	-	-	-	-	-	-
Richardson	21.1	16.4	4.8	21.1	16.4	4.8	0.0	0.0	0.0
Riley	18.6	18.6	18.6	18.6	18.6	18.6	0.0	0.0	0.0
Sam Houston	34.7	33.4	19.8	34.7	32.7	18.5	0.0	0.7	1.3
Sheridan	4.9	4.9	4.9	4.9	4.9	4.9	0.0	0.0	0.0
Stewart Hunter	7.7	302.4	445.8	7.7	302.4	445.8	0.0	0.0	0.0
Wainright	27.2	16.9	63.6	19.4	16.1	29.3	7.8	0.7	34.3
Total	3978.9	2987.5	4253.3	3932.4	2918.2	4144.8	46.5	69.2	108.6

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[36] Source: V.J. Ciccone and Associates, Inc., p C-4.

Table 3

List of Sources Ranked in Order of Importance

Rank	Source Types	Numbers	Numbers and Quantities of Waste Streams	Minimization Potential	Total
I	Motor pools and vehicle maintenance facilities	5	5	5	15
II	Industrial maintenance, small arms shops, etc.	4	5	5	14
III	Aviation maintenance facilities	4	4	5	13
IV	Paint shops	4	4	4	12
V	Photography printing and arts/craft shops	3	4	4	11
VI	Hospitals, clinics, and laboratories	4	3	3	10
VII	Heating and cooling plants	2	3	3	8
VIII	Grounds maintenance and entomology shops	3	3	2	8
IX	Electrical maintenance facilities	2	2	2	6
X	Hazardous waste storage facilities	1	2	1	4
XI	Wastewater treatment facilities	1	1	1	3
XII	POL storage yards	1	1	1	3

Table 4

Motor Pools and Vehicle Maintenance (MPVM) Facilities

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1 1st Battalion 10th Infantry - Motor Pool - Building 2992

2 1st Battalion 12th Infantry - Motor Pool - Building 2792

3 3rd Battalion 68th Armor - Motor Pool - Building 3092

4 2nd Brigade Headquarters - Headquarters Company - Motor Pool - Building 1852

5 2nd Battalion 8th Infantry - Motor Pool - Building 1982

6 4th Battalion 68th Armor - Motor Pool - Building 1882

7 1st Battalion 77th Armor - Motor Pool - Building 2082

8 1st Battalion 8th Infantry - Motor Pool - Building 2392

9 2nd Battalion 77th Armor - Motor Pool - Building 2492

10 2nd Battalion 35th Armor - Motor Pool - Building 2692

11 1st Battalion 27th Field Artillery - Motor Pool - Building 1682

12 5th Battalion 29th Field Artillery - Motor Pool - Building 1682

13 3rd Battalion 29th Field Artillery - Motor Pool - Building 1392

14 1st Battalion 29th Field Artillery - Motor Pool - Building 1692

15 4th Division Support Command (DISCOM) - Headquarters Company - Motor Pool - Building 8300

16 4th Support Battalion - Motor Pool - Building T-800

17 4th Support Battalion - Motor Pool - Building T-804; DSU - Building 8030

18 204th Support Battalion - Motor Pool - Building 8200; DSU - Building 8030

19 64th Support Battalion - Motor Pool - Building 1001; DSU - Building 8030

20 704th Support Battalion - Motor Pool - Building 8300; DSU - Building 8030, Building 8000

21 68th Transportation Battalion - Motor Pool - Building 8152

22 73rd Maintenance Company - Motor Pool - Building 8030; DSU - Building 8142

23 183rd Maintenance Company - Engineer and Ground Equipment Repair, Automotive and Armament Repair, Building 8142

24 52nd Engineer Battalion - Motor Pool - Building 3292

Table 4 (Cont'd)

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25 19th Military Police Battalion - Motor Pool - Building 2840

26 4th Engineer Battalion -Motor Pool - Building 9072

27 4th Battalion 61st Air Defense Artillery - Motor Pool - Building 639

28 2nd Sanadron 7th Cavalry - Motor Pool - Building 3192

29 104th Military Intelligence Battalion - Motor Pool - Building 749

30 DEH - Operations Division - Maintenance Facility - Building 1302

31 Colorado National Guard - Motor Pool - Building 8110

32 DPCA - Auto Crafts Shop, Skills Center - Building 2427

33 4th Aviation Brigade - Headquarters Service Company - Motor Pool - Building 9628

34 2-158 Aviation Regiment - Motor Pool - Building 9628

35 2-58 ATC - Motor Pool - Building 9628

36 4th Aviation Brigade Headquarters - Headquarters Company - Motor Pool - Building 9628

37 4th Aviation Brigade - E. Company - Motor Pool - Building 9628

38 4th Aviation Brigade - D. Company - Motor Pool - Building 9628

39 4th Aviation Brigade - F. Company - Motor Pool - Building 9628

40 571st Medical Detachment - Motor Pool - Building 8152

41 517 Medical Company - Motor Pool - Building 8152

42 10th MASH Headquarters - Headquarters Company - Motor Pool - Building 8162

43 DOL - Transportation Motor Pool - Building 301

44 DEH - Equipment Concentration Site #42 - Maintenance Facility - Building 8930

45 DPTM - Range Division - Motor Pool - Building 2740

46 DOL - Maintenance Operations Branch - Combat and Engineering Construction Equipment Repair - Maintenance Section I - Building 8000

47 AAFES Main Service Station - Building 1515

Table 5

Quantities of Wastes Generated at MPVM Facilities*

Wastes	MPVM #	1	2	3	4	5	6	7	8	9	10	11	12	13
Spent degreasing solvent**		7854	7854	7854	***	7854	7854	7854	7854	7854	7854	3142	4712	7854
Used oil		48650	14000	42000	7000	49000	25200	24500		100800	10800	8400	4200	6300
Antifreeze solution			17600	2112	1760	8800	2112	6160			5280		73920	68640
Lead-acid batteries		6000	18750	1000	15000	18000				18000	3000	7200	6600	
Sulfuric acid					500									
Caustic wash					50		10560			13728		1584		
Contaminated dirt							600			2000				
Contaminated fuel		2394	350	1680		2100		1400					5040	6300
Oily rags			500	600	500	4300	1000			1000		4000	6000	6120
Spent sorbent			10000	1200	500	13000	2400	3000		12000	6000	15000	16800	14400
Transmission fluid			350		700		9240	350						840
Hydraulic fluid											3500			
Brake fluid						70								
Empty containers					150									
Faulty Parts				120	50		120							
Carburator Cleaner														
Contaminated GAA Grease														
Carbon remover														
Chlorinated motor oil														
Asbestos materials														
Mixed miscellaneous														

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*Quantities are reported in pounds per year.

**Low flash point solvent (105 °F) - Safety Kleen Recycle

***A blank in this and similar tables does not mean zero generation. Where data is unavailable, Fort Carson should make every effort to locate the data and update the tables. Proper inventory control will generate data for future use in helping meet HAZMIN goals.

Table 5 (Cont'd)

Wastes	MPVM #	14	15	16	17	18	19	20	21	22	23	24	25
Spent degreasing solvent	7854	1570	3142	1570	4712	1570	4712	3142	7854	6283	6283	1570	
Used oil		5040	1050	1400	18900	1400	21420	34692		16800	6000	42000	
Antifreeze solution		10560	1320		440	264	10912	5368		2640	6336	2640	
Lead-acid batteries							3250				10000		6000
Sulfuric acid				20	140						3000[†]		
Caustic wash													
Contaminated dirt		1500		600	1600			450					
Contaminated fuel		3220					70			385		105	
Oily rags			100		1000	150	700	600		500		1800	
Spent sorbent		360	60		900	500	1200	1800		500	2400	4000	
Transmission fluid			420		1400	210	840			1400	1638		
Hydraulic fluid		336					140						
Brake fluid		336			3500					504			
Empty containers				90						450			
Faulty Parts							250			1000			
Carburator Cleaner													
Contaminated GAA Grease													
Carbon remover													
Chlorinated motor oil													
Asbestos materials													
Mixed miscellaneous													

[†] Drained sulfuric acid is drummed and transported to C Company, 704th MNT Bn. (Building 8000) for neutralization.

Table 5 (Cont'd)

Wastes	MPVM #		26	27	28	29	30	31	32	33	34	35	36	37
Spent degreasing solvent		6283	6283	7854	1570	3142	3142	3142	315	315	315	315	315	
Used oil			31500		25200		8400	1[illegible]0	28000	770	420	350	189	578
Antifreeze solution			1936		10560					968	616	44	493	132
Lead-acid batteries			41250		5000		1000	10000	N/A			400		1750
Sulfuric acid			N/A						N/A					
Caustic wash														
Contaminated dirt										20				
Contaminated fuel			1400		1400			2800					126	
Oily rags								2200		300	100	50	300	
Spent sorbent			4000		2000		120	6000		400	300	25	240	600
Transmission fluid			385		140							18		
Hydraulic fluid			8400		1008									
Brake fluid					140		84			10				35
Empty containers														
Faulty Parts														
Carburator cleaner (methylene chloride)								792						
Contaminated GAA Grease		300												
Carbon cleaner														
Chlorinated motor oil														
Asbestos materials														
Mixed miscellaneous														

Table 5 (Cont'd)

Wastes	MPVM #	38	39	40	41	42	43	44	45	46	47	Survey Total	IDMS Total
Spent degreasing solvent		315	315	196	1570	1570	1570	1570	1570	10210	1570	190103	137900
Used oil		420	11	1400	2660	1050		5600	1155	17252	9800	635507	105000
Antifreeze solution		440	26	176	246	264		1920		2200	616	247501	
Lead-acid batteries		4000	100	150	500	500	2400		1000		21000[ff]	201850	38301
Sulfuric acid					84							3744	
Caustic wash												25922	
Contaminated dirt												6770	105000
Contaminated fuel			35	175	70	105				3500		32655	20487
Oily rags		375		200	50	40				2100	240	34825	
Spent sorbent		500	25	200		50				200		120680	9500
Transmission fluid				28	196					686	4200	23041	
Hydraulic fluid				158						800		14342	4070
Brake fluid		30	1		5	8		10		86	84	4903	1148
Empty containers												690	
Faulty parts												1540	647
Carburator Cleaner												792	
Contaminated GAA Grease											300		
Carbon remover													81917
Chlorinated motor oil													1160
Asbestos materials										685		685	
Mixed miscellaneous		350										350	

'Private recycling contract (*American Battery Company, Colorado Springs, CO*).

Table 6

Quantities of Hazardous/Nonhazardous Materials Used at MPVM Facilities*

Wastes	MPVM#	1	2	3	4	5	6	7	8	9	10	11	12
Degreasing solvent		9032	9032	9032		9032	9032	9032	9032	9032	9032	3613	5419
Carburetor cleaner													
Engine oil		64295		33600	10500	52465	31227			151200		8400	5880
Antifreeze		37268		2112	2640	30087	9838				2640	528	36960
Lead-acid batteries				18750	1000	15000	18000				18000	3000	7200
Caustic wash												24	
Floor wash detergent					50		350				12		
Spent sorbent				600	500	11000	2000				6000	1500	16800
Diesel fuel				691509		2000000				49000	714000		
Mogas fuel					64379	141652						4200	16800
Dirty rags				600	500	4000	240			1000		4000	6000
Transmission fluid				700		567							
Brake fluid						588	840						
Hydraulic fluid						1568							
De-icer													
Lithium batteries													
Lacquer thinner													

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*Quantities are reported in pounds per year.

Table 6 (Cont'd)

Wastes	MPVM #		13	14	15	16	17	18	19	20	21	22	23
Degreasing solvent		9032	9032	1806	3613	1806	5419	1806	5419	3613	9063	7226	
Carburetor cleaner													
Engine oil		6720	37800	2100			700	16030	36000		3500		
Antifreeze		36960	36960	1760		440	616	10560	8882		4400		
Lead-acid batteries		6600						250					
Caustic wash													
Floor wash detergent					20			1008		2016			
Spent sorbent		12000		100		900	500	1200			500	2400	
Diesel fuel		78750	840000	3500						350			
Mogas fuel			84000										
Dirty rags		4800		100		1000	150	700	450		500		
Transmission fluid		1260	756	420		1400					1400		
Brake fluid			1008			3500							
Hydraulic fluid			1008										
De-icer													
Lithium batteries													
Sulfuric acid													
Lacquer thinner													

Table 6 (Cont'd)

Wastes	MPVM #	24	25	26	27	28	29	30	31	32	33	34
Degreasing solvent		7226	1806	7226	7226	9032	1806	3613	3613	3613	362	362
Carburetor cleaner										792		
Engine oil							4620	8400	11550		1050	700
Antifreeze		1320					5280	4224	5280		968	616
Lead-acid batteries				41250			5000		1000	10000		
Caustic wash												
Floor wash detergent								55000		840		
Spent sorbent		4000		4000				5000	120	6020	400	300
Diesel fuel							1540	0	336000			
Mogas fuel									210000			
Dirty rags									2400		300	100
Transmission fluid							3640					
Brake fluid								84				
Hydraulic fluid												
De-icer												
Lithium batteries									20			
Sulfuric acid								9	2100			

Table 6 (Cont'd)

Wastes	MPVM #	35	36	37	38	39	40	41	42	43	44	45	46	47
Degreasing solvent		362	362	362	362	362	231	1806	1806	1806	1806	1806	12012	1806
Carburetor cleaner										275				795
Engine oil		539	210	875	700	49	2744	2660	1225	1500	7000	1540	3500	
Antifreeze		44	528	132	440	44	176	44	440	660		484	1100	
Lead-acid batteries		400		1750	4000	100	150	500	500	2400		1000		
Caustic wash														
Floor wash detergent							42							
Spent sorbent		25	240	600	500	25	200		150				200	
Diesel				20664			1750	70000		350000				3500
Mogas			420			35	3500							
Dirty rags			50	300		375		200	50	40				
Transmission fluid		18					105	196						
Brake fluid												8		
Hydraulic fluid							252					126	800	
De-icer														
Lithium batteries														
Sulfuric acid							42	84						

Table 7

Industrial Maintenance and Small Arms Shops (IMSS)

1. DOL - Maintenance Operations Branch - Tactical and MHE repair - Maintenance Section II - Building 8000
2. DOL - MOB - Unit overhaul, fuel and electrical systems repair, and special support - Maintenance Section III - Building 8000
3. DOL - MOB - Communication and electronic equipment repair - Maintenance Section IV - Building 8000
4. DOL - MOB - Radiator service and machine shop - Maintenance Section V - Building 8000
5. AOAP Lab - Building 8000*
6. 704th MNT Bn C Company - Battery service and repair shop - Maintenance Section III - Building 8000**

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* Private contractor operated. (Trowell Inc.)

** Charlie Company of the 704th MNT Bn is a direct support element of DISCOM which operates under the guidance of DOL - MOB, Maintenance Section III.

Table 8

Quantities of Waste Generated at IMMS*

Materials	IMSS #	1	2	3	4	5	6
Spent 1,1,1 trichloroethane (TCA)		N/A	7700		N/A		N/A
Spent degreasing solvent**		12566	13351	1570	1570		
Antifreeze solution		5896	11440	N/A	3080		
Used motor oil		19000	42000	10		12580	
Contaminated sorbent		540	300				
Contaminated fuel		42700					
Oily rags		2100					
Transmission fluid		686					
Brake fluid		80					
Hydraulic fluid		4375					
Hazardous, faulty parts		685					
Contaminated fluid filters		3700					
TCA solvent tank bottom sludge			5280				
Spent Li-So$_2$ batteries				5			
Spent NICAD batteries				10			
Spent paint thinner					15		
Contaminated cutting oil					70		
Caustic wash (NaOH)					2500		
Chlorinated motor oil						1600	
Lead acid battery casings							300,000
Spent sulfuric acid							90,000***

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* Quantities are reported in pounds per year.

** Low flash point type solvent (105°F) - Safety Kleen recycle.

***Drained sulfuric acid is neutralized with sodium bicarbonate and discharged to the post IWTP.

Table 9

Quantities of Hazardous/Nonhazardous Materials Used at IMSS

Materials	IMSS #	1	2	3	4	5	6
1,1,1 Trichloroethane		N/A	29722	N/A	N/A		
Degreasing solvent		14786	15709	1848	1848		
Motor oil		16200	70000	10			
Antifreeze solution		2992	15840	N/A	1540		
Sorbent		1200	400				
Diesel fuel		31500					
Mogas		25200					
Rags		2100					
Transmission fluid		686					
Brake fluid		210					
Hydraulic fluid		4375					
Fluid filters		3700					
Paint thinner					72		
Cutting oil					70		
Sodium Hydroxide					2288		
Sodium bicarbonate					75000		
Sulfuric acid							90000

Table 10

Aviation Maintenance Facilities (AMF)

1. 4th Aviation Regiment - Aviation Maintenance Facility - Butts Army Airfield - Building 9620
2. 2-158 Aviation Regiment - Aviation Maintenance Facility - Butts Army Airfield - Building 9620
3. 4th Aviation Brigade - F Company Aviation Maintenance Facility - Butts Army Airfield - Building 9604
4. 4-4 Task Force - Aviation Maintenance - Butts Army Airfield
5. 4th Aviation Brigade - E Company Aviation Maintenance - Building 9604
6. DOL - Aircraft Maintenance Bay - Butts Army Airfield - Building 9604

Table 11

Quantities of Wastes Generated at AMF*

Wastes	AMF #	1	2	3	4	5	6	Survey Total	IDMS Total
Spent degreasing solvent**		3142	3142	2356	425	2356	1570		12991
MEK degreaser		155		15	2			172	85
Paint stripper		77	8	8			39	132	
Paint thinner		77			2			79	135
Filters (paint booth)		24						24	
Empty containers		10		150	50	25		235	
Aircraft engine oil		1400	462	18	385	385	385	3035	1035
De-icer solution									
Nickel-cadmium batteries									20250
Potassium hydroxide				2				2	
Caustics		485		9		220		714	
Detergent floor wash		465		8		210		683	
Contaminated dirt									3500
Spent sorbent		100		100		100	300	600	
Contaminated JP - 4			1820	70		385		2275	1750
Oily rags		400		8		400	500	1308	
Solution sludge				8				8	
Contaminated water				400				400	
Hydraulic fluid			105				35	140	1700
Carbon Remover									171
Unused Paint									290
Grease									345
Alcohol									1031
Acetone									216
Cleaning Compound, NOS									275

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[*] Quantities are reported in pounds per year.

[**] Low flash point type (105°F) - Safety Kleen recycle.

Table 12

Quantities of Hazardous/Nonhazardous Materials Used at AMF

Wastes	AMF #	1	2	3	4	5	6
Degreasing solvent		693		424	424	424	
MEK degreaser and cleaner				155		31	2
Paint stripper		77	8	8			
Paint thinner		92			?		
Filters (paint booth)		24					
Aircraft engine oil		1400	924	42	385	385	
De-icer solution			420				
Nickel-cadmium batteries							
Potassium hydroxide					42		
Caustics		485	352	18		220	
Detergent solution		465		8		210	
Spent sorbent		100		100		100	
Contaminated JP-4 fuel					3500		385
Dirty rags		400		8		400	
Hydraulic fluid			280				

Table 13

Paint Shops (PS)

1. DOL - Maintenance Operations Branch - Body and Paint Shop - Maintenance Section II - Building 8000
2. DPCA - Auto Skills Center - Vehicle Paint Booths - Building 2427

Table 14

Quantities of Wastes Generated at PS*

Wastes	PS #	1	2	Survey Total	IDMS Total
Hazardous empties		600		600	
Spoiled paint		600	50	650	19679
Paint thinner		4290	430	4720	7040
Paint stripper		90		90	
Caustics					
Detergent floor wash					
Contaminated dirt					
Spent sorbent		600		600	
Contaminated rags		150		150	
Tank sludge					
Contaminated water					
Spent paint filters		600	280	880	
Respiratory cartridges		240		240	
Coveralls		480		480	
Methylene chloride					65
Sealant					478
Bondo					284
Rust remover					140
Adhesive					210

---

*Quantities are reported in pounds per year.

Table 15

Quantities of Hazardous/Nonhazardous Materials Used at PS*

Materials	PS # 1	2
Paint thinner	17160	
Toluene	4290	
Paint stripper	90	
Caustics		
Detergent floor wash		
Spent sorbent		
Contaminated rags	75	
Paint filters	600	
Respirator cartridges	240	
Coveralls	480	

---

*Quantities are reported in pounds per year.

Table 16

Photography, Printing, Arts/Crafts Shops (PPAS)

1. DPTM - Training and Support Center - Photographic Section - Building 6010
2. DPTM - Training and Support Center - Graphics Section - Building 6103
3. DPTM - Training and Support Center - Devices Section - Building 6084
4. DPTM - Training and Support Center - Photographic section - Building 6138
5. DOIM - USAISC - Building 6120
6. DPCA - Photography Skill Center - Building 2200

Table 17

Quantities of Waste Generated at PPAS*

Wastes	PPRF #	1	2	3	4	5	6	Survey Total	IDMS Total
Bleach		1060			448		288	1796	102
Activator		720						720	
Developer		3632	192		576	408	1728	6128	4945
Cleaner		216						216	125
Fixer		2912	288		448		480	4128	
Toner			8				28	36	2946
Rinse			4					4	215
Stabilizer							288	288	
Lacquer thinner		215		15				230	
Enamel thinner		72						72	
Turpentine			14					14	
Stencil			200					200	
Silk screen			20					20	
Hexcell uralite		1000						1000	
Photo conditioner						96		96	
Waste inks					1			1	
Solvent rags									
Cleaning solvent						96		96	
Wetting solution						96		96	
Blankrola						739		739	863
Deglazing solvent					96			96	
Electrostatic ink					1500			1500	
Electrostatic solution					2002			2002	
Hypo							192	192	
Step bath							488	488	
Conversion solution									198
Adhesive									1071
Imager									88

---

*Quantities are in pounds per year.

Table 18

Quantities of Hazardous/Nonhazardous Materials Used at PPAS*

Wastes	PPRF #	1	2	3	4	5	6
Bleach		1060			448		288
Activator		720					
Developer		3632	192		576		1728
Cleaner		216					
Fixer		2912	288		448		480
Toner			8				28
Rinse			4				
Stabilizer							288
Lacquer thinner				350			
Enamel thinner							
Turpentine							
Stencil							
Silk screen							
Hexcell Duralite							
Empty containers							
Photo conditioner						96	
Waste inks							
Solvent rags					100		
Cleaning solvent						96	
Wetting solution						96	
Blankrola						739	
Electrostatic solution							92
Waste ink mix					92		
Hype							192
Step bath							488

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*Quantities are reported in pounds per year.

Table 19

Hospitals, Clinics, and Laboratories (HCL)

1. DHS - Evans Army Community Hospital - Building 7500
2. DENTAC - Dental Clinic Number 3 - Building 6225
3. Veterinary Hospital - Building 6001

Table 20

Quantities of Wastes Generated at HCL*

Wastes	HCL #	1	2	3	Survey Total	IDMS Total
Pathological		732		15600	16332	
Infectious		360000	149650		509650	
Pharmaceutical		90			90	90
Chemical						492
Radioactive						
Silver recovery		19			19	
Formaldehyde						430
Alcohol						915
Mercury						215
Benzene						280
Potassium phosphate						320
Disinfectant						185
Chloroform						75
Photo developer						460
Photo toner						216
Photo wash						290
Soda lime						215
Toluene						518
Xylene					308	480

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*Quantities are reported in pounds per year.

Table 21

Quantities of Hazardous/Nonhazardous Materials Used at HCL[*]

Materials	HCL #	1	2	3
Xylene		293		
Mercury				
Photochemical				
Acids				
Bases				
Alcohols				
Formalin				
Formaldehyde				

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[*] Quantities are reported in pounds per year.

Table 22

Heating and Cooling Plants (HCP)

1. DEH - Boiler Plant Section - Building 1860
2. DEH - Boiler Plant Section - Building 403
3. DEH - Boiler Plant Section - Building 9609
4. DEH - Boiler Plant Section - Building 6290
5. DEH - Boiler Plant Section - Building 6290
6. DPTMSEC-Museum Div.-FSH Museum; Bldg. 123

Table 23

Quantities of Waste Generated at HCP[*]

Materials	HCP #	1	2	3	4	5
Spent degreasing solvent			1400			
Contaminated fuel oil						
Cyclohexyl						
Caustic soda						
Boiler blowdown		1600	16000	80000	8000	160000
Toxic emissions						
Ash						
Miscellaneous						

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[*] Quantities are reported in pounds per year.

Table 24

Quantities of Hazardous/Nonhazardous Materials Used at HCP[*]

Materials	HCP #	1	2	3	4	5
Degreasing solvent			1400			
Used oil		183890				
Fuel oil		289485				
Natural gas		336167				
Cyclohexyl			2	40		
Caustic soda		61	5	184	12	12
Tripolyphosp			8	454		52
Tannin			8	135		75
Sodium sulfite		373	4	95	3	50
Morpholine						211

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[*] Quantities are reported in pounds per year.

Table 25

Waste Generation Summary

Waste Generating Operation, Process, or Condition	Waste Category	lb/yr	lb/yr/unit			Waste Stream Unit
			Survey	IDMS	Suggest	
Motor Pools and Vehicle Maintenance Facilities	1	191861	190103		190103	Spent petroleum naphtha
				1758	1758	Spent degreasing solvent, NOS
	2	1442		647	647	Carbon remover
			795		795	Carburetor cleaner
	3	247501	247501		247501	Spent antifreeze solution
	4	717424	635507	105000	635507	Used motor oil
				81917	81917	Chlorinated motor oil
	8	3744	3744		3744	Spent sulfuric acid
	10	32655	32655	20487	32655	Contaminated diesel, Mogas
	12	201850	201850	38301	201850	Spent lead-acid batteries
	13	305491	4903	1148	4903	Used brake fluid
			23041		23041	Used transmission fluid
			14342		14342	Used hydraulic fluid
			120680	95000	120680	Spent sorbent
			34825		34825	Contaminated rags
			6770	105000	105000	Contaminated soil
			1540		1540	Hazardous faulty parts
			685	1160	1160	Asbestos containing materials
Industrial Maintenance Small Arms Shops	1	29057	29057		29057	Spent degreasing solvent
	2	7700	7700		7700	Spent 1,1,1-trichloroethane
	3	20416	20146		20146	Spent antifreeze solution
	4	75190	73590		73590	Used motor oil
			1600		1600	Chlorinated motor oil
	7	15	15		15	Spent paint thinner
	8	92500	90000		90000	Spent sulfuric acid
			2500		2500	Spent sodium hydroxide
	10	42700	42700		42700	Contaminated fuels
	12	300015	300000		300000	Lead-acid battery casings
			5		5	Spent Li-So_2 batteries
			10		10	Spent NICAD batteries
	13	17816	686		686	Used transmission fluid
			80		80	Used brake fluid
			4375		4375	Used hydraulic fluid
			840		840	Contaminated sorbent
			685		685	Hazardous faulty parts

Table 25 (Cont'd)

Waste Generating Operation, Process, or Condition	Waste Category	lb/yr	lb/yr/unit			Waste Stream Unit
			Survey	IDMS	Suggest	
			3700		3700	Contaminated fluid filters
			70		70	Contaminated cutting oil
			2100		2100	Oily rags
			5280		5280	TCA tank bottom sludge
	1	13379	12991		12991	Spent petroleum naphtha
			172	85	172	Spent MEK
		446		216	216	Spent acetone
	2			171	171	Carbon remover
				275	275	Cleaning compound, NOS
	4	3035	3035	1035	3035	Aircraft engine oil
	7	842	132		132	Spent paint stripper
			79	135	135	Spent paint thinner
			285		285	Spent paint filters
				290	290	Unused, spoiled paint
	3	716	714		714	Caustics
			2		2	Potassium hydroxide
	10	2275	2275	1750	2275	Contaminated JP-4
	12	20250		20250	20250	Spent NICAD batteries
	13	11866	140	1700	1700	Contaminated hydraulic fluid
			600		600	Spent sorbent
				345	345	Grease, NOS
			4375		4375	Contaminated hydraulic fluid
			30		30	Hazardous empties
			1308		1308	Contaminated rags
			8		8	Solvent tank sludge
				3500	3500	Contaminated soil, solids
Paint Shops	2	65		65	65	Spent methylene chloride
	4	1750	1750		1750	Used motor oil
	5	1031	1031		1031	Spent alcohol, NOS
	7	29521	4720	7040	7040	Spent paint thinner
			90		90	Spent paint stripper
			880		880	Spent paint filters
			240		240	Spent respirater cartridges
				478	478	Sealant
				284	284	Bondo
				140	140	Rust Remover
				210	210	Adhesive, NOS

Table 25 (Cont'd)

Waste Generating Process, Operation, or Condition	Waste Category	lb/yr	lb/yr/unit			Waste Stream Unit
			Survey	IDMS	Suggest	
			480		480	Paint covered overalls
			650	19679	19679	Unused, spoiled paint
	13	4115	2600		2600	Spent oil, fuel filters
			840		840	Spent sorbent
			600		600	Hazardous empties
			75		75	Contaminated rags
Photography, Printing and Arts/Crafts Shops	1	96	96		96	Spent deglazing solvent
	2	1079	216	125	216	Spent film cleaner
			739	863	863	Spent blankrola solvent
	6	5621	288		288	Spent photo stabilizer
			1796	102	1796	Spent photo bleach
				215	215	Spent photo rinse
			36	2946	2946	Spent offset toner solvent
			92		92	Spent electrostatic solvent
			92		92	Spent electrostatic ink and toner
			192		192	Spent hypo. cleaning agent
			720		720	Spent photo activator
	7	316	230		230	Laquer thinner
			72		72	Enamel thinner
			14		14	Turpentine
	8	10663	6128	4945	4945	Spent photo developer
			4128		4128	Spent Photo fixer
			96		96	Ink roller conditioner
			488		488	Acetic acid photo bath
				198	198	Conversion solvent, NOS
				88	88	Imager
Hospitals, Clinics, and Laboratories	1	1278	308	480	480	Spent xylene
				280	280	Spent benzene
				518	518	Spent toluene
	2	505		430	430	Spent formaldehyde
				75	75	Spent chloroform
	5	915		915	915	Spent alcohol, NOS
	6	966		460	460	Spent photo developer
				216	216	Spent photo toner
				290	290	Spent photo wash
	9	185		185	185	Spent disinfectant, NOS
	11	90	90	90	90	Shelf-life pharmaceuticals
	13	511624		215	215	Contaminated mercury

Table 25 (Cont'd)

Waste Generating Process, Operation, or Condition	Waste Category	lb/yr	lb/yr/unit			Waste Stream Unit
			Survey	IDMS	Suggest	
	6			320	320	Potassium phosphate
				215	215	Soda lime
			732		732	Pathological wastes
			509650		509650	Medical infections
				492	492	Miscellaneous chemicals
Heating and Cooling Plants	1	1400	1400		1400	Spent petroleum naptha
	8	265600	265600		265600	Caustic boiler blowdown
G E (formerly DEH)	7	8263		3702	3702	Unused, spoiled paint
				3451	3451	Sealant
				1110	1110	Polyurethane
	12	171		171	171	Furniture polish
Troop	9	18441		4762	4762	Shelf-life DS-2
				10717	10717	Shelf-life STB
				1854	1854	Calcium hydride
				1108	1108	Calcium hypochlorite
	12	13248		8461	8461	Spent mercury batteries
				1019	1019	Spent alkaline batteries
				3768	3768	Spent lithium batteries
	13	10559		1210	1210	Insecticides, NOS
				9349	9349	Magnesium carbon
Miscellaneous	2	125		100	100	Spent dichlorodifluoromethone
				25	25	Spent freon
	5	3720		3720	3720	Spent methonol
	8	750		750	750	Spent acetic acid
	13	1184		1184	1184	Detergent, NOS

Waste Categories: 1: Spent degreasing solvents (nonhalogenated); 2: Spent degreasing solvents (halogenated); 3: Spent antifreeze solution; 4: Used motor oil; 5: Used alcohols; 6: Spent photo and print chemicals; 7: Paint related materials; 8: Spent acids and bases; 9: Decontamination agents; 10: Contaminated fuels; 11: Pharmaceutical wastes; 12: Spent batteries; 13: Miscellaneous wastes

Table 26

Total Waste Generation Rates Sorted by Waste Categories*

Generator	Total	1	2	3	4	5	6	7	8	9	10	11	12	13
MPVM	1701968	191861	1442	247501	717424				3774		32655		201850	305491
IMSS	585409	29057	7700	20416	75190			15	92500		42700		300015	17816
AMF	52809	13379	446		3035			842	716		2275		20250	11866
PS	36482		65		1750	1031		29521						4115
PPAS	17775	96	1079				5621	316	10663					
HCL	515563	1278	505			915	966			185		90		511624
HCP	267000	1400							265600					
DEH	8434							8263					171	
Troop	42248									18441			13248	10559
Miscellaneous	5779		125			3720			750					1184
TOTAL	3233467	237071	11362	267917	797399	5646	6587	38957	373973	18626	77630	90	535534	862655

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*Quantities are reported in pounds per year.

5 WASTE MINIMIZATION FOR MOTOR POOLS AND VEHICLE MAINTENANCE FACILITIES AND AVIATION MAINTENANCE FACILITIES

The typical maintenance and repair operations conducted in a vehicle or aviation maintenance facility are: oil and grease removal; engine, parts, and equipment cleaning; rust removal; and solution replacement. Table 27 lists the operations, the corresponding materials used, and the wastes generated. Table 28 lists the process descriptions and the corresponding waste descriptions according to hazardous waste codes and Department of Transportation (DOT) classifications. These waste descriptions are used when shipping the wastes offsite. Most of the wastes generated at MPVM are: parts cleaning solutions and miscellaneous detergent solutions, oil and grease from engine cleaning, spent automotive fluids, and lead-acid batteries. AMF generated most of the above wastes (except automotive fluids and lead-acid batteries) and nickel-cadmium batteries. Paint removal and painting operations may also occur at both MPVM and AMF. The minimization of wastes from such activities is discussed in Chapter 7.

Some of the equipment used, primarily in parts cleaning operations, are solvent sinks, hot tanks, and jet spray washers. Proper operation of this equipment minimizes material use and waste generation. The solvent in the sinks is recirculated continuously from a tank to the parts wash tray. The solvent (e.g., PD680-II) is replaced periodically. Hot tanks contain aqueous detergent or caustic solutions for immersion cleaning. These tanks are equipped with air or mechanical agitation devices and electrical heating devices to heat the solution to 356 °F. The jet spray washers consist of nozzles that emit rotating water jets to clean parts immersed in an aqueous wash solution. The contaminated liquid and sludge from both the hot tanks and jet sprays are removed periodically.

Most of the minimization options discussed below have been obtained from *Waste Audit Study - Automotive Repairs*,[36] and other references.[37]

Source Reduction

All Wastes - Better Operating Practices

Better housekeeping practices are necessary to minimize the quantity and toxicity of wastes or emissions generated. Some of the methods include: closing the lids of containers (e.g., solvent sinks) containing volatile substances (e.g., Stoddard solvent); conveniently locating cleaning equipment near service bays; increasing employee awareness of proper waste handling and disposal procedures; labeling hazardous waste containers properly; segregating wastes in separate containers; and separating trash/solids before waste collection for recycling or treatment.[38] Draining wastes to a sewer is not a good practice and may be illegal in many states. Inadvertent losses (spills) can also be minimized by using good housekeeping practices.

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[36] W.M. Toy, *Waste Audit Study - Automotive Repairs* (Prepared for the California Department of Health Services, Sacramento, CA, 1987).

[37] *Hazardous Waste Reduction Checklist - Automotive Repair Shops* (California Department of Health Services, Toxic Substances Control Division, 1988); *Hazardous Waste Reduction Assessment Handbook - Automotive Repair Shops* (California Department of Health Services, Toxic Substances Control Division, 1988).

[38] W.M. Toy, pp 27-28.

All Wastes - Better Operating Practices - Segregation

Segregation of waste streams is a very good practice that minimizes hazardous waste generation and also increases the recyclability of wastes. It is extremely important not to mix solvents and oils. Mixing results in a liquid with very little recycle value and increases the costs of disposal.[39] Minimizing the quantity of contaminants in solvents improves the purity of reclaimed solvent (in onsite recycling) and its market value (in offsite recycling). Used oils, after being drained from engines are known to be contaminated with parts cleaning solvent, carburetor cleaner, fuels, rags, water, trash, etc.[40] These contaminants may make the used oil a hazardous waste due to ignitability, corrosivity, or toxicity, thereby reducing the possibility of energy recovery by burning it in boilers or reducing its market value (for offsite reclamation).

All Wastes - Better Operating Practices - Periodic Maintenance and Cleanup of Equipment

All the equipment, including solvent sinks, hot tanks, and spray washers, must be properly maintained. The tank bottoms must be cleaned frequently to reduce sludge accumulation and contamination of replacement solutions.

Solvent (PD680-I) - Material Substitution - PD680-II

Petroleum distillate Type I (PD680-I) is a flammable substance with a flash point of 102 °F, which is below the USEPA's flammability hazard limit of 140 °F. It must be substituted with petroleum distillate Type II (PD680-II) that has a flash point of 140 °F or above. Changes must be made in the local and centralized procurement processes to prevent users from obtaining PD680-I. When ordering solvent, the user must specify that substitution is not acceptable.

Solvent (PD680-II) - Better Operating Practices

A parts cleaning solvent, such as PD680-II, must not be used to clean floors or hands. It is expensive and must be dedicated to the intended purpose of parts cleaning only. Immersion and removal of parts from the solvent sinks must be done slowly to minimize splashes and rapid evaporation of solvent.

Solvent (PD680-II) - Better Operating Practices - Emissions Minimization

Among the good housekeeping practices, efforts to reduce air emissions are probably the most significant in terms of reducing hazardous wastes released to the environment. Using covers on solvent sinks (or cold cleaning tanks) can result in a 24 to 50 percent reduction in solvent losses.[41] Several standard methods are available for minimizing emissions from immersion cleaning, wipe cleaning, and spray cleaning operations.[42]

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[39] R.H. Salvesan Associates, *Used Oil and Solvent Recycling Guide*, Final Report (Naval Energy and Environmental Support Activity, Port Hueneme, CA, June 1985).

[40] L.C. Chicoine, G.L. Gerdes, and B.A. Donahue, *Reuse of Waste Oil at Army Installations*, Technical Report N-135/ADA123097 (USACERL, September, 1982).

[41] ICF Associates, Inc., *Guide to Solvent Waste Reduction Alternatives: Final Report* (Prepared for the California Department of Health Services, October 1986), pp 4-11 through 4-13.

[42] ASTM Standard D3640-80, "Standard Guidelines for Emission Control in Solvent Metal-Cleaning Systems," *Annual Book of American Society of Testing and Materials Standards*, Vol 15.05 (American Society of Testing and Materials [ASTM], 1988).

Solvent (PD680-II) - Process Change

If dip tanks or dunk buckets full of solvent are used for parts cleaning, the process must be modified. Solvent sinks clean parts more effectively and are easy to use. Spillage and evaporation is less from solvent sinks than from dip tanks or buckets. Equipment leasing services (see Table 29) lease solvent sinks. The equipment, raw materials, maintenance, and waste removal are part of the contract and are included in the service price (see Table 30). Testing of solvents (discussed below) before changing must be included in the contract.

If a leasing service is not desirable economically, a solvent sink must be purchased and the waste solvent recycled. Table 31 lists the sizes and the approximate costs of solvent parts washers. Local vendors must be contacted for exact information.

Solvent (PD680-II) - Process Change - Testing

Solvents are normally replaced periodically, based on the operator's perception of "dirtiness." Simple tests to estimate the "solvation power" of the spent solvent can be used to extend the life of the solvent before disposal. The physicochemical tests most useful for used solvent testing are: absorbence, specific gravity, viscosity, and electrical conductivity.[43] Testing instruments (optical probe colorimeter, electronic specific gravity meter, Ostwald viscometer, and electrical conductivity meter) are commercially available. By obtaining a measure of these properties, the usefulness of the solvent can be determined based on Table 32. If the total score (sum of the ratings for all the properties) is less than 6, the solvent is not "spent." If the score is greater than 6, the solvent should be recycled. The criteria provided in Table 32 are only recommendations; they must be revised based on site-specific use and testing. Using solvent testing will reduce raw material and waste disposal costs and minimize the wastes generated.

Solvent (PD680-II) - Process Change - Solvent Sinks (Equipment) Modifications

Solvent losses can be minimized by adding drip trays and lids to existing solvent sinks. About 25 to 40 percent of the solvent is lost because of spillage and about 20 percent because of evaporation.[44] Racks or baskets may be designed and fitted to the solvent sinks to drain parts after cleaning. Minimizing solvent losses results in cost savings for the raw material and waste handling/disposal.

Carburetor Cleaner - Product Substitution

Carburetor cleaners typically contain methylene chloride (< 47 percent), 1,1,1-trichloroethane (< 5 percent), cresylic acid (< 27 percent), and wetting agents. The automobile industry has reformulated them to exclude the use of 1,1,1-trichloroethane.[45] Substitute cleaners must be used.

Used Oil - Better Operating Practices - Selective Segregation

Segregation of used oils and related products is not a source reduction alternative in the strictest sense of the term, yet selective segregation of used oil products may ultimately reduce the large volumes of hazardous wastes[46] that could be produced by mixing used oils with radiator drainings

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[43] B.A. Donahue, et al., *Used Solvent Testing and Reclamation, Volume I: Cold-Cleaning Solvents*, Technical Report N-89/03/ADA204731, Vol I (USACERL, December 1988).

[44] W.M. Toy, pp A-1 - A-23.

[45] W.M. Toy, p 20.

[46] D.W. Brinkman, M.L. Whisman, and C.J. Thompson, *Management of Used Lubricating Oil at Department of Defense Installations: A Guide*, NIPER B06711-2, (National Institute for Petroleum and Energy Research, 1986), p 26.

(containing oxylates, phenols, ketones, and acids) and used solvents. Product segregation is initially cost-intensive, but many factors favor selective segregation of used oils. These factors include but are not limited to: the increasing costs of hazardous waste disposal, particularly for mixed waste disposal; the fact that the British thermal unit (Btu) value of used oil for burning as a fuel is lowered by the presence of solvents; and under USEPA regulations, hazardous wastes cannot be burned except in boilers with air pollution controls and secondary burners. These factors effectively prohibit blending used oil with boiler fuel if the used oil is listed as a hazardous waste.

Used Oil - Process Change - Fast Lube Oil Change System (FLOCS)

The Fast Lube Oil Change System (FLOCS) is a quick and efficient method of draining crankcase oil from vehicles. The model 30A FLOCS oil evacuation unit is designed to evacuate oil from crankcases under a vacuum. The engines must be fitted with quick-connect couplings to provide easy access to the oil drain, eliminating the need for lifts or pits. Because the oil is evacuated under vacuum pressure, sludge buildup in the oil pans is reduced. Spills are virtually eliminated and a substantial savings in time, labor costs, and equipment can be realized. All FLOCS units are designed to accommodate manual draining of the oil pan when necessary.

A single FLOCS unit was tested at Peterson Air Force Base (AFB), CO, from February 1982 to April 1983 to determine if FLOCS afford sufficient advantages over the normal lube oil change methods to warrant its adoption in the Air Force. Savings during 1 year of operation totaled $1,176.00 for 25 vehicles. A total savings of $7,526.40 was expected based on a conservative 8-year life expectancy for the unit. A payback of 1.6 years was projected. The economic success of the FLOCS unit, along with the elimination of spills that could result in accidents to shop personnel, prompted recommendations that the FLOCS evacuation unit be adopted for Air Force use.[47]

Caustic Wastes - Product Substitution

Caustic cleaning compounds are used in hot tanks and jet spray washers. Substitution of detergent compounds minimizes the amount of hazardous (corrosive) wastes produced. Caustic compounds are necessary for cleaning engines made of iron or iron alloys. With the rapid change to manufacturing engine blocks of aluminum, the use of detergent solutions for cleaning is also increasing.

Caustic Wastes - Process Change - Hot Tank (Equipment) Modifications

A major waste from hot tank operations is the tank bottom sludge containing heavy metals, oil, grease, etc. A typical practice is to dislodge the sludge from the bottom of the tank and dump it into a sump. Installing a collection tray with an overflow to the sump will allow for proper capture and disposal of the sludge. Hot tanks must also be equipped with drip trays and pans for collecting solution that drips off the parts after cleaning. The solution in the trays or pans must then be emptied back into the hot tank.

Aqueous or Caustic Wastes - Process Change - Dry Ovens

Hot tanks or spray washers are typically used for engines/parts washing. If the parts are small enough, ovens could be used to burn off the grease, oil, and particles. The dry ash can then be removed from the parts using shot blasters (preferably with plastic beads) and disposed of in a landfill. The ash must be tested for toxicity before assigning a disposal method. Testing the oven stack emis-

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[47] *Management/Equipment Evaluation Program*, Report H82-1B (1st Space Support Group, U.S. Air Force, Peterson Air Force Base, CO, 1983).

sions for air pollutants may be required. However, using a dry oven will eliminate hazardous (corrosive and toxic) wastes that contain caustics, heavy metals, and oily dirt.

Aqueous Wastes - Process Change - Two-Stage Cleaning in Jet Spray Operations

Most of the parts covered with oil, grease, and heavy dirt residues are cleaned using jet spray operations. If many parts need to be cleaned, a two-stage cleaning operation might provide cleaner parts in a shorter time. Two washers can be connected in series with the first removing most of the heavier residue and the second providing the final rinse. The cleaning solution from the second tank is transferred to the first tank (countercurrent processing).

Antifreeze Solution - Better Operating Practice - No Draining

Current practice is to dispose of spent antifreeze solution from radiators by emptying it directly into either a municipal or installation sanitary sewer system. Although the solution contains primarily ethylene glycol (which is poisonous), it is biodegradable and is neither carcinogenic nor mutagenic. Therefore, disposal in a sewer system should not present a problem.[48] However, the U.S. Army Mobility Equipment Research and Development Command has documented the presence of phenols, ketones, acids, oxylates, and aldehydes in radiator drainings formed during the use of ethylene glycol as a coolant.[49] Antifreeze wastes are considered hazardous wastes in some states (e.g., California) because ethylene glycol's oral human lethal dose (LD_{50}) is 1400 mg/kg, which is far below the state toxicity limit of 5000 mg/kg. As other state and local regulations lower the levels of phenols permitted in drinking water and sewage treatment plant effluents, antifreeze waste may have to be disposed of as a hazardous waste.

Antifreeze Solution - Product Substitution

Biological treatment of the ethylene glycol waste stream is difficult and the chlorination processes (commonly used in a waste treatment plant) generate other toxic chlorinated hydrocarbons. Substituting propylene glycol for ethylene glycol in antifreeze formulas will reduce the toxicity of the waste stream. Propylene glycol is a nontoxic compound commonly used as a food additive.[50]

Antifreeze Solution - Process Change - Testing

Testing the antifreeze solution, which may currently be drained into the sanitary sewers, before draining and disposal can help minimize the amount of wastes generated. Standard methodologies available for testing engine coolants in cars and light trucks[51] may be adapted for other types of vehicles. Electrochemical tests based on the measurement of galvanic currents have proven useful for measuring the levels of corrosion inhibitors and corrosivity of the antifreeze solution in a radiator (or any other heat tranfer device).[52] Such test methods allow continuous monitoring of the solution to

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[48] Union Carbide Corporation, *Ecological Aspects of UCAR Deicing Fluids and Ethylene Gylcol* (Hazardous Materials Technical Center, Rockville, MD, 1984).

[49] J.H. Conley and R.G. Jamison, *Reclaiming Used Antifreeze*, Report 2168/ADA027100 (U.S. Army Mobility Equipment Research and Development Command [USAMERDC], Fort Belvoir, VA, 1976).

[50] F.E. Mark and W. Jetter, "Propylene Glycol, A New Base Fluid for Automotive Coolants," in *Engine Coolant Testing: Second Symposium*, R.E. Beal, Ed., ASTM STP 887 (American Society of Testing and Materials [ASTM], 1986), pp 61-77.

[51] ASTM Standard D2847-85, "Standard Practice for Testing Engine Coolants in Car and Light Truck Service," *Annual Book of American Society of Testing and Materials Standards*, Vol 15.05 (ASTM, 1988).

[52] R.L. Chance, M.S. Walker, and L.C. Rowe, "Evaluation of Engine Coolants by Electrochemical Methods," in *Engine Coolant Testing: Second Symposium*, R.E. Beal, Ed., ASTM STP 887 (ASTM, 1986), pp 99-102; C. Fiaud, et al., "Testing of Engine Coolant Inhibitors by an Electrochemical Method in the Laboratory and in Vehicles," in *Engine Coolant Testing: Second Symposium*, R.E. Beal, Ed., ASTM STP 887 (ASTM, 1986), pp 162-175.

determine the exact time of change (rather than change on a periodic basis, such as 6 months, or when the mechanic thinks it is "dirty").

Antifreeze Solution - Process Change - Extend Life

A Military Specification, MIL-A-53009[53], developed by the U.S. Army Research and Development Center, Fort Belvoir, VA, allows the use of antifreeze (MIL-A-46153)[54] whose inhibitor system has reached a marginal condition.[55] The military additive can extend the life of the antifreeze by more than 1 year. It was originally developed for use if new antifreeze was in short supply. During 1987 and 1988, ethylene glycol was in short supply because of the unavailability of ethylene (base stock) and the retail price doubled. In addition to environmental incentives, economic incentives to minimize the quantities of ethylene glycol wastes generated also exist.

Brake Shoes (Asbestos Waste) - Better Operating Practices

Asbestos dust, released when replacing brake shoes, is a hazardous waste. Friable (crushed under hand pressure) asbestos must be carefully collected and handled as a hazardous waste. Some equipment leasing companies may also provide asbestos collection services.

Recycling Onsite/Offsite

Solvent (PD680-II) - Onsite Recycling - Distillation

If large quantities of solvents are used (i.e., over 4000 gal/yr) they can be recycled onsite using distillation stills. These units offer a quick investment payback (i.e., less than 3 years).[56] In the distillation process, the solvent is boiled and the vapors are condensed and collected in a separate container. Substances with a higher boiling point than the solvent (e.g., oils, metal residues, etc.) remain in the bottom of the still. A smaller amount of contaminants will result in a higher purity for the reclaimed solvent. Therefore, it is very important to segregate solvent wastes from oils and other contaminants in the service bays. Table 33 lists some of the major suppliers of solvent distillation equipment. Detailed comparisons of the economics of distillation and solvent management options discussed in this chapter are available elsewhere.[57]

Solvent (PD680-II) - Offsite Recycling - Contract/Leased Recycling

Solvent sinks for parts cleaning can be owned or leased. In a lease arrangement, the contractor (e.g., Safety-Kleen [SK]) replaces fresh solvent periodically (specified in the contract) and takes the spent solvent for recycling. Wastes can thus be better contained and the solvent recycled rather than

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[53] Military Specification MIL-A-53009, *Additive, Antifreeze Extender, Liquid Cooling System* (Department of Defense [DOD], 6 August 1982).

[54] Military Specification MIL-A-46153, *Antifreeze, Ethylene Glycol, Inhibited, Heavy Duty, Single Package* (DOD, 31 July 1979).

[55] J.H. Conley and R.G. Jamison, "Additive Package for Used Antifreeze," in *Engine Coolant Testing: Second Symposium*, R.E. Beal, Ed., ASTM STP 887 (ASTM, 1986), pp 78-85.

[56] R.H. Salvesan Associates, pp 35-36.

[57] B.A. Donahue and M.B. Carmer, *Solvent "Cradle-To-Grave" Management Guidelines for Use at Army Installations*, Technical Report N-168/ADA137063 (USACERL, December 1983); *Economic Analysis of Solvent Management Options*, Technical Note 86-1 (Department of the Army, May 1986).

disposed of. Contract recycling has been accepted as a good practice by the automobile industry.[58] Table 29 lists some of the equipment leasing and service companies.

Solvent and Carburetor Cleaner - Offsite Recycling

Solvent and carburetor cleaner wastes can also be sent to a solvent contractor/recycler for offsite recycling. A number of companies (Table 29) provide this service.

Carburetor Cleaner - Offsite Recycling - Contract/Leased Recycling

Some companies distill spent carburetor cleaners and return the cleaner to the user. Equipment similar to solvent sinks are available for lease or purchase. The contract fees include the cost of periodic pickup and disposal of sink bottoms. Companies that provide equipment leasing services for carburetor cleaners are listed in Table 29.

Used Oil - Onsite Recycling - Gravity Separation/Blending

A state-of-the-art RACOR™ oil-to-fuel blending system that will help avoid the problem of disposing of used oils has been developed. The RACOR system is typically used in conjunction with a fuel reservoir or tank. The system blends waste diesel crankcase oil with diesel fuel. It also filters/recycles and transfers diesel fuel from the fuel holding tank. The system comes with a waste holding tank and oil injection system. Used oil from the system's holding tank is blended into diesel fuel (not to exceed 5 percent) and cycled through a three-stage filter to remove water and solid contaminants, resulting in a fuel that is 99.5 percent free of emulsified water and solid particulates. Use of a closed-loop system such as the RACOR system may satisfy all technical requirements and military specifications for oil/fuel blends[59] and should be tested.

Used Oil - Offsite Recycling - Closed-Loop Contract

A closed-loop re-refining contract stipulates that the re-refiner agrees to process the used oil furnished by the generator, returning it to original quality for a contracted price per gallon. The re-refiner does not take ownership of the used oil but merely assumes custody of the oil until it is returned to the generator.

Among the possible disadvantages of a closed-loop contract is that installations may wish to offer used oil, solvents, and synthetic lubricants as a package. Of more immediate and important concern, is that before re-refined oil can be used in government vehicles and engines, it requires approval for the Qualified Products List. Approval is a costly procedure but ensures that the product meets specifications. With estimates of $50,000 for an engine sequence test (1982 dollars) to qualify used oil to meet Army requirements,[60] many re-refiners are reluctant to enter into a contractual agreement unless the cost of such tests can be included in the closed-loop contract.[61] More recent studies have placed the cost of such a qualification procedure at $75,000.[62]

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[58] W.M. Toy, pp 29-30.

[59] D.W. Brinkman, W.F. Marshall, and M.L. Whisman, *Waste Minimization Through Enhanced Waste Oil Management*, NIPER B06803-1 (National Institute for Petroleum and Energy Research, 1987); T.C. Bowen, Personal Communication, U.S. Army, Belvoir R&D Center, Materials, Fuels, and Lubricants Laboratory, Fort Belvoir, VA, 1987.

[60] Mil-L-46152, *Lubricating Oil, Internal Combustion Engine, Administrative Service, Metric* (DOD, 1 August 1988).

[61] L.C. Chicoine, G.L. Gerdes, and B.A. Donahue, pp 16-19.

[62] D.W. Brinkman, M.L. Whisman, and C.J. Thompson, p S-3.

Used Oil - Offsite Recycling - Sale to Recyclers

Sale of used lubricating oils may be the most economical answer for an installation. Although burning and closed-loop recycling agreements offer increased economic rewards, constraints may limit the options available to an installation and make selling used oil the only feasible alternative. The cost of selling or disposing of used oil includes sampling and testing the oil, storage before the sale, 55-gal drums for sale/disposal, inventorying expenses, advertising for bid solicitations, bid evaluation, bid letting, and accounting. Draft USEPA regulations, when finalized, could increase the workload of sales personnel slightly by requiring the selling installation (or DRMO/DRMS) to notify the USEPA of the intent to market used lubricating oil and obtain an identification number. Certified analyses on each batch of used oil will also be required, and if the oil is classified as a hazardous waste, it must be manifested and transported by a licensed hazardous waste hauler and may be distributed only to an industrial user.

Antifreeze Solutions - Onsite Recycling

In addition to reducing the quantity of waste produced, there is a major economic incentive for recycling and reusing antifreeze solutions. Because of the shortage of ethylene, the price of antifreeze has more than doubled in the past 2 years ($3 to $8/gal) and it is in short supply. A simple recycling method is available.[63] This method includes mechanical filtration that removes large particles before the solution is pumped into a large tank. An antifreeze extender is added to the tank based on the measured pH. The extender neutralizes the acidic byproducts in used antifreeze. The whole recycling system is available as a skid-mounted, 100-gal batch unit.

Lead-Acid Batteries - Offsite Recycling

Because of their weight, lead-acid batteries are the largest quantity of waste generated from vehicle maintenance facilities. Battery recyclers pay between $1.00 and $1.50 per battery (or $0.20 to $0.40 per pound, wet or dry). The batteries are rebuilt or processed to recover lead. Approximately 20 percent of the batteries can be rebuilt. Table 29 lists processors and smelters of lead-acid batteries. Installation logistics personnel can transport "intact" lead-acid batteries to a recycling facility if one is located nearby. A bill of lading is required if more than 10 batteries are transported at any time. Use of a registered hazardous waste hauler is not required and the waste does not have to be manifested. However, cracked or broken batteries must be transported as hazardous waste by registered haulers.

Aqueous or Caustic Wastes - Equipment Leasing

Hot tanks and spray washers are also available from equipment leasing companies (Table 30). The leasing service fee is site-specific and usually includes the raw materials, equipment maintenance, and waste disposal costs.

Dirty Rags/Uniforms - Onsite/Offsite Recycling - Laundry Service

Rags used to wipe up spills or clean off grease must not be disposed of as trash in a solid waste container. They must be collected and sent with dirty uniforms to a laundry for cleaning.

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[63] *GLYCLEAN - Anti-freeze Recycling System*, brochure (FPPF Chemical Co., Inc., 117 W. Tupper St., Buffalo, NY 14201, 1988).

Treatment

Used Oil - Onsite Pretreatment - Filtration

A number of filtration devices are available for removing solids from used oil. Simple screen filters must be used when draining oil into containers to prevent entry of large objects (e.g., rags, cans, trash, etc.). Other filter media ranging from sand to fibrous material are available in filtration units for removing solids and even water.

Used Oil - Onsite Pretreatment - Gravity Separation

Gravity separation units are composed of a series of tanks used to contain oil and allow for gradual sedimentation of solids and water because of gravitational force and buoyancy. These units usually include skimmers and pumps to remove the water and solids. Some of the units use heat to enhance separation. Gravity separators are effective on used oils that do not contain emulsions and when a sufficient residence time can be provided for settling to occur.[64]

Used Oil - Onsite Treatment - Blending/Burning

Used oil exceeding any of the specification levels for toxic metals, flash point, or total halogen content is termed "off specification used oil" and is subject to regulatory controls. Furthermore, an installation without an industrially classified boiler and whose used oil has hazardous characteristics (heavy metals, halogens, toxics) must blend the oil to meet burning specifications. Regulations regarding used oil for burning can be found in a DOD Memorandum.[65]

Classification as an industrial boiler requires that energy from the boiler be used in manufacturing operations. The manufacture of steam or heat does not satisfy this criteria.[66] The amount of used oil to be blended with the fuel is not likely to have short-term impacts on the *combustion efficiency* of a boiler, but long-term use will likely present a problem in repeated clogging of pipes and nozzles, accelerated corrosion of pipes and tanks, and a reduction of heat transfer efficiency.[67] Current Navy regulations limit the amount of used oil in fuel oil blends to 1 percent.[68] Mixtures up to 5 percent oil, however, appear to have no appreciable impact on the Btu value of the fuel oil mixture and result in only minor additional maintenance costs, although long-term impacts of blending/mixing on operating parameters of boilers are unknown.

Before blending and burning, used oils must be filtered to remove any large impurities. Other important characteristics of used oils as a boiler fuel are API gravity and viscosity. Viscosity will impact the flow rate of the fuel and the spray pattern from the nozzle as the fuel is introduced to the boiler. The API gravity of an oil is a function of the specific gravity and is related to the heat of the burning oil. Firing temperatures for a given viscosity and discussions of the relationships between specific gravity, API gravity, and heating value can be found in literature.[69]

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[64] R.H. Salvesan Associates, pp 54-57.

[65] DOD Memorandum for Deputy of Environment, Safety and Occupational Health, OASA (I&L); Deputy Director for Environment, OASN (S&L); Deputy for Environment and Safety and Occupational Health (SAF/MIQ); Director, Defense Logistics Agency (DLA-S); 28 January 1986, subject: Regulation of Used Oil for Burning.

[66] D.W. Brinkman, M.L. Whisman, and C.J. Thompson, p 34.

[67] L.C. Chicoine, G.L. Gerdes, and B.A. Donahue, pp 33-43.

[68] C.W. Anderson, *Cost-Effectiveness Analysis of Lubricant Reclamation by the Navy*, Technical Note 1481 (Naval Civil Engineering Research Laboratory [NCEL], Port Hueneme, CA, 1977).

[69] T.T. Fu and R.S. Chapler, *Utilization of Navy-Generated Waste Oils as Boiler Fuel - Economic Analysis and Laboratory Tests*, Technical Note N-1570 (U.S. Navy Construction Battalion Center, 1980), pp 14-44.

Aqueous Wastes - Onsite Pretreatment - Filtration

Installing filters on aqueous waste streams to collect grit and heavy residue increases the life of the wash solution. In one case,[70] providing a pump-around loop through a 25-micron filter bag (on a slipstream from jet spray washer) extended the solution life by 2 weeks, thus minimizing the quantity requiring subsequent treatment or disposal.

Aqueous Wastes - Onsite Treatment - Evaporation

Aqueous wastes consist primarily of water with various amounts of contaminants. Evaporating the water minimizes the amount of waste requiring disposal. In an evaporation device, the water is heated away (using an electric or natural gas heating device) leaving behind a semisolid or solid residue requiring disposal. Oil, if present in the waste, could inhibit boiling. Solid residue accumulated on the inner surface of the evaporator could inhibit heat transfer and, therefore, it may have to be cleaned frequently. Table 34 is a list of suppliers of aqueous waste volume reduction equipment.

Aqueous Wastes - Onsite Treatment - Waste Treatment

Onsite batch treatment devices that neutralize and precipitate heavy metals from aqueous wastes are available.[71] A pretreatment system is included to separate oil and grease. Sulfuric acid is added to reduce the pH to between 2 and 3 to reduce any hexavalent chrome to a trivalent state. Adding sulfites leads to precipitation of trivalent chrome. Sodium hydroxide is then added to raise the pH and precipitate the remaining metallic species. The precipitates settle to the bottom as a sludge and the water decanted from the top may be reused in cleaning processes. A filter press is included to reduce the water content of the sludge produced, thus also minimizing the volume to be disposed of.

Carburetor Cleaner - Offsite Treatment

Some solvent recyclers (e.g., SK, Safe-Way Chemical) send spent carburetor cleaners to another company (e.g., Solvent Services) for treatment. This treatment process produces a lacquer wash from the spent carburetor cleaner.[72] Lacquer wash can be recycled and used in paint stripping processes.

Antifreeze Solution - Offsite Treatment

If large quantities of spent antifreeze solutions are generated at vehicle maintenance operations, the solutions can be treated at an approved treatment facility (Table 29) for recovery of ethylene glycol that may be used as waste fuel.

Lead-Acid Battery Electrolyte - Treatment

Lead-acid batteries must not be drained. These batteries are not a hazardous waste if they are sold to a recycler. Draining the batteries creates two types of wastes: lead dross, and spent sulfuric acid contaminated with lead. The electrolyte, if drained, must be neutralized and tested for lead and lead salts and neutralized before draining into the sewer.

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[70] W.M. Toy, p 27.
[71] W.M. Toy, p 25-27.
[72] W.M. Toy, pp 31-32.

NICAD Battery Electrolyte - Treatment

NICAD battery cells contain a caustic potassium hydroxide solution (31 percent by weight). This electrolyte is corrosive. The electrolyte also contains cadmium and cadmium salts that are listed by the USEPA as hazardous wastes. The electrolyte must therefore be tested for cadmium and neutralized before disposal in the sewer.

Table 27

Typical MPVM and AMF Operations With Materials Used and Wastes Generated*

Process/ operation	Materials used	Ingredients	Wastes generated
Oil and grease removal	degreasers - (gunk), carburetor cleaners, engine cleaners, varsol, solvents, acids/alkalis	petroleum distillates, aromatic hydrocarbons, mineral spirits	ignitable wastes, spent solvents, combustible solids, waste acid/alkaline solutions
Engine, parts, and equipment cleaning	degreasers - (gunk), carburetor cleaners, engine cleaners, solvents, acids/alkalis cleaning fluids	petroleum distillates, aromatic hydrocarbons, mineral spirits, benzene, toluene, petroleum naptha	ignitable wastes, spent solvents, combustible solids, waste acid/alkaline solutions
Rust removal	naval jelly, strong acids	phosphoric acid, hydrochloric acid, hydrofluoric acid, sodium hydroxide	waste acids, waste alkalis
Solution replacement	antifreeze solution, petroleum oil	ethylene glycol, petroleum distillates	hazardous liquid, combustible liquid
Lead-acid batteries; recharging, repair, draining	automobile, truck, tracked vehicle, and other equipment batteries	lead dross, less than 3 percent free acids	used lead-acid batteries, strong acid
NICAD batteries; repair, draining	helicopter and airplane batteries	Battery cells containing KOH	used NICAD battery cells, strong alkali

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*Source: H. Winslow, *Hazardous Waste SQG Workbook* (Intereg Group, Inc., Chicago, IL, 1986).

Table 28

Waste Classification for MPVM and AMF*

Process Description		Waste Description			
Typical process/ operation	Materials used/ wastes produced	HW code	DOT shipping name	Hazard class	Number
Vehicle oil changes	Used crankcase oil (not manifested)	None	Waste petroleum oil, NOS	Combustible liquid	NA1270
Oil/grease removal and equipment cleaning	Acids	D002	Depends on type of acid	Corrosive material	Varies
	Potash	D002	Waste potassium hydroxide	Corrosive material	UN1814
	Caustic soda	D002	Waste sodium hydroxide solution	Corrosive material	UN1824
	Carburetor cleaners	F002/F004	Waste solvent NOS	ORM-A	UN1591/3
	Chlorinated solvents	F001	Waste (main ingredient)	ORM-A	Varies
	Ignitable (flammable) degreasers	D001	Waste flammable liquid NOS	Flammable liquid	UN1268
	Mineral spirit solvents	D001	Waste naptha	Flammable liquid	UN2553
	Petroleum naptha	D001	Waste naptha	Flammable liquid	UN1255
	Petroleum distillates	D001	Waste petroleum distillate	Flammable liquid	UN1268
	1,1,1-trichloroethane	F001	Waste 1,1,1-trichloroethane	ORM-A	UN2831
	Trichloroethylene	F001	Waste trichloroethylene	ORM-A	UN1710
	"MEK"	F005	Waste Methylethylketone	Flammable liquid	UN1193
Rust removal	Acids	D002	Depends on type of acid	Corrosive material	Varies
	Naval jelly	D002	Waste phosphoric acid	Corrosive material	UN1805
Solution replacement	Ethylene glycol	None	Waste hazardous liquid	ORM-E	UN9189
Used lead-acid batteries	Sulfuric acid	D002	Waste sulfuric acid	Corrosive material	UN1830
	Lead dross/scrap	D008	Hazardous waste solid NOS	ORM-C	NA9189
Used NICAD batteries	Potassium hydroxide	D002	Waste potassium hydroxide	Corrosive material	UN1814
	Battery cells	D002/D006	Hazardous waste solid NOS	ORM-C	NA9189

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*[*] *Vehicle Maintenance/Equipment Repair*, Hazardous Waste Fact Sheet (Small Quantity Generators Activities Group, Minnesota Technical Assistance Program, 1986).

Table 29

Partial Listing of Waste Recyclers, Haulers, Equipment Leasing Companies, and Equipment Manufacturers*

Company and address	Telephone and services	Solvent waste	Caustic waste	Waste oil	Used antifreeze	Used batteries
Acto-Kleen P.O. Box 278 Pico Rivera, CA 90660	(213) 723-5111 (714) 944-3330 Hauler, seller	X				
American Labs 5701 Compton Avenue Los Angeles, CA 90011	(213) 588-7161 Hauler, transfer facility, and recycler	X	X			
Antifreeze Environmental Svc. Corp. 2081 Bay Rd., P.O. Box 50757 Palo Alto, CA 94303	(415) 325-2666 Recycler					X
Antifreeze Environmental Svc. Corp. 16031 E. Arrow Hwy, Unit H Irwindale, CA 91706	(818) 337-3877 Recycler				X	
Appropriate Technologies II 1700 Maxwell Road Chula Vista, CA 92011	(619) 421-1175 Processor	X	X			
Baron Blakeslee, Inc. 3596 California Street San Diego, CA 92101	(619) 295-0041 Hauler, processor, seller	X				
Baron Blakeslee, Inc. 8333 Enterprise Drive Newark, CA 94560	(415) 794-6511 Hauler, processor, seller	X				
Battery Exchange 2195 Story Road San Jose, CA 95122	(408) 251-3493 Lead-acid battery processor, 7,000 lb/month processed					X
Bayday Chemical 2096-B Walsh Avenue Santa Clara, CA 95050	(408) 727-8634 Hauler, processor	X				
Bud's Oil Service, Inc. 1340 West Lincoln Street Phoenix, AZ 85007	(602) 258-6155 Processor			X		
California Oil Recyclers, Inc. 977 Bransten Road San Carlos, CA 94070	(415) 795-4410 Processor			X	X	
Chem-Tech Systems 3650 East 26th Street Los Angeles, CA 90023	(213) 268-5056 Processor			X		

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*Source: *Hazardous Waste Reduction Checklist - Automotive Repair Shops*, pp 17-20.

Note: Names of other companies specific to each area can be obtained from trade publications, associations, and local telephone directories.

Table 29 (Cont'd)

Company and address	Telephone and services	Solvent waste	Caustic oil	Waste oil	Used antifreeze	Used batteries
Chem-Tak 1719-B Marshall Court Los Altos, CA 94022	(415) 968-1861 Equipment leasing and service company		X			
Demenno/Kerdoon 2000 North Alameda Street Compton, CA 90222	(213) 537-7100 Processor			X		
Detrex Chemical Industries 3027 Fruitland Avenue Los Angeles, CA 90058	(213) 588-9214 Hauler, processor	X				
Environmental Pacific Corp. 5258 SW Meadows Rd, Suite 120 Lake Oswego, OR 97035	(916) 989-5130, (503) 226-7331 Processor, recycler All lead batteries					X
Equipment Manufacturing Corp. 1433 Lidcombe Avenue South El Monte, CA 91733	(818) 575-1644 Hot tank and jet spray washer manufacturer		X			
Evergreen Oil 6880 Smith Avenue Newark, CA 94560	(415) 795-4400 Recycler			X		
EKOTEC 27833 Industrial Pk, Bldg 1, Unit 1 Valencia, CA 91355	(805) 257-9390 Processor, recycler			X		
Fuel Processors, Inc. P.O. Box 1407 Woodland, WA 98674	(503) 286-8352 Rerefiner			X		
Gibson Oil & Refining Co. 3121 Standard Street Bakersfield, CA 93308	(805) 327-0413 Processor			X		
GNB, Inc. - Metals Division 2700 South Indiana Street Los Angeles, CA 90023	(213) 262-1101, Lead-acid battery processor, 9,000 lbs. min, non-metallic cases					X
Hedrick Distributors, Inc. 210 Encinal Street Santa Cruz, CA 95060	(408) 427-3773 Hauler, storage			X		
Holchem/Service Chemical 1341 East Maywood Santa Ana, CA 92706	(714) 546-5890 (714) 538-4554 Processor	X				
Hot Tank Supply 3733 E. Clinton Avenue Fresno, CA 93703	(209) 229-0565 Equipment leasing and service		X			
Industrial Oils, Inc. P.O. Box 1221 Klamath Falls, OR 97601	(503) 884-4685 Rerefiner			X		
IT Corp/Vine Hill Facility 4575 Pacheco Blvd. Martinez, CA 94553	(415) 372-9100 Hauler, Processor	X	X			

Table 29 (Cont'd)

Company and address	Telephone and services	Solvent waste	Caustic oil	Waste oil	Used antifreeze	Used batteries
JJS Warehouse, Inc. 1076 Park Avenue San Jose, CA	(408) 294-9717 Solvent parts washer manufacturer	X				
Kinsbursky Bros. Supply North Lemon Street Anaheim, CA 92801	(714) 738-8516 Recycler, Spent batteries					X
Lubrication Co. of America 4212 East Pacific Way Los Angeles, CA 90223	(213) 264-1091 Hauler, processor			X		
McKesson Chemical Co. 5353 Jillson Street Commerce, CA 90040	(213) 269-9531 Hauler, Seller	X				
Nelco Oil Refining Corp. 600 West 12th Street National City, CA 92050	(619) 474-7511 Processor					
Oil and Solvent Process Co. 1704 West First Street Azusa, CA 91702	(818) 334-5117 Hauler, processor, seller	X				
Omega Chemical Company 12504 W. Whittier Blvd. Whittier, CA 90602	(213) 698-0991 Hauler, processor, seller	X				
Orange County Chemical Co. 425 Ancleason Drive Escondido, CA 92025	(619) 489-0798 Hauler, seller	X				
Orange County Chemical Co. 1230 E. Saint Gertrude Place Santa Ana, CA 92707	(714) 546-9901 Hauler, seller, processor	X				
Pacific Treatment Corp. 2190 Main Street San Diego, CA 92113	(619) 233-0863 Processor		X	X		
Pepper Oil Company, Inc. 2300 Tidelands Avenue National City, CA 92050	(619) 477-9336 Processor			X		
Petroleum Recycling Corp. 1835 East 29th Street Signal Hill, CA 90806	(213) 595-4731 Processor			X		
Plastic Materials, Inc. 3033 West Mission Road Alhambra, CA 91083	(818) 289-7979 Hauler, seller, processor	X				
Rho-Chem Corporation 425 Iris Avenue Inglewood, CA 90301	(213) 776-6233 Hauler, processor	X				
Romic Chemical Corp. 2081 Bay Road East Palo Alto, CA 94303	(415) 324-1638 Hauler, processor	X				

Table 29 (Cont'd)

Company and address	Telephone and services	Solvent waste	Caustic oil	Waste oil	Used antifreeze	Used batteries
RSR Quemetco, Inc. 720 South 7th Avenue City of Industry, CA 91746	(800) 527-9452 Lead acid battery processor					X
Safety-Kleen Corporation 777 Big Timber Rd Elgin, IL 60120	(800) 323-5740 Equipment leasing & service from locations throughout CA	X				
Safe-Way Chemical 909 Stockton Avenue San Jose, CA 95110	(408) 292-9289 Equipment leasing and service company	X	X			
SDI Company P.O. Box 835 Upland, CA 91785	(714) 982-0553 Solvent parts washer manufacturer	X				
Solvent Services 1021 Berryessa Road San Jose, CA 95113	(408) 286-6446 Hauler, processor	X				
Tanks-A-Lot 220 W. Santa Ana Anaheim, CA 92805	(714) 778-5155 Radiator flush booth manufacturer				X	
Triad Marine & Industrial Cleaning 1668 National Avenue San Diego, CA 92113	(619) 239-2024 Processor			X	X	
Van Waters and Rogers 2256 Junction Avenue San Jose, CA 95131	(408) 435-8700 Hauler, seller	X				
Van Waters and Rogers 1363 S. Bonny Beach Place Los Angeles, CA 90023	(213) 265-8123 Hauler, seller	X				

Table 30

Equipment Leasing Costs*

Equipment	Size	Approximate cost (November 1986 prices)
Solvent Sink Includes monthly leasing of solvent sink with recirculation pump, monthly maintenance service, removal of spent solvent, and replacement with fresh solvent.	11 gal of solvent with 22-gal barrel	$38/mon
	10 gal of solvent with 16-gal barrel	$33.75/mon
	10 gal of solvent with 16-gal barrel	$36.75/mon
Hot Tank Includes monthly hot tank leasing, monthly maintenance service, removal of 10 gal of solution and sludge, and recharge of solution with caustic detergent and water.	60 gal	$93/mon
Jet Spray Washer Includes monthly jet spray washer leasing, monthly maintenance service, removal of 10 gal of solution and sludge, and recharge with caustic detergent and water.	90 gal	$242/mon

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*Source: *Hazardous Waste Reduction Assessment Handbook - Automotive Repair Shops*, p 20.

Table 31

Parts Cleaning Equipment Purchase Costs*

Equipment	Size	Approximate cost (November 1986 prices)
Solvents parts washer	Small: fill/capacity = 11/22 gal or 10/16 gal	\$200 - \$300
	Large: fill/capacity = 15/30 gal or 20/30 gal	\$250 - \$400
Jet spray washer	45 gal	\$3,400
	85 gal	\$3,800
	100 gal	\$4,500
Hot tank	60 gal	\$300

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*Source: *Hazardous Waste Reduction Assessment Handbook - Automotive Repair Shops,* p 20.

Table 32

Test Criteria for Used Cleaning Solvent (PD680-II)

Rating	Absorbence (500 nm)	Specific Gravity (17°C)	Viscosity cp (18°C)	Conductivity nmho (23°C)
0	< 0.6	< 0.773	< 1.35	< 22.5
1	0.6 - 0.8	0.773 - 0.779	1.35 - 1.85	> 22.5
2	0.8 - 1.0	0.779 - 0.785	> 1.85	
3	1.0 - 1.2	> 0.785		
4	> 1.2			

Table 33

Solvent Recovery Equipment

Supplier	Model	Capacity	Temperature limits	Approximate cost*
Acra Electric Corp 3801 N. 25th Avenue Schiller Park, IL 60176 (solvent: TCE, 1,1,1-TCE,PCE,etc.)	SD-15	5 gal	--	$750
Artisan Industries 73 Pond Street Waltham, MA 02154	--	5-1440 gal/h	--	$4,000 to $1.4 million
Baron Blakesless, Inc. 2001 N. Janice Avenue Melrose Park, IL 60160 (solvents: TCE, 1,1,1-TCE, PCE)	NRS-60	45-60 gal/h	--	--
	HRS-60	45-60 gal/h	--	--
Branson Cleaning Equipment Co. Parrot Drive, P.O. Box 768 Shelton, CT 06484 *(solvents:* 1,1,1-TCE, Freon TF)	S111W	9-15 gal/h	--	--
	S121W	21-31 gal/h	--	--
Crest Ultrasonics Corporation Scotch Road Mercer County Airport Trenton, NJ 08628 (solvents: TCE, 1,1,1-TCE, PCE)	CRS-10H	10 gal/h	--	--
	CRS-10U	10 gal/h	--	--
	CRS-20H	20 gal/h	--	--
	CRS-20U	20 gal/h	--	--
DCI Corporation 5752 W. 79th Street Indianapolis, IN 46268 (solvents: chlorinated, aliphatic, aromatic fluorocarbons)	D1-DG-15	15 gal/h	--	--
Detrex Chemical Industries, Inc. P.O. Box 501 Detroit, MI 48232 (solvents: TCE, 1,1,1-TCE, Freon TF)	FC-6-EW	7-25 gal/h	--	--
	FC-6-ER	7-25 gal/h	--	--

Table 33 (Cont'd)

Supplier	Model	Capacity	Temperature limits	Approximate cost
Finish Engineering Company 921 Greengarden Road Erie, PA 16501 (814)455-4478, (415)821-4154 (Hazardous waste solvents)	LS-Jr.	3-5 gal/8h	<320 °F	$2,995
	LS-15	15 gal/8h	<320 °F	$5,895
	LS-15V	15 gal/8h	<320 °F	$9,390
Garden Machinery Corp. 700 N. Summit Avenue Charlotte, NC 28233 (Petroleum solvents and oils)	#50	50-60 gal/h	--	$4,950
Hoyt Corporation Westport, MA 02790 Hazardous waste solvents)	EP8	4-8 gal/h	<330 °F	$14,500
	EP20	<20 gal/h	<330 °F	$26,945
Interel Corporation P.O. Box 4676 Englewood, CO 80155 (solvents: chlorinated, Petroleum)	--	7.5 gal/h	--	$8,950
	--	15 gal/h	--	$11,850
Kontes Scientific Glassware/Instruments Spruce Street, P.O. Box 729 Vineland, NJ 08360	K-547100	0.8 gallons	--	$1,961
	K-547700	2.5 gallons	--	$2,723
O-I/Shott Process Systems, Inc. 1640 SW Blvd., P.O. Box T Vineland, NJ 08360	--	13.2 gallons	--	--
	--	26.4 gallons	--	--
Phillips Manufacturing Co. 7343 N. Clark Street Chicago, IL 60626	RS-1	2-5 gal/h	--	--
	RS-3	4-10 gal/h	--	--
	RS-5	6-12 gal/h	--	--
	RS-15	13-28 gal/h	--	--
	RS-20	17-37 gal/h	--	--
Progressive Recovery, Inc. P.O. Box 521 Trumbull, CT 06611 (solvents: MEK, toluene, xylene, TCE, Freon, etc.)	SC-Jr.	1-2 gal/h	<400 °F	$4,795
	SC-25	2-4 gal/h	--	$6,495
Recyclene Product, Inc. 405 Eccles Ave. South San Francisco, CA 94080 (415)589-9600	R-2	5 gal/4h	<375 °F	$2,495
	RS-20	5-7 gal/h (1)	<375 °F	$11,000
	RS-35AF	6-8 gal/h (2)	<375 °F	$21,000
	RX-35AF	12-16 gal/h (2)	<375 °F	$25,850
Unique Industries, Inc. 11544 Sheldon Street Sun Valley, CA 91353 (solvents: chlorinated and fluorinated)	1100-10W	12 gal/h	--	
	1100-10RW	12 gal/h	--	$5,270
	1100-10RA	12 gal/h	--	$8,250
				$8,600

Table 34

Aqueous Waste Volume Reduction Equipment Suppliers[*]

Supplier	Model	Capacity	Approximate Cost
EMC Manufacturing 1433 Lidcombe Ave. El Monte, CA 91733 (818) 575-1644	EVAP-85E	85 gallons	$ 1995
Nordale Fluid Eliminator 990 Xylite Ave., N.E. Minneapolis, MN 55434 (603) 658-7111 (714) 885-0691	FE-150	150 gallons	$ 8000 - $13,000
Wastewater Treatment Systems 440 N. Central Ave. Campbell, CA 95008 (408) 374-3030	BM-50	50 gallons	$15,000 - $18,000

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[*] Source: *Hazardous Waste Reduction Asessment Handbook - Automotive Repair Shops*, p 22.

6 WASTE MINIMIZATION FOR INDUSTRIAL MAINTENANCE, SMALL ARMS SHOPS

Most of the hazardous wastes generated from IMSS operations can be categorized as corrosive wastes (acids and alkalis), spent solvents, paint stripping wastes, and wastes containing toxic metals. The operations that generate these wastes include: equipment and vehicle repair, metal cleaning, surface preparation, and metal finishing. A summary of processes, wastes generated, and DOT classifications are listed in Table 35. The minimization options for vehicle maintenance repair wastes are discussed in Chapter 5.

Chlorinated or nonchlorinated solvents are commonly used to clean or degrease parts before repair, rebuilding, or finishing. Nonchlorinated solvents (e.g., petroleum distillates) are normally used in cold cleaning operations using solvent sinks or dip tanks. Chlorinated solvents such as TCE, 1,1,1-trichloroethane, methylene chloride (MC), and perchloroethane (PC), are used in vapor degreasers, where condensing solvent vapors remove the grease, oil, or wax from the dirty parts. 1,1,1-trichloroethane is the safest of these four solvents and is the most commonly used. Of the several different vapor degreasers commercially available, the open top vapor degreasers are the most common at Army installations. In such a vapor degreaser, the heater coils at the bottom of a tank boil nonflammable solvent. The solvent vapors that are denser than air, displace the air and form a vapor zone. A condensing coil at the top of the tank prevents the vapors from escaping from the open top. The parts are lowered into the vapor zone and pure solvent vapors condense on them and solubilize the soil and grease. The solvent drips off or evaporates as the parts are removed after they are cleaned. The soil accumulates at the bottom of the tank. This contaminates the solvent which has to be changed periodically. Also, because the solvent evaporates, fresh solvent must be added frequently.

Cleaning with caustic compounds or detergents also occurs at IMSS operations. Cleaning is usually followed by surface preparation such as painting or scale stripping. Sand, glass, or shot blasting are common methods of removing paint or scale. In some cases, paint stripping is accomplished with solvent (MC) or caustic strippers.

Metal finishing operations, such as surface finishing of small arms, and metalworking, such as cutting and threading are also common at IMSS. A small arms shop conducts weapons rebuilding on many types of small arms. Chemicals such as chromic acid, phosphoric acid, etc., are used. Manganese phosphate coatings are the most common surface finishing treatments used on small arms components. The phosphate coating is dull black and provides wear resistance to the cast iron/steel surfaces. The first step in the process is to clean the parts. The methods include: vapor degreasing or alkali cleaning, blasting with sand/walnut shells, self-emulsified solvent treatment, and phosphoric acid-solvent-detergent cleaning. The parts are then rinsed in water and coated with phosphate. The parts are rinsed in water immediately after the phosphate coating. The next step is to use a hot oil conditioning rinse and then dry the coated and rinsed surfaces. Any supplementary coatings are then applied.[73] The typical coating time is 15 to 40 minutes. The phosphate immersion coating bath is maintained between 200 and 210 °F. The phosphate tank and heating elements are usually made of acid-resistant material. Some of the equipment used in the immersion coating process include: conveying equipment, if necessary; work-supporting equipment such as hooks, racks, baskets, and tumbling barrels; tanks associated with water and heat (steam or electricity); a drain to the sewer line; ventilation equipment; and drying equipment such as ovens, air heaters, fans, and compressors.[74] The

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[73] A. Douty and E.A. Stockbower, "Surface Protection and Finishing Treatments - A. Phosphate Coating Processes," revised by W.C. Jones, in *Electroplating Engineering Handbook*, Fourth Edition, L.J. Durney, Ed. (Van Nostrand Reinhold Co., 1984), pp 366-390.

[74] A. Douty and E.A. Stockbower.

operator of the small arms shop must account for all materials used in the process. The potential for severe environmental hazards exists in the operation of a small arms shop.

The metalworking operations in IMSS use petroleum and synthetic oils and small quantities of solvents in cleaning, cutting, and threading metallic pipes and other surfaces. Used oil and waste solvents are commonly generated. Painting vehicles, equipment, and parts is also conducted by IMSS. The minimization options for painting and surface coating are discussed in Chapter 7.

The five major categories of processes, relevant to Fort Carson, considered for discussion in this chapter are: solvent cleaning, alkaline cleaning, dry media blasting, and cutting and threading.

Source Reduction - Solvent Cleaning

PC/MC/TCE - Product Substitution

If PC, MC, or TCE are still being used in vapor degreasing, 1,1,1-trichloroethane should be substituted. The hazards associated with it are much less than those with PC, MC, or TCE. It also has a higher threshold limit value (TLV, 350 ppm), in terms of worker safety, than PC (100 ppm) and TCE (100 ppm). Although MC has a higher TLV (500 ppm), it is a known carcinogen.[75]

TCE/PC/1,1,1-Trichloroethane - Better Operating Practices - Testing

Solvents are replaced in a vapor degreasing tank based on the operator's perception of its contamination or "dirtiness." A more scientific methodology must be used to determine a solvent's "solvation" power and cleaning efficiency. Chlorinated solvents have physicochemical and electrical properties that can be used to determine this capacity.[76]

A combination of tests including visible absorbence, viscosity, conductivity, and acid acceptance value (AAV), must be used to determine if a solvent is spent based on recommended scores listed in Tables 36, 37, and 38. If the solvent has a score of six or more, it is ready for reclamation disposal. Among all the tests, AAV is the most important because it determines the concentration of amine and alpha epoxide inhibitors left in the solvent. A standard titration procedure,[77] reacting the solution with excess hydrochloric acid which in turn is neutralized with sodium hydroxide, is used to measure the total AAV. Direct measurement instruments (UV/visible Spectrophotometer, Ostwald viscometer, and Conductivity meter) are available for the other tests. Eventually solvent test kits will be available for use at Army installations.[78] With continued use of the testing procedures, more accurate scores can be developed and substituted for those suggested in Tables 36, 37, and 38.

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[75] Technical Note 86-2, *Solvent Minimization and Substitution Guidelines* (Facilities Engineering Division, U.S. Army, Office of the Chief of Engineers Washington, D.C., 1986), 18 pp.

[76] B.A. Donahue, et al., *Used Solvent Testing and Reclamation, Volume II: Vapor Degreasing and Precision Cleaning Solvents*, Technical Report N-89/03/ADA204732 (USACERL, December 1988).

[77] ASTM Standard D 2942-86, "Standard Test Method for Total Acid Acceptance for Halogenated Organic Solvents (Nonreflux Methods)," *Annual Book of American Society of Testing and Materials Standards*, Vol 15.05 (1988).

[78] A.R. Tarrer, Personal Communication (Auburn University Department of Chemical Engineering, Auburn, Alabama).

1,1,1-Trichloroethane - Better Operating Practices - Aluminum Scratch Test

A standard method[79] is available to qualitatively determine the amount of inhibitor present in 1,1,1-trichloroethane to prevent its degradation in the presence of aluminum or aluminum alloys. This test determines the stability of the solvent being used in a degreaser and also that of recycled material.

In this test, a cleaned/degreased aluminum coupon is immersed in inhibited 1,1,1-trichloroethane and scratched. Allowing sufficient time to elapse for a reaction to occur, the formation of dark resinous ("blood"-like) material, bubbling, and discoloration is noted. If the solvent is sufficiently inhibited, no reaction takes place. The reaction can be categorized into four groups: (1) no reaction; (2) bleeds but heals, no solvent discoloration; (3) bleeds but heals, solvent discoloration; and (4) bleeds with no healing. By continued use of this test method over a period of time, a site-specific semiqualitative procedure can be developed for determining when 1,1,1-trichloroethane is "spent" and should be recycled or disposed of.

1,1,1-Trichloroethane - Better Operating Practices - Emissions Minimization

Reducing air emissions is probably the most significant good operating practice in terms of reducing hazardous wastes released to the environment. Proper covers should be installed and used for both cold cleaning and vapor degreasing operations. The use of covers on vapor degreasing vats has been shown to result in a 24 to 50 percent reduction in solvent losses.[80] Boiling of solvent increases emissions by 81 percent as compared to covered-top vapor degreasers.[81] Standard guidelines[82] must be established to help minimize emissions from vapor degreasers that will reduce the hazards to workers, optimize system performance, and conserve material.

Other methods of reducing emissions from vapor degreasers include: increasing freeboard height (0.75 times or greater than the degreaser width); limiting hoist system speed to less than 11 ft/min; limiting the load's cross-sectional area to less than 0.5 times that of the degreaser width; installing a freeboard chiller with a minimum capacity of 100 Btu/hour/feet of perimeter coil; removing the load only when the liquid runoff has stopped; and protecting the degreaser from drafts, air currents, and excessively high velocity exhaust ducts.[83]

1,1,1-Trichloroethane - Better Operating Practices - Material Conservation

Proper handling is required for empty containers that contain residual quantities of 1,1,1-trichloroethane. They must be triple rinsed before disposal or use. The rinsing process generates a large quantity waste stream that requires proper treatment before drainage to a treatment plant. Purchasing 1,1,1-trichloroethane in minibulk (e.g., 55-gal drums) rather than large containers (e.g., tankers) is a good practice. After purchase it must be stored in containers of 230 gallons or less. Material transfer carts specifically designed for transfer from storage tanks to vapor degreasers must be dedicated for that use only. Cross-contamination may thus be prevented.

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[79] ASTM Standard D 2943-86, "Standard Method of Aluminum Scratch Test for 1,1,1-Trichloroethane," *Annual Book of American Society of Testing and Materials Standards*, Vol. 15.05 (1988).

[80] ICF Consulting Associates, Inc., *Guide to Solvent Waste Reduction Alternatives*, Final Report (Prepared for the California Department of Health Services, Sacramento, CA, 1986), pp 4-8 - 4-9.

[81] *Solvent Minimization and Substitution Guidelines.*

[82] ASTM Standard D 3640 80, "Standard Guidelines for Emission Control in Solvent Metal-Cleaning Systems," *Annual Book of American Society of Testing and Materials Standards*, Vol 15.05 (1988).

[83] ASTM Standard D 3640-80.

1,1,1-Trichloroethane - Better Operating Practices - Material Transfer and Storage

Sometimes stored new products may be cross-contaminated, making them unusable. This contamination is caused by using transfer equipment such as solvent pumps on drums containing several different products.

Degradable hazardous materials must not be stored in areas that are overheated. Also, contamination from the other materials present must be avoided. Hazardous material handlers must be trained in proper handling and storage of hazardous materials.

1,1,1-Trichloroethane - Better Operating Practices - Chemical Purchase

The purchase of new solvents must be controlled by proper inventory management. Overstocking must be avoided. The material safety data sheets that accompany new products must be reviewed to ensure worker safety and minimize environmental pollution.

1,1,1-Trichloroethane - Better Operating Practices - Operator Handling

The operators must be trained in the proper use of degreasers. The training must include not only the health and safety aspects, but also efficient use and proper waste handling/disposal. Training the operators in process control, proper equipment use, and handling, increases the performance efficiency and minimizes the wastes generated. Standard operating procedures must be written to include the above considerations.

1,1,1-Trichloroethane - Product Substitution - Aqueous Cleaners

Aqueous cleaners that are possible substitutes for chlorinated solvents are commercially available.[84] The advantages of substituting aqueous cleaners for solvents include minimizing the exposure of workers to solvent vapors, and reduced liability and disposal costs. Since aqueous cleaners are usually biodegradable, the wastewaters produced can be discharged directly to a wastewater treatment plant for further treatment--no disposal of used solvents is required. Substituting aqueous cleaners for solvents will require additional cleaning steps and equipment to achieve the same cleaning performance. Some of the aqueous solvents, that have been determined to be possible substitutes for chlorinated solvents, are listed in Table 39.

One disadvantage of aqueous cleaners is that they are generally more corrosive. Tanks liners must be installed to prevent excessive corrosion. This may present a problem for open top vapor degreasers with baffles and heating coils. Noncorrosive cleaners typically do not possess the necessary cleaning power required. Aqueous cleaners also require agitation to work properly; installation of a circulating pump or ultrasonic agitator is often required. Furthermore, aqueous cleaners leave metals wet after cleaning. Parts must be blow dried to guard against rust. Particular problems have been noted in cleaning galvanized metal which corroded appreciably when aqueous cleaning solutions were used. Finally, oil removed from parts during cleaning will typically float on top of aqueous cleaning solutions and must be skimmed by an internally floating oil skimming pump or a small external pump and hydrocyclone which continuously cleans the aqueous cleaner and returns it to the tank.[85]

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[84] J.M. Beller, et al., *Biodegradable Solvent Substitution - A Quick Look Report* (U.S. Air Force Logistics Command, 1988).

[85] ICF Consulting Associates, Inc.

1,1,1-Trichloroethane - Process Change - Ultrasonic Cleaning

Using an ultrasonic cleaning process instead of vapor degreasing will eliminate the problems associated with wastes management. Ultrasonic cleaners use high frequency sound to discharge fine particles attached to surfaces. Further treatment of the aqueous waste stream may be required, depending on the concentration of toxic contaminants in solution. Additional information about ultrasonic equipment can be obtained from manufacturers (e.g., Crest Ultrasonics Corporation, (609) 883-4000).

1,1,1-Trichloroethane - Process Change - Process Controls

Unnecessary changes of solvents from degreaser tanks must be avoided. A method of determining the need to change the solvent is to measure the vapor boiling temperature of the contaminated solvent. Solvent suppliers provide information about the boiling temperature range for all solvents. When a high temperature is reached, the cleaning efficiency of the solvent is minimum and a change is recommended. Other testing methodologies were mentioned above.

Controlling movement of parts in and out of the vapor degreaser (to less than 11 ft/min) can also be viewed as a process control technique that minimizes solvent dragout and emissions.[86] Speed control equipment (governors) must be used to allow for adequate draining time, and cooling and condesation of solvent in the chilling zone.

Vapor degreasers must not be used as drying chambers for parts that have been cleaned and rinsed with water. The wet parts introduce water into the solvent decreasing its useful life. The water may also react with 1,1,1-trichloroethane to form hydrochloric acid that corrodes equipment and contaminates the solvent. Use of water separators can extend the life of the solvent.

Recycling Onsite/Offsite - Solvent Cleaning

1,1,1-Trichloroethane - Onsite Recycling - Closed-Loop Distillation

A closed-loop distillation system must be designed and used to recover 1,1,1-trichloroethane from vapor degreasers. Solution from the vapor degreasing tank is pumped into a distillation still and the pure 1,1,1-trichloroethane is pumped back into the tank after the recovery process. Adding inhibitors will be required. The still bottoms from the distillation process have to be disposed of as a hazardous waste. A list of manufacturers of distillation equipment is provided in Table 33. In addition to recycling of solvent, this process also segregates 1,1,1-trichloroethane from other wastes, thus preventing cross-contamination with other cleaning wastes.

1,1,1-Trichloroethane - Onsite Recycling - Degreaser

In small degreasing operations, the vapor degreaser can be used part time for distillation. This is accomplished by diverting the vapor-return-to-sump line to a separate holding tank. The level of the "spent" solvent to be distilled must always exceed the level of heating coils. Usually this operation is undertaken during periods of slow workload or during off-hours.

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[86] ASTM Standard D 3640-80.

Treatment - Solvent Cleaning

1,1,1-Trichloroethane - Onsite Treatment - Filtration

Filtration devices, when used in a vapor degreasing operation, remove particles and thus extend the life of the solvent and reduce cleaning frequency. Equipment suppliers (e.g., Motor Guard Corporation, 415/569-9766) must be contacted to obtain additional information about filtration equipment.

1,1,1-Trichloroethane - Onsite Treatment - Freeze Crystallization

Freeze crystallization is a treatment process that selectively crystallizes certain components from waste solvent. The crystals can then be filtered and disposed of separately. A flow rate of 0.25 gal/min is required[87] for continuous operation of freeze crystallization equipment (e.g., Heist Engineering Corporation, 415/283-8121). Dissimilar metals may thus be removed from waste solvent. This treatment process must be designed on a case-by-case basis.

1,1,1-Trichloroethane - Offsite Treatment

Methods that solvent recyclers use for recovery of solvents include: distillation, solvent extraction, and ultrafiltration. A list of solvent recyclers is provided in Table 29. Thermal destruction of contaminated solvent in a hazardous waste incinerator for energy recovery is also a common treatment technique.

Treatment - Alkaline Cleaning

Caustic Wastes - Onsite Treatment

Cleaning of metal substrate using alkaline cleaners generates a corrosive waste that must be neutralized. In addition to neutralization, removing grease and heavy metals may also be necessary. Batch treatment units are commercially available. A precipitation/neutralization system can also be designed for onsite use. Sludge collected on the bottom of the treatment tank must be tested for hazard characteristics and disposed of properly.

Source Reduction - Dry Media Blasting

Dry Wastes - Product Substitution - Plastic Media Blasting

Plastic media blasting (PMB) is a relatively new method to remove paint and rust from a variety of metallic and alloy substrates such as aluminum, steel, titanium, copper, and zinc. It is a good substitute for organic chemical stripping (using mixtures of MC and other toxic compounds) and abrasive blasting with sand, glass beads, or agricultural media (walnut shells, rice hulls, corn cobs, etc.).

Agricultural media blasting has several drawbacks such as high explosion potential, poor paint/rust removal, high contamination, low recycle rate, and generation of large quantities of wastes. Comparatively, sand and glass beads are better for blast cleaning because of good performance and low

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[87] Fred C. Hart Associates, *Aerospace Waste Minimization Report* (Prepared for the California Department of Health Services and Northrop Corporation, CA, 1987).

explosion potential, however they also have a very low recycle rate. Some of the advantages of PMB are: (1) it is aggressive and requires less operating time (compared to agricultural media only); (2) the plastic maintains its size and hardness; (3) the plastic does not break up and thus can be recycled 10 to 20 times,[88] resulting in lower replacement and disposal costs; and (4) overall, the method is economically favorable.

PMB is slower than sand or glass bead blasting, however it produces a better quality finish. Also, the amount of waste produced in PMB is greatly reduced because most of the media can be recycled many times. Assuming a labor rate of $15/h and a media recycle rate of 90 percent, the costs of sand blasting and PMB are $0.62 and $0.36/sq ft, respectively.[89]

Suppliers of plastic media including: Aerolyte Systems, 1657 Rollins Rd., Burlingame, CA 94010, (415) 570-6000; E.I. du Pont de Nemours & Co., Inc., Fabricated Products Dept., Wilmington, DE 19898, (800) 441-7515; and U.S. Blast Cleaning Media, 328 Kennedy Drive, Putnam, CT 06260. The price of plastic media (available on a GSA contract, 1988 prices) ranges from $1.75 to $2.50 per pound.

Dry Wastes - Process Change - Plastic Media Blasting

Existing abrasive blasting machines can be replaced with more efficient plastic media blasting machines. A number of companies manufacture PMB machines; however, design consultants must be retained to design specific applications. Two types of PMB machines are available: cabinets and open blast systems. Cabinet systems are very similar to the conventional abrasive blasting machines. The most commonly used cabinet has an opening that measures about 5 ft by 4 ft. Small open blast systems are portable and self-contained.

Source Reduction - Cutting and Threading

Cooling/Cutting Oils - Better Operating Practices - Material Conservation

The application of cooling/cutting oils in metalworking must be limited to the area that has to be cooled without using it in excess. Efficient applicators or directional delivery systems, if used, can reduce the amount of coolant delivered to a surface. This efficient use extends the life of oils and minimizes the amount of oil purchased and wastes generated.

Cooling/Cutting Oils - Better Operating Practices - Proper Concentration Maintenance

The coolant performance depends on maintaining the proper coolant to water ratio. Accurate measurements of the concentrations can be obtained by using refractometers. Also, coolant proportioning devices are available to ensure accurate mixing. Specific information on coolant maintenance must be obtained from the manufacturer; the recommendations must be followed.

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[88] J. Gardner, *Dry Paint Stripping Utilizing Plastic Media: A New Solution to an Old Problem*, Technical Bulletin (Clemco Industries, 1987).

[89] C.H. Darvin and R.C. Wilmoth, *Technical, Environmental, and Economic Evaluation of Plastic Media Blasting for Paint Stripping*, EPA/600/D-87/028 (U.S. Environmental Protection Agency [USEPA], Water Engineering Research Laboratory, 1987); J.B. Mount, et al., *Economic Analysis of Hazardous Waste Minimization Alternatives*, Draft Technical Report (USACERL, 1989).

Cooling/Cutting Oils - Better Operating Practices - Proper Storage

Water soluble oils can be stored easily. Proper storage avoids deterioration by biodegradation. The manufacturer's storage recommendations must be followed.

Cooling/Cutting Oils - Better Operating Practices - Operator Handling/Segregation

The operators of metalworking equipment must be cautioned about minimal use of coolant. They should also be trained about the hazards of mixing oils and chlorinated/nonchlorinated solvents and the associated disposal problems.

Cooling/Cutting Oils - Better Operating Practices - Chemical Purchase

When purchasing oils, screen them for undesirable hazardous components. If such information is not available in the manufacturers' Material Safety Data Sheets (MSDSs), testing may be required.

Cooling/Cutting Oils - Better Operating Practices - Metal Chips Removal

Metal chips that accumulate in a coolant must be removed frequently. They interfere with the machine's performance and serve as a site for bacterial growth. Filter screens, when placed at the entrance to the sump and at the exit from the holding trays, can prevent chips from entering the sump. The chips can then be vacuumed from the screens.

Cooling/Cutting Oils - Product Substitution

Several different brands of water soluble oils are available. Some of them contain small amounts of hazardous materials such as cresol (< 1 percent). Only those oils that do not contain hazardous materials can be purchased.

Cooling/Cutting Oils - Process Change - Equipment Modifications

Worn equipment must be repaired or replaced to optimize performance and minimize waste generation (e.g., leaks). Older models should be replaced with automated equipment.

Adding skimmers (belts or disks) to remove "tramp" petroleum oil from the cooling/cutting oils can minimize the quantities of mixed wastes produced. These skimmers must be placed near the sump containing the coolant. Timers are also available to control equipment operation and to ensure that the quantities of coolant removed with the oil are minimal.[90]

Cooling/Cutting Oils - Process Change - Process Controls

The loss of cooling/cutting oils during metalworking operations must be minimized. Adding splash guards or drip trays allows the excess oils to be collected and possibly recycled/reused. Splash guards and drip trays can also be used to contain spills in the machining areas, thus reducing the use of adsorbent material (e.g., DRY-SWEEP) and wastes generated.

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[90] *Prolonging Machine Coolant Life*, Fact Sheet (Minnesota Technical Assistance Program, Minneapolis, MN, 1988).

Cooling/Cutting Oils - Process Change - Control Bacterial Growth

Bacterial growth in coolants can be controlled by: cleaning the sump whenever the coolant is replaced, using biocides, adjusting the pH, and adequately circulating the coolant.[91] The sump must be cleaned with steam or chemicals. In some cases, its design may have to be modified to provide sufficient access for cleaning tools.

When using biocides to control bacterial growth, it is important to realize the "ultimate" treatment or fate of the coolant. Bacterial test kits must be used to determine the exact amount of biocide to be added. The use of biocides can be minimized by proper pH control. Bacterial growth decreases the pH of the coolant. Measuring the pH (with a pH meter or litmus paper) and adjusting it (with caustic soda) to the manufacturer's recommended level can control bacterial growth. It is also necessary to maintain proper circulation of the coolant to ensure an oxygen enriched environment in the sump. A mixer or an agitator can be used for this.

Treatment - Cutting and Threading

Cooling/Cutting Oils - Onsite Treatment

Fine particles in oils, such as metal cuttings, can be removed in a pretreatment step by using a centrifuge. Batch centrifuges are available for small metalworking equipment. Large continuous centrifuges are available for removing particles from oils generated continuously in large volumes.

Mobile treatment services are provided by some companies to generators that produce large quantities of water soluble oils. The cost for such a service depends on the volume of oil and the concentration of contaminants.

Another physical treatment technique is ultrafiltration to remove fine particles. About 90 percent of the water fraction can be extracted and discharged directly to the sewer system.[92] The oil recovered is high quality and can be recycled.

Epsom salts (magnesium sulfate) can be used to reduce volume by precipitation and separation before disposal. However, this method is less efficient than other volume reduction techniques available.

To reuse water soluble oils, it is necessary to treat them by pasteurization followed by filtration. The biological contamination accumulated during use can thus be removed. The blend ratio of recycled oil to new oil is determined before use with a refractometer.

Cooling/Cutting Oils - Offsite Treatment

Several offsite treatment and recovery techniques are available for cutting/cooling oils, including ultrafiltration, evaporation, and thermal destruction by incineration. The choice of a method depends on the volume of wastes and their physical/chemical state.

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[91] *Prolonging Machine Coolant Life.*

[92] Fred C. Hart Associates, *Aerospace Waste Minimization Report* (California Department of Health Services, 1987).

Table 35

Waste Classification for IMSS

Process Description		Waste Description			
Process/operation	**Materials used wastes produced**	**HW code**	**DOT shipping name**	**Hazard class**	**Number**
Degreasing metal surfaces/parts and other metal surface preparation	Caustic soda	D002	Waste sodium Hydroxide solution	Corrosive material	UN1824
	Chlorinated solvents	F001	Waste (main ingredient)	ORM-A	Varies
	Freon	F001	Hazardous waste liquid, NOS	ORM-A	UN9189
	Ignitable (flammable) degreasers	D001	Waste flammable liquid, NOS	Flammable liquid	UN1993
	MEK	F005	Waste methylethylketone	Flammable liquid	UN1193
	Methylene chloride	F001	Waste methylene chloride	ORM-A	UN1593
	Mineral spirits solvents	D001	Waste naptha	Flammable liquid	UN2553
	Petroleum naptha	D001	Waste naptha	Flammable liquid	UN1255
	Petroleum distillates	D001	Waste petroleum distillate	Flammable liquid	UN1268
	1,1,1-trichloroethane	F001	Waste 1,1,1-trichloroethane	ORM-A	UN2831
	Trichloroethylene	F001	Waste trichloroethylene	ORM-A	UN1710
Metal finishing (including etching)	Spent acid solutions	D002	Waste chromic acid solution	Corrosive material	UN1755
	Chromic solutions	D002	Waste hydrochloric acid	Corrosive material	NA1789
	Hydrochloric solutions	D002	Waste nitric acid > 40%	Oxidizer	UN2031
	Nitric stripping solutions	D002	Waste nitric acid < 40%	Corrosive material	NA1760
	Phosphoric solutions	D002	Waste phosphoric acid	Corrosive material	UN1805
	Sulfuric solutions	D002	Waste sulfuric acid	Corrosive material	UN1832
Surface preparation	Acetone	F003	Waste acetone	Flammable liquid	UN1090
	Alcohols	D001	Waste alcohol, NOS	Flammable liquid	UN1987
	Caustic paint stripper	D002	Waste paint related material	Corrosive material	NA1760
	Methylene chloride stripper	F002	Waste methylene chloride	ORM-A	UN1593
	Mineral spirits	D001	Waste naptha	Flammable liquid	UN2553
				Flammable liquid	UN1263
Metalworking	Used oils (not manifested)	None	Waste petroleum oil, NOS	Combustible liquid	NA1270
	Spent solvents		Varies	Varies	Varies

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* Source: *Metal Manufacturing and Finishing*, Hazardous Waste Fact Sheet (Small Quantity Generators Activity Group, Minnesota Technical Assistance Program, Minneapolis, MN, 1987).

Table 36

Test Criteria for Trichloroethylene

Rating	Acid Acceptance Value (wt percent NaOH)	Absorbence (450 nm)	Viscosity (cp)	Conductivity (nanomho/cm)
0	>0.06	<0.50	0.57	> 27.0
1	--	0.50-0.67	0.571-0.590	27.0-24.0
2	--	0.68-0.84	0.591-0.600	23.9-20.0
3	--	0.85-1.00	>0.600	<20.0
4	0.06-0.03	>1.00	--	--
6	<0.03	--	--	--

Table 37

Test Criteria for Perchloroethylene

Rating	Acid Acceptance Value (wt percent NaOH)	Absorbence (500 nm)	Viscosity (cp)	Conductivity (nanomho/cm)
0	>0.06	<0.18	0.75	>29.4
1	--	0.18-0.42	0.76-0.77	29.4-26.7
2	--	0.43-0.66	0.78-0.80	26.6-24.0
3	--	0.67-0.90	>0.80	<24.0
4	0.06-0.03	>0.90	--	--
6	<0.03	--	--	--

Table 38

Test Criteria for 1,1,1-Trichloroethane

Rating	Acid Acceptance Value (wt percent NaOH)	Absorbence (400 nm)	Conductivity (nanomho/cm)
0	>0.06	<0.98	>22.7
1	--	0.980-0.986	22.7-21.1
2	--	0.987-0.994	21.0-19.5
3	--	0.995-1.00	<19.5
4	0.06-0.03	>1.00	--
6	<0.03	--	--

Table 39

Aqueous Solvents and Suppliers

Solvent	Supplier
Safety Solvent Degreaser	Bio-Tek Inc.
Exxate 1000, Exxate 1300, Exxate 600, Exxate 700, Exxate 800, Exxate 900	Exxon Chemical Co.
Desolve-It	Orange-Sol Inc.

7 WASTE MINIMIZATION FOR PAINT SHOPS

Paints are applied to metal or other surfaces (e.g., wood) for waterproofing, flameproofing, rustproofing, insulating, etc. There are three different categories of paints: architectural, original equipment manufacture (OEM), and special purpose. Architectural paints are used on buildings. OEM paints are used in industries that manufacture automobiles, appliances, and furniture.[93] Special purpose paints such as chemical agent resistant coating are used in maintenance operations in some industries, the armed services, and highways' maintenance. Forty-four percent of the special purpose coatings are used on automobiles, 18 percent in industrial maintenance, and the remaining distributed between aerosols, traffic paints, and other categories.[94]

The painting process involves: paint stripping and surface preparation, application of the paint, and curing. Paint stripping (using wet or dry techniques) and surface preparation are necessary to clean the substrate and prepare it for adhesion of the paint. Paint is then applied to the surface. The method used depends on the size, shape, complexity, and number of items. After painting, the items are placed in a curing oven to remove excess solvent and make the coating uniform. Some of the common painting techniques are: dip painting, flow painting, roll painting, curtain painting, spray painting, and bulk painting. Spray painting is the most commonly used technique and can be manual or automatic. Spray painting techniques (including conventional pressure/air atomized, and electrostatic centrifugal/air atomized) have transfer efficiencies that range from 30 to 95 percent. The overspray from the paint application process can be as high as 50 to 70 percent, and is in most cases collected and disposed of. The method of painting may sometimes be dictated by the type of paint formulation (e.g., water-based enamels cannot be sprayed).

Most paint formulations use solvents as carriers for binders such as pigments, powders, and adhesives. The solvent content can vary from 1 to 85 percent. Typical solvents include: acetone, n-butanol, o-dichlorobenzene, diethyl ether, ethyl acetate, butanol, MEK, methyl isobutyl ketone, MC, 1,1,1-trichloroethane, trichlorofluoro-methane, tetrahydrofuran, cyclohexanone, and petroleum derivatives such as naptha, xylene, toluene, or hexane. Powder or water-based paints do not contain solvents. Solvent-based paints (e.g., acrylic lacquers) have the advantage of durability, fast drying time, low corrosivity to substrate, and high gloss finish.[95] Some of the disadvantages include: emission control problems; worker exposure hazards; fire hazards; and waste management, disposal, and liability problems. The criteria used in choosing a solvent depends on the type of paint required, drying speed, the nature of the substrate, and the properties of the solvent.

In addition to the wastes from the painting process, large quantities of solvent wastes are generated during equipment cleaning. Table 40 describes the wastes generated from the painting process and lists the corresponding DOT classifications.

Source Reduction

Solvent-Based Paints - Product Substitution - Powder Coatings

Powder coating is an effective alternative to solvent-based paints. In a powder coating process, the paint powder is applied to a substrate with an electrostatic spray gun. The carrier is pressurized air, rather than solvents. The powder coating adheres to the surface because of electrostatic forces. Excess powder that does not cling to the surface can be recycled. Heating in the curing oven ensures

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[93] ICF Associates, Inc.

[94] P.L. Layman, "Paints and Coatings: the Global Challenge," *Chemical and Engineering News* (September 30, 1985), pp 27-68.

[95] ICF Associates, Inc.

that the powder fuses to the surface. Powder coatings can also be applied using a fluidized bed process where the heated objects are immersed in the fluidized bed.

Because powder coatings contain no solvents, emissions of volatile organic compounds and the related air pollution problems are eliminated. Fire hazard and insurance rates are reduced and better neighborhood relations develop as the odor associated with solvent-based application are eliminated. Preliminary toxicological studies indicate that many of the commercial powder formulations are nontoxic. Since the overspray powder can be recycled, material use is high and solid waste generation is minimal. Waste disposal and liability problems are reduced. The process also has a high transfer efficiency, resulting in a lower reject ratio of parts. Coating quality is claimed to be better than with solvent-based coating. The messy cleanup operations associated with liquid-based paints are avoided. Powder coating is easier to apply and it is easier to train people to use it. The operators' attitudes improve. The operation is less labor intensive. Maintenance is easier and the overall operating costs are lower. Powder costs are minimally affected by petroleum prices and the operation is more flexible to changing coating requirements.

However, powder application equipment is more expensive to install than solvent-based or high solids coating equipment. Another disadvantage is that powder coating must be done at elevated temperatures. It is not usable on heat sensitive substrates such as plastics, wood, and assemblies containing nonmetal parts. Formulations with lower cure temperatures (275 °F) are being developed.[96]

Solvent-Based Paints - Product Substitution - Water-Based Formulations

Water-based formulations reduce the amount of solvents used and emitted in the coating process. Solvent-based paint equipment can easily be modified to apply water-based paints/coatings. The paint overspray can easily be collected with water in the spray booth and recycled. Though this can also be done in a solvent-based process, a difficult-to-treat aqueous waste stream may result due to direct contact with the solvent. Disposal and liability issues associated with wastes from the solvent-based formulation are reduced and the fire and explosion hazards present with the solvent-based process are eliminated. Concerns about worker exposure to solvents are also eliminated. Energy savings can be achieved by recirculating hot air in the ovens used to cure the paint. Similar recirculation is not possible in a solvent-based operation as the solvent levels in the recirculated air may reach explosive levels. The installed capital cost of water-based units is lower than that for high solids or powder coating.[97]

A number of private companies and a naval installation (Naval Air Rework Facility, Pensacola, Florida) have successfully converted from solvent-based painting to a water-based painting operation.[98] Based on their experience, the annual cost to coat using water-based coating was higher compared to conventional solvent, high solids, or powder coating. The applied coating cost per square foot for a water-based unit is also higher and the coating may be inferior. The quality of water-based coatings varies with ambient conditions such as room temperature and humidity. The drying time is longer and could be a bottleneck in the production line. It may necessitate installating a drying unit. Surface treatment procedures may need extensive modification to convert to a water-based coating method.[99]

One company that unsuccessfully tried to convert to water-based painting reported that the increased drying time led to production scheduling problems. The new system took several hours for drying, compared to the 30 minutes required for the solvent based process. It required an increased amount of surface cleaning before the water-based coating could be applied. The time and cost

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[96] ICF Associates, Inc.

[97] ICF Associates, Inc.

[98] ICF Associates, Inc.

[99] ICF Associates, Inc.

involved in the extra cleaning were prohibitive. The water coating did not have the same hardness, durability, or gloss and the quality of the water-based paint varied with room temperature and humidity. The company also reported that the water environment was corrosive to galvanized steel. The existing equipment made of galvanized steel needed to be replaced with stainless steel, which involved considerable expense.[100]

Solvent-Based Paints - Product Substitution - Two-Component Catalyzed Coatings

Two-component catalyzed coatings are comprised of isocyanates (highly toxic compounds) and hydroxyl compounds. These compounds polymerize on a surface to form a polyurethane coating. Their use has been extensively investigated by the automobile industry.[101] Substituting two-component catalyzed coatings for solvent-based formulations is not justified because of the toxicity of the components.

Solvent-Based Paints - Product Substitution - Radiation-Curable Coatings

Radiation-curable coatings do not contain solvents and therefore could be good substitutes. A liquid prepolymer is allowed to react with a thinner under ultraviolet light to form a coating. These coatings have been found to be effective on a number of surfaces.[102]

Paint Wastes - Better Operating Practices - Segregation

The current practice for disposing of residual paint left in cans is to pour it into drums containing thinner wastes. However, segregating paints from thinner wastes maintains the purity of the thinner and improves its recyclability. Thinners can be recycled onsite or offsite and reused in painting and cleaning processes.

Excess paints should be given to customers for touchup use, thus reducing the improper disposal of cans containing liquid paint with other nonhazardous wastes. (Cans containing dried paint residue can be thrown out.)

Solvent Wastes - Better Operating Practices - Adopt Good Manual Spraying Techniques

When manual spraying practices are used, the amount of waste produced can be reduced by: using a 50 percent overlap in the spray pattern, maintaining a 6- to 8-in. distance between the spray gun and the surface, maintaining a gun speed of 250 ft/min, holding the gun perpendicular to the surface, and triggering at the beginning and end of each pass.[103] In addition to reducing the amount of waste produced, an increase in the production rate and a decrease in rejection rate can be realized.

Solvent Wastes - Better Operating Practices - Avoid Adding Excess Thinner

The tendency to use excess thinners should be avoided. If the paint is difficult to apply, adding thinner may make it easy. However, adding excess thinner affects the film thickness, density, and durability.[104]

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[100] ICF Associates, Inc.

[101] M.E. Campbell and W.M. Glenn, *Profit from Pollution Prevention - A Guide to Industrial Waste Reduction and Recycling* (The Pollution Probe Foundation, Toronto, Canada, 1982).

[102] M.E. Campbell and W.M. Glenn.

[103] J. Kohl, P. Moses, and B. Triplett, *Managing and Recycling Solvents: North Carolina Practices, Facilities, and Regulations* (North Carolina State University, Raleigh, NC, 1984).

[104] L.J. Durney, "How to Improve Your Paint Stripping," *Product Finishing* (1982), pp 52-53.

Solvent Wastes - Better Operating Practices - Avoid Excessive Air Pressures for Atomization

Using excessive air pressure to atomize paint particles leads to increased emissions and overspray, and must be avoided. By adjusting the air pressure, a 30 percent decrease in overspray and therefore a savings in raw material costs could be realized.[105]

Solvent Wastes - Better Operating Practices - Maintain Equipment Properly

Proper equipment maintenance is critical to reducing the number of reject products and improving productivity.[106] Proper maintenance also reduces the quantity of waste produced from paint stripping and repainting operations.

Solvent Wastes - Better Operating Practices - Lay Out Equipment Properly

Proper layout of equipment in a work area can also reduce emissions and improve the quality of the finished products. Solvent tanks must be kept away from heat sources such as curing ovens. This will help minimize evaporation of the solvents and will also prevent the solvent vapors from entering the curing oven and affecting the curing rate or decreasing the quality of the finish.[107]

Solvent Wastes - Better Operating Practices - Isolate Solvent-Based Spray Units From Water-Based Spray Units

Isolation of solvent-based spray units from water-based spray units is a good segregation practice. The oversprays from these operations should not be allowed to mix; the mixture could be classified as a hazardous waste. If the units are segregated, the filters from the water-based paint spray booths are not classified as hazardous waste.

Solvent Wastes - Better Operating Practices - Close Floor Drains in Production Area

Closing the floor drains will reduce the amount of water used to clean up spills. This practice promotes the use of rags that must be drycleaned. Thus the generation of large quantities of rinse water containing solvents can be minimized.[108]

Solvent Wastes - Better Operating Practices - Purchase Proper Quantities of Paints

Buying paint in large containers is preferable to buying the same quantity in smaller containers. The amount of residual materials can thus be reduced. Large containers can be returned to manufacturers for cleaning and reuse. Ordering extra paint for any given job should also be avoided. The exact amount of paint required must be calculated to reduce the number of small cans containing residues for disposal.

Solvent Wastes - Better Operating Practices - Segregate Wastes

Segregating wastes is extremely important to reducing the amount of hazardous wastes generated and to improve the recyclability of solvents. If many solvents are used, they should be segregated. Some solvents can be directly reused in equipment cleaning operations.

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[105] ICF Associates, Inc.

[106] ICF Associates, Inc.

[107] ICF Associates, Inc.

[108] L.J. Durney.

Proper labels must be attached to containers. Hazardous wastes must be segregated from nonhazardous wastes and handled and disposed of properly. Labeling a container containing nonhazardous waste as "hazardous" can result in an unnecessary increase in disposal costs.

Solvent Wastes - Better Operating Practices - Standardize Solvent Use

Standardizing solvent use will reduce the numbers of different types of thinners and solvents used in coating formulations. If fewer solvents are stocked, the possibility of mixing of the wastes is reduced. Only one type of thinner or solvent corresponding to each type of paint should be purchased.

Solvent Wastes - Product Substitution - Use High-Solids Formulations

High-solids formulations contain a reduced quantity of solvent. Using high-solids formulations will therefore reduce the amounts of wastes and emissions generated from the painting operations.

Solvent Wastes - Process Change - Choose Proper Coating Equipment

The proper choice of coating equipment can reduce the quantity of wastes produced and result in raw material savings. Overspray from painting operations generates the most waste. Equipment with high transfer efficiencies must be chosen.

Solvent Wastes - Process Change - Replace Conventional Spray Units With Electrostatic Units

Electrostatic units (either centrifugally- or air-atomized spray) have high transfer efficiencies. Converting from conventional equipment to electrostatic equipment may lead to a 40 percent reduction in overspray and considerable savings.[109] The overspray collects on the spray booth walls that are electrically grounded. Thus, the amount of residues in the rest of the work area is reduced. However, the complete conversion requires a lot of time and work in testing, visiting other plants, engineering, and maintenance.

Solvent Wastes - Process Change - Replace Air-Spray Guns With Pressure Atomized Spray Guns

Replacing air-spray guns with air-less spray guns increases the transfer efficiencies. A 23 percent reduction in raw material costs has been reported.[110] Also, the cleaning frequency is increased from once every 3 weeks to once a week.

Aqueous Wastes - Process Change - Dry Paint Booths

Large volumes of wastewater are generated from "water curtain" paint booths. The water curtain is used to remove the paint overspray particulates from the exhaust system. A significant concentration of paint, solvents, and flocculating/coagulating agents accumulates in the wastewater. This wastewater must be treated to remove hazardous contaminants and the sludge must be disposed of as a hazardous waste.

Converting from a wet to a dry paint booth eliminates the problem of wastewater generation. In a dry booth, the contaminated air (laden with paint particles) is drawn through fibrous filters which must then be disposed of as hazardous waste. A much smaller volume of waste is generated. Results

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[109] L.J. Durney.

[110] J. Kohl, P. Moses, and B. Triplett.

of a Navy study[111] indicate that converting to dry operation is technically feasible and cost effective (payback 8 months to 2 years) for small, medium, and large painting facilities.

Recycling Onsite/Offsite

Paint Wastes - Onsite Recycling - Recycle Paint Overspray/Sludge

In water curtain spray booths, the overspray impinges on a water curtain. The paint/water mixture is then pumped to a separator. If the paints used are immiscible in water, they can be separated out and recycled. Also, the water can be recycled back into the water curtain. Recycling of the water and paint reduces the amount of wastes produced and results in a savings in raw materials costs.

Solvent Wastes - Onsite Recycling - Ultrafiltration, Distillation, or Evaporation

In ultrafiltration, the sludge containing solvents is filtered using membranes with pore sizes of 0.01 microns. Paint particles, usually larger than 1 micron, collect on the membranes and are removed continuously. A series of membranes filter the waste to produce a pure solvent that can be recycled.[112]

Distillation stills can be used to recover solvents. The solvent is indirectly heated and the vapors are condensed and collected. Purities of 90 to 99 percent can be obtained by this process. Table 33 lists manufacturers of distillation stills and associated costs. The concentrated still bottoms containing paint sludge must be shipped for proper disposal as a hazardous waste. Another possibility is to ship the still bottoms to a cement kiln for use as a supplemental fuel through a waste exchange program.

Evaporation, using drum-dryers or thin-film evaporators, is effective on solvents that are heat-sensitive. Large scale equipment is necessary for evaporation and, therefore, is cost effective only for large quantities of solvents. Many commercial solvent recyclers use agitated thin-film evaporators.

Solvent Wastes - Offsite Recycling - Closed-Loop Contract

Wastes consisting primarily of thinners, paint sludge, and paint can be reclaimed at an offsite facility. This closed-loop service is provided by many paint and thinner suppliers. Usually the purchase price includes delivery, waste hauling, recycling, and disposal. Such a service removes the wastes when it delivers the new product. The waste is processed at a licensed treatment, storage, and disposal (TSD) facility. Processes used for recycling thinners are well-established and widely used.[113] Commerical recyclers have the versatility and have developed technologies for recycling large varieties of waste solvents. Between 70 and 80 percent of spent thinners can be recycled into a useful product.

Treatment

Solvent Waste - Onsite Pretreatment - Gravity Separation

Gravity separation is a relatively inexpensive option that is easy to implement. In this treatment process, the thinner and paint sludge mixture is allowed to separate by the force of gravity without

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[111] Acurex Corporation, *Navy Paint Booth Conversion Feasibility Study*, CR 89.004 (Prepared for the Naval Civil Engineering Laboratory [NCEL], Port Hueneme, CA, 1989).

[112] Y. Isooka, Y. Imamura, and Y. Sakamoto, "Recovery and Reuse of Organic Solvent Solutions," *Metal Finishing* (June 1984), pp 113-118; W.H. Reay, "Solvent Recovery in the Paint Industry," *Paints & Resins* (March/April 1982), pp 41-44.

[113] SCS Engineers, Inc., *Waste Audit Study - Automotive Paint Shops* (California Department of Health Services, January, 1987).

external disturbance or agitation. The heavier paint sludge particles settle to the bottom of the container and the supernatant can be decanted off. The decanted thinner can be used as a "wash thinner" for cleaning equipment or for thinning primer and base coatings.[114]

Paint/Solvent/Aqueous Wastes - Offsite Treatment

Although most waste associated with paint can be treated using a number of different physical, chemical, and biological techniques, these techniques are not feasible for most Army installations that generate small quantities. However, licensed TSD facilities can use a number of processes such as activated carbon adsorption, chemical oxidation, solvent extraction, solid/liquid separation, stabilization/solidification, thermal destruction, volume reduction, and biological treatment. The applicability of each technique will not be discussed here.

Table 40

Waste Classification for Paint Removal, Painting, and Brush Cleaning

	Waste Description			
Materials used/ wastes produced	**HW code**	**DOT shipping name**	**Hazard class**	**Number**
Acetone	F003	Waste acetone	Flammable liquid	UN1090
Alcohols	D001	Waste alcohol, NOS	Flammable liquid	UN1987
Caustic paint stripper	D002	Waste paint related material	Corrosive material	NA1760
Chlorobenzene	F002	Waste chlorobenzene	Flammable liquid	UN1134
Enamel liquids	D001	Waste enamel	Combustible liquid	UN1263
Ethylene dichloride		Waste ethylene dichloride	Flammable liquid	UN1184
MEK	F005	Waste methylethylketone	Flammable liquid	UN1193
Methylene chloride stripper	F002	Waste methylene chloride	ORM-A	UN1593
Mineral spirits	D001	Waste naptha	Flammable liquid	UN2553
Paint dryer	None	Waste paint dryer, liquid	Combustible liquid	UN1263
Paint liquids	D001	Waste paint	Flammable liquid	UN1263
Paint solids (toxic)	Varies	Hazardous waste (solid), NOS	ORM-E (if solid)	UN9189
Paint thinners, lacquers	D001	Waste paint related material	Flammable liquid	NA1263
Paint waste with heavy metals	Varies	Hazardous waste liquid, NOS	ORM-E	NA9189
		Hazardous waste solid, NOS	ORM-E	NA9189
Petroleum distillates	D001	Waste petroleum distillate	Flammable liquid	UN1268
Toluene (Toluol)	F005	Waste toluene	Flammable liquid	UN1294
VM&P naphtha	D001	Compound, paint removing liquid	Flammable liquid	NA1142
Xylene (Xylol)	F003	Waste xylene	Flammable liquid	UN1307

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[114] SCS Engineers, Inc.

8 WASTE MINIMIZATION FOR PHOTOGRAPHY, PRINTING, AND ARTS/CRAFTS SHOPS

Photography and photoprocessing are common operations at Army installations. Among the source types that use photography are: training and audiovisual centers, hospitals, dental clinics, and research laboratories (as discussed in Chapter 4). Printing operations are limited to training and audiovisual centers. The materials used in producing a photograph are paper, plastic film, or a sheet of glass containing light-sensitive photographic emulsion. The emulsion is a gelatineous substance containing silver halides (chloride, bromide, and iodide). Some photographic films may be made of cellulose acetate. However, most are made of polyester. In photography, a negative containing different shadings is produced. The dark portions on a negative contain heavy deposits of silver. The processing that follows the exposure of a film or emulsion consists of developing, fixing, and washing. Wastewater containing photoprocessing chemicals and silver is the primary wastestream of concern.

A printing process usually follows image processing, including typesetting and the photographic processing step discussed above. However, an intermediate step to prepare plates to carry the image to paper is necessary. A roller transfers ink onto a plate or a cylinder. The image on the plate or cylinder is transferred to a rubber blanket which in turn transfers it to paper. There are four different types of image carriers: manual - in screen printing; mechanical - for relief printing; electrostatic - in offset duplicating; and photomechanical - most common method of platemaking.[115] Preparation of plates is followed by the actual printing. Two common types of printing presses used are: sheet-fed presses that can print up to 3 impressions per second and web presses that operate at the rate of 1000 to 1600 feet per minute.[116]

In the printing process, the plate (a thin aluminum sheet) is first attached to the plate cylinder of the press. Each unit of a printing press then prints a single color. Four units (red, blue, yellow, and black) are required for a full color illustration. The raw materials typically used in a printing operation are ink, paper or other print substrate, and fountain solution. Wastes generated from a printing process include waste inks, used ink containers, used plates, damaged or worn rubber image transfer blankets, waste press oils, cleanup solvents, rags, and trash.[117]

The arts and crafts shops are educational and vocational shops that provide training in automobile maintenance/repair, metalworking, graphic arts, and woodworking. Only the minimization of wastes from the photography and printing section of arts and crafts shops is considered in this chapter. Minimization of wastes from automobile maintenance/repair and metalworking are discussed in Chapters 5 and 6, respectively. A summary of processes, corresponding waste streams, and DOT classifications is provided in Tables 41 and 42.

Most of the waste minimization options discussed in this chapter have been extracted from *Waste Audit Study - Commercial Printing Industry*.[118]

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[115] Jacobs Engineering Group, Inc., *Waste Audit Study - Commercial Printing Industry* (California Department of Health Services, Sacramento, CA, May 1988).

[116] Jacobs Engineering Group, Inc.

[117] Jacobs Engineering Group, Inc.

[118] Jacobs Engineering Group, Inc.

Source Reduction - Photography and Printing Operations

All Wastes - Better Operating Practices - Proper Material Handling and Storage

Raw materials may become obsolete and get spoiled due to improper storage and handling. Therefore, proper storage and handling is a good operating practice that will reduce the amount of waste generated and result in savings in raw materials costs.

Photographic and printing chemicals require proper storage, which is usually indicated on the containers. They are sensitive to light and temperature. Proper storage under recommended conditions increases their shelf life and results in savings in raw materials costs and disposal costs.

The storage area must be kept clean. One way to keep the storage area clean is to prohibit through traffic and restrict entry to only a few persons. Traffic increases the amount of dirt and the possibility of contamination. It is easier to contain spills if the entry is restricted to only a few persons.

Proper inventory control is necessary to decrease the possibility of the material's shelf life expiring before the materials are used. The materials should be arranged and labeled on shelves so that those that were purchased first must be used first. Computerized inventory control and materials tracking will help manage the inventory.

Material with an expired shelf life should not be discarded. Tests must be used to determine the effectiveness and usability. Waste disposal may thus be minimized. Excess material should be recycled through a manufacturer or a waste exchange.

Ordering excess material should be avoided. Material ordering should be based on use. Small printing operations should purchase inks in small containers to limit the possibility of the ink spoiling in large containers that may not be properly sealed. Large printing operations should order materials in large containers that can be returned to manufacturers for cleaning and reuse.

Raw materials should be inspected when they arrive and before use. Unacceptable and/or damaged items must be returned to manufacturers to avoid disposal problems and to avoid creating defective products.

Source Reduction - Photographic Operations

Photographic Chemicals - Better Operating Practices - Proper Chemical Storage

Many of the photographic chemicals degrade in the presence of air. Small photographic operations store chemicals in plastic containers. Adding glass beads to the containers to bring the liquid level up to the brim has been found to be useful.[119] The life of the chemicals can thus be extended.

Photographic Films - Material Substitution - Nonsilver Films

Substituting films containing silver with those containing nonhazardous chemicals reduces hazardous waste generation. The silver from silver films makes the photographic wastes (e.g., fixing

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[119] Jacobs Engineering Group, Inc.

bath solutions, rinse water, etc.) hazardous. Only very low silver concentrations are allowed in wastewaters treated at wastewater treatment plants operated by county sanitation districts.

Some substitutes to silver-halide films include vesicular (diazo), photopolymeric, and electrostatic films.[120] However the disadvantage of these films is that they are slower than silver films. Vesicular films consist of a honeycomb structure and are constructed from a polyester base coated with a thermoplastic resin. These films are also coated with a light-sensitive diazonium salt. Photopolymeric films use carbon black instead of silver. A weak alkaline solution is used to process these films. The spent bath solution is a nonhazardous waste that can be neutralized before disposal. An electrostatic charge makes electrostatic film light sensitive. The speed of this nonsilver film is comparable to silver films and it has a high resolution.

Other Photographic Wastes - Material Substitution

Other photographic wastes such as intensifiers and reducers also contain hazardous compounds (e.g., mercury, cyanide salts, etc.). Use of available nonhazardous substitutes will reduce the amount of hazardous wastes generated.

Fixing Bath Solutions - Process Change - Extended Bath Life

The life of fixing baths can be extended to reduce the quantities of wastes generated from photographic operations. Some of techniques that could be used include:[121]

1. Adding ammonium thiosulfate which increases the bath life by doubling the allowable silver concentration,

2. Using an acidic stop-bath before the fixing bath,

3. Adding acetic acid to the fixing bath to keep the pH low.

Photographic Wastewater - Process Change - Reduction in Water Use

Parallel rinsing is commonly used in photographic processing operations. Converting to countercurrent rinsing reduces the amount of wastewater generated. In countercurrent rinsing, the water flows in a direction that is opposite to the film movement. Thus, fresh water in the final tank is used in the final film washing stage after most of the contamination has been rinsed off. The most contaminated water is in the very first washing stage. A countercurrent system, however, requires more equipment and space.

Sponges or squeegees must be used in nonautomated operations to remove excess water from the films. Thus the dragout of chemicals from one tank to another can be reduced by almost 50 percent.[122] Minimizing contamination of processing baths has many advantages including: increasing the recyclability of solutions, extending solution life, and reducing the quantities of raw materials (replenishments) required.

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[120] Jacobs Engineering Group, Inc.
[121] Jacobs Engineering Group, Inc.
[122] Jacobs Engineering Group, Inc.

Another method of reducing waste chemicals is to add accurate amounts of replenishment chemicals and properly monitor the chemical concentrations of baths. Exposing the process baths to air must be minimized to prevent oxidation reactions.

All Photographic Wastes - Process Change

With the recent advances in desk top publishing systems and the use of personal computers, "electronic prepress photographic systems" are gaining widespread popularity. In such a system, the graphics, photographs, and layouts are scanned into the computer. Editing is accomplished on the monitor rather than on paper. Only the final version is printed on paper. Use of electronic sytems will greatly reduce the quantities of wastes generated from photographic operations conducted at printing facilities.

Source Reduction - Printing Operations

Metal Etching/Plating Wastes - Process Change

If printing operations still include metal etching and plating, alternative processes (e.g., lithographic plate, hot metal, flexographic, etc.) must be examined as substitutes. These alternative processes do not present the problems associated with treatment and disposal of hazardous wastes.

Metal Etching and Plating Wastewater - Process Change - Reducing Water Use

The wastewater produced from metal etching and plating is a hazardous waste. Efforts must be made to reduce the toxicity of wastewater by reducing the dragout from process tanks and by using countercurrent rinsing. Dragout reduction can be achieved by: (1) positioning parts on racks so they drain properly, (2) using drip bars and drain boards to collect the dragged-out chemicals and returning them to the process tanks, and (3) increasing the process tank temperature to reduce surface tension of the solution thereby minimizing its tendency to cling to parts.

Countercurrent rinsing reduces the amount of wastewater leaving an operation. However, it does not reduce the hazardous material content in wastewater.

Lithographic Plate Processing Chemicals - Better Operating Practices - Reduced Chemicals Use

The use of plate processing chemicals must be reduced. One way to reduce chemical consumption is to frequently monitor the pH, temperature, and chemical concentration of the bath. Bath life can thus be extended and changing of solutions can be reduced to only a few times a year. Using automatic plate processors facilitates precise monitoring of bath conditions.

Lithographic Plate Processing Plates - Better Operating Practices - Proper Storage/Recycling

Proper storing of plates reduces the possibility of them getting spoiled and maintains their effectiveness. Used plates are not a hazardous waste and must be collected and sold to an aluminum recycler.

Lithographic Plate Processing Plates - Material Substitution

Alternative "presensitized plates" are available that can be processed with water. Other plates available include "Hydrolith" plates manufactured by 3M Corporation.[123] 3M has also developed a platemaking system that eliminates the need for photoprocessing, and has been found to be economical for large plating operations.[124]

Web Press Wastes - Process Change - Break Detectors

Using break detectors in web presses prevents severe damage to the presses and also reduces the quantities of wastes from spillage of inks, fountain solutions, and lubricating oil. Web break detectors detect tears in a web as it passes through a high speed press. Broken webs tend to wrap around rollers and force them out of their bearings.

Waste Inks/Cleaning Solvents/Rags - Better Operating Practices

Rags dampened with cleaning solvents are used to clean presses. The amount of solvent and number of rags used can be minimized by reducing the cleaning frequency and by properly scheduling cleaning. Ink fountains must be cleaned only when a different color ink is used or if the ink has dried out. Overnight drying of ink may be reduced by using compounds that are dispensed as aerosol sprays.[125] Thus, the amount of waste ink, solvents, and rags is reduced.

Waste Inks - Better Operating Practices

The amount of waste ink generated can be reduced by implementing better operating practices. Only the required amount of ink must be put in an ink fountain before starting a print job. Resealing the ink containers after use is a good practice that prevents contamination by dust/dirt, formation of a "skin" on the ink surface, loss of solvents, and hardening. As much of the ink as possible must be scraped from the container for use.

Automatic ink levelers, when used in large presses, improve the print quality and reduce the amount of trash and the likelihood of accidental spills.

Waste (Flexographic) Inks - Product Substitution - Water-Based Inks

Substituting water-based inks for solvent-based inks in flexographic printing reduces the quantity of hazardous wastes generated. Use of water-based inks also eliminates the problems encountered with volatilization of solvents. Some of the disadvantages of water-based inks include: limited range of colors, higher energy requirement for drying because of high heat of vaporization, higher equipment operating costs, lower capacity, lower speed, and difficult cleaning requirements.[126] Water-based inks are not available for lithographic printing operations.

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[123] M.E. Campbell and W.M. Glenn.
[124] M.E. Campbell and W.M. Glenn.
[125] Jacobs Engineering Group, Inc.
[126] Jacobs Engineering Group, Inc.

Waste Inks - Product Substitution - UV Inks

Ultraviolet (UV) inks are those that dry when exposed to UV light. UV inks contain: monomers, photosynthesizers, and pigments rather than solvents. Because they do not dry in fountains, the need for cleaning is reduced. The advantages of UV inks include:[127]

1. UV inks eliminate "set-off" -- the unintentional transfer of ink from one sheet to the back of the preceding sheet after the sheets have been stacked, which occurs when the ink has not completely dried.

2. UV inks eliminate the need for anti-offset sprays that prevent set-off.

3. UV inks eliminate the need for ventilated storage of sheets when using oxidative drying processes.

Disadvantages of UV inks include:[128]

1. The cost is 75 to 100 percent higher than conventional heat-set inks.

2. UV light is a hazard to plant personnel.

3. The interaction of UV light and atmospheric oxygen forms ozone.

4. Conventional paper recycling procedures will not deink paper printed by this process. This creates a waste source from an otherwise recyclable material.

5. Some of the chemicals in the inks are toxic.

Waste Inks - Product Substitution - EB Inks

Electron beam (EB) inks are those that are dried by electron beams and are similar to UV inks in operational concept. They have the same advantages as UV inks. However, operator protection from X-rays is necessary and these inks degrade the paper.

Waste Inks - Product Substitution - Heat Reactive Inks (Web Presses)

Heat reactive inks contain a prepolymer, a cross-linking resin, and a catalyst. At 350 °F, the inks are activated to polymerize and set. These inks contain much less solvent than the conventional heat-set inks.

Cleaning Solvents - Good Operating Practices - Pour Cleaning

Whenever possible "pour" cleaning with solvent followed by "wipe" cleaning with a rag could be used to clean presses. The drained solvent must be collected and recycled. Although more solvent is used in this process, less ink ends up on the rags. Cross-contamination of inks must be avoided. The used solvent can be used to clean rollers and blankets, thus reducing the amount of fresh solvent used.

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[127] Jacobs Engineering Group, Inc.

[128] Jacobs Engineering Group, Inc.

Use of wipe cleaning with rags may be preferable to pour cleaning in some cases because the quantity of solvent wastes is considerably reduced.

Cleaning Solvents - Good Operating Practices

Detergents or soap solutions rather than solvents should be used for general cleaning. Use of solvents should be limited to removing inks and oils.

Cleaning Solvents - Product Substitution - Nonhazardous Formulations

Hazardous materials such as benzene, carbon tetrachloride, TCE, and methanol were previously used as cleaning solvents. Several "blanket washes" containing glycol ethers and other heavy hydrocarbons that are less toxic and flammable are now available. Using nonhazardous blanket washes is recommended for all cleaning requirements in a printing operation.

Fountain Solutions - Product Substitution

Conventional fountain solutions contain water, isopropyl alcohol, gum arabic, and phosphoric acid. These compounds are transferred to the printing paper or they evaporate causing volatile organic compounds to be released. Substitute formulations must be used to reduce the emissions.

Waste Paper - Good Operating Practices - Reduce Use

Printing operations generate a large quantity of waste paper. Although paper is not a hazardous waste, reducing paper consumption and thus the purchase of new paper is a good operating practice.

Recycling Onsite/Offsite - Photographic Operations

Spent Fixing Bath Solution - Onsite Recycling - Silver Recovery

Spent fixing bath solutions contain silver that can be recovered. Following recovery, the bath can be reused or discharged to a sewer. Some of the reasons for recovering silver from the solution include:[129] reducing the amount of hazardous silver compounds in wastewaters, extending the useful life of fixing baths, and redeeming the precious metal value of silver.

Electrolytic deposition is the most common method of recovering silver. The electrolytic recovery units have carbon anodes and steel cathodes. Applying a low voltage results in the plating of metallic silver on the cathode. The fixing bath solution, after silver removal, can be mixed with fresh solution and reused in the photographic development process.

A second method of silver recovery is the use of steel wool cartridges to replace silver in an oxidation-reduction reaction. In this process, the spent fixing bath solution is pumped through the steel wool cartridge and iron replaces silver in the solution. Silver sludge settles to the bottom of the cartridge.

A detailed discussion of methods and procedures for silver recovery including: general procedures for hypo collection and recovery, procedures for removing silver from recovery units, recommended recovery procedures for use with automatic film processors, and procedures for using the metallic

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[129] Jacobs Engineering Group, Inc.

replacement recovery cartridges are outlined in the Defense Logistics Agency's *Defense Utilization and Disposal Manual.*[130]

Photographic Films - Offsite Recycling - Silver Recovery

Photographic laboratories and many other facilities that use X-ray films generate used photographic films that contain 1 percent (0.15 troy ounces) of silver.[131] These films must be sold to recyclers for silver recovery.

Recycling Onsite/Offsite - Printing Operations

Metal Etching and Plating Wastewater/Sludge - Onsite/Offsite Recycling - Material Recovery

The wastewater from metal etching and plating operations contains heavy metals and various quantities of process chemicals. Material recovery processes can be implemented to recover some of the process chemicals and thus reduce raw material costs.

Used Metal Wastes - Offsite Recycling

Linotype operations used for letterpress printing generate used metal wastes. The process uses an alloy with a low melting point to create the letters in lines of text. The metal must be melted in the linotype machines and/or recycled. The manufacturer or metal supplier may be willing to buy the used metal and recycle it.

Waste Inks - Onsite Recycling

A simple recycling technique is to blend all the waste inks together to form black ink. It may be necessary to add small amounts of color and toner to obtain an acceptable black color. The reformulated black ink is similar in quality to new newspaper ink. Most newspaper printing presses use recycled black ink.[132]

Waste Inks - Offsite Recycling

Contract recycling of waste inks can be used to produce black ink. This black ink can be used to print newspapers or flyers. In such a contract, waste inks are bottled and shipped to the recycler (or manufacturer) and the reformulated black ink is shipped back. The costs of buying new black inks and disposing of waste inks can thus be reduced.

Cleaning Solvents - Onsite Recycling - Distillation

Small distillation units are available for recycling solvent used in pour cleaning. Proper segregation of solvents and trash is necessary. Still bottoms have to be disposed of as hazardous waste.

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[130] *Defense Utilization and Disposal Manual,* DOD 41620.21-M (Defense Logistics Agency, Office of the Assistant Secretary of Defense, Alexandria, VA, September 1982), pp VI-42 and XVII-A-5 through XVII-A-10.

[131] *Defense Utilization and Disposal Manual.*

[132] C. Woodhouse, *Waste Ink Reclamation Project* (California Department of Health Services, Toxic Substances Control Division, August 1984).

Waste Paper - Offsite Recycling

Waste paper must be collected and recycled. Manufacturers or paper recyclers remove the ink and repulp the paper. Pulp from recycled paper adds strength and durability to many other paper products.

Treatment - Printing Operations

Wastewater from metal etching and plating operations is classified as hazardous and must be treated before discharge to a municipal sewer. If not treated, it must be put in drums and disposed of as hazardous waste. Packaged treatment units that neutralize and precipitate the heavy metals are available. The sludge generated from treatment is also a hazardous waste and is banned from land disposal.

Table 41

Typical PPAS Operations With Materials Used and Wastes Generated*

Process/ operation	Materials used	Ingredients on labels	Wastes generated
Apply light sensitive coating	resins, binders, emulsion, photosensitizers, gelatin, photoinitiators	PVA/ammonium dichromate, polyvinyl cinnamate, fish glue/albumin, silver halide/gelatin emulsion, gum arabic/ammonium dichromate	photographic waste
Develop plates	developer	lactic acid, zinc chloride, magnesium chloride	photographic waste
Wash/clean plates	alcohols, solvents	ethyl alcohol, isopropyl alcohol, methyl ethyl ketone, trichloroethylene, perchloroethylene	spent solvents
Apply lacquer	resins, solvents, vinyl lacquer	PVC, PVA, maleic acid, methyl ethyl ketone	spent solvents
Counter-etch to remove oxide	phosphoric acid	phosphoric acid	acid/alkaline wastes
Deep-etch coating of plates	deep etch bath	ammonium dichromate, ammonium hydroxide	acid/alkaline waste, heavy metal solutions, waste etch bath
Etch baths	etch bath for plates	ferric chloride (copper), aluminum chloride/zinc chloride/hydrochloric acid (chromium), nitric acid (zinc, magnesium)	waste etch bath, acid/alkaline waste, heavy metal solutions
Printing (Ink)	pigments, dyes, varnish, drier, extender, modifier	titanium oxide, iron blues, molybdated chrome orange, phthalocyanine pigments, oils, hydrocarbon solvents, waxes, cobalt/zinc, magneze oleates, plasticizers	waste ink with solvents/heavy metal, ink sludge with chromium/lead
Making gravure cylinders	acid plating bath	copper hydrochloric acid	spent plating waste

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*Source: H. Winslow, *Hazardous Waste SQG Workbook* (Intereg Group, Inc., Chicago, IL, 1986), pp 146-147.

Table 42

Waste Classification for PPAS

Process Description		Waste Description			
Process/ operation	**Materials used/ wastes produced**	**HW code**	**DOT shipping name**	**Hazard class**	**Number**
Photographic processing	Carbon tetrachloride	F001	Waste carbon tetrachloride	ORM-A	UN1846
	Waste solutions with heavy metals (Cd, Cr, Pb, etc.)	Varies	Hazardous waste solution, NOS	ORM-E	NA9189
Washing, cleaning plates; press cleanup	Ethyl alcohol	D001	Waste ethyl alcohol	Flammable liquid	UN1170
	Isopropyl alcohol	D001	Waste isopropyl alcohol	Flammable liquid	UN1219
	Methylethylketone	F005	Waste methylethylketone	Flammable liquid	UN1193
	Naptha	D001	Waste naptha	Flammable liquid	UN2553
	Perchloroethylene	F002	Waste perchloroethylene	ORM-A	UN1897
	Petroleum distillates	D001	Waste petroleum distillates	Flammable liquid	UN1268
	Press wash	D001	Waste flammable liquid, NOS	Flammable liquid	UN1993
	Trichloroethylene	F001	Waste trichloroethylene	ORM-A	UN1710
	Xylene	D001	Waste xylene	Flammable liquid	UN1307
Etching, plating	Ammonium hydroxide	D002	Waste ammonium hydroxide	Corrosive material	NA2672
	Hydrochloric acid (Cr)	D002	Waste hydrochloric acid	Corrosive material	NA1789
	Nitric acid (Zn, Mg)	D002	Waste nitric acid	Corrosive material	NA1760
	Phosphoric acid	D002	Waste phosphoric acid	Corrosive material	UN1805
Printing	Waste ink (containing various solvents and heavy metals)	D002	Waste ink	Combustible liquid Flammable liquid	UN2867 UN1210
	Ink sludge (heavy metals - Cr or Pb)	D002	Hazardous waste liquid, NOS Hazardous waste solid, NOS	ORM-E ORM-E	NA9189 NA9189

9 WASTE MINIMIZATION FOR HOSPITALS, CLINICS, AND LABORATORIES

Army hospitals, veterinary clinics, dental clinics, and other laboratories are usually tenants located on an installation. The types of wastes generated by these activities can be divided into infectious wastes (IW), pathological wastes (PW), sharps, pharmaceutical wastes (PhW), radioactive wastes (RW), laboratory wastes (LW), chemotherapy wastes (CW), infectious linen (IL), and general wastes (GW). Only the LW and CW are hazardous wastes by the RCRA and HSWA definition.

For this discussion, some of the definitions for hospital wastes are extracted from Army Regulation (AR) 40-5.[133] Detailed definitions and classifications of infectious wastes can be obtained from USEPA's *Guide to Infectious Waste Management.*[134]

IW is from patients in strict or respiratory isolation, or with wound and skin precautions; wastes from microbiological laboratories; and surgical waste (at the discretion of the operating room supervisor). PW includes anatomical parts, excluding human corpses and animal carcasses. Sharps include discarded hypodermic needles, syringes, pipettes, broken glass, and scalpel blades that pose infection and physical injury hazards through cuts or puncture wounds. GW is all the waste not classified as infectious, pathological, or hazardous, for example: refuse generated from general patient units, emergency rooms, dental areas, surgical suites, administrative areas, and supply areas. PhW consists primarily of outdated medicines (drugs, vaccines, and physiological solutions). RW wastes emit ionizing radiation (such as alpha, beta, gamma, or X-rays).

The activities that generate most of the highly infectious wastes are: general surgery/recovery, vascular surgery, plastic surgery, pathology, blood bank, microbiology laboratory, labor and delivery rooms, obstetrics, emergency room isolation, and the morgue. Among the wastes generated are: (1) significant laboratory waste, including all tissue or blood elements, excreta, and secretions obtained from patients or laboratory animals and disposable fomites (items that may harbor or transmit pathogenic organisms); (2) surgical specimens and attendant disposable fomites; (3) disposable materials from outpatient areas and emergency departments; (4) equipment, instruments, utensils, and fomites of a disposable nature from isolation rooms; (5) animal feces, animal bedding, supplies, and fomites resulting from and/or exposed to infectious animal care and laboratory procedures; and (6) all disposable needles and syringes.[135]

Radioactive wastes are usually generated by the radiology ward, nuclear medicine, clinical pathology, and laboratories that use radionuclides. Some of the radionuclides administered to patients during treatment include: $^{99\text{-M}}$Technetium, ^{51}Chromium, ^{32}Phosphorus, and ^{131}Iodine.[136] Most of the radioactive wastes that require special handling and disposal are generated by the use of radionuclides such as ^{14}Carbon, ^{4}Hydrogen, and ^{131}Iodine, in clinical laboratories.

A number of different types of hazardous wastes are generated in HCL, although in small quantities. Table 43 lists processes and operations that generate wastes, and the corresponding DOT classifications. LW is mostly chemical wastes, including ignitable/chlorinated solvents and miscellaneous used chemicals (e.g., xylene, formalin, mercury, etc.) generated in analytical and clinical laboratories. These wastes may also be generated in maintenance, pharmacy, and nursing areas.

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[133] Army Regulation (AR) 40-5, *Preventive Medicine* (HQDA, 30 August 1986).

[134] *Guide to Infectious Waste Management*, EPA/530-SW-86-014 (USEPA, Washington, D.C., 1986).

[135] D. Kraybill, T. Mullen, and B.A. Donahue, *Hazardous Waste Surveys of Two Army Installations and an Army Hospital*, Technical Report N-90/ADA088260 (USACERL, August 1980), pp 46-48.

[136] D. Kraybill, T. Mullen, and B.A. Donahue.

Photographic films and chemicals are used in radiology. Other toxics and corrosives are used throughout the hospitals.

CW is a large quantity HW generated by the use of antineoplastic, or cytotoxic agents in chemotherapy solutions administered to patients. The chemicals themselves are only a small volume of the waste; most of it consists of protective clothing and gauze pads that are lightly contaminated.

Most of the guidance on proper management and minimization of wastes discussed in this chapter has been obtained from *Protocol Health Care Facility Waste Management Surveys*,[137] and *Waste Audit Study - General Medical and Surgical Hospitals*.[138] The minimization of photographic wastes is discussed in Chapter 9.

Regulations

On October 21, 1988, the U.S. Congress passed the Medical Waste Sanctions Act (MWSA) which requires strict control on generation and disposal of medical wastes, and prohibits anyone from dumping the wastes in oceans and large water bodies (such as the Great Lakes).[139] MWSA was initiated as an amendment to the original Marine Protection, Research and Sanctuaries Act (MPRSA) of 1972. MPRSA and MWSA define "medical waste" to include "isolation wastes; infectious agents; human blood and blood products; pathological wastes; sharps; body parts; contaminated bedding; surgical wastes and potentially contaminated laboratory wastes; dialysis wastes; and other equipment and material that the Administrator of the USEPA determines may pose a risk to public health, welfare, or the marine or Great Lakes environment." Of the 160 million tons of waste generated in the United States each year, 3.2 million tons of them are medical wastes from hospitals.[140] These medical wastes do not include refuse from doctors' offices, laboratories, home health care, veterinary clinics, and blood banks. Of the 3.2 million tons of medical wastes, USEPA estimates that 10 to 15 percent are infectious.

MWSA was passed because medical wastes could be regulated under the RCRA and HSWA but are not under the USEPA rules. MWSA requires USEPA to develop rules and regulations for a cradle-to-grave manifest system to track the medical wastes from generation to disposal, and for record-keeping, reporting, and proper segregation (from ordinary refuse) and disposal requirements. The States have been given the authority to enforce MSWA more stringently than the USEPA requirements. Therefore, States such as Delaware, Louisiana, Maryland, Minnesota, New York, and Pennsylvania, have passed stricter laws for tracking and disposing of medical wastes.

In the private sector, research and testing laboratories such as those located in Army hospitals and associated research facilities would be regulated as small quantity generators of hazardous laboratory waste. All the rules of RCRA and HSWA would apply and cradle-to-grave management and development of minimization strategies would be necessary.

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[137] *Protocol Health Care Facility Waste Management Surveys* (USAEHA, 1987).

[138] Ecology and Environment, Inc., *Waste Audit Study - General Medical and Surgical Hospitals* (California Department of Health Services, Sacramento, CA, 1988).

[139] *Medical Waste Sanctions Act of 1988*, Report 100-1102 (House of Representatives, 100th Congress, October 1988).

[140] *Medical Waste Sanctions Act of 1988*.

Source Reduction - All Wastes

IW/PW/GW/Sharps - Better Operating Practices - Segregation

IW and PW must be segregated from GW and sharps. GW such as surgical glove wrappers should not be placed in IW containers (e.g., red bags in rigid containers). Sharps must be placed in separate containers (e.g., rigid plastic boxes) in every room where they are used. Separate containers (e.g., yellow or white bags) must be used for general wastes including paper and trash.

Source Reduction - Infectious and Pathological Wastes

IW/PW - Better Operating Practices - Segregation/Labeling

All the containers must be rigid and must be lined with impervious, tear resistant, and distinctively colored bags (e.g., red bags for infectious wastes only). The same type and color bags must be used at all waste generation points and marked/labeled with the universal biohazard symbol. Standardized procedures (labeling, color, etc.) reduce confusion among personnel and improve waste management, thus, minimizing quantities of wastes generated.

IW/PW - Better Operating Practices - Collection/Transportation

Sufficient numbers of IW/PW containers must be provided and conveniently located in all rooms where the wastes are generated. They should also be located in such a way as to minimize patients/personnel exposure to the wastes. The containers must be cleaned and disinfected every time they are emptied. All the containers should have tight-fitting lids and the lids should be in place when the containers are not in use. *To minimize exposure* for patients and staff, IW/PW must be collected frequently from all the generation points by trained personnel only. The transport containers must have tight-fitting lids and should be used exclusively for IW/PW. The interior of the transport containers must be cleaned and disinfected regularly.

IW/PW - Better Operating Practices - Storage

All IW/PW storage areas (including access doors, containers, freezers, refrigerators, etc.) must be labeled and marked with the universal biohazard symbol.

Treatment - Infectious and Pathological Wastes

IW/PW - Treatment/Better Operating Practices - Incineration

Incineration is one of the options used to treat infectious wastes. The manufacturer's operating instructions and standard operating procedures must be posted on the incinerator. A State or local air quality permit must be obtained and the incinerator must be operated in compliance by following the manufacturer's recommended temperature to reduce emissions and opacity problems.

The incinerator ash could be a hazardous waste. It should be tested annually for hazardous characteristics. Testing of incinerator ash at Army installations[141] has revealed that it is Extraction Procedure (EP) toxic for heavy metals.

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[141] *Protocol Health Care Facility Waste Management Surveys.*

The red bags used to contain IW/PW burned in incinerators are made of chlorinated plastics (PVC). Burning these red bag wastes generates a number of air pollutants of concern including: hydrochloric acid, dioxins, furans, and particles. These toxic stack emissions are a significant hazard to the community. As public concern increases (and regulations change) proper flue-gas cleanup will be required. Some of the air emission control devices that could be installed include: dry impingement separators, dry cyclonic separators, venturi scrubbers, electrostatic precipitators, fabric filters, wet acid gas scrubbing devices, and dry scrubbing systems.

IW/PW - Treatment/Better Operating Practices - Autoclaves/Retorts

Autoclaves or retorts are used in several hospitals to disinfect IW/PW before landfill disposal. All the operators should be trained in proper equipment use. The bags used in autoclaves should allow sufficient steam penetration and yet contain the wastes. Compaction of wastes must always follow the autoclaving process. Spore strips should be used to check the effectiveness of the operation.

Source Reduction - Sharps

Clipping needles after use is prohibited by AR 40-5 to prevent generation of pathogen-containing aerosols. Used syringes must be placed only in rigid impervious containers marked with the universal biohazard symbol. Adequate containers must be provided and managed by trained personnel.

Source Reduction - Hazardous Wastes

HW - Better Operating Practices - Inventory

A current and comprehensive inventory must be developed for all the hazardous materials used and hazardous wastes generated. The inventory must contain the following for each HW: a description; hazard code; USEPA (or State) number; physical form; rate of generation; method of treatment, storage, and disposal; and an indication if the waste is infectious. All HW on the inventory must be reviewed annually and reported to the installation environmental office.

Infectious hazardous wastes could be generated at the histology (waste xylene), parasitology (hazardous fluids), and radiology (waste barium) laboratories. A proper inventory must be developed for these wastes. The procedures for handling these wastes are outlined in *Infectious Hazardous Waste Handling and Disposal.*[142]

HW - Better Operating Practices - Proper Storage

Proper containers must be used to store hazardous wastes; they must be properly labeled. They must contain liners compatible with the wastes. Upon exceeding the 55-gal (or 1 qt for acute HW) storage limit in the satellite accumulation areas, the 90-day temporary storage requirements[143] have to be complied with and the wastes must be turned in to the installation's hazardous wastes storage building.

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[142] *Infectious Hazardous Waste Handling and Disposal*, Technical Guide Number 147 (USAEHA, 1986).
[143] 40 CFR 262.34, *Onsite Accumulation Requirements*.

HW (solvents) - Better Operating Practices - Segregation

Solvent wastes must be segregated according to the recycling or treatment processes used for their recovery or disposal. Some of the criteria useful for segregation are:[144] flash point, Btu value, viscosity, halogen content (e.g., chlorine), and water content. Segregating wastes as individual chemicals (with minimal contamination) simplifies waste management.

HW (solvents) - Product Substitution

Nonhalogenated solvents must be substituted for halogenated solvents (e.g., TCE, 1,1,1-trichloroethane, MC, etc.). Simple alcohols and ketones are good substitutes for petroleum hydrocarbons (e.g., toluene, xylene, etc.). Aqueous reagents must be used whenever possible. The feasible substitutions have to be determined by laboratory managers on a case-by-case basis.

Xylene is commonly used as a tissue clearing agent at hospitals. Use of a nonhazardous substitute (such as Histoclear™) must be examined to determine its effectiveness.

HW (solvents) - Process Change

Cleaning processes that use alcohol-based disinfectants must be modified to use ultrasonic or steam cleaning methods. Premixed containerized test kits must be used for solvent fixation (making slides). Calibrated solvent dispensers must be used for routine tests. Minimizing the sizes of cultures or specimens in the pathology, histology, and other laboratories, minimizes the quantities of solvent wastes produced.

Modifying laboratory methodologies to use modern technologies (e.g., monoclonal antibodies, radioisotope labeled immunoassays, and ultrasensitive analytical devices) minimizes or even eliminates the need for extractions and fixation with solvents. Sensitive analytical equipment can reduce analyte volume requirements.

LW - Better Operating Practices - Disposal

All the laboratory hazardous wastes that may be discharged into the sanitary sewer must be identified. Approval must also be obtained from local authorities. According to USEPA requirements [40 CFR 261.3(a)(2)(iv)(E)] the following conditions must be met:

1. Only low toxic hazard, and biodegradable wastes may be discharged,

2. The annualized average flow rate of laboratory wastewater must not exceed 1 percent of the total wastewater flow into the inflow of the wastewater treatment plant,

3. The combined annualized average concentration must not exceed one part per million (ppm) of the inflow to the wastewater treatment plant.

Proper standard operating procedures must be developed and used for disposal of chemicals in the sanitary sewer system.[145] Disposal actions must be coordinated with the installation's environmental office. Sewer disposal is an environmentally unsound practice and must be avoided.

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[144] Ecology and Environment, Inc., pp 5-1 -- 5-3.

[145] National Research Council, *Prudent Practices for Disposal of Chemicals from Laboratories* (National Academy Press, Washington, DC, 1983).

HW (mercury) - Better Operating Practices

Waste mercury can be recycled and must be recovered from spills and from crevices of broken devices. All the residual mercury contained in broken thermometers, blood pressure reservoirs, or other devices should be drained. However, proper spill cleanup and handling operations have to be designed to protect the employees. Special mercury vacuums and spill absorbing kits are available.

HW (mercury) - Process Change

Many hospitals in the United States are using electronic piezometric sensing devices instead of mercury-based thermometers and blood pressure instruments. Such a substitution eliminates both the hazards and cleanup costs associated with broken glass and spilled mercury.

HW (formaldehyde) - Better Operating Practices

Reducing both the cleaning frequency of hemodialysis and reverse osmosis (RO) water supply equipment and the solution strength will minimize the quantities of waste formaldehyde generated. The membranes used in RO units have to occasionally be flushed with formalin. A laboratory standard for formalin solutions should be developed based on microbial culture studies that compare microbial residue with variations in strength, cleaning frequency, and water supply systems.[146]

HW (formaldehyde) - Process Change

The dialysis equipment used in the hospital can be used to capture and concentrate waste formalin (containing 4 percent formaldehyde, 1 percent methanol, and 95 percent water).[147] Formaldehyde extracted and concentrated with the used dialysis membranes can then be sent for proper disposal (e.g., incineration) thus minimizing the waste and associated costs.

CW - Better Operating Practices - Collection/Disposal

Special dedicated containers must be used to collect antineoplastics, cytotoxins (cancer treatment agents), and other controlled drugs. Many of these drugs are listed hazardous wastes and must be managed using proper turn-in procedures.

CW - Better Operating Practices

Segregation of CW from other wastes is an effective minimization practice. Personnel must be properly trained and separate containers (with distinct labels) must be placed in all the drug handling areas.

The cleaning frequency for hoods used for compounding drugs should be reduced. According to OSHA recommendations, hoods should be wiped down daily with 70 percent acohol and decontaminated weekly with an alkaline solution.[148] However, the actual cleaning frequency must be determined based on the use and amount of spillage in the hood.

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[146] Ecology and Environment, Inc.

[147] Ecology and Environment, Inc.

[148] Ecology and Environment, Inc.

Spill cleanup kits, for small and large spills, must be readily available in the drug compounding and use areas. The garments, except gloves, worn by employees should be disposed of with non-hazardous refuse if no spills occurred.

The location of compounding and administration areas should be centralized to minimize spillage and exposure hazards. Drug purchases must be controlled such that only the appropriate container sizes are procured and no residue is left for disposal. Outdated drugs should be returned to the manufacturer.

CW - Product Substitution

Antineoplastics and cytotoxic agents are highly toxic and environmentally persistent. They must be substituted with biodegradable drugs. In some cases, the shelf life can be used as an indicator of environmental persistence. Doctors and pharmacists must be encouraged to choose less environmentally hazardous drugs of equal effectiveness.

RW - Product Substitution

A knowledge of the properties of radionuclides is required for the minimization of RW. A stable radionuclide with a short half-life, low energy, nontoxic decay product, and minimal extraneous radiation emissions must be chosen. Extraneous radiation is the radiation generated that is not required in a test or procedure. If a beta emitter is required, a radionuclide with minimal gamma emissions must be chosen. Containment of gamma rays is difficult.

A radiation safety committee should be established to advise researchers about alternative isotopes that are less environmentally hazardous than those currently in use.

RW (^{226}Radium) - Product Substitution

^{226}Radium is the most hazardous radionuclide used for cancer treatment in hospitals. It has a very long half-life and its decay products are unstable. ^{192}Iridium or ^{137}Cesium needles have been found to be good substitutes for ^{226}Radium needles.[149]

Recycling Onsite/Offsite - Hazardous Wastes

HW (xylene, other solvents) - Recycle Onsite - Distillation

All the spent solvents generated in the laboratories must be accumulated in proper segregated containers. The recyclability of solvents is greater if contamination is minimal. Small distillation stills can be used to recover solvents for reuse.

Table 33 lists manufacturers of industrial distillation equipment. For laboratories, stills made of glassware (process-spinning band distillation[150]) may be more suitable. Appropriate manufacturers (e.g., B/R Instrument Corporation, P.O. Box 7, Pasadena, MD 21122; (301) 647-2894) must be contacted for information on technical feasibility and costs.

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[149] Ecology and Environment, Inc.

[150] L.M. Gibbs, "Recovery of Waste Organic Solvents in a Health Care Institution," *American Clinical Products Review* (November/December 1983).

Xylene wastes generated at the hospitals are contaminated with paraffin and tissue samples, and their recyclability depends on the content of the contaminants. Small stills can be used to distill out pure xylene for reuse. The still bottoms must be properly disposed of as HW. The still can be used to recycle other solvents (e.g., ethanol).

HW (solvents) - Offsite Recycling

A number of commercial recyclers process solvents for reuse. Table 29 lists some of them.

HW (mercury) - Offsite Recycling

If more than 10 lb of liquid mercury is accumulated, it can be sold to a commercial reprocessor.[151] Large quantities can be sent in standard (76-lb) flasks supplied by the reprocessor. These reprocessors are willing to purchase from institutions rather than individuals. Therefore, DRMO must pursue this option for Army installation generators such as hospitals, laboratories, etc.

HW (formaldehyde) - Onsite Recycling - Reuse

Direct reuse of formaldehyde solutions in autopsy and pathology laboratories is possible, depending on the type of specimen. Reuse is possible because the specimen holding times are short and formalin solutions retain their properties for a long time. Additionally, the desired preservative properties may be more effective at lower concentrations than the 10 percent formaldehyde solutions commonly used in pathology laboratories.[152] Minimum effective strength of formalin solutions should be determined based on microbial culture studies.

HW (photographic chemicals) - Recycle Onsite/Offsite - Silver Recovery

Silver recovery methods such as those described in Chapter 7 must be used.

Treatment - Hazardous Wastes

HW (solvents) - Onsite Treatment - Incineration

If recovery by distillation is not a feasible option, onsite incineration should be considered. A permit is needed to operate an incinerator to burn solvents. Therefore, onsite incineration may not be a practical option for most Army hospitals. However, with the increase in offsite incineration costs and the ban on land disposal of liquid wastes and long-term liabilities, onsite incineration may become a feasible treatment method in the future.

Waste designated for incineration must have a high Btu content, a high flash point, low specific gravity, and a low solids content. The incinerator must be designed to achieve complete destruction while generating negligible quantities of air pollutants. Both technical and institutional problems have to be addressed before acquiring an incinerator to burn small amounts of a wide variety of chemical wastes.[153]

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[151] National Research Council, pp 44-55.

[152] National Research Council, Chapter 4.

[153] National Research Council, Chapter 9, pp 111-125.

HW (solvents) - Offsite Treatment - Incineration

Use of offsite facilities to incinerate solvent wastes may be a feasible option for most laboratories. Commercial incineration facilities require generators to segregate wastes and arrange for transportation.

LW (acids/alkalis) - Treatment - Neutralization

Elementary neutralization of corrosive liquids is exempt from treatment permit requirements. Acids (pH < 2) and alkalis (pH > 12.5) must be neutralized before they are allowed to flow into the drain.

Table 43

Waste Classification for HCL

Process Description		Waste Description			
Typical process/ operation	**Materials used/ wastes produced**	**HW code**	***DOT* shipping name**	***Hazard class***	***Number***
Analytical/clinical laboratories, Pathology, Histology, Embalming, Sterile processing, Facilities maintenance, Laundry	Nonhalogenated solvents:	F003	Waste acetone	Flammable liquid	UN1090
	Acetone	D001	Waste acetonitrile	Flammable liquid	UN1648
	Acetonitrile	F003	Waste ethyl alcohol	Flammable liquid	UN1170
	Ethanol	F003	Waste ethyl acetate	Flammable liquid	UN1173
	Ethyl acetate	D001	Waste isopropyl acohol	Flammable liquid	UN1219
	Isopropanol	F003	Waste methanol	Flammable liquid	UN1230
	Methanol	F005	Waste toluene	Flammable liquid	UN1294
	Toluene	F003	Waste xylene	Flammable liquid	UN1307
	Xylene				
	Halogenated solvents:		Waste chloroform	ORM-A	UN1888
	Chloroform	F001	Hazardous waste liquid, NOS	ORM-A	UN9189
	Freon	F001	Waste methylene chloride	ORM-A	UN1593
	Methylene chloride	F001	Waste 1,1,1-trichloroethane	ORM-A	UN2831
	1,1,1-trichloroethane	F001	Waste trichloroethylene	ORM-A	UN1710
	Trichloroethylene				
	Acids/bases:	D002	Waste acetic acid (solution)	Corrosive material	UN2790
	Acetic acid	D002	Waste hydrochloric acid	Corrosive material	UN1789
	Hydrochloric acid	D002	Waste nitric acid, > 40%	Oxidizer	UN2031
	Nitric acid	D002	Waste Nitric Acid, ≤ 40%	Corrosive material	NA1760
		D002	Waste sulfuric acid	Corrosive material	UN1830
	Sulfuric acid	D002	Waste sulfuric acid, spent	Corrosive material	NA1831
		D002	Waste ammonium hydroxide, < 12%	ORM-A	NA2672
	Ammonium hydroxide	D002	Waste ammonium hydroxide, ≥ 12% < 44%	Corrosive material	NA2672
		D002	Waste potassium hydroxide, solid	Corrosive material	UN1813
	Potassium hydroxide	D002	Waste potassium hydroxide, liquid	Corrosive material	UN1814
		D002	Waste sodium hydroxide, solid	Corrosive material	UN1823
	Sodium hydroxide	D002	Waste sodium hydroxide, liquid	Corrosive material	UN1824
	Others:	D009	Waste mercury	ORM-A	UN2809
	Mercury		Waste oxidizer, NOS	Oxidizer	UN1479
	Oxidizers		Waste oxidizer, corrosive, liquid, NOS	Oxidizer	NA9193
			Waste oxidizer, corrosive, solid, NOS	Oxidizer	NA9194
	Poisons		Waste poison B, liquid, NOS	Poison B	UN2810
			Waste poison B, solid, NOS	Poison B	UN2811
			Waste corrosive liquid, poisonous, NOS	Corrosive material	UN2922
	Poisonous, oxidizers		Waste poisonous solid, corrosive, NOS	Poison B	UN2928
	Nonspecific hazardous Wastes		Waste oxidizer, poisonous, liquid, NOS	Oxidizer	NA9199
			Waste oxidizer, poisonous, solid, NOS	Oxidizer	NA9200
			Hazardous waste liquid, NOS	ORM-E	NA9189
				ORM-E	NA9189

Table 43 (Cont'd)

Process Description		Waste Description			
Typical process/ operation	**Materials used/ wastes produced**	**HW code**	**DOT shipping name**	**Hazard class**	**Number**
Chemotherapy, pharmacy, clinics	Antineoplastics Cytotoxic drugs		Hazardous waste solid, NOS		UN2209 UN1198
Radiology	Photographic chemicals: Fixer Developer			ORM-A ORM-A	
Hemodialysis, Pathology, Autopsy, Embalming, Nursing	Formaldehyde		Waste formaldehyde solution, flash point > 141 °F Waste formaldehyde solution, flash point ≤ 141 °F		
Clinical Testing	Radioisotopes				

10 WASTE MINIMIZATION FOR OTHER SOURCE TYPES

Heating and Cooling Plants

Army installations have a number of heating and cooling plants that generate power and steam. Hazardous wastes are generated by using various combustible (e.g., cyclohexylamine) and corrosive (e.g., caustic soda, caustic potash, hydrochloric acid) chemicals to adjust pH, prevent scaling or corrosion, clean the interior of the boiler, and to test feedwater. In addition, boiler blowdown liquid mixed with water is a hazardous waste generated periodically. Waste oil blended with virgin fuel oil is burned in boilers at some installations. The waste oil may be a hazardous waste, depending on the content, and should be burned only in permitted facilities.

A number of efficiency related boiler maintenance procedures can be used to minimize environmental pollution, while correcting malfunctions in boiler operation and preventing performance degradation. Component malfunction or performance degradation can cause increases in: stack gas temperature; excess air requirements; carbon monoxide, smoke, or unburned carbon in ash; convection or radiation losses from the boiler exterior, ductwork, and piping; blowdown above that required to maintain permissible water concentrations; and auxiliary power consumption by fans, pumps, or pulverizers. In addition to the normal maintenance recommended by manufacturers, efficiency-related maintenance procedures must be performed to extend equipment life and for personnel safety. These procedures include:[154] efficiency spotchecks of combustion conditions, establishing best achievable performance goals, monitoring performance (boiler log) to document deviations, periodic equipment inspection, and troubleshooting. Boiler tuneups also improve efficiency and fuel conservation.

Some modifications to the boiler operating practices improve boiler efficiency, save fuel, and reduce continuous blowdowns. These practices include: reducing boiler steam pressures, controlling the water quality by continuous blowdowns instead of infrequent blowdowns, and proper load management. Efficient boiler operation also minimizes the amounts of air pollutants (particulates, carbon monoxide, nitrogen oxides, sulfur dioxide, hydrocarbons, and oxidants) released to the atmosphere.

Inventory management of chemicals and reducing their use in water treatment and scale removal minimizes the amounts of wastes produced. Nonhazardous substitutes must be developed and used instead of the combustible and corrosive chemicals normally found at heating and cooling plants.

Used Oil Burning

Used lubricating oil generated by vehicle maintenance activities can be recycled as a fuel and blended and burned in boilers. Before burning, however, it is necessary to determine if the oil meets fuel specifications (Table 44). Used oil that meets the specifications can be burned in any burner

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[154] *Efficient Boiler Operations Sourcebook*, F.W. Payne, Ed. (The Fairmont Press, Inc., Atlanta, GA, 1986), pp 79-106.

(space heater, nonindustrial boiler, industrial boiler, utility boilers, and industrial furnaces),[155] whereas other waste oils can only be burned in high-efficiency industrial boilers, industrial process furnaces, or boilers that have demonstrated compliance with performance standards set for hazardous waste incinerators. Nonspecification used oils can be blended with virgin oil to meet specifications and burned in an industrial or nonindustrial boiler.

It is necessary to test the used oil for halogen and heavy metal content before burning. Other treatment techniques such as filtration, oil-water separation, etc. (discussed in Chapter 5), must be used to improve the quality of the oil and its heating value.

Laundry and Drycleaning Facilities

Laundry and drycleaning facilities on a Army installation are the responsibility of the DOL. Caustic soda and other corrosive chemicals are used in the laundry. Perchloroethylene (PERC) is the most common drycleaning solvent used. The two other solvents used are Valclene™ (fluorocarbon 113 or tetrachloroethylene), and petroleum solvent (Stoddard). Use of solvents and corrosive chemicals in these processes results in the generation of contaminated wastewater and dry wastes (Table 45). Table 46 lists the wastes generated and the corresponding DOT classifications.

PERC drycleaning plants generate: (1) still residues from solvent distillation (entire weight), (2) spent filter cartridges (total weight of cartridge and solvent remaining after draining), and (3) cooked filter residue (the total weight of drained powder residue from diatomaceous or other powder filter systems after heating to remove excess solvent). Valclene plants generate still residues and spent filter cartridges. Petroleum solvent plants generate still residues only. Proper disposal is required for all the hazardous wastes generated at laundry and drycleaning facilities. Among the acceptable options are recycling, incineration, or disposal in an authorized hazardous waste landfill. However, source reduction by material substitution seems to be the most effective minimization technique for drycleaning operations. The possibility of replacing PERC or Valclene with Stoddard (PD680-II) or petroleum naptha must be explored. As is obvious from Table 45, using Stoddard produces the smallest amount of hazardous waste. If the petroleum solvent has a flash point greater than 140 °F, the wastes are not considered hazardous and are exempt from reporting requirements. Drycleaning plants generally have stills for continuous distillation of solvents, which are constantly recycled. However, the still bottoms must be disposed of properly.

Woodworking and Preserving

Table 47 lists the woodworking and preserving operations and corresponding waste classifications. Some of the wastes are generated by carpentry shops that manufacture or refinish wooden cabinets, softwood and hardwood veneer and plywood, household or office furniture, and other furniture (including reupholstery and repair). Typical wood preserving operations used to condition wood

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[155] Industrial boilers are defined as utility or power boilers used to supply heated or cooled air or steam for a manufacturing process, and are usually rated at greater than 25 x 10^6 Btu/hour. In addition to being located at a manufacturing facility, it must be a device using controlled flame combustion and have the following characteristics: (1) a combustion chamber and primary energy recovery section of integral design, (2) thermal energy recovery efficiency of at least 60 percent, and (3) at least 75 percent of recovered energy must be exported.
Utility boilers are boilers not located at a manufacturing facility and have the above listed characteristics. They must be used to generate electric power, steam, heated or cooled air, or other gases or fluids for sale.
Nonindustrial boilers are those that do not fall in the above two categories. They are subject to prohibition.

include: steaming, boultonizing, kiln or air drying (under pressure or vacuum), and applying agents such as creasote, pentachlorophenol (PCP), and other arsenical compounds.

Inventory control and management is an effective technique for minimizing hazardous wastes associated with woodworking and preserving. Proper disposal practices must also be used.

Pesticide Users

Army installations have a number of pesticide users including the entomology shop (pest control services), the garden shop (lawn, garden, and tree services), and the golf courses. Table 48 lists a variety of pesticides used and their waste classifications. Use of pesticides in activities ranging from protecting food and structures to pest and disease control, results in generation of hazardous rinsewater, empty containers with pesticide residue, unused pesticides, and possibly contaminated soil.

Very dilute rinsewaters or soil contaminated with very low concentrations may not be hazardous. However, chemical analysis is necessary to verify the concentrations. Pesticide containers are not a hazardous waste if they are triple rinsed. The rinsewater, however, is a hazardous waste. Some pesticides that contain flammable solvents or ignitable material are also hazardous wastes when discarded. A number of pesticides exhibit acute toxicity characteristics. Therefore, all the discarded and off-specification products, containers, and spill residues containing acute toxic species are listed as "P" hazardous wastes [40 CFR 261.33(e)]. All the hazardous material/wastes related to pesticides must be managed carefully to prevent environmental problems and to protect the health and safety of personnel.

The amounts of pesticide rinsewaters generated can be minimized by using multiple rinse tanks, installing drain boards and drip tanks, and recycling and reusing the water for rinsing.[156] Treatment methods include destruction with chlorine or lime, incineration, and carbon adsorption.[157] Minimization of empty containers and contaminated soil wastes is discussed in Chapter 11.

Open Burning/Open Detonation

Open burning/open detonation (OB/OD) is one option used to demilitarize ordnance containing propellants, explosives, and pyrotechnics (PEP). Other methods are washout/steamout/meltout and deactivation in a furnace. Ingredients of some common explosive compounds are listed in Table 49. OB/OD is the simplest and has been the primary method of demilitarization used at Army installations.[158] Active and inactive sites of OB/OD are commonly found. The environmental contaminants generated from OB/OD activity include gases and particles (carbon, soot, etc.) released into the atmosphere and as residues in soils. The soil residues are comprised mainly of undetonated PEP materials and combustion/detonation products. Table 50 lists the elements found in soils, including some that are regulated under RCRA and HSWA. Soils at all the active and inactive sites must be analyzed to determine the chemical content and proper disposal.

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[156] Ventura County Environmental Health, *Hazardous Waste Reduction Guidelines for Environmental Health Programs* (California Department of Health Services, Sacramento, CA, 1987).

[157] *Standard Handbook of Hazardous Waste Treatment and Disposal*, H.M. Freeman, Ed. (McGraw Hill, New York, NY, 1989).

[158] D.W. Layton, et al., *Demilitarization of Conventional Ordnance: Priorities of Data-Base Assessments of Environmental Contaminants*, UCRL-15902 (U.S. Army Medical Research and Development Command [USAMRDC], Fort Detrick, MD, 1986).

Some of the materials in the demilitarization inventories at installations may have a recovery value in excess of the cost of the original item because of the increase in material and manufacturing costs.[159] Recovery and reuse of such materials before burning will reduce raw material costs and production requirements, and, thereby, minimize wastes generated. A number of processes (e.g., resolvation of ground propellants, selective solvent extraction, disposal of scrap propellant, solution-pelletization, etc.) are available for recovery and reuse of propellants or their ingredients. Processing propellants by such reclamation techniques[160] minimizes environmental discharges, conserves strategic materials, and provides cost savings.

Under USEPA and State regulations, OB/OD is considered a treatment technique for hazardous wastes (ordnance). Therefore, installations are required to obtain a Part B permit. The generation of contaminated soil residues from OB/OD activity can be minimized by conducting the activity on steel "burn-pans" instead of on open ground. Incineration must also be explored as a possible minimization alternative. Controlled incineration allows for better control of air pollutants. However, proper disposal is required for residues generated in any of the operations.

Firefighting and Training

Aqueous film forming foam (AFFF) is considered a hazardous material in a number of states. Firefighting operations that use AFFF must be replaced with nonhazardous substitutes. All other wastes generated by maintenance of fire trucks and other equipment can be minimized by methods discussed in Chapters 5 and 6.

Another waste generated from fire training activities is contaminated soils in the training pits. Typically, contaminated fuel (e.g., JP-4, gasoline) is used to generate a fire in the pits for training exercises. The soil from the pits must be analyzed for chemical contaminants and properly disposed of.

Underground Storage Tanks (USTs)

Discovery of a number of leaking USTs throughout the United States prompted Congress to add Subtitle I to RCRA in 1984. Subtitle I requires the USEPA to develop regulations for leaking USTs to safeguard human health and environment. In September 1988, USEPA finalized the UST rules and regulations[161] that cover the technical requirements for designing, installing, testing, and monitoring USTs, and the requirements for cleanup following releases from leaking USTs. Many USTs are located on each Army installation. They must all be tested for leaks and any leaking tanks must be managed according to the rules. Proper management of USTs will minimize the quantities of vapor emissions, soil contamination, and potential groundwater contamination.

A data base of information of Army-owned USTs was developed at USACERL.[162] Many of the Army's USTs are more than 30 years old, greater than 10,000 gal, may contain hazardous substances, are made of steel, and have a high potential for leakage. A leak potential index (LPI)

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[159] D.W. Layton, et al.

[160] F.W. Nester and L.L. Smith, *Propellant Reuse Technology Assessment*, AMXTH-TE-CR-86076 (USATHAMA, Aberdeen Proving Ground, MD, 1986).

[161] 40 CFR Parts 280-281, *Underground Storage Tanks: Technical Requirements and State Program Approval; Final Rule*, pp 37081 - 37247.

[162] B.A. Donahue, T.J. Hoctor, and K. Piskin, *Managing Underground Storage Tank Data Using dBase III Plus*, Technical Report N-87/21/ADA182452 (USACERL, June 1987).

associated with the data base has been devised to indicate the likelihood of individual tank leakage.[163] The LPI is a tool that enables tank managers to group tanks based on the likelihood of leaks. This information indicates which tanks should be monitored more closely, which should be tested, and which should be considered for replacement.

The HAZMIN technique of inventory control is very effective in detecting tank leaks. This method requires regular measurement of the level of substances in the tanks. Records must also be maintained concerning addition and withdrawl of products. Comparison of inflow, outflow, and the inventory indicates product loss. Other leak detection methods can be grouped into volumetric methods, nonvolumetric methods, and leak effects monitoring.[164] Volumetric methods measure the change in volume with time and are the most fully developed and popular. Site-specific decisions have to be made regarding the use of the most appropriate leak detection method. Nonvolumetric methods measure changes in a variable, such as a tracer gas or acoustic signal, to determine changes in the level of the tank contents. Leak effects monitoring refers to methods used to determine leaks in the surrounding environment (e.g., soil vapor analysis).

Table 44

Used Oil Fuel Specifications*

Constituent or Property	Allowable Level
Arsenic	5 mg/kg maximum
Cadmium	2 mg/kg maximum
Chromium	10 mg/kg maximum
Lead	100 mg/kg maximum
Total Halogens	4,000 mg/kg maximum**
Flashpoint	37.7 °C (100 °F) minimum

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[163] S. Dharmavaram, et al., "A Profile and Management of the U.S. Army's Underground Storage Tanks," *Environmental Management*, Vol 13 (1989), pp 333-338.

[164] J. Makwinski and P.N. Cheremisinoff, "Special Report: Underground Storage Tanks," *Pollution Engineering*, Vol 20 (1988), pp 60-69.

* Source: Federal Register, Vol 50, No. 23, pp 49,164 - 49,249.

** Used oil containing more than 1000 mg/kg total halogens must be shown not to have been mixed with hazardous waste. This is called the "rebuttable presumption."

Table 45

Amounts of Typical Hazardous Wastes Generated from Drycleaning Operations*

Waste Type	Cleaning Solvent**		
	PERC	**Valclene**	**Stoddard**
Still Residues	25	10	20
Spent Cartridge Filters			
Standard (carbon core)	20	15	***
Adsorptive (split)	30	20	***
Cooked Powder Residue	40	n/a	n/a
Drained Filter Muck	n/a	n/a	***

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* Source: H. Winslow, *Hazardous Waste SQG Workbook* (Intereg Group, Inc., Chicago, IL, 1986), p 144.

** In pounds per 1000 pounds of clothes cleaned.

*** Well-drained filter cartridges and filter muck are solids that do not meet the criteria for classification as an ignitable solid, and are therefore not considered hazardous wastes.

Table 46

Drycleaning and Laundry Operations and Wastes Classification*

Process/ operation	Materials used	Waste Description			
		HW code	**DOT shipping name**	**Hazard class**	**Number**
Drycleaning	PERC	F002	Waste perchloroethylene or waste tetrachloroethylene	ORM-A	UN1897
	Valclene	F002	Hazardous waste liquid or solid, NOS	ORM-E	UN9189
	Petroleum solvents	D001	Waste petroleum distillate	Combustible liquid	UN1268
			Waste petroleum naptha	Combustible liquid	UN1255
Laundering	Caustic soda	D002	Waste sodium hydroxide	Corrosive material	UN1824
	Cleaning compound	D001	Hazardous waste liquid, NOS	Flammable liquid	UN9189

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*Source: *Drycleaning and Laundry Plants*, Hazardous Waste Fact Sheet (Small Quantity Generators Activity Group, Minnesota Technical Assistance Program, University of Minnesota, Minneapolis, MN, 1988).

Table 47

Wastes Classification: Woodworking and Preserving Operations*

Process/ operation	Materials used	Waste Description			
		HW code	DOT shipping name	Hazard class	Number
Wood cleaning and wax removal	Petroleum distillates	D001	Waste flammable liquid	Flammable liquid	UN1993
	White spirits	D001	Waste naptha	Combustible liquid	UN2553
			Waste naptha solvent	Flammable liquid	UN2553
			Waste naptha solvent	Combustible liquid	UN1256
				Flammable liquid	UN1256
Refinishing/ stripping; brush cleaning and spray gun cleaning	Paint strippers (containing methylene chloride)	F002	Hazardous waste liquid or waste methylene chloride	ORM-E ORM-A	UN2553 UN1593
	Paint removers (containing distillates, acetone, toluene)	D001	Waste flammable liquid, NOS	Flammable liquid	UN1993
	Paint removers (containing caustic)	D002	Corrosive liquid	Corrosive material	NA1760
Staining	Stains (mineral spirits, alcohols, pigments)	D001	Waste flammable liquid	Flammable liquid	UN1993
Painting	Paints (enamels, lacquers, epoxy, alkyds, acrylics)	D001	Waste paint or enamel liquid	Flammable liquid	UN1263
Finishing	Varnish, shellac, lacquer	D001	Waste flammable liquid, NOS	Flammable liquid	UN1993
Preserving	Creosote	K001	Hazardous waste liquid or solid, NOS	ORM-E	NA9189
	Pentachlorophenol	K001	Waste pentachlorophenol, liquid or solid	ORM-E	NA2020
	Chromated copper arsenate	D004/ D007	Waste arsenical compounds, liquids	Poison B	UN1557
	Ammoniacal copper arsenate	D004	Waste arsenical compounds, solids	Poison B	UN1556
			Waste arsenical compounds, liquids	Poison B	UN1557
			Waste arsenical compounds, solids	Poison B	UN1556
	Other wood preservatives	Varies	Hazardous waste liquid or solid, NOS	ORM-E	NA9189

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*Source: H. Winslow, *Hazardous Waste SQG Workbook* (Intereg Group, Inc., Chicago, IL, 1986), pp 146-147.

Table 48

Waste Classification: Pesticides*

		Waste Description		
Process/operation	**Materials used**	**DOT shipping name**	**Hazard class**	**Number**
Pesticides Containing Arsenic:				
Arsenic pentoxide	Arsenic acid anhydride Arsenic (V) oxide	Waste arsenic pentoxide, solid	Poison B	UN1559
Arsenic trioxide	Arsenic sesquioxide Arsenic (III) oxide Arsenous acid (anhydride) White arsenic	Waste arsenic trioxide, solid	Poison B	UN1561
Cacodylic acid	Hydroxydimethylarsine oxide	Waste arsenical pesticide, solid, NOS[3]	Poison B	UN2759
	Dimethylarsinic acid	Waste arsenical pesticide, liquid, NOS	Poison B	UN2759
	Phytar	Waste arsenical pesticide, liquid, NOS	Flammable liquid	UN2760
Monosodium Methanearsonate	MSMA Ansar 170 H.C. and 529 H.C.	Waste arsenical pesticide, solid, NOS	Poison B	UN2759
	Arsanote liquid Bueno 6	Waste arsenical pesticide, liquid, NOS	Poison B	UN2759
	Daconate 6 Dal-E-Rad Herb-All Merge 823 Mesamate Monate Trans-Vert Weed-E-Rad Weed-Hoe	Waste arsenical pesticide, liquid, NOS	Flammable liquid	UN2760
Disodium Monomethanearsonate	DSMA	Waste arsenical pesticide, solid, NOS	Poison B	UN2759
	Ansar 8100	Waste arsenical pesticide, liquid, NOS	Poison B	UN2759
	Arrhenal Arsinyl Dinate Di-Tac DMA Methar 30 Sodar Versar DSMA-LQ Weed-E-Rad	Waste arsenical pesticide, liquid, NOS	Poison B	UN2759

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*Source: H. Winslow, *Hazardous Waste SQG Workbook* (Intereg Group, Inc., Chicago, IL 1986), pp 150-161.

Table 48 (Cont'd)

		Waste Description		
Process/operation	**Materials used**	**DOT shipping name**	**Hazard class**	**Number**
Pesticides Containing Carbamates:				
Temik	Aldicarb	Waste carbamate pesticide, solid, NOS	Poison B	UN2757
	OMS 771	Waste carbamate pesticide, liquid, NOS	Poison B	UN2757
	UC 21149	Waste carbamate pesticide, liquid, NOS	Flammable liquid	UN2758
Pesticides Containing Mercury				
2-Methoxyethyl-mercuric Chloride	MEMC Agallol Cekusil Universal-C Ceresan-Universal-Nassbeize Emisan 6	Waste mercury based pesticide, solid, NOS	Poison B	UN2777
		Waste mercury based pesticide, liquid, NOS	Poison B	UN2777
		Waste mercury based pesticide, liquid, NOS	Flammable liquid	UN2778
Phenylmercuric acetate	PMA PMAS Agrosan Cekusil Celmer Gallotox Hong Nien Liquidphene Mersolite Pamisan Phix Seedtox Shimmer-ex Tag HL 331	Waste mercury based pesticide, solid, NOS	Poison B	UN2777
		Waste mercury based pesticide, liquid, NOS	Poison B	UN2777
		Waste mercury based pesticide, liquid, NOS	Flammable liquid	
Pesticides Containing Substituted Nitrophenols:				
Dinitrocresol	DNC DNOC Chemset Detal Elgetol 30 Nitrador Selinon Sinox Trifocide Trifrina	Waste substituted nitrophenol pesticide, solid, NOS	Poison B	UN2779
		Waste substituted nitrophenol pesticide, liquid, NOS	Poison B	UN2779
		Waste substituted nitrophenol pesticide, liquid, NOS	Flammable liquid	UN2780
Dinoseb	DNBP Basanite Caldon Chemox general Chemox PE Dinitro Dinitro general Dynamite Elgetol 318 Gebutox	Waste substituted nitrophenol pesticide, solid, NOS	Poison B	UN2779
		Waste substituted nitrophenol pesticide, liquid, NOS	Poison B	UN7890
		Waste substituted nitrophenol pesticide, liquid, NOS	Flammable liquid	UN2780

Table 48 (Cont'd)

		Waste Description		
Process/operation	**Materials used**	**DOT shipping name**	**Hazard class**	**Number**
Dinoseb (Cont'd)	Hel-Fire			
	Nitropone C			
	Premerge 3			
	Sinox general			
	Subitex			
	Vertac general weed killer			
	Vertac selective weed killer			
Organophosphate pesticides:				
Dimetboate	AC-12880	Waste organophosphorous pesticide, solid, NOS	Poison B	UN2783
	Bi 58 EC			
	Cekuthoate	Waste organophosphorous pesticide, liquid, NOS	Poison B	UN2783
	Cygon			
	Daphene	Waste organophosphorous pesticide, liquid, NOS	Flammable liquid	UN2784
	De-Fend			
	Demos-L40			
	Devigon			
	Dimet			
	Dimethogen			
	Perfekthion			
	Rebelate			
	Rogdial			
	Rogor			
	Roxion			
	Trimetion			
Disulfoton	Bay 19639 and S276	Waste disolfoton	Poison B	NA2783
	Dithiodemeton	Waste disulfoton mixture, dry	Poison B	NA2783
	Dithiosystox	Waste disulfoton mixture, liquid	Poison B	NA2783
	Di-Syston	Waste organophosphorous pesticide, liquid, NOS	Flammable liquid	UN2784
	Ethylthiodemeton			
	Frumin AL			
	M-74			
	Solvirex			
	Thiodemeton			
Famphur	Bash	Waste organophosphorous pesticide, solid, NOS	Poison B	UN2783
	Bo-Ana			
	Dovip	Waste organophosphorous pesticide, liquid, NOS	Poison B	UN2783
	Famfos			
	Warbex	Waste organophosphorous pesticide, liquid, NOS	Flammable liquid	UN2784
Methylparathion	Cekumethion	Waste methyl parathion, liquid	Poison B	NA2783
	E-601	Waste methyl parathion mixture, dry	Poison B	NA2783
	Devithion	Waste methyl parathion mixture, liquid, (containing 25% or less methylparathion)	Poison B	NA2783
	Folidon M			
	Fosferno M50			
	Gearphos	Waste methyl parathion mixture, liquid, (containing more than 25% methylparation)	Poison B	NA2783
	Methacide			
	Metaphos			
	Nitrox 80	Waste organophosphorous pesticide, liquid, NOS	Flammable liquid	UN2784
	Parataf			
	Paratox			
	Partron M			

Table 48 (Cont'd)

Process/operation	Materials used	Waste Description		
		DOT shipping name	Hazard class	Number
Methylparathion (Cont'd)	Penncap-M Wofatox			
Parathion	AC-3422 Alkron Alleron Aphamite Bladan Corothion E-605 ENT 15108 Ethyl parathion Etilon Folidol E-605 Fosterno 50 Niran Orthophos Panthion Paramar Paraphos Parathene Parawet Phoskil Rhodiatox Soprathion Stathion Thiophos	Waste parathion, liquid Waste parathion mixture, dry Waste parathion mixture, liquid Waste organophosphorous pesticide, liquid, NOS	Poison B Poison B Poison B Flammable liquid	NA2783 NA2783 NA2783 UN2784
Strychnine Pesticides:				
Strychnine	Strychnine salts	Waste strychnine, solid Waste strychnine salt, solid	Poison B Poison B	UN1692 UN1692
Thallium Sulfate Pesticides:				
Thallium sulfate	Thallous sulfate Ratox Zelio	Waste thallium sulfate, solid Waste flammable liquid, poisonous, NOS	Poison B Flammable liquid	NA1707 UN1992
Triazine Pesticides:				
Amitrole	Amerol Amino triazol weedkiller 90 Amizol AT-90 AT liquid Azolan Azole Cytrol Diurol Farmco Herbizole Simazol Weedazol Weedazol TL	Waste triazine pesticide, solid, NOS Waste triazine pesticide, liquid, NOS Waste triazine pesticide, liquid, NOS	Poison B Poison B Flammable liquid	UN2763 UN2763 UN2764

Table 48 (Cont'd)

		Waste Description		
Process/operation	**Materials used**	**DOT shipping name**	**Hazard class**	**Number**
Flammable Solvents Used in Pesticides:				
Methyl alcohol	Methanol	Waste methyl alcohol	Flammable liquid	UN1230
Ethyl alcohol	Ethanol Alcohol	Waste ethyl alcohol	Flammable liquid	UN1170
Isopropyl alcohol	Isopropanol	Waste isopropanol	Flammable liquid	UN1219
Toluene	Methyl benzene Toluol	Waste toluene (tuluol)	Flammable liquid	UN1294
Xylene	Dimethyl benzene Xylol	Waste xylene (xylol)	Flammable liquid	UN1307
Solvent mixtures		Waste combustible liquid, NOS Waste flammable liquid, NOS	Combustible liquid Flammable liquid	NA1993 UN1993
Phenoxy Pesticides:				
2,4-D	Amoxone Brush Killer Brush-Rhap Chloroxone Crop Rider D50 DMA 4 Dacamine Ded-Weed Desormone Dinoxol Emulsamine BK and E3 Envert DT and 171 Hedonal Miracle Pennamine D Rhodia Salvo Super-D Weedone Verton Visko-Rhap Weed Tox Weed-B-Gone Weed-Rhap Weedar Weedone Weedtrol	Waste 2,4-dichlorophenoxyacetic acid Waste 2,4-dichlorophenoxyacetic acid ester Waste phenoxy pesticide, liquid, NOS	ORM-A ORM-E Flammable liquid	NA2765 NA2765 UN2766
2.4,5-T	Brush-Rhap Dacamine Ded-Weedon Esteron Farmco Fence Rider Forron Inverton 245 Line Rider	Waste 2.4,5-trichlorophenoxyacetic acid Waste 2.4,5-trichlorophenoxyacetic acid (amine, ester, or salt) Waste phenoxy pesticide, liquid, NOS	ORM-A ORM-E Flammable liquid	NA2765 NA2765 UN2766

Table 48 (Cont'd)

Process/operation	Materials used	Waste Description		
		DOT shipping name	Hazard class	Number
2.4,5-T (Cont'd)	Super D Weedone			
	Tormona			
	Transamine			
	U 46			
	Veon 245			
	Weedar			
	Weedone			
Silvex	2.4,5-TP	Waste 2-(2.4.5-trichlorophenoxy) propionic acid	ORMA-A	NA2765
	Fenoprop			
	AquaVex	Waste 2-(2.4.5-trichlorophenoxy) propionic acid ester	ORM-E	NA2765
	Double Strength			
	Fruitone T	Waste phenoxy pesticide, liquid, NOS	Flammable liquid	UN2766
	Kuron			
	Kurosal			
	Silver-Rhap			
	Weed-B-Gone			
Organochlorine Pesticides:				
Aldrin	HHDN	Waste aldrin	Poison B	NA2761
	Aldrex 30			
	Aldrite	Waste aldrin mixture, dry (with more than 65% aldrin)	Poison B	NA2761
	Aldrosol			
	Altox	Waste aldrin mixture, liquid (with or less aldrin)	ORM-A	NA2761
	Drinox			
	Octalene	Waste aldrin mixture, liquid (with more than 60% aldrin)	Poison B	NA2762
	Seedrin liquid			
		Waste aldrin mixture, liquid (with 60% or less aldrin)	ORM-A	NA2762
		Waste organchlorine pesticide, liquid, NOS	Flammable liquid	UN2762
Chlordan	Belt	Waste chlordane, liquid	Flammable liquid	NA2762
	Chlordan			
	ChlorKil	Waste chlordane, liquid	Combustible liquid	NA2762
	Chlortox			
	Corodane			
	Gold Crest C-100			
	Kypchlor			
	Vesicol 1068			
	Topiclor 20			
	Niran			
	Octachlor			
	Octa-Klor			
	Ortho-Klor			
	Synklor			
	Termi-Ded			
DDT	Dedelo	Waste DDT	ORM-A	NA2761
	Didimac			
	Digmar	Waste organochlorine pesticide, liquid, NOS	Flammable liquid	UN2762
	Genitox			
	Gyron			
	Gildit			
	Kopsol			
	Neocid			

Table 48 (Cont'd)

		Waste Description		
Process/operation	**Materials used**	**DOT shipping name**	**Hazard class**	**Number**
DDT (Cont'd)	Pentachlorin Rukseam Zerdand			
Dichloropropene	1.3-dichloropropene Telone II Soil Fumigant	Waste dichloropropene	Flammable liquid	UN2047
Dieldrin	Dieldrex Dieldrite Octalox Panoram D-31	Waste dieldrin Waste organochlorine pesticide, liquid, NOS	ORM-A Flammable Liquid	NA2761 UN2762
Endrin	Endrex Hexadrin	Waste Endrin Waste Endrin mixture, liquid Waste organochlorine pesticide, liquid, NOS	Poison B Poison B Flammable liquid	NA2761 NA2761 UN2762
Endosulfan	Beosit Chlorthiepin Crisulfan Cyclodan Endocel EnSure FMC 5462 Hildan Hoc 2671 Malix Thifor Thimul Thiodan Thiofor Thionex Tiovel	Waste Endosulfan Waste Endosulfan mixture, liquid Waste organochlorine pesticide, liquid, NOS	Poison B Poison B Flammable liquid	NA2761 NA2761 UN2762
Heptachlor	Gold Crest H-60 Drinox H-34 Heptamul Heptox Chlordecone	Waste Heptachlor Waste organochlorine pesticide, liquid NOS	ORM-E Flammable liquid	NA2761 UN2762
Kepone	Exagama Forlin	Waste Kepone Waste organochlorine pesticide, liquid, NOS	ORM-E Flammable liquid	NA2761 UN2762
Lindane	Gallogama Gamaphex Gammex Inexn Isotox Lindafor Lindagam Lindagrain Lindagranox Lindalo Lindamul Lindapoudre	Waste Lindane Waste organochlorine pesticide, liquid, NOS	ORM-A Flammable liquid	NA2761 UN2762

Table 48 (Cont'd)

		Waste Description		
Process/operation	**Materials used**	**DOT shipping name**	**Hazard class**	**Number**
Lindane (Cont'd)	Lindaterra			
	Novigam			
	Silvanol			
Methoxychlor	Flo Pro McSeed Protectant	Waste Methoxychlor	ORM-E	NA2761
	Marlate	Waste organochlorine pesticide, solid, NOS	Poison B	UN2761
		Waste organochlorine pesticide, liquid, NOS	Poison B	UN2761
		Waste organochlorine pesticide, liquid, NOS	Flammable liquid	UN2762
Propylene Dichloride	1.2-dichloropropane	Waste propylene dichloride	Flammable liquid	UN1279
Toxaphene	Attac 4-2, 4-4, 6, 6-3, 8	Waste toxaphene	ORM-A	NA2761
	Camphochior	Waste organochlorine pesticide, liquid, NOS	Flammable liquid	UN2762
	Motox			
	Phenacide			
	Phenatox			
	Strobane T-90			
	Toxakil			
	Toxon			
Other Pesticides:				
Thiram	TMTD	Waste Thiram	ORM-A	NA2771
	AAtack	Waste flammable liquid, poisonous, NOS	Flammable liquid	UN1992
	Arasan			
	Aules			
	Evershield T Seed Protectant			
	Fermide 850			
	Fernasan			
	Flo Pro T Seed Protectant			
	Hexathir			
	Mercuram			
	Nomersan			
	Pomarsolforte			
	Polyram-Ultra			
	Spotrete-F			
	Tetrapom			
	Thimer			
	Thionock			
	Thiotex			
	Thiramad			
	Thiuramin			
	Tirampa			
	Trametan			
	Tripomol			
	Thylate			
	Tudas			
	Vancide TM			
Warfarin	Co-Rax	Hazardous waste solid, NOS	ORM-E	NA9189
	Cov-R-Tox			
	Kypfarin	Hazardous waste liquid, NOS	ORM-E	NA9189
	Liqua-Tox			

Table 48 (Cont'd)

Process/operation	Materials used	Waste Description DOT shipping name	Hazard class	Number
Warfarin (Cont'd)	RAX	Waste flammable liquid, NOS	Flammable liquid	UN1993
	Rodex			
	Rodex Blax	Waste combustible liquid, NOS	Combustible liquid	NA1993
	Tox Hid			
Pentachlorophenol	PCP	Waste pentachlorophenol	ORM-E	NA2020
	Penta			
	Penchlorol	Waste flammable liquid, NOS	Flammable liquid	UN1993
	Pentacon			
	Penwar	Waste combustible liquid, NOS	Combustible liquid	NA1993
	Sinitudo			
	Santophen			
Pentachloronitrobenzene	PNCB	Hazardous waste, solid	ORM-E	NA9189
	Avicol			
	Botrilex	Hazardous waste, liquid	ORM-E	NA9189
	Brassicol			
	Earthcide	Waste flammable liquid, NOS	Flammable liquid	UN1993
	Folosan			
	Kobu	Waste combustible liquid, NOS	Combustible liquid	NA1993
	Pentagen			
	Saniclor 30			
	Terraclor			
	Tilcarex			
	Tritesan			
Hexachlorobenzene	Perchlorobenzene	Hazardous waste, solid	ORM-E	NA9189
	Anticarie			
	Ceku C.B.	Hazardous waste, liquid	ORM-E	NA9189
	HCB			
	No Bunt	Waste flammable liquid, NOS	Flammable liquid	UN1993
	DBCP	Waste combustible liquid, NOS	Combustible liquid	NA1993
1,2-Dibromo 3-Chloropropane	Nemafume	Hazardous waste, solid, NOS	ORM-E	NA9189
	Nemanox	Hazardous waste, liquid, NOS	ORM-E	NA9189
	Nemaset	Waste flammable liquid, NOS	Flammable liquid	UN1993
	Nematocide	Waste combustible liquid, NOS	Combustible liquid	NA1993

Table 49

Ingredients Contained in Propellants, Explosives, and Pyrotechnics

Compound	Type
2,4,6-Trinitrotoluene (TNT)	EX*
Cyclotrimethylenetrinitramine (RDX)	EX
Pentaerythritol Tetranitrate (PETN)	EX
2,4,6-Trinitrophenylmethylnitramine (Tetryl)	EX
Ammonium Picrate (Explosive D)	EX
Cyclotetramethylenetetranitramine (HMX)	EX
2,4-Dinitrotoluene (DNT)	PP
Nitroglycerin (NG)	PP
Nitroguanidine (NQ)	PP
Dibutyl phthalate	PP
Diethyl phthalate	PP
Diphenylamine	PP
Benzene	EX
Toluene	EX
Sodium Nitrate	PY
Barium Nitrate	PY
Magnesium Nitrate	PY
Strontium Peroxide	PY
Strontium Oxalate	PY
Calcium Resinate	PY

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*EX = explosives; PP = propellants; PY = pyrotechnics.

Table 50

Common Elements Found in PEP and OB/OD Soil Residue

Element	OB	OD
	% of samples greater than EP toxic limits	
Strontium		
Cadmium	2.5	1.3
Arsenic	0.3	0.0
Antimony		
Lead	6.0	0.7
Mercury	0.6	0.0
Barium		

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*Source: D.W. Layton, p 29.

11 WASTE MINIMIZATION FOR MISCELLANEOUS WASTES

Polychlorinated Biphenyls

PCBs are chlorinated organic compounds with a wide range of physical properties. There are 209 possible PCBs of which tri-, tetra-, penta-, and hexachloro biphenyls are the most important. They were commonly used in coolants and insulation fluids in transformers. Some of the older products that may contain PCBs or oils with PCBs include: heat-transfer fluids, lubricants, paints, plastics, air conditioners, fluorescent lights, and televisions. PCBs were most widely used in capacitors and transformers because of their low conductivity and thermal stability.

In several cases of poisoning in Japan and Taiwan, PCBs and their secondary products such as polychlorinated dibenzofurans were found to be the major contaminants in bran oil used to cook rice. Since then, PCBs have been linked to severe health problems (e.g., gastric disorders, skin lesions, swollen limbs, cancers, tumors, eye problems, liver disorders, menstrual irregularities, etc.) and birth defects (e.g., reproductive failures, mutations, etc.). Compounding the problem of PCBs' toxicity is their bioaccumulation in cells and fatty tissues of micro-organisms and animals, which are then consumed by other animals higher in the food chain.

PCBs are regulated by the Toxic Substances Control Act (TSCA) passed in 1976. Manufacture of PCBs was banned under TSCA and deadlines were provided for removing capacitors and transformers containing PCBs. One year was allowed for storage before disposal. If regulatory agencies determine that the use of PCB transformers poses no risk, the use will be allowed to continue. All capacitors were to have been removed by October 1988, and transformers of certain size in or near commercial buildings should be removed by October 1990.

If the concentration of PCBs in a product is greater than 50 parts per million (ppm), the product is regulated as hazardous under TSCA. Some States have set limits that are stricter than Federal limits (e.g., California, 5 ppm).

PCBs in Transformers

In the United States, there are 150,000 askarel (nonflammable electrical fluid) transformers, each of which contains thousands of pounds of PCBs with a wide range of concentrations.[165] Many of these tranformers develop leaks.

The transformers are generally classified as: PCB transformers (greater than 500 ppm), PCB-contaminated transformers (50 to 500 ppm), and Non-PCB transformers (less than 50 ppm). PCB transformers must be inspected quarterly for leaks; detailed records must be kept. No maintenance work involving removal of the coil or casing is allowed. PCB-contaminated transformers must be inspected annually. Their requirements for maintenance and recordkeeping are less restrictive than for PCB transformers. Non-PCB transformers are exempt from regulation.

The importance of analyzing all transformers for PCBs must be stressed. All the transformers on an installation must be inventoried and tested for PCBs. If the PCB levels are greater than 50 ppm, appropriate actions must be taken.

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[165] P.N. Cheremisinoff, "High Hazard Pollutants: Asbestos, PCBs, Dioxins, Biomedical Wastes," *Pollution Engineering*, Vol 21 (1989), pp 58-65.

PCB Wastes Management

There are no minimization options available for PCB wastes. Recycling of PCBs is illegal. Nevertheless, containers and oils contaminated with PCBs may be recycled if the PCBs are removed.

Federal regulations require that PCBs be destroyed in approved high-temperature incinerators. Oils containing 50 to 500 ppm PCBs can be burned in high-efficiency boilers. Alternate technologies capable of operating at the high incinerator efficiencies, such as the molten salt processes or UV/Ozonation may also be considered for "ultimate" treatment/disposal. In addition to incineration, which is the most common, chemical dechlorination technologies have also been successful. Table 51 lists the names and addresses of incineration facilities and available chemical dechlorination services.

The most common practice at Army installations is to retain PCB transformers in service until the end of their useful life or they leak. They are then replaced with non-PCB transformers. The other possible options that may be available are decontaminating and/or retrofilling the transformers. Table 52 lists the names and addresses of companies that provide retrofilling services.

USACERL's PCB Transformer System

A computer-aided, fate-decision analysis tool was developed at USACERL to help users make decisions about transformers containing PCB levels greater than 50 ppm. The computer model is available to Army users through the Environmental Technical Information System (ETIS) on the mainframe computer at USACERL. A PC-based model is also available.[*]

The model provides users with information about PCBs and appropriate regulations, and allows them to input information for risk assessment, fate-decision analysis, and life cycle cost analysis. The options considered in the final economic analysis are: retaining, retrofilling, decontaminating, and replacing transformers.

Onsite Mobile Treatment Units

Mobile incineration and chemical dechlorination units can decontaminate insulating oils from transformers. One dechlorination process, the "PCBX" process developed by ENSR, is a self-contained continuous-flow unit. It is designed and equipped to destroy PCBs (up to 2600 ppm) from transformer oil without moving the transformer. The operating capacity of the unit is up to 600 gallons per hour. Exceltech, Inc., based in California, also markets mobile dechlorination units for removing PCBs from transformers.

Lithium Batteries

Lithium batteries are discarded from troop equipment that uses batteries as a reserve power source. Six types of primary lithium batteries are commonly used: Li-CuO, Li-nnO2, Li-(CFx)n, Lithium Sulfur dioxide (Li-SO2), Li-SO2Cl2, and Lithium thionyl chloride (Li-SOCl2).

The U.S. Navy has proposed the development of a center of excellence to develop a fully permitted state-of-the-art, portable disposal technology for world-wide utilization.[166] A study conducted

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[*] For information, contact Bernard Donahue or Keturah Reinbold at USACERL-EN, P.O. Box 4005, Champaign, IL 61824-4005, or telephone 800-USACERL (outside Illinois) 800-252-7122 (within Illinois).

[166] Comarco, Inc., *U.S. Navy Lithium Battery Disposal*, Report No. CESD-88-179 (Prepared for the Naval Weapons Support Center, High Energy Battery Systems Branch, Crane, IN, January 1989).

by USAEHA to evaluate the disposal of lithium batteries under RCRA regulations,[167] noted that fully charged and duty-cycle discharge batteries were hazardous because of reactivity and/or ignitability characteristics and must be discharged through the DRMO. Fully discharged batteries are not hazardous and could be disposed of in a permitted landfill. Assurances must be sought that the batteries have reached their fully discharged state. Manual discharging methods such as soaking in an aqueous solution are not practical and alternative approaches must be explored.

A recent review presents general information regarding lithium batteries.[168] It includes information about battery technology, safety aspects, purchasing, packaging, transport, storage, and disposal.

Ordnance

A number of hazardous ordnance materials are used on Army installations. Ingredients contained in some of them were listed in Table 49. Further details are available in Technical Manual (TM) 9-1300-214.[169] Army directives prohibit burial of ordnance materials or dumping them in waste places, pits, wells, marshes, shallow streams, rivers, inland waterways, or at sea. All existing locations of buried explosives must be identified and marked accordingly. The only means of disposal available is destruction by burning and detonation (discussed in Chapter 10). Proper operating procedures for disposal of discarded ordnance materials should be developed and updated frequently to comply with Federal, State, and local regulations.

Contaminated Soil

Contaminated soil is generated because of leaks or spills of hazardous materials. Some effective source reduction techniques include: installing splash guards and dry boards on equipment, preventing tank overflow, using bellow sealed valves, installing spill basins, using seal-less pumps, secondary containment, plant maintenance, and personnel training to develop good operating practices.

A number of nonthermal and thermal treatment techniques are available for decontamination of soil.[170] Nonthermal techniques include: aeration, biodegradation, carbon adsorption, chemical dechlorination, solvent extraction, stabilization/fixation, and ultraviolet photolysis. Thermal treatment techniques include: stationary rotary-kiln incineration, mobile rotary-kiln incineration, liquid injection incineration, fluidized bed incineration, high-temperature fluid-wall destruction, infrared incineration, supercritical-water oxidation, plasma-arc pyrolysis, and in situ vitrification.

Empty Containers

Containers with residual hazardous materials/wastes must also be treated as hazardous wastes. Under HSWA, if a container with hazardous residue is found in a cleanup (Superfund) site or other landfill, the generator (Army) is liable and has to pay for part of the cost of cleanup. Even "triple rinsed" containers could contain some residue. Scrap dealers and landfills are becoming reluctant to accept "clean" empty 55-gal drums or other containers.

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[167] *Evaluation of Lithium Sulfur Dioxide Batteries, US Army Communications - Electronics Command and US Electronics Research and Development Command, Fort Monmouth, New Jersey*, USAEHA-37-26-0427-85 (USAEHA, Aberdeen Proving Ground, MD, 1985).

[168] W.N. Garrard, *Introduction to Lithium Batteries*, MRL-GD-0018; DODA-AR-005-652 (Materials Research Laboratory, Ascot Vale, Australia, 1988).

[169] Technical Manual (TM) 9-1300-214, *Military Explosives* (Headquarters, Department of the Army, 20 September 1984).

[170] *Standard Handbook of Hazardous Waste Treatment and Disposal.*

The problem of disposing of empty drums and containers can be minimized by giving careful consideration to the kinds and sizes of containers in which materials are originally received. When purchasing materials in bulk, the suppliers must be asked to send them in rinsable and/or recyclable containers. A number of commercial recyclers (listed in Regional Waste Exchange bulletins/newsletters or directories) accept containers less than 30 gal.[171] Treating empty containers by triple rinsing is a good waste minimization technique. However, the rinsate, if hazardous, must be properly managed.

Some of the other options to consider when procuring materials, and in the ultimate disposal of containers, are:[172] returning drums to suppliers, contracting with a drum conditioner, contracting with a scrap dealer, and, lastly, disposal in an approved landfill.

Returning Drums to Suppliers

When buying material, a purchase agreement must be established to include the option of returning empty containers to the suppliers. Cash deposits may be required and drums should be maintained in good condition. All the accessories, such as bungs, rings, and closures, must also be kept and returned with the drums.

Contracting With a Reconditioner

If the suppliers do not sell chemicals in returnable drums, ask them to send materials in heavy steel (18 to 20 gauge) drums that can be reconditioned when "empty." A typical 55-gal heavy drum should have a 20-gauge side and 18-gauge ends. A good market exists for these drums and they can be sent to reconditioning contractors for minimal or no cost. Empty heavy drums must be treated as a valuable asset and personnel should be trained in their proper handling (including keeping the bungs, rings, etc.). Another good practice is to avoid accumulating the drums for long periods of time, thus, preventing deterioration.

Contracting With a Scrap Dealer or Disposal in a Landfill

Scrap dealers and landfill operators usually require certain conditions to be met before they accept drums or other containers. Generators have to drain the drums or containers thoroughly, remove the residues by triple rinsing, certify that they do not contain hazardous materials, remove both the ends, crush them before transporting, and pay for disposal.

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[171] Ventura County Environmental Health, p 3-2.

[172] *Managing Empty Containers*, Fact Sheet (Minnesota Technical Assistance Program, University of Minnesota, Minneapolis, MN, 1988).

Table 51

PCB Replacement/Treatment/Disposal Services

Company	Address
ENSCO	P.O. Box 1975, El Dorado, AR 71730, (501) 863-7173
ENSR (formerly SunOhio)	1700 Gateway Blvd. SE, Canton, OH 44707, (216) 452-0837
USEPA Mobile Incinerator	Woodbridge Ave., Raritan Depot Bldg. 10, Edison, NJ 08837, (201) 321-6635
GSX Chemical Services	121 Executive Center Dr., Congaree Bldg. # 100, Columbia, SC 29221, (800) 845-1019
Rollins	P.O. Box 609, Deer Park, TX 77536, (713) 479-6001
General Electric	One River Road/Bldg 2-111B, Schenectady, NY 12345, (518) 385-9763
SCA Chemical Services	1000 E. 111th St., 10th Fl., Chicago, IL 60628, (312) 660-7200

Table 52

PCB Transformer Retrofilling Services

Company	Address
DOW Corning Corp	P.O. Box 0994, Midland, MI 48686-0994, (517) 496-4000
ENSR (formerly SunOhio)	1700 Gateway Blvd. SE, Canton, OH 44707, (216) 452-0837
General Electric	One River Road/Bldg 2-111B, Schenectady, NY 12345, (518) 385-9763
Hoyt Corporation	251 Forge Rd., Westport, MA 02790-0217, (800) 343-9411
Retrotex	1700 Gateway Blvd. SE, Canton, OH 44707, (216) 453-4677
Transformer Service Inc.	78 Regional Dr., P.O. Box 1077, Concord, NH 03301-9990, (603) 224-4006
Unison Transformer Services	1338 Hundred Oaks Dr., Charlotte, NC 28210, (800) 544-0030
Westinghouse/Industry Services	875 Greentree #8-MS 804, Pittsburgh, PA 15220, (800) 441-3134

12 ECONOMIC ANALYSIS FOR HAZARDOUS WASTE MINIMIZATION

HSWA requires generators of hazardous wastes to develop a waste minimization program that is economically practicable. Therefore, once the alternatives for minimization are identified, their economic feasibility must also be studied. A major source for funding for hazardous waste minimization projects has been through the Defense Environmental Restoration Account (DERA). If the payback from a project is expected to be 1 year or less, funding is also available from the Defense Productivity Enhancing Capital Investment (PECI) program. In many instances, minimization is a cost-effective means of conducting business. In such instances, any account may be used to finance minimization and benefit from the resultant savings. However, with the multiplicity of alternative treatment technologies available to treat various hazardous waste streams, it is imperative that installation environmental personnel use a standard methodology to evaluate hazardous waste minimization options.

In 1984, DOD initiated a Used Solvent Elimination (USE) program. In conjunction with the USE program, USACERL developed a model for performing an economic analysis on various alternatives for recycling or disposing of used solvents. Based on this earlier model, a microcomputer model has been developed for economic analysis of minimization options. (Refer to USACERL Draft Technical Report[173] for a detailed discussion of the process of economic analysis and use of the model.) A part of the model related to nonspecific or "general" waste types is used to determine the life cycle costs and comparison of alternatives for waste streams in this report. Many other publications on economic analysis are available.

The caveat of an "economically practicable" level of waste minimization, as defined in HSWA, is very important. It is not necessary (and is impossible in most cases) to completely eliminate generation of wastes. An economic analysis provides a reasonable methodology for choosing between options for waste minimization. The typical costs considered for any option are initial capital costs and operating costs such as labor, materials, transportation, and waste disposal. Benefits achieved from a waste minimization option (e.g., reduced liability) can also be quantified and given dollar values.

The costs are summed to obtain life cycle costs over the assumed economic life for each option. Net present value (NPV) of the total life cycle costs can be calculated for each option. Comparing the NPVs provides a basis for selecting a minimization technique. Results of detailed economic analysis for the selected waste streams are provided in the sections below.

Used Oil

A large quantity of used oil, primarily engine lubricating oil, is generated on Army installations. Fort Carson generates 114,000 gal/yr of used oil; 5700 gal/yr of it is chlorinated waste oil. Lubricating oil is drained from wheeled and tracked vehicles by the traditional drip-pan method and collected in 55-gal drums or larger storage tanks. Some of the contaminants found in used oil are trash/rags, solvents, hydraulic fluids, and wear metals. Oil is normally changed from vehicles based on the AOAP test.

A source reduction method for minimizing waste oil generation is a change in the process of draining the oil. A FLOC system can be implemented to replace the gravity-drain (drip-pan) method. A description of the technique is provided in Chapter 5. Adapters have to be purchased for all the

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[173] J.B. Mount, et al.

different types of Army vehicles. The major savings is in the labor costs. The amount of extraneous contaminants in the used oil is considerably reduced if the procedure is implemented.

A comparison of the life cycle (10-yr) costs for the two techniques was p[illegible]d for fleets ranging from 50 to 5000 vehicles.

Investment costs for the purchase of a FLOC evacuation unit and engine adapter kits are assumed to all occur in the first year. A 10-yr economic life and midyear discounting at a rate of 10 percent are assumed for both options. The model's default values retained for this analysis include: site preparation and installation - 15 percent of total equipment costs; logistics and procurement - 7 percent of installed equipment costs; contingencies - 10 percent of installed equipment costs; labor rate (manager) - $16.00 per hour; labor rate (laborer) - $11.00 per hour; adjustments for leave - 18 percent of total man hours; adjustments for fringe benefits - 36.2 percent of adjusted base labor cost; number of work days in a year - 247; average maintenance - 5 percent of equipment costs; transportation of hazardous waste - $0.04 per pound; and, annual logistics and procurement - 1.6 percent of other Operational and Maintenance (O & M) costs. Other assumptions made in the analysis were:

- The average crankcase oil per vehicle is 3.25 gal.
- The average number of oil changes per year is 2.
- Liability due to spills, including labor costs for cleanup, is $177 for the gravity drain system.
- The time required for an oil change using the gravity drain system is 15 minutes.
- The time required for an oil change using the FLOC system is 4.5 minutes.
- A labor time of 0.7 hours is assumed for removal of an accumulation of up to 50 gal in a 55-gal drum.
- The procurement cost of a small FLOC evacuation unit and engine adapter kits is approximately $2260. An additional $2265 is required to implement this system for costs of site preparation and personnel training. The cost of larger evacuation units increases with size.
- The system is used 260 working days per year.
- The utility cost for each FLOC unit is $75/yr/unit.
- Costs do not escalate.
- Repair and maintenance is $50/yr/unit.
- One FLOC unit can handle approximately 35 to 40 vehicles per day. If more than 10,000 oil changes are conducted annually, two or more units will be required.

Table 53 lists the saving to investment ratios (SIRs) and discounted payback periods (DPPs) for implementing a FLOC system to service 100, 250, 500, 1000, and 5000 vehicles twice per year. In almost every case, the SIR is 0.39 (1 = economical) and therefore provides no DPP within the expected economic life of the equipment. Table 54 lists the computer SIRs and DPPs when the average number of oil changes per vehicle increases from two up to six times per year for 1000 vehicles. Only when the number of oil changes per vehicle each year is six or greater, which is not likely to occur, does the FLOC system become cost effective to implement.

Other options analyzed for management of used oil include: (1) minimal processing, blending, and burning (status quo); (2) minimal processing, offsite disposal; (3) comprehensive processing, blending, and burning; (4) comprehensive processing, sale to an offsite recycler; and (5) minimal processing, sale to an offsite recycler. Proper segregation of used oil from other wastes generated on Fort Carson is a prerequisite for all management options analyzed. It is particularly important for option 5. The water content in the used oil cannot exceed 5 percent for a recycler to purchase it. Five percent of all the oil generated is assumed to contain halogenated contaminants at concentrations greater than 1000 ppm and has to be disposed of as a hazardous waste.

Investment costs for a vacuum dehydrator and degasifier[174] used in comprehensive processing are assumed to be all incurred in the first year. A 10-year economic life and midyear discounting at a rate of 10 percent are assumed for the options. The model's default values retained for analysis include:

- Site preparation and installation - 15 percent of total equipment costs,
- Logistics and procurement - 7 percent of installed equipment costs,
- Contingencies - 10 percent of installed equipment costs,
- Labor rate (manager) - $16.00/hr,
- Labor rate (laborer) - $11.00/hr,
- Adjustments for leave - 18 percent of total man hours,
- Adjustments for fringe benefits - 36.2 percent of adjusted base labor cost,
- Number of work days in a year - 260,
- Average maintenance - 5.75 percent of equipment costs,
- Transportation of hazardous waste - $0.04/lb, and,
- Annual logistics and procurement - 1.6 percent of other O&M costs.

The major assumptions made in the analysis were:

- Nonsegregated oil may be considered hazardous depending on the concentration of halogens and heavy metals.

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[174] Baron and Associates, Inc., Cookville, TN; (615) 528-8476.

- Hazardous oil, when burned in a boiler without permits, is subject to fines. Operating without permits or in violation of permits will cause the facility to be shut down by the regulating agency.

- Disposal cost for hazardous halogenated oil is $4.50/gal.

- Disposal cost for nonhazardous nonhalogenated oil is $0.75/gal.

- Disposal cost for oily sludge generated from comprehensive and minimal processing activities is $3.25/gal.
- Transportation cost for onsite transfer and consolidation of hazardous and nonhazardous used oil and oily sludge generated from processing activities is $0.10/gal.

- Sampling and testing costs for the oil before its transfer to the boiler facility and before burning, offsite disposal, or offsite sale are $0.036/gal and $0.006/gal, respectively.

- Fifty-five gallon disposal drums required for containerization of oily processing sludge are $20.00 each.

- Liability cost for onsite transportation and transfer of nonhazardous used oil, hazardous waste oil, and processing sludge is $0.002/gal. Liability costs associated with all offsite transportation is $0.008/gal.

- Labor costs are assumed to accrue at the following rates: onsite transfer of waste oil and processing sludge to DRMO for disposal - 0.01 hr/gal; onsite transfer of nonhazardous oil to the boiler facility - 0.0008 hr/gal; minimal processing at the boiler facility - 0.0016 hr/gal; and drumming of processing sludge and upkeep of minimal processing equipment - 0.0002 hr/gal.

- Managerial labor is assumed to accrue at a rate of 1 hr per 5000 gal of used oil burned, disposed, or sold.

- Maintenance and repair costs for minimal processing equipment and comprehensive processing equipment are $0.001/gal and $0.006/gal, respectively. Maintenance costs associated with boiler equipment for blending and burning options are $0.11/gal with minimal processing and $0.03/gal with comprehensive processing.

- Utility costs for minimal and comprehensive processing equipment are based on default values provided in the economic analysis model. For minimal processing of used oil, a cost of $0.005/gal is assumed; for comprehensive processing, it is $0.013/gal. An additional cost of $0.005/gal of used oil is assumed for wastewater treatment associated with comprehensive processing.

- Sale to an offsite recycler is applicable only to nonhazardous oil and is contingent upon proper segregation and prevention of excessive water contamination. Used oil can be sold to such a recycler for $0.05/gal after comprehensive processing, and for $0.015 with only minimal processing.

- Escalation rates used for some of the costs are as follows: transportation - 4 percent; liability -

4 percent; disposal - 8 percent; sampling and testing - 4 percent; other materials and supplies - 4 percent; maintenance and repair - 4 percent; and utility - 4 percent.

Figure 5 compares the NPVs of the life cycle (10-yr) costs for the five used oil management options. Oil mixed with solvents may be a hazardous waste and must be tested to prove otherwise. Burning hazardous waste in the Fort Carson boilers is prohibited. Option 2 (offsite disposal) is the most expensive option at any generation rate. The current practice (option 1) of minimal processing, blending, and burning in a boiler is the next most expensive option. Comprehensive processing requires investment in a vacuum dehydrator. Because of the reduced maintenance and repair associated with boiler and labor costs, option 3 is less expensive than option 1. The sale options (4 and 5) cost about the same. Used oil sale prices of \$0.05/gal and \$0.015/gal are used in options 4 and 5, respectively. Five percent of the oil still must be disposed of as a hazardous waste.

At the current generation rate (114,000 gal/yr), the NPV O&M cost for the status quo option is \$553,344 (\$55,334/yr). By investing \$17,855 in a vacuum dehydrator for comprehensive processing, blending, and then burning (option 3), an annual savings of \$8520 could be realized over the present operating costs. The SIR and DPP computed for this change are approximately 4.77 and 3.91 years, respectively. The sale of used oil, following comprehensive processing to lower its water content (option 4), could produce an annual savings over the status quo of \$14,541. The SIR and DPP computed for this comparison are approximately 8.14 and 2.36, respectively.

Sale of used oil following minimal processing or sale of used oil following comprehensive processing, are the lowest cost management options for Fort Carson. However, it is very difficult to find a recycler for used oil unless its water content is below 5 percent. Purchase of a vacuum dehydrator and implementation of option 3 is recommended. The proper storage and careful segregation of used oil from hazardous waste streams (i.e., solvents, hydraulic fluid, contaminated fuels, etc.) and other contaminants (i.e., rain water, dry sweep, etc.) must be strictly enforced at all the vehicle maintenance facilities.

Antifreeze Solution

MPVMs are the primary generators of waste antifreeze solution during regular maintenance of vehicles and major radiator repairs. Since the antifreeze solution is not considered a hazardous waste, it is diluted with water and drained into a sewer in most Army installations. Recycling of the waste solution is possible as discussed in Chapter 5. It was considered as a minimization alternative and the results of the economic analysis is presented below.

Investment costs for the antifreeze recycling machine are assumed to be all incurred in the first year. A 10-yr economic life and midyear discounting at a rate of 10 percent are assumed for the options. The model's default values retained for analysis include:

- Site preparation and installation - 15 percent of total equipment costs,
- Logistics and procurement - 7 percent of installed equipment costs,
- Contingencies - 10 percent of installed equipment costs,
- Labor rate (manager) - \$16.00/hr,

- Adjustments for leave - 18 percent of total man hours,

- Adjustments for fringe benefits - 36.2 percent of adjusted base labor cost,

- Number of work days in a year - 260,

- Average maintenance - 5.75 percent of equipment costs,

- Transportation of hazardous waste - $0.04/lb, and,

- Annual logistics and procurement - 1.6 percent of other O&M costs.

Some of the assumptions made in the economic analysis are:

- Disposal cost of antifreeze is $6.50/gal.

- Labor hours for manager (bids, etc.) - 1 hr/1000 gal; and laborers (drumming and transport) - 1 hr/100 gal.

- Cost of "Glyclean" recycling system is $2,368. Two "Glyclean" systems are required when waste generation rates exceed 10,000 gal/yr.

- The cost of a 55-gal drum of "Glyclean" additives is $26.65/gal. About 0.03 gal of additive is needed per 1 gal of antifreeze recycled.

- It takes about 0.5 hr to recycle 100 gal of used antifreeze.

- The purchase price of new antifreeze is $8.45 per gallon (on GSA schedule)

- Recycled antifreeze is equivalent to a 50 percent mixture of antifreeze and water.

- Utility costs associated with "Glyclean" machine operation is $0.02/gal of waste.

- A 50 percent dilution with water is used for the first year of purchase; no dilution is required in subsequent years.

- Repair and maintenance cost is $0.006/gal.

- The liability cost for both disposal and reuse is $0.01/gal.

- The industrial waste treatment cost after discharge is $3.10/1000 gal of wastewater.

- Escalation is 8 percent for disposal and 4 percent for others.

- Onsite transport cost from point of waste generation to recycling facility and back or to DRMO for disposal is $2.00/100 gal.

Figure 6 shows the comparison among the total life cycle (10-yr) costs for the following management options: (1) offsite disposal; (2) onsite recycling and reuse with one "Glyclean" recycling systems; (3) discharge to the IWTP (status quo); and (4) onsite recovery and reuse with two "Glyclean" systems. Recycling antifreeze solution onsite results in a considerable savings over both disposal and discharge options at any generation rate.

Fort Carson generates 30,445 gal/yr of spent antifreeze solution. The NPV of the current management practice amounts to $979,514 per 10 years (or $97,951/yr). Purchasing two recycling systems would require an NPV investment of $166,481. The resultant NPV savings would be $742,930 (or $74,293/yr). The SIR and DPP computed for this conversion are estimated at 4.46 and 2.57 years, respectively. The purchase of two "Glyclean" reconditioning systems and the implementation of an onsite recycling program for spent antifreeze is recommended.

Cleaning Solvent Waste

Cleaning solvents such as petroleum distillates (PD680-II), petroleum naptha, varsol, etc., are used in parts cleaning operations as discussed in Chapter 5. At Fort Carson, the most widely used practice is that of contract recycling. Safety Kleen (SK) is the contractor that leases parts cleaning equipment and replaces the solvent periodically. The estimated waste generation rate is 30,610 lb/yr (5940 gal/yr).

Management options chosen for economic analysis in this section are: (1) onsite distillation and reuse through the purchase of a 55-gal batch still; (2) contract recycling with low flash point solvent and leased parts-washing equipment (LE 105); (3) contract recycling with low flash point solvent and government owned parts-washing equipment (OE 105); and (4) contract recycling with high flash point solvent and leased equipment (LE 140). Investment costs required for distillation equipment and a startup volume of fresh solvent in option 1 are assumed to be incurred in the first year. A 10-yr economic life and a midyear discounting at a rate of 10 percent are assumed for all the options. The model's default values retained for this analysis include:

- Logistics and procurement - 7 percent of installed equipment costs,
- Contingencies - 10 percent of installed equipment costs,
- Labor rate (manager) - $16.00/hr,
- Labor rate (laborer) - $11.00/hr,
- Adjustments for leave - 18 percent of total man hours,
- Adjustments for fringe benefits - 36.2 percent of adjusted base labor cost,
- Number of work days in a year - 260,
- Average maintenance - 5.75 percent of equipment costs,

- Transportation of hazardous waste - $0.04/lb, and
- Annual logistics and procurement - 1.6 percent of other O&M costs.

Some of the other major assumptions applied in the calculations are listed below.

- An annual escalation rate of 4 percent was applied to raw materials, replacement materials, maintenance and repair, other materials and supplies, utilities, sampling and testing, and liability.
- Escalation rates of 8 percent and 6 percent were used for disposal and contractual costs, respectively.
- The liability costs were assumed as follows: onsite distillation and reuse, $0.03/gal; offsite disposal/sale, $0.03/gal; and contract recycling, $0.01/gal;
- Twenty percent of the solvents are assumed lost because of open lids (evaporation) and other poor operating practices such as carry-off and spillage.
- Volume of the still bottoms is assumed to be 10 percent of the total waste stream.
- Fresh solvent make-up is expected to be 30 percent of the waste volume to be purchased every year.
- Repair and maintenance costs are calculated to be 5.75 percent of the original cost of the equipment (in $/year) and are based on 2080 hours of operation per year. If the equipment is used less, the costs are adjusted.
- Laboratory analytical costs are assumed to be a minimum of $50.00/yr.
- Transporting and warehousing costs are based on the volume of wastes generated; about $2.00/100 gal.
- The cost of electricity is $0.05 per kWh.
- The cost of disposal of still bottoms (assumed hazardous) is $4.00/gal.
- Cost of new solvents (SK - flash point 105 °F, boiling point 310-400 °F) is $1.60/gal, and PD 680-II (NSN 6850-00-285-8011) is $2.24/gal.
- Because the boiling point of solvent is above 325 - 350 °F (PD680-II - b.p. > 350 °F), a vacuum attachment must be used in the distillation process.
- Labor cost for loading and unloading the still will be less than 2.0/hr. According to manufacturers, the loading and unloading of a 55-gal still varies from 1/4 to 1/2 hr/batch.

- Utility costs are often provided by still manufacturers. Typical utility costs range from $0.06 to $0.12/gal of solvent distilled ($0.10/gal was used for a 55-gal still).

- Labor associated with the transport of spent solvent to the distillation site is 1 hr/100 gal.

- Two different size (20- and 30-gal) parts washers are used in calculations for contract recycle options.

- A one-time installation charge associated with 30-gal capacity washers is $30.00 per wasner and is considered an investment cost.

- The still prices on GSA schedule (quoted by Finish Engineering, Table 55) were used in the analysis. Recyclene and Progressive Recovery, Inc., do not have GSA contracts. Shipping costs for equipment are not included in the price. The purchase price for a 55-gal still with vacuum attachment is $24,609.

- Seventy percent of the initial purchase of raw materials is included in the investment cost. The remaining 30 percent is included in the annual O&M costs.

- Same generation (accounting for frequency of change) is assumed for owned equipment and disposal and contract recycling at 12.5 changes (services) per year.

Figure 7 shows the comparison of the NPV total life cycle (10-yr) costs for the different management options over a waste generation range between 5000 and 40,000 gal/yr.

SK is a private vendor of cleaning and degreasing solvent recycling services (on GSA schedule through June 1991) that currently maintains a contract with Fort Carson (option 2). With few exceptions, most of the vehicle maintenance facilities on Fort Carson have been equipped with parts-washing equipment leased from SK. The cleaning equipment varies in style and capacity from 5-gallon, multi-level units up to 40-gallon stationary tanks that require special installation. Each unit is serviced monthly by SK and replenished with clean, recycled solvent. The solvent supplied by the vendor is roughly equivalent to PD680-I in flash point and chemical composition. SK assumes the responsibility for spent solvent containerization, transport to the recycling facility, and disposal of solvent tank bottom' The spent solvent and tank bottoms are manifested as hazardous waste based on the flashpoint ot the fresh solvent (105 °F). Although a nonhazardous solvent with a higher flashpoint (140 °F) is available from the vendor, it has not been requested by Fort Carson because of its prohibitive cost. The annual operating costs of the current contract with SK are estimated at $71,000. Switching to a higher flashpoint solvent (option 4) would require an addition $29,000/yr at the current contract volume. Option 4 is the most expensive management alternative examined in this analysis.

Onsite distillation (option 1) with a 55-gal still is the most economical option. An investment of $60,162 results in NPV savings of $330,971 (or $33,097/yr) when compared to the status quo (option 2). The SIR and DPP are 5.50 and 2.73, respectively. Although onsite distillation is an economical option, switching to it would cause a number of logistics and other problems in procurement of new solvent, transport of solvent, full-time operation of a still, etc.

Contract offsite recycling (with leased equipment) is an effective waste minimization option. Its continuation with a higher flash point solvent (option 4) is therefore recommended.

Lead-Acid Batteries/Battery Acid

An estimated 6300 nonserviceable lead-acid vehicle batteries were generated on Fort Carson in FY 1988-1989. The acid from all nonserviceable batteries is drained and neutralized with sodium bicarbonate. At the time of this investigation, only one of the installation's three lead-acid battery shops was functioning as a neutralization point (DOL - Bldg 8000). Neutralization at the other two shops had been halted due to problems with inadequate ventilation and space (Bldg 8030) and with the neutralization sump drainage connect at Bldg 8142. The acid from batteries brought to Bldg 8142 is still drained, but into 55-gal plastic drums for transport to Bldg 8000 for neutralization. All empty battery casings are inverted, deliberately punctured, and strapped to wooden pallets for shipment to a contractor of the Department of Energy (DoE) in Idaho Falls, ID, for lead recovery.

An economic analysis was performed to compare the costs and benefits of four different management options for nonserviceable lead-acid batteries. Options formulated for comparison are: (1) draining batteries for casing transfer to DoE and disposal of acid as hazardous waste; (2) no draining by recycling the batteries with their acid through a local contractor (assuming no cracked batteries are generated); (3) recycling noncracked batteries with their acid through a local contractor and then draining and neutralizing the acid from cracked batteries (assuming 10 percent of the nonserviceable batteries are cracked); and (4) draining and neutralizing acid from all nonserviceable batteries and transfer of the dry casings to DoE (status quo).

Investment costs for neutralization in options 3 and 4 are assumed to be incurred in the first year. A 10-yr economic life and midyear discounting at a rate of 10 percent are assumed for the options. The model's default values retained for analysis include:

- Site preparation and installation - 15 percent of total equipment costs,
- Logistics and procurement - 7 percent of installed equipment costs,
- Contingencies - 10 percent of installed equipment costs,
- Labor rate (manager) - $16.00/hr,
- Labor rate (laborer) - $11.00/hr,
- Adjustments for leave - 18 percent of total man hours,
- Adjustments for fringe benefits - 36.2 percent of adjusted base labor cost,
- Number of work days in a year - 260,
- Average maintenance - 5.75 percent of equipment costs,
- Transportation of hazardous waste - $0.04/lb,
- Annual logistics and procurement - 1.6 percent of other O&M costs.

Some of the other assumptions used in the calculations are:

- Weight of a typical battery without electrolyte is 50 lb.

- Volume of electrolyte per battery is 1.5 gal. (@ 9.99 lb/gal).

- Weight of electrolyte per battery is 15 lb (density - 10 lb/gal).

- Sale price of casings through DRMO is $0.0214/lb as scrap.

- The cost of disposal of drummed electrolyte is $6.00/gal.

- Cost escalation factors: disposal, 8 percent; liability, 4 percent; raw materials, 4 percent; other materials/supplies, 4 percent; sampling/testing, 4 percent; maintenance and repair, 4 percent; and IWTP costs, 4 percent.

- Transportation and storage cost is $0.07/battery and $0.04/gal of electrolyte.

- Transportation cost of sump sludge to DRMO is $0.02/gal of treated electrolyte.

- Liability costs for disposal, $0.013; transport, $0.002/lb of casings, and draining, $0.001; or precipitation, $0.001/lb of electrolyte.

- Cost of sodium bicarbonate is $0.13/gal of electrolyte neutralized;

- The quantity of neutralized sludge produced is 0.05 lb/lb of electrolyte.

- Neutralized sludge disposal cost (including labor) is $0.05/lb.

- Wastewater treatment cost is $3.10/1000 gal.

- Labor hours in bringing batteries to DRMO is 1 hr/150 units.

- Labor hours for bringing drummed electrolyte to DRMO is 0.5 hr/55 gal drum.

- The purchase price of a 55-gal plastic disposal drum is $20.00.

- Battery salvage value is $0.0214/lb.

- The labor hours for draining and drumming of electrolyte is 0.04 hr/gal.

- The labor hours for monthly neutralization sump maintenance (cleaning, drum, and transport to DRMO) is assumed to be 2 hr.

- Costs associated with neutralization sump and pH meter upkeep are $10.00/1000 gal of electrolyte treated ($0.01/gal).

- Labor hours required for neutralization is 0.02 hr/gal of electrolyte.

- Labor hours for manager (for bid preparation, etc.) is 1 hr/500 batteries.

- Batteries are sold to a recycler (American Battery Company, Colorado Springs, CO) at $2.25/65 lb.

- No site preparation costs.

- Sampling and testing costs are $0.05/gal.

Figure 8 shows a comparison of the total life cycle (10-yr) costs of options 1 through 4. Option 1 is always more expensive than options 2, 3, and 4 over the range of 1000 to 200,000 gal/yr. Wet recycling (option 2) results in net earnings rather than costs and is therefore the best option. Assuming that 10 percent of the batteries are cracked, disposal of spent electrolyte from them and the wet recycle of uncracked batteries (option 3) is less expensive than draining and neutralization (option 4). The actual number of cracked batteries may be a lot smaller than the assumed 10 percent and will lower the slope of the line corresponding to option 3 in Figure 7.

Fort Carson generates 9500 gal/yr of spent electrolyte. At this rate, switching to wet recycling will result in NPV savings of $87,615 (or $8615 per year) and additional revenue of $26,740 in 10 years (or $2674 per year). Assuming that 10 percent of the batteries get cracked, wet recycling of uncracked batteries and disposal of acid would result in a net savings of $52,813 (or $5281 per year). Disposal of all the acid as a hazardous waste can be done at an annual operating costs of $64,691.

The onsite neutralization of battery acid with sodium bicarbonate on Fort Carson constitutes elementary treatment and is permissible under State and Federal regulations provided the discharged effluent is not laden with lead or other EP Toxic heavy metals. The only effluent parameter regularly tested has been pH. In June 1990, grab samples were collected from the neutralization sump in Bldg 8000 for heavy metal analysis. Should the sump samples test positive for EP Toxicity, a strong possibility exists that discharged effluent could also be toxic. In terms of regulatory compliance and future liability associated with environmental contamination, the continued practice of draining and neutralizing the acid from all the nonserviceable lead-acid batteries generated on Fort Carson is not sound. Private battery recyclers, as well as the contractor currently employed through the DoE, are willing to accept nonleaking batteries with their acid. From legal, waste minimization, and economic perspectives, wet recycling through a local contractor is the best management option for nonserviceable lead-acid vehicle batteries generated on Fort Carson, and is strongly recommended.

Spent 1,1,1-Trichloroethane/Degreaser Tank Bottoms

A 250-gal capacity, vapor spray degreaser that uses 1,1,1-trichloroethane is regularly used at Bldg 8000 (DOL - Maintenance Operations Branch - Consolidated Maintenance Building) for the rapid degreasing of large vehicle assemblies and related components. The degreaser is set into the floor of the maintenance bay and is as old as the building (1973). Because of its age, the degreaser is exempt from current air pollution emission standards enforced by the State for this type of equipment. Because of its older design, with hinged, gull-winged door covers and low freeboard height, and from impatient operating practices involving rapid equipment drag out, a large quantity of solvent is lost to drippage outside the confines of the tank and to evaporation during its operation. Hazardous waste streams generated from its operation include spent 1,1,1-trichloroethane and degreaser tank bottoms; which contain solvent residues, grease and dirt, and trash (torn gaskets and other small items loosened from parts during cleaning). Fifty-five gallons of fresh solvent is added to the tank's sump weekly to replenish loses to evaporation and carry-off. The degreaser is shut down approximately four times each year for cleaning and maintenance. During each cleaning, the sump is completely drained and refilled with 250 gallons of fresh solvent. Approximately 5280 pounds of degreaser tank bottoms and fallen debris are removed from the degreaser annually. An economic analysis was performed to determine the practicality of retrofitting the existing degreaser with new equipment to improve its operating efficiency and to achieve a reduction in generated wastes. Technologies considered in this analysis include: online and batch-type solvent distillation equipment; a motorized, biparting, horizontal power cover; and increasing the freeboard height. The substitution of different cleaning agents for 1,1,1-trichloroethane or replacing the process altogether with high pressure jet washers were not considered practical options given the variability in size and desired cleaning precision of equipment used in the degreaser, the frequency of its use, and the increased drying times associated with aqueous or caustic based cleaners.

Investment costs for the equipment modifications are assumed to be all incurred in the first year. A 10-yr economic life and midyear discounting at a rate of 10 percent are assumed for the options. The model's default values retained for analysis include:

- Site preparation and installation - 15 percent of total equipment costs,
- Logistics and procurement - 7 percent of installed equipment costs,
- Contingencies - 10 percent of installed equipment costs,
- Labor rate (manager) - $16.00/hr,
- Labor rate (laborer) - $11.00/hr,
- Adjustments for leave - 18 percent of total man hours,
- Adjustments for fringe benefits - 36.2 percent of adjusted base labor cost,
- Number of work days in a year - 260,
- Average maintenance - 5.75 percent of equipment costs,
- Transportation of hazardous waste - $0.04/lb,
- Annual logistics and procurement - 1.6 percent of other O&M costs.

Some of the other assumptions made in this economic analysis are given below.

- An escalation rate of 4 percent was applied to the recurring costs of raw replacement materials, replacement materials, liability, utilities, other materials and supplies, maintenance and repair, and sampling and testing.
- An escalation rate of 8 percent was assumed for offsite disposal costs.

- Liability costs were assumed as follows: onsite distillation and reuse - \$0.03/gal, vapor degreaser operation - \$0.01/gal, and offsite disposal - \$0.08/gal.

- During the batch recycling process, it was assumed that 20 percent of the waste stream was lost with each distillation cycle. Ten percent of the waste was assumed to have evaporated and 10 percent was lost to still bottom residue.

- With the closed-loop (continuous) recycling process (in-line, continuous flow distillation unit) 10 percent of the waste stream was assumed lost to still bottoms, with no evaporative loss.

- Evaporative loss from operating the vapor degreaser as it is presently equipped was assumed to be 55 gal/week. Thirty seven percent less evaporative loss was estimated to result from the implementation of a motorized power cover and a 15 in. increase in freeboard height.

- During 1 year, 660 gal of degreaser tank sludge were generated and required disposal as a hazardous waste.

- Repair and maintenance costs for major equipment were based on use rates and 5.75 percent of the original purchase prices. If equipment was used less than 2080 hr/yr, costs were adjusted.

- Fifty-gal drums needed for disposal of vapor degreaser tank bottoms, distillation residue, and spent solvent were estimated to cost \$20.00 per drum.

- Disposal costs for solvent tank bottoms, and distillation residue are \$3.00/gal.

- The purchase cost for fresh solvent is \$6.75/gal.

- Transportation costs for solvent still residue, and tank sludge from point of generation to DRMO for disposal are \$2.00/gal.

- Costs of cooling water and electricity were assumed to be \$0.70/1000 gal and \$0.05 per kWh, respectively. Annual utility costs for vapor degreaser operation (which requires steam, cooling water, and electricity) were approximately \$2288/yr. Utility costs for batch and online distillation units are \$0.10/gal of recycled 1,1,1-trichloroethane.

- Sampling and testing costs are \$50/yr.

- Labor costs associated with the vapor degreaser cleaning, maintenance, and solvent replenishment (status quo) were estimated from a requirement of 109 hr/yr. This estimate was held constant for options using batch distillation units. A 37 percent reduction in replenishment time and a 50 percent reduction in cleaning and replacement time were predicted with the implementation of an on-line distillation unit and a motorized power cover with increased freeboard height.

- Labor hours associated with the transport of spent solvent tank bottoms and distillation residue were held constant for all options at 1 hr/100 gal.

- Labor hours associated with the operation of batch distillation units (loading and unloading) were based on manufacturer estimates of 3/4 hr/batch for a 15-gal still and 1-1/2-hr/batch for a 55-gal still. Similar labor costs were not associated with the in-line unit.

- Managerial labor costs were assumed to accrue in a supervisory capacity at a rate of 1 hr for every 24 laborer hours.

- Major equipment costs used in this analysis were as follows: 15-gal batch still - $10,128, 55-gal batch still - $24,609, 40 gal/hr in-line distillation unit (Detrex Model FC-15-SW) - $15,500 (including installation), and motorized bi-parting power cover (from Detrex) with a 15 in. increase in freeboard height - $20,000 (including installation).

- Startup expenses for all options included initial purchase of 80 percent of the 1,1,1-trichloroethane normally used.

With the above assumptions, life cycle (10-yr) costs were calculated for: (1) offsite disposal and purchase of fresh solvent (status quo), (2) onsite distillation with a 15-gal still, (3) onsite distillation with a 55-gal still, and (4) onsite, in-line distillation with a 40 gal/hr distillation unit with the addition of 15 in. to the freeboard height and a motorized, bi-parting power cover.

Table 56 shows the detailed comparison of all the options at the current waste generation and material usage rates. The NPV O&M costs for the current practice is $295,122 ($29,512 per year). Investing $44,767 in the equipment modifications will result in an annual savings of $13,956. The SIR and DPP are 3.12 and 4.22, respectively. Therefore, such an investment is recommended for Fort Carson. The investment will lead to both waste minimization and economic payoff (i.e., payback in 4.22 years).

Paint Thinner Waste

Paint thinner waste is generated from the cleaning of painting equipment as discussed in Chapter 7. Onsite distillation (with a 5-gal batch still) and contract recycling were the two options examined and compared with the current practice of purchasing fresh thinner and offsite disposal (1004 gal/yr).

Investment costs for onsite distillation are assumed to be all incurred in the first year. A 10-yr economic life and mid-year discounting at a rate of 10 percent were assumed for all the options. The model's default values retained for analysis include:

- Site preparation and installation - 15 percent of total equipment costs,

- Logistics and procurement - 7 percent of installed equipment costs,

- Contingencies - 10 percent of installed equipment costs,

- Labor rate (manager) - $16.00/hr,

- Labor rate (laborer) - $11.00/hr,

- Adjustments for leave - 18 percent of total man hours,

- Adjustments for fringe benefits - 36.2 percent of adjusted base labor cost,

- Number of work days in a year - 260,

- Average maintenance - 5.75 percent of equipment costs,

- Transportation of hazardous waste - $0.04/lb,

- Annual logistics and procurement - 1.6 percent of other O&M costs.

Some of the other assumptions made in this economic analysis are given below.

- An escalation of 4 percent was applied to raw materials and replacement materials, maintenance and repair, other materials and supplies, liability, sampling and testing, and utilities.

- An escalation rate of 8 percent was assumed for offsite disposal costs, and 6 percent for contract recycling costs.

- Liability costs were assumed as follows: onsite distillation and reuse, $0.03/gal; offsite disposal, $0.08/gal; and contract recycle, $0.01/gal.

- In the recycling process, it is assumed that 20 percent of the material is replaced with new material in each cycle. Ten percent of the material is assumed to evaporate and 10 percent is disposed of with residue. Residue and thinner make up 20 percent of the original volume for disposal purposes.

- Repair and maintenance is an annual cost that is 5.75 percent of the original cost of the equipment and is based on a continual use of 2080 hr/yr. If the equipment is not used for the total time, the costs are adjusted accordingly.

- Laboratory analytical costs are estimated to be a certain percentage of labor costs. However, the minimum laboratory cost per sample may be substantially higher than the computed value for wastes generated in small volumes. A minimum of $50.00 is assumed.

- Transportation and warehousing costs depend on the volume of waste handled and the distance between points of waste generation and distillation based on cost of $0.50/mi.

- Costs of cooling water and electricity are assumed to be $0.70/1000 gal and $0.05/kWh, respectively.

- Disposal cost of thinner waste is $3.00/gal (1989 price - DRMO).

- Distillation stills are available with and without vacuum attachments. If the boiling point of the solvent is below 300 or 350 °F, a still without vacuum attachment is considered. For recovery of solvents with boiling points between 300 and 500 °F, a vacuum attachment is necessary.

- Most of the dope, lacquer thinners (NSN 8010-00-160-5787) have a boiling point of less than 300 °F. Therefore, vacuum attachments are not required.

- GSA price for 5-gal size paint thinner is $3.65/gal. If available in a 55-gal drum, the price could be even lower. For purpose of this analysis a price $3.65/gal is assumed.

- Labor costs for loading and unloading of the still, especially for batch 5-gal or 15-gal sizes, will be less than 2 hr (default value in the model). The labor requirement for operating 5-gal and 15-gal stills are 1/2 and 3/4 hr/batch, respectively.

- Utility costs (electricity and water) for still operation can be determined from the power input to the still and the rate of cooling water used. Currently, it is estimated that the cost of power per gallon of solvent distilled is $0.10.

- Equipment manufacturers such as Finish Engineering, Recyclene, and Progressive Recovery, Inc., were contacted for the price of distillation equipment. The price of one manufacturer was competitive with the price of similar equipment of another manufacturer (Table 55). Since Finish Engineering currently has a GSA contract, the corresponding GSA prices (5-gal, $2770; 15-gal, $10,128) for stills with no vacuum attachment were used.

- Eighty percent of the cost of initial purchase of raw materials is included with the initial cost of equipment. The remaining 20 percent was included as an annual operations and maintenance cost.

- Cost of leasing equipment and supply/recycle of thinner obtained from SK is $75 per batch. The volume of each batch is 7.5 gal. Liability costs associated with the contract, transportation, and ultimate disposal in this arrangement is assumed to be $0.01/gal.

With the above assumptions, life cycle costs were calculated for: (1) offsite disposal and purchase of fresh thinner (status quo or current practice), (2) contract closed-loop recycling or disposal, (3) onsite distillation with a 5-gal still, and (4) onsite distillation with a 15-gal still. Net present values of total 10-yr costs were calculated for the above options for a number of annual generation rates ranging from 100 to 2000 gal/yr. Figure 9 shows the comparison between the NPVs for all the options.

There are no investment costs associated with options 1 and 2. A 5-gal still (option 3) is cost effective beyond 150 gal/yr when compared to offsite disposal. It is more cost effective than contract recycling (option 2) from volumes as low as 50 gal/yr. Option 2 is, therefore, the most expensive option for generation rates beyond 50 gal/yr.

Fort Carson generates about 1004 gallons per year of paint thinner waste which is disposed of through DRMO. The NPV operating costs for the current practice are $114,933 ($11,493/yr). Investing $18,568 for a 15-gal still will result in an annual savings of $7260. The SIR and DPP are 3.91 and 3.53, respectively. The purchase of a 15-gal still is therefore recommended. In addition to minimizing wastes, a payback can be expected in less than 4 years.

Table 53

SIRs and DPPs From a Comparison of the Costs of Gravity Drain With FLOCS

Number of Vehicles	SIR	DPP
100	0.38	> 10
250	0.39	> 10
500	0.39	> 10
1000	0.39	> 10
5000	0.39	> 10

Table 54

SIRs and DPPs From a Comparison of the Costs of Gravity Drain With FLOCS for 1000 Vehicles

Number of Oil Changes	SIR	DPP
2	0.39	> 10
4	0.79	> 10
5	0.98	> 10
6	1.17	9.99

Table 55

Purchase Cost (1989) of Distillation Stills

Manufacturer	Model	Capacity (gal)	Price ($) no vacuum attachment	Price ($) vacuum attachment
Finish Engineering	LS-Jr	5	$ 2770	$ 4338
	LS-15IID	15	$ 10,128	$ 13,361
	LS-55IID	55	$ 20,123	$ 24,609
Recyclene	R-2	5	$ 2995	
	RS-20	20-25	$ 11,900	
Progressive Recovery, Inc.	SC-25	15	$ 7290	$ 12,865
	SC-50	35	$ 11,300	$ 16,895

Table 56

Comparison of Minimization Options for 1,1,1-Trichloroethane Wastes

Option Name	Inv. Costs. ($)	O&M Costs	Total	SIR	DPP
Offsite disposal (current practice)	0	295,122 (29,512)	295,122	-	-
15-gal Batch Still	$16,453	220,631 (22,063)	237,084	4.53	3.51
55-gal Batch Still	$32,613	218,170 (21,817)	250,783	2.36	5.99
40 gal/h In-line Still with power cover and 15 in. freeboard increase	$44,767	155,565 (15,557)	200,332	3.12	4.22

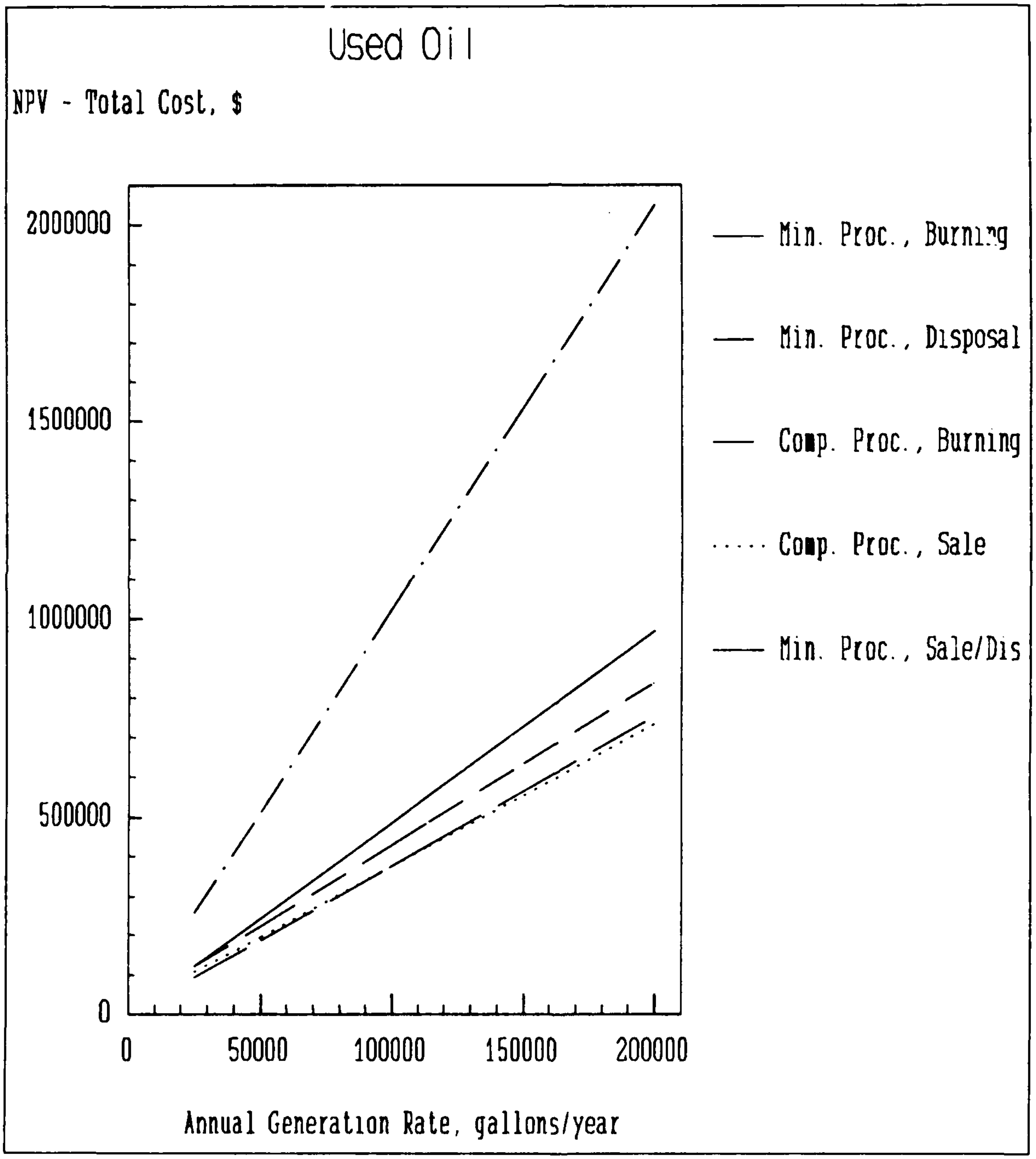

Figure 5. **Comparison of the NPVs of the total 10-yr costs of implementing options for the minimization of used oil.** Minimal processing and then burning defines the status quo.

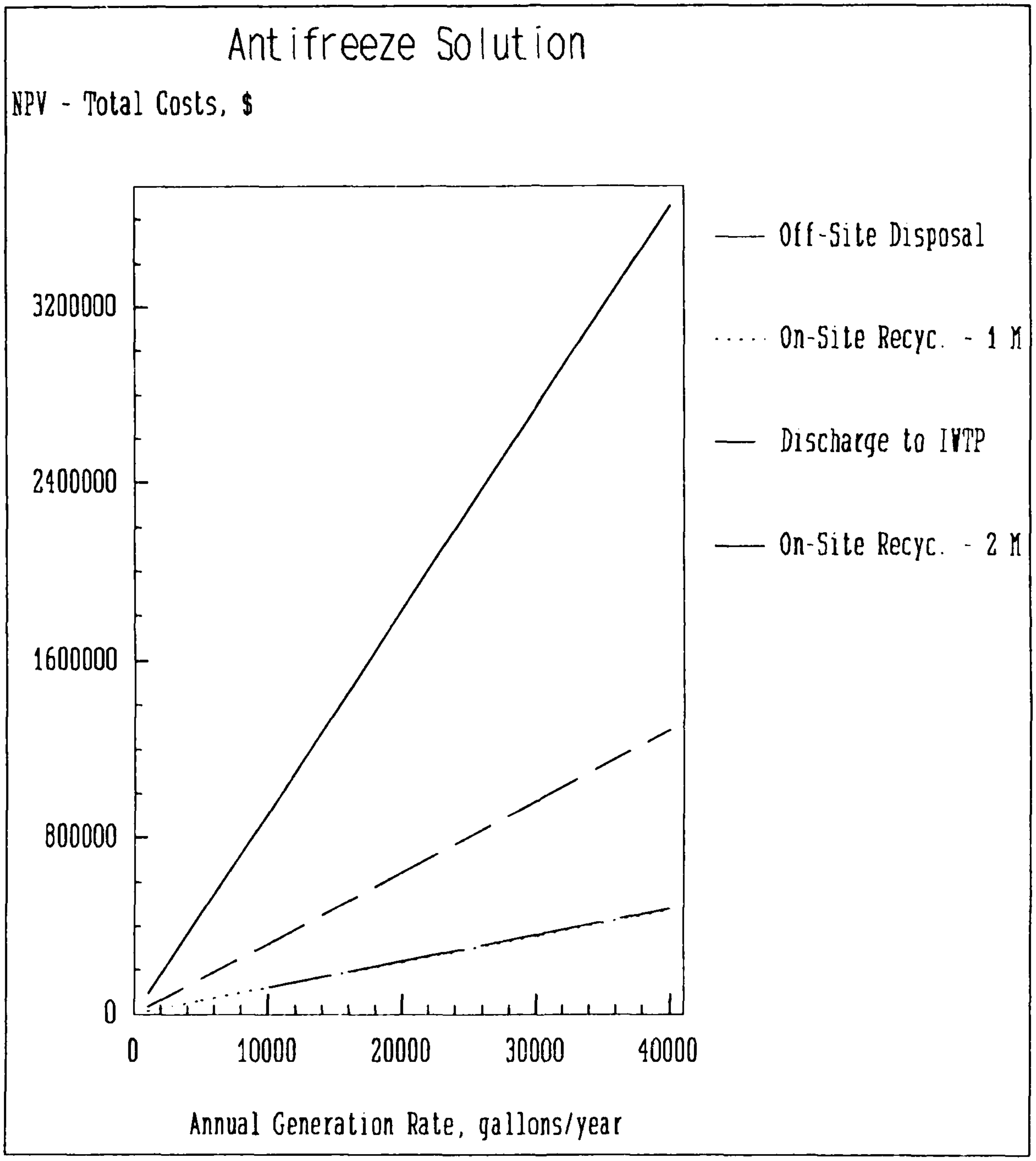

Figure 6. **Comparison of the NPVs of the total 10-yr costs for implementing options for the minimization of spent antifreeze.** Discharge to the IWTP defines the status quo.

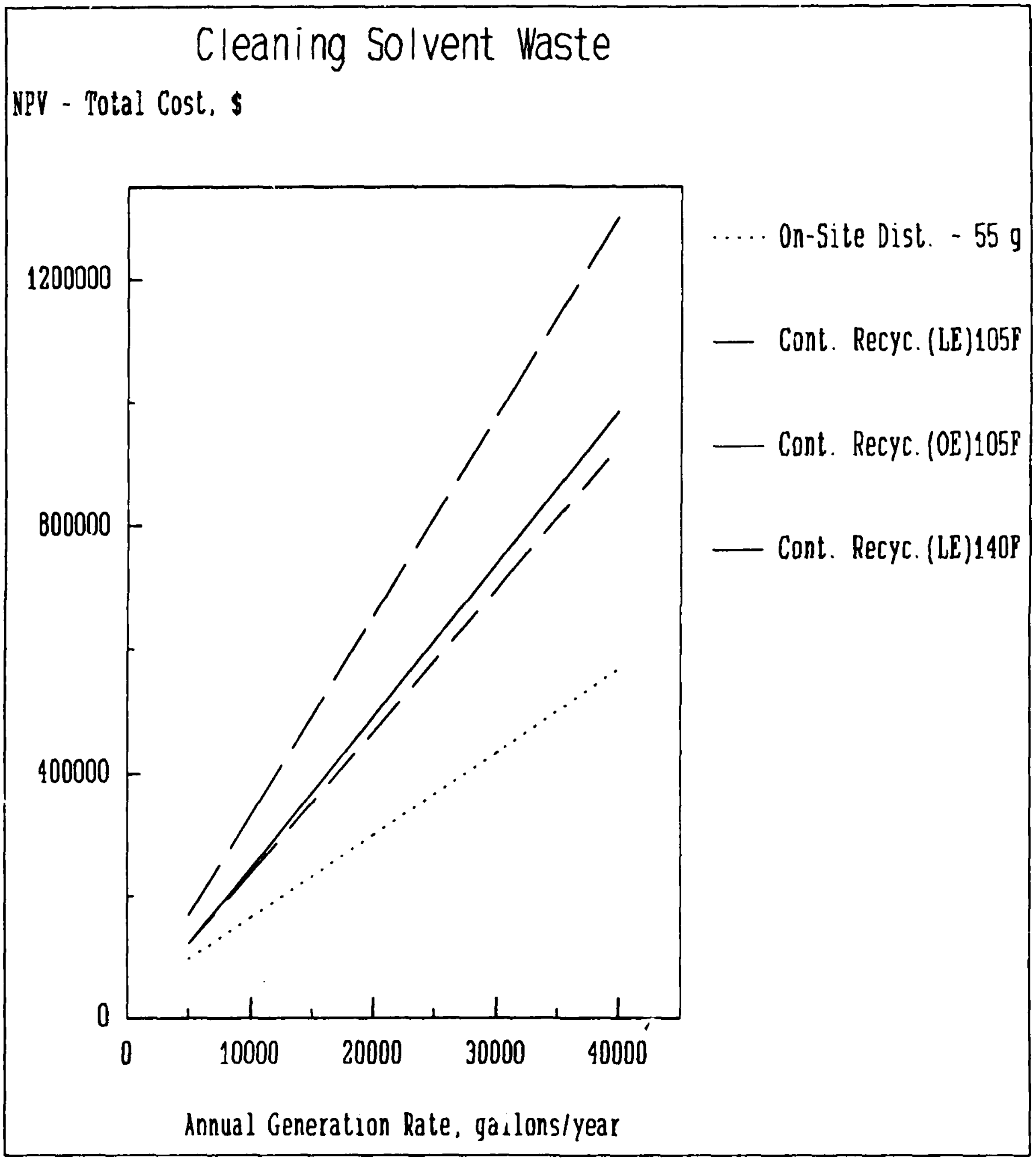

Figure 7. **Comparison of the NPVs of the total 10-yr costs for implementing options for the minimization of cleaning solvent waste.** Contract recycle (LE 105 F) defines the status quo.

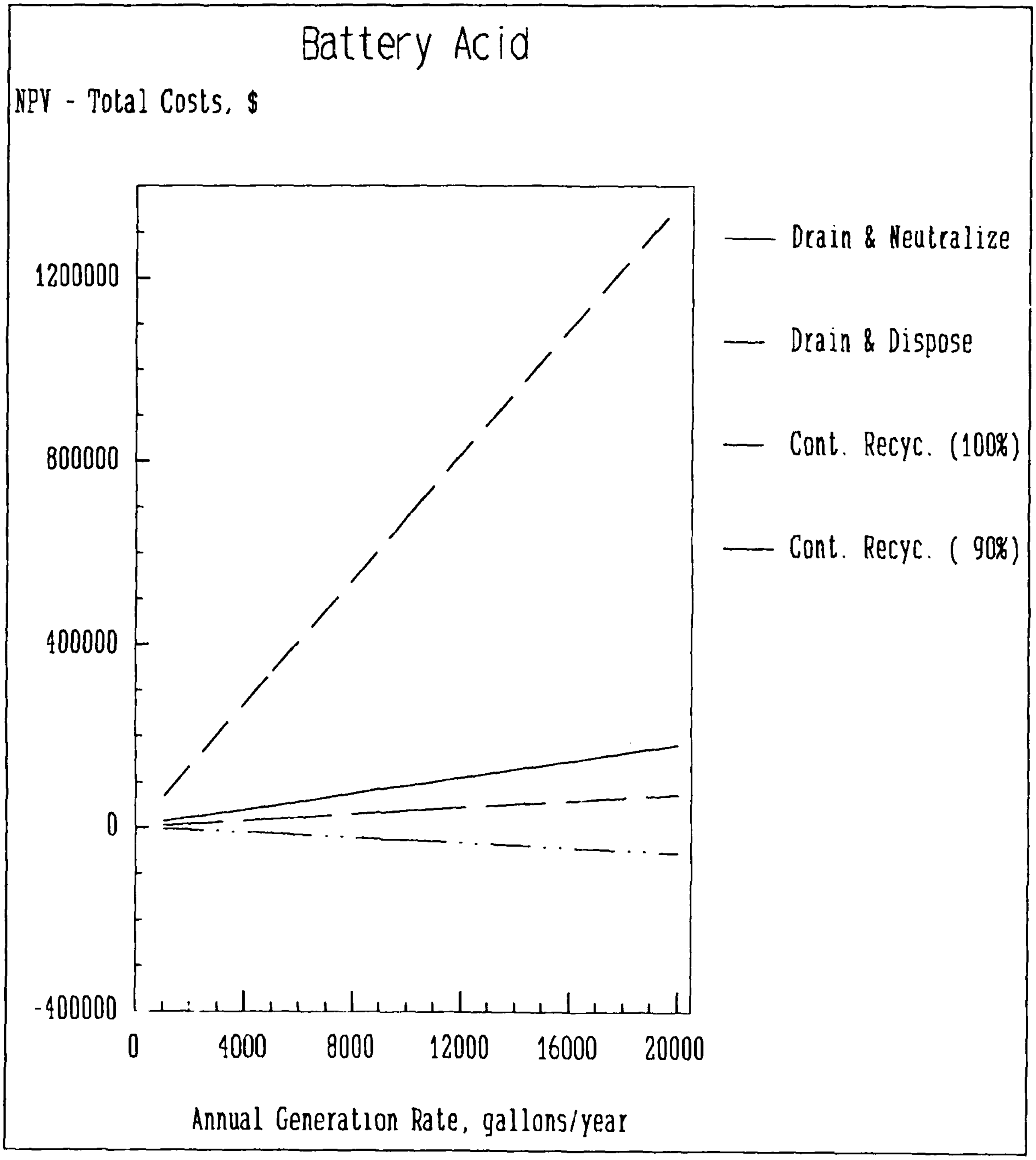

Figure 8. **Comparison of the NPVs of the total 10-yr costs for implementing options for the minimization of spent battery acid.** Draining and neutralization define the status quo.

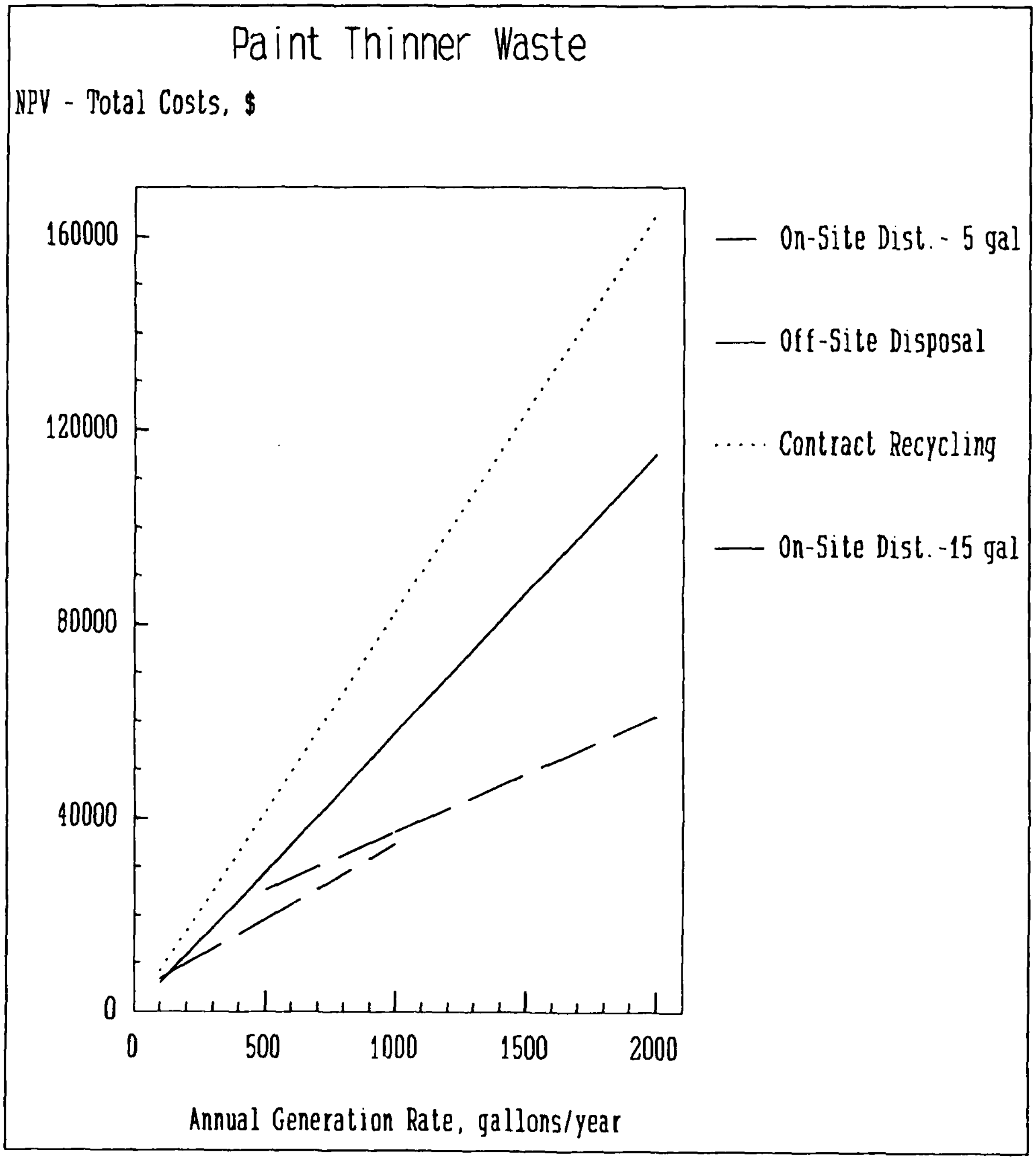

Figure 9. **Comparison of the NPVs of the total 10-yr costs for implementing options for the minimization of paint thinner waste.** Offsite disposal defines the status quo.

13 SUMMARY AND RECOMMENDATIONS

Summary

All Army installations that are generators or small quantity generators (according to RCRA definitions) are required to implement programs to reduce hazardous waste generation. Waste minimization is a method of preventing pollution with the primary focus on reducing waste generation. A number of benefits are accrued by implementing a waste minimization program. The benefits can be classified into the following four categories: economic, regulatory compliance, reduced liability, and positive public image/community relations.

Minimization of a particular waste can best be achieved by an appropriate combination of source reduction, recycling onsite/offsite, and treatment techniques. Source reduction is on the top of USEPA's heirarchy of waste management priorities. It is followed by recycling, waste separation and concentration, waste exchange, energy/material recovery, waste incineration/treatment, and, finally, ultimate disposal. A number of waste minimization techniques have been discussed in this report pertaining to wastes generated from: motor pools/vehicle maintenance facilities; aviation maintenance facilities; industrial maintenance, small arms shops; paint shops; printing, photography, arts/crafts shops; hospitals, clinics, and laboratories; and other miscellaneous sources on an Army installation.

Fort Carson is a troop installation with few tenants. It is regulated by the USEPA and the State of Colorado as a generator of hazardous waste and owner of treatment, storage, and disposal facilities.

A good HW management program has been established. A HW inventory was developed according to AR 420-47, however it is not comprehensive and should be updated.

The HW management plan is not up-to-date.

Used oil is the largest quantity waste generated at the rate of 797,399 lb/yr. Used solvents and other HW are occasionally mixed with used oil at many of the individual activities, creating large quantities of "hazardous" waste oil. Mixing of water from floor washing with oil in underground storage tanks results in a liquid with very little recycle value. Following minimal processing (oil/water separation), the used oil is currently blended with natural gas and burned in one of the boilers in Bldg 1860.

Spent lead-acid battery acid is generated at the rate of 93,744 lb/yr and neutralized with sodium bicarbonate in Bldg 8000. The neutralized acid is released into the sanitary sewer system; drained batteries are strapped to wooden pallets and turned in to DRMO for recycling. The acid is likely to be EP toxic for lead. Therefore, the practice of neutralization and draining into the sewer may be illegal.

A closed-loop (Safety Kleen [SK]) contract has been established for recycling parts cleaning solvent used (235,309 lb/yr) by all the vehicle maintenance facilites. However, a hazardous (ignitable) solvent (flash point 105 °F) is being used. It should be replaced with a nonhazardous solvent (flash point $\geq$ 140 °F).

Some of the other wastes generated are: battery casings (535,534 lb/yr), other corrosives (280,229 lb/yr), spent antifreeze solution (267,917 lb/yr), contaminated fuels (77,630 lb/yr), paint related material (38,957 lb/yr), decontaminating agents (18,626 lb/yr), spent halogenated solvents (11,362 lb/yr), photographic/printing chemicals (6587 lb/yr), used alcohols (5646 lb/yr), other nonhalogenated solvents (1762 lb/yr), pharmaceutical wastes (90 lb/yr), and miscellaneous wastes (862,655/yr).

An estimated total of 1646 tons/yr of wastes are generated. This estimate does not include PCB transformers. Half of it consists of lead-acid battery casings, medical infectious wastes, and boiler blowdown. Only 448 tons/yr of "potentially" hazardous wastes are generated.

The wastes selected for technical economic analysis are used oils, spent antifreeze solution, spent cleaning solvent, battery acid, 1,1,1-trichloroethane and its sludge, and paint thinner. The options examined include current practices (offsite disposal, burning, etc.), onsite recycling (distillation, filtration, etc.), contract recycling, segregation/processing, and process equipment modification. Most of the other wastes (e.g., contaminated fuels) can be minimized by implementing simple source reduction techniques ("better operating practices").

Recommendations

A training program was established in 1988 by the EENR office to train personnel from each of the individual units. It concentrates on POL management and should be updated to include proper HW management (including packaging, labeling, storing, transport, etc.) and minimization.

The training program for handling hazardous material and management of hazardous wastes must be improved to ensure compliance with 40 CFR 264.16 and enhance minimization.

The waste analysis plan to characterize and define all (air, water, liquid, and solid) wastes from all the generators should be revised to include frequency of analysis, etc., to ensure compliance with Federal and State of Colorado laws.

The EENR Office personnel must conduct monthly inspections, minimization audits, and periodic training classes in recognition/handling/storage of hazardous materials and wastes. A comprehensive survey of waste generation and management helps in the development of inventories of quantities of hazardous materials used and wastes generated. These inventories must be updated periodically to reflect changes and disbanding of certain activities.

A HM and HW tracking (manifest) system should be implemented. Tracking HM from the supply warehouse to generators and HW from the generators to final storage before disposal, will provide a mass balance and improve minimization opportunities.

All generators must develop an inventory system and maintain proper records of materials procured and wastes generated from each of the activities. These records must be inspected regularly by the supervisors and EENR office personnel.

The hazardous waste management plan must be updated.

Implementation of the HAZMIN plan (Appendix A) must begin immediately; the plan should be updated annually.

Plan Implementation

Careful planning and a systematic approach are required to implement a successful waste minimization program. Three key elements (policy, commitment, and responsibility) are necessary for a strong program foundation.

The Commander must prepare a formal, written policy on waste minimization and pollution control, including its philosophy, objectives, and proper practices. Such a policy must be publicized in the installation newsletters and distributed to all military and civilian employees.

The installation command heirarchy and the commanders of tenant activities must adopt and support the policy statement. They should also willingly commit resources necessary to launch and support the waste minimization program.

A leader (such as the Chief, EECO) should be appointed to oversee, direct, and assume all responsibility for the program. Supervisors and other employees of waste generating activities must be committed to the program for it to be effective. To encourage such a commitment, the Commanders and supervisors must implement motivational techniques. They must set goals for achieving waste/emissions reduction and provide incentives and awards for implementation of waste minimization ideas.

All waste generators must immediately implement HAZMIN options that require little or no capital investment (e.g., procedural or administrative changes) as discussed in Chapters 5 through 11. These options are generally characterized as "better operating practices," a subcategory of source reduction that does not require detailed technical and economic evaluation. Better operating practices are methods that achieve source reduction by:[175] (1) segregation (e.g., eliminate mixing of hazardous and nonhazardous wastes to improve their recyclability); (2) improved material handling and inventory practices (e.g., avoid accumulation of expired shelf-life materials, avoid spills, etc.); (3) preventive maintenance (e.g., prevent leaks and spills); (4) production scheduling (e.g., minimize quantities of unused raw materials and batch-generated wastes); and (5) minor operational changes. Implementation of "better operating practices" usually requires only minimal employee training and changes to standing operating procedures/practices (SOPs).

The feasible options, discussed in Chapter 12, for minimization of used oil, antifreeze solution, cleaning solvent waste, batteries/battery acid, spent 1,1,1-trichloroethane and its sludge, and paint thinner waste must be funded and implemented. The practice of burning used oil must be modified to include a preprocessing step using a vacuum dehydrator and degasifier (investment cost - $17,855). Implementation of proper segregation practices, and periodic testing with test kits and by laboratory analyses must be implemented. An annual savings of $8520 can be expected.

Contract recycling of cleaning solvent through SK must be continued. However, a modification of the contract to require supply of a higher flash point solvent is recommended. The additional annual cost is estimated to be $28,664.

A large quantity of antifreeze solution is drained into the sanitary sewer system at Fort Carson. Spent antifreeze can be recycled as discussed in Chapter 5. An investment of $166,481 is required to

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[175] National Association of Manufacturers, *Waste Minimization: Manufacturers' Strategies for Success* (ENSR Consulting and Engineering, 1989).

purchase two Glyclean recycling machines. With an annual savings of $74,293 when compared to wastewater treatment and discharge losses, a payback period of 2.57 years is expected.

Wet recycling of lead-acid batteries is recommended in place of the current practice of draining and neutralizing spent electrolyte. A savings of $8762/yr and an additional revenue of $2674 can be expected when sold to a battery recycler.

For paint thinner waste, it is recommended that a small, 15-gal batch still be purchased at a total investment cost of $15,783. The annual operating cost is $2116 and payback can be expected in 5.41 years.

Equipment modifications to include an on-line distillation unit, motorized power cover, and increase in freeboard height, are required to reduce the wastes and emissions generated from the vapor degreaser located in Bldg 8000. A total investment cost of $44,767 and an annual operating cost $15,557 is anticipated. These modifications will result in an annual savings of $12,437, with payback in 4.22 years.

Generation of all other wastes can be reduced by more than 30 percent by managerial changes, training, and implementation of "better operating practices" and other appropriate minimization techniques as discussed in Chapters 5 through 11.

The Fort Carson Hazardous Waste Management Board, chaired by the Installation Commander, must adopt the HAZMIN plan and establish policies and procedures required for its implementation. The expected implementation date is 31 September 1990.

After implementing HAZMIN techniques at the generating activities, progress must be monitored and results recorded. The quantities of wastes generated before and after implementation of the techniques must be monitored and the achievements in waste minimization (e.g., percent minimized) documented. Waste minimization of 37 percent and "hazardous" waste minimization of 54 percent (see Appendix A, and Table A3) are to be expected upon proper implementation.

A waste minimization program never ends. Preventing waste generation and thereby reducing the pollution of air, land, and water, must be a continuous quest. The goal of such a program must be to reduce wastes to the maximum extent possible. All waste generating processes must be continuously assessed and reassessed to account for changes in economic status (e.g., increase in disposal costs), changes in design of production processes, maintenance procedures, and/or technical/technological breakthroughs.

METRIC CONVERSION TABLE

1 Btu = 0.293 W
1 gal = 3.785 L
1 in. = 25.4 mm
1 mi = 1.6 km
1 lb = 0.37 kg
1 psi = 6.89 kPa
1 ton = 0.9 MT
°C = 5 (°F - 32)/9

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APPENDIX A:

FORT CARSON - HAZMIN PLAN

1. BACKGROUND

The Hazardous and Solid Wastes Amendments (HSWA)[1] to the Resource Conservation and Recovery Act (RCRA),[2] passed in 1984, require the generators of hazardous wastes to certify that they have a waste minimization program. Every waste shipment manifest is accompanied with the following declaration, in compliance with Section 3002 (b) of HSWA:

> The generator of the hazardous waste has a program in place to reduce the volume and toxicity of such waste to the degree determined by the generator to be economically practicable;...

Therefore, all facilities that meet the RCRA definitions of Generator (more than 1000 kg or 2205 lb/month) and Small Quantity Generator (100 to 1000 kg or 220 to 2205 lb/month) of HW have to implement waste minimization programs.

HSWA [Section 3002(a)] also requires the generators of hazardous wastes to submit a biennial report, including documentation on efforts to reduce the volume and toxicity of wastes generated. Facilities that treat, store, or dispose of hazardous wastes are required [HSWA, Section 3005(h)] to submit annual reports accompanied with similar declarations on waste minimization.

In the broadest sense, HAZMIN may be defined as the process of reducing the net outflow of hazardous waste effluents from a given source (or generating process). Minimization would include any source reductions in the generation of hazardous wastes as well as any recycling activities that would result in either a reduction in the total volume or quantity of hazardous wastes, or a reduction in the toxicity of hazardous wastes produced or both as long as it is consistent with the national goal of minimizing present and future threats to the environment.[3] HAZMIN, therefore, can be achieved by:

> Source Reduction - which refers to reduction or elimination of waste generation at the source, usually within a process. It also implies any action taken to reduce the amount of waste leaving a process;
>
> Recycling Onsite/Offsite - which is the use or reuse of a waste as an effective substitute for a commercial product, or as an ingredient or feedstock in a process. Recycling also implies the reclamation of useful constituent fractions from within a waste or removal of contaminants allowing it to be reused; and/or

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[1] Public Law 98-616, *Hazardous and Solid Waste Amendments*, 1984.

[2] Public Law 94-480, *Resource Conservation and Recovery Act*, 1976.

[3] *Minimization of Hazardous Waste. Executive Summary and Fact Sheet*, EPA/530/SW-86/033A (EPA, Office of Solid Waste, Washington, D.C., 1986).

Treatment - eliminating hazardous characteristics of a waste making it nonhazardous to human health and environment.

For any particular waste, the minimization options must be evaluated in the hierarchy of source reduction first, followed by recycling (including, recovery and reuse), and, finally, treatment. There may always remain some small amount of residue (e.g., ash) which will require "ultimate" disposal (e.g., landfill burial). Although attempts have been made to clearly define the three HAZMIN categories, there may be overlap for certain specific techniques. Maximum waste reduction is usually achieved by using the best combination of suitable techniques from all three categories.

Recognizing the liabilities of improper disposal and the advantages of waste minimization, the Joint Logistics Commanders set a DOD-wide goal of 50 percent reduction in hazardous waste generation by 1992, based on the baseline generation in 1985. The Department of Army has adopted this DOD goal and established a policy[4] applicable to all Active Army, Reserve, and National Guard installations.

2. PURPOSE

The purpose of the Fort Carson Installation Hazardous Waste Minimization (HAZMIN) plan is to provide a specific plan of action to reduce the quantities and toxicities of hazardous wastes (HW) generated within the installation boundaries.

3. SCOPE

The scope of the plan extends to all the HW regulated under the Resource Conservation and Recovery Act (RCRA), the Hazardous and Solid Wastes Amendments (HSWA), and the State of Colorado Hazardous Waste Regulations.

4. GOALS

4.1 Department of Army (DA) HAZMIN Goals

Process, Operation, or Condition	Percent HW Reduction Desired by 1992
Cleaning/degreasing	40
Transportation vehicle maintenance	0
Fueling operations	30
Battery shop operations	50
Painting	50

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[4] Office of the Assistant Chief of Engineers, "Hazardous Waste Minimization (HAZMIN) Policy," Department of the Army, 1989, 15 pages.

Sand blasting	60
Metalworking	15
Graphic Arts	40
Electrical maintenance	60
Waste treatment sludge	60

4.2 Fort Carson HAZMIN Goals

Same as DA goals.

4.3 HAZMIN Reduction Estimation

Percent HW reduction for any calender year (CY) =

$$\frac{(\text{Baseline Year HW Generation - CY HW Generation}) * 100}{\text{Baseline Year HW Generation}}$$

5. PROGRAM MANAGEMENT

5.1 Fort Carson will manage the HAZMIN program according to AR 200-1 and AR 420-47. The installation's Hazardous Waste Management Board (HWMB) shall review and adopt this plan, and establish other policies and procedures for implementation. The HWMB is to be chaired by the Assistant Division Commander (Support) and consists of the following members:

Assistant Division Commander (Support) (ADC/S)
Garrison Commander (GS)
Director of Engineering and Housing (DEH)
Director, Environment, Energy, and Natural Resources (EENR)
Director of Logistics (DOL)
Director of Personnel and Community Activities (DPCA)
Director of Reserve Component Support (DRCS)
Director of Plans, Training, and Mobilization (DPTM)
Assistant Chief of Staff (ACofS, G1/AG)
Assistant Chief of Staff (ACofS, G2)
Assistant Chief of Staff (ACofS, G3)
Assistant Chief of Staff (ACofS, G4)
Assistant Chief of Staff (ACofS, G5)
Deputy Chief of Staff (DC/S)
Inspector General (IG)
Director, Defense Reutilization and Marketing Office (DRMO)
Installation Safety and Occupational Health Manager
Public Affairs Officer (PAO)
Staff Judge Advocate (SJA)

Director of Resource Management (DRM)
Director of Health Services (DHS)
Director of Dental Services (DDS)
Commander, 1st Brigade
Commander, 2nd Brigade
Commander, 3rd Brigade
Commander, Division Artillery
Commander, Division Support Command
Commander, 43rd Support Group
Commander, 4th Battalion, 61st Air Defense Artillery
Commander, 4th Engineering Battalion
Commander, 124th Signal Battalion
Commander, 104th Military Intelligence Battalion
Commander, 4th Aviation Brigade (Combat)
Commander, Headquarters Command

5.2 The activities at Fort Carson that are generators of hazardous waste, used oil, and miscellaneous toxic wastes; and references to the appropriate chapter (in the assessment technical report) are:

	Chapter Number
Motor Pools/Vehicle Maintenance Facilities	4, 5
Aviation Maintenance Facilities	4, 5
Industrial Maintenance, Small Arms Shops, etc.	4, 6
Paint Shops	4, 7
Photography, and Printing Operations	4, 8
Hospitals, Clinics, and Laboratories	4, 9
Other Generators	4, 10

6. TRAINING

6.1 Personnel Training

A training program will be developed, by the Director, EENR for personnel involved in handling of hazardous materials and management of hazardous wastes to ensure compliance with 40 CFR 264.16.

6.2 Training Content, Schedules, and Techniques

Personnel from HW generating activities must be given supervised on-the-job training as well as formal courses. The formal courses must be designed similar to the program offered by the U.S. Army Environmental Hygiene Agency, or the U.S. Army Logistics Management Center. Refresher courses must be taught by the Environmental Personnel from the DEH Environment, Energy, and Natural Resources division.

The objective of a formal (or refresher) course must be to provide each student with the abilities to:[5]

1. Recognize, identify, and classify hazardous materials.

2. Take actions necessary to prevent hazardous chemical incidents, protect personnel health, and prevent damage to the environment.

3. Properly package, label, store, handle, and transport hazardous materials and hazardous waste.

4. Take immediate action in response to hazardous materials spills or other emergencies.

5. Implement appropriate HAZMIN techniques.

6. Properly manage the resources under his/her control to prevent violation of applicable laws, regulations, and policies.

6.3 Implementation of Training Program

The Chief of the Training Division (DPTM) will direct a training program designed by the Director, EENR. All new and/or reassigned personnel will not work in positions dealing with hazardous materials/wastes unless they have completed the appropriate program within 6 months of the date of employment or reassignment. All supervisors will, annually, review the training status of their personnel.

6.4 Records

a. The Personnel Directorate (Fort Carson and tenant activities) will maintain records pertaining to job experience and the training completion requirements. The records must include description of the type/nature of initial and continuing training each person receives.

b. Fort Carson will maintain records of all current personnel until deactivation of a particular unit/organization or the entire base. Training records of past employees must be kept for at least 3 years after the date of last employment.

7. HAZMIN ACTIONS

7.1 General Actions

7.1.1 Command Initiatives: For the HAZMIN program to be successful, the Commander and the chain of command for all the troops and tenants must make a commitment to all the goals (section 2) and establish specific goals at the generator (or activity) level.

The Installation Commander will develop an environmental policy statement emphasizing pollution minimization and assign direct responsibility to all personnel as protectors of the

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[5] *Defense Hazardous Materials Handling Course (DHMHC)*, U.S. Army Logistics Management Center (ALMC), Fort Lee, Virginia.

environment in their day-to-day work. All personnel will be notified (through the *Mountaineer* and inter-office memorandums) regarding the command commitment and goals.

Personnel incentives (such as awards, commendation, etc.) must be provided to encourage new HAZMIN ideas and to reward implementation of successful HAZMIN projects.

7.1.2 The installation must solicit cooperation with the host community (Colorado Springs) for success of HAZMIN projects.

7.1.3 Participation is required among appropriate personnel from: Directorate of Logistics (DOL) - responsible for supply/procurement, transportation; Directorate of Engineering and Housing (DEH) - responsible for interim and long term storage, compliance with federal/state environmental laws, and pollution control guidance; and Defense Reutilization and Marketing Office (DRMO) - responsible for proper disposal; in implementation, programming, and budgeting HAZMIN programs.

7.1.4 A hazardous material (HM) and hazardous waste (HW) tracking (manifest) program will be implemented at Fort Carson (including all the tenants). Tracking HM from the supply warehouse to generators and HW from the generators to final storage before disposal, will provide a mass balance and improve minimization opportunities.

7.1.5 HAZMIN programs will be incorporated into the agenda of the Environmental (and Hazardous Waste) Management Board Meetings. Proper coverage must be provided in the installation newspaper (*Mountaineer*) to ensure wide acceptance among personnel.

7.1.6 Director, EENR, and the Installation Safety and Occupational Health Manager will combine resources to develop a training program for personnel in hazardous materials/waste handling and emergency response (according to Section 6) which is required by law.

7.1.7 Director, EENR, will develop a waste analysis program to characterize and define all (air, water, liquid, and solid) waste streams from all the generators to ensure compliance with Federal and State laws.

7.1.8 Director, DRMO, and the Director, EENR, will examine the use of waste exchange programs as a proper recycle methodology for some of the hazardous wastes.

7.1.9 The EENR Hazardous Waste Program Manager will conduct monthly inspections, minimization audits, and periodic training classes in recognition/handling/storage of hazardous materials and wastes.

7.2 Generator Actions

7.2.1 All generators must program for disposal of hazardous wastes following the decentralization of funding beginning in Fiscal 1990.

7.2.2 All generators will appoint environmental (hazardous waste) coordinators who would be responsible for minimizing generation (of air emissions, water pollution and solid wastes), proper interim storage, and turn-in of hazardous wastes.

7.2.3 The environmental (or hazardous waste) manager should interface with the EENR Hazardous Waste Program Manager in all matters pertaining to waste management and minimization.

Individuals appointed to this duty will devote more time than is customary for a typical "extra duty."

7.2.4 All environmental managers will maintain proper records (logbooks) of materials procured and wastes generated from each activity and report on a monthly basis to the EENR.

7.2.5 All generators must, with the help of EENR, completely characterize (in terms of composition, periodicity of generation, why and how generated, etc.) all the waste streams, document and provide relevant data when requested by the EENR.

7.2.6 All generators will include HAZMIN requirements ("Better Operating Practices" as outlined in Chapters 5 through 11) and specified by the EENR in their standing operating procedures (SOPs).

7.3 Current HAZMIN Projects

7.3.1 Cleaning Solvent - Recycle Onsite/Offsite - Contract Recycling

A used solvent recycling program has been designed to collect and recycle used cleaning solvent (Petroleum Naphtha) used in motor pools, vehicle/aviation maintenance facilities, and other parts cleaning activities. Source reduction (e.g., better operating practices, testing, etc.) must be implemented by all generators to reduce the quantities used. Use of a substitute (e.g., Citrikleen) must also be explored.

From the economics of solvent use (at a total rate of 30,160 gal/yr) it is determined that onsite distillation (using a 55-gal batch still) is more economical than the current closed-loop (Safety Kleen [SK])[6] contract recycling for minimizing cleaning solvent wastes.

Estimated Cost: Investment - $60,162; Annual O&M - $38,105

Estimated Annual Savings: $33,100

Estimated Payback Period: 2.73 years

However, some of the practical aspects of disbanding current operations, purchase of new equipment, logistics of setting-up, operating a recycling center, and transporting spent solvent to the central location and recycled solvent back to the users, etc., makes the change to onsite distillation undesirable. The current practice of SK contract recycling should be continued and extended to include other generators who have government-owned solvent cleaning tanks.

The existing SK contract should be modified to substitute the solvent (flash point 105 °F) being delivered with a nonignitable solvent (flash point > 140 °F). The solvent waste in such a case is a nonhazardous waste and is exempt from reporting requirements.

Estimated Cost: Annual O&M - $99,866

Estimated "Additional" Annual Cost: $28,664

Estimated Waste Reduction (Recycling Alone): 0 percent

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[6] Safety Kleen, Inc., is a commercial solvent recycling contractor.

Estimated Waste Reduction (Source Reduction and Recycling): 40 percent

Estimated "Hazardous" Waste Reduction: 100 percent

7.3.2 Used Oil - Treatment - Burning

Used oil is currently accumulated by all the generators and a contractor transports it to a tank farm located near the main boiler house. About 114,000 gal/yr of used oil is generated. Five percent of it is contaminated with halogenated solvents and has to be treated as a hazardous waste.

Comprehensive processing followed by continued burning of used oil at one of the boilers is recommended. Proper segregation of waste oil is required at all the generators. Chlorine detection kits (e.g., CLOR-D-TECT™1000 and CLOR-D-TECT™Q4000)[7] must be used to detect the level of chlorinated solvent contamination of oil at the generators before the oil is transported to the boiler for burning. If oil samples are found to contain chloride, a complete laboratory analysis is required to determine flash point, and the total halogens, sulfur, and heavy metals (As, Cd, Cr, Pb) content. If the halogen content is less than 1000 ppm and the heavy metals are within specifications, the oil can be blended and burned. An air pollution permit has to be obtained.

Estimated Cost: Investment - $17,855; Annual O&M - $46,815

Estimated Annual Savings: $8,520

Estimated Payback Period: 3.91 years

Estimated Waste Reduction (Treatment Alone): 0 percent

Estimated Waste Reduction (Source Reduction and Treatment): 30 percent

Estimated "Hazardous" Waste Reduction: 0 percent

7.4 Future HAZMIN Projects

7.4.1 Spent Lead-Acid Batteries/Battery Acid - Source Reduction - No Draining/Sale

The current practice at Fort Carson is to drain the lead-acid batteries and neutralize the spent acid. About 9500 gal/yr of acid is generated.

Lead-acid batteries (sealed and unsealed) must be accumulated at the generators (e.g., motor pools) on pallets. These batteries, when bound securely to the pallets, can be recycled through a recycler. If the batteries are being recycled, they are exempt from RCRA reporting requirements and, therefore, do not require reporting and manifesting paperwork necessary for other hazardous wastes.

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[7] CLOR-D-TECT is a trademark of the Dexsil Corporation [1 Hamden Park Drive, Hamden, CT 06517, (203) 288-3509]. CLOR-D-TECT 1000 is a go-no-go kit for determining if used oil is contaminated with chlorinated solvents. CLOR-D-TECT Q4000 is a quantitative test for determination of chloride (0 to 4000 ppm) in used oil.

Estimated Price: Annual O&M - $2674 (revenue)

Estimated Annual Savings: $8762

Estimated Waste Reduction (Source Reduction/Recycling): 100 percent

Estimated "Hazardous" Waste Reduction: 100 percent

7.4.2 Used Antifreeze Solution - Onsite Recycling

Used antifreeze solution is generated at the rate of 30,445 gal/yr by the vehicle maintenance facilities at Fort Carson. It is drained into the industrial sewer. Although antifreeze is not a hazardous waste, it is difficult to treat and can cause an upset at the sewage treatment plant. In addition, the price of new antifreeze has more than doubled in the past two years ($4.00 to $8.45/gal). A technology (Glyclean filtration system - unit price: $2,400) exists for recycling the 50 percent antifreeze solution.

Use of the Glyclean system is recommended.

Estimated Cost: Investment - $166,481; Annual O&M - $9795

Estimated Annual Savings: $74,293

Estimated Payback Period: 2.57 years

Estimated Waste Reduction (Recycling Alone): 100 percent

Estimated Waste Reduction (Source Reduction and Recycling): 100 percent

Estimated "Hazardous" Waste Reduction: 0 percent

7.4.3 Paint Thinner/Residue - Recycle Onsite/Offsite - Distillation

The Paint Shop belonging to the DOL Operations Maintenance Branch (Bldg 8000) will purchase a 15-gal distillation still for recycling paint thinner wastes. Thinner wastes generated elsewhere on Fort Carson will be brought to the DOL shop and distilled. The still bottoms have to be disposed of as hazardous waste. Permit requirements, if any, will be reviewed by the environmental office before the installation and operation of the still.

Estimated Price: Investment - $15,783; Annual O&M - $2116

Estimated Annual Savings: $3630

Estimated Payback Period: 5.41 years

Estimated Waste Reduction (Recycling Alone): 80 percent

Estimated Waste Reduction (Source Reduction and Recycling): 90 percent

Estimated "Hazardous" Waste Reduction: 90 percent

7.4.4 1,1,1-Trichloroethane/Degreaser Tank Bottoms - Source Reduction and Recycle Onsite/Offsite - Equipment Modifications and Continuous Recycling

The Maintenance Operations Branch of the DOL owns an old (i.e., 1975) vapor-spray-vapor degreaser (VS 800-S-H, manufactured by DETREX Chemical Industries, Inc.) which is located in Maintenance Section III of the DOL Consolidated Maintenance Building (Bldg 8000). It is a large machine (≈ 500 cu ft) used to clean oversize (e.g., engine blocks, canon barrels, etc.) and small parts.

The vapor degreasing operations use nearly 3860 gal/yr of 1,1,1-trichloroethane. Approximately, 2860 gal/yr of it is lost because of its volatility and poor operating practices of the personnel. The total hazardous waste generated includes spent solvent (250 gal/3 months), and tank bottoms (5280 lb/yr). An investment in a biparting motorized cover, a 40 gal/hr inline distillation unit, and an increase in freeboard height to 15 in. is recommended. Better operating practices and process controls (as discussed in Chapter 5) must also be implemented.

Estimated Cost: Investment - $44,767; Annual O&M - $15,557

Estimated Annual Savings: $12,437

Estimated Payback Period: 4.22 years

Estimated Waste Reduction (Source Reduction and Recycling): 54 percent

Estimated Emissions Reduction (Source Reduction): 37 percent

Estimated "Hazardous" Waste Reduction: 54 percent

7.4.5 Other Wastes - Source Reduction

Implement "better operating practices" and other appropriate minimization techniques according to references in Section 5.2.

Estimated Waste Reduction: 30 percent

Estimated "Hazardous" Waste Reduction: 20 percent

7.5 Overall Estimate of Expected Waste Reduction

Expected Waste Reduction: 37 percent

Expected "Hazardous" Waste Reduction: 54 percent

8. REFERENCES

8.1 Fort Carson installation waste generation data is given in Tables A1 and A2.

8.2 The calculations for the "overall" estimated waste reduction (in Section 7.5) are presented in Table A3.

8.3 This plan is in Appendix A of the *Hazardous Waste Minimization Assessment: Fort Carson, Colorado Springs, Colorado.*

9. IMPLEMENTATION

Estimated Implementation Date: September 31, 1990.

10. RESPONSIBILITIES

10.1 The duties and responsibilities of persons directly responsible for implementation of this plan and success of the HAZMIN program are described in this section. The following personnel will form the Fort Carson HAZMIN committee that will oversee the implementation of this plan and keep it revised and updated in the future.

Job Title	Name	HAZMIN Activity
Director, Environmental, Energy and Natural Resources Office	T. Warren	Overview of the entire program; chair the committee; and others as noted in section 10.3.
Deputy Director, EENR, Environmental Program	M. Barber	Vicechair of the committee. Help the Director, EENR and coordinate implementation with the hazardous waste program manager and other committee members.
Hazardous Waste Program Manager, EENR	T. Tjerandsen	Establish a hazardous materials/ waste training program; establish waste inventory and inspection program; establish a HW/HM tracking program; coordinate with Safety Officer, Fire Director, DRMO and all the environmental coordinators.
Installation Safety and Occupational Health Manager	R. Whitmore	Establish a chemical inventory program; flag and control purchase of hazardous materials; coordinate with the environmental engineer regarding maintaining and updating inventory.
Director, Defense Reutilization and Marketing Office	W. Tilley	Establish proper waste turn-in procedures; waste contract management; explore offsite reclamation and waste exchange options.

Project Manager, GE Operations	J. McDavid	Inventory control of materials and wastes; vehicle/equipment maintenance, painting and laboratory wastes minimization; pesticides management; PCB transformer inventory management.
Chief, DEH Fire Department	V. Witham	Coordinate with safety office; inventory flammable/toxic materials; SARA Title III compliance.
Chief, DOL Transportation Management Branch	E. Mestas	Inventory control of materials and wastes; vehicle maintenance wastes minimization.
Chief, DOL Maintenance Operations Branch	D. Ganshow	Inventory control of materials and wastes; painting, machining, and weapons cleaning wastes minimization.
Chief, DOL Aircraft Maintenance Branch	E. Mestas	Inventory control of materials and wastes; aviation maintenance wastes minimization.
Chief, DOL Supply Activity	M. Olliver	Flag and control procurement of hazardous materials; coordinate with Safety and EENR; establish chemical usage inventory and demand history by each generator.
Manager, GE Supplies Division	R. Rosemark	Flag and control procurement of hazardous materials; coordinate with Safety and EENR; establish chemical usage inventory and demand history by each generator.
Chief, MEDDAC Logistics Materiel Branch	CPT K. LaFrance	Flag and control procurement of hazardous materials; coordinate with Safety and EENR; establish chemical usage inventory and demand history by each laboratory and generator.
Chief, DPCA Education Center	W. Ensminger	Inventory control of materials and wastes; vehicle maintenance wastes minimization.
Chief, DPTM Training and Audiovisual Support Center	N. Amodeo	Inventory control of materials and wastes; photographic and printing wastes minimization.

Chief, Preventive Medicine Evans Army Community Hospital	CPT E. Selzer	Establish inventory of hazardous materials/wastes; establish waste generators monitoring program; coordinate minimization and proper disposal practices (infectious, hazardous, and radioactive wastes) with environmental office.
XO, 1st Brigade	LTC C.G. Bailey	Inventory control of materials and wastes; vehicle maintenance wastes minimization.
XO, 2nd Brigade	LTC D.M. Harris	Inventory control of materials and wastes; vehicle maintenance wastes minimization.
XO, 3rd Brigade	LTC L.L. Harrold	Inventory control of materials and wastes; vehicle maintenance wastes minimization.
XO, 4th Aviation Brigade	LTC F.A. Treyz	Inventory control of materials and wastes; aviation and vehicle maintenance wastes minimization.
XO, Division Artillery	LTC W.J. Carden	Inventory control of materials and wastes; vehicle maintenance wastes minimization.
XO, Division Support Command	LTC J.H. Lantz	Inventory control of materials and wastes; vehicle maintenance, and industrial maintenance wastes minimization.
XO, 43rd Support Group	LTC C.R. Coffer, Jr.	Inventory control of materials and wastes; vehicle maintenance wastes minimization.
CO, 4th Battalion, 61st Air Defense Artillery	LTC O.A. Nagel	Inventory control of materials and wastes; vehicle maintenance wastes minimization.
CO, 4th Engineering Battalion	LTC P.K. Bailey	Inventory control of materials and wastes; vehicle maintenance wastes minimization.
CO, 124th Signal Bn.	LTC W.E. Francis, Jr.	Inventory control of materials and wastes; vehicle maintenance wastes minimization.
CO, 104th MI Battalion	MAJ K.A. Dickinson	Inventory control of materials and wastes; vehicle maintenance wastes minimization.

XO, Headquarters Command	MAJ M.L. Magrini	Inventory control of materials and wastes; vehicle maintenance wastes minimization.
CO, Naval Reserve Center	LCDR T.E. McKee	Inventory control of materials and wastes; vehicle maintenance wastes minimization.
CO, 3rd Battalion 87th Infantry (USAR)	LTC F.H. Mann	Inventory control of materials and wastes; vehicle maintenance wastes minimization.
Environmental (or Hazardous Waste) Managers		As discussed in Section 10.4.

10.2 Responsibilities of all HAZMIN Committee Members (except Director, EENR)

10.2.1 Identify and prioritize activities required to achieve the goals outlined in this plan.

10.2.2 Provide information on HAZMIN techniques to the actual generators of hazardous waste.

10.2.3 Organize a team to conduct annual HAZMIN assessments (or audits) to determine sources, types, and quantities of hazardous materials used and hazardous wastes generated.

10.2.4 Report on the status of the HAZMIN program to the Director, EENR regularly.

10.2.5 Assist the Director, EENR, in preparing an Annual HAZMIN status report.

10.3 Responsibilities of the Director, Environment, Energy and Natural Resources Office

10.3.1 Oversee and provide resources (including technological assistance) for conducting the annual HAZMIN assessments. Report the state of the HAZMIN program to the commander.

10.3.2 Revise and update this plan annually.

10.3.3 Prepare a HAZMIN status report when requested by HQFORSCOM or HQDA.

10.3.4 Program funds necessary to accomplish HAZMIN goals.

10.3.5 Chair the HAZMIN Committee.

10.3.6 Conceive, develop, and implement HAZMIN techniques consistent with this plan.

10.4 Responsibilities of Environmental (or Hazardous Waste) Managers

10.4.1 Establish goals for minimizing all forms of environmental pollution (air, water, solid, and hazardous waste).

10.4.2 Obtain training (organized by EENR) on all the applicable environmental laws and train all subordinate personnel.

10.4.3 Implement "better operating practices" through: inventory control (maintaining logbooks for materials procured and pollution generated); segregation of wastes; spill and leak prevention; and scheduling frequent preventive maintenance of equipment.

10.4.4 Examine and implement the use of substitute nonhazardous or less hazardous materials in place of hazardous materials.

10.4.5 Examine and implement "process changes" such as: process modifications; equipment modifications; and changes in operation settings, to reduce the quantities of pollution generated.

10.4.6 Examine and implement technologies for recycling, reuse, or treatment of wastes. Information about technologies and equipment suppliers can be obtained from environmental personnel at EENR.

Table A1

Summary of Fort Carson Waste Generation

Waste Generating Operation Process, or Condition	Waste Category*	lb/yr	lb/yr/unit Survey	IDMS	Suggest	Waste Stream Unit
Motor Pools and Vehicle Maintenance Facilities	1	191861	190103		190103	Spent Petroleum Naphtha
				1758	1758	Spent Degreasing Solvent, NOS
	2	1442		647	647	Carbon Remover
			795		795	Carburetor Cleaner
	3	247501	247501		247501	Spent Antifreeze Solution
	4	717424	635507	105000	635507	Used Motor Oil
				81917	81917	Chlorinated Motor Oil
	8	3744	3744		3744	Spent Sulfuric Acid
	10	32655	32655	20487	32655	Contaminated Diesel, Mogas
	12	201850	201850	38301	201850	Spent Lead Acid Batteries
	13	305491	4903	1148	4903	Used Brake, Fluid
			23041		23041	Used Transmission Fluid
			14342		14342	Used Hydraulic Fluid
			120680	95000	120680	Spent Sorbent
			34825		34825	Contaminated Rags
			6770	105000	105000	Contaminated Soil
			1540		1540	Hazardous Faulty Parts
			685	1160	1160	Asbestos Containing Materials
Industrial Maintenance Small Arms Shops	1	29057	29057		29057	Spent Degreasing Solvent
	2	7700	7700		7700	Spent 1,1,1 Trichloroethane
	3	20416	20146		20146	Spent Antifreeze Solution
	4	75190	73590		73590	Used Motor Oil
			1600		1600	Chlorinated Motor Oil
	7	15	15		15	Spent Paint Thinner

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*1: spent degreasing solvents (nonhalogenated), 2: spent degreasing solvents (halogenated), 3: spent antifreeze solution, 4: used motor oil, 5: used alcohols, 6: spent photo and print chemicals, 7: paint related materials, 8: spent acids and bases, 9: decontamination agents, 10: contaminated fuels, 11: pharmaceutical wastes, 12: spent batteries, and 13: miscellaneous wastes.

Table A1 (Cont'd)

Waste Generating Operation, Process, or Condition	Waste Category	lb/yr	lb/yr/unit Survey	 IDMS	 Suggest	Waste Stream Unit
	8	92500	90000		90000	Spent Sulfuric Acid
			2500		2500	Spent Sodium Hydroxide
	10	42700	42700		42700	Contaminated Fuels
	12	300015	300000		300000	Lead-acid Battery Casings
			5		5	Spent Li-So$_2$ Batteries
			10		10	Spent NICAD Batteries
	13	17816	686		686	Used Transmission Fluid
			80		80	Used Brake Fluid
			4375		4375	Used Hydraulic Fluid
			840		840	Contaminated Sorbent
			685		685	Hazardous Faulty Parts
			3700		3700	Contaminated Fluid Filters
			70		70	Contaminated Cutting Oil
			2100		2100	Oily Rags
			5280		5280	TCA Tank Bottom Sludge
Aviation Maintenance Facility	1	13379	12991		12991	Spent Petroleum Naphtha
			172	85	172	Spent MEK
				216	216	Spent Acetone
	2	446		171	171	Carbon Remover
				275	275	Cleaning Compound, NOS
	4	3035	3035	1035	3035	Aircraft Engine Oil
	7	842	132		132	Spent Paint Stripper
			79	135	135	Spent Paint Thinner
			285		285	Spent Paint Filters
				290	290	Unused, Spoiled Paint
	3	716	714		714	Caustics
			2		2	Potassium Hydroxide
	10	2275	2275	1750	2275	Contaminated JP-4
	12	20250		20250	20250	Spent NICAD Batteries

Table A1 (Cont'd)

Waste Generating Operation, Process, or Condition	Waste Category	lb/yr	Survey	lb/yr/unit IDMS	Suggest	Waste Stream Unit
	13	11866	140	1700	1700	Contaminated Hydraulic Fluid
			600		600	Spent Sorbent
				345	345	Grease, NOS
			4375		4375	Contaminated Hydraulic Fluid
			30		30	Hazardous Empties
			1308		1308	Contaminated Rags
			8		8	Solvent Tank Sludge
				3500	3500	Contaminated Soil, Solids
Paint Shops	2	65		65	65	Spent Methylene Chloride
	4	1750	1750		1750	Used Motor Oil
	5	1031	1031		1031	Spent Alcohol, NOS
	7	29521	4720	7040	7040	Spent Paint Thinner
			90		90	Spent Paint Stripper
			880		880	Spent Paint Filters
			240		240	Spent Respirater Cartridges
				478	478	Sealant
				284	284	Bondo
				140	140	Rust Remover
				210	210	Adhesive, NOS
			480		480	Paint Covered Overalls
			650	19679	19679	Unused, Spoiled Paint
	13	4115	2600		2600	Spent Oil, Fuel Filters
			840		840	Spent Sorbent
			600		600	Hazardous Empties
			75		75	Contaminated Rags
Photography, Printing, and Arts/Crafts Shops	1	96	96		96	Spent Deglazing Solvent
	2	1079	216	125	216	Spent Film Cleaner
			739	863	863	Spent Blankrola Solvent

Table A1 (Cont'd)

Waste Generating Operation, Process, or Condition	Waste Category	lb/yr	lb/yr/unit			Waste Stream Unit
			Survey	IDMS	Suggest	
	3	5621	288		288	Spent Photo Stabilizer
			1796	102	1796	Spent Photo Bleach
				215	215	Spent Photo Rinse
			36	2946	2946	Spent Offset Toner Solvent
			92		92	Spent Electrostatic Solvent
			92		92	Spent Electrostatic Ink and Toner
			192		192	Spent Hypo. Cleaning Agent
			720		720	Spent Photo Activator
	7	316	230		230	Laquer Thinner
			72		72	Enamel Thinner
			14		14	Turpentine
	8	10663	6128	4945	4945	Spent Photo Developer
			4128		4128	Spent Photo Fixer
			96		96	Ink Roller Conditioner
			488		488	Acetic Acid Photo Bath
				198	198	Conversion Solvent, NOS
				88	88	Imager
Hospitals, Clinics, and Laboratories	1	1278	308	480	480	Spent Xylene
				280	280	Spent Benzene
				518	518	Spent Toluene
	2	505		430	430	Spent Formaldehyde
				75	75	Spent Chloroform
	5	915		915	915	Spent Alcohol, NOS
	6	960		460	460	Spent Photo Developer
				216	216	Spent Photo Toner
				290	290	Spent Photo Wash
	9	185		185	185	Spent Disinfectant, NOS

Table A1 (Cont'd)

Waste Generating Operation, Process, or Condition	Waste Category	lb/yr	lb/yr/unit Survey	lb/yr/unit IDMS	Suggest	Waste Stream Unit
	11	90	90	90	90	Shelf-Life Pharmaceuticals
	13	511624		215	215	Contaminated Mercury
				320	320	Potassium Phosphate
				215	215	Soda Lime
			732		732	Pathological Wastes
			509650		509650	Medical Infections
				492	492	Miscellaneous Chemicals
Heating and Cooling Plants	1	1400	1400		1400	Spent Petroleum Naptha
	8	265600	265600		265600	Caustic Boiler Blowdown
G E (formerly DEH)	7	8263		3702	3702	Unused, Spoiled Paint
				3451	3451	Sealant
				1110	1110	Polyurethane
	12	171		171	171	Furniture Polish
Troop	9	18441		4762	4762	Shelf-Life DS-2
				10717	10717	Shelf-Life STB
				1854	1854	Calcium Hydride
				1108	1108	Calcium Hypochlorite
	12	13248		8461	8461	Spent Mercury Batteries
				1019	1019	Spent Alkaline Batteries
				3768	3768	Spent Lithium Batteries
	13	10559		1210	1210	Insecticides, NOS
				9349	9349	Magnesium Carbon
Miscellaneous	2	125		100	100	Spent Dichlorodifluoromethone
				25	25	Spent Freon
	5	3720		3720	3720	Spent Methonol
	8	750		750	750	Spent Acetic Acid
	13	1184		1184	1184	Detergent, NOS

Table A2

Total Waste Generation Rates by Waste Categories*

Generator	Total	1	2	3	4	5	6	7	8	9	10	11	12	13
MPVM	1701968	191861	1442	247501	717424				3774		32655		201850	305491
IMSS	585409	29057	7700	20416	75190			15	92500		42700		300015	17816
AMF	52809	13379	446		3035			842	716		2275		20250	11866
PS	36482		65		1750	1031		29521						4115
PPAS	17775	96	1079				5621	316	10663					
HCL	515563	1278	505			915	966			185		90		511624
HCP	267000	1400							265600					
GE (DEH)	8434							8263					171	
Troop	42248									18441			13248	10559
Miscellaneous	5779		125			3720			750					1184
TOTAL	3233467	237071	11362	267917	797399	5646	6587	38957	373973	18626	77630	90	535534	862655

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*Quantities are reported in pounds per year.

Table A3

Calculation of the Overall Waste Reduction Factors

Waste	Quantity lb/yr (gal/yr)	Estimated Reduction	Estimated "HW" Reduction
Cleaning Solvent	235,309 (30,610)	0.00	1.00
Used Oil	797,399 (114,000)	0.30	0.10
Battery Acid	93,744 (9500)	1.00	1.00
Antifreeze	267,917 (30,445)	1.00	0.00
Paint Thinner	7040 (1000)	0.80	0.90
TCA	7700 (1000)	0.80	0.90
Degreaser Tank Bottoms	5280	0.00	0.00
Other Wastes	530,034*	0.30	0.20
	Weighted Average	0.37	0.54**

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[*] Does not include: boiler blowdown - 265,600 lb/yr; infectious wastes - 509,650 lb/yr; lead-acid batteries/casings - 501,850.

[**] Since (nonchlorinated) used oil and antifreeze are not "hazardous wastes" they have been excluded from this calculation.

APPENDIX B:

HAZMIN PROTOCOL AND SURVEY FORMS

HAZMIN Protocol

Goals

1. Define current status of waste generation and management practices.
2. Identify and evaluate new waste minimization alternatives.
3. Identify support for existing alternatives/activities.
4. Identify areas/activities requiring further research and development.

Approach

I. Review information available at the installation.

II. Talk to several groups of individuals.

III. Develop a list of waste streams and rank them.

IV. Develop information on each waste stream.

V. Identify minimization options for each waste stream.

VI. Evaluate and rate options (preliminary or first screen) for each waste stream.

VII. Conduct detailed technical and economic feasibility analysis of select minimization options for high priority waste streams.

HAZMIN Protocol

I. Review information available at the installation.

The information reviewed by the survey team includes:

1. Installation policies/programs on waste minimization, if any.
2. Hazardous waste manifests, annual (and biennial) reports, and other RCRA information since 1985.
3. State and local regulations that are more stringent than federal regulations.
4. Environmental audit/review reports.
5. Emission inventories.
6. Permit and/or permit applications, and any regulatory violations.
7. Contracts with waste management firms.
8. Waste assays and/or tests.
9. Materials purchase orders, purchase records.
10. Maps, organizational charts, list of activities associated with different buildings.
11. Production/maintenance schedules.
12. Operator data logs, batch sheets.
13. Operation manuals, process descriptions, standard operating procedures (SOPs).
14. Process flow diagrams (PFDs) and facilities layout.
15. Heat and material balances for production processes and pollution control systems.
16. Safety procedures for handling hazardous materials.

Products:

1. List of information sources.
2. Waste stream list.
3. Survey agenda or checklist detailing what is to be accomplished.
4. List of questions that need to be resolved.
5. List of information that needs to be gathered.

HAZMIN Protocol

II. Talk to several groups of individuals.

Identify appropriate individuals to interview among:

1. Environmental personnel
    - who compile USEPA/State reports
    - who compile DRMO reports
2. Waste generators
    - supervisors
    - shop foremen and production employees
3. Hazardous waste managers
    - operators of on-site treatment, storage, and disposal (TSD) facilities
    - transporters of waste from generation points to TSD facilities
4. Individuals responsible for purchasing/acquisition of hazardous materials (for possible substitution alternatives, costs of purchase, etc.)
5. Individuals with broad HAZMIN responsibilities
    - finance and accounting
    - construction/renovation of facilities
    - higher levels of management
    - legal advisors

HAZMIN Protocol

III. Develop a list of waste streams and rank them.

Develop a waste generation inventory based on reports, permits, and observation. Inventory must be representative of "normal" operations.

Ranking criteria:

1. Composition
2. Quantity (volume or mass generated per year and unit of production)
3. Degree of hazard (toxicity, flammability, corrosivity, etc.)
4. Method and cost of disposal
5. Potential for minimization and recycling
6. Compliance status (in or out)
7. Potential liability (past spills or accidents; proximity to water)
8. Degree of acceptability of changes at the installation
9. Installation personnel preference for options

Products:

1. Waste description with rationale for selection
2. Description of facilities, processes, and waste streams

HAZMIN Protocol

IV. Develop information on each waste stream.

The following information must be developed on each waste stream based on observation and available reports:

1. Waste characterization
   - chemical/physical analysis
   - reason for hazardous nature
2. Waste source
3. Baseline generation
4. Present method of TSD and associated costs
5. Past/present minimization efforts and associated costs

Some points to be reviewed in the above determination are:

- actual point of generation
- details about subsequent handling/mixing
- "hazardous" versus nonhazardous
- physical and chemical characteristics
- quantities by waste treatability category
- potential variations in the rate of production, maintenance, etc.
- potential for contamination or upset
- true costs for management, onsite and offsite including tax, fringe, and overhead for labor; cost of space; vehicle insurance, maintenance, fuel, etc.

V. Identify minimization options for each waste stream.

Follow USEPA guidelines on waste minimization. The categories arranged in a heirarchical order are:

1. Source reduction
   a. product/material substitution
   b. source control
      i. input material changes (e.g., dilution, purification)
      ii. technology changes (e.g., process changes, layout changes, etc.)
      iii. procedural/institutional changes
2. Recycle/reuse
   a. onsite
   b. offsite
3. Waste separation and concentration
4. Waste exchange
5. Energy/material recovery
6. Waste incineration/treatment
7. Treatment
8. Ultimate disposal

VI. Evaluate and rate options (preliminary or first screen) for each waste stream.

Some considerations for a preliminary evaluation and rating of minimization options for each waste stream are:

1. Waste reduction effectiveness (i.e., reduction of waste quantity and/or toxicity)
2. Extent of current use in the facility
3. Industrial precedent
4. Technical soundness
5. Cost (preliminary capital and operating cost evaluation)
6. Effect on product quality
7. Effect on operations
8. Implementation period
9. Resources availability and requirement

VII. Detailed technical and economic feasibility analysis of select minimization options for high priority waste streams.

The following aspects must be considered in the final detailed analysis:

1. Technical soundness and commercial availability
2. Evaluation of detailed life cycle costs of all the options for each waste stream
3. Detailed comparison of costs of the current practices with alternative options to obtain savings to investment ratios and discounted payback periods
4. Implementation period

HAZMIN Survey Forms

Installation____________________**Date**__________**POC**____________________
Phone_________

WASTE STREAM/MATERIALS USAGE: Motor Pools & Vehicle Maintenance Facilities

Generator (Unit Name)________________**Building**________**DODAAC**________**UIC**____

Waste Stream	**Generation Rate** (indicate units: gal/yr lb/yr, pints/mo, etc.)	**Material Input**	**Usage Rate** (indicate units: gal/yr lb/yr, pints/mo, etc.)
Spent cleaning solvent		Cleaning solvent	
Carburetor cleaner		Carburetor cleaner	
Waste oil		Engine oil	
Antifreeze solution		Antifreeze	
Lead-acid batteries		Lead-acid batteries	
Battery acid		Battery acid	
Aqueous detergent or caustic wastes (engine/radiator washing)		Caustic/detergent	
Detergent solution from floor wash		Detergent floor wash	
Oily dirt with heavy metals			
Spent sorbent (Dry-Sweep)		Sorbent	
Contaminated fuel (mogas/diesel)		Fuel: diesel mogas	
Dirty rags		Rags	
Solvent tank-bottom sludges			
Contaminated water			
Other fluids (transmission, brake, etc.)		Other fluids (transmission, brake, etc.)	
Mixed wastes			
Hazardous faulty parts (e.g., brake pads)			
Miscellaneous (specify)		Miscellaneous (specify)	

Installation____________________**Date**__________**POC**______________________
Phone________

WASTE STREAM/MATERIALS USAGE: Aviation Maintenance Facilities

Generator (Unit Name)________________**Building**_______**DODAAC**______**UIC**_____

Waste Stream	**Generation Rate** (indicate units: gal/yr lb/yr, pints/mo, etc.)	**Material Input**	**Usage Rate** (indicate units: gal/yr lb/yr, pints/mo, etc.)
Spent cleaning solvent		Cleaning solvent	
MEK degreaser & cleaner		Methyl ethyl ketone	
Calibrating fluid (specify)		Calibrating fluid (specify)	
Paint stripper (specify)		Paint stripper (specify)	
Paint thinner (specify)		Paint thinner (specify)	
Filters (paint booth)		Filters (paint booth)	
Used paint cans			
Waste engine oil		Engine oil	
Deicer solution		Deicer	
Nickel-cadmium batteries		Nickel-cadmium batteries	
NICAD battery electrolyte		Battery electrolyte (pottasium hydroxide)	
Aqueous detergent or caustic wastes (engine washing)		Caustic/detergent (engine washing)	
Detergent solution from floor wash		Detergent floor wash	
Oily dirt with heavy metals			
Spent sorbent (Dry-Sweep)		Sorbent	
Contaminated fuel (Avgas)		Fuel (Avgas)	
Dirty rags		Rags	
Solvent tank-bottom sludges			
Contaminated water			
Miscellaneous (specify)		Miscellaneous (specify)	

Installation____________________**Date**__________**POC**______________________
Phone_________

WASTE STREAM/MATERIALS USAGE: Industrial Maintenance, Small Arms Shops, etc.

Generator (Unit Name)________________**Building**________**DODAAC**______**UIC**_____

Waste Stream	**Generation Rate** (indicate units: gal/yr lb/yr, pints/mo, etc.)	**Material Input**	**Usage Rate** (indicate units: gal/yr lb/yr, pints/mo, etc.)
Degreasing solvent (trichloroethylene)		Trichloroethylene	
Degreasing solvent (1,1,1-trichloroethane)		1,1,1-trichloroethane	
Degreasing solvent (others)		Degreasing solvent (others, specify)	
Paint thinners (specify)		Paint thinners (specify)	
Surface cleaners (specify)		Surface cleaners (specify)	
Paint wastes			
Waste oil		Lubricating oil	
Hydraulic/cutting fluids		Hydraulic & cutting fluids	
Corrosive chemicals (caustic soda)		Caustic soda	
Corrosive chemicals (phosphoric acid)		Phosphoric acid	
Corrosive chemicals (chromic acid)		Chromic acid	
Corrosive chemicals (phosphate solution)		Phosphate	
Corrosive chemicals (others, specify)		Corrosive chemicals (others, specify)	
Tank bottoms (specify)			
Paint/sand blasting wastes			
Steam cleaning compound (alkali wastes)		Alkali	
Radioactive wastes		Radioactive sources	
Batteries (lead-acid, NICAD)		Batteries: Lead-acid Nickel-cadmium	
Battery electrolyte (specify)		Battery electrolyte (specify)	
Miscellaneous (specify)		Miscellaneous (specify)	

Installation____________________**Date**__________**POC**______________________
Phone_________

WASTE STREAM/MATERIALS USAGE: Paint Shops

Generator (Unit Name)________________**Building**_______**DODAAC**______**UIC**______

Waste Stream	**Generation Rate** (indicate units: gal/yr lb/yr, pints/mo, etc.)	**Material Input**	**Usage Rate** (indicate units: gal/yr lb/yr, pints/mo, etc.)
Old/used paint cans			
Old/used paint			
Paint thinners (specify)		Paint thinners (specify)	
Paint strippers (specify)		Paint strippers (specify)	
Caustic wastes		Caustic soda	
Detergent solution from floor wash		Detergent floor wash	
Oily dirt with heavy metals			
Spent sorbent (Dry-Sweep)		Sorbent	
Dirty rags		Rags	
Solvent tank-bottom sludges			
Contaminated water			
Filters from paint booths		Filters (paint booths)	
Sludges from water-wall booths			
Miscellaneous (specify)		Miscellaneous (specify)	

Installation____________________**Date**__________**POC**______________________
Phone_________

WASTE STREAM/MATERIALS USAGE: Hospitals, Clinics, and Laboratories

Generator (Unit Name)________________**Building**_______**DODAAC**________**UIC**___

Waste Stream	**Generation Rate** (indicate units: gal/yr lb/yr, pints/mo, etc.)	**Material Input**	**Usage Rate** (indicate units: gal/yr lb/yr, pints/mo, etc.)
Pathological wastes (specify)			
Medical infectious wastes (specify)			
Pharmaceutical wastes (specify)			
Chemical wastes (specify)		Laboratory chemicals (xylene)	
		Laboratory chemicals (mercury)	
		Laboratory chemicals (others, specify)	
Radioactive wastes (specify)			
Photographic wastes (specify)		Photographic chemicals (specify)	
Miscellaneous (specify)		Miscellaneous (specify)	

Installation____________________**Date**__________**POC**_____________________
Phone_________

WASTE STREAM/MATERIALS USAGE: Photography, Printing, Arts/Crafts Shops, etc.

Generator (Unit Name)________________**Building**_______**DODAAC**_______**UIC**_____

Waste Stream	**Generation Rate** (indicate units: gal/yr lb/yr, pints/mo, etc.)	**Material Input**	**Usage Rate** (indicate units: gal/yr lb/yr, pints/mo, etc.)
Solvents (specify)		Solvents (specify)	
Inks (specify)		Inks (specify)	
Photographic chemical wastes (specify)		Photographic chemicals (specify)	
Printing chemical wastes (specify)		Printing chemicals (specify)	
Bath dumps			
Paint wastes			
Paint/sand blasting wastes			
Other dry wastes			
Miscellaneous (specify)		Miscellaneous (specify)	

Installation____________________**Date**__________**POC**____________________
Phone_________

WASTE STREAM/MATERIALS USAGE: Heating and Cooling Plants

Generator (Unit Name)________________**Building**_______**DODAAC**_______**UIC**___

Waste Stream	**Generation Rate** (indicate units: gal/yr lb/yr, pints/mo, etc.)	**Material Input**	**Usage Rate** (indicate units: gal/yr lb/yr, pints/mo, etc.)
		Waste oil	
Contaminated fuel oil		Fuel oil	
		Natural gas	
Combustible chemicals (cyclohexylamine)		Combustible chemicals (cyclohexylamine)	
Combustible chemicals (other, specify)		Combustible chemicals (others, specify)	
Corrosive chemicals (caustic soda/potash)		Corrosive chemicals (caustic soda/potash)	
Corrosive chemicals (other, specify)		Corrosive chemicals (other, specify)	
Boiler blowdown			
Toxic emissions			
Ash			
Miscellaneous (specify)		Miscellaneous (specify)	

Installation________________ __**Date**__________**POC**______________________
Phone_________

WASTE STREAM/MATERIALS USAGE: Laundry and Drycleaning Facilities

Generator (Unit Name)________________**Building**_______**DODAAC**_______**UIC**____

Waste Stream	**Generation Rate** (indicate units: gal/yr lb/yr, pints/mo, etc.)	**Material Input**	**Usage Rate** (indicate units: gal/yr lb/yr, pints/mo, etc.)
Corrosive chemicals (caustic soda)		Corrosive chemicals (caustic soda)	
Corrosive chemicals (others, specify)		Corrosive chemicals (others, specify)	
Drycleaning compound (perchloroethylene)		Perchloroethylene	
Drycleaning compound (others, specify)		Drycleaning compound (others, specify)	
Equipment filters		Filters	
Contaminated water			
Other dry wastes (specify)			
Miscellaneous (specify)		Miscellaneous (specify)	

Installation____________________ Date__________ POC______________________
Phone_________

WASTE STREAM/MATERIALS USAGE: Miscellaneous Generators

Generator (Unit Name)________________ Building_______ DODAAC_______ UIC____

Waste Stream	**Generation Rate** (indicate units: gal/yr lb/yr, pints/mo, etc.)	**Material Input**	**Usage Rate** (indicate units: gal/yr lb/yr, pints/mo, etc.)
Wet chemical wastes (specify)		Wet Chemicals (specify)	
Dry chemical wastes (specify)		Dry Chemicals (specify)	
Off-shelf life chemicals			
Used chemicals (pesticides, etc.)			
Batteries (specify)		Batteries (specify)	
Battery electrolyte (specify)		Battery electrolyte (specify)	
Contaminated soil			
Demilitarized ammunition			
Decontaminating agents (STB, DS2, etc.)			
Hazardous empty containers (drums etc.)			
Contaminated equipment (PCB transformers etc.)			
Contaminated water		Water	
Sludge from water treatment		Water treated	
Leachate into groundwater			
Infectious wastes			
Ordnance			
Fire-fighting foam		Fire fighting foam	
Miscellaneous (specify)		Miscellaneous (specify)	

Installation____________________**Date**__________**POC**__________________________
Phone_________

WASTE STREAM/MATERIALS USAGE: Motor Pools & Vehicle Maintenance Facilities

Generator (Unit Name)________________**Building**_______**DODAAC**__________**UIC**_______

Waste Stream	**Generation Rate** (indicate units: gallons/yr pounds/yr, pints/mo, etc.)	**Material Input**	**Usage Rate** (indicate units: gallons/yr pounds/yr, pints/mo, etc.)
Spent cleaning solvent		Cleaning solvent	
Carburetor cleaner		Carburetor cleaner	
Waste oil		Engine oil	
Antifreeze solution		Antifreeze	
Lead-acid batteries		Lead-acid batteries	
Battery acid		Battery acid	
Aqueous detergent or caustic wastes (engine/radiator washing)		Caustic/detergent	
Detergent solution from floor wash		Detergent floor wash	
Oily dirt with heavy metals			
Spent sorbent (Dry-Sweep)		Sorbent	
Contaminated fuel (mogas/diesel)		Fuel: diesel mogas	
Dirty rags		Rags	
Solvent tank-bottom sludges			
Contaminated water			
Other fluids (transmission, brake, etc.)		Other fluids (transmission, brake, etc.)	
Mixed wastes			
Hazardous faulty parts (e.g. brake pads)			
Miscellaneous (specify)		Miscellaneous (specify)	

Installation____________________**Date**__________**POC**__________________________
Phone_________

WASTE STREAM/MATERIALS USAGE: Aviation Maintenance Facilities

Generator (Unit Name)_____________**Building**______**DODAAC**___________**UIC**________

Waste Stream	Generation Rate (indicate units: gallons/yr pounds/yr, pints/mo, etc.)	Material Input	Usage Rate (indicate units: gallons/yr pounds/yr, pints/mo, etc.)
Spent cleaning solvent		Cleaning solvent	
MEK degreaser & cleaner		Methyl ethyl ketone	
Calibrating fluid (specify)		Calibrating fluid (specify)	
Paint stripper (specify)		Paint stripper (specify)	
Paint thinner (specify)		Paint thinner (specify)	
Filters (paint booth)		Filters (paint booth)	
Used paint cans			
Waste engine oil		Engine oil	
Deicer solution		Deicer	
Nickel-cadmium batteries		Nickel-cadmium batteries	
NICAD battery electrolyte		Battery electrolyte (pottasium hydroxide)	
Aqueous detergent or caustic wastes (engine washing)		Caustic/detergent (engine washing)	
Detergent solution from floor wash		Detergent floor wash	
Oily dirt with heavy metals			
Spent sorbent (Dry-Sweep)		Sorbent	
Contaminated fuel (Avgas)		Fuel (Avgas)	
Dirty rags		Rags	
Solvent tank-bottom sludges			
Contaminated water			
Miscellaneous (specify)		Miscellaneous (specify)	

Installation____________________ **Date**__________ **POC**__________________________
Phone_________

WASTE STREAM/MATERIALS USAGE: Industrial Maintenance, Small Arms Shops, etc.

Generator (Unit Name)______________ **Building**______ **DODAAC**__________ **UIC**_________

Waste Stream	Generation Rate (indicate units: gallons/yr pounds/yr, pints/mo, etc.)	Material Input	Usage Rate (indicate units: gallons/yr pounds/yr, pints/mo, etc.)
Degreasing solvent (trichloroethylene)		Trichloroethylene	
Degreasing solvent (1,1,1-trichloroethane)		1,1,1-trichloroethane	
Degreasing solvent (others)		Degreasing solvent (others, specify)	
Paint thinners (specify)		Paint thinners (specify)	
Surface cleaners (specify)		Surface cleaners (specify)	
Paint wastes			
Waste oil		Lubricating oil	
Hydraulic/cutting fluids		Hydraulic & cutting fluids	
Corrosive chemicals (caustic soda)		Caustic soda	
Corrosive chemicals (phosphoric acid)		Phosphoric acid	
Corrosive chemicals (chromic acid)		Chromic acid	
Corrosive chemicals (phosphate solution)		Phosphate	
Corrosive chemicals (others, specify)		Corrosive chemicals (others, specify)	
Tank bottoms (specify)			
Paint/sand blasting wastes			
Steam cleaning compound (alkali wastes)		Alkali	
Radioactive wastes		Radioactive sources	
Batteries (lead-acid, NICAD)		Batteries: Lead-acid Nickel-cadmium	
Battery electrolyte (specify)		Battery electrolyte (specify)	
Miscellaneous (specify)		Miscellaneous (specify)	

Installation____________________ **Date**__________ **POC**__________________________
Phone_________

WASTE STREAM/MATERIALS USAGE: Paint Shops

Generator (Unit Name)______________ **Building**_______ **DODAAC**__________ **UIC**_________

Waste Stream	**Generation Rate** (indicate units: gallons/yr pounds/yr, pints/mo, etc.)	**Material Input**	**Usage Rate** (indicate units: gallons/yr pounds/yr, pints/mo, etc.)
Old/used paint cans			
Old/used paint			
Paint thinners (specify)		Paint thinners (specify)	
Paint strippers (specify)		Paint strippers (specify)	
Caustic wastes		Caustic soda	
Detergent solution from floor wash		Detergent floor wash	
Oily dirt with heavy metals			
Spent sorbent (Dry-Sweep)		Sorbent	
Dirty rags		Rags	
Solvent tank-bottom sludges			
Contaminated water			
Filters from paint booths		Filters (paint booths)	
Sludges from water-wall booths			
Miscellaneous (specify)		Miscellaneous (specify)	

Installation____________________**Date**__________**POC**__________________________
Phone_________

WASTE STREAM/MATERIALS USAGE: Hospitals, Clinics, and Laboratories

Generator (Unit Name)_______________**Building**_________**DODAAC**_________**UIC**_________

Waste Stream	**Generation Rate** (indicate units: gallons/yr pounds/yr, pints/mo, etc.)	**Material Input**	**Usage Rate** (indicate units: gallons/yr pounds/yr, pints/mo, etc.)
Pathological wastes (specify)			
Medical infectious wastes (specify)			
Pharmaceutical wastes (specify)			
Chemical wastes (specify)		Laboratory chemicals (xylene) Laboratory chemicals (mercury) Laboratory chemicals (others, specify)	
Radioactive wastes (specify)			
Photographic wastes (specify)		Photographic chemicals (specify)	
Miscellaneous (specify)		Miscellaneous (specify)	

Installation____________________**Date**__________**POC**____________________________
Phone_________

WASTE STREAM/MATERIALS USAGE: Photography, Printing, Arts/Crafts Shops, etc.

Generator (Unit Name)____________**Building**______**DODAAC**_________**UIC**___________

Waste Stream	**Generation Rate** (indicate units: gallons/yr pounds/yr, pints/mo, etc.)	**Material Input**	**Usage Rate** (indicate units: gallons/yr pounds/yr, pints/mo, etc.)
Solvents (specify)		Solvents (specify)	
Inks (specify)		Inks (specify)	
Photographic chemical wastes (specify)		Photographic chemicals (specify)	
Printing chemical wastes (specify)		Printing chemicals (specify)	
Bath dumps			
Paint wastes			
Paint/sand blasting wastes			
Other dry wastes			
Miscellaneous (specify)		Miscellaneous (specify)	

Installation____________________**Date**__________**POC**__________________________
Phone_________

WASTE STREAM/MATERIALS USAGE: Heating and Cooling Plants

Generator (Unit Name)______________**Building**______**DODAAC**__________**UIC**__________

Waste Stream	Generation Rate (indicate units: gallons/yr pounds/yr, pints/mo, etc.)	Material Input	Usage Rate (indicate units: gallons/yr pounds/yr, pints/mo, etc.)
		Waste oil	
Contaminated fuel oil		Fuel oil	
		Natural gas	
Combustible chemicals (cyclohexylamine)		Combustible chemicals (cyclohexylamine)	
Combustible chemicals (other, specify)		Combustible chemicals (others, specify)	
Corrosive chemicals (caustic soda/potash)		Corrosive chemicals (caustic soda/potash)	
Corrosive chemicals (other, specify)		Corrosive chemicals (other, specify)	
Boiler blowdown			
Toxic emissions			
Ash			
Miscellaneous (specify)		Miscellaneous (specify)	

Installation______________________**Date**____________**POC**______________________________
Phone__________

WASTE STREAM/MATERIALS USAGE: Laundry and Drycleaning Facilities

Generator (Unit Name)______________Building______DODAAC__________UIC__________

Waste Stream	**Generation Rate** (indicate units: gallons/yr pounds/yr, pints/mo, etc.)	**Material Input**	**Usage Rate** (indicate units: gallons/yr pounds/yr, pints/mo, etc.)
Corrosive chemicals (caustic soda)		Corrosive chemicals (caustic soda)	
Corrosive chemicals (others, specify)		Corrosive chemicals (others, specify)	
Drycleaning compound (perchloroethylene)		Perchloroethylene	
Drycleaning compound (others, specify)		Drycleaning compound (others, specify)	
Equipment filters		Filters	
Contaminated water			
Other dry wastes (specify)			
Miscellaneous (specify)		Miscellaneous (specify)	

Installation____________________**Date**__________**POC**__________________________
Phone_________

WASTE STREAM/MATERIALS USAGE: Miscellaneous Generators

Generator (Unit Name)______________**Building**______**DODAAC**__________**UIC**__________

Waste Stream	Generation Rate (indicate units: gallons/yr pounds/yr, pints/mo, etc.)	Material Input	Usage Rate (indicate units: gallons/yr pounds/yr, pints/mo, etc.)
Wet chemical wastes (specify)		Wet Chemicals (specify)	
Dry chemical wastes (specify)		Dry Chemicals (specify)	
Off-shelf life chemicals			
Used chemicals (pesticides, etc.)			
Batteries (specify)		Batteries (specify)	
Battery electrolyte (specify)		Battery electrolyte (specify)	
Contaminated soil			
Demilitarized ammunition			
Decontaminating agents (STB, DS2, etc.)			
Hazardous empty containers (drums etc.)			
Contaminated equipment (PCB transformers etc.)			
Contaminated water		Water	
Sludge from water treatment		Water treated	
Leachate into groundwater			
Infectious wastes			
Ordnance			
Fire-fighting foam		Fire fighting foam	
Miscellaneous (specify)		Miscellaneous (specify)	

LIST OF ABBREVIATIONS AND ACRONYMS

AAFES	Army Air Force Exchange Service
AFPMB	Armed Forces Pest Management Board
AHS	Academy of Health Sciences
AMF	Aviation Maintenance Facility
AOAP	Army Oil Analysis Program
APCD	Air Pollution Control Division
APEN	Air Pollution Emissions Notice
AQCR	Air Quality Control Region
AR	Army Regulation
ARCOM	U.S. Army Reserve Command
BMO	Battalion Maintenance Officer
BOD	Biochemical Oxygen Demand
Btu	British thermal unit
CARC	Chemical Agent Resistant Coating
CCR	Colorado Code of Regulations
CDH	Colorado Department of Health
CE	Corps of Engineers
CEWI	Combat Electronic Warfare Intelligence
CFR	Code of Federal Regulations
COD	chemical oxygen demand
DA	Department of the Army
DEH	Directorate of Engineering and Housing
DENTAC	U.S. Army Dental Activity
DESR	Defense Environmental Status Report
DLA	Defense Logistics Agency

DOD	Department of Defense
DOL	Directorate of Logistics
DOT	Department of Transportation
DPCA	Directorate of Personnnel and Community Affairs
DPTM	Directorate of Plans, Training, and Mobilization
DRMO	Defense Reutilization and Marketing Office
DRMS	Defense Reutilization and Marketing Service
EA	Environmental Assessment
EENR	Energy, Environment, and Natural Resources Division
EOD	Explosive Ordnance Disposal
EOR	Environmental Operations Review
FLOCS	Fast Lubricating Oil Change System
FORSCOM	U.S. Army Forces Command
FR	Federal Register
FY	Fiscal Year
GE	General Electric
HAZMIN	Hazardous Waste Minimization
HCL	Hospitals, Clinics, and Laboratories
HMTC	Hazardous Materials Technical Center
HSC	Health Services Command
HSWA	Hazardous and Solid Waste Amendments
HW	Hazardous Waste
HWMB	Hazardous Waste Management Board
IDMS	Integrated Database Management System
IMSS	Industrial Maintenance, Small Arms Shops
INSCOM	U.S. Army Intelligence and Security Command
ISC	U.S. Army Information Systems Command

ISCP	Installation Spill Contingency Plan
IWTP	Industrial Wastewater Treatment Plant
JAG	Judge Advocate General
JLC	Joint Logistics Commanders
LAO	Logistics Assistance Office
MACOM	Major Command
MAIT	Maintenance Assistance and Indstruction Team
MEDDAC	Medical Department Activity
MGD	Million Gallons Per Day
MI	Military Intelligence
MPVM	Motor Pools and Vehicle Maintenance
MSB	Main Support Battalion
MSDS	Material Safety Data Sheet
NAAQS	National Ambient Air Quality Standard
NIPDWR	National Interim Primary Drinking Water Regulations
NIPER	National Institute for Petroleum and Energy Research
NPDES	National Pollutant Discharge Elimination System
NSDWR	National Secondary Drinking Water Regulations
NSN	National Stock Number
OB/OD	Open Burning/Open Detonation
OSHA	Occupational Safety and Health Administration
PCB	Polychlorinated Biphenyl
PCMS	Pinon Canyon Maneuver Site
PL	Public Law
PMB	Plastic Media Blasting
POL	Petroleum, Oils, and Lubricants
PPAS	Photography, Printing, and Arts/Crafts Shops

PS	Paint Shops
RCRA	Resource Conservation and Recovery Act
SIP	State Implementation Plan
SOP	Standing Operating Procedure
SPCCP	Spill Prevention Control and Countermeasures Plan
SQG	Small Quantity Generator
SS	Suspended Solids
TASC	Training and Audiovisual Support Activity
TMP	Transportation Motor Pool
TOPO	Defense Maping Agency, Hydrographic/Topographic Center
TSDF	Treatment, Storage, or Disposal Facility
TSP	Total Suspended Particulates
TSS	Total Suspended Solids
USACERL	U.S. Army Construction Engineering Research Laboratory
USACIC	U.S. Army Criminal Investigation Command
USAEHA	U.S. Army Environmental Hygiene Agency
USEPA	U.S. Environmental Protection Agency
USATHAMA	U.S. Army Toxic and Hazardous Materials Agency
USE	Used Solvent Elimination
UST	Underground Storage Tank
VOC	Volatile Organic Compounds
WWII	World War II
WWTP	Wastewater Treatment Plant
XO	Executive Officer

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4555 OVERLOOK AVE SW
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IN REPLY REFER TO
9555
Ser 6180/0394
SEP 19 2000

From: Commanding Officer, Naval Research Laboratory
To: Distribution

Subj: DOD AFFF ENVIRONMENTAL MEETING

Encl: (1) Minutes of subject meeting

1. The Navy Technology Center for Safety and Survivability of the Naval Research Laboratory hosted the DOD AFFF Environmental Meeting on 2-3 August 2000. The meeting was held to exchange information on environmental issues surrounding AFFF. The meeting was sponsored jointly by The Naval Facilities Engineering Command and the Naval Air Systems Command.

2. Enclosure (1) is a copy of the minutes of the meeting.

3. The NRL point of contact for this program is Dr. Frederick W. Williams, Code 6180, (202) 767-2476, email: fwilliam@ccs.nrl.navy.mil.

JAMES S. MURDAY
By direction

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6180/0394A:FWW
September 12, 2000

Minutes
Of the
DOD AFFF Environmental Meeting

Held at the Naval Research Laboratory
Navy Technology Center for Safety and Survivability
Washington, D.C.
On
2-3 August 2000

Encl (1) to NRL Ltr
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Minutes of
DOD AFFF Environmental Meeting
Naval Research Laboratory
2-3 August 2000

Summary

A meeting to discuss AFFF environmental issues within the Department of Defense (DoD) was held at the Naval Research Laboratory (NRL), Washington, D.C., on 2-3 August 2000. The meeting was hosted by Dr. Fred Williams, NRL, Director, Navy Technology Center for Safety and Survivability. The meeting was jointly sponsored by the Naval Facilities Engineering Command (NAVFAC) and the Naval Air Systems Command (NAVAIR). The agenda for the meeting is shown in Appendix (1). A list of attendees is provided in Appendix (2), along with a photo of attendees present at the opening general session on 2 August 2000. To facilitate future exchanges of information on this subject, Appendix (2) includes mailing addresses, phone numbers and E-Mail addresses for each attendee.

Objective

The overall objective of the meeting was to provide a forum for open discussion on AFFF environmental issues within DoD. Additionally, the meeting was called to address three specific objectives:

(1) Assist NAVFAC in the development of a DoD design policy for AFFF systems in aircraft hangars and other shore facilities to minimize adverse environmental impact.

(2) Obtain information to assist NAVAIR in finalizing their AFFF Environmental Safety and Health Need Assessment Summary (ESH NAS) and in preparing the follow-on Development Plan.

(3) Provide information for attendees on the relevant issues surrounding the decision by the 3M Company to phase-out production of AFFF and other products containing perfluorooctyl sulfonate (PFOS).

Background

There has been growing concern in the past few years about the potential adverse environmental impact of AFFF. This concern has been spawned by a number of factors:

- The establishment by EPA in 1994 of threshold quantities for reporting spills of AFFF due to the butyl carbitol commonly used as a solvent in AFFF
- Inadvertent activations of AFFF systems in hangars and the resultant clean-up and disposal
- Reports of problems created by the discharge of AFFF to waste water treatment facilities

- Limitations on overboard discharges of AFFF by ships under the Uniform National Discharge Standards (UNDS) of the Clean Water Act
- Anecdotal reports of damage to aquatic life by discharge of AFFF to streams and waterways
- Various designations of AFFF waste, necessitating expensive disposal by specialty contractors
- Recognition of the persistence and limited biodegradability of the fluorocarbon surfactants in AFFF
- Publicity surrounding 3M's decision to phase-out production of AFFF and other chemicals containing perfluorooctyl sulfonate (PFOS)
- Claims by vendors of so-called "environmentally-friendly" AFFF alternatives

As a result of these concerns, the affected Navy Systems Commands have undertaken various actions:

- NAVFAC, under the auspices of the DoD Fire Protection Coordinating Committee, has started the development of design policy for shore facility AFFF systems to minimize discharges and to address environmental issues.
- NAVAIR has funded Concurrent Technologies Corporation to draft an ESH Need Assessment Study on AFFF, to be followed by a Development Plan that will recommend future action to alleviate identified problems.
- NAVSEA has reduced the frequency of testing of shipboard AFFF systems to minimize overboard AFFF discharge in compliance with the UNDS regulations.

The meeting was called to share recent information and discuss issues relevant to the above concerns and on-going actions.

Meeting Scope/Presentations

The meeting consisted of general session discussions and presentations as well as two specifically focused breakout sessions. Copies of the general session presentations are provided as Appendices (3) – (10). Presentations given at the Hangar Facility breakout session are contained in Appendices (11) and (12). Overall summaries of each breakout session are provided in Appendices (13) and (14).

Significant Discussion and Presentation Points

There were many important points raised during discussion sessions or contained in formal presentations. Those considered to be the most significant are summarized below (additional details are contained in the appendices):

- AFFF is a vital fire fighting agent for controlling and extinguishing flammable liquid fires. Within DoD, it is especially critical for fire scenarios where life safety is paramount, where ordnance is exposed or high value assets are threatened.

- The AFFF military specification (Mil Spec) is considerably more demanding than the applicable UL standard relative to speed of extinguishment of a flammable liquid pool fire.
- The AFFF Mil Spec is widely cited in procurement specifications in the civil sector, especially at municipal airports.
- There are currently 5 manufacturers that have AFFFs on the Mil Spec Qualified Products List.
- There are many fire fighting foams that are commercially available. However, no non-AFFFs have been able to match the rapid fire extinguishment performance of AFFF.
- At present there is no regulation or directive to modify the AFFF Mil Spec.
- There is no recognized or universally accepted definition of "environmentally friendly" fire fighting foam.
- NAVSEA is the designated DoD technical custodian of the existing AFFF Mil Spec. Only NAVSEA can formally change the Mil Spec, though it may be possible to develop a separate specification just for shore-based applications.
- Inconsistent policy and guidance have led to expensive and questionable secondary containment designs in recent shore facility projects.
- 3M is voluntarily phasing-out production of AFFF because the fluorocarbon surfactant in their AFFF biodegrades to perfluorooctyl sulfonate (PFOS). PFOS has been identified by EPA as environmentally persistent, bio-accumulative in blood, and toxic to aquatic life and laboratory animals (the degree varies by species).
- Levels of PFOS measured in humans and found in blood banks is not considered to present a heath hazard at present levels. Concern is the potential for build-up over time.
- Other AFFF manufacturers do not produce AFFF that is currently believed to biodegrade to PFOS.
- It is not known if other AFFFs have a similar problem. EPA is currently in a fact-finding mode relative to other AFFFs.
- At present the EPA does not prohibit or limit specifically the manufacturing of AFFF.
- A comprehensive review of federal and local environmental regulations applicable to AFFF (and other foam agents) has just been completed (see Appendix (8)).
- All fire fighting foams have environmental properties and/or constituents that are regulated.
- Adverse impact on waste water treatment facilities is a major concern, primarily due to foaming.
- A "risk based" approach, using the Frequency Vs Severity concepts in Military Standard 882C, has been shown to be feasible for managing AFFF environmental issues in shore facilities. Such an approach may be applicable to other AFFF applications as well.
- The NAVFAC Facility AFFF Management Working Group will continue development of policy, with a completion goal of approximately 6 months.

The next meeting of the NAVFAC Working Group is scheduled for October 12, 2000.

- NAVAIR will complete the AFFF Need Assessment Study and prepare the Development Plan to recommend a future course of action.
- There was a general consensus that a second follow-on DoD meeting should be held (host, location, dates – TBD). Depending on developments between now and the next meeting, a decision could be made to establish a governing charter for a DoD AFFF Environmental Steering Group and perhaps to designate a formal DoD "advocate" for the effort.

List of Appendices

(1) Meeting Agenda

(2) List of attendees and photo

(3) Presentation: "AFFF Performance Perspective," R. Darwin, Hughes Associates

(4) Presentation: "NAVSEA Comments on the AFFF Mil Spec", R. Williams, NAVSEA

(5) Presentation: "Hangar Facility AFFF Management Breakout Session Introduction", J. Gott, NAVFAC

(6) Presentation: "AFFF Environmental Impact Breakout Session Introduction", J. Hoover, NAWCWD China Lake

(7) Presentation: "Issues With 3M's Withdrawal from the Market", C. Hanauska, Hughes Associates

(8) Presentation: "AFFF Environmental Impact Review", W. Ruppert, Hughes Associates

(9) Presentation: "AFFF Management – Risk Based Approach", D. Verdonik, Hughes Associates

(10) Presentation: "Phasing out a Problem: Perfluorooctyl Sulfonate", M. Dominiak, EPA

(11) Presentation: Facilities Background and AFFF Issues", J. Simone, NAVFAC

(12) Presentation: "AFFF Risk Assessment", A. Wakelin, Hughes Associates

(13) Presentation: "Summary of Shore Facility AFFF Management Breakout Session", D. Verdonik, Hughes Associates

(14) Presentation: "Summary of AFFF Environmental Breakout Session", J. Hoover NAWCWD China Lake and R. Darwin, Hughes Associates

APPENDIX (1)

Meeting Agenda

DOD AFFF Environmental Meeting

Location:

Building 207 (Chemistry Building)
Naval Research Laboratory,
4555 Overlook Ave,
Washington DC, 20735

Agenda:

Wednesday August 2nd

0830 – 0845	Welcome and Introduction – Dr Fredrick Williams, NRL, Director, Navy Technology Center for Safety and Survivability.
0845 – 0915	AFFF Performance Perspective – Robert Darwin, Senior Engineer, Hughes Associates, Inc.
0915 – 0925	NAVSEA Comments on the AFFF Military Specification - Robert Williams, NAVSEA Fire Protection and Damage Control Division
0925 – 0935	Hangar Facility AFFF Management Breakout Session Introduction – Joseph Gott, NAVFAC, Director, Navy Facilities Safety and Health Office
0935 – 0945	AFFF Environmental Impact Breakout Session Introduction – Dr. Jim Hoover, NAWCWD, Head, Combustion Research Branch
0945 – 1000	Break
1000 – 1015	Issues Surrounding 3M Withdrawal from the Market – Chris Hanauska, Senior Engineer, Hughes Associates, Inc.
1015 – 1100	Presentation of AFFF Environmental Regulatory Aspects – Bill Ruppert, Senior Environmental Engineer, Hughes Associates, Inc.
1100 – 1130	Summary Presentation on Risk Assessment for Hangar Facilities – Dr. Dan Verdonik, Hughes Associates, Inc.
1130 – 1230	Lunch
1230 – 1600	Breakout sessions

Thursday August 3rd

0830 – 0930	3M Withdrawal from Market – Mary Dominiak, EPA, Chemical Control Division, Office of Prevention, Pesticides & Toxic Substances.
0930 – 1230	Presentation of Breakout Session Conclusions. Discussion of any further requirements to complete breakout session action items.

Hangar Facility AFFF Management Breakout Session

Session Objectives and Details:

The objectives of the Naval Facility Engineering Command (NAVFAC) hangar facility AFFF Management breakout session are:

- To begin efforts toward developing a policy that details requirements for hangar facilities that will provide "adequate measures" to:
    - (a) prevent an accidental AFFF discharge,
    - (b) limit any adverse environmental impacts from a release.

- To achieve an agreement on the definition of "adequate measures" and to begin to establish design criteria to meet them.

Initial draft design criteria and costs of specific engineering solutions will be presented and discussed as a starting point.

Agenda

1230 – 1315	Facility Background and Issues – Joe Simone, Head Fire Protection Engineer, Naval Facilities Engineering Command
1315 – 1430	Risk Assessment for Hangar Facilities – Alison Wakelin, Fire Protection Engineer, Hughes Associates, Inc.
1430 – 1600	Design Criteria Discussion and Development

List of Breakout Session Attendees:

D. Verdonik (Chair)
J. Gott
W. Ruppert
A. Wakelin
J. Simone
V. Donnally
T. Ruffini
D. Roderique
G. Sadler
L. Wolf
K. Ellis
M. Doherty
K. Kochar
B. Scott
R. Talbot
R. Hansen
J. Shah
F. Williams

AFFF Environmental Impact Breakout Session

Session Objectives and Details:

The objective of this meeting is to share the technical data related to the environmental impact, status and the planned future use of AFFF. NAVAIR will use output from this session to ensure their Environmental Safety and Health (ESH) Need Assessment Summary (the where we are today) is accurate and complete, and to ensure their Development Plan (the where we go from here) is consistent with the need to provide sound fire protection in an environmentally responsible manner.

The AFFF Environmental Impact working group will address the following questions:

- What current and future environmental regulations impact AFFF use and why (data and politics)?
- What data do we have (or lack) on the environmental impact of AFFF?
- What technology or products exist that could help reduce AFFF releases into our environment or mitigate the impact of those releases?
- What technology or products could be applied to recycle or reuse AFFF?
- What alternatives to AFFF currently exist and how do they compare in effectiveness, cost, environmental impact, availability, etc?

List of Breakout Session Attendees:

J. Hoover (Chair)
R. Darwin
J. Scheffey
C. Hanauska
W. Leach
D. McCrory
R. Williams
S. Wade
M. Wade
K. Bagot
R. Morris
B. Parks
S. Johnson
P. Bungcayo
R. Lee
R. DiAngelo
D. Dierdorf
J. LaPoint
I. Young

APPENDIX (2)

List of Attendees and Photo

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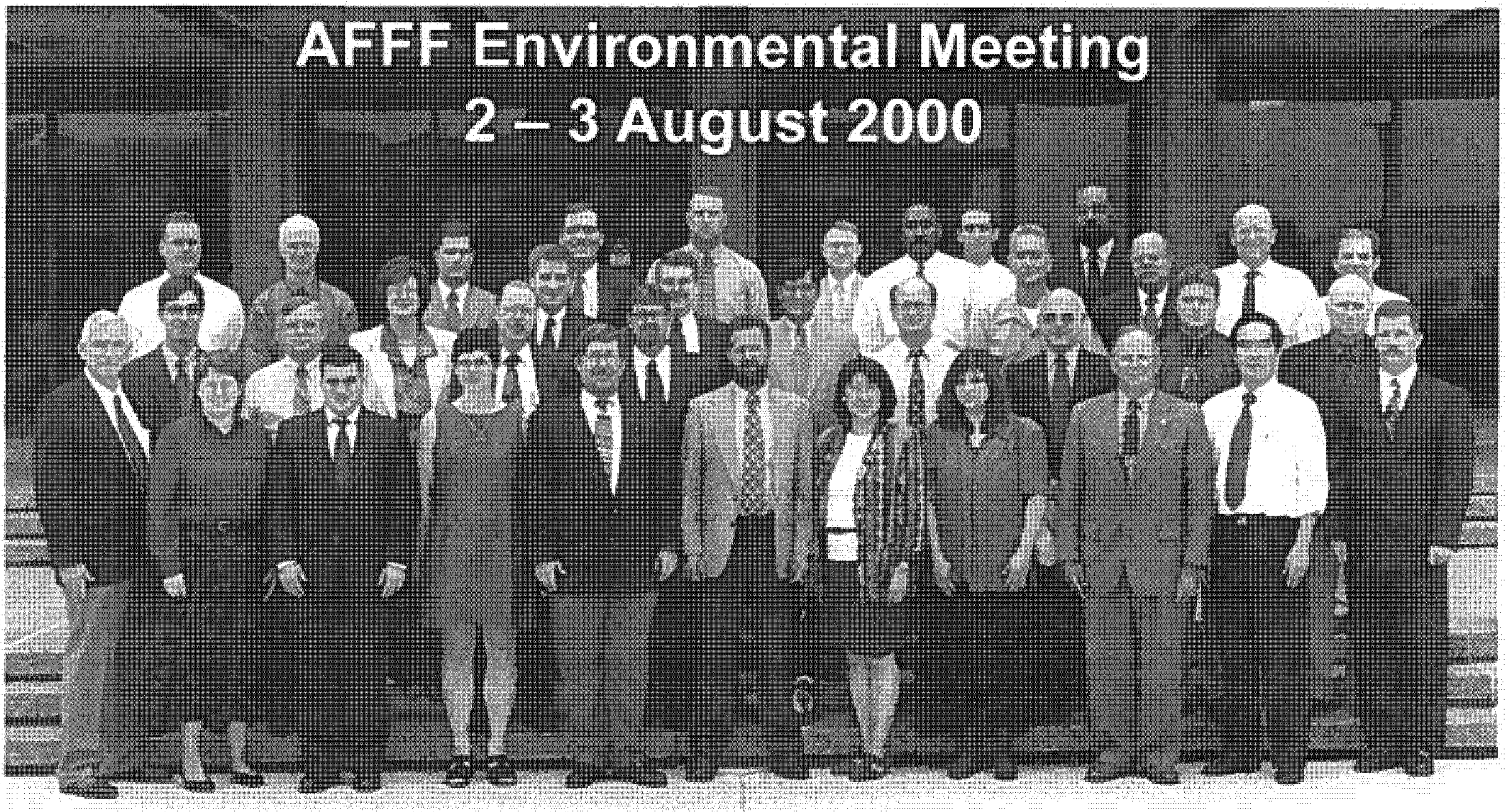

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Middle Row: W. Ruppert, B. Williams, D. Roderique, J. Hoover, J. Gott, J. Scheffey, D.Verdonik, J. Shah, W. Leach, P. Bungcayo, R. Darwin, K. Kochar, R. Talbot, S. Wade

Bottom Row: F. Williams, R. Morris, T. Ruffini, A. Wakelin, D. Dierdorf, B.R. Scott, I. Young, K. Ellis, G. Sandler, R. Lee, M. Wade

APPENDIX (3)

Presentation: "AFFF Performance Perspective"

R. Darwin,
Hughes Associates, Inc.
Baltimore MD

AFFF

Performance Perspective

Robert L. Darwin, PE
Senior Engineer
Hughes Associates, Inc.

2 August 2000

History of Foam

1920-40 Chemical Foam

1940-70 Protein Foam (Air Foam)

1970- 2000 AFFF

AFFF Key Events:

1961 First experiments with fluorocarbon surfactants at NRL

1962 First Mil-Spec (Mil-F-23905, 1 Nov 63)
  25 % concentration (fresh water only)
  Emphasis on twin agent application

1963 Large scale tests at NAS pensacola
  Led to procurement of 100 twin agent units

1964 Helo air borne TAU tests at NAS Miramar

1965 6 % concentration developed by 3M (FC-194)

1966 Testing of FC-194 in airfield crash trucks
  Selective conversion of some crash trucks

1967 Flight deck conflagration on USS Forrestal
  TAUs to aircraft carriers
  Push to develop seawater-compatible AFFF

1967 Seawater –compatible AFFF developed by 3M/NRL

1968 Additional crash truck tests at NAS Miramar

1968 Shipboard equipment tests w/ seawater at NAS Jacksonville
  First edition of seawater/AFFF mil spec (Mill-F-24385)

1969 Flight deck conflagration on USS Enterprise
  Push to convert ships to AFFF

1970 Navy starts comprehensive conversion of ship systems and crash trucks

1973 USAF starts converting all USAF crash trucks

UL Listed Foams

(Per UL 162-"Foam Equipment & Liquid Concentrates")

AFFF – Aqueous Film Forming Foam
FFFP – Film Forming Fluoroprotein
FP – Fluoroprotein
PF – Protein Foam

	Manufacturers	Concentrates
AFFF	24	110
FFFP	5	16
FP	12	26
PF	5	6

Mil Spec Qualified Product List (QPL)

Ansul

Ansulite 3 (AFC-5A) *	Type 3
Ansulite 6 (AFC-5) *	Type 6

3M

FC-203C	Type 3
FC-203CE *	
FC-203CF *	
FC-206C	Type 6
FC-206CE	
FC-206CF *	

Chemguard

C-301MS *	Type 3

National Foam

Aer-O-Water 3-EM *	Type 3
Aer-O-Water 6-EM *	Type 6

Angus

Tridol M	Type 3

* Also UL Listed

"Application Density" (Defined as the Gallons of Agent Per Unit Area of Pool Fire Size) is the best measure of effectiveness for a flammable liquid pool fire

Application Rate = GPM/Sq Ft of fire area

Application Rate x Ext Time = Application Density

GPM/Sq Ft x Minutes = Gals/Sq Ft

Example

Fire Area = 1000 Sq Ft
Appl Rate of Agent = 200 GPM
Ext Time = 0.5 minutes

Appl Rate = 200 GPM/1000 Sq Ft = 0.2 GPM/Sq Ft

Appl Density = Appl Rate x Time
= 0.2 GPM/SqFt x 0.5 minutes
= 0.1 Gals/SqFt

AFFF Performance Requirements

Mil Spec (Mil-F-24385):

Max Appl Density

2 gpm/28 sq ft x 30/60 minutes = .036 gal/sq ft

2 gpm/50 sq ft x 50/60 minutes = .033 gal/sq ft

Underwriters Laboratory:

2 gpm/50 sq ft x 3 minutes = .12 gal/sq ft

(Maximum extinguishment time is 5 minutes for fluoroprotein and protein foam)

Rapid Extinguishment of Pool Fires is Critical When:

- Pool fire threatens high value assets (such as an aircraft hangar)
- Pool fire under an occupied aircraft (must maintain fuselage integrity and rescue occupants)
- Pool fire exposes weapons to potential "cook off"

Relative Performance of Foam Agents on Pool Fires

(Best)	AFFF (Mil-Spec)
	AFFF (UL listed, non Mil-Spec)
	AFFF (non UL, non Mil-Spec)
	FFFP
	FP
	PF
(Worse)	Wetting Agents

UL Listed Wetting Agents
(Based on NFPA 18)

“ A liquid concentrate for addition to water to produce a solution having a greater fire extinguishing efficiency than plain water”

Manufacturers: 11

Agents: 13

If Use Non-Film Formers:

- Extinguishment time will be slower, unless application rate is increased
- Higher application rate causes
  - Greater system cost
  - Greater quantity of agent emitted
- Must consider possible need for “air aspiration”
  - Replace nozzles
  - Less reach than “non air aspirated”

AFFF Environmental Issue - 1994

Glycol Ethers (Butyl Carbitol), solvent in most AFFFs, placed on EPA list of hazardous air pollutants.

Since no reporting threshold had been established, a default quantity of one pound per day was established for required reporting under CERCLA.

Because Diethylene Glycol Butyl Ether (DGBE) typically comprises about 20 % of AFFF, spills of just a few gallons of AFFF had to be reported to the National Response Center and to State and local officials.

One pound per day reporting requirement dropped in 1996.

Some manufacturers substituted Propylene Glycol for Ethylene Glycol and declared their foam to be "environmentally friendly".

DOD Uses of AFFF

- Shipboard Foam Systems
- CFR Vehicles at Airfields
- Aircraft Hangar Foam Systems
- Misc Shore Facilities
    - Hush Houses
    - Jet Engine Test Facilities
    - Hardened Aircraft Shelters
    - Aircraft Fueling Stations
    - Fuel Farms
- Foam Sytems on Structural Pumpers

DOD AFFF Discharges

- Fires
- Training Evolutions
- System Tests and Maintenance
- Accidental/Malicious Discharges
- Research and Development

There is a Need to Quantify and Characterize:

- All DOD AFFF applications (What precisely do we use it for ?)
- Precise quantities in service and in reserve stocks (How much do we have ?)
- Annual emmisions (type and quantity) (How much do we discharge ?)

APPENDIX (4)

Presentation: 'NAVSEA Comments on the AFFF Mil Spec"

R. Williams,
Naval Sea Systems Command

NAVSEA Comments
On the
AFFF Military Specification
Mil-F-24385F
(Amendment 1 of 8/94)

(Talking Points)

Presentation to DOD AFFF Environmental Meeting
2 August 2000

Robert B. Williams
Fire Protection & Damage Control Division
Naval Sea Systems Command
(Technical Custodian of the AFFF Mil-Spec)

1. I would like to express appreciation to NAVFAC and NAVAIR for sponsorship of this Conference. Also, I appreciate the opportunity to establish the NAVSEA perspective up front.

2. This conference is important and timely:

Recently there has been a proliferation of Navy groups active in AFFF; usually with no focus, some scattered and uncoordinated EPA contacts.

Recently there has been aggressive commercial marketing of so-called "environmentally friendly foams"; yet there is no established definition of "environmentally friendly foam".

AFFF is subject of considerable hype: effect on sewage plants, danger to aquatic life, exposure results in mutant first born, etc.

AFFF spills are media friendly- very visible, makes for good "films at 11", photos provide permanent record, helps stir up environmental activists

Real issues from my perspective:

3M withdrawal and fall out relative to other QPL AFFFs

Restrictions by AHJs; technical basis or not

Unknown forthcoming EPA activity

All are on agenda to be addressed

3. The product I personally desire of this conference is to specifically identify what the problems are regarding MILSPEC AFFF, and problems that are inherent to any foam alternative (visible, wastewater treatment plants).

Appears money is & will be directed at AFFF.

My concern is that funding needs to be attached to a focus on specifics that are documented as requiring resolution.

Navy labs and contractors see a golden egg out there on this topic; I personally don't want to see them going off into the sunset with a generic task to find an environmentally friendly firefighting agent. (whatever friendly means).
The specific problems to be resolved require documentation before charging onto a search for solutions; doesn't always happen in correct order.

The agenda appears to support what I hope is the conference objective.

4. A few quick comments about the MILSPEC and shipboard applications:

NAVSEA is custodian; only NAVSEA can revise. Self appointed cannot.

However, an alternate extinguishing agent specification under someone else's cognizance could be created.

For example, it might be feasible to develop a separate specification just for shore facility use (fresh water only, one percent, universal foam, no refractive index requirement, etc).

NAVSEA goal regarding the spec: Satisfy environmental requirements without degradation of firefighting effectiveness. If maintaining performance requirements is not possible, then where do we draw the trade-off line in the sand? (fish vs. sailors; national defense vs. environment)

MILSPEC contents - shipboard oriented, even though it is essentially the national standard ashore and afloat:

AFFF is for two dimensional shallow spill fires, rapid control and extinguishment are essential. No "foam-of-the-month" has matched the performance of mil-spec AFFF.

Environmental provisions in spec; fish kill, BOD/COD limits, chemical restrictions.

Compatibility: seawater effectiveness, intermixing of products from different manufacturers on QPL.

It is an integrated match with our capital investment in hardware: viscosity, corrosion, pipe & tank materials, effect on seals/gaskets, a refractive index, container size & strength.

5. Our primary environmental involvement has been with the Uniform National Discharge Standards (UNDS) program which is relative to overboard discharge of liquids; basically a Clean Water Act action item.

Our imput to EPA, which has been accepted thus far, is discharge management:

New construction/alterations - no repeat testing, at sea

Preventative Maintenance - reliable hardware, reduced testing periodicity

Fewer ships

Geographic restrictions: no discharges within 3 miles of coast, must be making at least 10 knots for discharges within 3-12 miles, preference for only discharging when greater than 12 miles out

6. In closing, I pass along that as custodian of the MILSPEC, I have no direction, pressure, or formal or informal tasking to conduct an environmental review of MILSPEC AFFF aside from the UNS. At NFPA aviation committee meetings I have queried major airport fire chiefs, all of whom stated no direction to pursue an alternative to MILSPEC AFFF. However, we at NAVSEA know whether politically, technically, or regulatory driven, environmental restrictions on AFFF may be coming. We fully support this conference, identification of problems & potential problems, and initiation of remedial research/actions.

APPENDIX (5)

Presentation: "Hangar Facility AFFF Management Breakout Session Introduction"

J. Gott,
Naval Facilities Engineering Command

Hangar Facility AFFF Management Breakout Session Introduction

(Talking Points)

Presentation to AFFF Environmental Meeting
2 August 2000

Joseph Gott
Director, Navy Facilities Safety and Health Office
Naval Facilities Engineering Command

AFFF DOD Meeting Talking Points

- Need a consistent DOD position on AFFF management
- If we are not proactive, AFFF will become our next halon 1301
- AFFF is only product on market right now that meets our needs
- Time for the design engineers, and environmental engineers to come together
- The services have already done this with the Unified Design Guidance Group
- As past chair of DOD FPE committee, we wrote the first tri-service design criteria
- Fixed containment systems are affecting our mission because they have already caused the omission of AFFF from some hangars resulting in the air wings inability to perform their mission
- This is the beginning of a working group to address this important issue
- Need to get all the right players
- Need to address AFFF management from a risk assessment approach
- Need to dismiss all the myths and fears and address the facts
- Need to give the local regulators something to reference as adequate protection
- Need to determine if additional research is needed to produce a different AFFF
- Discuss changes to NFPA 409 - mandatory drains, reduced AFFF, various protection options
- NAVFAC has long history in fixed AFFF systems, their behavior, problems, and design characteristics

APPENDIX (6)

Presentation: "AFFF Environmental Impact Breakout Session Introduction"

J. Hoover,
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China Lake CA

AFFF Environmental Impact Breakout Session Introduction

(Talking Points)

Presentation to DOD AFFF Environmental Meeting
2 August 2000

Dr. Jim Hoover
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NAWCWD China Lake

The purpose of the AFFF Environmental Impact Breakout Session will be to share technical information within the DoD on AFFF use and environmental impact. This information will be used to assist the completion of two environmental planning documents used by the Naval Air Systems Command (NAVAIR) - an Environmental Safety and Health Needs Assessment Summary (NAS) and a Development Plan. The NAS will provide a "snap-shot" of technical issues surrounding AFFF use and environmental impact, and the Development Plan will recommend a strategy for future efforts within NAVAIR.

Background: The importance of AFFF in protecting Navy personnel and assets must not be understated. Likewise, public safety and commercial assets are highly dependent on AFFF for fire protection. Its firefighting performance remains unmatched and much remains unknown about its human health and environmental effects.

Other services and agencies have data and experiences with AFFF that could assist the Navy in future decision making, so a forum for technical information exchange is needed. In planning for the future, all aspects of technical knowledge about AFFF (and all of its formulated components) should be considered. These should include costs, performance/function, human health and environmental effects, availability, inventory, alternatives, etc.

Break-out Session Format:

The following questions will be asked of the participants to promote discussion and information exchange. Participants will be invited to provide other questions.

1. What current and future environmental regulations impact AFFF use and why (data and politics)?

2. What data do we have (or lack) on the environmental impact of AFFF?

3. What technology or products exist that could help reduce AFFF releases into our environment or mitigate the impact of those releases?

4. What technology or products could be applied to recycle or reuse AFFF?

5. What alternatives to AFFF currently exist and how do they compare in effectiveness, cost, environmental impact, availability, etc?

6. What related planning documents exist with other services or agencies?

7. What follow-on strategies should be considered?

APPENDIX (7)

"Issues With 3M's Withdrawal From the Market"

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Issues with 3M's Withdrawal from the Market

AFFF DoD Meeting

Christopher Hanauska

HUGHES ASSOCIATES, INC.
FIRE SCIENCE & ENGINEERING

August 2, 2000

Purpose of this Presentation

- Mary Dominiak of EPA will provide more detailed information tomorrow
- Provide some background for her presentation
- Frame the issue relative to the subjects of this meeting
- *This presentation is only an executive summary*

Fluorochemical Surfactants (FC's)

- FC's are a component of AFFF
  - One of several components in AFFF
  - FC's are difficult and expensive to make
  - Formulators have minimized (and attempted to eliminate) the FC content for 30 years
  - Necessary for performance (especially for CFR)
    - rapid fire knockdown
    - relatively low application rates

What is an FC?

- C8F17-functional group
- Length of carbon chain varies
- Fluoronated carbon chain is very stable
- Functional group gives different properties

FC's for AFFF Do Not Fully Biodegrade

- 3M's FC's => PFOS (Perfluorooctyl Sulfonate)
- Other FC's => ?
- Functional group may biodegrade, but something is always left
- Ultimate fate unknown
- "Persistent"

3M Performed Testing

(Last 2 Years)

- Found PFOS
  - in blood banks around the US
  - in fish and birds
- Discovered toxicity issues
  - reproductive sub-chronic studies
- “Bioaccumulative” and “Toxic”

3M Voluntarily Phasing Out PFOS Related Chemicals

- Scotchguard, Scotchban, industrial uses, AFFF
- About 2 years for complete halt of production
- Decision made at highest level of 3M
  - were in discussion with EPA at the time
- An unexpected and extreme action

If Only 3M PFOS FC's are a Problem

- Other non-PFOS FC based AFFF's are on the QPL
- Possibly a short term supply issue
- Should not be a major fire protection/environmental concern

Do Non-PFOS FC's Have a Problem?

- EPA has asked manufacturers to examine and test
- What constitutes a "problem" uncertain
  - "Bioaccumulative" "Toxic"
- EPA will do risk/benefit and risk/risk analysis
  - Understanding of importance of AFFF to fire protection

Conclusions

- No FC specific regulations exist
- No apparent short term (1 year) problems
- Mid-term (2-3 years) problems related to supply only
  - as 3M withdraws from market
- Potentially no long term problems (3+ years)
- *Unless other FC's have significant problems*

APPENDIX (8)

Presentation: "AFFF Environmental Impact Review"

W. Ruppert
Hughes Associates, Inc.
Baltimore MD

Aqueous Film Forming Foam (AFFF) ENVIRONMENTAL IMPACT REVIEW

Bill Ruppert

HUGHES ASSOCIATES, INC.
FIRE SCIENCE & ENGINEERING

Background:
AFFF Constituents

- MILSPEC based on Performance, not Constituents
- Must be on Qualified Products List - QPL
- Main Ingredients in Firefighting Strength Foam:
  - WATER = 98%-99%
  - Butyl Carbitol (Glycol Ether) = 0.5%–1.1%
  - Fluorosurfactants & Hydrocarbon Surfactants = 0.03%–0.45%
  - Ethylene Glycol (Not in all formulations) = 0.34%–0.60%
  - Urea (Not in all formulations) = 0.2–0.4%

Background:
AFFF 'Environmental' Properties

- MIL-F-24385F Requirements
  - Chemical Oxygen Demand
    - 3% Concentrate - 1,000,000 mg/L Max
    - 6% Concentrate - 500,000 mg/L Max
    - Calculated Firefighting Strength ~ 30,000 mg/L Max
  - Biochemical Oxygen Demand (20 Day)
    - =(0.65 X COD) or greater
  - Aquatic Toxicity (LC50, Killiefish)
    - 3% Concentrate - 500 mg/L Min
    - 6% Concentrate - 1000 mg/L Min
    - Calculated Firefighting Strength ~ 16,667 mg/L Min
- Persistence and Bioaccumulation
  - Only Fluorosurfactants - Not in other constituents
  - example: Butyl Carbitol log BCF = 0.46
- Foams

Background: AFFF Properties
MILSPEC vs. Typical QPL Product

Property	MIL-F-24385F Requirements			Typical QPL Product		
	3%	6%	FF	3%	6%	FF
Chemical Oxygen Demand (mg/L)	1,000,000 Max	500,000 Max	30,000 Max	750,000	341,000	22,500
Biochemical Oxygen Demand (mg/L)	BOD_{20} > 0.65 x COD			720,000 (0.96*COD)	274,000 (0.80*COD)	21,600
Aquatic Toxicity (Killiefish) (mg/L)	500 Min	1000 Min	16,667	>1000	>1000	>16,777 or >33,333

Codes and Standards Survey
Approach

- Electronic Review
- Federal Environmental Regulations
  - "AFFF"
  - MILSPEC AFFF Constituents (19)
    - Surfactants
    - Fluorosurfactants
    - Glycol Ethers
    - Urea, etc.
  - AFFF "Environmental" Properties
    - Biochemical And Chemical Oxygen Demands
    - Aquatic Toxicity
    - Foaming
- DOD, State And Local Regulations
  - "AFFF"
  - MILSPEC AFFF Constituents

Codes and Standards Survey
Federal Environmental Regulations

- Clean Air Act (CAA)
  - Air Emissions
  - Air Discharge Permits
- Emergency Planning and Community Right-to-Know Act (EPCRA)
  - Toxics Release Inventory (TRI)
  - Chemical Storage and Use
- Comprehensive Environmental Response, Compensation, & Liability Act (CERCLA)
  - Superfund Amendments and Re-authorization Act (SARA)
  - Spills and Clean-up Of Spills
- Resource Conservation and Recovery Act (RCRA)
  - Hazardous Waste
- Safe Drinking Water Act (SDWA)
  - Regulates Contaminants in Treated Drinking Water
- Clean Water Act (CWA)
  - Water Discharges
  - Water Discharge Permits

Federal Environmental Regulations
Results

- Clean Air Act (CAA)
  - Glycol Ethers In AFFF Are Hazardous Air Pollutants (HAPs)
  - HAP Releases Are Regulated by the Installation Air Permit
    - Major Sources for HAPs Might Have Potential Permit Issue
- EPCRA and TRI
  - Glycol Ethers are Covered Because CAA Defines them as HAPs
  - Chemicals Released Above a Reportable Quantity (RQ) Must Be Reported
    - Default RQ was One (1) Pound
    - EPA Established a No RQ
  - AFFF Discharges Do Not Currently Need to Be Reported Under EPCRA and TRI
  - Ethylene Glycol Specifically Listed
  - No Other Constituent is Currently Regulated by EPCRA and TRI

Federal Environmental Regulations

Results

- CERCLA and SARA
  - Glycol Ethers are Covered Because CAA Defines them as HAPs
  - Glycol Ethers May Need to Be "Cleaned Up" After a Spill
    - Air Pollutants So Expected to be Volatile
      - Are not volatile when mixed with water
    - Biodegradable So Might Be "Cleaned Up" Naturally
- Resource Conservation And Recovery Act (RCRA)
  - AFFF and Its Constituents are Not Classified as Hazardous Waste
  - RCRA Does Not Apply
- Safe Drinking Water Act:
  - Primary Drinking Water Regulations (Health Properties)
    - Does not regulate AFFF or its constituents
  - Secondary Drinking Water Regulations (Aesthetic Properties):
    - Foaming Agents <0.5 mg/L in drinking water
    - Do not regulate foaming agents in source water
    - Guideline for State Regulations Only (Not Federally Enforceable)

Federal Environmental Regulations

Results (Continued)

- Clean Water Act (CWA)
  - Installations Require Discharge Permits
    - Storm Water
    - Treated Sewage from Installation Wastewater Treatment Plant
    - Raw Sewage to Public Wastewater Treatment Plant (Locale Specific)
  - Regulates Wastewater that:
    - Foam
    - Remove Oxygen From Water
    - Disrupt Wastewater Treatment Plants, etc.
  - AFFF
    - Persistent Foam
    - Removes High Amounts of Oxygen From Water (High BOD and/or COD)
    - Untreated, Undiluted AFFF Will Disrupt Wastewater Treatment Plant
    - (Even Diluted AFFF Can Disrupt Wastewater Treatment Plant) SDWA

Codes and Standards Survey

State/Local Environmental Regulations

- State Regulations Can be More Strict Than Federal
  - No Specific Instances Found for AFFF
  - Storm Sewer Regulations Emphasized
- Nothing Additional in County and City Regulations
- Representative Jurisdictions
  - Telephone Surveys
  - Focused on Jurisdictions In:
    - Virginia
    - Hawaii
    - Florida
    - California
- Local Anecdotal AFFF 'Problems'
  - Sewage Treatment Plants Becoming 'Bubble Baths'
  - Pump Stations 'Burned-up'
  - Storm Sewer Overflowing With Foam

State/Local Environmental Regulations
(Continued)

- Foaming the Greatest Concern
- Perception:
  - Foam Is Highly Toxic to Everything
  - No Concentration is Okay for a WWTP
- Results
  - Local Jurisdictions **CAN** and **DO** Regulate AFFF by Name
  - Have Water Discharge Permit Authority
  - Local Waste Water Treatment Plants Often Ban AFFF
    - Based on Direct Experience with a Disruption
    - High Oxygen Demand
    - Foaming

Environmental Consequences

- Media Considered
  - Air
  - Groundwater
  - Soil
  - Surface Water
    - Via storm water
    - Via wastewater treatment plant
- Both Constituent Characteristics and AFFF Solution Properties

Environmental Consequences
Media: Air

- HAPS: Butyl Carbitol, Ethylene Glycol
- Low Migration Potential (All Constituents)
  - Highly Soluble in Water
    - Tends to stay with liquid water
    - Not very volatile
  - If Volatilized, Half-lives in Air 4 Hr - 3.5 Days

Environmental Consequences
Media: Groundwater

- Consequence Varies Depending on Subsurface Conditions
- Fluorosurfactants: Not Mobile
- All Other Constituents:
  - Highly Soluble, Highly Mobile
  - Degrades Rapidly in Soil
    - 30% Degradation Over 24 Hour Period
- Drinking Water Wells 'Under the Influence of Surface Water' Could Receive Undegraded AFFF Constituents

Environmental Consequences

Media: Soil

- Consequence varies depending on soil type
- Fluorosurfactants and break-down products
  - Persistent in soil
  - No quantified environmental impact
  - EPA will discuss further tomorrow
- Other constituents highly mobile in water, will not adsorb to soil

Environmental Consequences

Media: Surface Water Via Storm Water

- Foaming:
  - Aesthetic Concern
- Oxygen Demand
  - Robs Oxygen from Water
  - Usually near water's surface
- Aquatic Toxicity
  - Considered 'Practically Nontoxic' by the US Fish and Wildlife Service.
  - Lowest toxicity value in 40 CFR 300
    - LC50 > 1000 mg/L in concentrate
    - ~160 mg/L in most sensitive species
    - Much Lower Toxicity in Firefighting Strength
  - Anecdotal Reports of Higher Toxicity
- Surface Water May influence Groundwater
- 'Environmental' Threat
  - Depends on Sensitivity of Receiving Water: Worst Cases
    - Kaneohe Bay, HI Risk Analysis - "Potential for significant ecological damage … relatively small"
    - Wetlands
      - Waterfowl-Fluorosurfactant Interaction being studied in St. Johns River Basin in Florida.

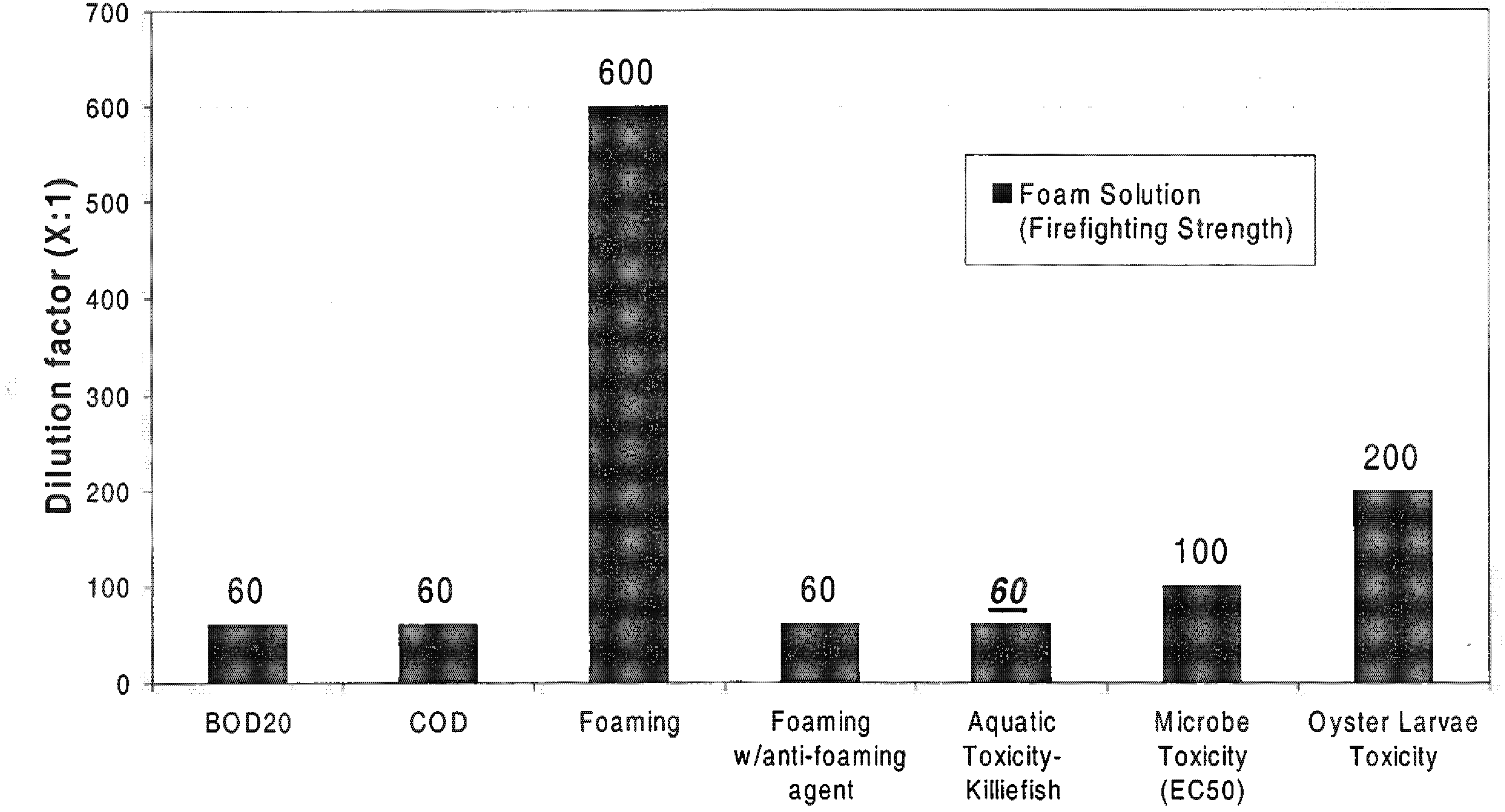
Environmental Consequences

Media: Surface Water Via Direct Discharge to WWTP

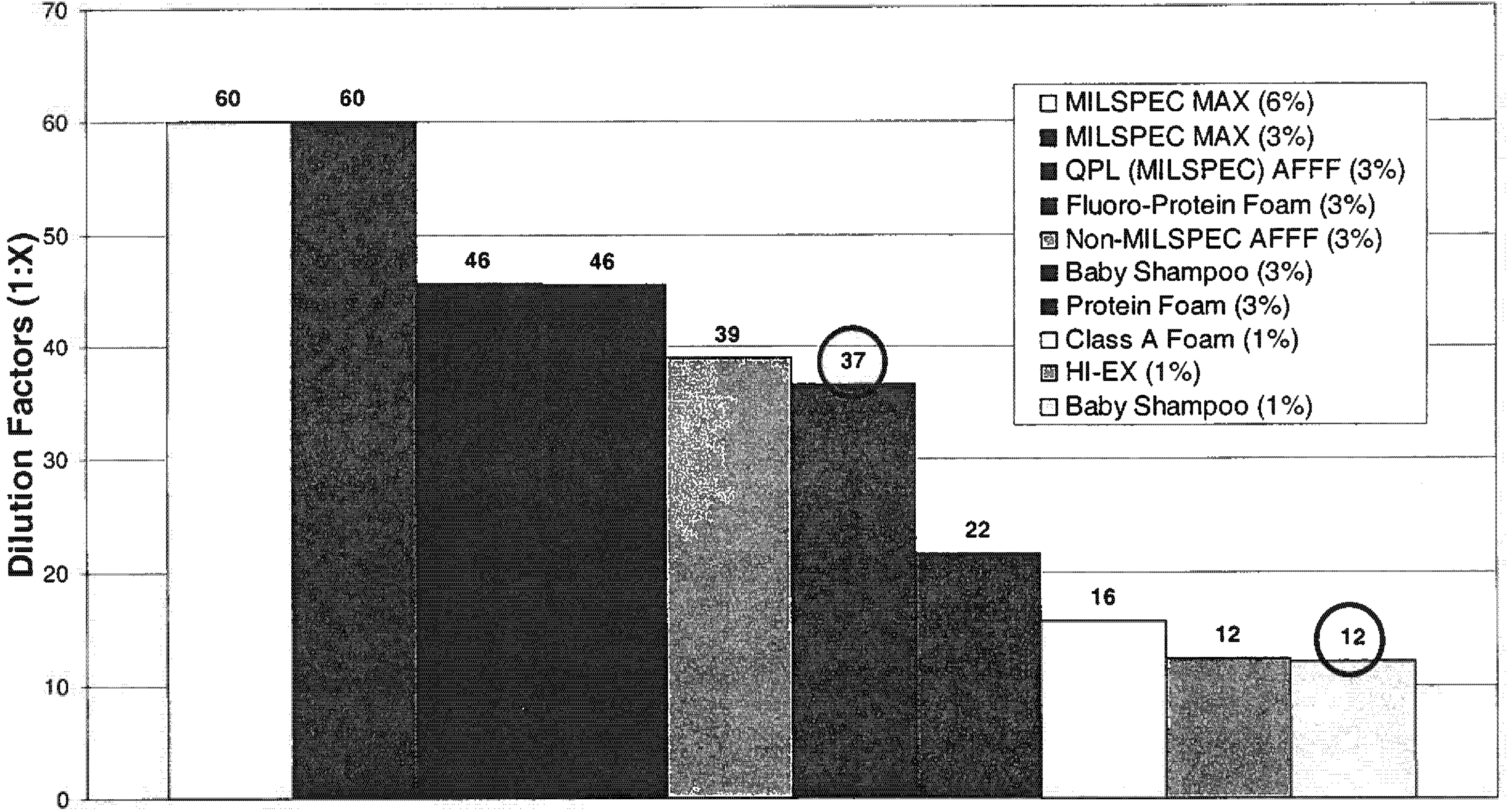
- Disrupts plant through:
  - Foaming
    - Disrupts mechanical devices
    - Causes 'sludge bulking'
    - Causes Froth
  - High Oxygen Demand
    - Removes all oxygen - killing microorganisms used to treat sewage
    - Causes 'sludge bulking'.
  - Aquatic Toxicity
    - Of lower concern than Foaming and Oxygen Demand
    - May cause 'sloughing' of organisms from certain processes

- Disrupted plant:
  - Contaminates receiving water
  - Could cause fish kill
  - Makes water unfit for:
    - Drinking
    - Recreation, etc.

Representative Dilution Factors for Treatment of MAX MILSPEC AFFF at a WWTP



Representative Dilution Factors for COD of Foam Solution (Firefighting Strength)



Summary

- Under Context of Current Laws/Regulations, AFFF and all other Foams Regulated Based On:
  - Properties
    - BOD, COD, Foaming and Aquatic Toxicity
  - "Listed" Chemical Constituents
    - Butyl Carbitol, Surfactants, Ethylene Glycol, Urea, etc.
  - Water Issues are Most Prevalent
  - Foaming is Major Issue for WWTP
- Potential Environmental Impacts Generally Low
  - Impacts Consequence of
    - Foaming
    - O_2 Demand
    - Aquatic Toxicity
  - Upset of WWTP Creates Greatest Impact

APPENDIX (9)

Presentation: AFFF Management – Risk Based Approach"

D. Verdonik
Hughes Associates, Inc.
Baltimore MD

AFFF Management
Risk Based Approach

Dr. Dan Verdonik

HUGHES ASSOCIATES, INC.
FIRE SCIENCE & ENGINEERING

Why a Risk Based Approach?

- From Environmental Review
  - AFFF / Foams have Similar Environmental Impacts
    - Based on the Properties of Foams in General
    - Worst Impact for WWTP
  - Hazard Exists
  - Cannot Alter What Would Happen IF Released
- Can Reduce the <u>If</u> or <u>Likelihood of Release</u>
  - Example - Double Hulled Oil Tankers
    - Hazard Exists from Potential Oil Spill
    - Double Hull Reduces <u>Probability</u> of Having the Oil Spill
    - Double Hull Does Not Reduce <u>Environmental Impact</u> IF Have Oil Spill
    - Reducing Probability Reduces the Risk to the Environment
- Need to Evaluate Probability of Foam Release
- Probability + Severity = Risk

Risk and Risk Assessments

- Military Standard 882C: System Safety Program Requirements
  - Define Terms
    - Risk - Combination of hazard severity AND hazard probability
    - Hazard Probability: <u>Aggregate</u> probability of the <u>individual events</u>
    - Hazard Severity: Consequences of worst credible mishap
    - Control: Action to Eliminate Hazard or Reduce Risk
  - Applicable to All DOD Systems and Facilities
  - Identify the Hazards and Impose Design Requirements and Management Controls to Prevent Mishaps
  - Tailor to Application
    - AFFF/Foam Discharge from Facility Fixed Fire Suppression System
    - Accidental Discharge
    - Pre-planned testing
- Have Hazard Severity, Need Hazard Probability
  - Determine Risk
  - Risk Decision

MIL-STD-882C
4.5.2 Hazard Probability

- Potential occurrences per unit of time, events, population, items, or activity
  - Quantitative probability for potential design generally not possible
  - Qualitative probability
    - Derived from research, analysis, and evaluation of historical data
- Given for Specific Individual Item or Fleet / Inventory
- Assign Probability of Having Environmental Consequence

Qualitative Probability Levels
Specific Individual Item

FREQUENT	(A)	Likely to occur frequently
PROBABLE	(B)	Will occur several times in the life of an item
OCCASIONAL	(C)	Likely to occur some time in the life of an item
REMOTE	(D)	Unlikely but possible to occur in the life of an item
IMPROBABLE	(E)	So unlikely, it can be assumed occurrence may not be experienced

MIL-STD-882C
4.5.1 Hazard Severity

- Hazard Severity Category Definition
  - Provide Qualitative Measure of Worst Credible Mishap
  - Result of:
    - Personnel Error
    - Environmental Conditions
    - Design Inadequacies
    - Procedural Deficiencies
    - System, Subsystem or Component Failure or Malfunction

Qualitative Hazard Severity Categories

CATASTROPHIC	(1)	Death, System Loss, or Severe Environmental Damage
CRITICAL	(2)	Severe Injury, Severe Occupational Illness, Major System or Environmental Damage
MARGINAL	(3)	Minor Injury, Minor Occupational Illness, Minor System or Environmental Damage
NEGLIGIBLE	(4)	Less Than Minor Injury, Occupational Illness, Less Than Minor System or Environmental Damage

Risk Assessment and Acceptance

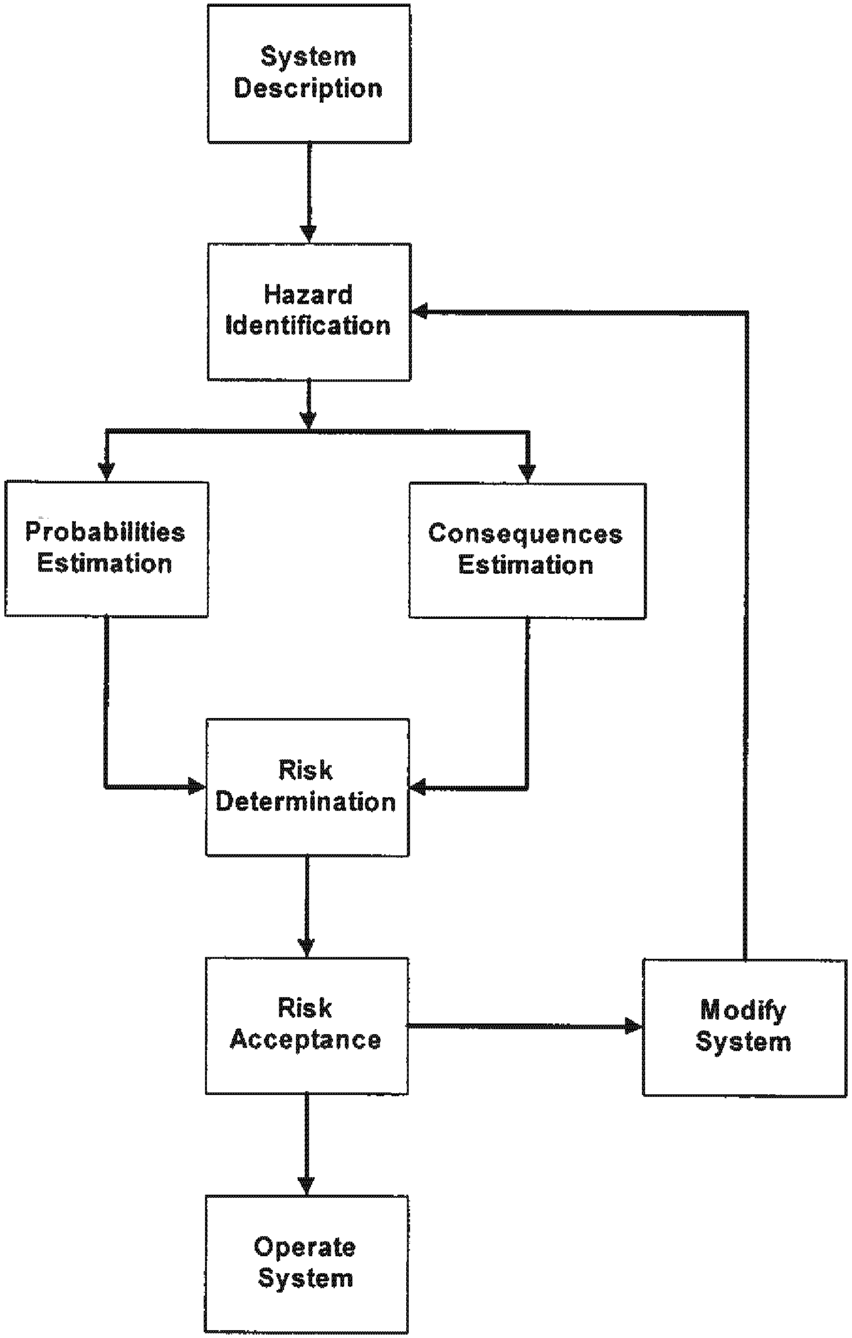
CATEGORY FREQUENCY	1 CATASTROPHIC	2 CRITICAL	3 MARGINAL	4 NEGLIGIBLE
A – FREQUENT	1A	2A	3A	4A
B – PROBABLE	1B	2B	3B	4B
C – OCCASIONAL	1C	2C	3C	4C
D – REMOTE	1D	2D	3D	4D
E - IMPROBABLE	1E	2E	3E	4E

- Risk Index - Suggested Acceptance Criteria in MIL-STD-882C

Unacceptable:	1A, 1B, 1C, 2A, 2B, 3A
Undesirable:	1D, 2C, 2D, 3B, 3C
Acceptable w/ Review by Managing Activity:	1E, 2E, 3D, 3E, 4A, 4B
Acceptable w/out Review:	4C, 4D, 4E

Design Criteria

- Design for minimum risk
  - Review design criteria for inadequate or overly restrictive requirements
  - Design to eliminate hazards
  - If hazard cannot be eliminated
    - Reduce risk to an acceptable level through design selection
    - Interlocks, redundancy, fail safe design, system protection, fire suppression, and protective clothing, equipment, devices, and procedures
- Recommend new design criteria supported by study, analyses, or test data


System Description
Hazard Identification
Probabilities Estimation
Consequences Estimation
Risk Determination
Risk Acceptance
Modify System
Operate System

Probability Estimation

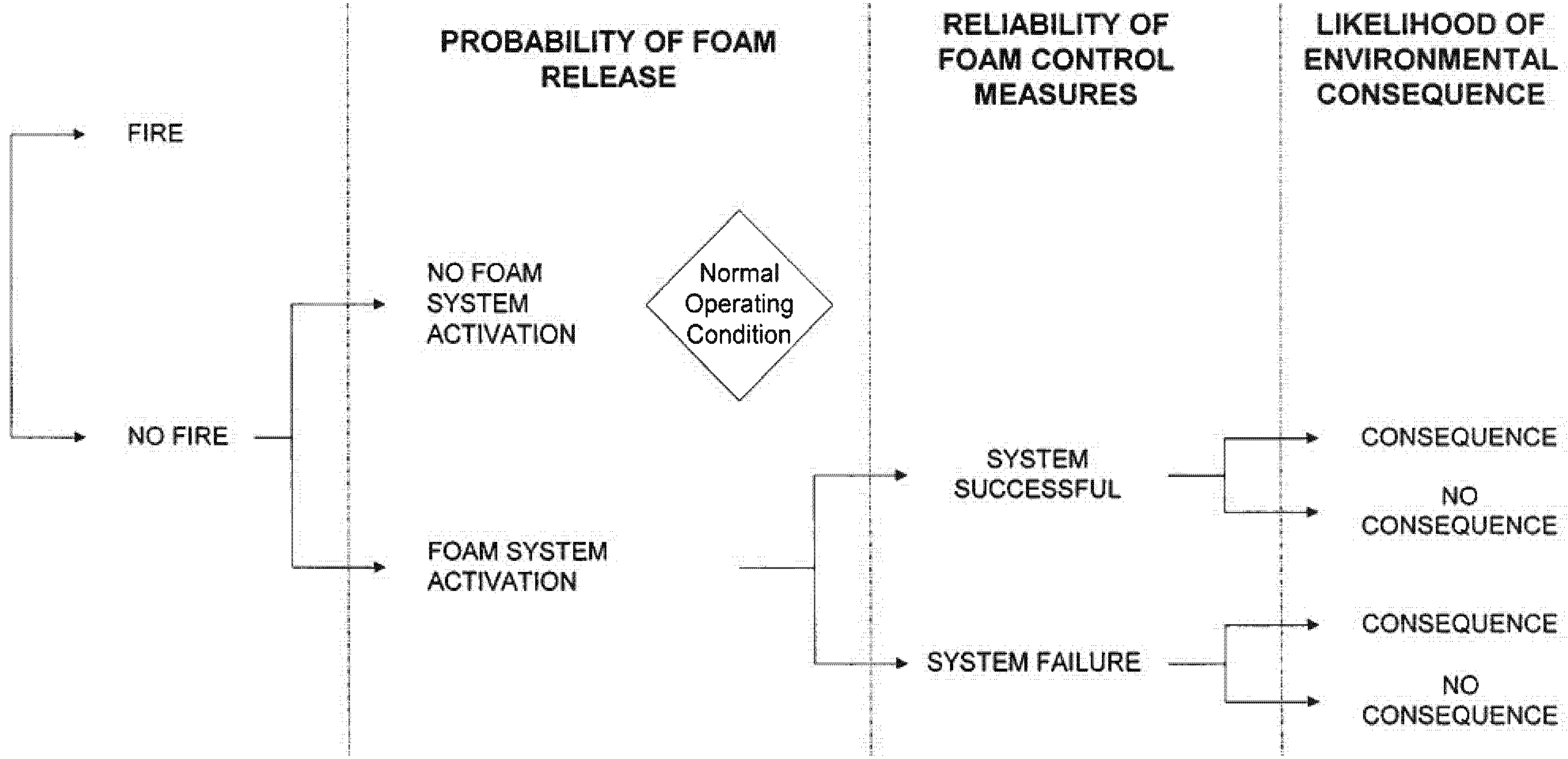
3 Parts to Probability Estimation

Probability of foam release

Reliability of system controlling foam movement

Likelihood of environmental consequence

Probability Estimation



PROBABILITY OF FOAM RELEASE

RELIABILITY OF FOAM CONTROL MEASURES

LIKELIHOOD OF ENVIRONMENTAL CONSEQUENCE

FIRE

NO FIRE

NO FOAM SYSTEM ACTIVATION

Normal Operating Condition

FOAM SYSTEM ACTIVATION

SYSTEM SUCCESSFUL

SYSTEM FAILURE

CONSEQUENCE

NO CONSEQUENCE

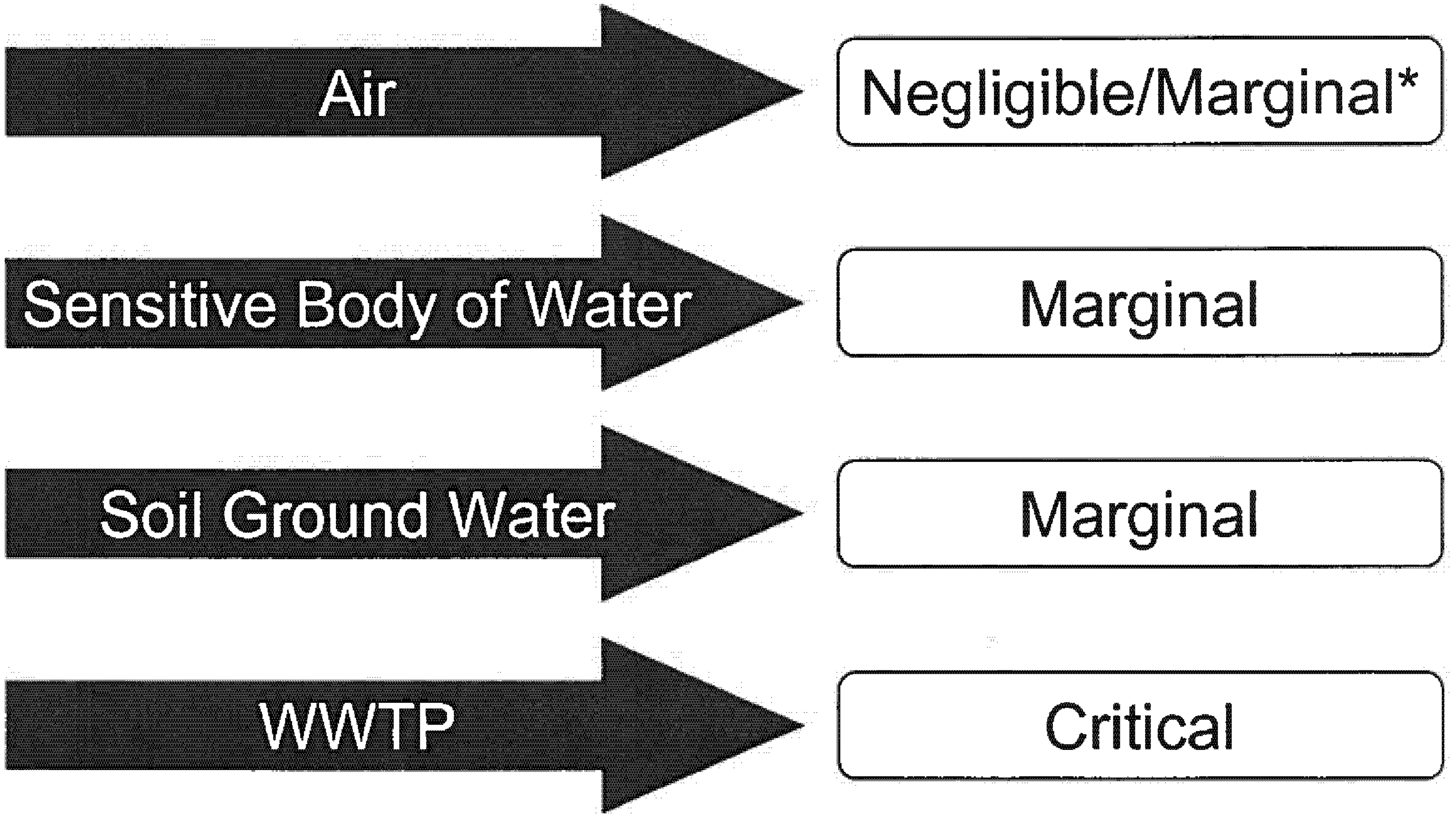
CONSEQUENCE

NO CONSEQUENCE

Accident Probability Estimation Of Environmental Consequence

	AIR	Sensitive Body of Water	Soil Ground Water	Wastewater Treatment Plant
1. Sanitary sewer, WWTP	E	C	E	C
2. Segregated Storm Sewer	E	C	E	E
3. Plugged, Storm Sewer	E	D	E	D
4. Pavement, Plugged Storm Sewer/drains	E	D	E	E
5. Pavement, Plugged Combined Sewer/drains	E	D	E	D
6. Pavement, Combined Sewer WWTP	E	C	E	C
7. Pavement, Storm Sewer	E	C	E	E
8. Unlined Pond, Percolates	E	E	E	E
9. Lined Pond, Pump Off-Site	E	E	E	E
10 Lined Pond, evaporate	E	E	E	E
11. Lined Pond, Meter WWTP	E	D	E	D
12. Lined Pond, Meter Storm Sewer	E	C	E	D
13. Lined Pond, Degrade WWTP	E	D	E	D
14. Lined Pond, Degrade Storm Sewer	E	D	E	D
15. Tank, Pump Off-Site	E	E	E	E
16. Tank, Meter WWTP	E	D	E	D
17. Tank Meter Storm Sewer	E	C	E	D
18. Tank, Degrade WWTP	E	D	E	D
19. Tank, Degrade Storm Sewer	E	D	E	D

Consequence Estimation
Severity of Environmental Impact



Air → Negligible/Marginal*

Sensitive Body of Water → Marginal

Soil Ground Water → Marginal

WWTP → Critical

*Air becomes marginal if foam in WWTP

Risk Assessment and Acceptance

	AIR	Sensitive Body of Water	Soil Ground Water	Wastewater Treatment Plant
1. Sanitary sewer, WWTP	3E	3C	3E	2C
2. Segregated Storm Sewer	4E	3C	3E	2E
3. Plugged, Storm Sewer	4E	3D	3E	2D
4. Pavement, Plugged Storm Sewer/drains	4E	3D	3E	2E
5. Pavement, Plugged Combined Sewer/drains	4E	3D	3E	2D
6. Pavement, Combined Sewer WWTP	3E	3C	3E	2C
7. Pavement, Storm Sewer	4E	3C	3E	2E
8. Unlined Pond, Percolates	4E	3E	3E	2E
9. Lined Pond, Pump Off-Site	4E	3E	3E	2E
10 Lined Pond, evaporate	4E	3E	3E	2E
11. Lined Pond, Meter WWTP	3E	3D	3E	2D
12. Lined Pond, Meter Storm Sewer	4E	3C	3E	2D
13. Lined Pond, Degrade WWTP	3E	3D	3E	2D
14. Lined Pond, Degrade Storm Sewer	4E	3D	3E	2D
15. Tank, Pump Off-Site	4E	3E	3E	2E
16. Tank, Meter WWTP	3E	3D	3E	2D
17. Tank Meter Storm Sewer	4E	3C	3E	2D
18. Tank, Degrade WWTP	3E	3D	3E	2D
19. Tank, Degrade Storm Sewer	4E	3D	3E	2D

Summary

- ■ Control and Management of AFFF Solutions
  - Based on Risk of Environmental Consequence
    - Risk Decision
    - Probability AND Severity
  - No "Unacceptable" Risks from Accidental Discharge
  - "Undesirable" Risks Avoidable through Design
  - Remaining Options All have Equivocal Residual Risk
- ■ Basis for Design Criteria
  - Ensure Risk is "Acceptable w/ Review by Managing Activity" Category
  - Minimizes Risk to the Environment
  - Does Not Increase Risk to Life-Safety/ Fire Loss

APPENDIX (10)

Presentation: "Phasing Out a Problem: Perfluorooctyl Sulfonate"

M. Dominiak
Environmental Protection Agency

Phasing Out a Problem: Perfluorooctyl Sulfonate (PFOS)

Mary F. Dominiak
U.S. Environmental Protection Agency

Naval Research Laboratory
3 August 2000

What is PFOS?

- Perfluorooctyl sulfonates; *acids, salts, halides, etc.*
- Man-made: do not occur in nature
- Produced since 1950's for use in surface treatment, paper protection, and performance chemical (surfactant and insecticide) products
- Also produced by breakdown/degradation of other sulfonyl-based fluorochemicals
- Made mostly by 3M Company

What is PFOS used for?

- Soil and stain resistant coatings on textiles, carpets, leather (2.3 million lbs/year)
- Oil, grease, and water resistance on paper products, including paperboard and food contact papers (2.6 million lbs/year)
- Performance chemicals: fire fighting foams, industrial surfactants, acid mist suppression, etc. (1.5 million lbs/year)

Why is PFOS a problem?

- PFOS is a PBT chemical:

  <u>P</u>ersistent

  <u>B</u>ioaccumulative

  <u>T</u>oxic

- PFOS has been found in the blood of the general US population, in wildlife, and in people overseas

Why is PFOS a problem?

- Persistent:
  - PFOS is a very stable chemical that does not break down or degrade in the environment; *once it's there, it stays*
- Bioaccumulative:
  - PFOS can build up over time; *its half-life in human blood is about 4 years*
  - Higher-ups in the food chain are exposed to the full dose of what has built up in their food

Why is PFOS a problem?

- Toxicity:
  - PFOS is only moderately toxic via acute oral exposure; *rat* LD_{50} *of 251 mg/kg*
  - In repeat oral dose subchronic and reproductive toxicity studies, however, serious effects seen
    - *Post-natal deaths in rats at 3.2 and 1.6 mg/kg/day*
    - *In repeat-dose treated Rhesus monkeys, death within 3 weeks at 10 mg/kg/day; within 7 weeks at 4.5 mg/kg/day. Adverse effects in cynomolgus monkeys at 0.75 mg/kg/day*

Why is PFOS a problem?

- Detected in blood not only in workers handling the chemical, but in the general US population and in wildlife
  - *High as 12.83 ppm in manufacturing workers*
  - *In pooled serum from general population, 30-40 ppb; small sample of children, mean 54 ppb*
  - *In eagles, wild birds, and fish, in ppb range*

How did PFOS get in people?

- We don’t know the precise exposure route, but studies are underway
- Possibilities include:
  - Dietary intake from food wrapped in papers treated with PFOS derivatives
  - Inhalation from aerosol applications
  - Inhalation, dietary, or dermal exposures during manufacturing, use, or disposal of chemicals and treated products

Why haven't PFOS problems been addressed before?

- PFOS was always known to be persistent, but much information on bioaccumulation and toxicity is recent
  - Improved detection technologies find PFOS at much lower levels in humans, wildlife
  - PFOS doesn't fit normal bioaccumulation model; *partitions to blood, not fat*
  - Newest toxicity tests raise greatest concerns

How big a risk is PFOS?

- EPA does not believe that the current situation presents an imminent health risk to the general US population; *blood levels low, concentration in surface-treated products (carpets/textiles) low*
- However, serious concern for potential future risk to humans and wildlife if PFOS continues to be produced, released, built up in the environment
- Studies underway to determine relationship of current blood levels to potential for adverse effects
- Questions/concerns on occupational exposures

What is being done about PFOS?

- 3M conducted studies, shared results with EPA, and discussed concerns
- On 5/16/2000, 3M publicly announced voluntary phase-out of perfluorooctanyl chemistries, most by end of 2000
- 3M submitted phase-out plan to EPA on 6/16/2000, amended on 7/7/2000
- 3M continues aggressive research program

What does the 3M PFOS phaseout plan involve?

- 3M will stop manufacture of PFOS for surface treatment products by 12/31/2000; *includes fabric/carpet/leather soil and stain resistance and paper coating products, including food contact*
- 3M will phase out manufacture of PFOS for performance products by 12/31/2002
- *Caveat:* May request permission for extended production for specific performance uses for which adequate substitutes do not exist or can't be qualified in time; *risk/risk tradeoffs, national security, technical performance issues*

What does EPA think of 3M's PFOS phaseout plan?

- EPA agrees that continued manufacture and use of PFOS represents an unacceptable technology that should be eliminated to protect human health and the environment from long term consequences
- 3M's voluntary phaseout will accomplish this goal more quickly than regulation could
- EPA may use regulation to "close the door" on PFOS after 3M's exit; *concerned parties will be able to comment and to dialogue with EPA*

What does this mean for fire fighters using PFOS foams?

- Fire fighting foams are in the performance category of products; continue through 2002
- 3M and EPA will be assessing health, safety and environmental implications of possible substitutes; *will welcome dialogue!*
- If qualified substitutes not available by end of 2002, 3M may request continued PFOS production for specific uses

What about using chemicals other than PFOS?

- Initial actions and phaseout apply to PFOS chemicals only
- EPA will be expanding review to assess other perfluorinated chemicals and related chemistries; *PFOA, telomers*
- Assessment activities will be international
- Industry group already proposing voluntary two-year research effort on some major telomers to begin 9/2000
- Too early to anticipate outcomes

How will EPA make decisions on PFOS issues?

- Toxic Substances Control Act (TSCA)
- Risk/benefit balancing requirements allow flexibility; *TSCA lets EPA take risk/risk tradeoffs, economic issues into account*
- Possible actions include:
  - Bans
  - Restrictions on uses
  - Production volume limits
  - Data collection and new testing requirements
  - Labeling, hazard communication

Where can I find information on PFOS and EPA actions?

- All documents on PFOS in public EPA Administrative Record, File AR-226
  - Includes all health studies submitted on PFOS
  - Available in hard copy or on CD-ROM
  - 401 M St, SW, Room NE B-607, Wash., DC, noon to 4 PM Eastern, Monday-Friday; telephone 202-260-7099
- Working on website; *not up yet, stay tuned*
- Interim EPA "Voice of PFOS:" Mary Dominiak, phone 202-260-7768; *dominiak.mary@epa.gov*

APPENDIX (11)

Presentation: "Facilities Background and AFFF Issues"

J. Simone
Naval Facilities Engineering Command

Facilities Background
And
AFFF Issues

Presentation to Hangar Facilities Breakout Session
DOD AFFF Environmental Meeting
2 August 2000

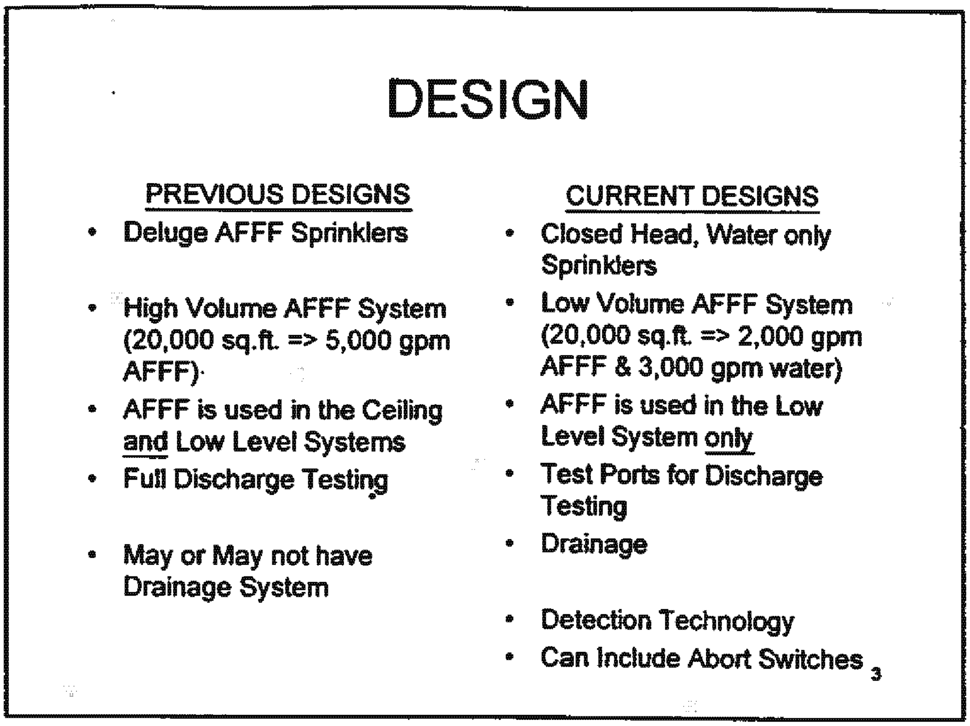
Joe Simone
Naval Facilities Engineering Command

FACILITIES BACKROUND

- Facilities that use AFFF - Aircraft Hangars, HAZ/FLAM Buildings, Fire Fighters Test Facilities, Hush Houses, and others
- Variety of Fire Protection Criteria in the Last 10 Years
- Variety of Containment Requirements
- No Risk Analysis with respect to Environmental
- Budget Proposals Guess or Don't Address Funding

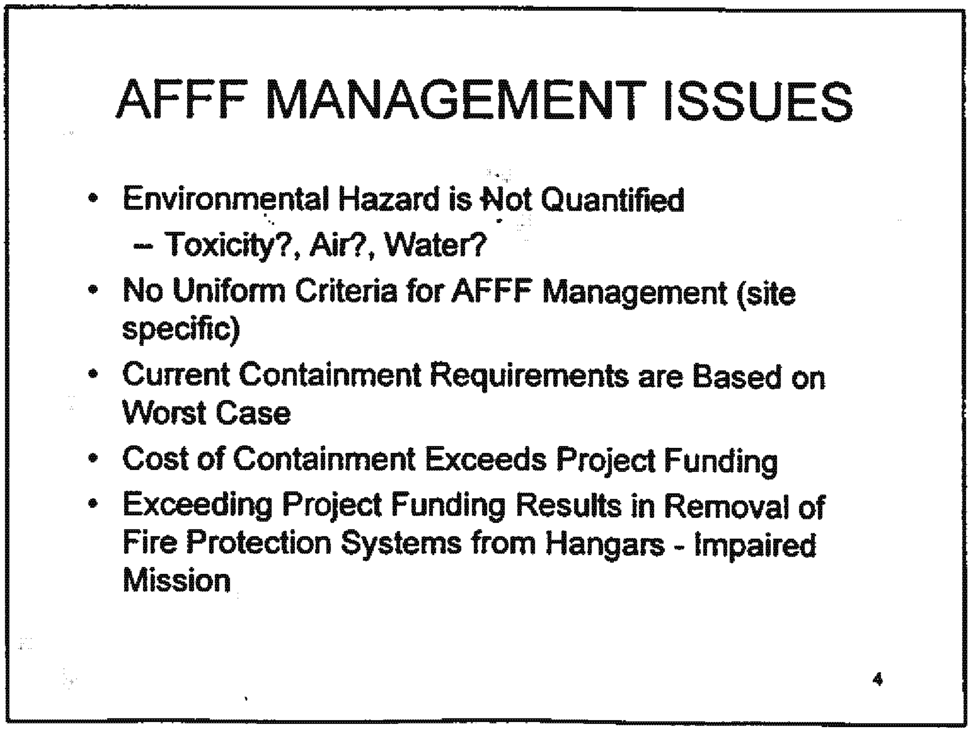
NAVAIR/NAVFAC HANGAR PROJECTS

- Evaluated Detector & Sprinkler Response Time in Hangars
- Evaluated Removing AFFF from Overhead Sprinkler Systems
    - Evaluated Using Lower AFFF Application Rate
- Evaluated New Low Level AFFF Distribution Systems
- Evaluated Variety of Optical Flame Detectors
- Developed New Fire Protection Criteria



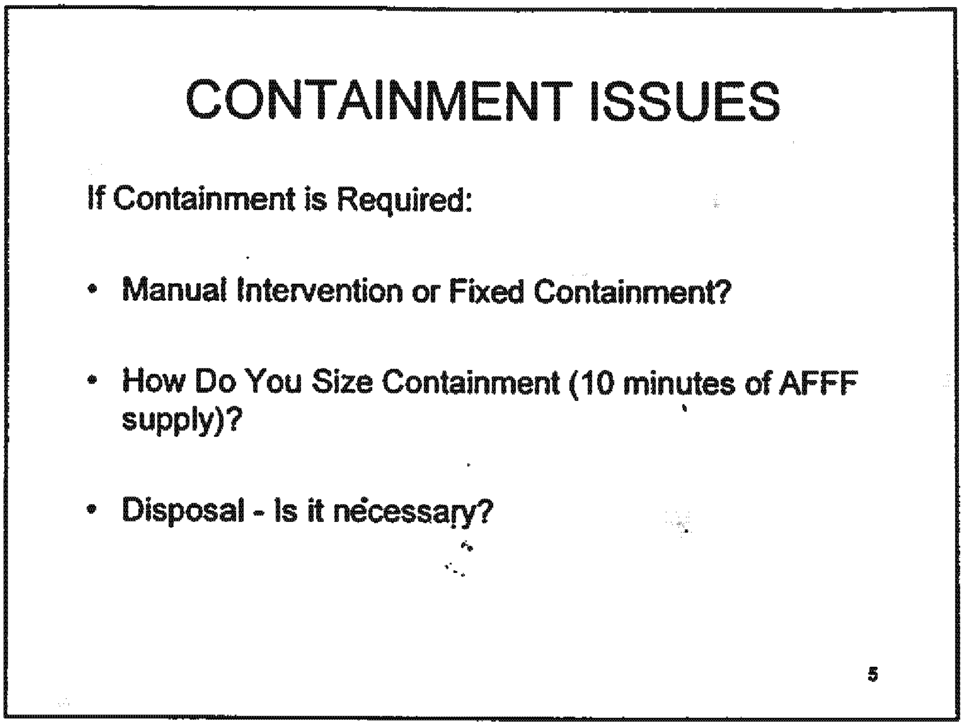
DESIGN

PREVIOUS DESIGNS	CURRENT DESIGNS
• Deluge AFFF Sprinklers	• Closed Head, Water only Sprinklers
• High Volume AFFF System (20,000 sq.ft. => 5,000 gpm AFFF)	• Low Volume AFFF System (20,000 sq.ft. => 2,000 gpm AFFF & 3,000 gpm water)
• AFFF is used in the Ceiling <u>and</u> Low Level Systems	• AFFF is used in the Low Level System <u>only</u>
• Full Discharge Testing	• Test Ports for Discharge Testing
• May or May not have Drainage System	• Drainage
	• Detection Technology
	• Can Include Abort Switches



AFFF MANAGEMENT ISSUES

- Environmental Hazard is Not Quantified
  - Toxicity?, Air?, Water?
- No Uniform Criteria for AFFF Management (site specific)
- Current Containment Requirements are Based on Worst Case
- Cost of Containment Exceeds Project Funding
- Exceeding Project Funding Results in Removal of Fire Protection Systems from Hangars - Impaired Mission



CONTAINMENT ISSUES

If Containment is Required:

- Manual Intervention or Fixed Containment?
- How Do You Size Containment (10 minutes of AFFF supply)?
- Disposal - Is it necessary?

APPENDIX (12)

Presentation: "AFFF Risk Assessment"

A. Wakelin
Hughes Associates, Inc.
Baltimore MD

Aqueous Film Forming Foam (AFFF) Risk Assessment

For discharges of AFFF from fixed fire protection systems in shore facilities

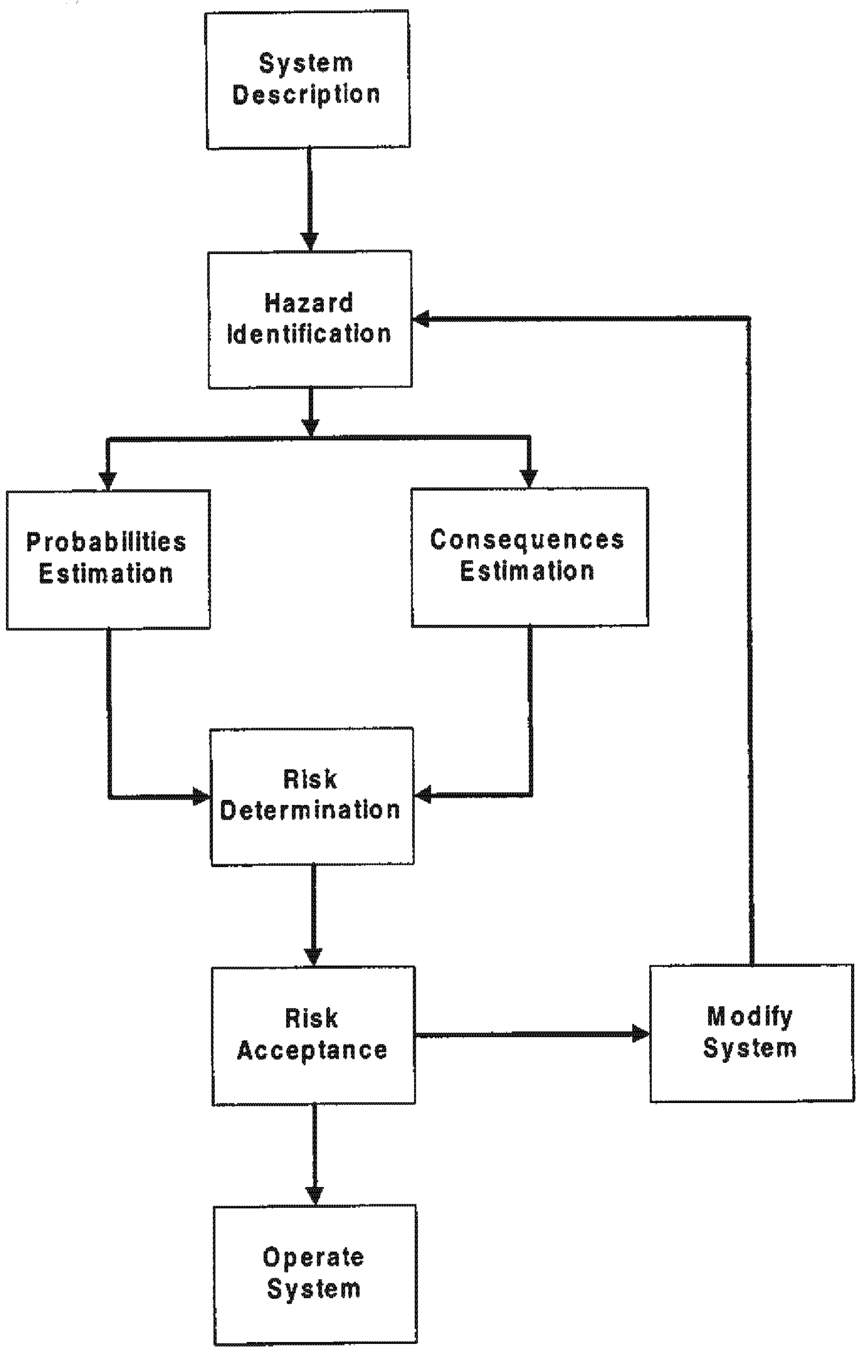
Alison Wakelin

HUGHES ASSOCIATES, INC.
FIRE SCIENCE & ENGINEERING

August 2, 2000

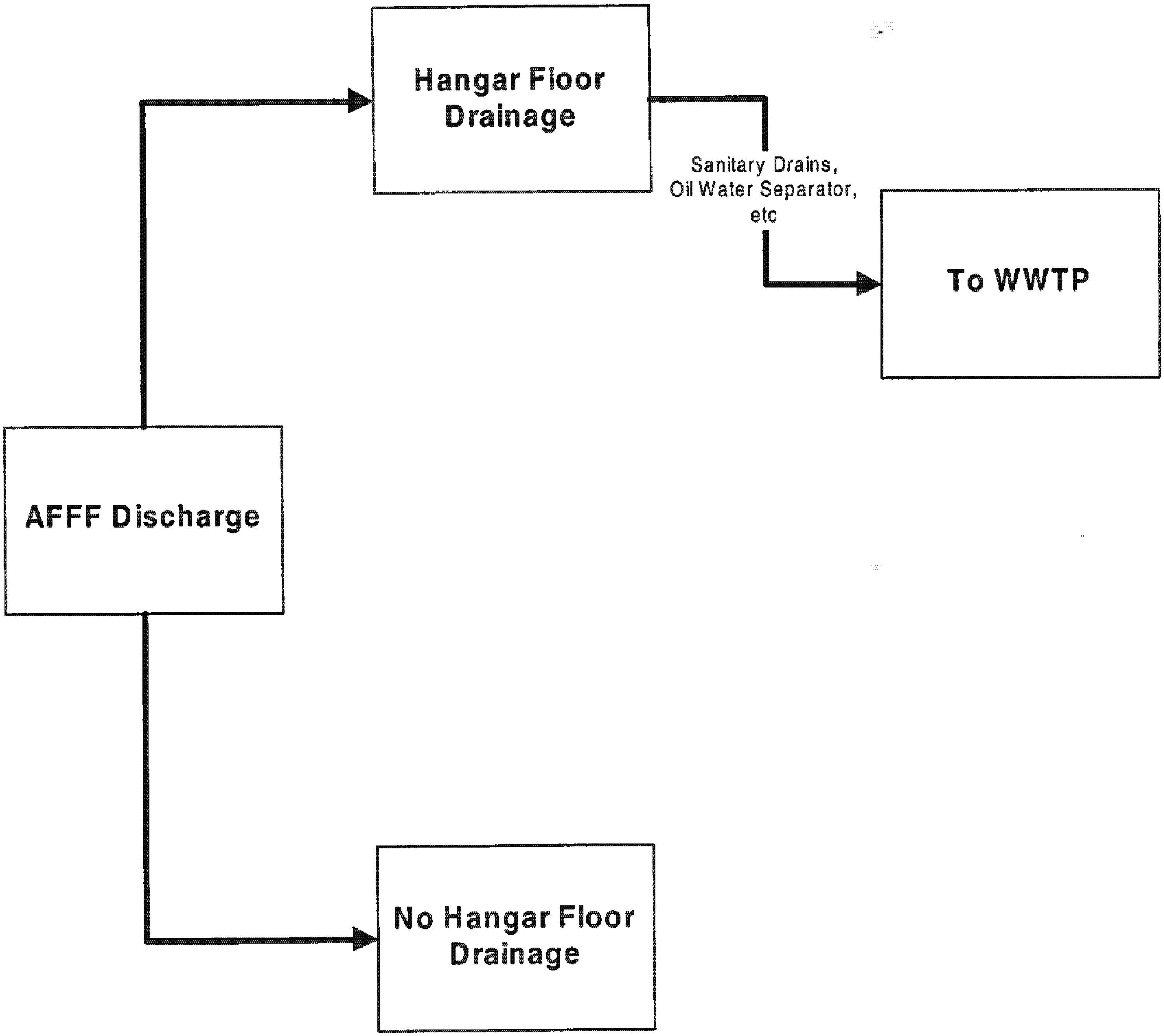
Overview

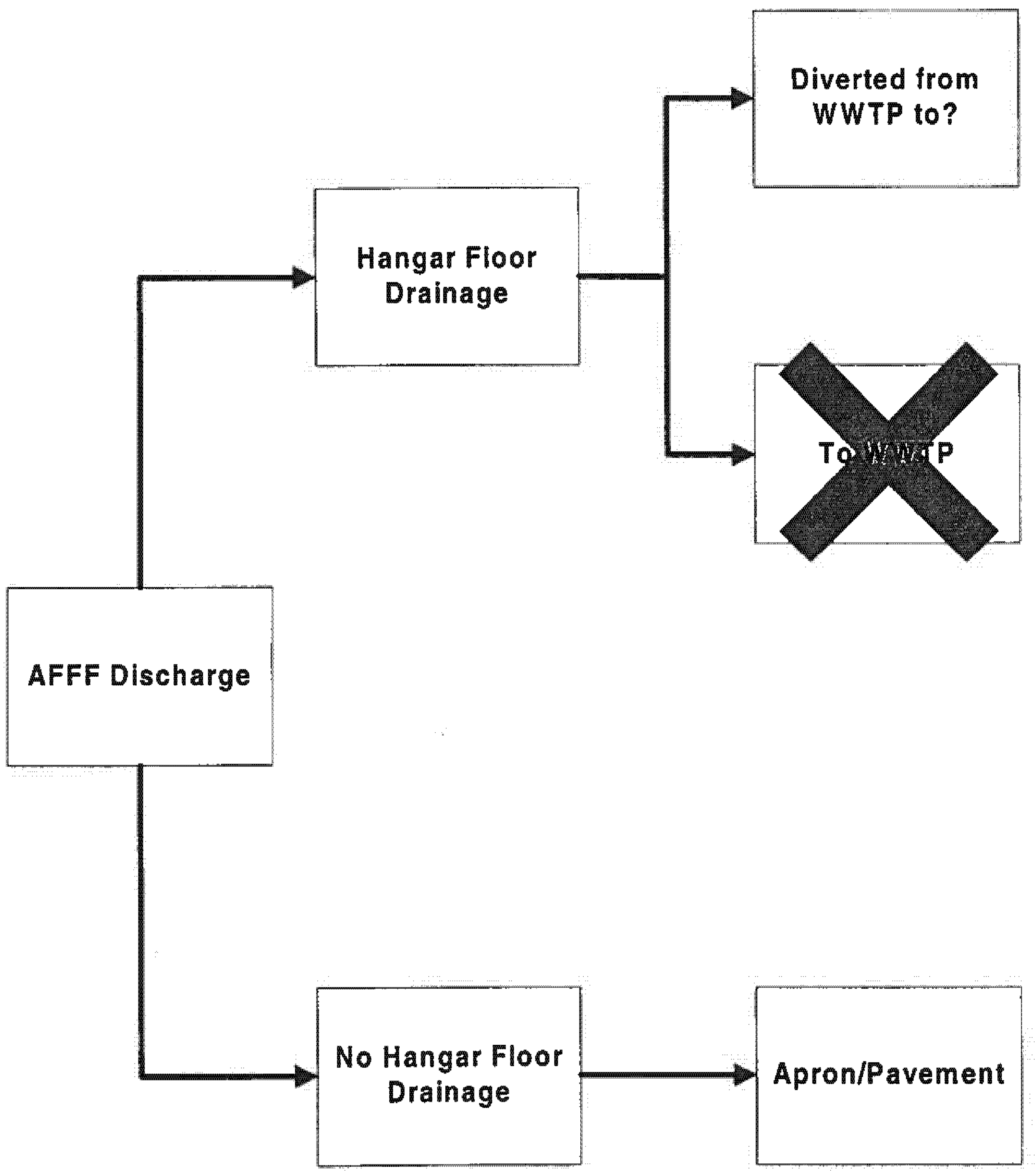
- Develop physical control options
  - Performance Criteria
- Probability Estimation
- Consequence Estimation
- Risk Assessment

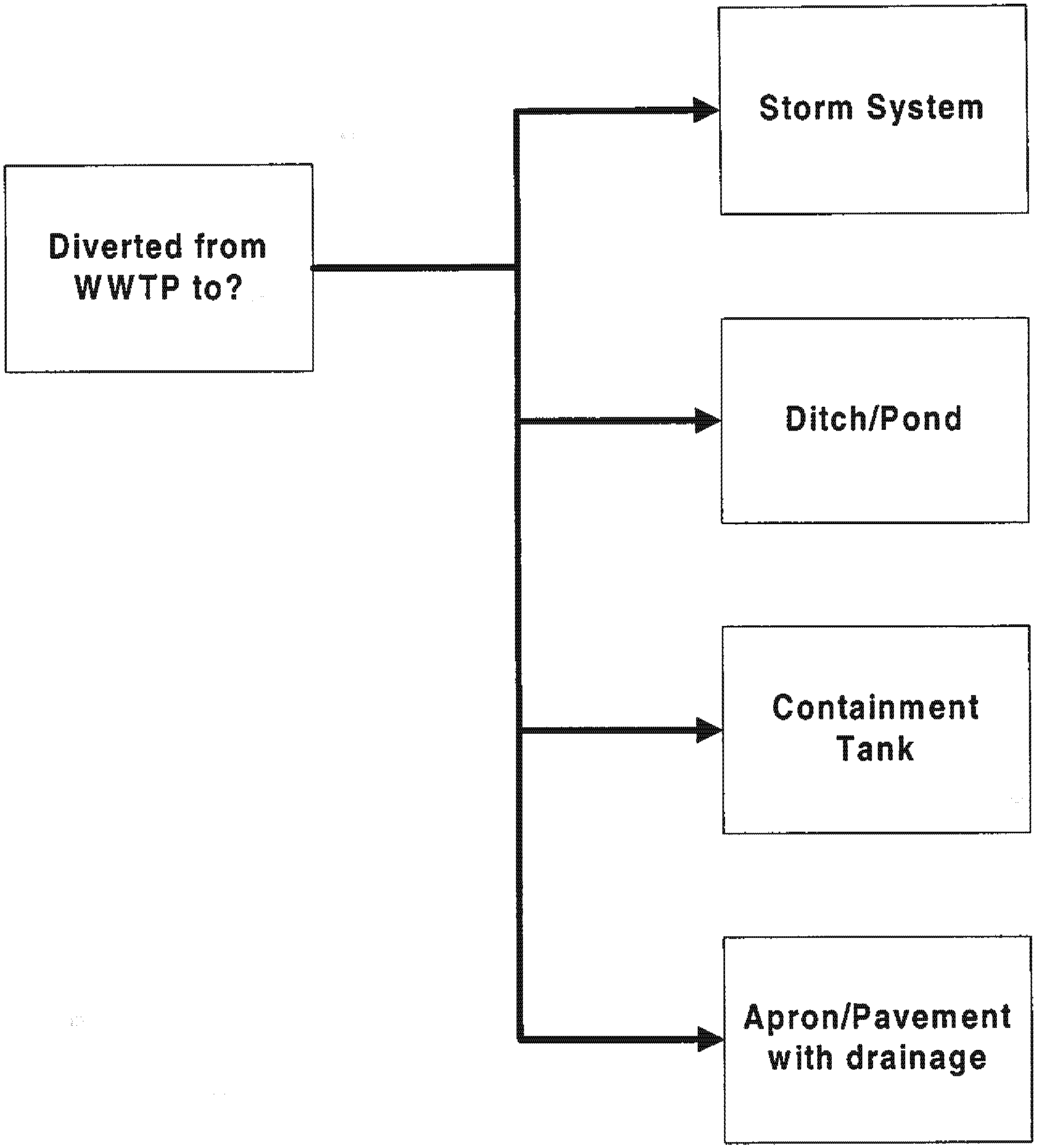

System Description
Hazard Identification
Probabilities Estimation
Consequences Estimation
Risk Determination
Risk Acceptance
Modify System
Operate System

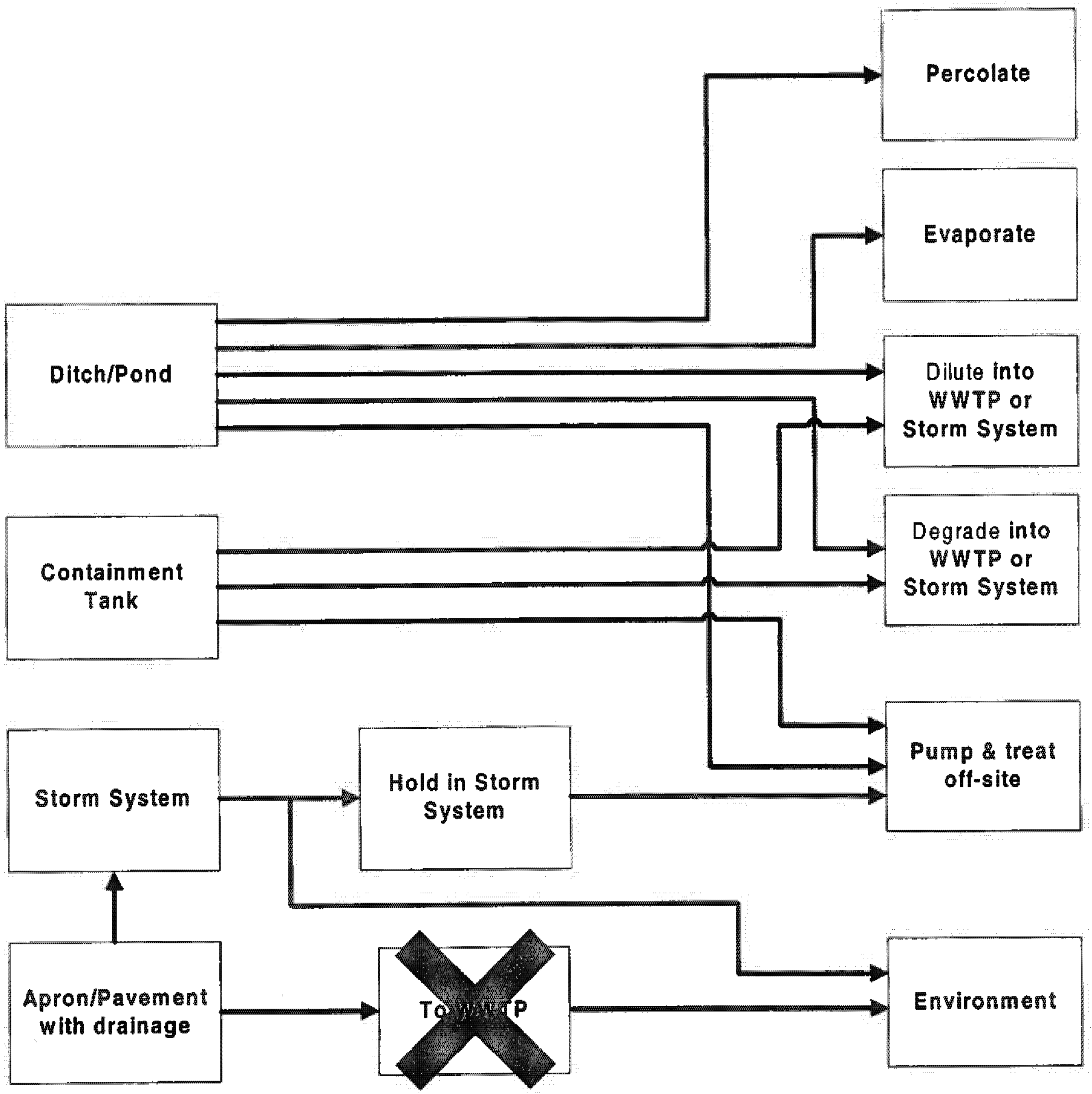
Develop Physical Control Options

- Hangar drainage requirements (NFPA 409)
- Foam to the WWTP?
- Other options for maintaining positive control of foam


AFFF Discharge
Hangar Floor Drainage
Sanitary Drains, Oil Water Separator, etc
To WWTP
No Hangar Floor Drainage


AFFF Discharge
Hangar Floor Drainage
No Hangar Floor Drainage
Diverted from WWTP to?
~~To WWTP~~
Apron/Pavement


Diverted from
WWTP to?
Storm System
Ditch/Pond
Containment
Tank
Apron/Pavement
with drainage


Percolate
Evaporate
Ditch/Pond
Dilute into WWTP or Storm System
Degrade into WWTP or Storm System
Containment Tank
Pump & treat off-site
Storm System
Hold in Storm System
Apron/Pavement with drainage
To WWTP
Environment

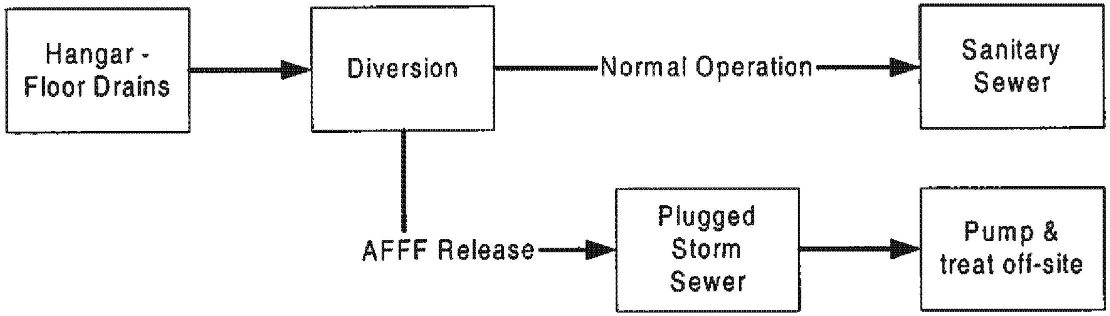
Physical Control Options

- 19 different control options
- Sufficient number to show range of risks
- Three options will be presented
  - data from all available on request

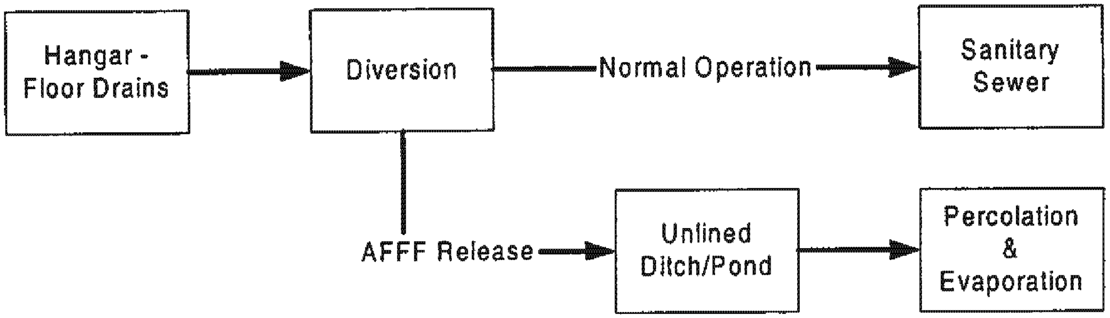
Example Physical Control Options

1. Sanitary sewer with direct access to WWTP

2. Plugged, totally segregated storm sewer



3. Pond, Percolate (drains into soil)



Performance Criteria

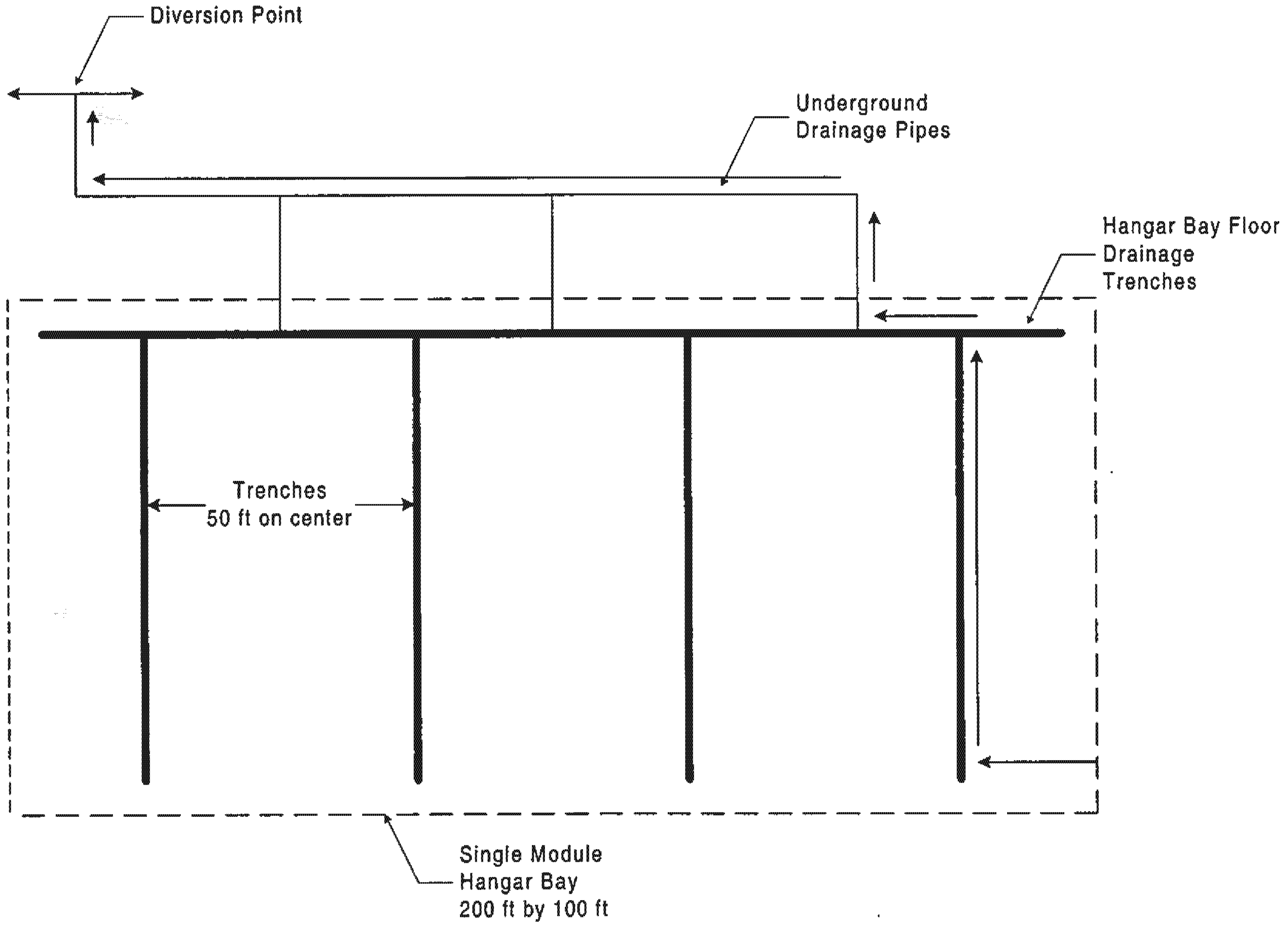
- Detailed investigation of control options
- What are performance goals of control options?
  - How much of a discharge needs to be controlled?
- Accidental discharge shut-off in 3 mins?
- Accidental discharge of all foam?

Proposed Foam Control Criteria

- Conservative approach all foam has drained to beyond diversion point
- No emergency shut-off
- 6 min drainage time
- Single “module” hangar 100 ft by 200 ft
- Total flow
  - 16 min @ 2000 gpm = 32,000 gal

Proposed Foam Control Criteria

Drainage



Probability Estimation

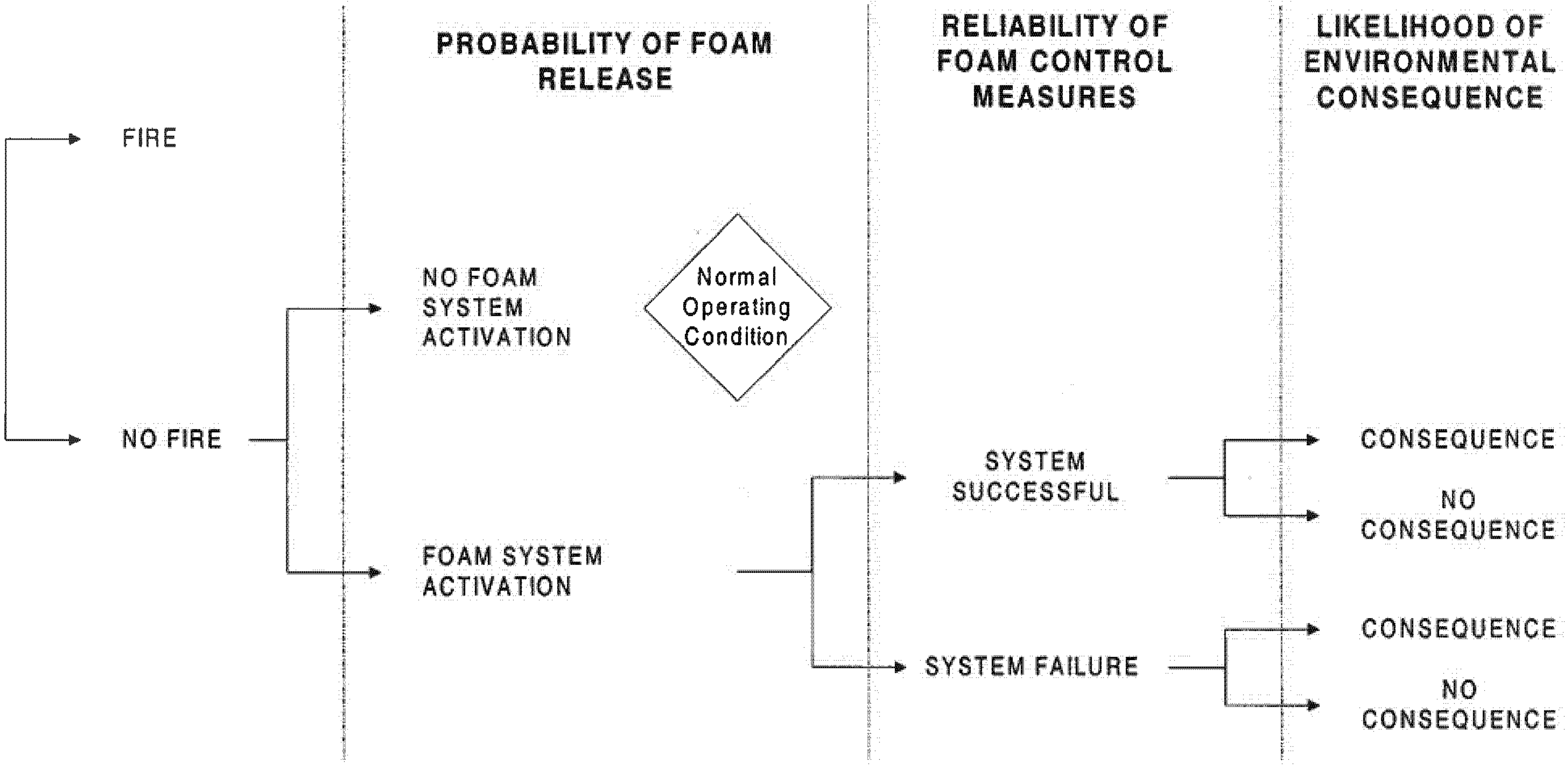
3 Parts to Probability Estimation

Probability of foam release

Reliability of system controlling foam movement

Likelihood of environmental consequence

Probability Estimation



PROBABILITY OF FOAM RELEASE

RELIABILITY OF FOAM CONTROL MEASURES

LIKELIHOOD OF ENVIRONMENTAL CONSEQUENCE

FIRE

NO FIRE

NO FOAM SYSTEM ACTIVATION

Normal Operating Condition

FOAM SYSTEM ACTIVATION

SYSTEM SUCCESSFUL

SYSTEM FAILURE

CONSEQUENCE

NO CONSEQUENCE

CONSEQUENCE

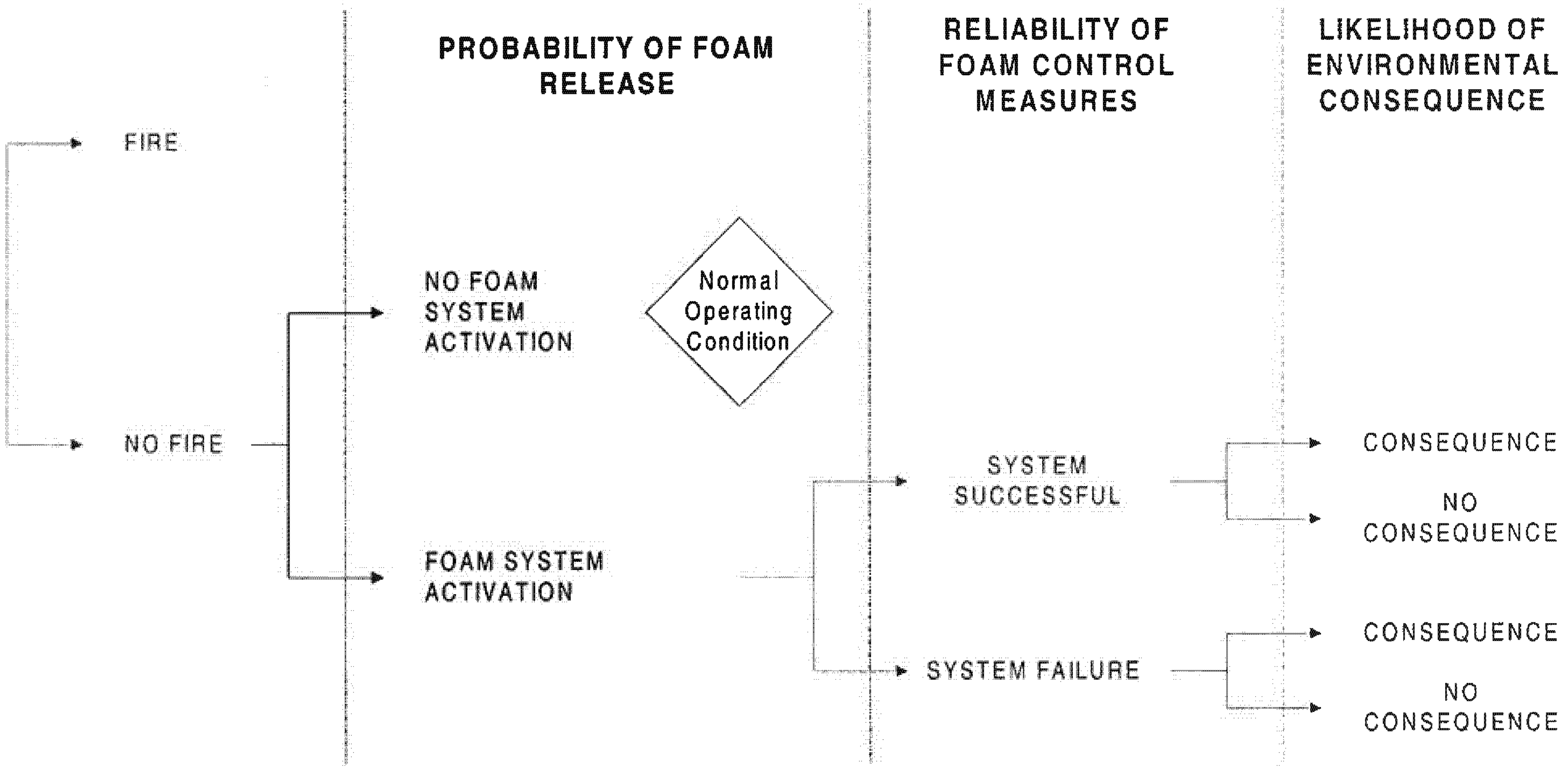
NO CONSEQUENCE

Probability Estimation

A	FREQUENT	Likely to occur frequently
B	PROBABLE	Will occur several times in the life of an item
C	OCCASIONAL	Likely to occur some time in the life of an item
D	REMOTE	Unlikely but possible to occur in the life of an item
E	IMPROBABLE	So unlikely, it can be assumed occurrence may not be experienced

Probability Estimation

Foam System Activation



PROBABILITY OF FOAM RELEASE

RELIABILITY OF FOAM CONTROL MEASURES

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Normal Operating Condition

FOAM SYSTEM ACTIVATION

SYSTEM SUCCESSFUL

SYSTEM FAILURE

CONSEQUENCE

NO CONSEQUENCE

CONSEQUENCE

NO CONSEQUENCE

Probability Estimation

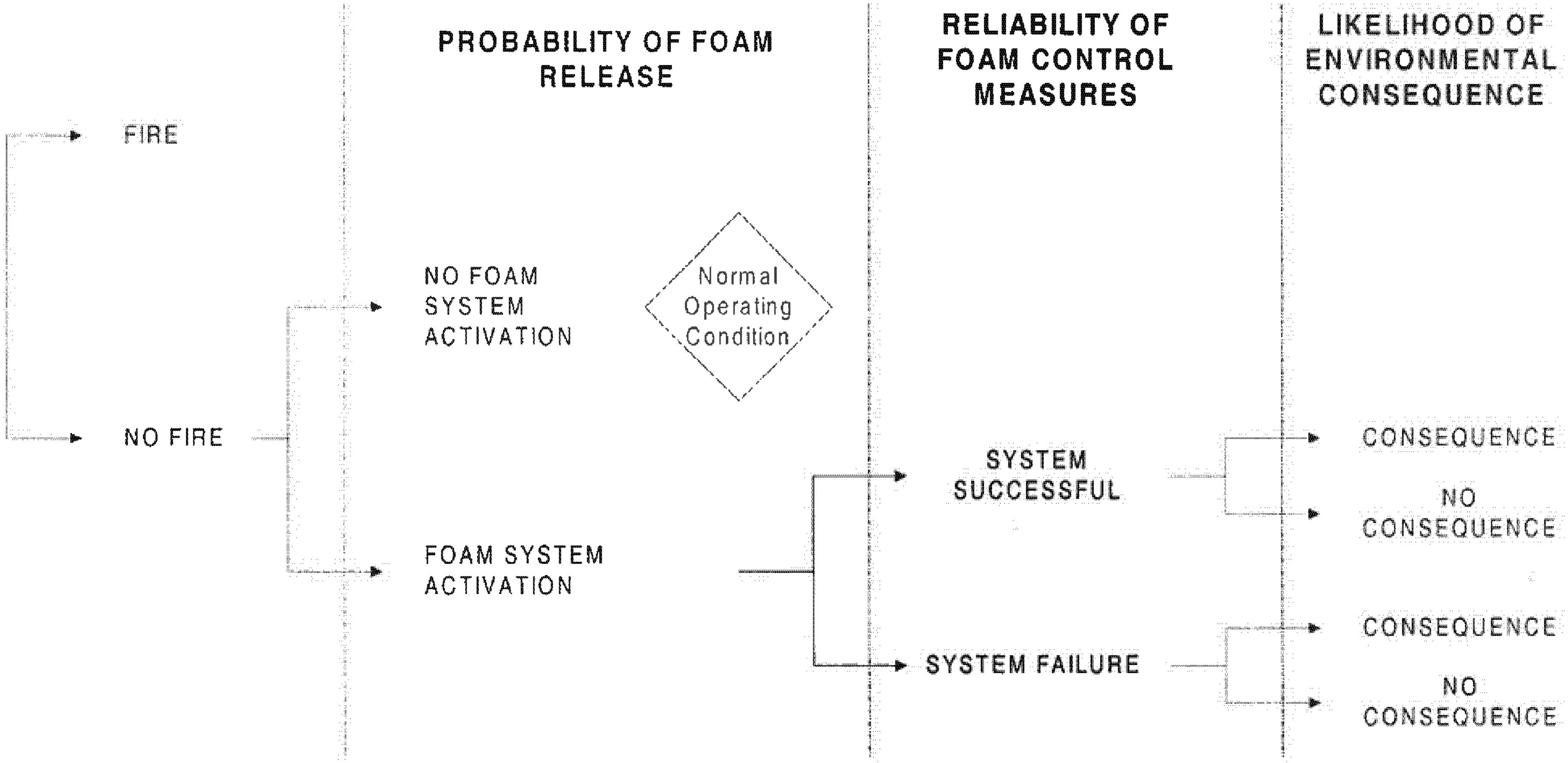
Foam System Activation

- Accidental activation of a low level foam system
- Likely to occur some time in the life of an item

⇒ Occasional C

Probability Estimation

Foam Control Measures



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NO FOAM SYSTEM ACTIVATION

Normal Operating Condition

FOAM SYSTEM ACTIVATION

SYSTEM SUCCESSFUL

SYSTEM FAILURE

CONSEQUENCE

NO CONSEQUENCE

CONSEQUENCE

NO CONSEQUENCE

Probability Estimation

Foam Control Measures

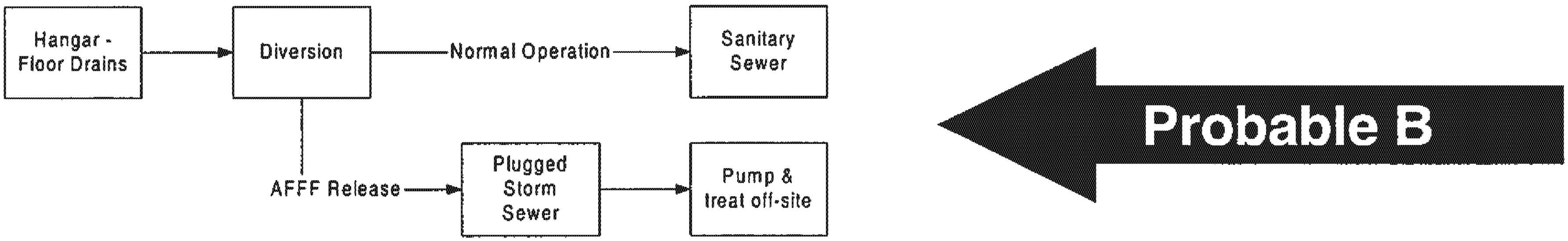
- An engineered design of each control measure is evaluated for:
  - Reliability
    - Likelihood of Control System Failure is Established
    - Failure based on complexity of system

Probability Estimation

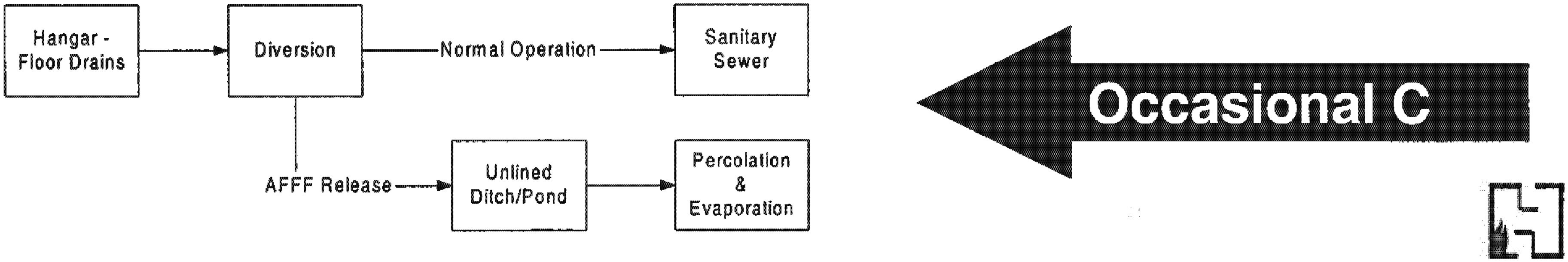
Likelihood of system failure

1. Sanitary sewer with direct access to WWTP

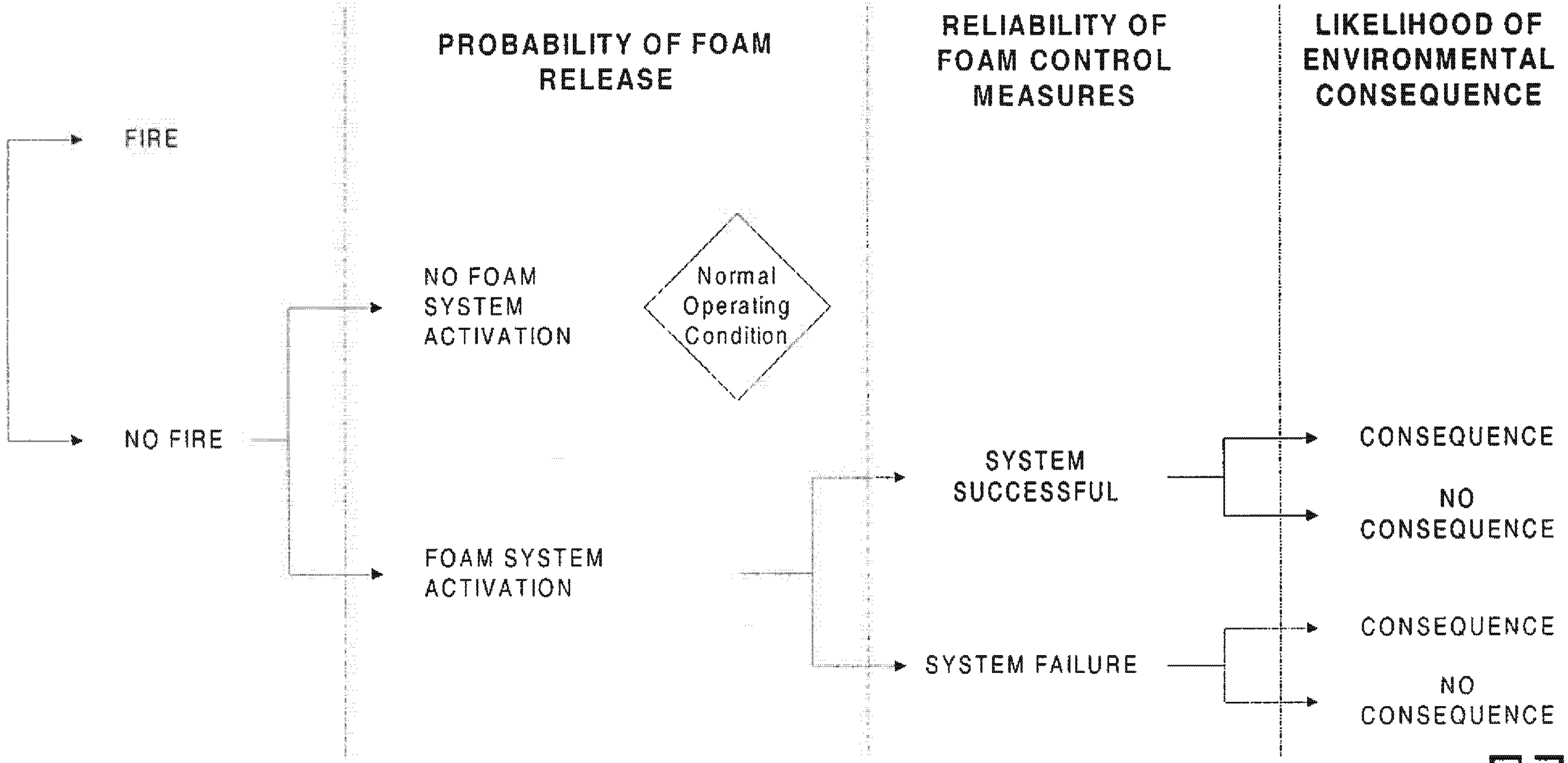
2. Plugged, totally segregated storm sewer



3. Pond, Percolate (drains into soil)



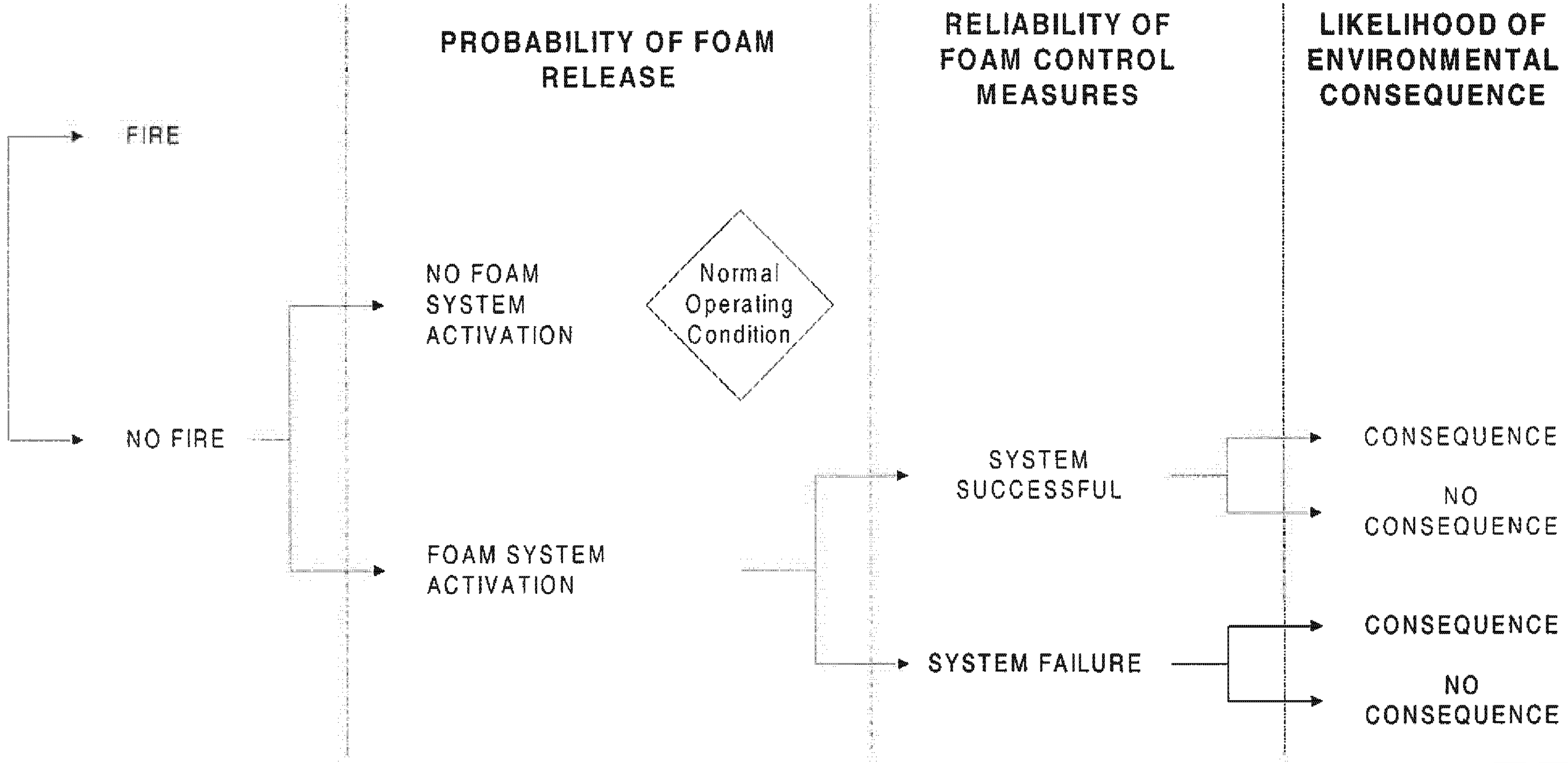
Probability Estimation
Environmental Consequence



Probability Estimation
Environmental Consequence

Successful Foam Control (Risk By Media)				
	AIR	**Sensitive Body of Water**	**Soil Ground Water**	**Wastewater Treatment Plant**
1. Sanitary sewer, WWTP	Remote	Frequent	Improbable	Frequent
2. Plugged, Storm Sewer	Remote	Improbable	Improbable	Improbable
3. Unlined Pond, Percolates	Remote	Remote	Remote	Improbable
Unsuccessful Foam Control (Risk By Media)				
	AIR	**Sensitive Body of Water**	**Soil Ground Water**	**Wastewater Treatment Plant**
1. Sanitary sewer, WWTP	Remote	Frequent	Remote	Frequent
2. Plugged, Storm Sewer	Remote	Occasional	Remote	Occasional
3. Unlined Pond, Percolates	Remote	Occasional	Occasional	Occasional

Probability Estimation
Environmental Consequence



PROBABILITY OF FOAM RELEASE

RELIABILITY OF FOAM CONTROL MEASURES

LIKELIHOOD OF ENVIRONMENTAL CONSEQUENCE

FIRE

NO FIRE

NO FOAM SYSTEM ACTIVATION

Normal Operating Condition

FOAM SYSTEM ACTIVATION

SYSTEM SUCCESSFUL

SYSTEM FAILURE

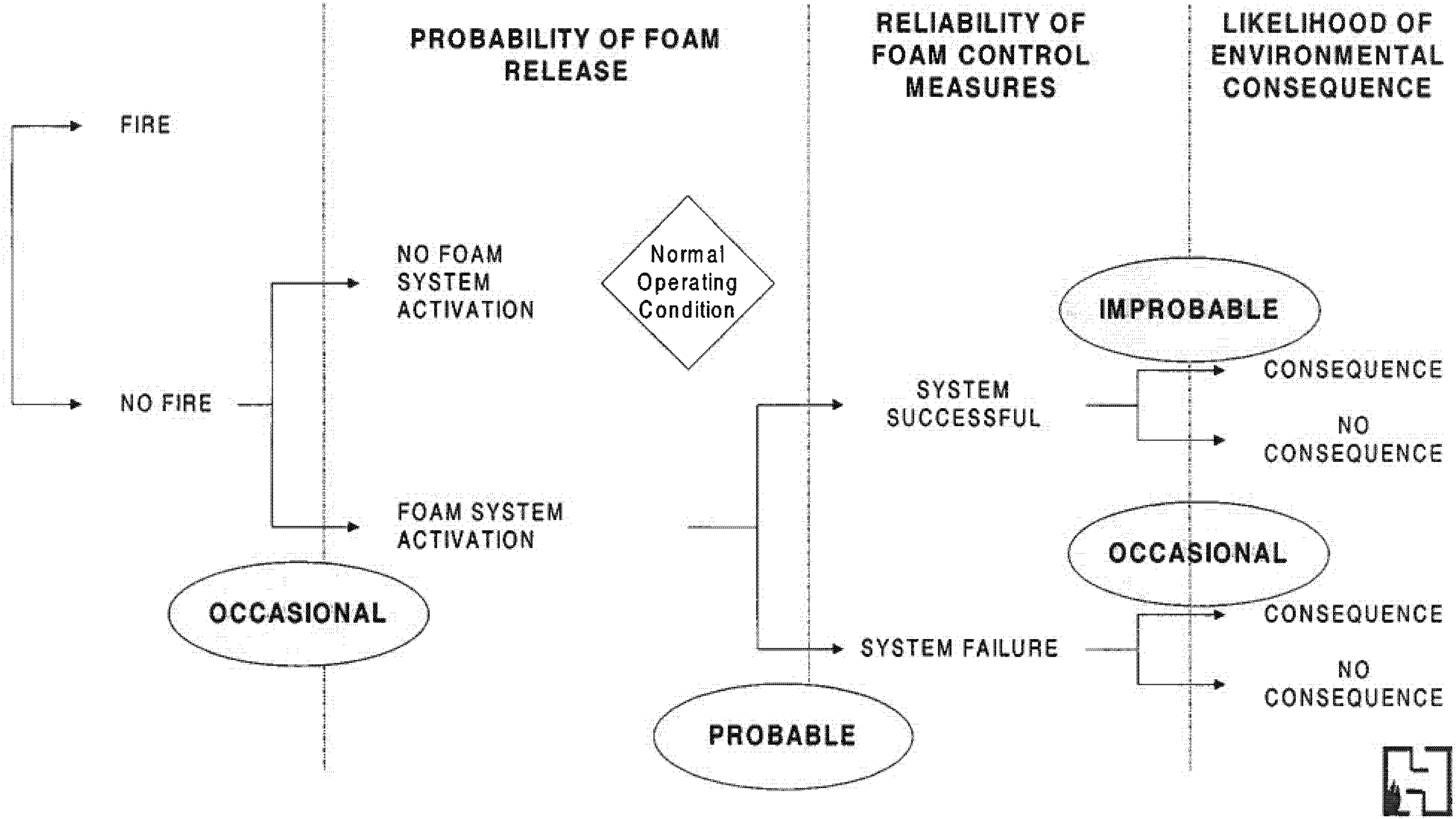
CONSEQUENCE

NO CONSEQUENCE

CONSEQUENCE

NO CONSEQUENCE

Probability Estimation
Environmental Consequences
Option 2: Plugged storm sewer Sensitive body of water



PROBABILITY OF FOAM RELEASE

RELIABILITY OF FOAM CONTROL MEASURES

LIKELIHOOD OF ENVIRONMENTAL CONSEQUENCE

FIRE

NO FIRE

NO FOAM SYSTEM ACTIVATION

FOAM SYSTEM ACTIVATION

OCCASIONAL

Normal Operating Condition

SYSTEM SUCCESSFUL

SYSTEM FAILURE

PROBABLE

IMPROBABLE

CONSEQUENCE

NO CONSEQUENCE

OCCASIONAL

CONSEQUENCE

NO CONSEQUENCE

Probability Estimation

Frequency Estimation		Suggested Range
A	FREQUENT	$X > 10^{-1}$
B	PROBABLE	$10^{-1} > X > 10^{-2}$
C	OCCASIONAL	$10^{-2} > X > 10^{-3}$
D	REMOTE	$10^{-3} > X > 10^{-6}$
E	IMPROBABLE	$10^{-6} > X$

Probability Estimation
Environmental Consequence

	AIR	Sensitive Body of Water	Soil Ground Water	Wastewater Treatment Plant
1. Sanitary sewer, WWTP	E	C	E	C
2. Plugged, Storm Sewer	E	D	E	D
3. Unlined Pond, Percolates	E	E	E	E

Consequence Estimation

Severity of Environmental Impact

Air	Negligible/Marginal*
Sensitive Body of Water	Marginal
Soil Ground Water	Marginal
WWTP	Critical

*Air becomes marginal if foam in WWTP

Risk Assessment & Acceptance

CATEGORY FREQUENCY	1 CATASTROPHIC	2 CRITICAL	3 MARGINAL	4 NEGLIGIBLE
A – FREQUENT	1A	2A	3A	
B – PROBABLE	1B	2B	3B	
C – OCCASIONAL	1C	2C	3C	4C
D – REMOTE	1D	2D		4D
E - IMPROBABLE				4E

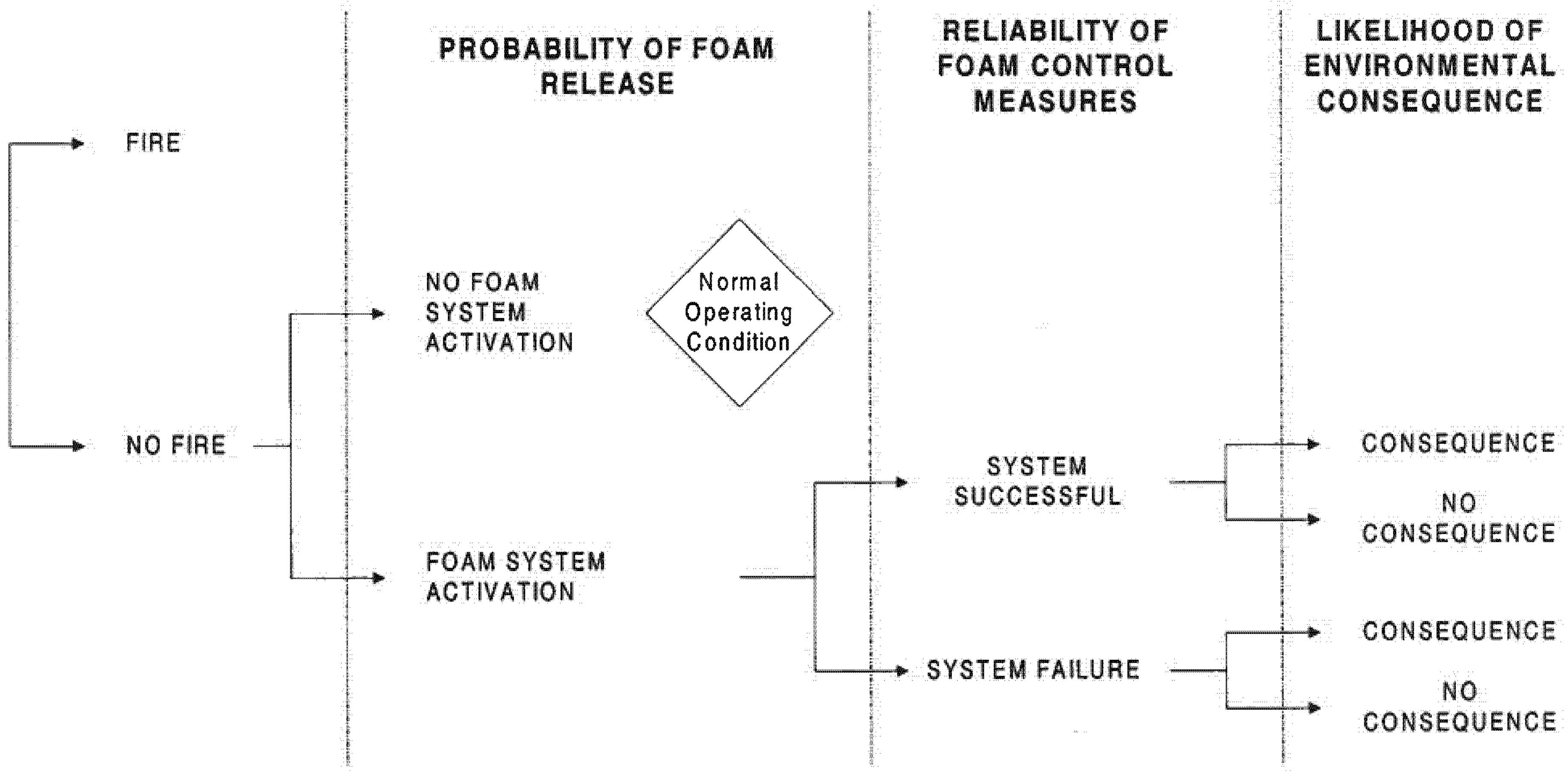
UNACCEPTABLE:	1A, 1B, 1C, 2A, 2B, 3A
UNDESIRABLE:	1D, 2C, 2D, 3B, 3C
ACCEPTABLE WITH REVIEW:	
ACCEPTABLE WITHOUT REVIEW:	4C, 4D, 4E

Risk Assessment

Environmental Consequence

	AIR	Sensitive Body of Water	Soil Ground Water	Wastewater Treatment Plant
1. Sanitary sewer, WWTP		3C		2C
2. Plugged, Storm Sewer	4E			2D
3. Unlined Pond, Percolates	4E			

Probability Estimation
Foam System Activation



PROBABILITY OF FOAM RELEASE

RELIABILITY OF FOAM CONTROL MEASURES

LIKELIHOOD OF ENVIRONMENTAL CONSEQUENCE

FIRE

NO FIRE

NO FOAM SYSTEM ACTIVATION

Normal Operating Condition

FOAM SYSTEM ACTIVATION

SYSTEM SUCCESSFUL

SYSTEM FAILURE

CONSEQUENCE

NO CONSEQUENCE

CONSEQUENCE

NO CONSEQUENCE

Probability Estimation

Foam System Testing

- Should foam control systems be used for testing?
- Foam system activation becomes probable
- Reliability improved as testing supervised

Risk Assessment
Environmental Consequence

For Foam Testing				
	AIR	Sensitive Body of Water	Soil Ground Water	Wastewater Treatment Plant
1. Sanitary sewer, WWTP		3B		2B
2. Plugged, Storm Sewer	4D			2D
3. Unlined Pond, Percolates	4D			
For Accidental Release				
	AIR	Sensitive Body of Water	Soil Ground Water	Wastewater Treatment Plant
1. Sanitary sewer, WWTP		3C		2C
2. Plugged, Storm Sewer	4E			2D
3. Unlined Pond, Percolates	4E			

Risk Assessment
Environmental Consequence

	AIR	Sensitive Body of Water	Soil Ground Water	Wastewater Treatment Plant
1. Sanitary sewer, WWTP		3C		2C
2. Segregated Storm Sewer	4E	3C		
3. Plugged, Storm Sewer	4E			2D
4. Pavement, Plugged Storm Sewer/drains	4E			
5. Pavement, Plugged Combined Sewer/drains	4E			2D
6. Pavement, Combined Sewer WWTP		3C		2C
7. Pavement, Storm Sewer	4E	3C		
8. Unlined Pond, Percolates	4E			
9. Lined Pond, Pump Off-Site	4E			
10 Lined Pond, evaporate	4E			
11. Lined Pond, Meter WWTP				2D
12. Lined Pond, Meter Storm Sewer	4E	3C		2D
13. Lined Pond, Degrade WWTP				2D
14. Lined Pond, Degrade Storm Sewer	4E			2D
15. Tank, Pump Off-Site	4E			
16. Tank, Meter WWTP				2D
17. Tank Meter Storm Sewer	4E	3C		2D
18. Tank, Degrade WWTP				2D
19. Tank, Degrade Storm Sewer	4E			2D

Costs

- Single module, 16 minutes of foam discharge
- Costs options we have identified are in the $0–200K range
- More stringent control criteria can lead to much greater costs
- However risk of an environmental consequence is not reduced

APPENDIX (13)

Presentation: "Summary of Shore Facility AFFF Management Breakout Session"

D. Verdonik
Hughes Associates, Inc.
Baltimore MD

Summary of Shore Facility AFFF Management Break-Out Session

Dan Verdonik

3 August 2000

Facility AFFF Management Working Group

- Decision to ‘formalize’ a Working Group
  - Develop Facility Policy for AFFF Management
    - Changed name from “Hangar” to “Facility” to reflect broader scope
    - Target for Completion: Approximately 6 months
  - Develop a draft DoDI
    - Staff Through Environmental Side of Services
    - Present to OSD
  - Next Meeting Scheduled for October 12
- Accepted-in-Principle the Risk Based Approach
  - Use as the Basis for the Policy
  - Need to Review Details and Back-up Information
  - Report will be Provided Prior to Next Meeting

Facility AFFF Management Working Group - Membership

Service	**Office**	**Name**
Navy	HQ NAVFAC	Joe Gott
Navy	HQ NAVFAC	Joe Simone
Navy	NAVFAC	Vincent Donnally
Navy	CNO N457C	Ms. Kathy Ellis
Navy	NAVAIR	Larry Wolf
Navy	HQ NAVFAC (Contractor Representative)	Kim DePaul Dawn Roderique
Army	USACE	Bob DiAngelo
Army	USACE	K.C. Kochhar
Army	ACSIM F&H	Bruce Park
Army	USACE/ACE	Billy Ray Scott
USAF	AFCESA	Fred Walker
USAF	HQ USAF ILEV	Jayant Shah
USMC	HQUSMC DCS/I&LFL	Michael Doherty
USMC	HQUSMC DCS/I&LFF	Kevin King

- Additional Members To Be Identified Prior to Next Meeting

APPENDIX (14)

Presentation: Summary of AFFF Environmental Breakout Session"

J. Hoover
Naval Air Warfare Center
China Lake CA

R. Darwin
Hughes Associates, Inc.
Baltimore MD

Summary
Of
AFFF Environmental Impact
Breakout Session

Naval Research Laboratory
3 August 2000

Dr. Jim Hoover
Head, Combustion Research Branch
NAWCWD China Lake

Robert Darwin
Senior Engineer
Hughes Associates, Inc.

Purpose of Breakout Session

Share Information on AFFF

History, performance, chemical composition

Environmental and human health impacts

Regulations – current and future

Replacement activity and status

Future management strategy

(1) What current and future environmental regulations impact AFFF and why (data and policies)?

Current:

Different regulations affect different components of AFFF

Presentation by Bill Ruppert yesterday provided good summary

Except for UNDS, there are no definitive restrictions at present and no identified directives for change

Future:

Depends on future EPA assessment of AFFF as data is reviewed

(2) What data do we have (or lack) on the environmental impact of AFFF?

Lacking:

Component toxicity/BOD/Persistence (Fate)/Bio-accumulation

Accurate and appropriate dilution factors when AFFF discharged in open bodies of water

Predictive capability/data regarding releases for estimating potential environmental damage. Must consider where the release occurs (shore hangars, runways, unpaved ground, ship bilges, at sea, etc)

(3) What technology or products exist that could help reduce AFFF releases into our environment or mitigate the impact of those releases?

Depends on the type and location of the release

Reducing releases:
    Reduction in system tests, efficiency improvements
    Spill response/advance planning/preparedness

Mitigation:
    ASH (Air-sparged hydrocyclone)
    RO (Reverse osmosis)
    Biological/microbial systems

Education and Planning:
    DOD guidance/standards on prevention, clean-up and disposal, training, intentional discharges

(4) What technology or products could be applied to recycle or reuse AFFF?

Not considered to be feasible or cost effective (reformulation, losses, contamination)

(5) What alternatives to AFFF currently exist and how do they compare in effectiveness, cost, environmental impact, availability, etc ?

None meet performance specification (mil spec)

Development of an AFFF alternative was proposed as project under ONR Future Naval Capability Platform Protection Program

Potential SERDP statement of need

Some UK effort on environmentally friendly foam

(6) What related planning documents exist with other services or agencies?

UK is reportedly working on a standard definition of “biodegradability”

EPA presentation mentioned international dialog on AFFF PFOS issue

USAF needs included in draft NAVAIR ESH-Needs Assessment

(7) What follow-on strategies should be considered ?

Need accurate quantitative definition of the problem
- DOD inventory status
  - How much AFFF in DOD/where used/in-service and reserve stocks/concentrate types
- DOD AFFF discharges
  - How much released/consumed annually (training, system testing and maintenance, accidental discharges, research, fires)
- Review current DOD regs and policy

Need a definition of "environmentally friendly" (need "green" definition—what are acceptable thresholds from an environmental standpoint)
- Biodegradability
- BOD/COD
- Toxicity
- Persistence
- Bio-accumulation

Follow-On Strategies (con't)

Need for future research
    SBIR
    Goals for Universities
    ONR

Need to develop small scale screening tests

Develop "SNAP-equivalent" guidance

Need for "worst case" transition plan (short/mid/long term)

Information distribution to all levels (users, requirers, trainers, regulators, etc)

Develop AFFF detection capability (learn method used by 3M)

Define hazard protocols and appropriateness of AFFF (use and response)

Follow-On strategies (con’t)

- Assess commercial state-of-the-art
  - CBD announcement
  - “Turkey shoot” of all available AFFF alternatives
  - Quantify performance, chemical and physical properties
  - Obtain EPA endorsement of screening tests

- Consider future mods to AFFF mil spec
  - Prioritze requirements
  - Consider trade-offs

- Establish formal AFFF working group
  - Info sharing
  - Formal charter
  - DOD primary advocate?
  - Future meetings/host/agenda topics

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Establish formal AFFF working group
  - Info sharing
  - Formal charter
  - DOD primary advocate?
  - Future meetings/host/agenda topics

MEMORANDUM FOR SEE DISTRIBUTION

SUBJECT: Aqueous Film Forming (AFFF) Workshop

We would like you to attend a one day workshop to discuss the impact of the U.S. Environmental Protection Agency' s (U.S.EPA) proposed rule which has the potential to ban future production and import of perfluorooctyl sulfonates (PFOS) chemicals to the Department of Defense. The Mil Spec for AFFF allows the use of PFOS, perfluorooctanoic acid (PFOA), and telomers as foaming agents. The U.S.EPA released data this past year that indicates PFOS chemicals are persistent, bioaccumulating and toxic. PFOS has been found in the blood of the general US population, in wildlife, and in people overseas. The 3M Company, the sole United States producer of ninety PFOS chemicals, has chosen to discontinue their manufacture and sale of all uses globally by December 31, 2002, and substantially reduce their manufacture for the most widespread uses of these chemicals by December 31, 2000.

The U.S. EPA is evaluating PFOA and telomer chemicals as a substitute for PFOS. PFOA and telomer are also persistence in the environment and more toxic than PFOS. Because of this, they also may be subject to manufacturers' withdrawal from the market place (similar to 3M's action for PFOS) or future EPA rule making. AFFF is used in a number of critical life saving situations in DoD. Currently, there are no known substitutes that are as effective as the materials in the Mil Spec. We've asked the Air Force Research Laboratory, Materials and Manufacturing Directorate to present recommendations and discuss potential substitutes. We plan to discuss "high-risk" uses of PFOS and what should be done to reduce or eliminate environmental releases of PFOS. We will also determine if DoD should switched to PFOA or telomer instead of PFOS. We need a multi-disciplinary team to conduct this review and develop an AFFF replacement strategy.

The workshop will be held on March 16, 2001, from 0800hrs - 1630hrs, in the OSD Conference Center, 1E801, Room 4, Pentagon. We also requested the Defense Logistic Agency to brief DoD's uses of PFOS. Attached is the meeting agenda. My POC for this Workshop is Lt Col Isaac Atkins, Director Occupational Health Policy, ODUSD (ES)/FP. He can be reached at (703) 604-1628, if you have any questions.

Curtis Bowling
Assistant Deputy Under Secretary of Defense
Force Protection

Attachment:
As stated

Aqueous Film Forming (AFFF) Workshop

Agenda

Introduction (Overview)	Mr. Curtis Bowling
AFFF Environmental Issues	Dr. Doug Dierdorf, AFRL
Toxicity of PFOS, PFOA, Telomer	TBD, USEPA
Impact of AFFF Voluntary Production Ban on Army	TBD, DASA(ESOH)
Impact of AFFF Voluntary Production Ban on Navy	TBD, (E&S)
Impact of AFFF Voluntary Production Ban On AF	TBD, DASAF(ESOH)
Overview of AFFF Uses and Impact to Fire-fighting Operations	TBD, National Fire Protection Association
Impact AFFF Voluntary Production Ban On FAA	TBD, Federal Aviation Administration
PFOS Uses	TBD, Defense Logistics Agency
The Way Ahead	Workshop Members

Distribution

DASAF(ESOH)
DASN(E&S)
DASA(ESOH)
Defense Logistics Agency
AFRL/MMD
USEPA
Federal Aviation Administration
National Fire Protection Association

From: Toncray Bradley A NNVA
To: Bennett David C NNVA; Chapman Keith D NNVA; Hancock Donald L NNVA; Lowe Donald J NNVA; Geithmann Gary R CONT NNVA; Carty Jeffrey L NNVA; Earehart James NNVA; Korzun Joel A NNVA; Kelly Art G NNVA; Yarashus Thomas R NNVA; Wood Leesa M NNVA
Sent: 3/9/2001 2:20:08 PM
Subject: FW: Ban on AFFF
Attachments: Jeff_F-1.TIF

-----Original Message-----
From: Parish Benjamin A NNVA
Sent: Friday, March 09, 2001 8:53 AM
To: Toncray Bradley A NNVA; Michael A Turner (CNAP N4342P) (E-mail)
Subject: FW: Ban on AFFF

Just thought you would like to know.
Ben

-----Original Message-----
From: Lewis Edward A NSSC [mailto:LewisEA@NAVSEA.NAVY.MIL]
Sent: Friday, March 09, 2001 8:41 AM
To: Corley Wesley S NSSC
Cc: Plunkett R Bryan CONT NSSC; Ngo Tien M NSSC; Parish Benjamin A NNVA; Speca Aaron M NNVA; Wujick Christine A NSSC; Montgomery Mike L CONT NSSC; 'Mike Turner'
Subject: FW: Ban on AFFF

Wes,

FYI. We will continue to monitor this situation and it's potential impact to the CVN 70 RCOH.

V/R,

Ed Lewis
PEO Aircraft Carriers
RCOH Ship Design Manager
(703) 607-1818 x 331 (Voice)
(703) 607-2495 (Fax)
(703) 505-6728 (Cell)
Lewisea@navsea.navy.mil

-----Original Message-----
From: Fink Jeff E NSSC
Sent: Friday, March 09, 2001 8:05 AM
To: Raber James D NSSC; Snyder CF (Charles) NSSC; Bergner Richard L NSSC; Wujick Christine A NSSC; McAllister Keith R NSSC; Lewis Edward A NSSC; Gimbel Weldon K NSSC; Orski Gary A NSSC; Ngo Tien M NSSC; Waldman Jack S NSSC; Plunkett R Bryan CONT NSSC; Bob Morris (E-mail); Jim Counts (E-mail); Sean Kiely (E-mail)
Subject: Ban on AFFF

Just wanted to keep everyone up to date on the AFFF issue. For those of you who do not know EPA has proposed a rule which has the potential to ban future production and import of chemicals that are integral to the production of AFFF.

Background AFFF was developed by the Navy Labs in the 1960s to provide better fire protection than the older protein foam. AFFF is used in machinery rooms, flight decks and hangar bays on most Navy ships. Mil-Std AFFF is used at most airports throughout the world and is considered by the insurance industry as the premier fire fighting agent.
Some of the chemical components of AFFF are categorized as Perfluorocytl Sulfonates (PFOS) which can potentially degrade into PFOSA (acid). PFOSA is highly persistent in the environment and has a strong tendency to bioaccumulate. (which means, like lead, the body absorbs this chemical, but does not get rid of it. Over time the body can accumulate this chemical to toxic levels) Studies indicate that exposure to PFOSA is widespread and recent tests have raised concerns about long term effects in people and wildlife.
There are four manufacturers on the QPL for AFFF. 3M won the current contract to supply AFFF to DOD. This contract expires in Dec '02. 3M, worried about the potential future problems, has decided to get out of the market as soon as the contract is over. They have already stopped their production of things like ScotchGuard that have the same PFOS.
James Rudroff of N452C wrote a point paper on this issue. (see attachment)

I have been told be NAVSEA 05L4 that there is a question as to whether the other manufacturers will stay in the market knowing that 3M got out and why they got out. There is an AFFF Workshop being held on March 16th at the Pentagon sponsored by the Assistant Deputy Under Secretary of Defense Force Protection in which NAVSEA 05L4, EPA, DLA will be in attendance. If production of AFFF is discontinued there will certainly be a major impact to Carriers as well as the rest of the Navy. The scope of effort to replace AFFF will be larger than the Freon elimination program. The effort could be on the magnitude of Asbestos elimination. However it is to early to panic and to discuss corrective action. We need to let the tech community and industry experts have a chance to assess the total picture and develop a POA. The Aux and Crew Team here at PEO Carrier will be closely monitoring the situation.

Jeff_F-1.TIF
Jeff Fink
PEO - E
DSEM Aux & Crew
(703) 607-1701 x343

From: Bowling, Curtis, Mr, OSD-ATL
To: <Atkins>;<Isaac>;<LtCol>;<OSD-ATL>
Sent: 3/31/2001 6:24:00 PM
Subject: FW: Fluorotelomer Chemicals and Related Fluoroorganics

We need to talk about the occupational exposure of telomers.

>-----Original Message-----
>From: Dierdorf Doug S Contr AFRL/MLQD
>[mailto:Doug.Dierdorf@tyndall.af.mil]
>Sent: Friday, March 30, 2001 2:08 PM
>To: Curtis Bowling (E-mail)
>Cc: Carr Virgil J Contr AFRL/MLQD; Vickers Dick N Civ
>AFRL/MLQD; Galindo
>Bob Contr AFRL/MLQD
>Subject: FW: Fluorotelomer Chemicals and Related Fluoroorganics
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>From: Stephen H Korzeniowski
>[mailto:Stephen.H.Korzeniowski@USA.dupont.com]
>Sent: Friday, March 30, 2001 12:11 PM
>To: doug.dierdorf@tyndall.af.mil
>Subject: Fluorotelomer Chemicals and Related Fluoroorganics
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>Doug, I obtained your name from Mary Dominiak of the US EPA.
>We met and
>spoke again on Tuesday at the public hearing held by the US
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>this week in Arlington, VA.
>I have a dual role in DuPont. One is as a business manager for a
>fluorosurfactants and additives business. And the other is an external
>company role in working with the global regulatory agencies and Telomer
>consortium (see below).
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>You were copied on an E-mail note to Mary written by Lt. Col.
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>further study our products. I can also describe this in
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>Please let me know how you would like to proceed.
>I can be reached by E-mail by just responding to this note or using
>stephen.h.korzeniowski@usa.dupont.com. This is usually the
>easiest way to
>reach me due to my travel schedule. I can also be reached by phone on
>302-992-3672 and fax - 302-892-1135.
>
>I look forward to discussing these matters with you.
>
>Thank you in advance for your consideration.
>
>Steve
>

From: Phull, Kotu K COL ASA-I&E
To: <Atkins>;<Isaac>;<LtCol>;<OSD/ATL>
Sent: 3/28/2001 10:48:00 AM
Subject: FW: AFFF

Ike: Per conversation this morning.

Please call me if you have any questions.

Regards,

KOTU K (KK) PHULL
COL, MS
Office of the Deputy Assistant Secretary of the Army
for Environment, Safety, and Occupational Health
110 Army Pentagon, Room 2E577
Washington, DC 20310-0110
(703) 697-0440, DSN 227
FAX - (703) 693-8149

-----Original Message-----
From: Bowling, Curtis, Mr, OSD-ATL [mailto:Curtis.Bowling@osd.mil]
Sent: Wednesday, March 28, 2001 6:28 AM
To: Phull, Kotu K COL ASA-I&E
Subject: RE: AFFF

Thanks

>-----Original Message-----
>From: Phull, Kotu K COL ASA-I&E
>Sent: Tuesday, March 27, 2001 4:17 PM
>To: Bowling, Curtis, Mr, OSD/ATL
>Cc: Fatz, Raymond J Mr ASA-I&E
>Subject: AFFF
>
>
>Curtis:
>
>As requested at the 16 March AFFF Workshop, we feel that the
>DOD/users would
>need to answer the following questions to minimize the impact
>of a future
>AFFF ban by the EPA. I have also included a list of the potential Army
>organizations that should be considered for membership on the DOD AFFF
>Steering Group. Our response is based on limited
>coordination, due to the
>short time available. We will ensure a wider Army-wide
>coordination upon
>receiving further instructions/tasking from your Office.
>Please call me, if
>you have any questions. AFFF = All PFOS's, PFOAs, and telomers.
>
>A. QUESTIONS:
>
>
>1. Quantity of these substances used in the Army
>
>2. Quantity of AFFF that the Army can afford to store as the
>Reserves for
>continued, critical uses past the phase out
>
>3. Operations where these substances are used. Although the
>discussion at

>the Workshop focused primarily on the use of AFFF in
>firefighting, we would
>need to determine other operations/products related to the use of AFFF,
>e.g., aviation hydraulic fluids, semiconductors, etc.
>
> - Need to identify all MILSPECs/STDs, NSNs, and/or commercial
>/industry specs that define these materials.
>
>4. Critical uses. We would need to define "critical uses" to ensure
>consistency in responses received from the field.
>
>5. Areas where uses can be eliminated, e.g., training
>
>6. Quantity of AFFF that the Army can afford to store
>(COST)/must store
>(CRITICAL USES) as reserves for continued use past the phase-out
>
>7. Impact of the use of non-Aqueous Film Forming Foams -
>Operational, e.g.,
>process modifications for fire-fighting; Cost
>
>8. Environmental Impact of potential releases of AFFF into
>the environment
>
>9. Current and projected research, in-house and in partnership with
>Industry - ASA(ALT)
>Development of AFFF substitutes with AFFF-like performance;
>Technology enhancements to improve the performance of non-AFFF products
>
>10. Procurement strategies, i.e., availability and production
>capabilities
>for alternatives; how to budget and POM for increased
>reserves, if the DOD
>decides to continue the use of AFFF past the EPA ban, for
>increased costs
>associated with use of AFFF substitutes, e.g., system
>retrofitting, need for
>additional equipment, etc.; cost of disposal of excess stored
>materials that
>may have to be disposed of as "hazardous material"
>
>11. Need for occupational assessments and medical monitoring
>based on the
>review of available data
>- Exposure monitoring
>- Medical monitoring
>- Population to be monitored
>- Cost
>
>12. Environmental, Safety, and health considerations for AFFF
>substitutes
>
>B. DOD STEERING GROUP MEMBERSHIP. Some of the following
>offices/organizations should be considered for membership:
>ACSIM (Assistant
>Chief of Staff for Installation Management, ODCSLOG (Deputy
>Chief of Staff
>for Logistics, APPSO (Army Acquisition Pollution Prevention
>Support Office
>(to represent AMC (Army Materiel Command and ASA/ALT
>(Assistant Secretary of
>the Army for Acquisition, Logistics, and Technology), OTSG
>(Office of the
>Surgeon General), and this Office. ODCSLOG would appear to be
>ideal Army
>Lead.
>
>Regards,

>
>KOTU K (KK) PHULL
>COL, MS
>Office of the Deputy Assistant Secretary of the Army
> for Environment, Safety, and Occupational Health
>110 Army Pentagon, Room 2E577
>Washington, DC 20310-0110
>(703) 697-0440, DSN 227
>FAX - (703) 693-8149
>
>

MEMORANDUM FOR SEE DISTRIBUTION

SUBJECT: Request Information on Usage of Perfluorooctly Sulfonates Containing Materials

We would like you to provide information on the impact of the U.S. Environmental Protection Agency's (U.S.EPA) proposed rule that calls for the phase-out of 90 perfluorooctly sulfonate (PFOS) chemicals (See attachment). The Mil Spec for Aqueous Film Forming (AFFF) allows the use of PFOS, perfluorooctanoic acid (PFOA), and telomers to produce fluorochemical surfactants which are key to helping other AFFF's agents meet low fire-fighting surface tension requirements. AFFF is used in a number of critical life saving situations in DoD and currently, there are no known substitutes that are as effective as the materials in the Mil Spec. The U.S. EPA released data this past year that indicates PFOS chemicals are persistent, bioaccumulating and toxic. PFOS has been found in the blood of the general US population, in wildlife, and in people overseas.

The U.S.EPA will prevent manufacture or import of PFOS after the phase-out period, including PFOS-based AFFF, unless a 90-day notice is filed and approved. They are also evaluating PFOA and telomer chemicals. PFOA and telomer are also persistence in the environment and may pose significant health risks. Because of this, PFOA and telomer may also be subject to manufacturers' withdrawal from the market place (similar to 3M's action for PFOS) or future EPA rule making.

Request you perform an assessment of the impact of EPA's phase-out of PFOS to your organization and provide a copy to my office **by 08 Jul 01**. This assessment should include the quantity (in lbs.) and type of materials that contain PFOS. Include the amount of AFFF or PFOS-containing material in stock, number of systems and the amount (in lbs.) used per year. Also list the operations where AFFF or PFOS-containing materials are used and identify all mission critical uses, amounts, usage rate, stockpile, and potential substitutes, if any. Mission critical uses are uses where there are no available substitutes and phase-out of PFOS will negatively impact operational effectiveness and operational suitability of combat missions or contribute significantly to the degradation of combat capability.

In addition, please explain the mission impacts if a fire suppression system is not replaced, cost of replacement options and estimate quantities needed for stockpiling for mission critical uses. Identify any operations that release PFOS-containing materials to the environment and take appropriate steps to prevent or stop these releases. We will use this information to develop a DoD AFFF and PFOS-containing material replacement strategy. My POC is Mr. Gary Hamilton.

He can be reached at (703) 604-1820, email: gary.hamilton@osd.mil. If you have any questions, please contact him

Curtis M. Bowling
Assistant Deputy Under Secretary of Defense
(Force Protection)

Attachment:
As stated

DISTRIBUTION

DASA (ESOH)
DASN (E&S)
DASAF (ESOH)
DEFENSE LOGISTICS AGENCY
DEFENSE AGENCIES' DESIGNATED AGENCY
SAFETY AND HEALTH OFFICIAL

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To: <Atkins>;<Isaac>;<LtCol>;<OSD-ATL>
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>Thank you in advance for your consideration.
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>Steve
>

Mr. Stephen H. Korzeniowski
Business Manager
Fluorosurfactants and Additives
E. I. Dupont de Nemours & Co., Inc

Dear Mr. Korzeniowski:

Thank you for your letter to Dr. Dierdorf expressing your interest in our Aqueous Film Forming (AFFF) Workshop of March 16, 2001. The purpose of the workshop was to provide a forum for discussion of the Environmental Protection Agency's (EPA) proposed rule that calls for the voluntary phase-out of perfluorooctly sulfonate (PFOS) chemicals to the Department of Defense by 2003. DoD is concerned about the availability of PFOS for use in AFFF and the pending phase-out rule's impact on military fire-fighting capabilities. Dr. Dierdorf asked me to respond to you because I am the author of the letter mentioned in your correspondence.

The application of AFFF in firefighting is inherently dispersive and results in the distribution of AFFF's chemical components on the surface and in the groundwater. Concern about this distribution prompted Military Service Departments to investigate the biodegradation, possible remediation, toxicity, fate and transport of many of AFFF's components. These studies date back to 1983 or earlier and are on going. Based on these studies and published literature, the "Lowest Observed Adverse Effect Level" (LOAEL) for perfluorinated carboxylic acids is 0.1 mg/kg/day for mice.[1] The LOAEL for perfluorooctanyl sulfonates is 0.4 mg/kg/day.[2] My assertion that PFOA is more toxic than PFOS is based on these data. The association of this result with telomer is based on the below unpublished Air Force tests.

Several weeks after a large-scale fire-fighting operation using AFFF in Jacksonville Bay, Florida, allegations of surfactant related bird kill caused the Air Force to screen AFFF's components to determine if they were non-persistent. The perfluorinated carboxylic and sulfonic acid surfactants were known to be persistent, leaving telomer surfactants as the only potentially non-persistent, commercially available, fluorosurfactant candidates. During 1998, the Air Force Research Laboratory, Fire Technology Group at Tyndall Air Force Base, Florida conducted the screening by monitoring the changes in "Soluble Chemical Oxygen Demand" (COD) and surface tension during biodegradation. Standard procedures for measuring "Biological Oxygen Demand" over a period of 28 days were used. Purely by coincidence, the telomer-tested surfactant samples were identified as "Zonyl" branded surfactants, which were supplied by your company.

Results indicated that the telomer fluorosurfactant did biodegrade as shown by decreased soluble COD, however, the surface tension remained essentially unchanged. Control samples of hydrocarbon

---

[1] **Developmental toxicity of perfluorodecanoic acid in C57BL/6N mice.** Harris MW, Birnbaum LS, Fundam Appl Toxicol, 1989, 442-8 (1989).

[2] **3M Submissions in EPA Docket AR-226.**

surfactants showed decreased soluble COD indicating biodegradation and as expected an increase in surface tension to that of water. The research staff involved in this work found the results consistent with the degradation of telomer surfactants to perfluorocarboxylic acids. In the case of Zonyl TBS, the only biodegradable segment is the 1,1,2,2 tetrahydro segment, which can only result in formation of perfluorononanoic acid. They considered this information insignificant at the time with the required documentation being extensive research notes.

I'm sure industry efforts in this area are being revived in light of the EPA's pending regulatory action. Dr. Dierdorf has been collaborating with manufacturers of fluorosurfactants to ensure non-persistent surfactants are developed and commercially available. These chemicals provide the properties essential to effective AFFF fire fighting. If you want a copy of the Air Force's unpublished experimental data, please contact Mr. Dick Vickers at (850) 283-3707, Dick.Vickers@tyndall.af.mil.

Curtis M. Bowling
Assistant Deputy Under Secretary of Defense
(Force Protection

AN ABSTRACT OF THE THESIS OF

Cheryl Moody Bartel for the degree of Doctor of Philosophy in Chemistry presented on November 23, 1999. Title: Occurrence and Distribution of Perfluorinated Surfactants in Groundwater Contaminated by Fire-Fighting Activity

Redacted for privacy

Abstract approved:

Jennifer A. Field

Aqueous film forming foams (AFFFs) are used to extinguish hydrocarbon-fuel fires and repetitive use, particularly at military sites, has led to AFFF-laden wastewater and subsequent groundwater contamination. Perfluorinated surfactants are an important class of specialty chemicals that are used in AFFF agents and have physio-chemical properties that differentiate them from hydrocarbon surfactants. In the past, the environmental behavior of perfluorinated surfactants has received little attention, and how the unique properties affect the behavior of perfluorinated surfactants in the environment and their potential impact on co-contaminant transport and biodegradation are unknown. An analytical method was developed to determine perfluorocarboxylates in groundwater. Solid-phase extraction and in-vial derivatization techniques were used to form the methyl esters of perfluorocarboxylates that were then analyzed by gas chromatography/mass spectrometry. Perfluorocarboxylates containing 6 to 8 carbons were detected in groundwater samples collected from Naval Air Station Fallon, NV, Tyndall Air Force Base, FL, and Wurtsmith Air Force Base, MI, with total concentrations

ranging from 3 to 7,090 μg/L. The homologous series of perfluorocarboxylates observed in groundwater from the three military sites as well as in commercial AFFF mixtures consisted of even and odd number perfluorinated carboxylates, which is indicative of the electrochemical fluorination synthesis process. At Wurtsmith Air Force Base, MI, perfluorocarboxylates detected 500 m from the source area were estimated to have a minimum residence time of 5 to 15 years. Additionally, the perfluorocarboxylate concentrations observed in groundwater are significantly lower than the corresponding methylene blue active substances concentrations, which indicates that there are additional anionic surfactant species present in the groundwater. Perfluorinated carboxylates measured at Naval Air Station Fallon, NV, Tyndall Air Force Base, FL, and Wurtsmith Air Force Base, MI, which have not been used since 1988, 1992, and 1986, respectively, provide direct field evidence that this class of perfluorinated surfactants persist under prevailing groundwater conditions and potentially could be used as unique tracers of groundwater impacted by repetitive fire-training exercises.

Occurrence and Distribution of Perfluorinated Surfactants in Groundwater Contaminated by Fire-Fighting Activity

by

Cheryl Moody Bartel

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PREFACE

Chapter 1 provides an introduction to aqueous film forming foams (AFFFs), which are used to extinguish hydrocarbon-fuel fires. Their repetitive use, particularly at military sites, has led to AFFF-laden wastewater and subsequent groundwater contamination. Perfluorinated surfactants are an important class of specialty chemicals that are used in AFFF agents and in the past, the environmental behavior of perfluorinated surfactants has received little attention.

The second chapter of this study describes the isolation, identification and quantification of perfluorinated carboxylates in groundwater impacted by fire-training activities at Naval Air Station Fallon, NV and Tyndall Air Force Base, FL. Strong anion exchange disks were used to extract perfluorocarboxylates from groundwater collected from fire-training sites located at the two military facilities. The developed method is the primary tool that was then used to quantitatively determine perfluorocarboxylates in groundwater samples collected for a more extensive groundwater study described in Chapter 3.

The work presented in Chapter 3 aids in the understanding of the environmental behavior of one class of perfluorinated surfactants, perfluorocarboxylates, since virtually no information exists on their occurrence, transport, and biodegradability in the environment. Commercial AFFF mixtures containing perfluorinated surfactants were applied at Wurtsmith Air Force Base, Oscoda, MI, including the Fire-Training Area 2 and a site where an airplane crashed. Comparison of the perfluorocarboxylate concentrations to other bulk chemical indicators such as specific conductance, total organic carbon, and methylene blue active substances, add context to the environmental occurrence and distribution of perfluorocarboxylate surfactants.

Occurrence and Distribution of Perfluorinated Surfactants in Groundwater Contaminated by Fire-Fighting Activity

Chapter 1

Introduction: Perfluorinated Surfactants and the Environmental Implications of their Use in Fire-Fighting Foams

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Abstract

The recent identification of one class of fluorinated surfactants in groundwater impacted by fire-fighting activity has created an awareness of the potential environmental issues resulting from the use of aqueous film forming foam (AFFF) agents. Aqueous film forming foams are used to extinguish hydrocarbon-fuel fires and their repeated usage particularly at military sites has led to AFFF-contaminated groundwater. Formulations of AFFF agents include fluorinated surfactants, which are an important class of specialty chemicals that have physio-chemical properties that differentiate them from hydrocarbon surfactants. Little is known about the occurrence, transport, biodegradation and toxicity of fluorinated surfactants in the environment. The fact that fluorinated surfactants as well as other AFFF components co-occur with priority pollutants (e.g., jet fuel components and chlorinated solvents) complicates studies on their fate and effect in the environment. Research is needed to sufficiently characterize the structures and environmental properties of fluorinated surfactants. Additionally, the environmental behavior of the AFFF mixtures and complex AFFF-wastewaters needs to be investigated.

Introduction

Fluorinated surfactants constitute an important class of fluorinated compounds that are utilized in fire-fighting applications, herbicide and insecticide formulations, cosmetics, greases and lubricants, paints, polishes, and adhesives *(1-4)*. For example, perfluorooctane sulfonate is an important surfactant itself as well as a precursor to other fluorinated surfactants and pesticides *(5)*. The Organization for Economic Cooperation and Development (OECD) lists perfluorinated C5-C18 compounds, which includes most perfluorinated surfactants, as high-production-volume (HPV) chemicals. High-production volume chemicals are those chemicals manufactured or imported in the U.S. in volumes exceeding 1 million pounds *(6)*.

Fluorinated surfactants are distinctly different from hydrocarbon surfactants. Although the polar head groups may be similar between hydrocarbon and fluorocarbon surfactants, the non-polar perfluorocarbon tail is both *hydrophobic* and *oleophobic* (oil-repelling), which is in contrast to the tail group of hydrocarbon surfactants, which are only considered hydrophobic in nature. For this reason, fluorinated surfactants exhibit both hydrophobic and oleophobic characteristics, which accounts for their unique physio-chemical properties as will later be addressed *(1)*. Fluorinated surfactants may be classified as either perfluorinated, in which all hydrogen atoms are substituted by fluorine atoms, or as partially-fluorinated where some carbons contain hydrogen atoms. Like other surfactant classes, fluorinated surfactants generally are classified into one of four categories: nonionic, anionic, cationic, and amphoteric, with anionic fluorinated surfactants being the most important class *(1)*.

Fluorinated surfactants comprise a unique class of specialty chemicals whose environmental behavior has received little attention. Consequently little information is available to permit a complete life-cycle analysis. The focus of this review is to 1) characterize the unique properties of fluorinated surfactants, 2) describe how the unique properties are utilized for the purpose of fighting fires, and 3) evaluate how the unique properties might affect the behavior of perfluorinated surfactants in the environment and their potential impact on co-contaminant transport and biodegradation. Finally, the need for new analytical methods to measure perfluorinated surfactants is highlighted as a requirement for addressing questions about the occurrence, behavior, and impact of this specialty chemical class in the environment.

Perfluorinated Surfactant Synthesis and Properties

Two principal processes used in the manufacturing of fluorinated surfactants are electrochemical fluorination and telomerization *(1)*. With electrochemical fluorination, the substance to be fluorinated is dissolved in hydrofluoric acid and an electric current is passed through the media *(1, 7)*. All hydrogen molecules are replaced by fluorine and perfluorinated molecules result. Despite low to moderate yields of perfluorinated compounds and many side products, electrochemical fluorination is economically attractive because of the relatively low cost of electricity as well as that of the hydrogen fluoride reagent *(7)*. With the electrochemical fluorination process, perfluorinated compounds with homologous series of even and odd number perfluorocarbons are generated *(1, 8)*. In contrast, the telomerization process reacts a molecule called a telogen, with two or more unsaturated molecules called taxogens, which creates a telomer that contains only an even number of carbon atoms *(1)*. Because odd and even number perfluorocarbons result from electrochemical fluorination, the occurrence of odd *and* even carbon perfluorinated surfactants in the environment can potentially be traced to manufacturers that use the electrochemical fluorination process *(9)*.

When fluorine is a substituent in organic compounds, unique chemical properties are observed due to the electronegativity of fluorine as well as the overlap between the 2s and 2p orbitals of fluorine and the corresponding orbitals of carbon *(1, 7)*. The presence of fluorine atoms contributes to the rigidity of perfluorocarbon chains *(2,3)* relative to hydrocarbon chains. The highly polarized carbon fluorine bond is the strongest of known covalent bonds *(1)* with the average C-F bond approximately 25 kcal/mole stronger than the corresponding C-Cl bond in monochloroalkanes *(7)*. Additionally, fluorination usually strengthens the adjacent C-C bonds *(7)*.

The properties of hydrocarbons and, therefore, surfactants, are altered significantly when fluorine atoms are substituted for hydrogen atoms *(1)*. Perfluorinated surfactants are more thermally-stable than their corresponding hydrocarbon analogues. In particular, perfluorocarboxylic acids and perfluoroalkanesulfonic acids are considered the most thermally-stable fluorinated surfactants *(1)*. In addition to thermal stability, perfluorinated surfactants are stable to acids, bases, oxidants and reductants *(1)*. This stability allows fluorinated surfactants to remain intact in environments where hydrocarbon surfactants are degraded.

Perfluorinated anionic surfactants have high-acid strength relative to their hydrocarbon analogs due to the electron-withdrawing effects of fluorine substitution. For example, the replacement of hydrogen atoms by fluorine atoms on octanoic acid to form perfluorooctanoic acid decreases the pKa from 4.89 to 2.80 (Table 1.1) *(1, 7)*. Perfluorinated surfactants are much more surface active than hydrocarbon surfactants *(1, 10)*. The substitution of fluorine atoms for hydrogen atoms decreases their surface activity for aqueous solutions, which promotes micellization at lower concentrations (i.e., the critical micelle concentration (CMC)) and lowers the surface tension relative to that of other hydrocarbon analogs *(1)*. For example, the surface tension of perfluorooctanoic acid has been reported as 15.2 dynes/cm *(1)*. The CMC values for C7 and C8 fluorinated surfactants (i.e., perfluorocarboxylates and perfluoroalkane sulfonates) are approximately equal to those of C11 and C12 hydrocarbon surfactants *(1)*.

The cost of fluorinated surfactants is higher relative to that of hydrocarbon surfactants. Because of the high prices of fluorinated surfactants, fluorosurfactant applications are limited to problems that conventional, lower-priced surfactants can not address *(4, 11)*. Within a specific application, fluorinated surfactants are typically cost effective because their relatively high price is offset by the low concentrations needed to achieve the reduction in interfacial tension or to form micellar solutions *(1)*. In some applications such as AFFF, a mixture of a fluorinated surfactant and a hydrocarbon-based surfactant are more cost effective and/or perform better than either surfactant separately *(1)*.

Perfluorinated Surfactants in Aqueous Film Forming Foams

Hydrocarbon-fuel fires pose a serious threat to life and property, and require immediate response. To enable a quick response to hydrocarbon-fuel fires, effective and

Table 1.1. Properties of perfluorooctanoic acid.

Property	Perfluorooctanoic acid
pKa[1]	2.80
Critical micelle concentration[2]	8.7-9.0
Interfacial tension[3]	15.2

[1] *(1)*.

[2] Units for critical micelle concentrations are mMoles/L *(1)*.

[3] Units for surface tension are dynes/cm *(10)*.

efficient fire-extinguishing agents are needed to prevent damage and re-ignition of the fires. Aqueous film forming foams (AFFFs) were developed in the 1960s as important tools for extinguishing fires involving flammable liquid fuels (i.e., gasoline, kerosene) *(12)*.

Due to the presence of large quantities of flammable liquids, municipal (i.e., fire departments), hydrocarbon-processing industry (i.e., oil refineries), and military sectors utilize AFFFs (Figure 1.1), with the military comprising 75% of the total market, while the municipal and hydrocarbon-processing industry represents 13% and 5%, respectively *(13)*. In 1985, the United States market for AFFF products (i.e., 3% and 6% concentrates) was 6.8 million L with a total revenue of 10 million dollars in U. S. sales *(13)*. The military was the single largest consumer of AFFF agents in 1985, with consumption totaling 5.1 million L *(13)*. For historical reasons, the U. S. Department of Defense Military Specifications Regulations have driven the requirements for AFFF performance by establishing performance criteria.

Commercial AFFF formulations are complex proprietary mixtures whose major components include a solvent, which is typically butyl carbitol; fluorocarbon (perfluorinated anionic and partially-fluorinated amphoteric) surfactants; and hydrocarbon-based surfactants (Table 1.2). Fluorinated surfactants in AFFF mixtures contribute to the performance of foams as the primary fire extinguishing chemical and as vapor sealants that prevent re-ignition of fuel and solvents *(1, 14, 15)*. To evaluate the spreading of AFFFs and the spontaneous formation of films, a spreading coefficient can be calculated. The spreading coefficient (SC) *(16)* evaluates the reduction in surface and

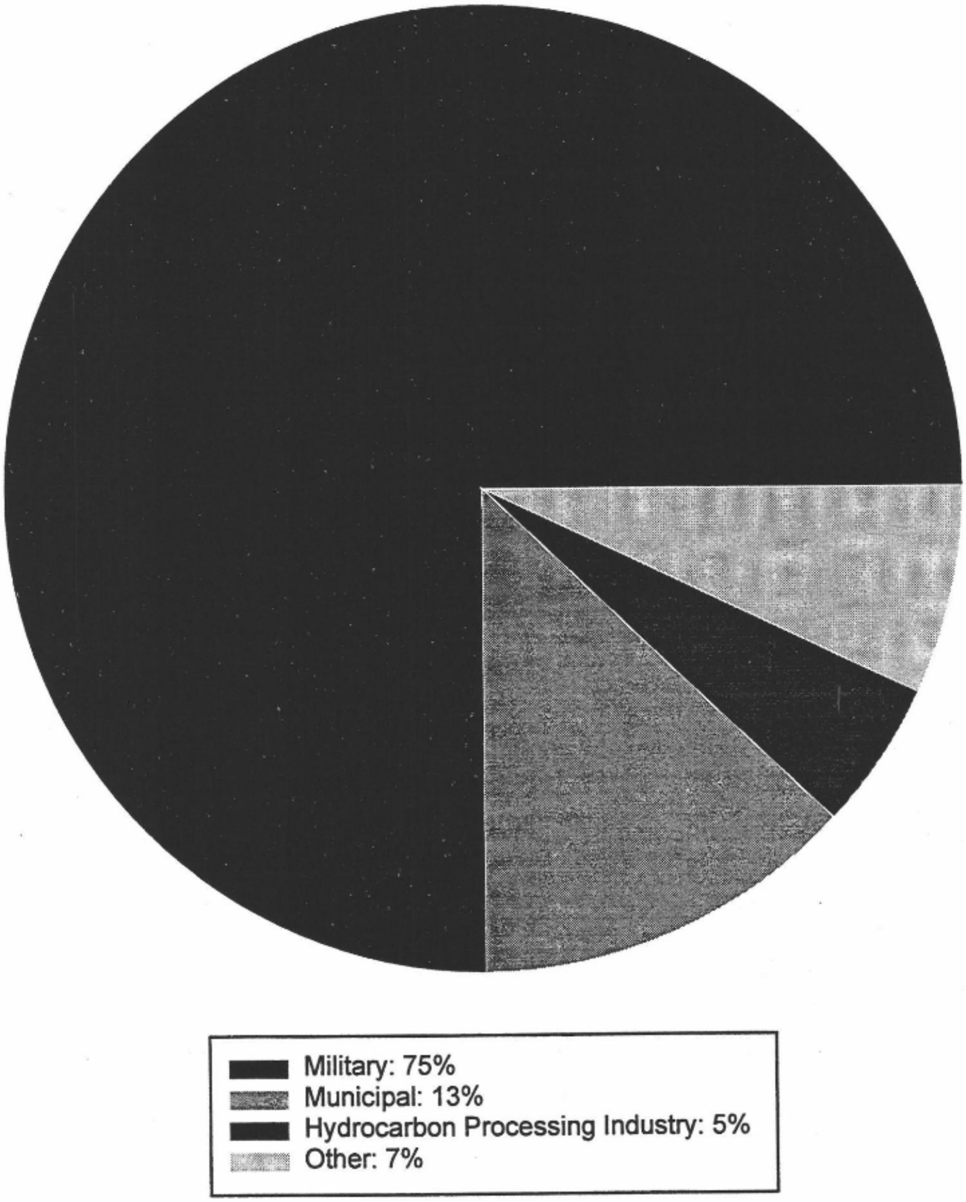

Figure 1.1. Percentage breakdown of United States consumers of AFFF products, where the hydrocarbon processing industry and municipal represent entities such as oil refineries and fire departments, respectively *(13)*.

interfacial tension and is defined as the difference between the surface tension of a model hydrocarbon phase ($\gamma_{cyclohexane}$) (such as cyclohexane at 25 dynes/cm), the surface tension of the aqueous solution ($\gamma_{aqeuous}$), and the interfacial tension between the aqueous solution and hydrocarbon phase($\gamma_{interfacial}$) *(17)*.

$$SC_{(aqueous/cyclohexane)} = \gamma_{cyclohexane} - \gamma_{aqeuous} - \gamma_{interfacial} \qquad (1)$$

For military specifications the spreading coefficient of the mixture calculated from Equation (1) must be positive *(18)*. For example, the fluorinated surfactant components in AFFFs lower the surface tension of the aqueous solution to 15-20 dynes/cm while hydrocarbon surfactants lower the interfacial tension between the aqueous solution and the hydrocarbon phase (i.e., burning fuel) to 0-2 dynes/cm *(19)*. Thus, the films formed by fluorocarbon and hydrocarbon solutions consist of two-mixed monolayers of surfactants where the air-aqueous phase monolayer is dominated by the fluorocarbon surfactant and the aqueous-hydrocarbon phase monolayer is dominated by the hydrocarbon surfactant (Figure 1.2) *(19)*.

AFFF Wastewater and its Impact on Wastewater Treatment Facilities

At installations, such as military bases, fire-training exercises are part of emergency preparedness plans and therefore are conducted with some frequency. A fire-training exercise typically consists of flooding a fire pit with flammable liquids (e.g., off-

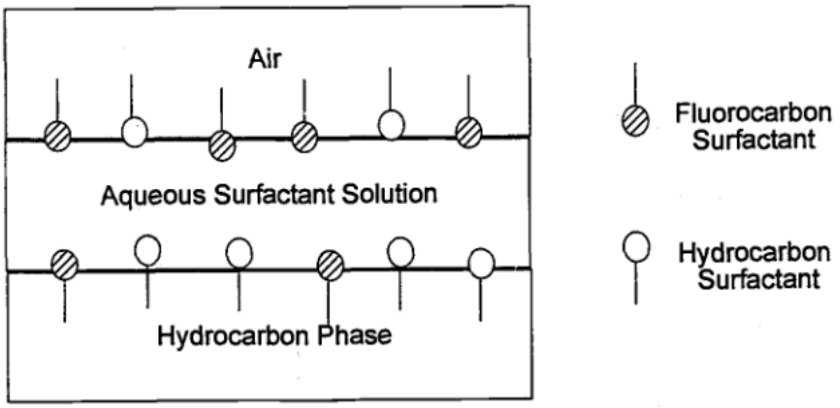

Figure 1.2. Mixed monolayers at the air-aqueous and aqueous-hydrocarbon phase interfaces. Adapted from Reference *(19)*.

specification jet fuel and waste solvents such as chlorinated solvents *(20-22)*), igniting the fluids, and subsequently extinguishing the fire with fire-fighting agents *(21)*. For example, training exercises occurred on a weekly to monthly basis *(9)* at Naval Air Station (NAS) Fallon, NV, and consisted of igniting fuel (average 3000 L/week) *(21)* and extinguishing the fire with 1200-3200 L (3%-6%) of aqueous AFFF solutions. Typically, at this site and others, disposal options for AFFF wastewater included discharge into a wastewater treatment facility and/or directly onto the ground adjacent to the training facilities.

If too much fire-fighting foam is discharged to a wastewater treatment facility at one time, excess foaming may occur, which results in aesthetic and operational problems in sewers and wastewater treatment facilities. Another concern for wastewater treatment facilities is that in-coming AFFF wastewaters have high biological (BOD) and chemical oxygen demands (COD) *(23)*. For example, for 3M Light Water™ AFFF product FC-203 as a 3% solution, the BOD_5 (5 day biological oxygen demand), BOD_{20} (20 day biological oxygen demand) and COD are 1.7×10^4 mg/L, 3.2×10^4 mg/L, and 3.2×10^4 mg/L, respectively, and can lead to significantly higher values than those normally found at treatment plants (100-400 mg/L BOD_5 *(23)*) *(23, 24)*. One of the principle contributors to the high BOD and COD of AFFF is the organic solvent component, butyl carbitol (Table 1.2).

In addition to the foaming BOD and COD problems associated with AFFF, residual fuel is part of AFFF wastewater *(12, 25)*. Residual fuel in combination with AFFF components and potential combustion products complicates the characterization of AFFF wastewater and thus its disposal in an economically-and environmentally-

Table 1.2. Chemical Composition of 3M FC-203CF Light Water™ Aqueous Film Forming Foam Concentrate (St. Paul, MN) *(73)*.

Chemical Name	Percent of Total Composition
Water	69.0-71.0
Diethylene glycol butyl ether (butyl carbitol)	20.0
Amphoteric fluoroalkylamide derivative	1-5
Alkylsulfate salts	1.0-5.0
Perfluoroalkyl sulfonate salts	0.5-1.5
Triethanolamine	0.5-1.5
Tolyltriazole (corrosion inhibitor)	0.05

acceptable manner *(26)*. Solutions containing free and emulsified oil, fuel, and AFFF components were shown to adversely affect activated sludge processes *(12, 25)* and the performance of anaerobic sludge digestors *(27)* in wastewater treatment facilities. Because of the potential problems at wastewater treatment facilities, characterization of AFFF wastewater is required in some instances prior to gaining approval to discharge the waste to a wastewater treatment facility. Characterization methods generally are lacking, and thus some fire-training facilities have had to impound AFFF wastewater over extended periods of time.

Aqueous film forming foam wastewater and its treatment have been the focus of investigative studies by the U. S. Department of Defense *(26)*. Several pre-treatments such as precipitation, coagulation, adsorption on activated carbon and ultrafiltration *(12, 26)* are being evaluated for the treatment of AFFF wastewater before dispensing it to a wastewater treatment facility *(23, 25, 28-30)*; however, few pre-treatment strategies are being implemented. Currently, treatment efficiency is judged using only general, non-specific parameters such as methylene blue active substances (MBAS) and total organic carbon. Unfortunately, analytical methods are not yet widely available that permit the specific assessment of the effectiveness of treatment technology efficiency on fluorinated surfactant removal.

Perfluorinated Surfactants in Groundwater

Plumes of contaminated groundwater are associated with past fire-training sites at several military bases in the United States *(20-22, 31-33)* including NAS Fallon, NV, Tyndall Air Force Base, FL, and Wurtsmith Air Force Base, MI, where AFFF wastewater has entered groundwater without prior treatment. Most of these plumes have been characterized with respect to fuel and solvent components unlike the surfactant components, which have received little attention primarily due to the lack of appropriate analytical techniques.

A few early reports tentatively identified the presence of fluorinated surfactants in groundwater impacted by fire-fighting activities at Tyndall Air Force Base, FL *(31, 34)*. A recent report described the development of an analytical method that permitted the definitive identification of perfluorocarboxylates surfactants in groundwater at NAS Fallon, NV, and Tyndall Air Force Base, FL, at concentrations ranging from 125 to 7090 μg/L *(9)*. A current study at Wurtsmith Air Force Base, MI, has revealed a plume of perfluorocarboxylates 500 m in length with concentrations ranging from 3 to 110 μg/L *(35, 36)*.

At each field site both even- and odd-numbered carbon perfluorocarboxylates were identified, which is indicative of product formulations manufactured by the electrochemical fluorination process *(9)*. This finding is consistent with the fact that the 3M Co., a company that uses electrochemical fluorination to manufacture perfluorinated surfactants, has held the military contract to supply AFFF for the last 25 years.

Laboratory and field data regarding the transport of fluorinated surfactants in groundwater are virtually nonexistent. In an attempt to address this data gap, we performed a single-well push-pull test *(37)* using perfluorooctane sulfonate in order to obtain *in-situ* transport information. The push-pull test consisted of the injection of a prepared test solution into the saturated zone of an aquifer using an existing monitoring well, followed by the extraction of the test solution/groundwater mixture from the same location. For this experiment, 50 L of injectate containing 97 mg/L bromide (non-reactive tracer) and 26 mg/L potassium perfluorooctane sulfonate, which is one of the major perfluorinated surfactants present in some AFFF mixtures, was injected into a well over a period of 4 hr. Immediately after injection, a total of 98 L was extracted from the well over a 9-hr period. Samples were taken during the extraction phase and analyzed for bromide and perfluorooctane sulfonate by ion chromatography and MBAS, respectively. It should be noted that the MBAS test is non-specific and does not allow for the detection and quantitation of individual anionic surfactant classes. However, for this field study where only a single perfluorinated surfactant was present in the injectate solution and none was present in the background groundwater, the limitations of MBAS did not hinder its application as the analytical method for perfluorooctane sulfonate.

Breakthrough curves were constructed for bromide and perfluorooctane sulfonate (Figure 1.3) by plotting the relative concentration C/C_o for each solute, where C is the measured concentration and C_o is the injected concentration, versus the cumulative extracted volume divided by the total injected volume of the test solution. Identical breakthrough curves for bromide and perfluorooctane sulfonate were observed indicating that perfluorooctane sulfonate was transported conservatively in this aquifer. In contrast, breakthrough curves for a mixture C10-C13 linear alkylbenzene sulfonate (LAS) obtained from a separate single-well push-pull test conducted in the same aquifer (data not shown) indicates the retardation of C10-C13 LAS relative to that of bromide *(38)*. Preliminary data indicates for a given site, perfluorooctane sulfonate (C8) is conservatively transported while its hydrocarbon surfactant analog of 2 to 5 more carbon atoms is

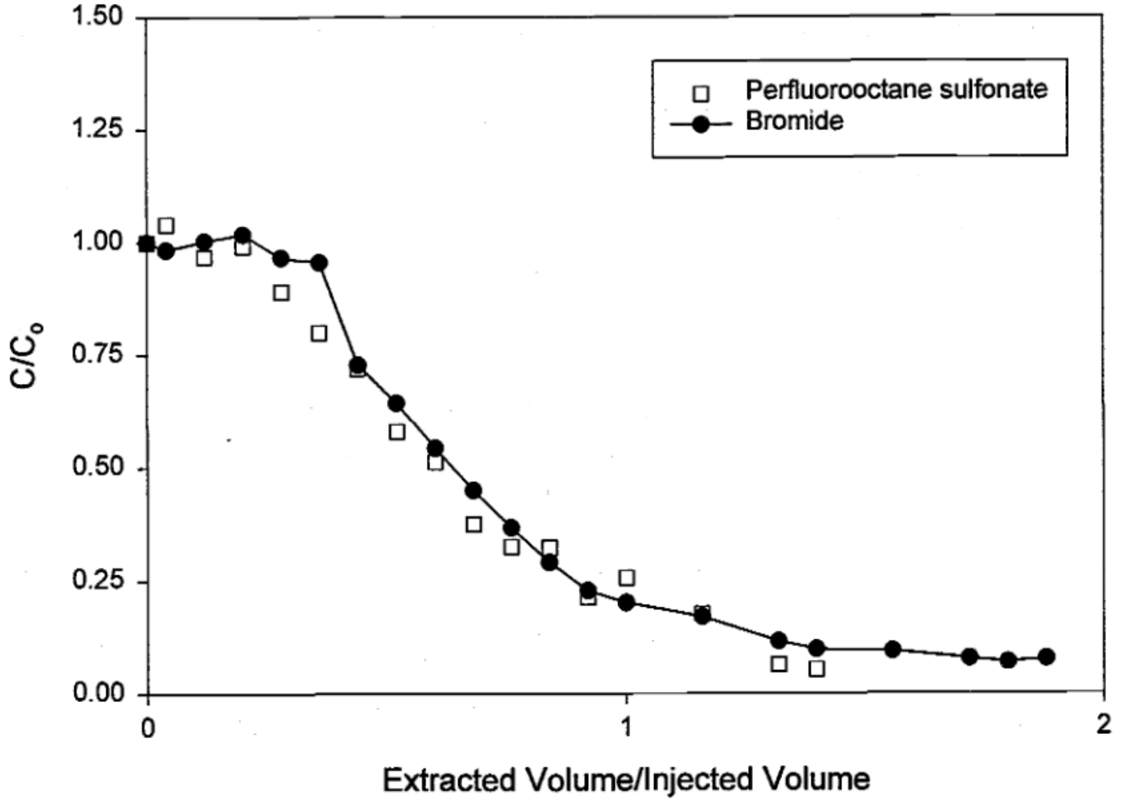

Figure 1.3. Breakthrough curves for bromide and perfluorooctane sulfonate obtained from a push-pull field test.

retarded. Because perfluorocarboxylates are weaker acids, their transport may be affected by pH and ionic strength. Therefore, research is required to fully investigate the transport behavior of the perfluorinated surfactants present in AFFF. However, the conservative transport perfluorooctane sulfonate observed in the field study indicates that perfluorinated surfactants may be good tracers for AFFF-contaminated groundwater.

Biodegradation

The extent to which AFFF components and priority pollutants in AFFF wastewater biodegrade is quite varied. A material safety data sheet for a current AFFF product states that the product contains one or more organic fluorochemicals that have the potential to resist degradation and persist in the environment *(39)*. The detection of perfluorocarboxylates in groundwater at NAS Fallon, NV, and Tyndall Air Force Base, FL, which have not been used for 7-11 years *(9)* is consistent with both AFFF product labeling and the widely-held view that perfluorinated surfactants are not biodegradable.

Few studies have been conducted to investigate the biodegradability of perfluorinated or partially-fluorinated surfactants *(2, 3, 12, 40)*. Perfluorooctane sulfonic acid was not degraded under aerobic or anaerobic conditions *(27)*, while a partially-fluorinated surfactant, 1H, 1H, 2H, 2H-perfluorooctane sulfonic acid, was partially degraded both aerobically and under sulfur-limiting conditions *(2, 3, 5)*. Biodegradation of partially-fluorinated surfactants appears to be limited to the non-fluorinated portion of the molecule *(2, 5, 41)*. For example, 1H, 1H, 2H, 2H-perfluorodecanol was biotransformed to perfluorooctanoate *(41)*. The recalcitrant nature of perfluorinated compounds is attributed, in part, to the strength of the carbon–fluorine bond *(1, 2, 42)* as well as the rigidity of the perfluorocarbon chain *(2, 43)*.

In contrast to the recalcitrant nature of the fluorinated surfactant components present in AFFF mixtures, the alkyl sulfate hydrocarbon surfactants (Table 1.2) *(26)* present in some AFFF formulations is considered biodegradable under aerobic and anaerobic conditions *(44)*. As mentioned previously, the solvent component of AFFF formulations is also biodegradable as indicated by high BOD values. As a result, the high BOD of butyl carbitol may influence the biogeochemical conditions of groundwater by consuming oxygen and thus driving systems anaerobic. Corrosion inhibitors (i.e., tolyltriazole) are a component found in AFFF formulations that have been shown to persist in the environment *(45, 46)*. While some information is available on individual AFFF components, virtually nothing is known about the biodegradation of this complex mixture and any synergistic effects of AFFF components upon priority pollutants biodegradation under actual subsurface conditions. Additional research is required to understand the biodegradation of AFFF components.

Co-Contaminant Transport and Degradation

Because some perfluorinated surfactants appear to persist in groundwater they may affect the environmental fate and transport of other co-contaminants (i.e., jet fuel and trichloroethylene) that are present in AFFF wastewater. Unfortunately, the physical character (e.g., number of liquid phases) and chemical composition of AFFF wastewaters have not been widely characterized. However, it is likely that AFFF wastewaters resulting from the application of AFFF on burning solvents, some of which form dense non-aqueous phase liquids or DNAPLs, are multi-phased systems. Due to the complex nature of AFFF wastewater there are a number of potential interactions between AFFF components and co-contaminants that can affect co-contaminant transport and biodegradation. For example, some hydrocarbon surfactants above their CMC are known to enhance the apparent solubility and/or the mobility of DNAPL in contaminated aquifers *(47-49)*. Because surfactants can cause large reductions in water-DNAPL interfacial tension, surfactants may promote the displacement of residual DNAPL and hence its more rapid migration in the subsurface. The ability of hydrocarbon surfactants to increase the solubility or mobility of DNAPLs is dependent on the physical properties of the particular surfactant. Given the oleophobic nature of the perfluorocarbon chain, it is likely that on a per carbon basis, perfluorocarbon surfactants are less effective in increasing the solubility of DNAPL than hydrocarbon surfactants as well as less effective in lowering aqueous-DNAPL interfacial tensions *(1)*. However, to date studies have not been conducted to determine the extent to which fluorinated surfactants can increase the solubility and/or mobility of DNAPL in the subsurface.

By analogy to wastewater treatment systems where AFFF wastewater adversely affected the performance, perfluorinated surfactants may have an effect on groundwater microbial populations and their ability to degrade co-contaminants *(12, 25, 27)*. No information exists on the potential impact of perfluorinated surfactants on microbial populations. Recent studies with hydrocarbon surfactants have indicated either inhibition *(50-52)* or promotion *(53-55)* of organic contaminant degradation *(47)*. The ability of a surfactant to promote or inhibit co-contaminant biodegradation also appears structure specific. Unfortunately, structure-activity relations have not been established for fluorinated surfactants. Therefore, it is not yet possible to predict *a priori* the effect that perfluorinated surfactants will have upon the biodegradation of other contaminants in AFFF-contaminated groundwater.

Toxicity

The toxicity of AFFF formulations to marine and freshwater organisms has been tested in laboratory studies *(24)*. Various diluted AFFF agents were considered mildly toxic to marine life at concentrations near 6.0 g/L *(24)*. Additional components of interest found in AFFF concentrate formulations are the corrosion inhibitors such as tolyltriazole. Recent toxicological studies on toyltriazoles have shown that these compounds have moderate to high toxicity *(45, 46)*. However, realistic toxicity evaluations of AFFF mixtures and AFFF wastewater in the environment are difficult because AFFF wastewaters are complex mixtures that contain AFFF components, primary pollutants, as well as toxic burn products. In addition, differential degradation during transport of AFFF wastewater components will change the mixtures composition and toxicity over distance and time. Finally, the toxicity of these types of complex mixtures is difficult to assess because of the potential synergistic effects between mixture components, making it difficult to predict *a priori* the toxicity of these mixtures in the environment.

Release of fluorinated surfactants to surface waters is not a recommended by AFFF manufacturers as a route of disposal for AFFF wastewater *(56)*. Fortunately, reports of AFFF wastewater discharge to surface waters are limited. However, AFFF wastewater released to a Florida river in 1993 has been the subject of investigation as a possible cause of sea bird illnesses and deaths in the region *(57, 58)*. By analogy to hydrocarbon surfactants, perfluorinated surfactants in AFFF wastewater can potentially cause birds to loose their natural oils, thus causing birds to die from hypothermia *(59)*.

Analytical Considerations

The determination of perfluorinated surfactants is problematic *(12)*, in part, because the surfactants are nonvolatile and generally do not contain chromophores, which limits their detection using commonly available analytical detectors. The scarcity of analytical methods for fluorinated surfactants is in sharp contrast to numerous methods available on hydrocarbon surfactant analysis *(11, 60-62)*. Creating an analytical method to isolate perfluorinated surfactants from environmental samples is complicated due to the proprietary nature of AFFF formulations and therefore, the lack of knowledge regarding the specific structure of perfluorinated surfactants. Furthermore, the isolation of perfluorinated surfactants from water is complicated by their high water solubility.

The non-specific determination of the total organofluorine content of a water sample may be obtained using the oxyhydrogen combustion method *(1, 63)*. A water sample (e.g., 10 mL) introduced into the oxyhydrogen torch for combustion is completely mineralized to the fluoride ion, which is then trapped in an aqueous solution *(1, 64, 65)*. The fluoride ion is then measured by an ion selective electrode *(1, 64, 66)*. As little as 20-40 μg/L fluorinated surfactant can be detected without the need to concentrate the water sample before combustion *(1)*. Although this method determines the total organofluorine content of a water sample, it does not provide structure-specific information. In addition, the mixtures of oxygen and hydrogen present a potentially significant safety hazard.

The methylene blue active substances test was used to detect the presence of anionic surfactants in groundwater at a fire-training area at Tyndall Air Force Base *(31)*. With the MBAS test, anionic surfactants form ion pairs with the methylene blue cation, which then are extracted into chloroform and determined spectrophotometrically *(67)*. However, the use of MBAS as a reliable means of detecting fluorinated surfactants in environmental wastewaters is limited because the MBAS test is non-specific and does not allow for the individual identification of anionic surfactants nor for the differentiation between anionic hydrocarbon and fluorocarbon surfactants.

When structural information is required to obtain definite identification of fluorinated surfactants in environmental samples, mass spectrometry is the method of choice. Chemical derivatization was combined with gas chromatography/mass spectrometry (GC/MS) for the determination of perfluorinated surfactants in groundwater at Tyndall Air Force Base, FL *(9, 34)*. Perfluorocarboxylates were quantitatively determined in groundwater by derivatizing the carboxylates to their methyl esters, which were detected and quantified by electron impact GC/MS and electron capture negative chemical ionization GC/MS. Perfluorooctane sulfonate, which is present in AFFF formulations, was not detected by this method. Although perfluoroalkanesulfonate esters may have been formed during the derivatization step, the esters are unstable due to excellent leaving group properties of the perfluoroalkanesulfonic group *(7, 68)*. In fact, perfluorooctane sulfonate esters are sold as *alkylating* reagents for the derivatization of *other* analytes. Therefore, derivatization with gas chromatography has limited utility for determining a broad range of perfluorinated surfactants.

Liquid chromatography/mass spectrometry (LC/MS) is an attractive option for the sensitive and quantitative analysis of non-volatile analytes such as perfluorinated surfactants. Liquid chromatography/mass spectrometry was used to qualitatively identify perfluorooctane sulfonate in groundwater from Tyndall Air Force Base, FL, NAS Fallon, NV, and Wurtsmith Air Force Base, MI *(35)*. To the best of our knowledge, only one other report characterizes the determination of fluorinated surfactants in water and wastewater by high performance liquid chromatography (HPLC) together with a thermospray interface and a tandem mass spectrometer *(69)*. Liquid chromatography/mass spectrometry will most likely prove to be the most useful tool for characterizing the compositions and concentrations of a range of perfluorinated surfactants in environmental samples.

Future Challenges

Hydrocarbon-fuel fires pose a serious threat to life and property and therefore the issue of fire safety must be balanced against the risks that AFFF and their perfluorinated surfactants potentially pose to the environment. Fluorinated surfactants are a unique class of chemicals that are directly discharged to natural and engineered aquatic systems. The variety of applications for these types of surfactants is increasing yet little information on the environmental behavior is available. Fluorinated surfactants differ significantly from hydrocarbon surfactants such that direct analogies can not be drawn between the two types of surfactants. Therefore, the environmental behavior of fluorinated surfactants is worthy of independent investigation.

Because commercial formulations of AFFF are complex mixtures, the employment of these mixtures in fire-training situations introduces both priority and non-priority pollutants into the environment. There are significant gaps in the knowledge of how chromatographic separation during transport affects these complicated mixtures. Because perfluorinated surfactants persist in the environment, they may impact the biogeochemical processes affecting the distribution and bioavailability of co-contaminants. The effect that AFFF components has upon subsurface microbial ecology and activity is unknown.

Several different technologies are being evaluated to solve current problems resulting from AFFF usage, including the development of products to replace AFFF. The 1998 Presidential Green Chemistry Challenge Award was recently presented to a company for the development of a biodegradable fire-extinguishing agent that does not contain glycol ethers or fluorinated surfactants *(70, 71)*. Another approach to addressing the problems associated with fluorinated surfactants is to discontinue their use in AFFF agents and to return to prior technology such as protein-based foams.

In a related issue, advances in fire-fighting product development includes the development and marketing of training foams that are designed to be used during training exercises in lieu of AFFF products that contain fluorinated surfactants. Training products are attractive for their cost savings due to the absence of expensive fluorinated surfactant components. Training products have the added benefit of being readily treated by conventional wastewater treatment facilities due to the increased biodegradability of the non-perfluorinated surfactant mixture and its reduced foaming properties. Such training foams eliminate the common environmental concern associated with AFFF and reduce training costs while still allowing for actual practice with fire-training equipment *(72)*. While training foams are designed to provide expansion characteristics similar to AFFF, they are inadequate fire extinguishing materials if used in an actual hydrocarbon-fuel fire. Because the possibility exists that training foams may be mistaken in an emergency for AFFF, some AFFF users do not employ training foams.

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Chapter 2

Analytical Method for the Determination of Perfluorocarboxylates in Groundwater Impacted by Fire-Fighting Activity

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Abstract

Perfluorinated surfactants are used in aqueous film forming foam (AFFF) formulations, which are used to extinguish hydrocarbon-fuel fires. Virtually nothing is known about the occurrence of perfluorinated surfactants in the environment, in particular, at fire-training areas and emergency response sites where AFFF entered groundwater without prior treatment. Strong anion exchange Empore disks were used to extract perfluorocarboxylates from groundwater collected from fire-training facilities located on Naval Air Station Fallon, NV, and Tyndall Air Force Base, FL. The carboxylates were simultaneously eluted from the disks and derivatized to their methyl esters for direct analysis by gas chromatography/mass spectrometry. Perfluorocarboxylates containing 6-8 carbons were detected in groundwater collected from the two field sites with total concentrations ranging from 125 to 7,090 μg/L. The detection of perfluorocarboxylates at field sites after 7 to 10 years of inactivity indicates their potential utility as markers for delineating groundwater impacted by fire-fighting activity.

Introduction

Aqueous film forming foams (AFFF) are complex mixtures of surfactants and other components used to extinguish hydrocarbon-fuel fires that occur at fire-training sites as well as in emergency situations. Aqueous film forming foams have been commercially available for fire-fighting applications since their development by the United States Navy and 3M Co. in the mid-1960s *(1)*. At fire-training areas that routinely used AFFF mixtures and military emergency response sites, AFFF-laden wastewater that entered surface water and groundwater without treatment has led to groundwater and soil contamination. For example, perfluorinated compounds were tentatively identified in groundwater impacted by fire-training activities at Tyndall Air Force Base *(2)*. Unfortunately, definitive identifications of the perfluorinated compounds were not reported.

Commercial AFFF mixtures are propreitary in nature and typically contain fluorinated and non-fluorinated surfactants *(1, 3-5)*. Due to the proprietary nature of AFFF formulations, the chemical structures of the actual perfluorinated surfactants used in commercial AFFFs are not known outside the companies that manufacture them *(5)*. Moreover, the analysis of anionic perfluorinated surfactants that are known to occur in AFFF formulations *(6)* is problematic because the surfactants are non-volatile and may not contain chromophores. As a result, analytical methods for AFFF formulation components are lacking and therefore it is difficult to assess their occurrence, fate, and transport in AFFF-contaminated groundwater. Because perfluorinated surfactants co-occur with other pollutants (e.g. fuel components, solvents, etc.) in groundwater, it is important to determine if perfluorinated surfactants affect the transport and biodegradation of other contaminants. Free and emulsified oil, fuel, and AFFF components were shown to adversely affect activated sludge processes *(6, 7)* and the performance of anaerobic sludge digestors *(8)* in wastewater treatment facilities. For this reason, perfluorinated surfactants may have an adverse affect on groundwater microbial populations and their ability to degrade co-contaminants present in AFFF-contaminated groundwater.

In addition to fluorinated surfactants use in fire-fighting foams, they are also utilized in herbicides and insecticides, cosmetics, greases and lubricants, and adhesives *(3)*. Fluorinated carboxylic acids of industrial significance include perfluorooctanoic acid (PFC8) and perfluorodecanoic acid (PFC10) *(9)*. There is concern regarding the potential toxicity of perfluorinated carboxylic acids. An in vivo study of rat liver response to PFC10 indicated the rapid onset of a low-level heptatotoxicity but no detectable damage to the DNA *(10)*. Perfluorodecanoic acid and PFC8 have been found to inhibit gap junction intercellular communication in rat liver epithelial cells *(11)* and may be involved in tumor promotion *(9)*.

In this paper, we describe the isolation, identification and quantification of perfluorinated carboxylates in groundwater impacted by fire-training activities at Naval Air Station (NAS) Fallon, NV, and Tyndall Air Force Base, FL. The development of analytical methods is necessary before investigating the occurrence and distribution of perfluorinated surfactants in AFFF-contaminated groundwater and their effect on co-contaminant transport and biodegradation.

Experimental Section

Standards and Reagents. Standards of PFC8 (98%), perfluorododecanoic acid (PFC12) (95%), and the internal standard, 2-chlorolepidine (99%) were purchased from Aldrich Chemical (Milwaukee, WI). Methyl iodide (neat) was used as purchased from Aldrich Chemical.

Field Sites and Sample Collection. From the mid-1950s to 1988, the crash crew training area at NAS Fallon, NV, (Figure 2.1a) was used to conduct fire-training activities, which consisted of flooding a fire pit with flammable liquids, igniting the fluids, and subsequently extinguishing the fire with fire-fighting agents including AFFF *(12)*. For a typical training exercise, approximately 75-100 L of AFFF concentrate were diluted with 1200-3200 L of water according to specifications (3% or 6% solution) and subsequently employed. During the years of activity at the NAS Fallon site, training exercises occurred on a weekly to monthly basis. At the NAS Fallon site, groundwater samples were collected from four monitoring wells located within a 120 m radius of the fire pit where the water table is located between 2 to 3 m below the land surface.

The Tyndall Air Force Base Fire-training Area FT-23 was used from 1980 to 1992 for similar activities (Figure 2.1b) *(13)*. Four groundwater samples were obtained from wells surrounding the fire-training area; the water table is located between 1 and 2 m below the land surface. All samples were collected in high density polyethylene brown bottles because perfluorinated carboxylates adsorb to glass *(14)*. Samples were shipped on ice without preservation and stored at 4 °C prior to analysis.

Solid-Phase Extraction and Derivatization. Samples (55-200 mL) were extracted through 25 mm strong anion exchange (SAX) disks in a manner similar to that

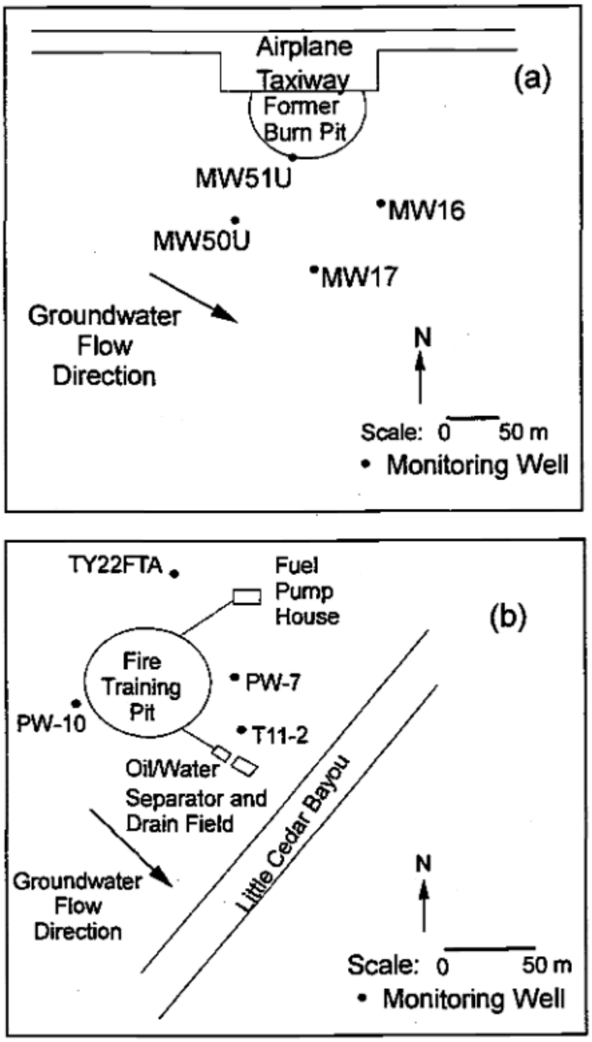

Figure 2.1. Map of (a) Naval Air Station Fallon, NV, and (b) Tyndall Air Force Base, FL, field sites indicating location of groundwater wells and direction of regional groundwater flow.

described by Field and Reed *(15)* with the exception that the SAX disks were pre-treated prior to use to remove interfering disk impurities. Pre-treatment consisted of soaking the disks in 12 mM HCl/acetonitrile for 2 days after which the disks soaked in pure acetonitrile for several hours. Just prior to use the disks were rinsed with a minimum of 350 mL of deionized water in order to sufficiently rinse the HCl from the disks and wet them prior to passing groundwater samples through them. Samples (55-200 mL) were passed through the disks under full vacuum and the disks were then allowed to dry. The disks containing the exchanged analytes were placed in a 2 mL autosampler vial together with 1 mL of acetonitrile, 51.2 μg of internal standard, and 100 μL of methyl iodide. When heated at 80 °C for 1 h, the acids were simultaneously eluted from the disk and derivatized to their methyl esters.

Spike and Recovery. Spike and recovery experiments were performed to determine the precision and accuracy of the SAX disk extraction and in-vial elution method. A set of experiments was performed on groundwater samples from NAS Fallon MW 50U and MW 17 that had been previously determined to contain neither PFC8 nor PFC12 above detection. Duplicate groundwater samples from wells MW 50U and MW 17 were spiked to contain a final concentration of 1,240 μg/L of PFC8 and 560 μg/L of PFC12.

Standard addition analyses were performed with NAS Fallon groundwater samples that contained measurable quantities of PFC8; the samples did not contain PFC12 above detection. Known amounts of PFC8 were added to samples to give a final concentration twice that of the background concentration. For example, groundwater from MW 51U and MW 16, which contained background concentrations of 6,570 μg/L and 460 μg/L, respectively, were spiked to give a final concentration of 12,900 μg/L and 1,000 μg/L of PFC8, respectively. Each sample also was spiked with 56.4 μg of PFC12. To determine the detection limit of the method, single samples of groundwater that contained no perfluorinated carboxylates above detection were spiked to give a range of final PFC8 concentrations from 18 to 54 μg/L.

Gas Chromatography/ Mass Spectrometry. Extracts were analyzed using a Hewlett Packard Model 5890 Series II Plus gas chromatograph (GC) equipped with a 30 m x 0.32 mm x 4.00 μm SPB-1 SULFUR column (Supelco Inc., Bellefonte, PA). An injection volume of 1 μL was used under splitless conditions with an injector temperature of 200 °C. The GC oven temperature was initially held for 6 min at 60 °C, increased by 6 °C/min to 190 °C, increased further by 30 °C/min to 270 °C, and then held for 5 min.

Quantification of perfluorocarboxylate methyl esters was performed using a Hewlett Packard Model 5972 mass selective detector operated in electron impact (EI) mode (70 eV). The mass selective detector was operated in full scan (50-450 amu) mode and in selected ion monitoring (SIM) mode using a dwell time of 100 ms for each ion. The scanning mode was used for qualitative identification while SIM mode was used for quantification. The ions of m/z 131 $[C_3F_5]^-$, m/z 169 $[C_3F_7]^+$, and m/z 219 $[C_4F_9]^+$, which are characteristic fragments of perfluorocarbons *(16-18)*, were used to identify and quantify the methyl esters of perfluorohexanoic acid (PFC6), perfluoroheptanoic acid (PFC7), PFC8 and PFC12. The internal standard, 2-chlorolepidine, was quantified with the ions m/z 177 and 115.

The identification of perfluorocarboxylate methyl esters was confirmed by electron capture negative ionization (ECNI) GC/MS, which gave unique molecular ions for each of the perfluorinated carboxylate methyl esters (e.g. m/z 328 for PFC6, m/z 378 for PFC7, m/z 428 for PFC8, and m/z 628 for PFC12). These measurements were performed with a Varian 3400 gas chromatograph interfaced with a Finnigan Model 4023 mass spectrometer. Methane was used as the reagent gas and the mass spectrometer was operated in full scan mode (100-650 amu). The gas chromatograph was operated with a column and temperature program identical to that used for the EI GC/MS.

Initially, samples prepared in deionized water were used as the matrix for constructing calibration curves and standard recoveries were low. However, when samples prepared in tap water, which contains inorganic cations and anions, were used as the matrix for constructing calibration curves quantitative recovery of standards was obtained. It is proposed that the 350 mL of deionzed water does not sufficiently rinse the disks of residual HCl and tap water is required to completely rinse the disks and obtain quantitative recovery of standards. Therefore, calibration curves for quantification of PFC8 were constructed by passing 100 mL tap water samples that had been spiked with 3.6 μg to 1,080 μg PFC8 through 25 mm SAX disks and derivatizing the acids to their methyl esters using the in-vial elution and derivatization technique. The calibration curve for PFC12 was constructed in a similar manner by adding 7.5 μg to 113 μg of PFC12 standard to 100 mL tap water. For all quantitation standards, a total of 51.2 μg of the 2-chlorolepidine internal standard was added to the autosampler vial just prior to the addition of methyl iodide. Both calibration curves were linear with r^2 typically greater than 0.99. Quantification of PFC6 and PFC7 was performed assuming a response factor equal to an equimolar amount of PFC8.

Results and Discussion

Gas Chromatography/Mass Spectrometry. A film thickness of 4 μm (30 m x 0.32 mm SPB-1 SULFUR; Supelco, Bellefonte, PA) was necessary to obtain sufficient retention times for the methyl esters of PFC8 and PFC12 to allow for the separation and quantification (Figure 2.2a). Initial attempts to separate and quantify the perfluorinated carboxylate methyl esters on a thin film (0.25 μm), 30 m x 0.25 mm DB-1 (J&W Scientific, Folsom, CA) column were unsuccessful regardless of the initial column temperature. Note that the stationary phases in the SPB-1 SULFUR and DB-1 columns are comparable. A standard of perfluorobutyric acid was not observed under any of the described GC conditions; it is most likely that an initial oven temperature less than 40 °C would be required.

The EI mass spectra of methyl PFC8 (Figure 2.3a) and PFC12 indicate characteristic perfluorocarbon fragmentation *(16, 17)* in which the major ions (e.g., 69, 119, 169, 219, etc.) differ by 50 amu, which corresponds to the mass of CF_2. Molecular ions were not observed for any of the perfluorinated carboxylate methyl esters under EI conditions; however, molecular ions $[M]^-$ were observed under ECNI conditions. For example m/z 428 (in Figure 2.3b) corresponds to the molecular ion of methyl PFC8.

Solid-Phase Extraction. Prior to developing a solid-phase extraction method, initial experiments were conducted using diazomethane as the derivatization reagent.

When perfluorinated carboxylates were derivatized using ethanol-based diazomethane, multiple peaks corresponding to methyl and ethyl esters were detected (unpublished data). Because EI GC/MS did not produce molecular ions, ECNI GC/MS was used to verify the formation of both methyl and ethyl esters. Consequently, if ethanol-based diazomethane was used for derivatization in conjunction with EI GC/MS, multiple peaks in a chromatogram could be erroneously interpreted as a greater number of perfluorinated compounds than are actually present. In contrast, only the methyl ester was obtained when butyl carbitol (2-(2-butoxyethoxy)ethanol) was used to prepare the diazomethane reagent. However, because of the hazards associated with the use of diazomethane and the time-consuming nature of diazomethane derivatization, an alternative method was desired.

Derivatization of the perfluorocarboxylates by the solid-phase extraction and the in-vial elution and derivatization technique gave only a single peak that corresponded to the methyl ester of each perfluorinated carboxylate standard; the identification of each methyl ester was confirmed by ECNI GC/MS. In addition, the solid-phase extraction approach combined the steps of isolation and derivatization, which greatly simplified the procedure and eliminated the use of diazomethane. Six replicate analyses of blank 25 mm SAX disks that had not been pre-rinsed with 12 mM HCl/acetonitrile prior to use, yielded an average of 21 ± 1 μg (4.8% relative standard deviation (RSD)) of PFC8 per disk. No other perfluorinated carboxylates were present in the disks above the detection limit. The PFC8 is associated with the Teflon matrix and not the embedded anion exchange particles (unpublished data). The background PFC8 was successfully removed

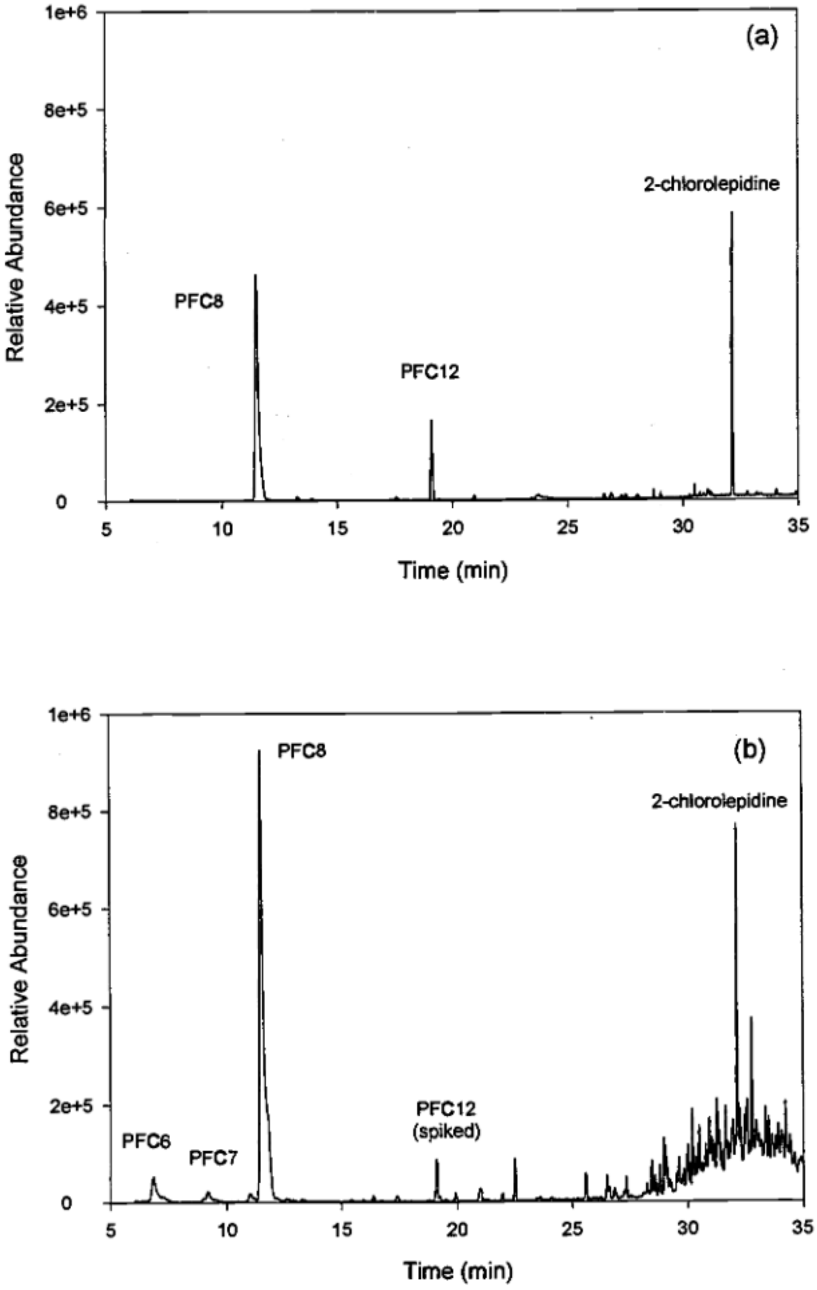

Figure 2.2. (a) Typical EI GC/MS chromatogram of PFC8 and PFC12 standards and (b) perfluorinated carboxylates, including PFC6, PFC7, PFC8 and PFC12 (spiked) in Naval Air Station Fallon, NV, groundwater.

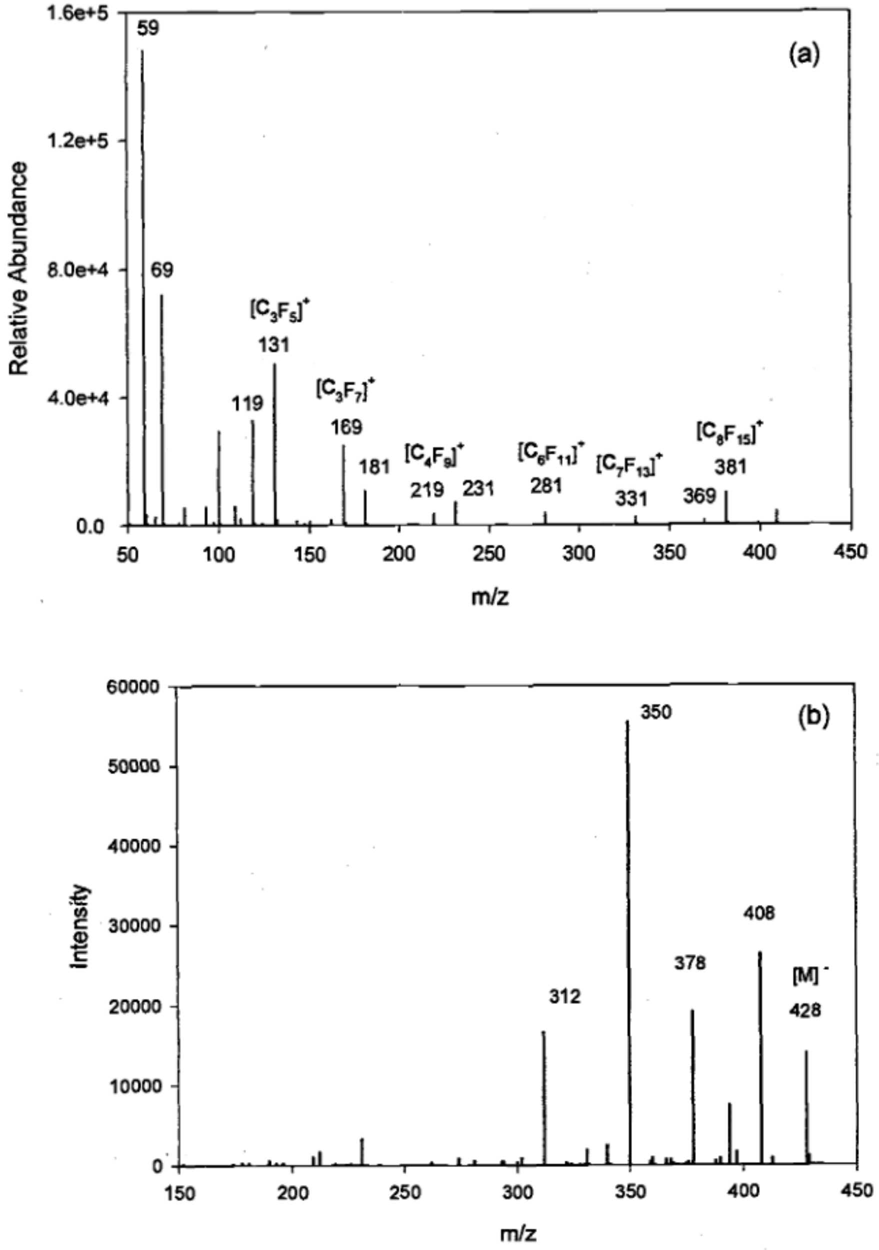

Figure 2.3. (a) EI mass spectrum of methyl PFC8 and (b) an ECNI mass spectrum of methyl PFC8.

by rinsing the disks prior to use with 12 mM HCl/acetonitrile followed by 350 mL of deionized water. It should be noted that benzoic acid and ethylhexylphthalic acid are also present in the disks as artifacts and are removed by the HCl/acetonitrile pre-rinse step.

Accuracy, Precision and Detection Limits. The recoveries of PFC8 from blank groundwater samples obtained from NAS Fallon wells MW 50U and MW 17 were 73 and 74%, respectively, while the recoveries of PFC12 were 77 and 88%, respectively (Table 2.1). Because detectable levels of PFC8 occurred in groundwater from MW 51U and MW 16, standard addition experiments were performed to determine the recoveries of PFC8. The recoveries of the PFC8 spiked into MW 51U and MW 16 groundwater to give a final concentration double that of the background concentration were 83 and 90%, respectively (Table 2.1). The recoveries of PFC12 from MW 51U and MW 16 groundwater, which did not contain background concentrations of PFC12, were 35 and 85%, respectively (Table 1). Although the recovery of PFC8 (83%) differs significantly from that of PFC12 (35%) in groundwater from MW 51U, the recoveries of PFC8 and PFC12 were nearly equivalent for the other groundwater samples. Monitoring well 51U is located closest to the fire pit where AFFF agents where applied to burning mixtures of fuels and solvents. Due to its proximity to the fire pit, the groundwater from MW 51U most likely contains the greatest diversity of inorganic and organic constituents, which may adversely affect PFC12 recoveries relative to that of PFC8. Therefore, although the original intent was to use the PFC12 as a surrogate standard because it did not occur in the groundwater samples, PFC12 appears more sensitive to matrix interferences

Table 2.1. Recovery of PFC8 and PFC12 spiked into groundwater samples from Naval Air Station Fallon, NV.[a]

Sample	PFC8 % recovery	PFC12 % recovery
NAS Fallon MW 51U[b]	83[c]	35
NAS Fallon MW 16	90[d]	85
NAS Fallon MW 50U	73	77
NAS Fallon MW 17	74	88

[a] Duplicate samples were analyzed. Sample volume was 100 mL unless otherwise noted.

[b] Sample volume was 55 mL.

[c] Calculated as the final measured concentration divided by background concentration plus spike concentration and multiplied by 100. The background concentration was 6,570 μg/L.

[d] Calculated as the final measured concentration divided by background concentration plus spike concentration and multiplied by 100. The background concentration was 460 μg/L.

compared to PFC8 so that it is an inappropriate choice for a surrogate standard. For this reason, all subsequent quantification was based on the 2-chlorolepidine internal standard.

The precision, indicated by the RSD, calculated from five replicate analyses each of groundwater from NAS Fallon MW 16 and Tyndall AFB T11-2 ranged from 3.7 to 14% (Table 2.2). The detection and quantitation limit of the method was defined as those concentrations of PFC8 needed to produce a signal to noise (S/N) of 3:1 and 10:1, respectively. The detection and quantitation limits for PFC8 were 18 μg/L and 36 μg/L, respectively.

Application to Groundwater Samples. Four groundwater samples from both NAS Fallon and Tyndall AFB were analyzed for perfluorinated carboxylates. Chromatograms obtained by EI GC/MS indicated the presence of multiple perfluorinated compounds all having characteristic perfluorocarbon fragmentation (Figure 2.2b). Analysis by ECNI GC/MS established the identification of PFC6, PFC7 and PFC8 in groundwater obtained from wells MW 51U and MW 16 from NAS Fallon. The molecular ions $[M]^-$ for methyl PFC6 (m/z 328) and methyl PFC7 (m/z 378) were observed for peaks eluting 4.7 and 2.3 min before that of PFC8 (Figure 2.4a and 2.4b). The ECNI mass spectrum for methyl PFC8 in MW 51U was similar to that of the PFC8 standard (Figure 2.2b).

The groundwater samples from NAS Fallon MW 51U and MW 16 had total perfluorinated carboxylate concentrations of 7,090 μg/L and 540 μg/L, respectively (Table 2). The PFC6 detected in NAS Fallon groundwater samples from MW 51U and MW 16 comprised 5.2% and 11%, respectively, of the total perfluorocarboxylates

Table 2.2. Concentrations of perfluorinated carboxylates in groundwater samples from Naval Air Station Fallon, NV, and Tyndall Air Force Base, FL.[a,b]

Sample	n	PFC6 (μg/L)	PFC7 (μg/L)	PFC8 (μg/L)	Total (μg/L)
NAS Fallon MW 51U	3	372 ± 4	149 ± 5	6,570 ± 150	7,090 ± 160
		(1.1%)	(3.4%)	(2.3%)	(2.3%)
NAS Fallon MW 16	5	57 ± 8	18 ± 2	460 ± 20	540 ± 20
		(14%)	(11%)[c]	(4.3%)	(3.7%)
NAS Fallon MW 50U	3	nd	nd	nd	nd
NAS Fallon MW 17	3	nd	nd	nd	nd
Tyndall AFB PW-10	2	144	38	116	298
Tyndall AFB PW-07	2	73	22 [c]	64	159
Tyndall AFB T11-2	5	64 ± 4	19 ± 1	42 ± 2	124 ± 8
		(6.3%)	(5.3%)[c]	(4.8%)	(6.5%)
Tyndall AFB TY22FTA	2	nd	nd	nd	nd

[a] The relative standard deviation is given in parentheses.

[b] nd, not detected above the detection limit.

[c] The reported value is near the detection limit ($S/N \leq 3$) and less than the quantitation limit ($S/N \leq 10$). The value has been included in the reported total concentration.

detected. The PFC7 was 2.1% and 3.3% respectively, of the total perfluorinated carboxylates detected in these wells. The dominant perfluorinated carboxylate, PFC8, accounted for 93% and 85%, respectively, of the total perfluorocarboxylate concentration.

The highest concentrations of perfluorocarboxylates were observed in groundwater collected from NAS Fallon MW 51U, which is the well located closest to the fire-training pit (Figure 2.1a). Monitoring well 16, which is located downgradient of MW 51U and the fire-training pit, had lower but detectable concentrations of perfluorocarboxylates. Groundwater from MW 50U and MW 17, which are located off gradient from the fire-training pit, contained no detectable perfluorinated carboxylates. Over the approximate 100 m distance between MW 51U and MW 16, the concentrations of the perfluorinated carboxylates decreased with increasing number of carbons. For example, the concentration of PFC6 decreased 85% over the 100 m compared to decreases of 88% and 93% for PFC7 and PFC8, respectively.

The groundwater samples from Tyndall AFB PW-10, PW-07 and T11-2 contained total perfluorinated carboxylate concentrations of 298 μg/L, 159 μg/L and 124 μg/L, respectively (Table 2.2). The compositions of Tyndall AFB groundwater collected from the three wells ranged from 46 to 52% for PFC6, 13 to 15% for PFC7 and 34 to 40% for PFC8. In contrast to the groundwater samples from NAS Fallon, the dominant perfluorinated carboxylate in Tyndall AFB groundwater was PFC6.

The highest concentrations of perfluorocarboxylates among the groundwater samples from Tyndall AFB were observed in PW-10 and PW-07, which are the two wells located closest to the fire-training pit (Figure 2.1b). Monitoring well T11-2, which is

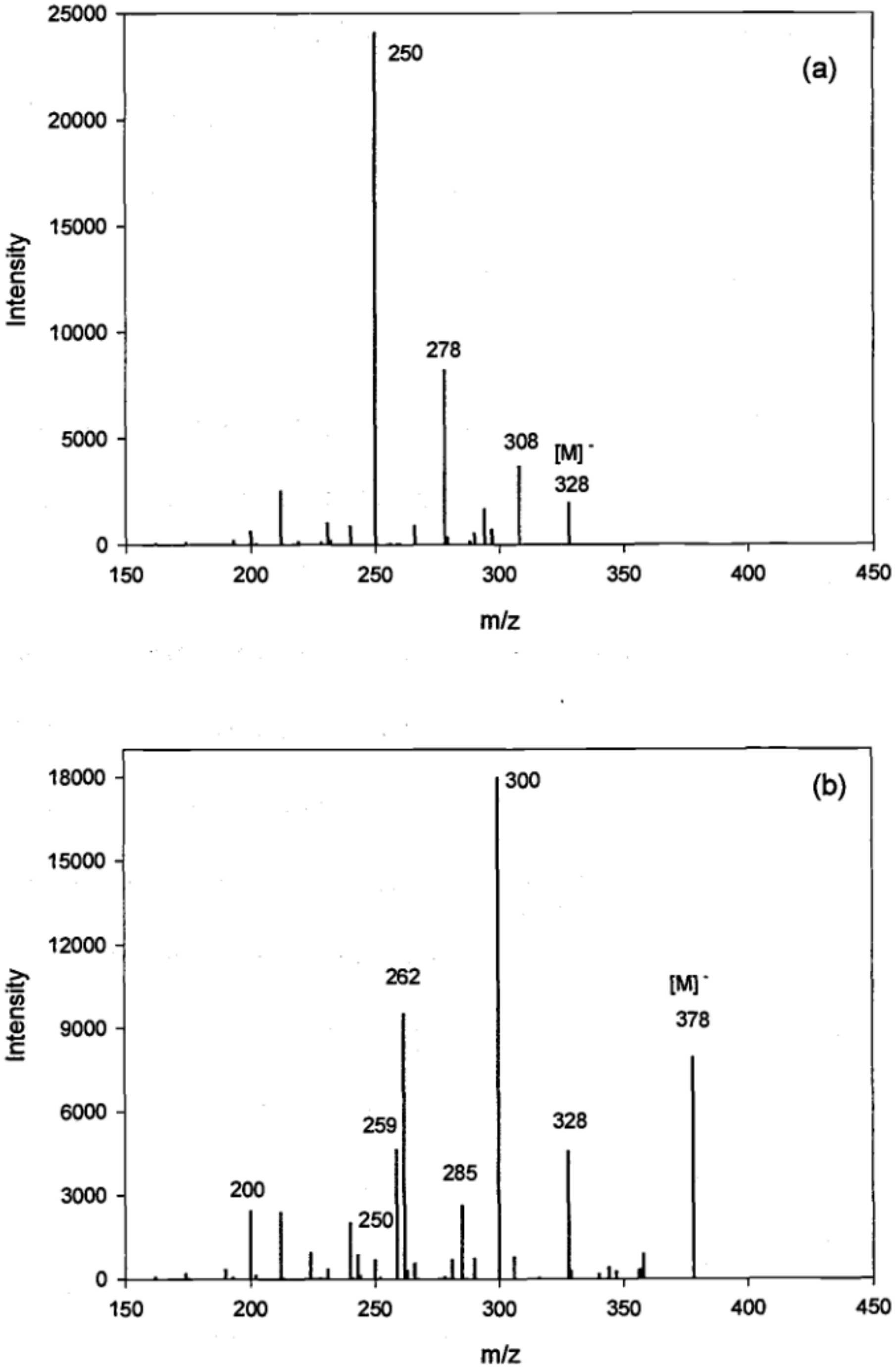

Figure 2.4. (a) ECNI mass spectrum of methyl PFC6 and (b) methyl PFC7.

located downgradient of the fire-training pit, had lower but detectable groundwater concentrations of perfluorocarboxylates. The groundwater collected from a well located north of the fire-training pit, TY22FTA, contained no perfluorinated carboxylates above the detection limit (18 μg/L).

It is not surprising to observe a suite of perfluorinated carboxylates since the raw materials used in the synthesis of perfluorinated organic compounds are mixtures *(3, 19)*. Different ratios of PFC6, PFC7 and PFC8 may result from the use of different AFFF formulations at the two fire-training areas. The observed homologous series consisting of even and odd number perfluorinated carboxylates is indicative of the electrochemical fluorination process used by 3M Co. *(3)*. Other fluorination processes, such as telomerization, produce only even number homologues *(3)*. Because of the proprietary nature of AFFFs, it is not known if perfluorinated carboxylates are present as one of the major surface active agents in AFFF formulations or as unreacted starting materials used in the synthesis of the principal perfluorinated surfactants used in AFFF formulations. In addition, the carboxylates may be combustion, biological or non-biological degradation products of the principal perfluorinated components in AFFF mixtures. Unfortunately, the exact source and history of AFFF applications at the two field sites are unknown, and, therefore, the relationship between the observed perfluorocarboxylate ratios and that of the original AFFF mixtures is unknown.

To the best of our knowledge, very little is known regarding the transport and fate of perfluorocarboxylates in groundwater. Adsorption to sludge at wastewater treatment facilities is considered a significant process for the removal of perfluorinated surfactants during treatment *(3)*. However, detection of perfluorinated carboxylates at the NAS Fallon and Tyndall AFB sites, which have not been used since 1988 and 1992, respectively, is consistent with the view that biodegradation of the long chain perfluorocarbon hydrophobe is unlikely *(6, 9, 19)*. The recalcitrant nature of perfluorinated compounds is attributed in part to the rigidity of the perfluorocarbon chain *(9, 20)* as well as the strength of the carbon – fluorine bond *(3, 9, 21)*.

To the best of our knowledge this is the first definitive identification of perfluorinated carboxylates in groundwater impacted by fire-fighting activity. Further work is needed to determine if additional perfluorinated components are present, such as perfluorooctane sulfonic acid, which is thought to be one of the principle components in some commercial AFFF formulations. In addition, it is of interest to relate the occurrence and distribution of perfluorinated compounds to other site characterization parameters such as dissolved organic carbon, inorganic constituents, and the distribution of co-contaminants and to understand the potential influence of perfluorinated compounds on the biotransformation and transport of other co-contaminants.

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Chapter 3

Occurrence and Distribution of Perfluorinated Surfactants in Groundwater at the Wurtsmith Air Force Base Fire-Training Area Two and KC-135 Crash Site

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Abstract

Perfluorinated surfactants are a major component in aqueous film forming foam (AFFF) formulations, which are used to extinguish hydrocarbon-fuel fires. As a result of past fire-training exercises, as well as response to emergency situations, AFFF-laden wastewater containing fuels, solvents, and other materials directly entered groundwater without prior treatment. Historically, AFFF mixtures containing perfluorinated surfactants were applied at Wurtsmith Air Force Base, MI, including at Fire-Training Area Two and a location where a KC-135 airplane crashed. Perfluorocarboxylate (containing 6 to 8 carbons) concentrations ranging from the detection limit (3 μg/L) to 110 μg/L were measured in groundwater sampled over an extensive well array at Fire-Training Area Two where as none were detected at the airplane crash site. Perfluorocarboxylates detected over 500 m from the source area have an approximate minimum residence time of 5 to 15 years, and provide direct field evidence that this class of perfluorinated surfactants persists under prevailing groundwater conditions. Significantly higher concentrations (e.g., 400-3600 μg/L) of methylene blue active substances which is an indirect measurement of anionic surfactants, indicates that the perfluorocarboxylates are only a small fraction of the anionic surfactant species present in the groundwater. The transport of perfluorocarboxylates in groundwater was not fully characterized such that additional research is needed to characterize the transport of perfluorocarboxylates in groundwater.

Introduction

In fluorinated surfactants, the hydrophobic portion of the surfactant molecule contains fluorine. To classify a surfactant as perfluorinated, all hydrogen atoms in the hydrophobic segment are replaced by fluorine atoms. The substitution of fluorine for hydrogen in fluorinated surfactants differentiates these surfactants from hydrocarbon surfactants. For example, fluorinated surfactants have unique wetting and spreading characteristics that make them better suited than hydrocartbon surfactants in coating, paint, ink, and polish applications *(1, 2)*. Because of the fluorocarbon hydrophobe, fluorinated surfactants are usually more physically, chemically, and biologically stable than hydrocarbon surfactants *(2)*.

Hydrocarbon-fuel fires pose serious threats to life and property, and aqueous film forming foams (AFFFs) are employed to extinguish these types of fires. Fluorinated surfactants are a major component in AFFF formulations *(3)*. Physical characteristics, such as the ability to lower surface tension, aid in the formation of a water film that forms over the surface of a hydrocarbon (e.g., fuel), which makes fluorinated surfactants well-suited for AFFF applications. While the stability of perfluorinated surfactants make them suitable for applications that involve extreme environments, it also leads to their apparent persistence in the environment *(4)*.

Due to the presence of large quantities of flammable liquids, municipal (i.e., fire departments), hydrocarbon-processing industry (i.e., oil refineries), and military sectors utilize AFFFs, with the military comprising 75% of the total market, while the municipal and hydrocarbon-processing industry represents 13% and 5%, respectively *(5)*. In 1985, the United States market for AFFF products (i.e., 3% and 6% concentrates) was 6.8

million L with a total revenue of 10 million dollars in U. S. sales *(5)*. The military was the single largest consumer of AFFF agents in 1985, with consumption totaling 5.1 million L *(5)*.

Currently, the Organization for Economic Cooperation and Development (OECD) classifies perfluorinated C5 to C18 compounds as high-production-volume (HPV) chemicals, where HPV chemicals are those chemicals manufactured or imported in the U.S. in quantities exceeding 1 million pounds *(6)*. This class of chemicals encompasses the perfluorinated and partially-fluorinated surfactants used in AFFF. Data is needed for an environmental and toxicological database that will be developed for HPV chemicals under a voluntary program led by the U.S. Environmental Protection Agency and the Chemical Manufacturer's Association. Planned database entries for the HPV chemical testing program include physical and chemical properties, environmental fate and pathways, fate and environmental distribution assessment, and mammalian toxicity *(7)*; currently much of this information for perfluorinated surfactants is either unknown or unavailable.

In preparation for hydrocarbon-fuel fires, training exercises at military bases often are conducted. As a result, at military emergency response sites and fire-training areas, the repetitive use of AFFF and release of AFFF-laden wastewater to the environment has led to groundwater contamination. Positive identification of one class of perfluorinated surfactants, perfluorocarboxylates, was reported for a limited number of groundwater samples obtained from Naval Air Station (NAS) Fallon, NV, and Tyndall Air Force Base, FL *(4)*. Although not listed as a component in material safety data sheets from AFFF manufacturers, the perfluorocarboxylates were found in some commercially-available

AFFF products (unpublished data). An additional report tentatively identifies perfluorinated compounds in groundwater impacted by fire-training activities at Tyndall Air Force Base *(8)*.

Few publications report the occurrence of perfluorinated surfactants in the environment, primarily due to the lack of sensitive and specific analytical methods. The methylene blue active substances (MBAS) test has been used as an indicator of hydrocarbon anionic surfactants in soils *(9)* and groundwater *(10-14)*. A study at Tyndall Air Force Base used MBAS to qualitatively identify the presence of anionic surfactants in groundwater *(15)*. With the MBAS test, anionic surfactants form ion pairs with the methylene blue cation, which then are extracted into chloroform and determined spectrophotometrically. Reasons for employing the MBAS test include that it is inexpensive, relatively simple, and field-ready. However, the MBAS method is non-specific and does not allow for the detection and quantitiation of the individual surfactants present. In the case of AFFF–contaminated groundwater, a number of anonic surfactants could be present including perfluorinated and non-fluorinated surfactants *(16-18)*. For these reasons, the use of MBAS should be limited to that of a screening tool for environmental samples *(13)*.

This field study addresses the gap in information concerning the occurrence, distribution, and transport of perfluorinated surfactants in the environment, specifically in AFFF-contaminated groundwater at Wurtsmith Air Force Base (WAFB) in Oscoda, MI. The concentrations of perfluorinated carboxylates detected in groundwater impacted by fire-training activities at WAFB provide information regarding the movement and persistence of perfluorinated surfactants in groundwater at Fire-Training Area Two.

Additionally, general chemical indicators, such as specific conductance, total organic carbon (TOC) and MBAS were measured for the study to further delineate the distribution of perfluorinated surfactants in groundwater contaminated by fire-training activities at this site.

Experimental Section

Field Site Descriptions. Wurtsmith Air Force Base is located in northeast Michigan and was decommissioned in June of 1993. Historically, Fire-Training Area Two (FTA-02) (Figure 3.1) at WAFB was used for U. S. military personnel training in fire-fighting procedures. The site was used from 1952-1986 for training exercises that consisted of flooding a fire pad with flammable liquids, igniting the fluids, and subsequently extinguishing the fire with fire-fighting agents including AFFF *(19, 20)*. Before the concrete pad was installed in 1982, as well as an oil/water separator, fuel was dumped directly onto a gravel area and ignited for each fire-training exercise *(19)*.

The aquifer at WAFB is comprised of alternating eolian sands and glacial out wash material that is highly permeable and exhibits hydraulic conductivities on the order of 30 m/day *(21-23)*. The water table is located between 5 and 8 m below land surface. Aquifer solids are comprised of greater than 85% quartz minerals, with organic carbon and inorganic carbon contents below 0.1% and approximately 6.0%, respectively *(21, 22)*. Flow in the sand and gravel upper aquifer is generally eastward towards Lake Van Etten and south-southeast to the Au Sable River discharge areas at average rates of 0.1 to 0.3 m/day *(22-24)*. Direction of groundwater flow at WAFB does not change significantly from season to season *(23)*.

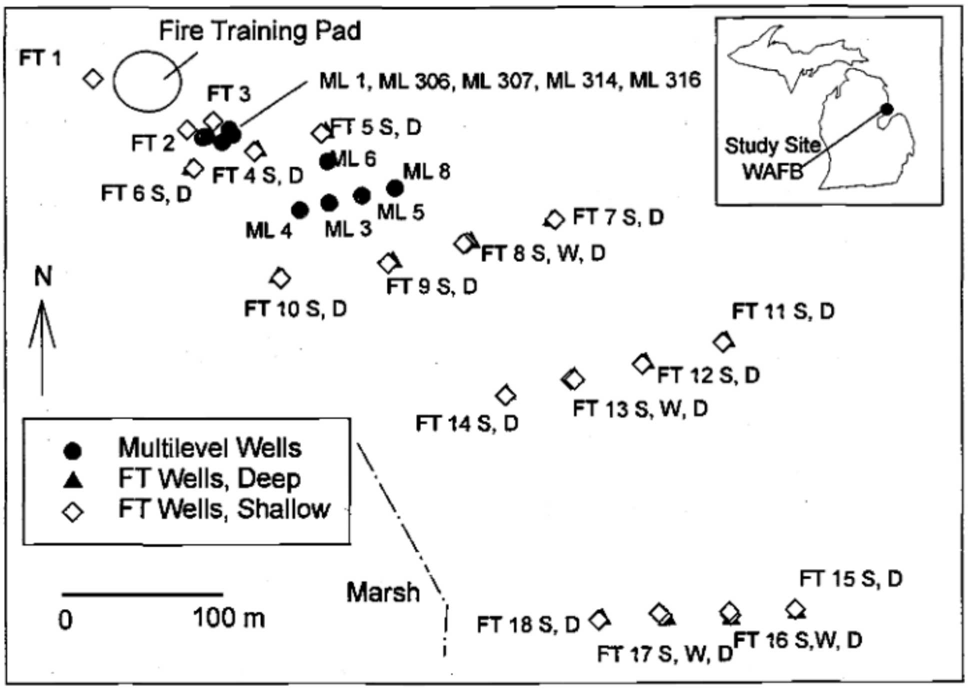

Figure 3.1. Map of Wurtsmith Air Force Base field site Fire-Training Area Two indicating locations of groundwater wells and direction of regional groundwater flow. The study site location is highlighted on the map of Michigan (inset).

At FTA-02, two types of monitoring wells have been installed over time. Monitoring wells with the identifier FT denote iron-cased 10 cm inner diameter wells with 1 to 6 m screened intervals. These wells consist of shallow wells with a screen set 3 to 6 m below the water table, and deep wells with screens set near the base of the aquifer *(23)*. Wells with ML notation describe multilevel sampling wells constructed from 2.5 cm inner diameter PVC casing with 0.3 m screened intervals that are vertically spaced from 0.5 to 2 m *(21)*.

Contaminants detected in WAFB groundwater include petroleum hydrocarbon-fuels, oils, and lubricants; chlorinated solvents (e.g., trichloroethylene and dichloroethylene); combustion products (e.g., napthalene and phenanthrene); and chlorinated aromatic compounds *(22)*. At FTA-02, concentrations of benzene, toluene, ethylbenzene and xylenes (BTEX) range from about 20 to 1000 μg/L in the contaminated plume *(21)*.

A second field site, the KC-135 Crash Site, is located near the main runway at WAFB. Contamination by JP-4 fuel resulted from the crash of a KC-135 fuel tanker in October 1988. The crash site had one-time application of AFFFs, which is in contrast to the repeated applications of fire-fighting materials associated with fire-training exercises at FTA-02. Several multilevel sampling wells (2.5 cm inner diameter, 0.3 m screen intervals) have been installed at this site *(25, 26)*.

Sample Collection. Groundwater was sampled from monitoring wells from FTA-02 and the KC-135 Crash Site in November 1998 and June 1999, and February 1998, respectively. As groundwater was removed from the monitoring well it was circulated through a closed cell and continuously monitored for pH and specific conductance (Purge Saver Model FC 2000, QED Environmental Systems, Inc. Ann Arbor, MI). Samples for MBAS and perfluorocarboxylate determinations were collected in high-density polyethylene bottles. Polyethylene was used due to a report that indicated perfluorinated carboxylates adsorb to glass *(27)*. For the FT wells at FTA-02, an additional sample from each well was collected in glass for TOC analysis. Samples were shipped on ice without preservation and stored at 4 °C prior to analysis.

Standards and Reagents for Laboratory Analyses. Standards of perfluorobutyric acid (PFC4) (99%), perfluorooctanoic acid (PFC8) (98%), and the internal standard, 2-chlorolepidine (99%) were purchased from Aldrich Chemical (Milwaukee, WI). Methyl iodide (neat) was used as purchased from Aldrich Chemical. Methylene blue was purchased from Mallinckrodt Chemical (Paris, KY). Standards for pH measurements were purchased from Micro Essential Laboratory (Brooklyn, NY).

Laboratory Analyses. Quantitative perfluorocarboxylate concentrations were measured by the method of Moody and Field *(4)*. Strong anion exchange Empore disks were used to extract perfluorocarboxylates from groundwater. The perfluorocarboxylates were simultaneously eluted from the disks and derivatized to their methyl esters for direct analysis by electron impact (EI) and electron capture negative ionization (ECNI) gas chromatography/mass spectrometry (GC/MS). The detection limit (defined as signal to noise greater than 3) and quantitation limit (defined as signal to noise greater than 10) for perfluorocarboxylates were 3 and 13 μg/L, respectively. Quantification of perfluorohexanoic acid (PFC6) was performed assuming a response factor equal to an equimolar amount of PFC8.

To semi-quantitatively determine MBAS present in groundwater, a 10 mL groundwater sample aliquot was placed in a 50 mL plastic centrifuge tube with 4 mL of chloroform and 0.5 mL of 3mM methylene blue. The mixture was shaken vigorously for 1 min and the aqueous phase removed. The chloroform layer was rinsed by adding 5 mL of deionized water to the tube containing the chloroform and shaking again for 1 min. After removing the wash-aqueous phase, the chloroform layer was measured spectrophotometrically at 652 nm *(28-30)*. Calibration standards were made using PFC8 and MBAS values are reported as µg/L (calculated as PFC8, molecular weight 414). The detection limit of the MBAS analysis was 200 µg/L. Unlike with more conventional MBAS methods, groundwater samples were not acidified to prevent underestimation of perfluorocarboxylates. For example, acidification protonates PFC8, which has a pKa of 2.8; the free acid partitions into the chloroform layer without the MBAS cation and therefore goes undetected. At the pH of the groundwater at FTA-02 which ranged from 5.5 to 8.6 (Table 3.1). MBAS concentrations measured potentially represent the cumulative concentration of all anionic surfactant species present. The response of amphoteric surfactants, which are known to occur in some AFFF formulations, to MBAS is not well understood.

Samples were analyzed for non-volatile total organic carbon using a TOC analyzer (Model Dohrman DC-190, Rosemount Analytical, Santa Clara, CA). The TOC analyzer separately measures total carbon (TC) and inorganic carbon (IC); the TOC concentration is obtained as the difference between TC and IC. The detection limit of the TOC method was 1.0 mg/L. Because perfluorinated surfactant are reportedly stable to oxidants *(2)*, standards of PFC4 and PFC8 were analyzed for TOC, where PFC4 was completely oxidized and PFC8 gave 85% of the expected response (unpublished data).

Results and Discussion

Fire-Training Area Two Groundwater Samples. At FTA-02, thirty groundwater samples collected from ML wells (multilevel wells screened over 0.3 m interval made of PVC materials) and thirty-eight groundwater samples collected from FT wells (single depth iron-cased wells screened over a 1 to 6 m interval) were evaluated. The data collected for some of the multilevel monitoring wells, ML 306, ML 307, ML 314, and ML 316 (Figure 3.1), were omitted for this study because these wells are thought to be influenced by a bioreactor-remediation process ongoing at FTA-02, which re-injects treated water near these ML wells. The ML samples were collected in November 1998 and the FT samples were collected in June 1999. Although the wells were sampled several months apart, the groundwater velocity was used to calculate travel distance over that elapsed time period. The small distance (approximately 20 m) indicates that combining the data from the two different sampling times does not affect interpolation of the data.

Because one class of perfluorinated surfactants, perfluorocarboxylates, was detected in a limited number of groundwater samples from two other U. S. military fire-training areas *(4)* as well as in commercial AFFF mixtures (unpublished data), the groundwater from FTA-02 was analyzed for these specific compounds. The groundwater samples from FTA-02 had total perfluorinated carboxylate concentrations ranging from below the detection limit (3 µg/L) to 110 µg/L (Table 3.1). Perfluorocarboxylates containing 6 (PFC6), 7 (PFC7) and 8 (PFC8) carbons in the perfluorocarbon chain were observed in 38 of the 68 groundwater samples analyzed.

The highest concentrations of perfluorocarboxylates were observed in groundwater collected from FT 2 and FT 3 which are two monitoring wells located close to the fire-training pad (Figure 3.2a), an established source point for jet fuel components, chlorinated solvents, and AFFF *(22)*. Groundwater collected from wells located down gradient of FT 2 and FT 3 wells (and the fire-training pad), had lower concentrations of perfluorocarboxylates (less than the detection limit to 26 µg/L). Groundwater collected from FT 18, which is 500 m from the fire-training pad, had total perfluorocarboxylate concentrations of 10 µg/L. Groundwater from a background well at WAFB contained no detectable perfluorinated carboxylates (less than 3 µg/L), indicating that the occurrence of perfluorocarboxylates in groundwater downgradient from the fire-training pad at FTA-02 is the result of AFFF applications and discharge during fire-training exercises.

In comparison, the total perfluorocarboxylate concentrations measured at FTA-02 are generally lower than those previously observed at Tyndall Air Force Base and NAS Fallon (124 to 298 µg/L and 54 to 7090 µg/L, respectively) *(4)*. The differences in total concentrations of perfluorocarboxylates observed in groundwater are apparent when comparing the concentrations observed near the source at three military sites. For example, the total perfluorocarboxylate concentration in groundwater sampled near the source at NAS Fallon was 7090 µg/L where groundwater concentrations observed near the source at Tyndall Air Force Base and WAFB were 298 and 110 μg/L, respectively *(4)*. Additionally, the frequency with which fire-training tests were conducted at the individual sites undoubtedly varied and is poorly documented. Over several years, testing conducted on a weekly basis versus a monthly basis could cause the observed differences in groundwater perfluorocarboxylate concentrations.

The dominant perfluorocarboxylate detected in the FTA-02 groundwater, PFC8, generally accounted for greater than 90% of the total perfluorocarboxylate concentration and is consistent with the relative abundance of PFC8 (93%) observed at the NAS Fallon fire-training facility *(4)*. Qualitative results from the analysis of commercial AFFF products indicate that PFC8 is the dominant perfluorocarboxylate homologue (65%) where PFC7 and PFC6 comprise 10% and 25%, respectively, of total perfluorocarboxylates (unpublished data). Perfluoroheptanoic acid (PFC7) was observed in a few of the FTA-02 groundwater samples and only at the detection limit (3 μg/L). Perfluorohexanoic acid concentrations represented less than 10% of the total perfluorocarboxylate concentration. This is in contrast to Tyndall AFB groundwater where PFC6 was the most abundant perfluorocarboxylate. Electron capture negative ionization GC/MS was used to confirm the identity of PFC6, PFC7 and PFC8. The presence of PFC6 to PFC8 homologues of perfluorocarboxylates in groundwater from three U. S. military sites indicates the potential for using these unique chemicals as markers of AFFF-contaminated groundwater.

Table 3.1. Summary of groundwater data from FTA-02 sampled wells in November 1998 and June 1999.

Parameter (units)	Range
pH	5.5-8.6
Total Perfluorocarboxylates (μg/L)[3]	d. l.-110
Methylene Blue Active Substances (μg/L)[2]	400-3600
Total Organic Carbon (mg/L)[1]	d. l.–69
Specific Conductance (μS/cm)	110–810

[1] Total organic carbon detection limit is 1 mg/L.

[2] MBAS detection limit is 200 μg/L and is reported as equivalent to PFC8.

[3] Total perfluorocarboxylate concentrations reported represent the summation of PFC6 and PFC8 concentrations. The detection limit is 3 μg/L.

The observation of a suite of perfluorocarboxylates was expected since the raw materials (i.e., carboxylates) used in the synthesis of perfluorinated organic compounds are mixtures *(2, 31)*. The homologous (even and odd number) series of perfluorinated carboxylates is indicative of the electrochemical fluorination synthesis process *(4, 32)*. Furthermore, the electrochemical fluorination technique is employed by the 3M Company, which has supplied AFFF agents to the U. S. military for the past two decades *(3, 4)*. In contrast, telomerization, one alternative technique for fluorocarbon synthesis, produces only even-numbered carbon perfluorocarbons.

In addition to perfluorocarboxylates, other anionic surfactants such as alkylsulfates and perfluoroalkylsulfonates are present in commercial AFFF formulations *(16-18)*. Because our GC/MS method does not detect additional anionic species, we used MBAS as a semi-quantitiative tool to detect all anionic surfactants (of which perfluorocarboxylates are one component) present in FTA-02 groundwater. The MBAS concentrations measured in groundwater from FTA-02 ranged from 400-3600 μg/L for all wells (Table 3.1). As was the case with perfluorocarboxylates, high MBAS concentrations were predominantly centered around the fire-training pad area (Figure 3.2b) while lower MBAS concentrations extended downgradient from the source. The MBAS concentrations above background (400 μg/L) indicate the presence of additional anionic surfactant components associated with past AFFF applications at FTA-02. The observation of anionic surfactant species in groundwater several hundred meters downgradient from the fire-training pad area indicates that the unidentified anionic

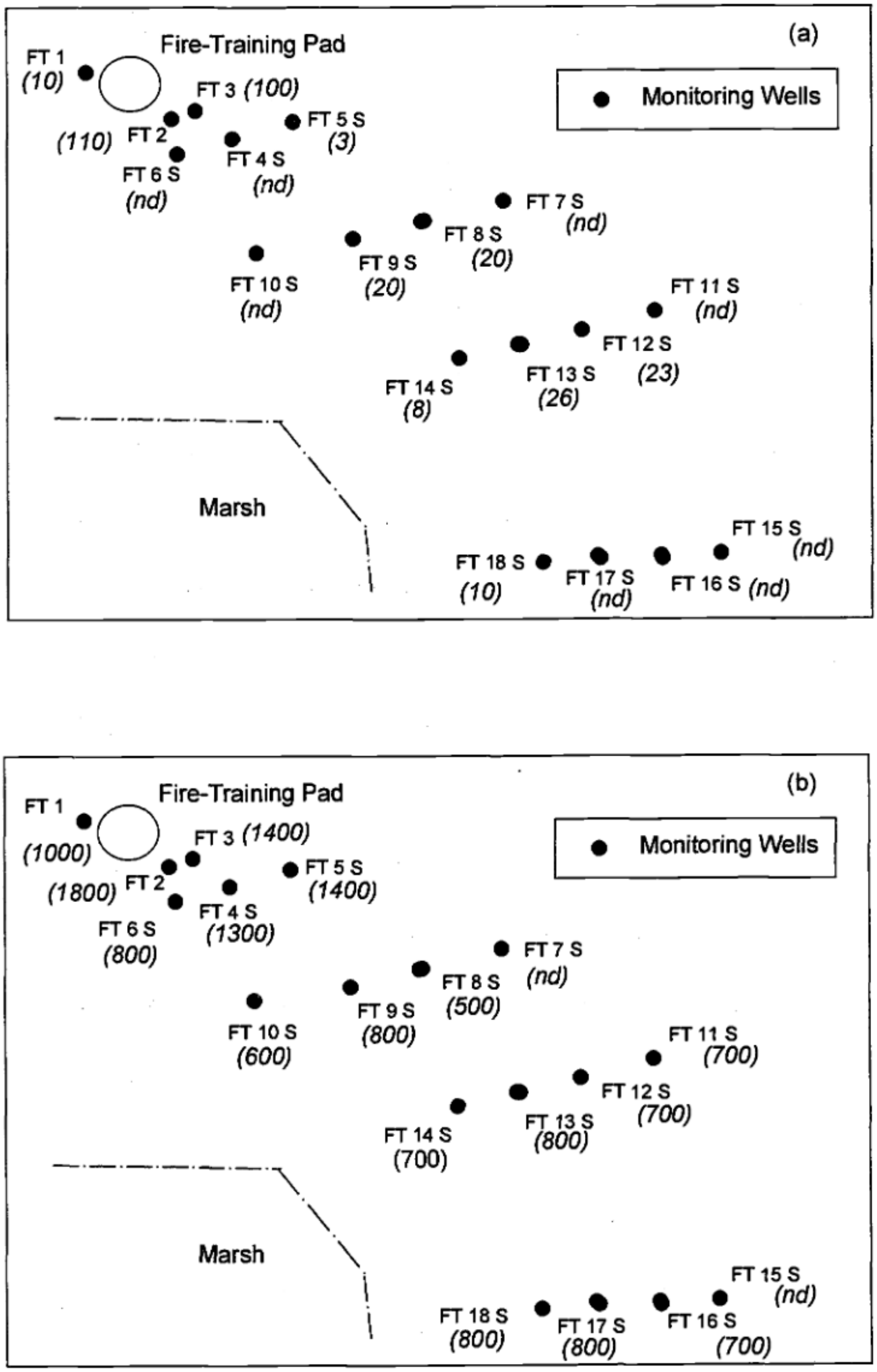

Figure 3.2. Distribution of (a) perfluorocarboxylate concentrations (µg/L) and (b) methylene blue active substances concentrations (µg/L) in shallow FT monitoring wells.

surfactants are transported by WAFB groundwater. The MBAS concentrations measured in groundwater at FTA-02 are of similar magnitude in concentration to those reported for sewage contaminated groundwater, which ranged from 300 to 2300 µg/L *(13)*.

The perfluorocarboxylate concentrations observed in groundwater from FTA-02 are significantly lower than the MBAS concentrations indicating that perfluorocarboxylate concentrations account for only a fraction of the anionic surfactants present in the groundwater at FTA-02. For example, the perfluorocarboxylates account for 6.1% and 1.3% of the MBAS concentrations measured in groundwater from FT 2 and FT 18, respectively. Liquid chromatography/mass spectrometry (LC/MS) was used to tentatively identify an additional class of perfluorinated surfactants, perfluorooctane sulfonate, in groundwater from FTA-02 *(33)*. Perfluoroalkylsulfonates are one of the major perfluorinated surfactant classes present in commercial AFFF formulations, which is indicated in product material safety data sheets. Additional method development is necessary to quantify perfluorooctane sulfonate and to identify other classes of fluorinated surfactants (such as amphoteric) potentially present in AFFF-contaminated groundwater.

Total organic carbon measurements were made to quantify all carbon containing compounds in the groundwater water at this site, which includes volatile contaminants (e.g., fuel components and chlorinated solvents) and non-volatile contaminants (e.g., AFFF components, including fluorocarbon- and hydrocarbon-based surfactants). The TOC values for the groundwater sampled from the wells sampled at FTA-02 ranged from the detection limit (1 mg/L) to 69 mg/L (Table 3.1) with high TOC values (i.e., 69 mg/L and 55 mg/L) close to the fire-training pad. The groundwater from the background well had a TOC value of 2 mg/L. Interestingly, perfluorocarboxylate and MBAS concentrations comprised only a small fraction of the measured TOC values. For example, near the fire-training pad perfluorocarboxylate and MBAS concentrations represent 0.2% and 2%, respectively, of the TOC concentration measured in monitoring well FT 2.

Despite a minimum of 13 years of inactivity at this site, significant concentrations of perfluorocarboxylates, MBAS, and TOC are still detected near the source. The soils in the vicinity of the fire-training pad could have a sorbed organic solid phase or a separate liquid phase. For example, FTA-02 sediments have total petroleum hydrocarbon concentrations of 13,650 mg/kg between 4.5 and 5.7 m below the ground surface *(34)*. This is likely a result of fire-training exercises at FTA-02 where unburned fuel and other priority pollutants as well as AFFF entered the subsurface. In addition, at several locations near the pad, a discontinuous layer of black, tar-like substance was observed at 0.3 to 0.9 m below the land surface. This layer is approximately 0.1 m thick, and is detected downgradient as far as monitoring well FT 4 (Figure 3.1) *(19)*, which is approximately 50 meters from the fire-training pad. A free/residual non-aqueous phase liquid (NAPL) plume comprised of jet fuel components and/or chlorinated solvents has been suggested by others to be present in the fire-training pad area *(24)*. The association, if any, between the perfluorinated and non-perfluorinated surfactants with NAPL is unknown.

In order to make a judgment about the transport of perfluorocarboxylates as well as other anionic perfluorinated surfactants in groundwater at FTA-02, a commonly used approach is to compare the distribution of perfluorinated compounds to that of a conservative plume component such as those that are measured by specific conductance. Specific conductance measurements at FTA-02 ranged from 110 to 810 μS/cm (Table 3.1) with the highest values measured near the fire-training pad area. The specific conductance of groundwater sampled from a well representing background conditions was 250 μS/cm. The distribution of specific conductance at FTA-02 (Figure 3.3) is consistent with previous reports of groundwater contamination at this site *(19, 21, 22, 34)* and indicates that the plume of contaminants may be turning to the southwest direction, away from FT wells 15-18 (Figure 3.1), and discharging into a marshy area. Unfortunately, no groundwater or surface water samples were collected from the marsh area for this investigation.

Because the terminus of the contaminant plume is undefined at this field site, the spatial relationship of perfluorocarboxylates to specific conductance can not be evaluated and therefore it is difficult to estimate perfluorocarboxylate transport relative to conservative components of the plume. If a well-defined terminus of the plume had been present, the transport distance of measured parameters combined with the time of operation of activities at the training area could be used to estimate flow rates as well as retardation factors for perfluorocarboxylates (and MBAS). It is known that perfluorocarboxylates present in groundwater 500 m from the fire-training area is approximately 5-15 years old assuming a 0.1-0.3 m/day groundwater velocity *(22-24)*.

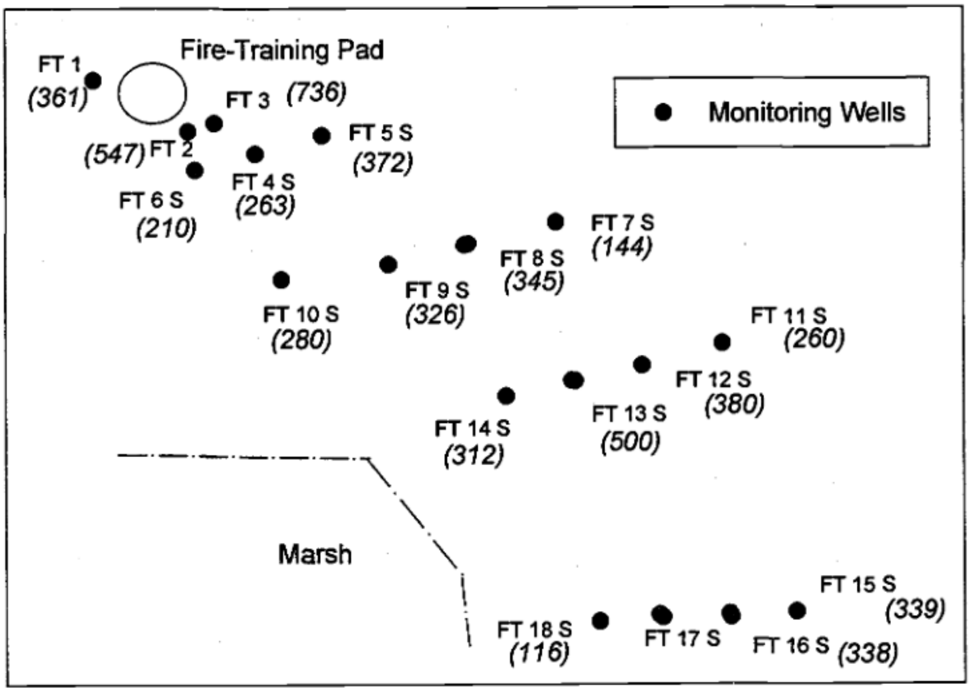

Figure 3.3. Distribution of specific conductance measurements (µS/cm) in shallow FT monitoring wells.

A minimum residence time of 5 years for perfluorocarboxylates in groundwater indicates the resistance of perfluorinated compounds to degradation under the prevailing groundwater conditions at this site. If perfluorocarboxylates moved conservatively away from the source, the edge of the contaminant plume should be 475-1425 m downgradient. However, the groundwater discharges to a marshy area at approximately 500 m from the fire-training pad area.

To accurately describe the transport of perfluorinated surfactants in groundwater at FTA-02 an independent measure of retardation such as an *in-situ* tracer test could be performed at this site. A single-well push-pull test can provide *in-situ* transport information *(35)*. At a different field site located in Corvallis, OR, a single-well push-pull test was performed with perfluorooctane sulfonate and bromide as the conservative tracer. Identical breakthrough curves for bromide and perfluorooctane sulfonate were obtained indicating that perfluorooctane sulfonate was conservatively transported *(3)*. Because conservative transport of perfluorooctane sulfonate was observed in that field study, perfluorinated surfactants also may be conservative tracers for AFFF-contaminated groundwater. Clearly more research is required to fully investigate the transport behavior of perfluorinated surfactants.

Implications. Perfluorocarboxylate concentrations measured at FTA-02 as well as at other U. S. military sites, indicate that this class of specialty chemicals is a potentially unique tracer for groundwater impacted by repetitive fire-training exercises. The detection of perfluorocarboxylates at the NAS Fallon and Tyndall Air Force Base military sites, which have not been used since 1988 and 1992, respectively, *(4)* as well as the detection of perfluorocarboxylates at FTA-02 after 13 years of fire-training inactivity is consistent with the widely-held AFFF-industry view that biodegradation of the long-chain perfluorocarbon hydrophobe does not occur *(31, 36-39)*. The strength of the carbon–fluorine bond *(2, 37, 40)* as well as the rigidity of the perfluorocarbon chain *(37, 41)* are thought to contribute to the recalcitrant nature of perfluorinated compounds.

In contrast to repetitive application of AFFF at fire-training areas such as FTA-02, the site of a KC-135 airplane crash at WAFB had a one-time application of fire-fighting agents. High TOC values were observed in groundwater from monitoring wells located closest to the crash site/point source, and are attributed to the estimated 3,000 gallons of JP-4 fuel *(25, 26)* spilled at the site as a result of the crash. Alternatively, perfluorocarboxylates as well as MBAS-responsive components were not detected in the sampled groundwater; this is not surprising since the impacted area had a one-time application of fire-fighting materials over ten years ago. By evaluating groundwater from these two different field sites, there appears to be little impact from a single application of AFFF (i.e., an emergency response situation) relative to long-term repetitive applications for training purposes at FTA-02. Because hydrocarbon-fuel fires pose a serious threat to life and property, the issue of fire safety must be balanced against the risks that these products, particularly perfluorinated surfactants, potentially pose to the environment.

Three U. S. military sites *(4)* have been identified to have the presence of what appears to be a biologically-stable specialty chemical. The occurrence of perfluorocarboxylates, and potentially other perfluorinated surfactants raises issues for military bases and other facilities where fire-training exercises are conducted routinely and wastewater is disposed of improperly. Because perfluorinated surfactants co-occur with other pollutants (e.g., fuel components, solvents, etc.) in groundwater, it is important to determine if perfluorinated surfactants affect the transport and biodegradation of other contaminants. Additionally, research is needed to further examine the possible presence of NAPLs and their influence of AFFF components on the solubility and transport of NAPLs in the subsurface at WAFB.

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Chapter 4

Summary

Aqueous film forming foam formulations are used to extinguish hydrocarbon-fuel fires that pose a serious threat to life and property. In preparation for such fires, training exercises are often conducted. Because of past fire-training exercises at military bases, as well as response to emergency situations, AFFF-laden wastewater containing fuels, solvents, and other materials directly entered groundwater without prior treatment, and has led to groundwater contamination. Fluorinated surfactants are a unique class of chemicals present in AFFFs that are directly discharged to the environment. Fluorinated surfactants differ significantly from hydrocarbon surfactants such that direct analogies can not be drawn between the two types of surfactants. The information contained in this thesis addresses the gap in knowledge regarding the occurrence, distribution, and transport of perfluorinated surfactants in the subsurface.

An analytical method based on the use of solid-phase extraction and followed by an in-vial elution and derivatization was used to quantitatively determine a suite of perfluorinated carboxylates (PFC6 to PFC8) in groundwater. Concentrations of perfluorocarboxylates ranged from 125 to 7,090 μg/L in a limited number of groundwater samples collected from NAS Fallon, NV, and Tyndall AFB, FL.

Historically, AFFF mixtures were applied at Wurtsmith Air Force Base (Oscoda, MI), at various locations including the Fire-Training Area Two and at the site of an airplane crash. Total perfluorocarboxylate concentrations (PFC6 to PFC8) ranging from near the detection limit (3 μg/L) to 110 μg/L were measured in groundwater sampled from an extensive well array at Fire-Training Area Two. Perfluorocarboxylate concentrations detected over 500 m from the source area have an approximate minimum residence time of 5 to 15 years. The observed methylene blue active substances concentrations indicate that perfluorocarboxylates are only a small fraction of the anionic surfactants present in the groundwater. This finding highlights the need for further analytical method development in order to fully characterize the contaminated groundwater.

In contrast to the repetitive application of AFFF at fire-training areas such as Fire-Training Area Two, the airplane crash site at Wurtsmith Air Force Base had a one-time application of fire-fighting agents. Not surprisingly, the MBAS concentrations were below the detection limit (0.2 mg/L) and total perfluorocarboxylate concentrations also were below the detection limit (0.3 μg/L). The analysis of groundwater from two sites with different AFFF application histories indicates a disparity between a single deployment of AFFFs (i.e., an emergency response situation) and repetitive applications for fire-training purposes.

The observed suites of perfluorocarboxylates containing 6 to 8 carbons in groundwater from the three military sites is consistent with the manufacture of these specialty chemicals, since the raw materials used in the synthesis of perfluorinated organic compounds are themselves mixtures. The specific ratios of perfluorohexanoic, perfluoroheptanoic, and perfluorooctanoic acids observed at the three military sites may be the result of different AFFF formulations used at each of the sites. The observed homologous series consisting of even and odd number perfluorinated carboxylates is indicative of the electrochemical fluorination process. In contrast, other fluorination processes, such as telomerization, produce only even-numbered homologues. The detection of perfluorinated carboxylates at NAS Fallon, NV, Tyndall Air Force Base, FL, and Wurtsmith Air Force Base, MI, military sites that have not been used since 1988, 1992, and 1986, respectively, is consistent with the view that long chain perfluorocarbon hydrophobes do not biodegrade. Because perfluorocarboxylates persist in the environment, they may serve as unique tracers of groundwater impacted by repetitive fire-training exercises.

Because commercial formulations of AFFF are complex mixtures, the employment of these mixtures in fire-training situations introduces both priority and non-priority pollutants into the environment. Questions remain regarding how chromatographic separation during transport affects these complicated mixtures. Because perfluorinated surfactants persist in the environment, they may impact the biogeochemical processes that affect the distribution and bioavailability of co-contaminants. Moreover, the effect, if any, that biodegradation of AFFF components has upon the microbial ecology and activity of the subsurface is unexplored. Finally, the need for additional analytical methods to measure perfluorinated surfactants is necessary to address questions about the occurrence, environmental behavior, and impact of these classes of specialty chemicals.

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Determination of Perfluorocarboxylates in Groundwater Impacted by Fire-Fighting Activity

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Abstract:

Perfluorinated surfactants are used in aqueous film forming foam (AFFF) formulations, which are used to extinguish hydrocarbon-fuel fires. Virtually nothing is known about the occurrence of perfluorinated surfactants in the environment, in particular, at fire-training areas and emergency response sites where AFFF entered groundwater without prior treatment. Strong anion exchange Empore disks were used to extract perfluorocarboxylates from groundwater collected from fire-training facilities located on Naval Air Station Fallon, NV, and Tyndall Air Force Base, FL. The carboxylates were simultaneously eluted from the disks and derivatized to their methyl esters for direct analysis by gas chromatography/mass spectrometry. Perfluorocarboxylates containing six to eight carbons were detected in groundwater collected from the two field sites with total concentrations ranging from 125 to 7090 µg/L. The detection of perfluorocarboxylates at field sites after 7-10 years of inactivity indicates their potential utility as markers for delineating groundwater impacted by fire-fighting activity.

[Full text in html]
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What is significance of findings?
Is this a bad thing?

Test site is trg ground.

Significance is it was funded by EPA. Indicates their getting interested in AFFF.

7/99

Determination of Perfluorocarboxylates in Groundwater Impacted by Fire-Fighting Activity

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Perfluorinated surfactants are used in aqueous film forming foam (AFFF) formulations, which are used to extinguish hydrocarbon–fuel fires. Virtually nothing is known about the occurrence of perfluorinated surfactants in the environment, in particular, at fire-training areas and emergency response sites where AFFF entered groundwater without prior treatment. Strong anion exchange Empore disks were used to extract perfluorocarboxylates from groundwater collected from fire-training facilities located on Naval Air Station Fallon, NV, and Tyndall Air Force Base, FL. The carboxylates were simultaneously eluted from the disks and derivatized to their methyl esters for direct analysis by gas chromatography/mass spectrometry. Perfluorocarboxylates containing six to eight carbons were detected in groundwater collected from the two field sites with total concentrations ranging from 125 to 7090 μg/L. The detection of perfluorocarboxylates at field sites after 7–10 years of inactivity indicates their potential utility as markers for delineating groundwater impacted by fire-fighting activity.

Introduction

Aqueous film forming foams (AFFF) are complex mixtures of surfactants and other components used to extinguish hydrocarbon–fuel fires that occur at fire-training sites as well as in emergency situations. Aqueous film forming foams have been commercially available for fire-fighting applications since their development by the United States Navy and 3M Co. in the mid-1960s (*1*). At fire-training areas that routinely used AFFF mixtures and military emergency response sites, AFFF-laden wastewater that entered surface water and groundwater without treatment has led to groundwater and soil contamination. For example, perfluorinated compounds were tentatively identified in groundwater impacted by fire-training activities at Tyndall Air Force Base (*2*). Unfortunately, definitive identifications of the perfluorinated compounds were not reported.

Commercial AFFF mixtures are proprietary in nature and typically contain fluorinated and nonfluorinated surfactants (*1, 3–5*). Due to the proprietary nature of AFFF formulations, the chemical structures of the actual perfluorinated surfactants used in commercial AFFFs are not known outside the companies that manufacture them (*5*). Moreover, the analysis of anionic perfluorinated surfactants that are known to occur in AFFF formulations (*6*) is problematic because the surfactants are nonvolatile and may not contain chromophores. As a result, analytical methods for AFFF formulation components are lacking, and therefore it is difficult to assess their occurrence, fate, and transport in AFFF-contaminated groundwater. Because perfluorinated surfactants co-occur with other pollutants (e.g. fuel components, solvents, etc.) in groundwater, it is important to determine if perfluorinated surfactants affect the transport and biodegradation of other contaminants. Free and emulsified oil, fuel, and AFFF components were shown to adversely affect activated sludge processes (*6, 7*) and the performance of anaerobic sludge digestors (*8*) in wastewater treatment facilities. For this reason, perfluorinated surfactants may have an adverse affect on groundwater microbial populations and their ability to degrade co-contaminants present in AFFF-contaminated groundwater.

In addition to fluorinated surfactants use in fire-fighting foams, they are also utilized in herbicides and insecticides, cosmetics, greases and lubricants, and adhesives (*3*). Fluorinated carboxylic acids of industrial significance include perfluorooctanoic acid (PFC8) and perfluorodecanoic acid (PFC10) (*9*). There is concern regarding the potential toxicity of perfluorinated carboxylic acids. An in vivo study of rat liver response to PFC10 indicated the rapid onset of a low-level heptatotoxicity but no detectable damage to the DNA (*10*). Perfluorodecanoic acid and PFC8 have been found to inhibit gap junction intercellular communication in rat liver epithelial cells (*11*) and may be involved in tumor promotion (*9*).

In this paper, we describe the isolation, identification and quantification of perfluorinated carboxylates in groundwater impacted by fire-training activities at Naval Air Station (NAS) Fallon, NV, and Tyndall Air Force Base, FL. The development of analytical methods is necessary before investigating the occurrence and distribution of perfluorinated surfactants in AFFF-contaminated groundwater and their effect on co-contaminant transport and biodegradation.

Experimental Section

Standards and Reagents. Standards of PFC8 (98%), perfluorododecanoic acid (PFC12) (95%), and the internal standard, 2-chlorolepidine (99%), were purchased from Aldrich Chemical (Milwaukee, WI). Methyl iodide (neat) was used as purchased from Aldrich Chemical.

Field Sites and Sample Collection. From the mid-1950s to 1988, the crash crew training area at NAS Fallon, NV (Figure 1a), was used to conduct fire-training activities, which consisted of flooding a fire pit with flammable liquids, igniting the fluids, and subsequently extinguishing the fire with fire-fighting agents including AFFF (*12*). For a typical training exercise, approximately 75–100 L of AFFF concentrate were diluted with 1200–3200 L of water according to specifications (3% or 6% solution) and subsequently employed. During the years of activity at the NAS Fallon site, training exercises occurred on a weekly to monthly basis. At the NAS Fallon site, groundwater samples were collected from four monitoring wells located within a 120 m radius of the fire pit where the water table is located between 2 and 3 m below the land surface.

The Tyndall Air Force Base Fire-Training Area FT-23 was used from 1980 to 1992 for similar activities (Figure 1b) (*13*). Four groundwater samples were obtained from wells surrounding the fire-training area; the water table is located between 1 and 2 m below the land surface. All samples were collected in high-density polyethylene brown bottles because

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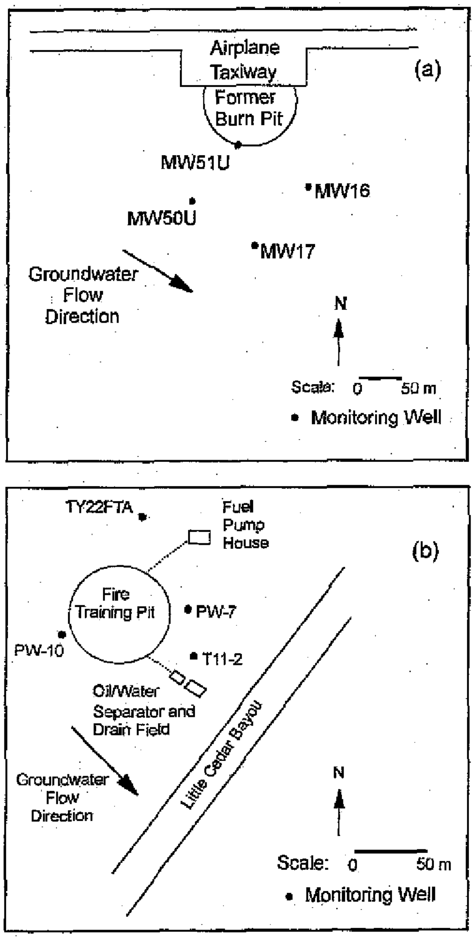

FIGURE 1. Map of (a) Naval Air Station Fallon and (b) Tyndall Air Force Base field sites indicating location of groundwater wells and direction of regional groundwater flow.

perfluorinated carboxylates adsorb to glass (*14*). Samples were shipped on ice without preservation and stored at 4 °C prior to analysis.

Solid-Phase Extraction and Derivatization. Samples (55–200 mL) were extracted through 25 mm strong anion exchange (SAX) disks in a manner similar to that described by Field and Reed (*15*) with the exception that the SAX disks were pretreated prior to use to remove interfering disk impurities. Pretreatment consisted of soaking the disks in 12 mM HCl/acetonitrile for 2 days after which the disks were soaked in pure acetonitrile for several hours. Just prior to use, the disks were rinsed with a minimum of 350 mL of deionized water in order to sufficiently rinse the HCl from the disks and wet them prior to passing groundwater samples through them. Samples (55–200 mL) were passed through the disks under full vacuum, and the disks were then allowed to dry. The disks containing the exchanged analytes were placed in a 2 mL autosampler vial together with 1 mL of acetonitrile, 51.2 μg of internal standard, and 100 μL of methyl iodide. When heated at 80 °C for 1 h, the acids were simultaneously eluted from the disk and derivatized to their methyl esters.

Spike and Recovery. Spike and recovery experiments were performed to determine the precision and accuracy of the SAX disk extraction and in-vial elution method. A set of experiments was performed on groundwater samples from NAS Fallon MW 50U and MW 17 that had been previously determined to contain neither PFC8 nor PFC12 above detection. Duplicate groundwater samples from wells MW 50U and MW 17 were spiked to contain a final concentration of 1240 μg/L of PFC8 and 560 μg/L of PFC12.

Standard addition analyses were performed with NAS Fallon groundwater samples that contained measurable quantities of PFC8; the samples did not contain PFC12 above detection. Known amounts of PFC8 were added to samples to give a final concentration twice that of the background concentration. For example, groundwater from MW 51U and MW 16, which contained background concentrations of 6570 and 460 μg/L, respectively, were spiked to give final concentrations of 12900 and 1000 μg/L of PFC8, respectively. Each sample also was spiked with 56.4 μg of PFC12. To determine the detection limit of the method, single samples of groundwater that contained no perfluorinated carboxylates above detection were spiked to give a range of final PFC8 concentrations from 18 to 54 μg/L.

Gas Chromatography/Mass Spectrometry. Extracts were analyzed using a Hewlett-Packard Model 5890 Series II Plus gas chromatograph (GC) equipped with a 30 m × 0.32 mm × 4.00 μm SPB-1 SULFUR column (Supelco Inc., Bellefonte, PA). An injection volume of 1 μL was used under splitless conditions with an injector temperature of 200 °C. The GC oven temperature was initially held for 6 min at 60 °C, increased by 6 °C/min to 190 °C, increased further by 30 °C/min to 270 °C, and then held for 5 min.

Quantification of perfluorocarboxylate methyl esters was performed using a Hewlett-Packard Model 5972 mass selective detector operated in electron impact (EI) mode (70 eV). The mass selective detector was operated in full scan (50–450 amu) mode and in selected ion monitoring (SIM) mode using a dwell time of 100 ms for each ion. The scanning mode was used for qualitative identification while SIM mode was used for quantification. The ions of m/z 131 $[C_3F_5]^+$, m/z 169 $[C_3F_7]^+$, and m/z 219 $[C_4F_9]^+$, which are characteristic fragments of perfluorocarbons (*16–18*), were used to identify and quantify the methyl esters of perfluorohexanoic acid (PFC6), perfluoroheptanoic acid (PFC7), PFC8, and PFC12. The internal standard, 2-chlorolepidine, was quantified with the ions at m/z 177 and m/z 115.

The identification of perfluorocarboxylate methyl esters was confirmed by electron capture negative ionization (ECNI) GC/MS, which gave unique molecular ions for each of the perfluorinated carboxylate methyl esters (e.g. m/z 328 for PFC6, m/z 378 for PFC7, m/z 428 for PFC8, and m/z 628 for PFC12). These measurements were performed with a Varian 3400 gas chromatograph interfaced with a Finnigan Model 4023 mass spectrometer. Methane was used as the reagent gas, and the mass spectrometer was operated in full scan mode (100–650 amu). The gas chromatograph was operated with a column and temperature program identical to that used for the EI GC/MS.

Initially, samples prepared in deionized water were used as the matrix for constructing calibration curves, and standard recoveries were low. However, when samples prepared in tap water, which contains inorganic cations and anions, were used as the matrix for constructing calibration curves, quantitative recovery of standards was obtained. It is proposed that the 350 mL of deionzed water does not sufficiently rinse the disks of residual HCl and tap water is required to completely rinse the disks and obtain quantitative recovery of standards. Therefore, calibration curves for quantification of PFC8 were constructed by passing 100 mL of tap water samples that had been spiked with 3.6–1080 μg of PFC8 through 25 mm SAX disks and derivatizing the acids to their methyl esters using the in-vial elution and derivatization technique. The calibration curve for PFC12 was constructed in a similar manner by adding 7.5–113 μg of PFC12 standard to 100 mL of tap water. For all quantitation

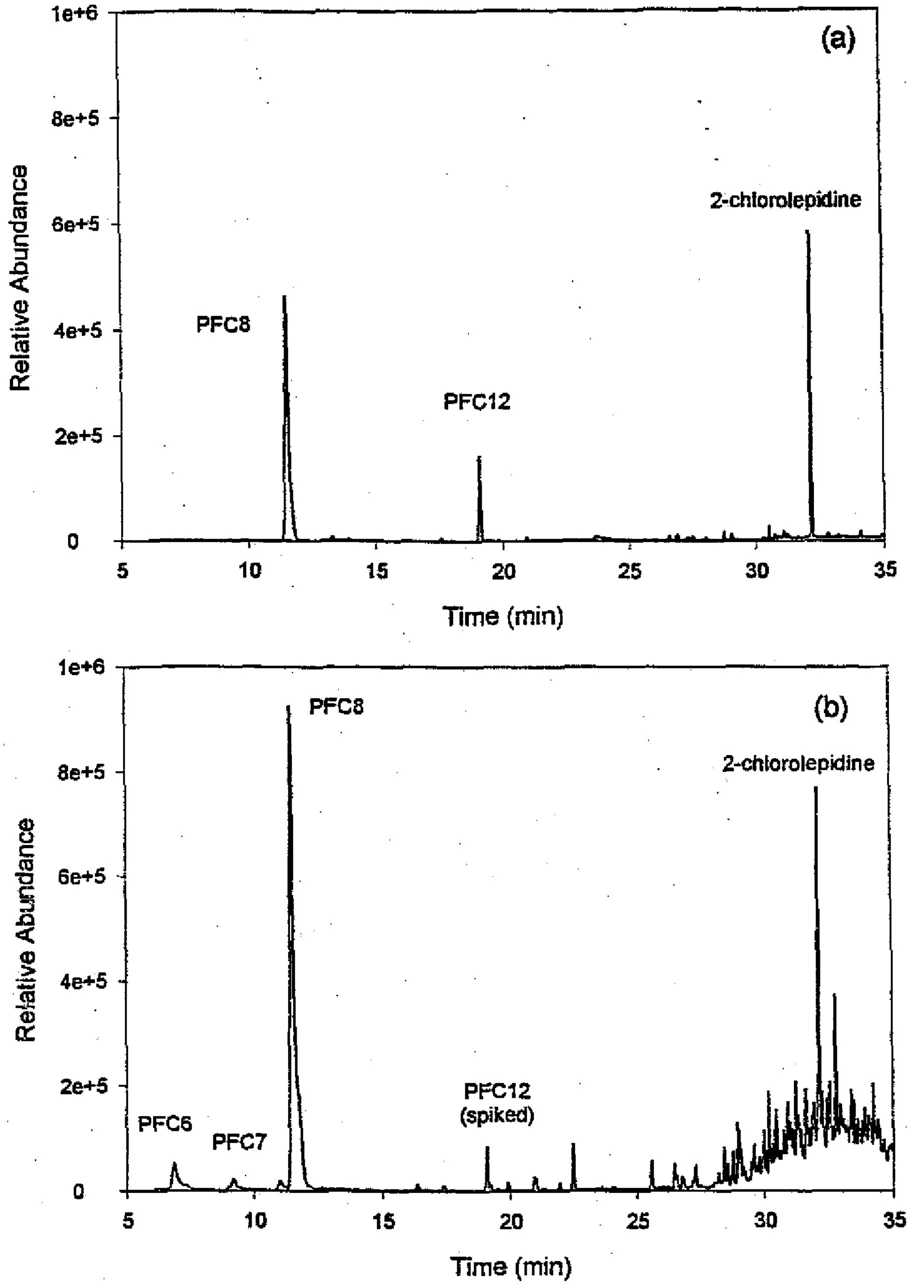

FIGURE 2. (a) Typical EI GC/MS chromatogram of PFC8 and PFC12 standards and (b) perfluorinated carboxylates, including PFC6, PFC7, PFC8, and PFC12 (spiked) in Naval Air Station Fallon groundwater.

standards, a total of 51.2 μg of the 2-chlorolepidine internal standard was added to the autosampler vial just prior to the addition of methyl iodide. Both calibration curves were linear with r^2 typically greater than 0.99. Quantification of PFC6 and PFC7 was performed assuming a response factor equal to an equimolar amount of PFC8.

Results and Discussion

Gas Chromatography/Mass Spectrometry. A film thickness of 4 μm (30 m × 0.32 mm SPB-1 SULFUR; Supelco, Bellefonte, PA) was necessary to obtain sufficient retention times for the methyl esters of PFC8 and PFC12 to allow for the separation and quantification (Figure 2a). Initial attempts to separate and quantify the perfluorinated carboxylate methyl esters on a thin film (0.25 μm), 30 m × 0.25 mm DB-1 (J&W Scientific; Folsom, CA) column were unsuccessful regardless of the initial column temperature. Note that the stationary phases in the SPB-1 SULFUR and DB-1 columns are comparable. A standard of perfluorobutyric acid was not observed under any of the described GC conditions; it is most likely that an initial oven temperature less than 40 °C would be required.

The EI mass spectra of methyl PFC8 (Figure 3a) and PFC12 indicate characteristic perfluorocarbon fragmentation *(16, 17)* in which the major ions (e.g., 69, 119, 169, 219, etc.) differ by 50 amu, which corresponds to the mass of CF_2. Molecular ions were not observed for any of the perfluorinated carboxylate methyl esters under EI conditions; however, molecular ions $[M]^-$ were observed under ECNI conditions. For example *m/z* 428 (in Figure 3b) corresponds to the molecular ion of methyl PFC8.

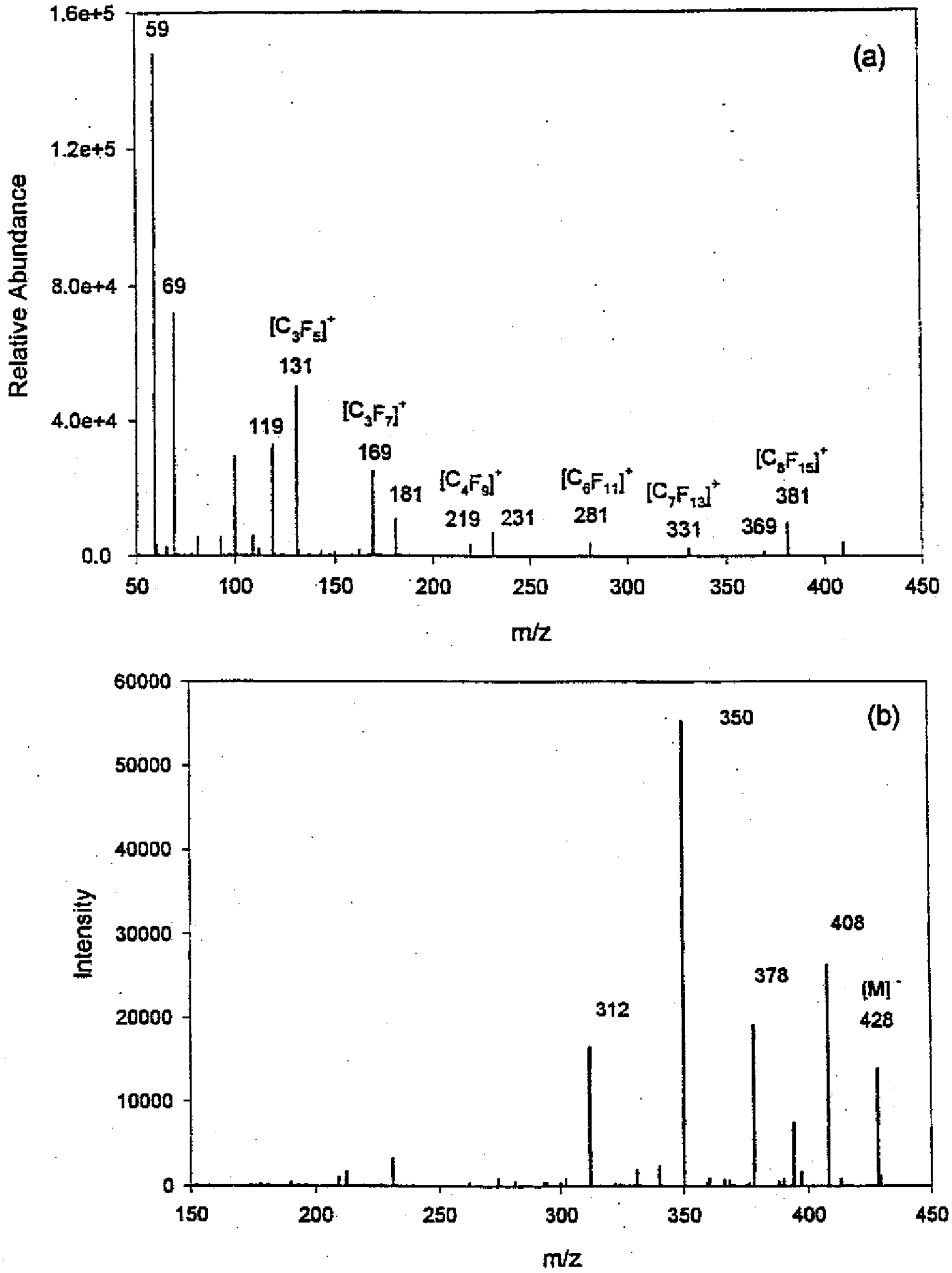

FIGURE 3. (a) EI mass spectrum of methyl PFC8. (b) ECNI mass spectrum of methyl PFC8.

Solid-Phase Extraction. Prior to developing a solid-phase extraction method, initial experiments were conducted using diazomethane as the derivatization reagent. When perfluorinated carboxylates were derivatized using ethanol-based diazomethane, multiple peaks corresponding to methyl and ethyl esters were detected (unpublished data). Because EI GC/MS did not produce molecular ions, ECNI GC/MS was used to verify the formation of both methyl and ethyl esters. Consequently, if ethanol-based diazomethane was used for derivatization in conjunction with EI GC/MS, multiple peaks in a chromatogram could be erroneously interpreted as a greater number of perfluorinated compounds than are actually present. In contrast, only the methyl ester was obtained when butyl carbitol (2-(2-butoxyethoxy)ethanol) was used to prepare the diazomethane reagent. However, because of the hazards associated with the use of diazomethane and the time-consuming nature of diazomethane derivatization, an alternative method was desired.

Derivatization of the perfluorocarboxylates by solid-phase extraction and the in-vial elution and derivatization technique gave only a single peak that corresponded to the methyl ester of each perfluorinated carboxylate standard; the identification of each methyl ester was confirmed by ECNI GC/MS. In addition, the solid-phase extraction approach combined the steps of isolation and derivatization, which greatly simplified the procedure and eliminated the use of diazomethane.

Six replicate analyses of blank 25 mm SAX disks that had not been prerinsed with 12 mM HCl/acetonitrile prior to use, yielded an average of 21 ± 1 μg (4.8% relative standard deviation (RSD)) of PFC8 per disk. No other perfluorinated carboxylates were present in the disks above the detection limit. The PFC8 is associated with the Teflon matrix and not

TABLE 1. Recovery of PFC8 and PFC12 Spiked into Groundwater Samples from Naval Air Station Fallon[a]

sample	% recovery	
	PFC8	PFC12
NAS Fallon MW 51U[b]	83[c]	35
NAS Fallon MW 16	90[d]	85
NAS Fallon MW 50U	73	77
NAS Fallon MW 17	74	88

[a] Duplicate samples were analyzed. Sample volume was 100 mL unless otherwise noted. [b] Sample volume was 55 mL. [c] Calculated as the final measured concentration divided by background concentration plus spike concentration and multiplied by 100. The background concentration was 6,570 μg/L. [d] Calculated as the final measured concentration divided by background concentration plus spike concentration and multiplied by 100. The background concentration was 460 μg/L.

the embedded anion exchange particles (unpublished data). The background PFC8 was successfully removed by rinsing the disks prior to use with 12 mM HCl/acetonitrile followed by 350 mL of deionized water. It should be noted that benzoic acid and ethylhexylphthalic acid are also present in the disks as artifacts and are removed by the HCl/acetonitrile prerinse step.

Accuracy, Precision, and Detection Limits. The recoveries of PFC8 from blank groundwater samples obtained from NAS Fallon wells MW 50U and MW 17 were 73 and 74%, respectively, while the recoveries of PFC12 were 77 and 88%, respectively (Table 1). Because detectable levels of PFC8 occurred in groundwater from MW 51U and MW 16, standard addition experiments were performed to determine the recoveries of PFC8. The recoveries of the PFC8 spiked into MW 51U and MW 16 groundwater to give a final concentration double that of the background concentration were 83 and 90%, respectively (Table 1). The recoveries of PFC12 from MW 51U and MW 16 groundwater, which did not contain background concentrations of PFC12, were 35 and 85%, respectively (Table 1). Although the recovery of PFC8 (83%) differs significantly from that of PFC12 (35%) in groundwater from MW 51U, the recoveries of PFC8 and PFC12 were nearly equivalent for the other groundwater samples. Monitoring well 51U is located closest to the fire pit where AFFF agents where applied to burning mixtures of fuels and solvents. Due to its proximity to the fire pit, the groundwater from MW 51U most likely contains the greatest diversity of inorganic and organic constituents, which may adversely affect PFC12 recoveries relative to that of PFC8. Therefore, although the original intent was to use the PFC12 as a surrogate standard because it did not occur in the groundwater samples, PFC12 appears more sensitive to matrix interferences compared to PFC8 so that it is an inappropriate choice for a surrogate standard. For this reason, all subsequent quantification was based on the 2-chlorolepidine internal standard.

The precision, indicated by the RSD, calculated from five replicate analyses each of groundwater from NAS Fallon MW 16 and Tyndall AFB T11-2 ranged from 3.7 to 14% (Table 2). The detection and quantitation limit of the method was defined as those concentrations of PFC8 needed to produce a signal-to-noise (*S/N*) of 3:1 and 10:1, respectively. The detection and quantitation limits for PFC8 were 18 and 36 μg/L, respectively.

Application to Groundwater Samples. Four groundwater samples from both NAS Fallon and Tyndall AFB were analyzed for perfluorinated carboxylates. Chromatograms obtained by EI GC/MS indicated the presence of multiple perfluorinated compounds all having characteristic perfluorocarbon fragmentation (Figure 2b). Analysis by ECNI GC/MS established the identification of PFC6, PFC7 and PFC8 in groundwater obtained from wells MW 51U and MW 16 from NAS Fallon. The molecular ions $[M]^-$ for methyl PFC6 (m/z 328) and methyl PFC7 (m/z 378) were observed for peaks eluting 4.7 and 2.3 min before that of PFC8 (Figure 4a,b). The ECNI mass spectrum for methyl PFC8 in MW 51U was similar to that of the PFC8 standard (Figure 2b).

The groundwater samples from NAS Fallon MW 51U and MW 16 had total perfluorinated carboxylate concentrations of 7090 and 540 μg/L, respectively (Table 2). The PFC6 detected in NAS Fallon groundwater samples from MW 51U and MW 16 comprised 5.2% and 11%, respectively, of the total perfluorocarboxylates detected. The PFC7 was 2.1% and 3.3% respectively, of the total perfluorinated carboxylates detected in these wells. The dominant perfluorinated carboxylate, PFC8, accounted for 93% and 85%, respectively, of the total perfluorocarboxylate concentration.

The highest concentrations of perfluorocarboxylates were observed in groundwater collected from NAS Fallon MW 51U, which is the well located closest to the fire-training pit (Figure 1a). Monitoring well 16, which is located downgradient of MW 51U and the fire-training pit, had lower but detectable concentrations of perfluorocarboxylates. Groundwater from MW 50U and MW 17, which are located off gradient from the fire-training pit, contained no detectable perfluorinated carboxylates. Over the approximate 100 m distance between MW 51U and MW 16, the concentrations of the perfluorinated carboxylates decreased with increasing number of carbons. For example, the concentration of PFC6 decreased 85% over the 100 m compared to decreases of 88% and 93% for PFC7 and PFC8, respectively.

The groundwater samples from Tyndall AFB PW-10, PW-07, and T11-2 contained total perfluorinated carboxylate concentrations of 298, 159, and 124 μg/L, respectively (Table 2). The compositions of Tyndall AFB groundwater collected from the three wells ranged from 46 to 52% for PFC6, from 13 to 15% for PFC7 and from 34 to 40% for PFC8. In contrast to the groundwater samples from NAS Fallon, the dominant perfluorinated carboxylate in Tyndall AFB groundwater was PFC6.

TABLE 2. Concentrations of Perfluorinated Carboxylates in Groundwater Samples from Naval Air Station Fallon and Tyndall Air Force Base[a,b]

sample	*n*	PFC6 (μg/L)	PFC7 (μg/L)	PFC8 (μg/L)	total (μg/L)
NAS Fallon MW 51U	3	372 ± 4 (1.1%)	149 ± 5 (3.4%)	6570 ± 150 (2.3%)	7090 ± 160 (2.3%)
NAS Fallon MW 16	5	57 ± 8 (14%)	18 ± 2 (11%)[c]	460 ± 20 (4.3%)	540 ± 20 (3.7%)
NAS Fallon MW 50U	3	nd	nd	nd	nd
NAS Fallon MW 17	3	nd	nd	nd	nd
Tyndall AFB PW-10	2	144	38	116	298
Tyndall AFB PW-07	2	73	22[c]	64	159
Tyndall AFB T11-2	5	64 ± 4 (6.3%)	19 ± 1 (5.3%)[c]	42 ± 2 (4.8%)	124 ± 8 (6.5%)
Tyndall AFB TY22FTA	2	nd	nd	nd	nd

[a] The relative standard deviation is given in parentheses. [b] nd: not detected above the detection limit. [c] The reported value is near the detection limit (*S/N* ≤ 3) and less than the quantitation limit (*S/N* ≤ 10). The value has been included in the reported total concentration.

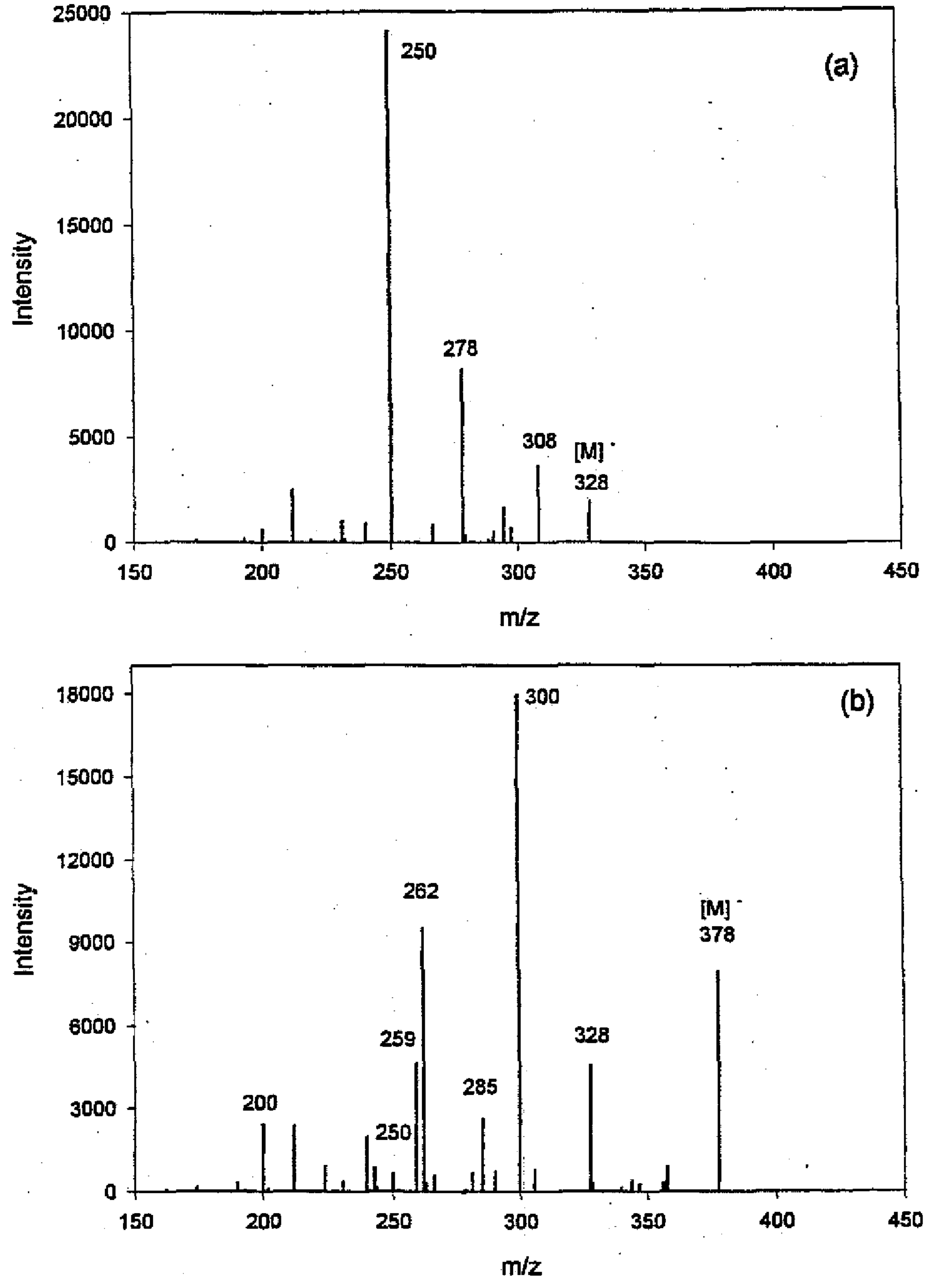

FIGURE 4. ECNI mass spectra of (a) methyl PFC6 and (b) methyl PFC7.

The highest concentrations of perfluorocarboxylates among the groundwater samples from Tyndall AFB were observed in PW-10 and PW-07, which are the two wells located closest to the fire-training pit (Figure 1b). Monitoring well T11-2, which is located downgradient of the fire-training pit, had lower but detectable groundwater concentrations of perfluorocarboxylates. The groundwater collected from a well located north of the fire-training pit, TY22FTA, contained no perfluorinated carboxylates above the detection limit (18 μg/L).

It is not surprising to observe a suite of perfluorinated carboxylates since the raw materials used in the synthesis of perfluorinated organic compounds are mixtures (*3*, *19*). Different ratios of PFC6, PFC7, and PFC8 may result from the use of different AFFF formulations at the two fire-training areas. The observed homologous series consisting of even and odd number perfluorinated carboxylates is indicative of the electrochemical fluorination process used by 3M Co. (*3*). Other fluorination processes, such as telomerization, produce only even number homologues (*3*). Because of the proprietary nature of AFFFs, it is not known if perfluorinated carboxylates are present as one of the major surface active agents in AFFF formulations or as unreacted starting materials used in the synthesis of the principal perfluorinated surfactants used in AFFF formulations. In addition, the carboxylates may be combustion, biological, or nonbiological degradation products of the principal perfluorinated components in AFFF mixtures. Unfortunately, the exact source and history of AFFF applications at the two field sites are unknown, and therefore, the relationship between the observed perfluorocarboxylate ratios and that of the original AFFF mixtures is unknown.

To the best of our knowledge, very little is known regarding the transport and fate of perfluorocarboxylates in groundwater. Adsorption to sludge at wastewater treatment facilities is considered a significant process for the removal of perfluorinated surfactants during treatment (*3*). However, detection of perfluorinated carboxylates at the NAS Fallon and Tyndall AFB sites, which have not been used since 1988 and 1992, respectively, is consistent with the view that biodegradation of the long chain perfluorocarbon hydrophobe is unlikely (*6, 9, 19*). The recalcitrant nature of perfluorinated compounds is attributed in part to the rigidity of the perfluorocarbon chain (*9, 20*) as well as the strength of the carbon–fluorine bond (*3, 9, 21*).

To the best of our knowledge this is the first definitive identification of perfluorinated carboxylates in groundwater impacted by fire-fighting activity. Further work is needed to determine if additional perfluorinated components are present, such as perfluorooctane sulfonic acid, which is thought to be one of the principle components in some commercial AFFF formulations. In addition, it is of interest to relate the occurrence and distribution of perfluorinated compounds to other site characterization parameters such as dissolved organic carbon, inorganic constituents, and the distribution of co-contaminants and to understand the potential influence of perfluorinated compounds on the biotransformation and transport of other co-contaminants.

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IN REPLY REFER TO
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From: Commanding Officer, Naval Research Laboratory
To: Distribution

Subj: DOD AFFF ENVIRONMENTAL MEETING

Encl: (1) Minutes of subject meeting

1. The Navy Technology Center for Safety and Survivability of the Naval Research Laboratory hosted the DOD AFFF Environmental Meeting on 2-3 August 2000. The meeting was held to exchange information on environmental issues surrounding AFFF. The meeting was sponsored jointly by The Naval Facilities Engineering Command and the Naval Air Systems Command.

2. Enclosure (1) is a copy of the minutes of the meeting.

3. The NRL point of contact for this program is Dr. Frederick W. Williams, Code 6180, (202) 767-2476, email: fwilliam@ccs.nrl.navy.mil.

James Murday

JAMES S. MURDAY
By direction

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    (Code 8.1 Wolfe)
NADEP (Code 4.3.4.7 Whitfield)
DSC (Code IDA Klein)

6180/0394A:FWW
September 12, 2000

Minutes
Of the
DOD AFFF Environmental Meeting

Held at the Naval Research Laboratory
Navy Technology Center for Safety and Survivability
Washington, D.C.
On
2-3 August 2000

Encl (1) to NRL Ltr
9555
6180/0394:FWW

Minutes of
DOD AFFF Environmental Meeting
Naval Research Laboratory
2-3 August 2000

Summary

A meeting to discuss AFFF environmental issues within the Department of Defense (DoD) was held at the Naval Research Laboratory (NRL), Washington, D.C., on 2-3 August 2000. The meeting was hosted by Dr. Fred Williams, NRL, Director, Navy Technology Center for Safety and Survivability. The meeting was jointly sponsored by the Naval Facilities Engineering Command (NAVFAC) and the Naval Air Systems Command (NAVAIR). The agenda for the meeting is shown in Appendix (1). A list of attendees is provided in Appendix (2), along with a photo of attendees present at the opening general session on 2 August 2000. To facilitate future exchanges of information on this subject, Appendix (2) includes mailing addresses, phone numbers and E-Mail addresses for each attendee.

Objective

The overall objective of the meeting was to provide a forum for open discussion on AFFF environmental issues within DoD. Additionally, the meeting was called to address three specific objectives:

(1) Assist NAVFAC in the development of a DoD design policy for AFFF systems in aircraft hangars and other shore facilities to minimize adverse environmental impact.

(2) Obtain information to assist NAVAIR in finalizing their AFFF Environmental Safety and Health Need Assessment Summary (ESH NAS) and in preparing the follow-on Development Plan.

(3) Provide information for attendees on the relevant issues surrounding the decision by the 3M Company to phase-out production of AFFF and other products containing perfluorooctyl sulfonate (PFOS).

Background

There has been growing concern in the past few years about the potential adverse environmental impact of AFFF. This concern has been spawned by a number of factors:

- The establishment by EPA in 1994 of threshold quantities for reporting spills of AFFF due to the butyl carbitol commonly used as a solvent in AFFF
- Inadvertent activations of AFFF systems in hangars and the resultant clean-up and disposal
- Reports of problems created by the discharge of AFFF to waste water treatment facilities

- Limitations on overboard discharges of AFFF by ships under the Uniform National Discharge Standards (UNDS) of the Clean Water Act
- Anecdotal reports of damage to aquatic life by discharge of AFFF to streams and waterways
- Various designations of AFFF waste, necessitating expensive disposal by specialty contractors
- Recognition of the persistence and limited biodegradability of the fluorocarbon surfactants in AFFF
- Publicity surrounding 3M's decision to phase-out production of AFFF and other chemicals containing perfluorooctyl sulfonate (PFOS)
- Claims by vendors of so-called "environmentally-friendly" AFFF alternatives

As a result of these concerns, the affected Navy Systems Commands have undertaken various actions:

- NAVFAC, under the auspices of the DoD Fire Protection Coordinating Committee, has started the development of design policy for shore facility AFFF systems to minimize discharges and to address environmental issues.
- NAVAIR has funded Concurrent Technologies Corporation to draft an ESH Need Assessment Study on AFFF, to be followed by a Development Plan that will recommend future action to alleviate identified problems.
- NAVSEA has reduced the frequency of testing of shipboard AFFF systems to minimize overboard AFFF discharge in compliance with the UNDS regulations.

The meeting was called to share recent information and discuss issues relevant to the above concerns and on-going actions.

Meeting Scope/Presentations

The meeting consisted of general session discussions and presentations as well as two specifically focused breakout sessions. Copies of the general session presentations are provided as Appendices (3) – (10). Presentations given at the Hangar Facility breakout session are contained in Appendices (11) and (12). Overall summaries of each breakout session are provided in Appendices (13) and (14).

Significant Discussion and Presentation Points

There were many important points raised during discussion sessions or contained in formal presentations. Those considered to be the most significant are summarized below (additional details are contained in the appendices):

- AFFF is a vital fire fighting agent for controlling and extinguishing flammable liquid fires. Within DoD, it is especially critical for fire scenarios where life safety is paramount, where ordnance is exposed or high value assets are threatened.

- The AFFF military specification (Mil Spec) is considerably more demanding than the applicable UL standard relative to speed of extinguishment of a flammable liquid pool fire.
- The AFFF Mil Spec is widely cited in procurement specifications in the civil sector, especially at municipal airports.
- There are currently 5 manufacturers that have AFFFs on the Mil Spec Qualified Products List.
- There are many fire fighting foams that are commercially available. However, no non-AFFFs have been able to match the rapid fire extinguishment performance of AFFF.
- At present there is no regulation or directive to modify the AFFF Mil Spec.
- There is no recognized or universally accepted definition of "environmentally friendly" fire fighting foam.
- NAVSEA is the designated DoD technical custodian of the existing AFFF Mil Spec. Only NAVSEA can formally change the Mil Spec, though it may be possible to develop a separate specification just for shore-based applications.
- Inconsistent policy and guidance have led to expensive and questionable secondary containment designs in recent shore facility projects.
- 3M is voluntarily phasing-out production of AFFF because the fluorocarbon surfactant in their AFFF biodegrades to perfluorooctyl sulfonate (PFOS). PFOS has been identified by EPA as environmentally persistent, bio-accumulative in blood, and toxic to aquatic life and laboratory animals (the degree varies by species).
- Levels of PFOS measured in humans and found in blood banks is not considered to present a heath hazard at present levels. Concern is the potential for build-up over time.
- Other AFFF manufacturers do not produce AFFF that is currently believed to biodegrade to PFOS.
- It is not known if other AFFFs have a similar problem. EPA is currently in a fact-finding mode relative to other AFFFs.
- At present the EPA does not prohibit or limit specifically the manufacturing of AFFF.
- A comprehensive review of federal and local environmental regulations applicable to AFFF (and other foam agents) has just been completed (see Appendix (8)).
- All fire fighting foams have environmental properties and/or constituents that are regulated.
- Adverse impact on waste water treatment facilities is a major concern, primarily due to foaming.
- A "risk based" approach, using the Frequency Vs Severity concepts in Military Standard 882C, has been shown to be feasible for managing AFFF environmental issues in shore facilities. Such an approach may be applicable to other AFFF applications as well.
- The NAVFAC Facility AFFF Management Working Group will continue development of policy, with a completion goal of approximately 6 months.

The next meeting of the NAVFAC Working Group is scheduled for October 12, 2000.

- NAVAIR will complete the AFFF Need Assessment Study and prepare the Development Plan to recommend a future course of action.
- There was a general consensus that a second follow-on DoD meeting should be held (host, location, dates – TBD). Depending on developments between now and the next meeting, a decision could be made to establish a governing charter for a DoD AFFF Environmental Steering Group and perhaps to designate a formal DoD "advocate" for the effort.

List of Appendices

(1) Meeting Agenda

(2) List of attendees and photo

(3) Presentation: "AFFF Performance Perspective," R. Darwin, Hughes Associates

(4) Presentation: "NAVSEA Comments on the AFFF Mil Spec", R. Williams, NAVSEA

(5) Presentation: "Hangar Facility AFFF Management Breakout Session Introduction", J. Gott, NAVFAC

(6) Presentation: "AFFF Environmental Impact Breakout Session Introduction", J. Hoover, NAWCWD China Lake

(7) Presentation: "Issues With 3M's Withdrawal from the Market", C. Hanauska, Hughes Associates

(8) Presentation: "AFFF Environmental Impact Review", W. Ruppert, Hughes Associates

(9) Presentation: "AFFF Management – Risk Based Approach", D. Verdonik, Hughes Associates

(10) Presentation: "Phasing out a Problem: Perfluorooctyl Sulfonate", M. Dominiak, EPA

(11) Presentation: Facilities Background and AFFF Issues", J. Simone, NAVFAC

(12) Presentation: "AFFF Risk Assessment", A. Wakelin, Hughes Associates

(13) Presentation: "Summary of Shore Facility AFFF Management Breakout Session", D. Verdonik, Hughes Associates

(14) Presentation: "Summary of AFFF Environmental Breakout Session", J. Hoover NAWCWD China Lake and R. Darwin, Hughes Associates

APPENDIX (1)

Meeting Agenda

DOD AFFF Environmental Meeting

Location:

Building 207 (Chemistry Building)
Naval Research Laboratory,
4555 Overlook Ave,
Washington DC, 20735

Agenda:

Wednesday August 2nd

0830 – 0845	Welcome and Introduction – Dr Fredrick Williams, NRL, Director, Navy Technology Center for Safety and Survivability.
0845 – 0915	AFFF Performance Perspective – Robert Darwin, Senior Engineer, Hughes Associates, Inc.
0915 – 0925	NAVSEA Comments on the AFFF Military Specification - Robert Williams, NAVSEA Fire Protection and Damage Control Division
0925 – 0935	Hangar Facility AFFF Management Breakout Session Introduction – Joseph Gott, NAVFAC, Director, Navy Facilities Safety and Health Office
0935 – 0945	AFFF Environmental Impact Breakout Session Introduction – Dr. Jim Hoover, NAWCWD, Head, Combustion Research Branch
0945 – 1000	Break
1000 – 1015	Issues Surrounding 3M Withdrawal from the Market – Chris Hanauska, Senior Engineer, Hughes Associates, Inc.
1015 – 1100	Presentation of AFFF Environmental Regulatory Aspects – Bill Ruppert, Senior Environmental Engineer, Hughes Associates, Inc.
1100 – 1130	Summary Presentation on Risk Assessment for Hangar Facilities – Dr. Dan Verdonik, Hughes Associates, Inc.
1130 – 1230	Lunch
1230 – 1600	Breakout sessions

Thursday August 3rd

0830 – 0930	3M Withdrawal from Market – Mary Dominiak, EPA, Chemical Control Division, Office of Prevention, Pesticides & Toxic Substances.
0930 – 1230	Presentation of Breakout Session Conclusions. Discussion of any further requirements to complete breakout session action items.

Hangar Facility AFFF Management Breakout Session

Session Objectives and Details:

The objectives of the Naval Facility Engineering Command (NAVFAC) hangar facility AFFF Management breakout session are:

- To begin efforts toward developing a policy that details requirements for hangar facilities that will provide "adequate measures" to:
  (a) prevent an accidental AFFF discharge,
  (b) limit any adverse environmental impacts from a release.

- To achieve an agreement on the definition of "adequate measures" and to begin to establish design criteria to meet them.

Initial draft design criteria and costs of specific engineering solutions will be presented and discussed as a starting point.

Agenda

1230 – 1315	Facility Background and Issues – Joe Simone, Head Fire Protection Engineer, Naval Facilities Engineering Command
1315 – 1430	Risk Assessment for Hangar Facilities – Alison Wakelin, Fire Protection Engineer, Hughes Associates, Inc.
1430 – 1600	Design Criteria Discussion and Development

List of Breakout Session Attendees:

D. Verdonik (Chair)
J. Gott
W. Ruppert
A. Wakelin
J. Simone
V. Donnally
T. Ruffini
D. Roderique
G. Sadler
L. Wolf
K. Ellis
M. Doherty
K. Kochar
B. Scott
R. Talbot
R. Hansen
J. Shah
F. Williams

AFFF Environmental Impact Breakout Session

Session Objectives and Details:

The objective of this meeting is to share the technical data related to the environmental impact, status and the planned future use of AFFF. NAVAIR will use output from this session to ensure their Environmental Safety and Health (ESH) Need Assessment Summary (the where we are today) is accurate and complete, and to ensure their Development Plan (the where we go from here) is consistent with the need to provide sound fire protection in an environmentally responsible manner.

The AFFF Environmental Impact working group will address the following questions:

- What current and future environmental regulations impact AFFF use and why (data and politics)?
- What data do we have (or lack) on the environmental impact of AFFF?
- What technology or products exist that could help reduce AFFF releases into our environment or mitigate the impact of those releases?
- What technology or products could be applied to recycle or reuse AFFF?
- What alternatives to AFFF currently exist and how do they compare in effectiveness, cost, environmental impact, availability, etc?

List of Breakout Session Attendees:

J. Hoover (Chair)
R. Darwin
J. Scheffey
C. Hanauska
W. Leach
D. McCrory
R. Williams
S. Wade
M. Wade
K. Bagot
R. Morris
B. Parks
S. Johnson
P. Bungcayo
R. Lee
R. DiAngelo
D. Dierdorf
J. LaPoint
I. Young

APPENDIX (2)

List of Attendees and Photo

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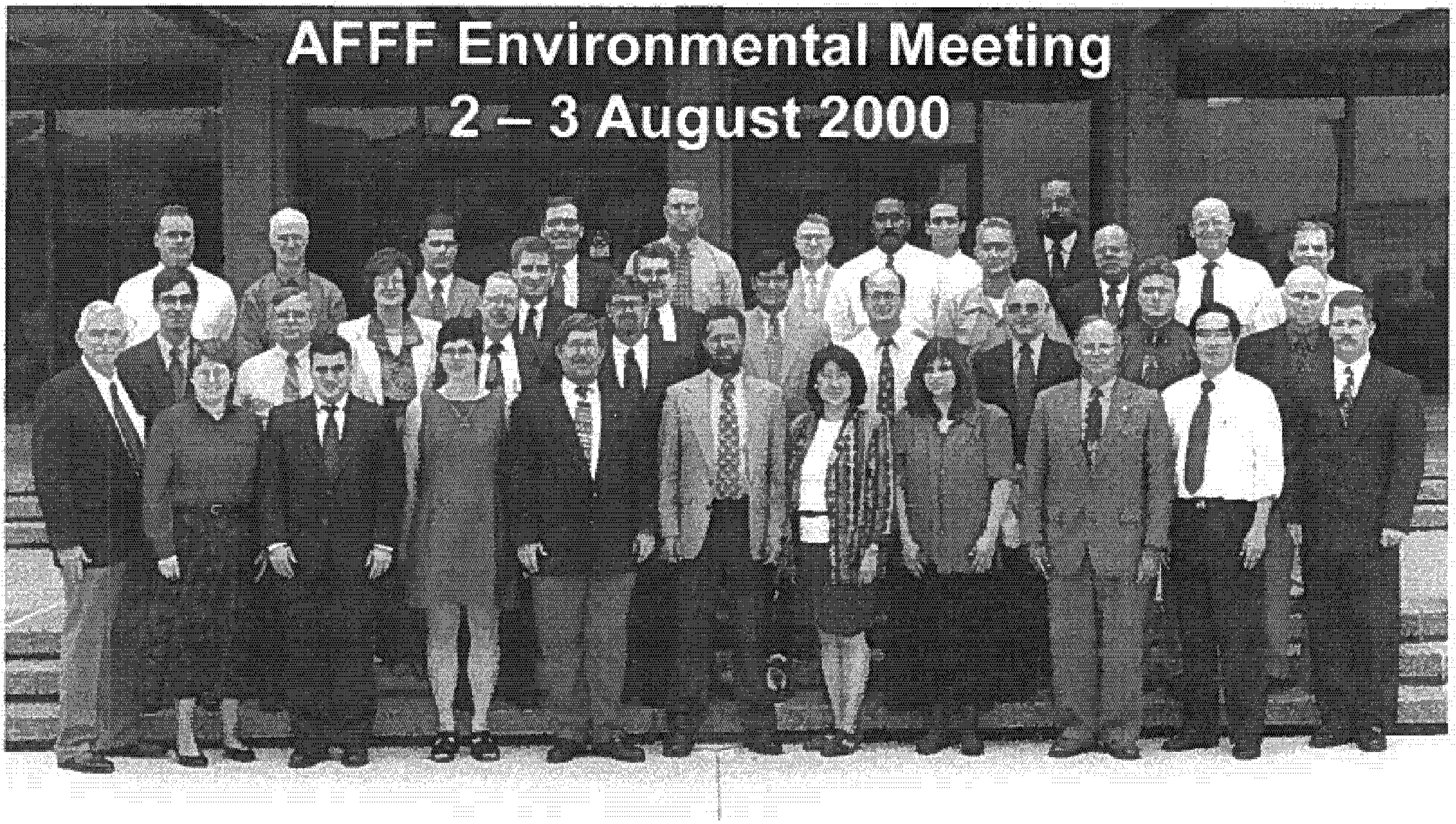

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Middle Row: W. Ruppert, B. Williams, D. Roderique, J. Hoover, J. Gott, J. Scheffey, D.Verdonik, J. Shah, W. Leach, P. Bungcayo, R. Darwin, K. Kochar, R. Talbot, S. Wade

Bottom Row: F. Williams, R. Morris, T. Ruffini, A. Wakelin, D. Dierdorf, B.R. Scott, I. Young, K. Ellis, G. Sandler, R. Lee, M. Wade

APPENDIX (3)

Presentation: "AFFF Performance Perspective"

R. Darwin,
Hughes Associates, Inc.
Baltimore MD

AFFF

Performance Perspective

Robert L. Darwin, PE
Senior Engineer
Hughes Associates, Inc.

2 August 2000

History of Foam

1920-40	Chemical Foam
1940-70	Protein Foam (Air Foam)
1970- 2000	AFFF

<u>AFFF Key Events:</u>

1961 First experiments with fluorocarbon surfactants at NRL

1962 First Mil-Spec (Mil-F-23905, 1 Nov 63)
  25 % concentration (fresh water only)
  Emphasis on twin agent application

1963 Large scale tests at NAS pensacola
  Led to procurement of 100 twin agent units

1964 Helo air borne TAU tests at NAS Miramar

1965	6 % concentration developed by 3M (FC-194)
1966	Testing of FC-194 in airfield crash trucks
	Selective conversion of some crash trucks
1967	Flight deck conflagration on USS Forrestal
	TAUs to aircraft carriers
	Push to develop seawater-compatible AFFF
1967	Seawater –compatible AFFF developed by 3M/NRL
1968	Additional crash truck tests at NAS Miramar
1968	Shipboard equipment tests w/ seawater at NAS Jacksonville
	First edition of seawater/AFFF mil spec (Mill-F-24385)
1969	Flight deck conflagration on USS Enterprise
	Push to convert ships to AFFF
1970	Navy starts comprehensive conversion of ship systems and crash trucks
1973	USAF starts converting all USAF crash trucks

UL Listed Foams

(Per UL 162-"Foam Equipment & Liquid Concentrates")

AFFF – Aqueous Film Forming Foam
FFFP – Film Forming Fluoroprotein
FP – Fluoroprotein
PF – Protein Foam

	Manufacturers	Concentrates
AFFF	24	110
FFFP	5	16
FP	12	26
PF	5	6

Mil Spec Qualified Product List (QPL)

Ansul

Ansulite 3 (AFC-5A) *	Type 3
Ansulite 6 (AFC-5) *	Type 6

3M

FC-203C	Type 3
FC-203CE *	
FC-203CF *	
FC-206C	Type 6
FC-206CE	
FC-206CF *	

Chemguard

C-301MS *	Type 3

National Foam

Aer-O-Water 3-EM *	Type 3
Aer-O-Water 6-EM *	Type 6

Angus

Tridol M	Type 3

* Also UL Listed

"Application Density" (Defined as the Gallons of Agent Per Unit Area of Pool Fire Size) is the best measure of effectiveness for a flammable liquid pool fire

Application Rate = GPM/Sq Ft of fire area

Application Rate x Ext Time = Application Density

GPM/Sq Ft x Minutes = Gals/Sq Ft

<u>Example</u>

Fire Area = 1000 Sq Ft
Appl Rate of Agent = 200 GPM
Ext Time = 0.5 minutes

Appl Rate = 200 GPM/1000 Sq Ft = 0.2 GPM/Sq Ft

Appl Density = Appl Rate x Time
= 0.2 GPM/SqFt x 0.5 minutes
= 0.1 Gals/SqFt

AFFF Performance Requirements

Mil Spec (Mil-F-24385):

		Max Appl Density
2 gpm/28 sq ft x 30/60 minutes	=	.036 gal/sq ft
2 gpm/50 sq ft x 50/60 minutes	=	.033 gal/sq ft

Underwriters Laboratory:

2 gpm/50 sq ft x 3 minutes = .12 gal/sq ft

(Maximum extinguishment time is 5 minutes for fluoroprotein and protein foam)

Rapid Extinguishment of Pool Fires is Critical When:

- Pool fire threatens high value assets (such as an aircraft hangar)
- Pool fire under an occupied aircraft (must maintain fuselage integrity and rescue occupants)
- Pool fire exposes weapons to potential "cook off"

Relative Performance of Foam Agents on Pool Fires

(Best) AFFF (Mil-Spec)

AFFF (UL listed, non Mil-Spec)

AFFF (non UL, non Mil-Spec)

FFFP

FP

PF

(Worse) Wetting Agents

UL Listed Wetting Agents

(Based on NFPA 18)

“ A liquid concentrate for addition to water to produce a solution having a <u>greater fire extinguishing efficiency than plain water”</u>

Manufacturers:	11
Agents:	13

If Use Non-Film Formers:

- Extinguishment time will be slower, unless application rate is increased

- Higher application rate causes

  Greater system cost

  Greater quantity of agent emitted

- Must consider possible need for "air aspiration"

  Replace nozzles

  Less reach than "non air aspirated"

AFFF Environmental Issue - 1994

Glycol Ethers (Butyl Carbitol), solvent in most AFFFs, placed on EPA list of hazardous air pollutants.

Since no reporting threshold had been established, a default quantity of one pound per day was established for required reporting under CERCLA.

Because Diethylene Glycol Butyl Ether (DGBE) typically comprises about 20 % of AFFF, spills of just a few gallons of AFFF had to be reported to the National Response Center and to State and local officials.

One pound per day reporting requirement dropped in 1996.

Some manufacturers substituted Propylene Glycol for Ethylene Glycol and declared their foam to be “environmentally friendly”.

DOD Uses of AFFF

- Shipboard Foam Systems
- CFR Vehicles at Airfields
- Aircraft Hangar Foam Systems
- Misc Shore Facilities
  - Hush Houses
  - Jet Engine Test Facilities
  - Hardened Aircraft Shelters
  - Aircraft Fueling Stations
  - Fuel Farms
- Foam Sytems on Structural Pumpers

DOD AFFF Discharges

- Fires
- Training Evolutions
- System Tests and Maintenance
- Accidental/Malicious Discharges
- Research and Development

There is a Need to Quantify and Characterize:

- All DOD AFFF applications (What precisely do we use it for ?)
- Precise quantities in service and in reserve stocks (How much do we have ?)
- Annual emmisions (type and quantity) (How much do we discharge ?)

APPENDIX (4)

Presentation: 'NAVSEA Comments on the AFFF Mil Spec"

R. Williams,
Naval Sea Systems Command

NAVSEA Comments On the AFFF Military Specification Mil-F-24385F (Amendment 1 of 8/94)

(Talking Points)

Presentation to DOD AFFF Environmental Meeting
2 August 2000

Robert B. Williams
Fire Protection & Damage Control Division
Naval Sea Systems Command
(Technical Custodian of the AFFF Mil-Spec)

1. I would like to express appreciation to NAVFAC and NAVAIR for sponsorship of this Conference. Also, I appreciate the opportunity to establish the NAVSEA perspective up front.

2. This conference is important and timely:

Recently there has been a proliferation of Navy groups active in AFFF; usually with no focus, some scattered and uncoordinated EPA contacts.

Recently there has been aggressive commercial marketing of so-called "environmentally friendly foams"; yet there is no established definition of "environmentally friendly foam".

AFFF is subject of considerable hype: effect on sewage plants, danger to aquatic life, exposure results in mutant first born, etc.

AFFF spills are media friendly- very visible, makes for good "films at 11", photos provide permanent record, helps stir up environmental activists

Real issues from my perspective:

3M withdrawal and fall out relative to other QPL AFFFs

Restrictions by AHJs; technical basis or not

Unknown forthcoming EPA activity

All are on agenda to be addressed

3. The product I personally desire of this conference is to specifically identify what the problems are regarding MILSPEC AFFF, and problems that are inherent to any foam alternative (visible, wastewater treatment plants).

Appears money is & will be directed at AFFF.

My concern is that funding needs to be attached to a focus on specifics that are documented as requiring resolution.

Navy labs and contractors see a golden egg out there on this topic; I personally don't want to see them going off into the sunset with a generic task to find an environmentally friendly firefighting agent. (whatever friendly means).
The specific problems to be resolved require documentation before charging onto a search for solutions; doesn't always happen in correct order.

The agenda appears to support what I hope is the conference objective.

4. A few quick comments about the MILSPEC and shipboard applications:

NAVSEA is custodian; only NAVSEA can revise. Self appointed cannot.

However, an alternate extinguishing agent specification under someone else's cognizance could be created.

For example, it might be feasible to develop a separate specification just for shore facility use (fresh water only, one percent, universal foam, no refractive index requirement, etc).

NAVSEA goal regarding the spec: Satisfy environmental requirements without degradation of firefighting effectiveness. If maintaining performance requirements is not possible, then where do we draw the trade-off line in the sand? (fish vs. sailors; national defense vs. environment)

MILSPEC contents - shipboard oriented, even though it is essentially the national standard ashore and afloat:

AFFF is for two dimensional shallow spill fires, rapid control and extinguishment are essential. No "foam-of-the-month" has matched the performance of mil-spec AFFF.

Environmental provisions in spec; fish kill, BOD/COD limits, chemical restrictions.

Compatibility: seawater effectiveness, intermixing of products from different manufacturers on QPL.

It is an integrated match with our capital investment in hardware: viscosity, corrosion, pipe & tank materials, effect on seals/gaskets, a refractive index, container size & strength.

5. Our primary environmental involvement has been with the Uniform National Discharge Standards (UNDS) program which is relative to overboard discharge of liquids; basically a Clean Water Act action item.

Our imput to EPA, which has been accepted thus far, is discharge management:

New construction/alterations - no repeat testing, at sea

Preventative Maintenance - reliable hardware, reduced testing periodicity

Fewer ships

Geographic restrictions: no discharges within 3 miles of coast, must be making at least 10 knots for discharges within 3-12 miles, preference for only discharging when greater than 12 miles out

6. In closing, I pass along that as custodian of the MILSPEC, I have no direction, pressure, or formal or informal tasking to conduct an environmental review of MILSPEC AFFF aside from the UNS. At NFPA aviation committee meetings I have queried major airport fire chiefs, all of whom stated no direction to pursue an alternative to MILSPEC AFFF. However, we at NAVSEA know whether politically, technically, or regulatory driven, environmental restrictions on AFFF may be coming. We fully support this conference, identification of problems & potential problems, and initiation of remedial research/actions.

APPENDIX (5)

Presentation: “Hangar Facility AFFF Management Breakout Session Introduction”

J. Gott,
Naval Facilities Engineering Command

Hangar Facility AFFF Management Breakout Session Introduction

(Talking Points)

Presentation to AFFF Environmental Meeting
2 August 2000

Joseph Gott
Director, Navy Facilities Safety and Health Office
Naval Facilities Engineering Command

AFFF DOD Meeting Talking Points

- Need a consistent DOD position on AFFF management
- If we are not proactive, AFFF will become our next halon 1301
- AFFF is only product on market right now that meets our needs
- Time for the design engineers, and environmental engineers to come together
- The services have already done this with the Unified Design Guidance Group
- As past chair of DOD FPE committee, we wrote the first tri-service design criteria
- Fixed containment systems are affecting our mission because they have already caused the omission of AFFF from some hangars resulting in the air wings inability to perform their mission
- This is the beginning of a working group to address this important issue
- Need to get all the right players
- Need to address AFFF management from a risk assessment approach
- Need to dismiss all the myths and fears and address the facts
- Need to give the local regulators something to reference as adequate protection
- Need to determine if additional research is needed to produce a different AFFF
- Discuss changes to NFPA 409 - mandatory drains, reduced AFFF, various protection options
- NAVFAC has long history in fixed AFFF systems, their behavior, problems, and design characteristics

APPENDIX (6)

Presentation: "AFFF Environmental Impact Breakout Session Introduction"

J. Hoover,
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China Lake CA

AFFF Environmental Impact Breakout Session Introduction

(Talking Points)

Presentation to DOD AFFF Environmental Meeting
2 August 2000

Dr. Jim Hoover
Head, Combustion Research Branch
NAWCWD China Lake

The purpose of the AFFF Environmental Impact Breakout Session will be to share technical information within the DoD on AFFF use and environmental impact. This information will be used to assist the completion of two environmental planning documents used by the Naval Air Systems Command (NAVAIR) - an Environmental Safety and Health Needs Assessment Summary (NAS) and a Development Plan. The NAS will provide a "snap-shot" of technical issues surrounding AFFF use and environmental impact, and the Development Plan will recommend a strategy for future efforts within NAVAIR.

Background: The importance of AFFF in protecting Navy personnel and assets must not be understated. Likewise, public safety and commercial assets are highly dependent on AFFF for fire protection. Its firefighting performance remains unmatched and much remains unknown about its human health and environmental effects.

Other services and agencies have data and experiences with AFFF that could assist the Navy in future decision making, so a forum for technical information exchange is needed. In planning for the future, all aspects of technical knowledge about AFFF (and all of its formulated components) should be considered. These should include costs, performance/function, human health and environmental effects, availability, inventory, alternatives, etc.

Break-out Session Format:

The following questions will be asked of the participants to promote discussion and information exchange. Participants will be invited to provide other questions.

1. What current and future environmental regulations impact AFFF use and why (data and politics)?

2. What data do we have (or lack) on the environmental impact of AFFF?

3. What technology or products exist that could help reduce AFFF releases into our environment or mitigate the impact of those releases?

4. What technology or products could be applied to recycle or reuse AFFF?

5. What alternatives to AFFF currently exist and how do they compare in effectiveness, cost, environmental impact, availability, etc?

6. What related planning documents exist with other services or agencies?

7. What follow-on strategies should be considered?

APPENDIX (7)

"Issues With 3M's Withdrawal From the Market"

C. Hanauska
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Issues with 3M's Withdrawal from the Market

AFFF DoD Meeting

Christopher Hanauska

HUGHES ASSOCIATES, INC.
FIRE SCIENCE & ENGINEERING

August 2, 2000

Purpose of this Presentation

- Mary Dominiak of EPA will provide more detailed information tomorrow
- Provide some background for her presentation
- Frame the issue relative to the subjects of this meeting
- *This presentation is only an executive summary*

Fluorochemical Surfactants (FC's)

- FC's are a component of AFFF
  - One of several components in AFFF
  - FC's are difficult and expensive to make
  - Formulators have minimized (and attempted to eliminate) the FC content for 30 years
  - Necessary for performance (especially for CFR)
    - rapid fire knockdown
    - relatively low application rates

What is an FC?

- C8F17-functional group
- Length of carbon chain varies
- Fluoronated carbon chain is very stable
- Functional group gives different properties

FC's for AFFF Do Not Fully Biodegrade

- 3M's FC's => PFOS (Perfluorooctyl Sulfonate)
- Other FC's => ?
- Functional group may biodegrade, but something is always left
- Ultimate fate unknown
- "Persistent"

3M Performed Testing
(Last 2 Years)

- Found PFOS
  - in blood banks around the US
  - in fish and birds
- Discovered toxicity issues
  - reproductive sub-chronic studies
- "Bioaccumulative" and "Toxic"

3M Voluntarily Phasing Out PFOS Related Chemicals

- Scotchguard, Scotchban, industrial uses, AFFF
- About 2 years for complete halt of production
- Decision made at highest level of 3M
    - were in discussion with EPA at the time
- An unexpected and extreme action

If Only 3M PFOS FC's are a Problem

- Other non-PFOS FC based AFFF's are on the QPL
- Possibly a short term supply issue
- Should not be a major fire protection/environmental concern

Do Non-PFOS FC's Have a Problem?

- EPA has asked manufacturers to examine and test
- What constitutes a "problem" uncertain
  - "Bioaccumulative" "Toxic"
- EPA will do risk/benefit and risk/risk analysis
  - Understanding of importance of AFFF to fire protection

Conclusions

- No FC specific regulations exist
- No apparent short term (1 year) problems
- Mid-term (2-3 years) problems related to supply only
  - as 3M withdraws from market
- Potentially no long term problems (3+ years)
- *Unless other FC's have significant problems*

APPENDIX (8)

Presentation: "AFFF Environmental Impact Review"

W. Ruppert
Hughes Associates, Inc.
Baltimore MD

Aqueous Film Forming Foam (AFFF) ENVIRONMENTAL IMPACT REVIEW

Bill Ruppert

HUGHES ASSOCIATES, INC.
FIRE SCIENCE & ENGINEERING

Background:
AFFF Constituents

- MILSPEC based on Performance, not Constituents
- Must be on Qualified Products List - QPL
- Main Ingredients in Firefighting Strength Foam:
  - WATER = 98%-99%
  - Butyl Carbitol (Glycol Ether) = 0.5%–1.1%
  - Fluorosurfactants & Hydrocarbon Surfactants = 0.03%–0.45%
  - Ethylene Glycol (Not in all formulations) = 0.34%–0.60%
  - Urea (Not in all formulations) = 0.2–0.4%

Background:
AFFF 'Environmental' Properties

- MIL-F-24385F Requirements
  - Chemical Oxygen Demand
    - 3% Concentrate - 1,000,000 mg/L Max
    - 6% Concentrate - 500,000 mg/L Max
    - Calculated Firefighting Strength ~ 30,000 mg/L Max
  - Biochemical Oxygen Demand (20 Day)
    - =(0.65 X COD) or greater
  - Aquatic Toxicity (LC50, Killiefish)
    - 3% Concentrate - 500 mg/L Min
    - 6% Concentrate - 1000 mg/L Min
    - Calculated Firefighting Strength ~ 16,667 mg/L Min
- Persistence and Bioaccumulation
  - Only Fluorosurfactants - Not in other constituents
  - example: Butyl Carbitol log BCF = 0.46
- Foams

Background: AFFF Properties

MILSPEC vs. Typical QPL Product

Property	MIL-F-24385F Requirements			Typical QPL Product		
	3%	6%	FF	3%	6%	FF
Chemical Oxygen Demand (mg/L)	1,000,000 Max	500,000 Max	30,000 Max	750,000	341,000	22,500
Biochemical Oxygen Demand (mg/L)	$BOD_{20} > 0.65 \times COD$			720,000 (0.96*COD)	274,000 (0.80*COD)	21,600
Aquatic Toxicity (Killiefish) (mg/L)	500 Min	1000 Min	16,667	>1000	>1000	>16,777 or >33,333

Codes and Standards Survey

Approach

- Electronic Review
- Federal Environmental Regulations
  - "AFFF"
  - MILSPEC AFFF Constituents (19)
    - Surfactants
    - Fluorosurfactants
    - Glycol Ethers
    - Urea, etc.
  - AFFF "Environmental" Properties
    - Biochemical And Chemical Oxygen Demands
    - Aquatic Toxicity
    - Foaming
- DOD, State And Local Regulations
  - "AFFF"
  - MILSPEC AFFF Constituents

Codes and Standards Survey
Federal Environmental Regulations

- Clean Air Act (CAA)
  - Air Emissions
  - Air Discharge Permits
- Emergency Planning and Community Right-to-Know Act (EPCRA)
  - Toxics Release Inventory (TRI)
  - Chemical Storage and Use
- Comprehensive Environmental Response, Compensation, & Liability Act (CERCLA)
  - Superfund Amendments and Re-authorization Act (SARA)
  - Spills and Clean-up Of Spills
- Resource Conservation and Recovery Act (RCRA)
  - Hazardous Waste
- Safe Drinking Water Act (SDWA)
  - Regulates Contaminants in Treated Drinking Water
- Clean Water Act (CWA)
  - Water Discharges
  - Water Discharge Permits

Federal Environmental Regulations

Results

- Clean Air Act (CAA)
  - Glycol Ethers In AFFF Are Hazardous Air Pollutants (HAPs)
  - HAP Releases Are Regulated by the Installation Air Permit
    - Major Sources for HAPs Might Have Potential Permit Issue
- EPCRA and TRI
  - Glycol Ethers are Covered Because CAA Defines them as HAPs
  - Chemicals Released Above a Reportable Quantity (RQ) Must Be Reported
    - Default RQ was One (1) Pound
    - EPA Established a No RQ
  - AFFF Discharges Do Not Currently Need to Be Reported Under EPCRA and TRI
  - Ethylene Glycol Specifically Listed
  - No Other Constituent is Currently Regulated by EPCRA and TRI

Federal Environmental Regulations

Results

- CERCLA and SARA
  - Glycol Ethers are Covered Because CAA Defines them as HAPs
  - Glycol Ethers May Need to Be "Cleaned Up" After a Spill
    - Air Pollutants So Expected to be Volatile
      - Are not volatile when mixed with water
    - Biodegradable So Might Be "Cleaned Up" Naturally
- Resource Conservation And Recovery Act (RCRA)
  - AFFF and Its Constituents are Not Classified as Hazardous Waste
  - RCRA Does Not Apply
- Safe Drinking Water Act:
  - Primary Drinking Water Regulations (Health Properties)
    - Does not regulate AFFF or its constituents
  - Secondary Drinking Water Regulations (Aesthetic Properties):
    - Foaming Agents <0.5 mg/L in drinking water
    - Do not regulate foaming agents in source water
    - Guideline for State Regulations Only (Not Federally Enforceable)

Federal Environmental Regulations
Results (Continued)

- Clean Water Act (CWA)
  - Installations Require Discharge Permits
    - Storm Water
    - Treated Sewage from Installation Wastewater Treatment Plant
    - Raw Sewage to Public Wastewater Treatment Plant (Locale Specific)
  - Regulates Wastewater that:
    - Foam
    - Remove Oxygen From Water
    - Disrupt Wastewater Treatment Plants, etc.
  - AFFF
    - Persistent Foam
    - Removes High Amounts of Oxygen From Water (High BOD and/or COD)
    - Untreated, Undiluted AFFF Will Disrupt Wastewater Treatment Plant
    - (Even Diluted AFFF Can Disrupt Wastewater Treatment Plant) SDWA

Codes and Standards Survey

State/Local Environmental Regulations

- State Regulations Can be More Strict Than Federal
  - No Specific Instances Found for AFFF
  - Storm Sewer Regulations Emphasized
- Nothing Additional in County and City Regulations
- Representative Jurisdictions
  - Telephone Surveys
  - Focused on Jurisdictions In:
    - Virginia
    - Hawaii
    - Florida
    - California
- Local Anecdotal AFFF ‘Problems’
  - Sewage Treatment Plants Becoming ‘Bubble Baths’
  - Pump Stations ‘Burned-up’
  - Storm Sewer Overflowing With Foam

State/Local Environmental Regulations

(Continued)

- Foaming the Greatest Concern
- Perception:
  - Foam Is Highly Toxic to Everything
  - No Concentration is Okay for a WWTP
- Results
  - Local Jurisdictions **CAN** and **DO** Regulate AFFF by Name
  - Have Water Discharge Permit Authority
  - Local Waste Water Treatment Plants Often Ban AFFF
    - Based on Direct Experience with a Disruption
    - High Oxygen Demand
    - Foaming

Environmental Consequences

- Media Considered
  - Air
  - Groundwater
  - Soil
  - Surface Water
    - Via storm water
    - Via wastewater treatment plant
- Both Constituent Characteristics and AFFF Solution Properties

Environmental Consequences

Media: Air

- HAPS: Butyl Carbitol, Ethylene Glycol
- Low Migration Potential (All Constituents)
  - Highly Soluble in Water
    - Tends to stay with liquid water
    - Not very volatile
  - If Volatilized, Half-lives in Air 4 Hr - 3.5 Days

Environmental Consequences

Media: Groundwater

- Consequence Varies Depending on Subsurface Conditions
- Fluorosurfactants: Not Mobile
- All Other Constituents:
  - Highly Soluble, Highly Mobile
  - Degrades Rapidly in Soil
    - 30% Degradation Over 24 Hour Period
- Drinking Water Wells ‘Under the Influence of Surface Water’ Could Receive Undegraded AFFF Constituents

Environmental Consequences

Media: Soil

- Consequence varies depending on soil type
- Fluorosurfactants and break-down products
  - Persistent in soil
  - No quantified environmental impact
  - EPA will discuss further tomorrow
- Other constituents highly mobile in water, will not adsorb to soil

Environmental Consequences

Media: Surface Water Via Storm Water

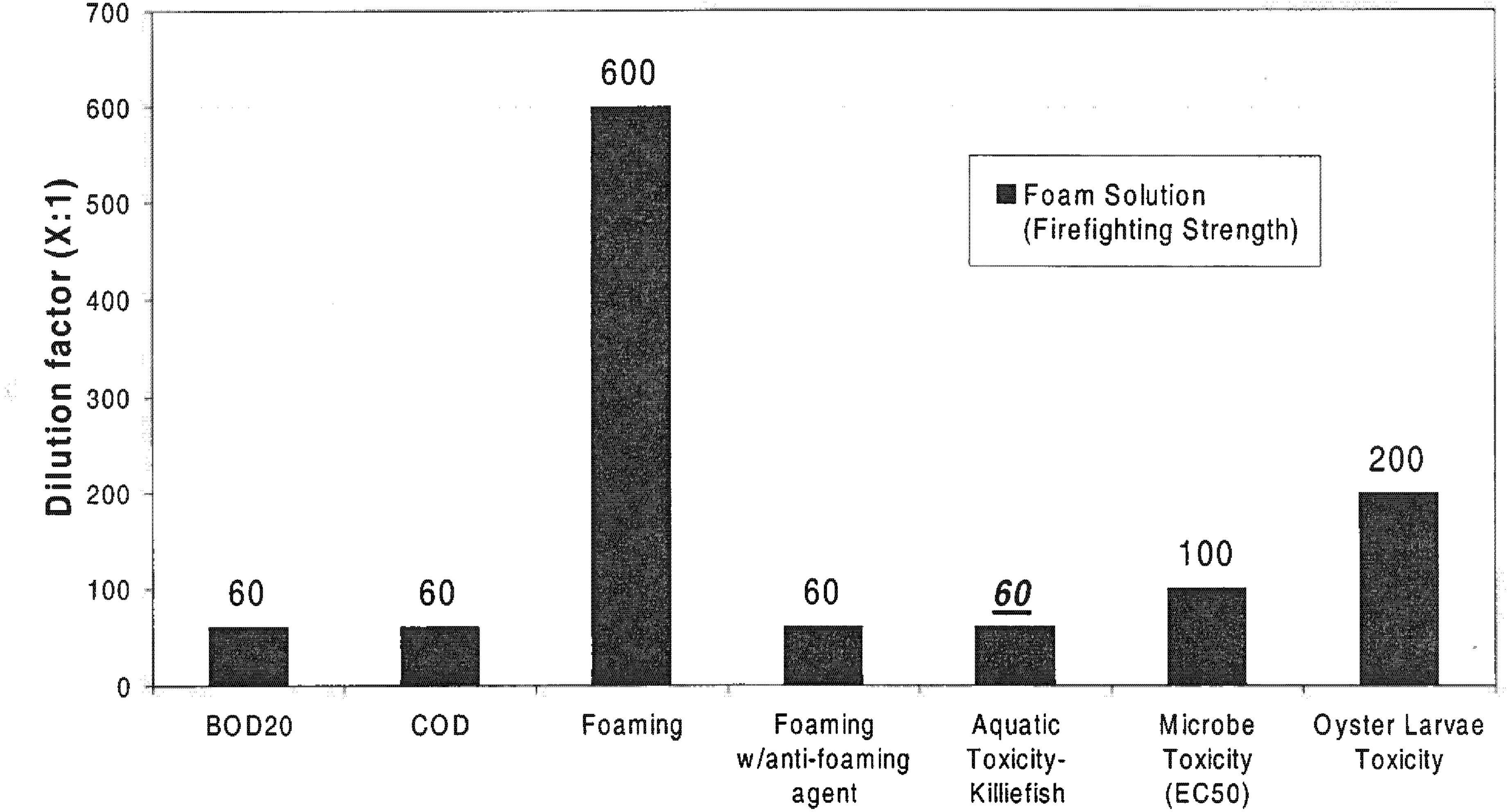
- Foaming:
  - Aesthetic Concern
- Oxygen Demand
  - Robs Oxygen from Water
  - Usually near water's surface
- Aquatic Toxicity
  - Considered 'Practically Nontoxic' by the US Fish and Wildlife Service.
  - Lowest toxicity value in 40 CFR 300
    - LC50 > 1000 mg/L in concentrate
    - ~160 mg/L in most sensitive species
    - Much Lower Toxicity in Firefighting Strength
  - Anecdotal Reports of Higher Toxicity
- Surface Water May influence Groundwater
- 'Environmental' Threat
  - Depends on Sensitivity of Receiving Water: Worst Cases
    - Kaneohe Bay, HI Risk Analysis - "Potential for significant ecological damage … relatively small"
    - Wetlands
      - Waterfowl-Fluorosurfactant Interaction being studied in St. Johns River Basin in Florida.

Environmental Consequences

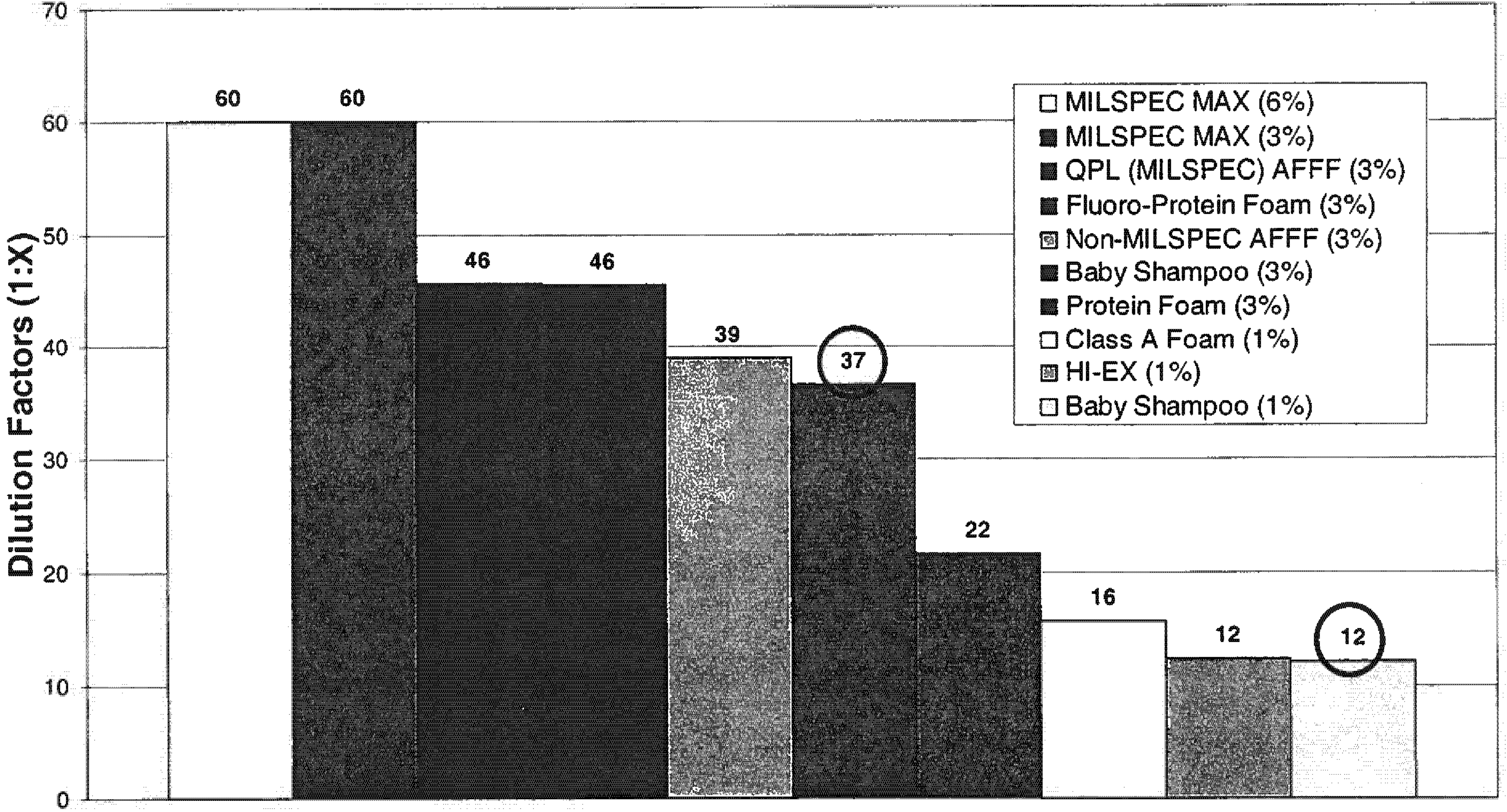
Media: Surface Water Via Direct Discharge to WWTP

- Disrupts plant through:
  - Foaming
    - Disrupts mechanical devices
    - Causes ‘sludge bulking’
    - Causes Froth
  - High Oxygen Demand
    - Removes all oxygen - killing microorganisms used to treat sewage
    - Causes ‘sludge bulking’.
  - Aquatic Toxicity
    - Of lower concern than Foaming and Oxygen Demand
    - May cause ‘sloughing’ of organisms from certain processes
- Disrupted plant:
  - Contaminates receiving water
  - Could cause fish kill
  - Makes water unfit for:
    - Drinking
    - Recreation, etc.

Representative Dilution Factors for Treatment of MAX MILSPEC AFFF at a WWTP



Representative Dilution Factors for COD of Foam Solution (Firefighting Strength)



Summary

- Under Context of Current Laws/Regulations, AFFF and all other Foams Regulated Based On:
  - Properties
    - BOD, COD, Foaming and Aquatic Toxicity
  - "Listed" Chemical Constituents
    - Butyl Carbitol, Surfactants, Ethylene Glycol, Urea, etc.
  - Water Issues are Most Prevalent
  - Foaming is Major Issue for WWTP
- Potential Environmental Impacts Generally Low
  - Impacts Consequence of
    - Foaming
    - O_2 Demand
    - Aquatic Toxicity
  - Upset of WWTP Creates Greatest Impact

APPENDIX (9)

Presentation: AFFF Management – Risk Based Approach"

D. Verdonik
Hughes Associates, Inc.
Baltimore MD

AFFF Management
Risk Based Approach

Dr. Dan Verdonik

HUGHES ASSOCIATES, INC.
FIRE SCIENCE & ENGINEERING

Why a Risk Based Approach?

- From Environmental Review
  - AFFF / Foams have Similar Environmental Impacts
    - Based on the Properties of Foams in General
    - Worst Impact for WWTP
  - Hazard Exists
  - Cannot Alter What Would Happen IF Released
- Can Reduce the If or Likelihood of Release
  - Example - Double Hulled Oil Tankers
    - Hazard Exists from Potential Oil Spill
    - Double Hull Reduces Probability of Having the Oil Spill
    - Double Hull Does Not Reduce Environmental Impact IF Have Oil Spill
    - Reducing Probability Reduces the Risk to the Environment
- Need to Evaluate Probability of Foam Release
- Probability + Severity = Risk

Risk and Risk Assessments

- Military Standard 882C: System Safety Program Requirements
  - Define Terms
    - Risk - Combination of hazard severity AND hazard probability
    - Hazard Probability: Aggregate probability of the individual events
    - Hazard Severity: Consequences of worst credible mishap
    - Control: Action to Eliminate Hazard or Reduce Risk
  - Applicable to All DOD Systems and Facilities
  - Identify the Hazards and Impose Design Requirements and Management Controls to Prevent Mishaps
  - Tailor to Application
    - AFFF/Foam Discharge from Facility Fixed Fire Suppression System
    - Accidental Discharge
    - Pre-planned testing
- Have Hazard Severity, Need Hazard Probability
  - Determine Risk
  - Risk Decision

MIL-STD-882C
4.5.2 Hazard Probability

- Potential occurrences per unit of time, events, population, items, or activity
  - Quantitative probability for potential design generally not possible
  - Qualitative probability
    - Derived from research, analysis, and evaluation of historical data
- Given for Specific Individual Item or Fleet / Inventory
- Assign Probability of Having Environmental Consequence

Qualitative Probability Levels Specific Individual Item

FREQUENT	(A)	Likely to occur frequently
PROBABLE	(B)	Will occur several times in the life of an item
OCCASIONAL	(C)	Likely to occur some time in the life of an item
REMOTE	(D)	Unlikely but possible to occur in the life of an item
IMPROBABLE	(E)	So unlikely, it can be assumed occurrence may not be experienced

MIL-STD-882C
4.5.1 Hazard Severity

- Hazard Severity Category Definition
  - Provide Qualitative Measure of Worst Credible Mishap
  - Result of:
    - Personnel Error
    - Environmental Conditions
    - Design Inadequacies
    - Procedural Deficiencies
    - System, Subsystem or Component Failure or Malfunction

Qualitative Hazard Severity Categories

CATASTROPHIC	(1)	Death, System Loss, or Severe Environmental Damage
CRITICAL	(2)	Severe Injury, Severe Occupational Illness, Major System or Environmental Damage
MARGINAL	(3)	Minor Injury, Minor Occupational Illness, Minor System or Environmental Damage
NEGLIGIBLE	(4)	Less Than Minor Injury, Occupational Illness, Less Than Minor System or Environmental Damage

Risk Assessment and Acceptance

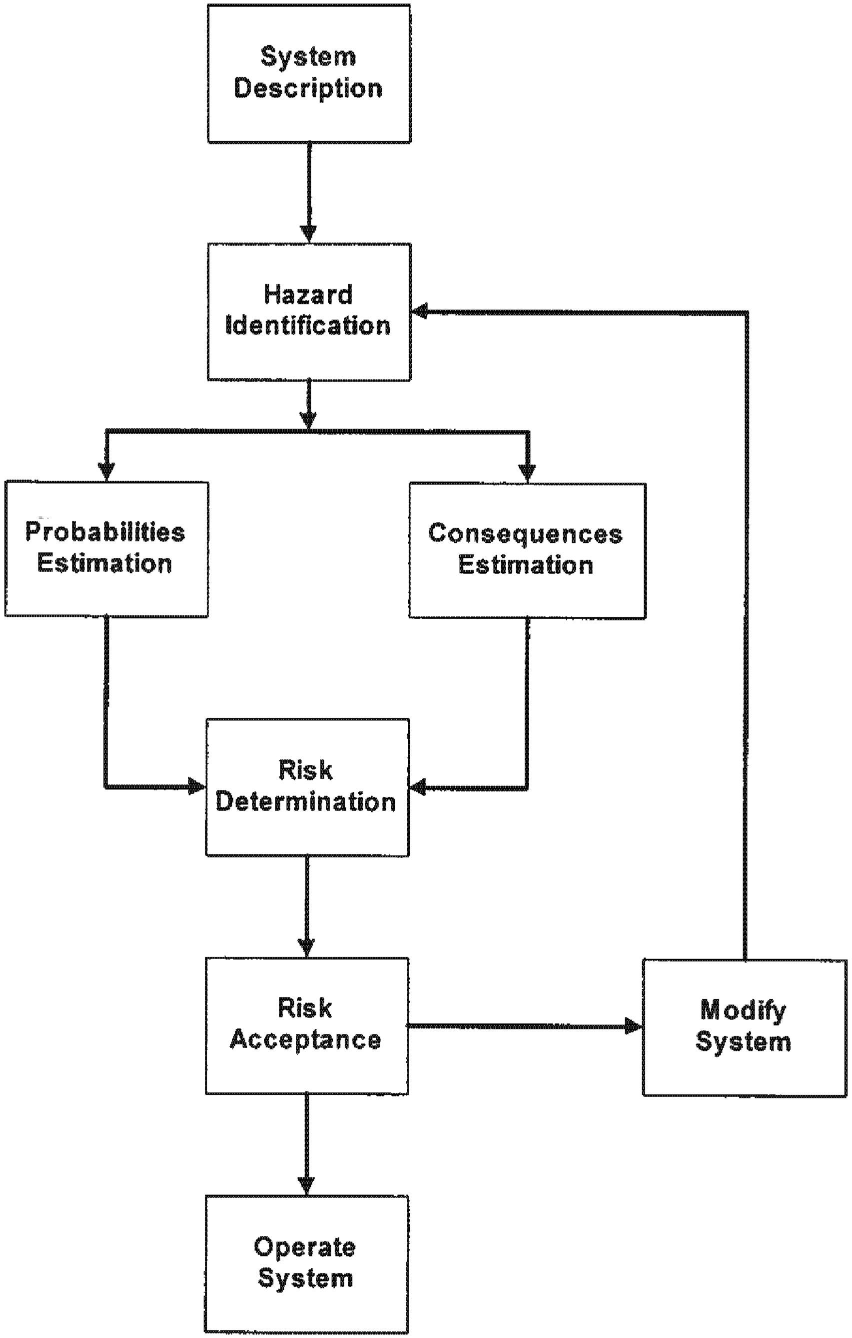
CATEGORY FREQUENCY	1 CATASTROPHIC	2 CRITICAL	3 MARGINAL	4 NEGLIGIBLE
A – FREQUENT	1A	2A	3A	4A
B – PROBABLE	1B	2B	3B	4B
C – OCCASIONAL	1C	2C	3C	4C
D – REMOTE	1D	2D	3D	4D
E - IMPROBABLE	1E	2E	3E	4E

- Risk Index - Suggested Acceptance Criteria in MIL-STD-882C

Unacceptable:	1A, 1B, 1C, 2A, 2B, 3A
Undesirable:	1D, 2C, 2D, 3B, 3C
Acceptable w/ Review by Managing Activity:	1E, 2E, 3D, 3E, 4A, 4B
Acceptable w/out Review:	4C, 4D, 4E

Design Criteria

- Design for minimum risk
  - Review design criteria for inadequate or overly restrictive requirements
  - Design to eliminate hazards
  - If hazard cannot be eliminated
    - Reduce risk to an acceptable level through design selection
    - Interlocks, redundancy, fail safe design, system protection, fire suppression, and protective clothing, equipment, devices, and procedures
- Recommend new design criteria supported by study, analyses, or test data



System Description

Hazard Identification

Probabilities Estimation

Consequences Estimation

Risk Determination

Risk Acceptance

Modify System

Operate System

Probability Estimation

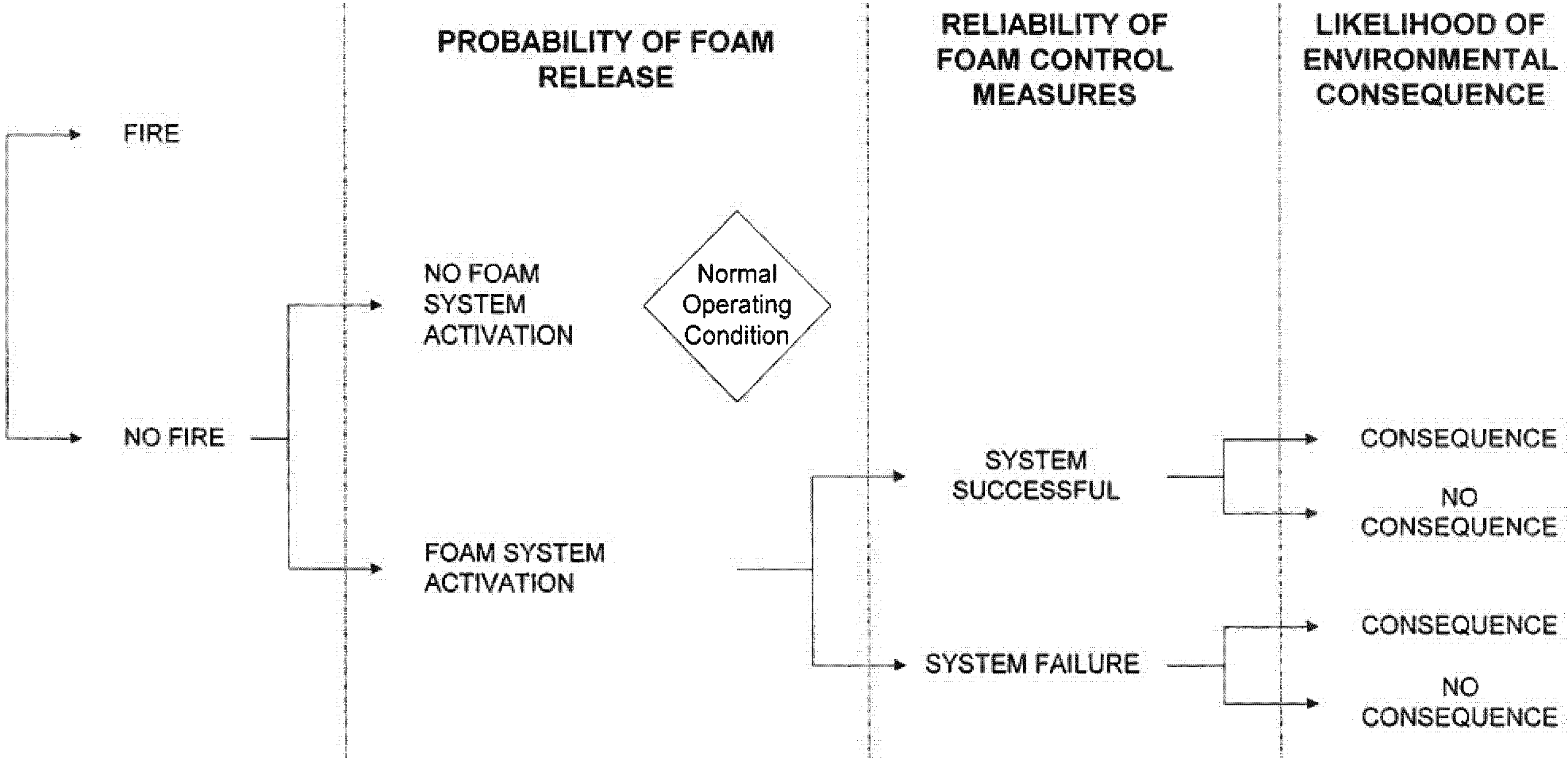
3 Parts to Probability Estimation

Probability of foam release

Reliability of system controlling foam movement

Likelihood of environmental consequence

Probability Estimation



Accident Probability Estimation Of Environmental Consequence

	AIR	Sensitive Body of Water	Soil Ground Water	Wastewater Treatment Plant
1. Sanitary sewer, WWTP	E	C	E	C
2. Segregated Storm Sewer	E	C	E	E
3. Plugged, Storm Sewer	E	D	E	D
4. Pavement, Plugged Storm Sewer/drains	E	D	E	E
5. Pavement, Plugged Combined Sewer/drains	E	D	E	D
6. Pavement, Combined Sewer WWTP	E	C	E	C
7. Pavement, Storm Sewer	E	C	E	E
8. Unlined Pond, Percolates	E	E	E	E
9. Lined Pond, Pump Off-Site	E	E	E	E
10 Lined Pond, evaporate	E	E	E	E
11. Lined Pond, Meter WWTP	E	D	E	D
12. Lined Pond, Meter Storm Sewer	E	C	E	D
13. Lined Pond, Degrade WWTP	E	D	E	D
14. Lined Pond, Degrade Storm Sewer	E	D	E	D
15. Tank, Pump Off-Site	E	E	E	E
16. Tank, Meter WWTP	E	D	E	D
17. Tank Meter Storm Sewer	E	C	E	D
18. Tank, Degrade WWTP	E	D	E	D
19. Tank, Degrade Storm Sewer	E	D	E	D

Consequence Estimation
Severity of Environmental Impact

Air	Negligible/Marginal*
Sensitive Body of Water	Marginal
Soil Ground Water	Marginal
WWTP	Critical

*Air becomes marginal if foam in WWTP

Risk Assessment and Acceptance

	AIR	Sensitive Body of Water	Soil Ground Water	Wastewater Treatment Plant
1. Sanitary sewer, WWTP	3E	3C	3E	2C
2. Segregated Storm Sewer	4E	3C	3E	2E
3. Plugged, Storm Sewer	4E	3D	3E	2D
4. Pavement, Plugged Storm Sewer/drains	4E	3D	3E	2E
5. Pavement, Plugged Combined Sewer/drains	4E	3D	3E	2D
6. Pavement, Combined Sewer WWTP	3E	3C	3E	2C
7. Pavement, Storm Sewer	4E	3C	3E	2E
8. Unlined Pond, Percolates	4E	3E	3E	2E
9. Lined Pond, Pump Off-Site	4E	3E	3E	2E
10 Lined Pond, evaporate	4E	3E	3E	2E
11. Lined Pond, Meter WWTP	3E	3D	3E	2D
12. Lined Pond, Meter Storm Sewer	4E	3C	3E	2D
13. Lined Pond, Degrade WWTP	3E	3D	3E	2D
14. Lined Pond, Degrade Storm Sewer	4E	3D	3E	2D
15. Tank, Pump Off-Site	4E	3E	3E	2E
16. Tank, Meter WWTP	3E	3D	3E	2D
17. Tank Meter Storm Sewer	4E	3C	3E	2D
18. Tank, Degrade WWTP	3E	3D	3E	2D
19. Tank, Degrade Storm Sewer	4E	3D	3E	2D

Summary

- Control and Management of AFFF Solutions
  - Based on Risk of Environmental Consequence
    - Risk Decision
    - Probability AND Severity
  - No "Unacceptable" Risks from Accidental Discharge
  - "Undesirable" Risks Avoidable through Design
  - Remaining Options All have Equivocal Residual Risk
- Basis for Design Criteria
  - Ensure Risk is "Acceptable w/ Review by Managing Activity" Category
  - Minimizes Risk to the Environment
  - Does Not Increase Risk to Life-Safety/ Fire Loss

APPENDIX (10)

Presentation: "Phasing Out a Problem: Perfluorooctyl Sulfonate"

M. Dominiak
Environmental Protection Agency

Phasing Out a Problem: Perfluorooctyl Sulfonate (PFOS)

Mary F. Dominiak
U.S. Environmental Protection Agency
Naval Research Laboratory
3 August 2000

What is PFOS?

- Perfluorooctyl sulfonates; *acids, salts, halides, etc.*
- Man-made: do not occur in nature
- Produced since 1950's for use in surface treatment, paper protection, and performance chemical (surfactant and insecticide) products
- Also produced by breakdown/degradation of other sulfonyl-based fluorochemicals
- Made mostly by 3M Company

What is PFOS used for?

- Soil and stain resistant coatings on textiles, carpets, leather (2.3 million lbs/year)
- Oil, grease, and water resistance on paper products, including paperboard and food contact papers (2.6 million lbs/year)
- Performance chemicals: fire fighting foams, industrial surfactants, acid mist suppression, etc. (1.5 million lbs/year)

Why is PFOS a problem?

- PFOS is a PBT chemical:

  Persistent

  Bioaccumulative

  Toxic

- PFOS has been found in the blood of the general US population, in wildlife, and in people overseas

Why is PFOS a problem?

- Persistent:
  - PFOS is a very stable chemical that does not break down or degrade in the environment; *once it's there, it stays*
- Bioaccumulative:
  - PFOS can build up over time; *its half-life in human blood is about 4 years*
  - Higher-ups in the food chain are exposed to the full dose of what has built up in their food

Why is PFOS a problem?

- Toxicity:
  - PFOS is only moderately toxic via acute oral exposure; *rat LD_{50} of 251 mg/kg*
  - In repeat oral dose subchronic and reproductive toxicity studies, however, serious effects seen
    - *Post-natal deaths in rats at 3.2 and 1.6 mg/kg/day*
    - *In repeat-dose treated Rhesus monkeys, death within 3 weeks at 10 mg/kg/day; within 7 weeks at 4.5 mg/kg/day. Adverse effects in cynomolgus monkeys at 0.75 mg/kg/day*

Why is PFOS a problem?

- Detected in blood not only in workers handling the chemical, but in the general US population and in wildlife
  - *High as 12.83 ppm in manufacturing workers*
  - *In pooled serum from general population, 30-40 ppb; small sample of children, mean 54 ppb*
  - *In eagles, wild birds, and fish, in ppb range*

How did PFOS get in people?

- We don't know the precise exposure route, but studies are underway
- Possibilities include:
    - Dietary intake from food wrapped in papers treated with PFOS derivatives
    - Inhalation from aerosol applications
    - Inhalation, dietary, or dermal exposures during manufacturing, use, or disposal of chemicals and treated products

Why haven't PFOS problems been addressed before?

- PFOS was always known to be persistent, but much information on bioaccumulation and toxicity is recent
  - Improved detection technologies find PFOS at much lower levels in humans, wildlife
  - PFOS doesn't fit normal bioaccumulation model; *partitions to blood, not fat*
  - Newest toxicity tests raise greatest concerns

How big a risk is PFOS?

- EPA does not believe that the current situation presents an imminent health risk to the general US population; *blood levels low, concentration in surface-treated products (carpets/textiles) low*
- However, serious concern for potential future risk to humans and wildlife if PFOS continues to be produced, released, built up in the environment
- Studies underway to determine relationship of current blood levels to potential for adverse effects
- Questions/concerns on occupational exposures

What is being done about PFOS?

- 3M conducted studies, shared results with EPA, and discussed concerns
- On 5/16/2000, 3M publicly announced voluntary phase-out of perfluorooctanyl chemistries, most by end of 2000
- 3M submitted phase-out plan to EPA on 6/16/2000, amended on 7/7/2000
- 3M continues aggressive research program

What does the 3M PFOS phaseout plan involve?

- 3M will stop manufacture of PFOS for surface treatment products by 12/31/2000; *includes fabric/carpet/leather soil and stain resistance and paper coating products, including food contact*
- 3M will phase out manufacture of PFOS for performance products by 12/31/2002
- *Caveat:* May request permission for extended production for specific performance uses for which adequate substitutes do not exist or can't be qualified in time; *risk/risk tradeoffs, national security, technical performance issues*

What does EPA think of 3M's PFOS phaseout plan?

- EPA agrees that continued manufacture and use of PFOS represents an unacceptable technology that should be eliminated to protect human health and the environment from long term consequences
- 3M's voluntary phaseout will accomplish this goal more quickly than regulation could
- EPA may use regulation to "close the door" on PFOS after 3M's exit; *concerned parties will be able to comment and to dialogue with EPA*

What does this mean for fire fighters using PFOS foams?

- Fire fighting foams are in the performance category of products; continue through 2002
- 3M and EPA will be assessing health, safety and environmental implications of possible substitutes; *will welcome dialogue!*
- If qualified substitutes not available by end of 2002, 3M may request continued PFOS production for specific uses

What about using chemicals other than PFOS?

- Initial actions and phaseout apply to PFOS chemicals only
- EPA will be expanding review to assess other perfluorinated chemicals and related chemistries; *PFOA, telomers*
- Assessment activities will be international
- Industry group already proposing voluntary two-year research effort on some major telomers to begin 9/2000
- Too early to anticipate outcomes

How will EPA make decisions on PFOS issues?

- Toxic Substances Control Act (TSCA)
- Risk/benefit balancing requirements allow flexibility; *TSCA lets EPA take risk/risk tradeoffs, economic issues into account*
- Possible actions include:
  - Bans
  - Restrictions on uses
  - Production volume limits
  - Data collection and new testing requirements
  - Labeling, hazard communication

Where can I find information on PFOS and EPA actions?

- All documents on PFOS in public EPA Administrative Record, File AR-226
  - Includes all health studies submitted on PFOS
  - Available in hard copy or on CD-ROM
  - 401 M St, SW, Room NE B-607, Wash., DC, noon to 4 PM Eastern, Monday-Friday; telephone 202-260-7099
- Working on website; *not up yet, stay tuned*
- Interim EPA "Voice of PFOS:" Mary Dominiak, phone 202-260-7768; *dominiak.mary@epa.gov*

APPENDIX (11)

Presentation: "Facilities Background and AFFF Issues"

J. Simone
Naval Facilities Engineering Command

Facilities Background
And
AFFF Issues

Presentation to Hangar Facilities Breakout Session
DOD AFFF Environmental Meeting
2 August 2000

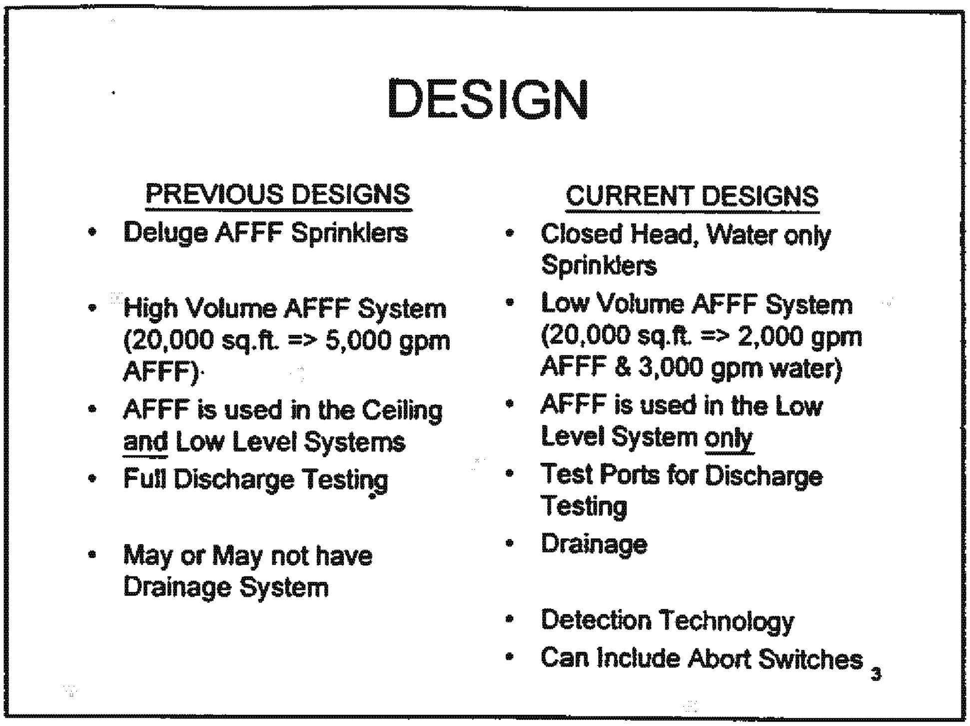
Joe Simone
Naval Facilities Engineering Command

FACILITIES BACKROUND

- Facilities that use AFFF - Aircraft Hangars, HAZ/FLAM Buildings, Fire Fighters Test Facilities, Hush Houses, and others
- Variety of Fire Protection Criteria in the Last 10 Years
- Variety of Containment Requirements
- No Risk Analysis with respect to Environmental
- Budget Proposals Guess or Don't Address Funding

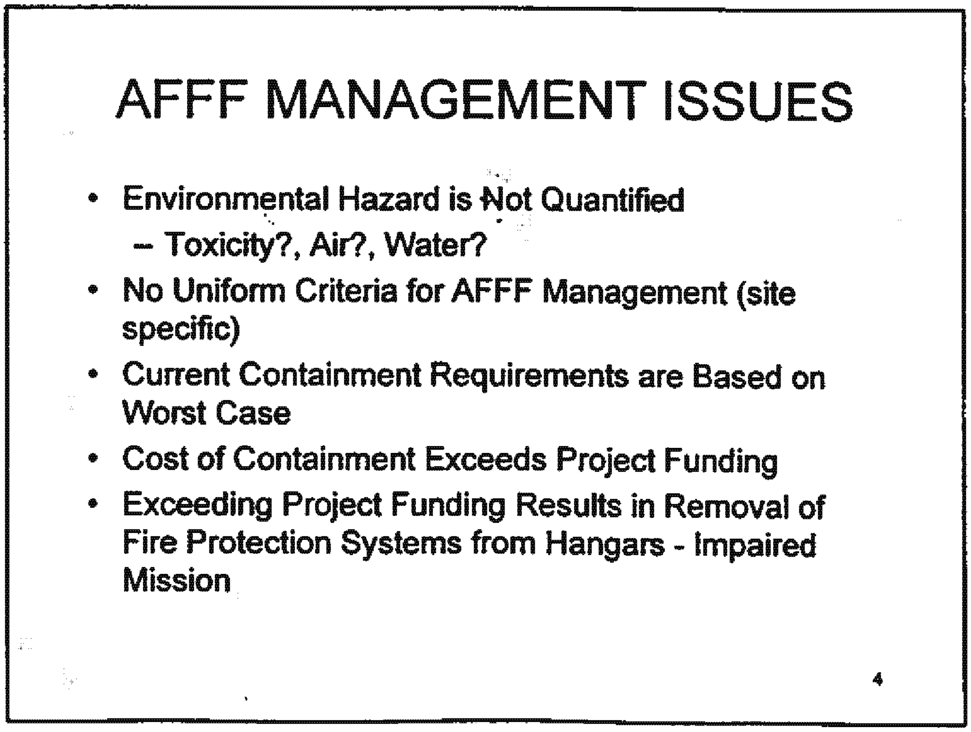
NAVAIR/NAVFAC HANGAR PROJECTS

- Evaluated Detector & Sprinkler Response Time in Hangars
- Evaluated Removing AFFF from Overhead Sprinkler Systems
  - Evaluated Using Lower AFFF Application Rate
- Evaluated New Low Level AFFF Distribution Systems
- Evaluated Variety of Optical Flame Detectors
- Developed New Fire Protection Criteria



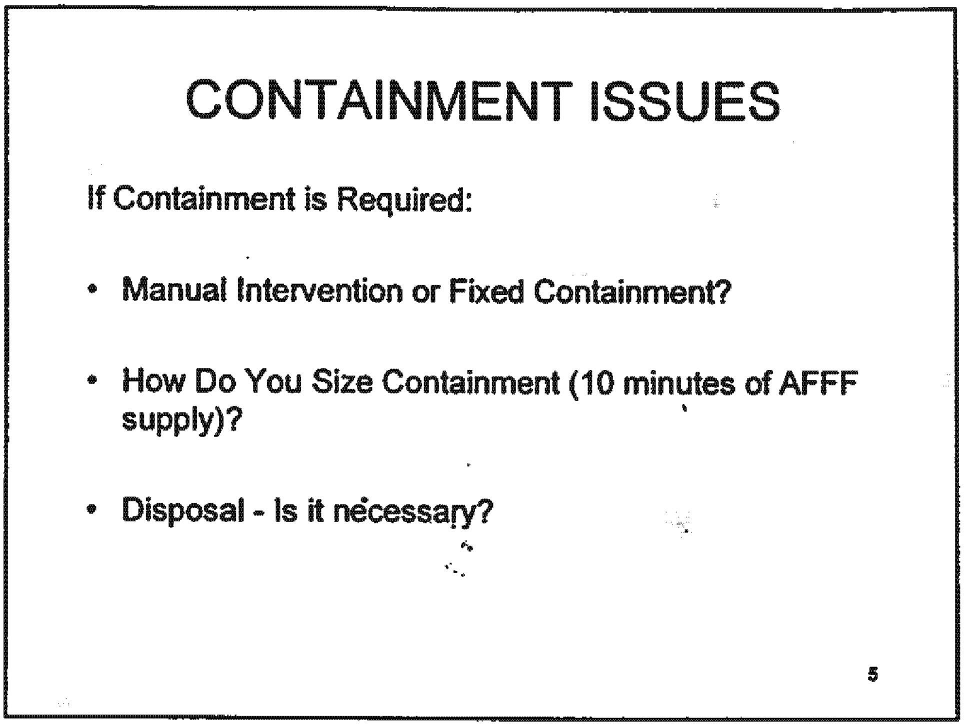
DESIGN

PREVIOUS DESIGNS	CURRENT DESIGNS
• Deluge AFFF Sprinklers	• Closed Head, Water only Sprinklers
• High Volume AFFF System (20,000 sq.ft. => 5,000 gpm AFFF)	• Low Volume AFFF System (20,000 sq.ft. => 2,000 gpm AFFF & 3,000 gpm water)
• AFFF is used in the Ceiling and Low Level Systems	• AFFF is used in the Low Level System only
• Full Discharge Testing	• Test Ports for Discharge Testing
• May or May not have Drainage System	• Drainage
	• Detection Technology
	• Can Include Abort Switches



AFFF MANAGEMENT ISSUES

- Environmental Hazard is Not Quantified
  - Toxicity?, Air?, Water?
- No Uniform Criteria for AFFF Management (site specific)
- Current Containment Requirements are Based on Worst Case
- Cost of Containment Exceeds Project Funding
- Exceeding Project Funding Results in Removal of Fire Protection Systems from Hangars - Impaired Mission



CONTAINMENT ISSUES

If Containment is Required:

- Manual Intervention or Fixed Containment?
- How Do You Size Containment (10 minutes of AFFF supply)?
- Disposal - Is it necessary?

APPENDIX (12)

Presentation: "AFFF Risk Assessment"

A. Wakelin
Hughes Associates, Inc.
Baltimore MD

Aqueous Film Forming Foam (AFFF) Risk Assessment

For discharges of AFFF from fixed fire protection systems in shore facilities

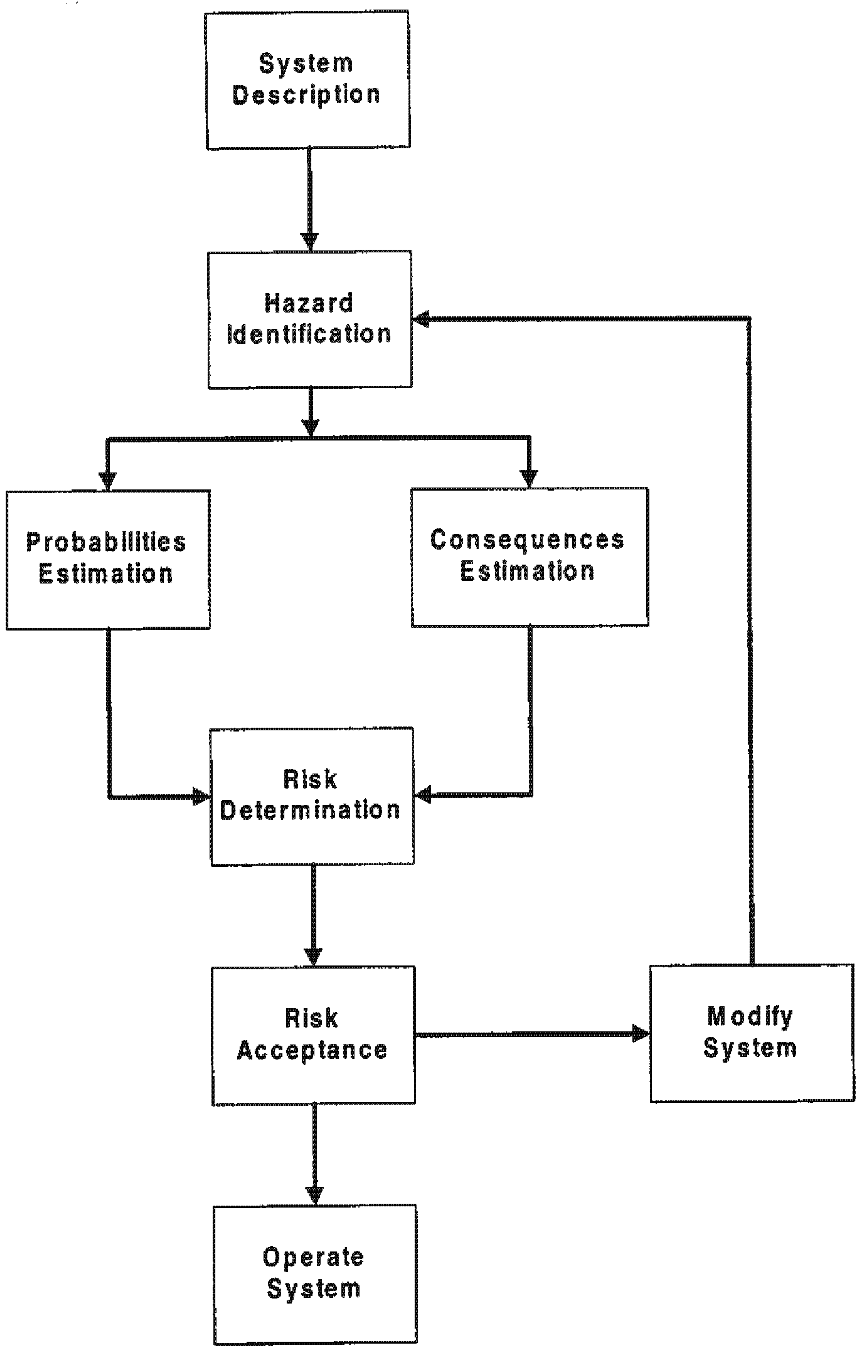
Alison Wakelin

HUGHES ASSOCIATES, INC.
FIRE SCIENCE & ENGINEERING

August 2, 2000

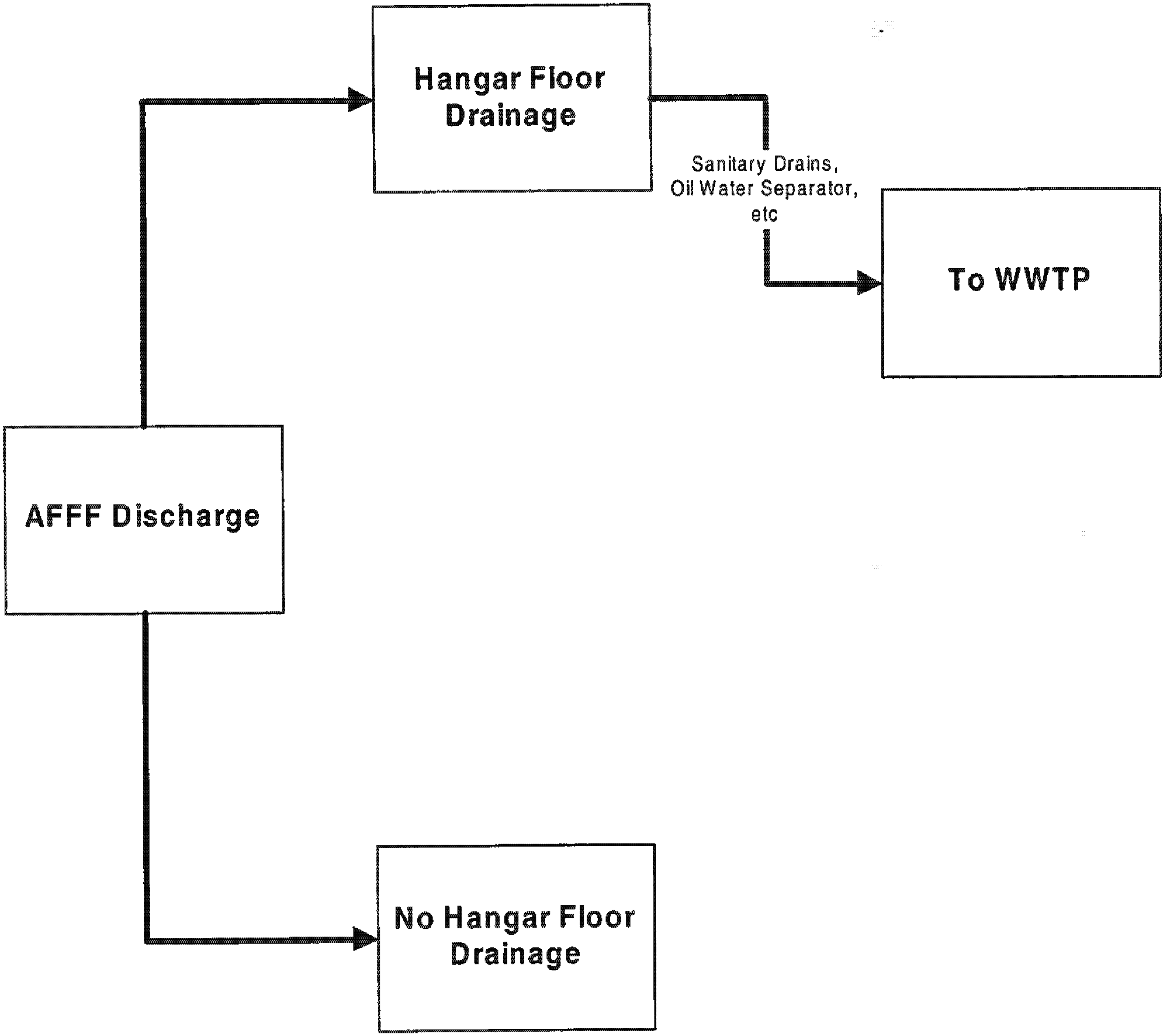
Overview

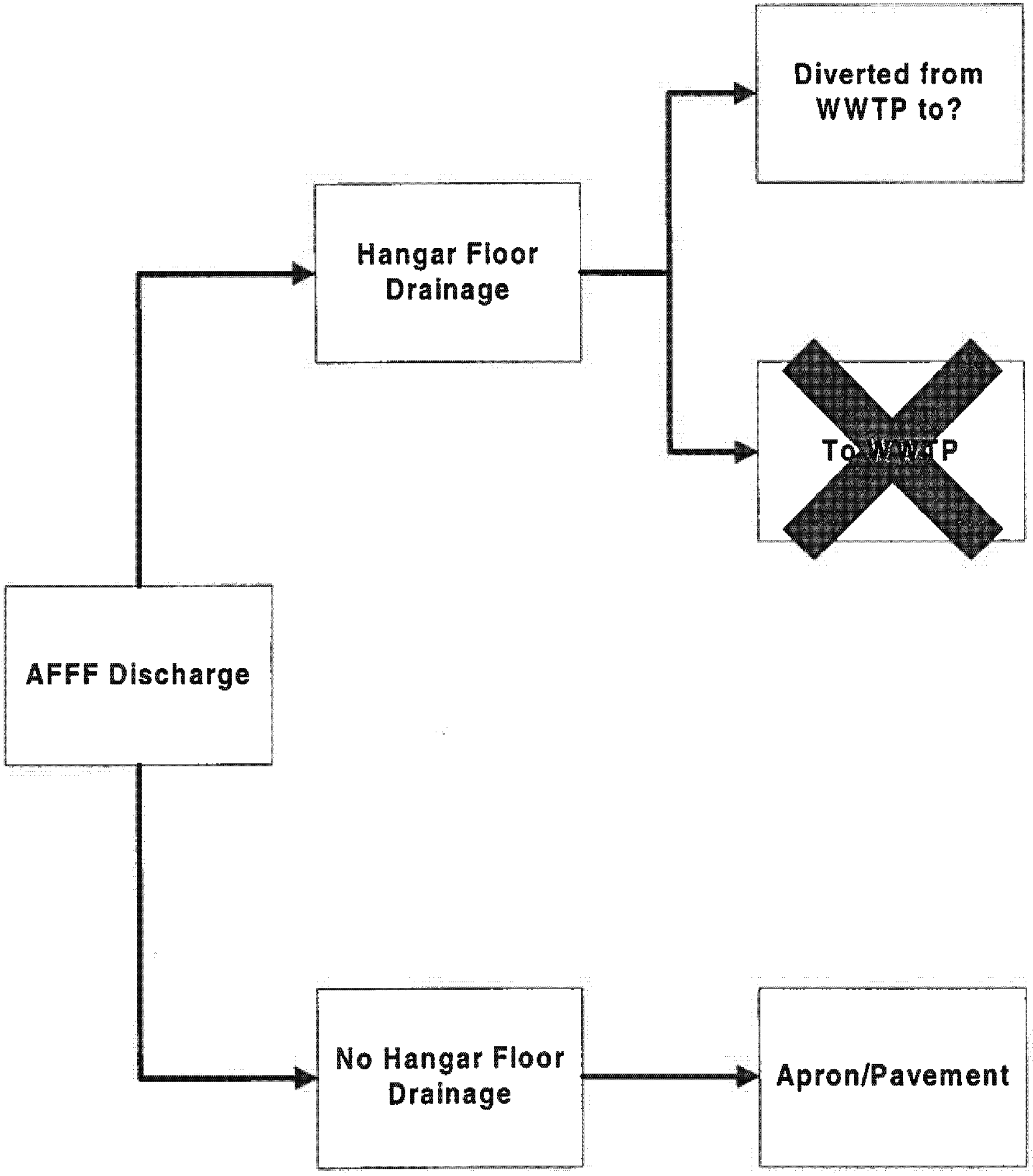
- Develop physical control options
  - Performance Criteria
- Probability Estimation
- Consequence Estimation
- Risk Assessment

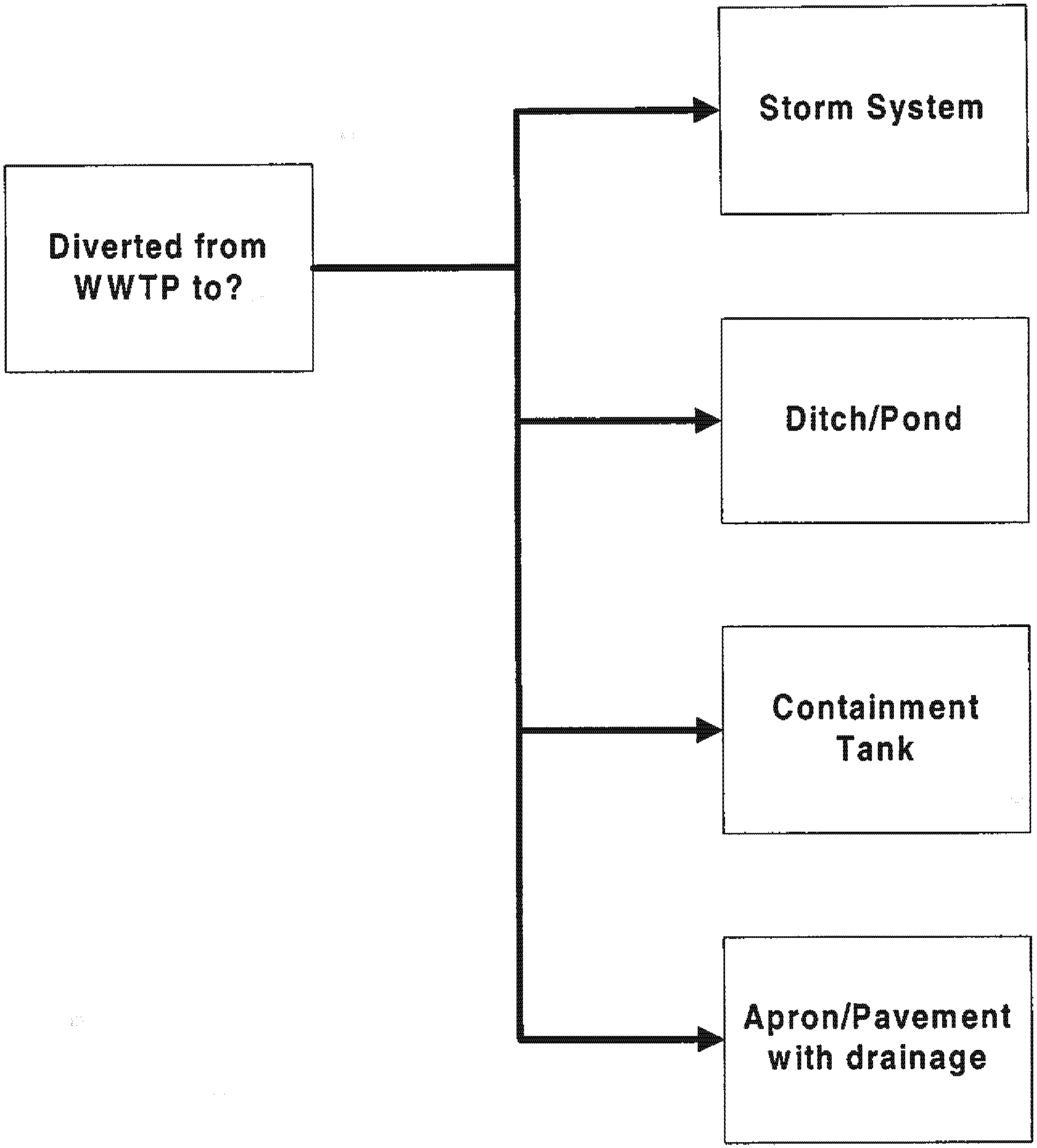

System Description
Hazard Identification
Probabilities Estimation
Consequences Estimation
Risk Determination
Risk Acceptance
Modify System
Operate System

Develop Physical Control Options

- Hangar drainage requirements (NFPA 409)
- Foam to the WWTP?
- Other options for maintaining positive control of foam


Hangar Floor Drainage
Sanitary Drains, Oil Water Separator, etc
To WWTP
AFFF Discharge
No Hangar Floor Drainage


AFFF Discharge
Hangar Floor Drainage
Diverted from WWTP to?
To WWTP
No Hangar Floor Drainage
Apron/Pavement



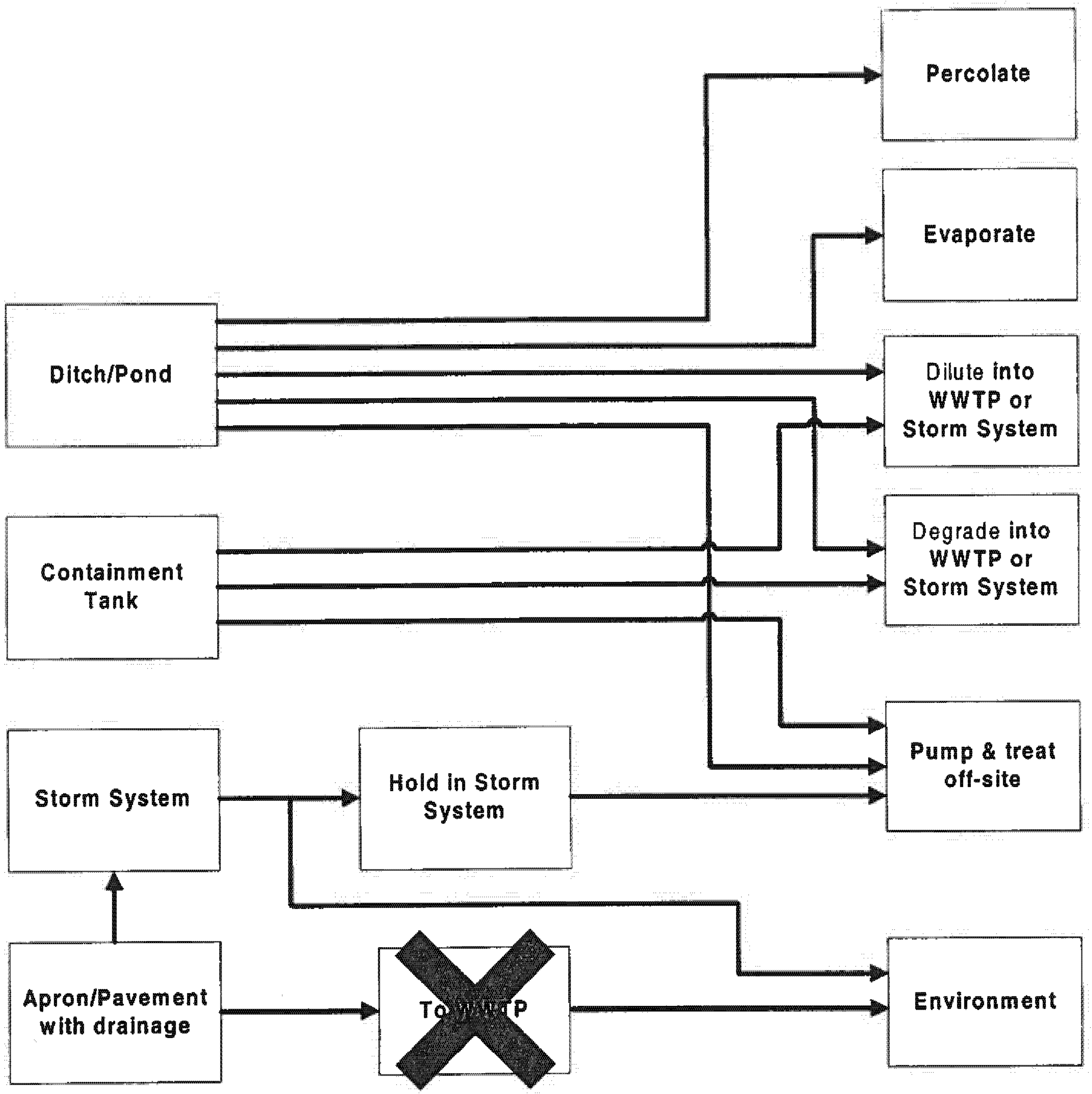
Diverted from WWTP to?

Storm System

Ditch/Pond

Containment Tank

Apron/Pavement with drainage


Percolate
Evaporate
Ditch/Pond
Dilute into WWTP or Storm System
Degrade into WWTP or Storm System
Containment Tank
Storm System
Hold in Storm System
Pump & treat off-site
Apron/Pavement with drainage
To WWTP
Environment

Physical Control Options

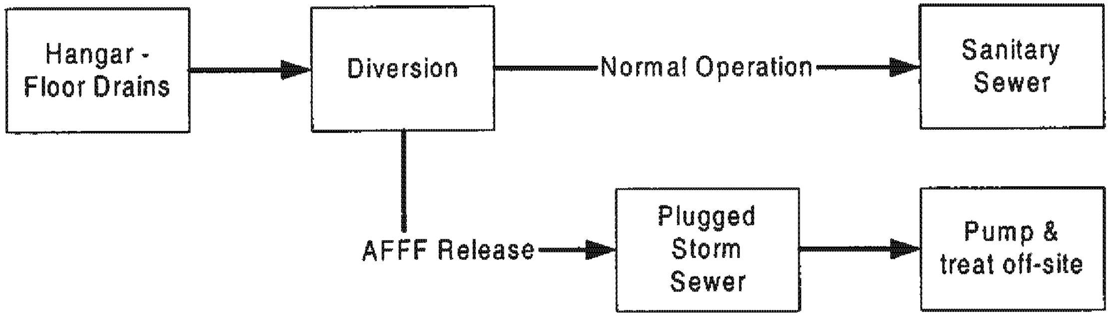
- 19 different control options
- Sufficient number to show range of risks
- Three options will be presented
  - data from all available on request

Example Physical Control Options

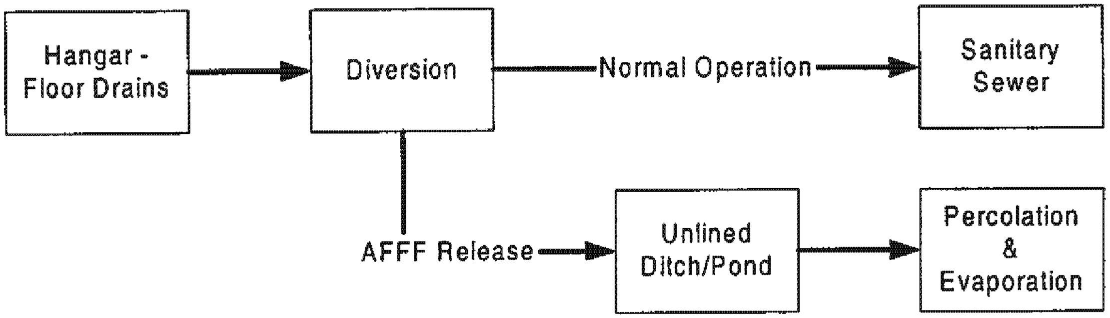
1. Sanitary sewer with direct access to WWTP


Hangar - Floor Drains
Sanitary System
WWTP

2. Plugged, totally segregated storm sewer


Hangar - Floor Drains
Diversion
Normal Operation
Sanitary Sewer
AFFF Release
Plugged Storm Sewer
Pump & treat off-site

3. Pond, Percolate (drains into soil)


Hangar - Floor Drains
Diversion
Normal Operation
Sanitary Sewer
AFFF Release
Unlined Ditch/Pond
Percolation & Evaporation

Performance Criteria

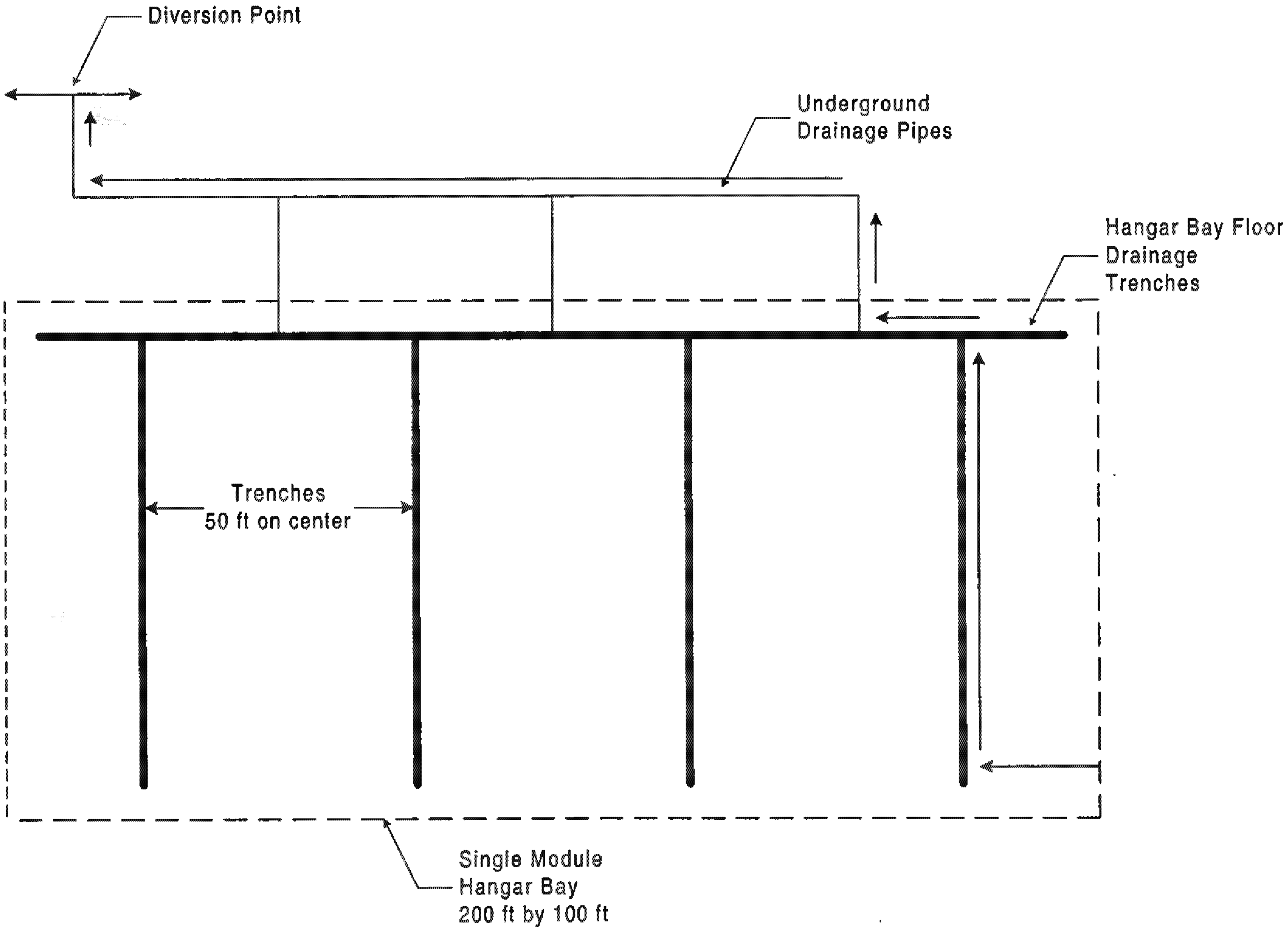
- Detailed investigation of control options
- What are performance goals of control options?
  - How much of a discharge needs to be controlled?
- Accidental discharge shut-off in 3 mins?
- Accidental discharge of all foam?

Proposed Foam Control Criteria

- Conservative approach all foam has drained to beyond diversion point
- No emergency shut-off
- 6 min drainage time
- Single "module" hangar 100 ft by 200 ft
- Total flow
  - 16 min @ 2000 gpm = 32,000 gal

Proposed Foam Control Criteria

Drainage



Probability Estimation

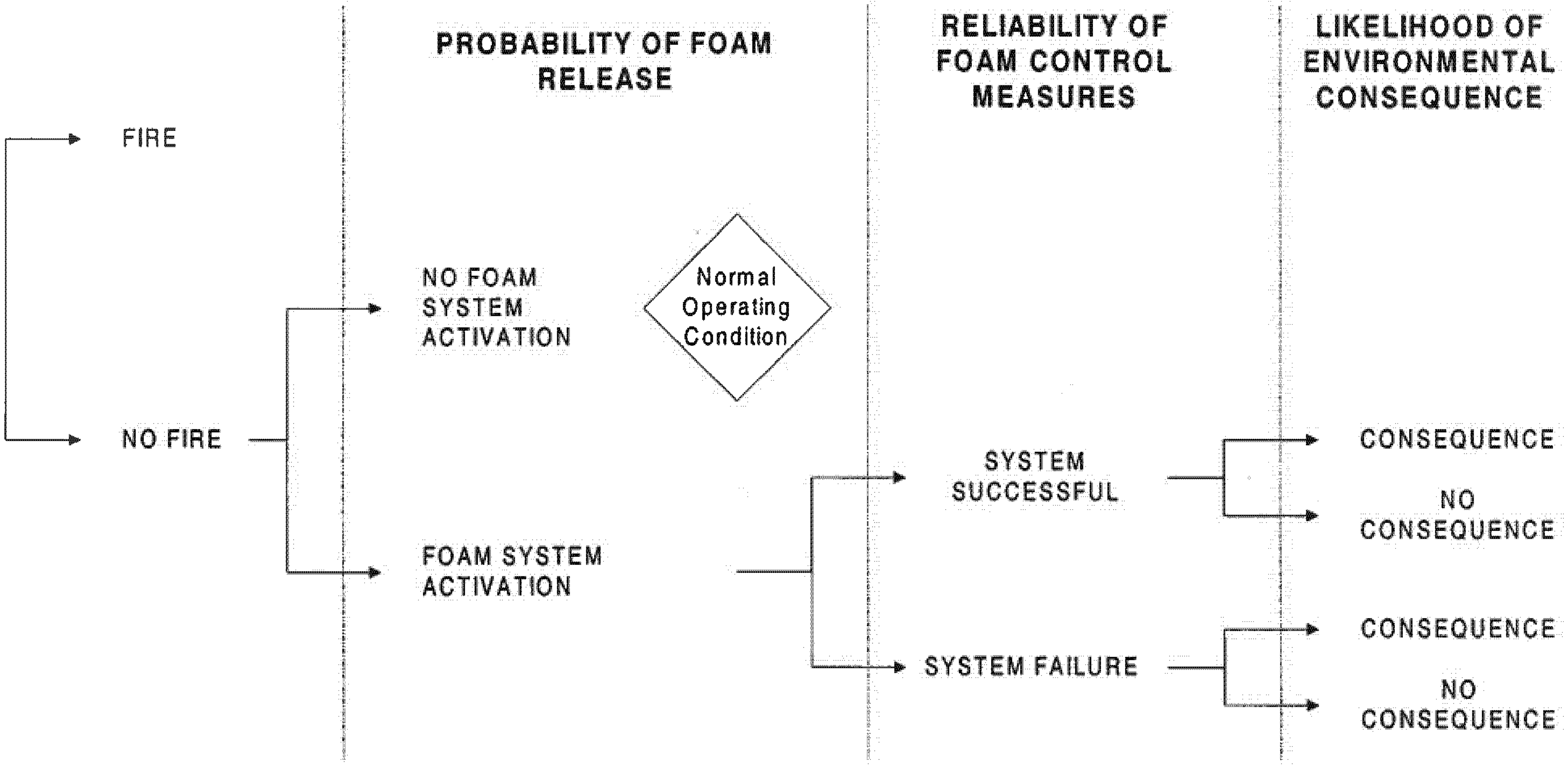
3 Parts to Probability Estimation

Probability of foam release

Reliability of system controlling foam movement

Likelihood of environmental consequence

Probability Estimation

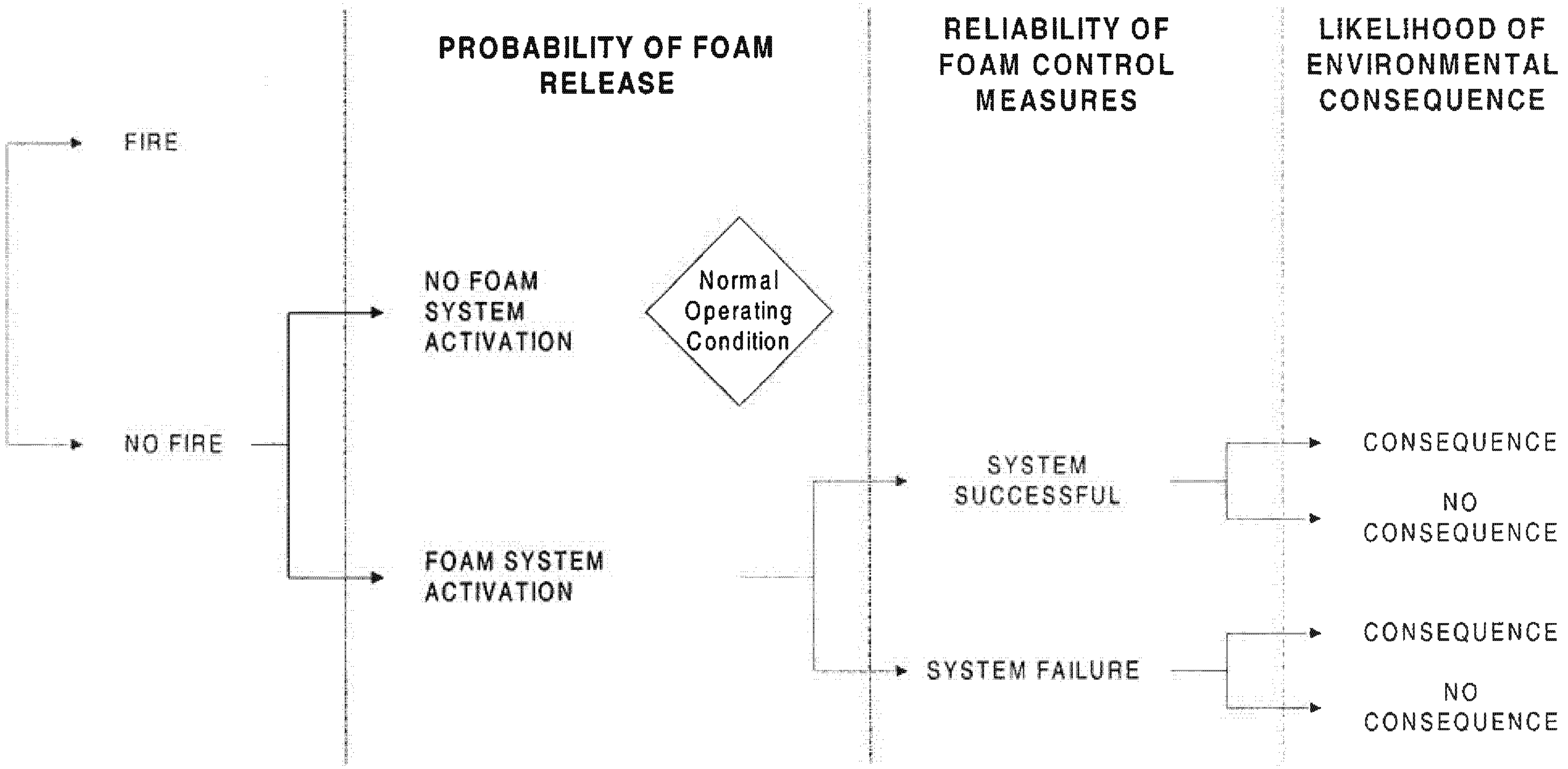


Probability Estimation

A	FREQUENT	Likely to occur frequently
B	PROBABLE	Will occur several times in the life of an item
C	OCCASIONAL	Likely to occur some time in the life of an item
D	REMOTE	Unlikely but possible to occur in the life of an item
E	IMPROBABLE	So unlikely, it can be assumed occurrence may not be experienced

Probability Estimation

Foam System Activation



Probability Estimation

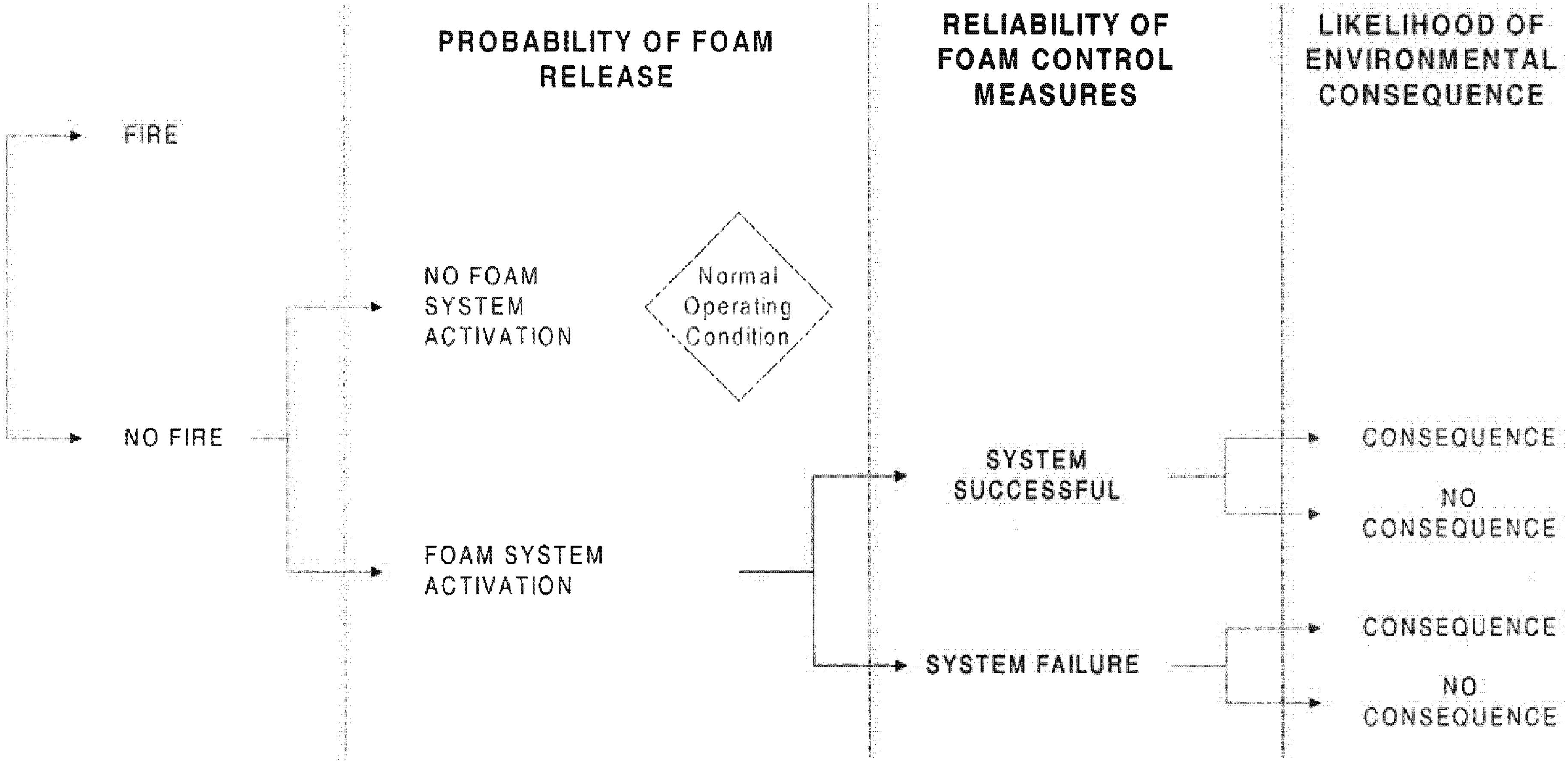
Foam System Activation

- Accidental activation of a low level foam system
- Likely to occur some time in the life of an item

⇒ Occasional C

Probability Estimation

Foam Control Measures



PROBABILITY OF FOAM RELEASE

RELIABILITY OF FOAM CONTROL MEASURES

LIKELIHOOD OF ENVIRONMENTAL CONSEQUENCE

FIRE

NO FIRE

NO FOAM SYSTEM ACTIVATION

Normal Operating Condition

FOAM SYSTEM ACTIVATION

SYSTEM SUCCESSFUL

SYSTEM FAILURE

CONSEQUENCE

NO CONSEQUENCE

CONSEQUENCE

NO CONSEQUENCE

Probability Estimation

Foam Control Measures

- An engineered design of each control measure is evaluated for:
  - Reliability
    - Likelihood of Control System Failure is Established
    - Failure based on complexity of system

Probability Estimation

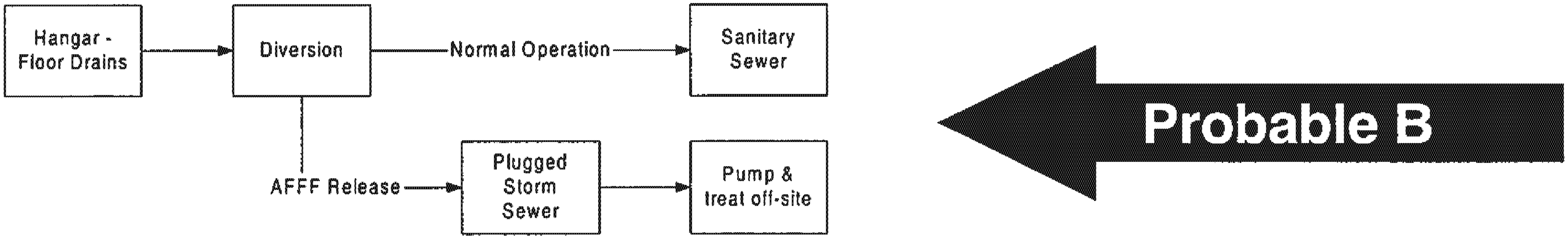
Likelihood of system failure

1. Sanitary sewer with direct access to WWTP

Hangar - Floor Drains → Sanitary System → WWTP

Improbable E

2. Plugged, totally segregated storm sewer

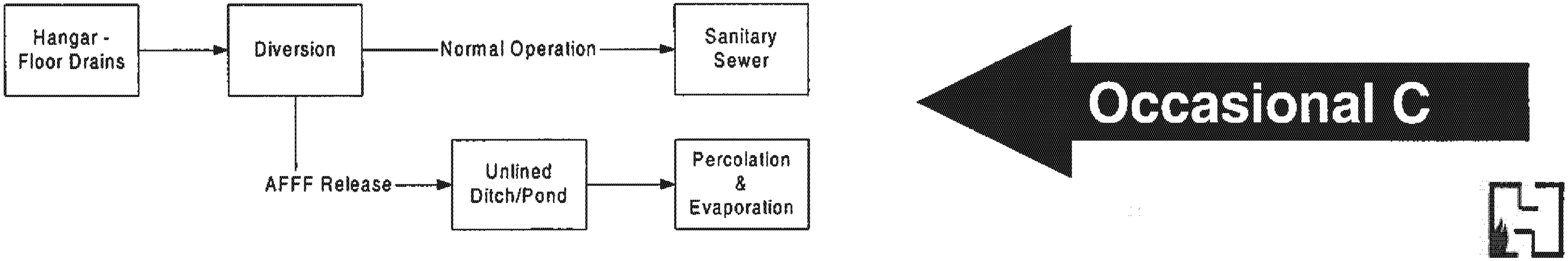


Hangar - Floor Drains → Diversion —Normal Operation→ Sanitary Sewer

Diversion — AFFF Release → Plugged Storm Sewer → Pump & treat off-site

Probable B

3. Pond, Percolate (drains into soil)



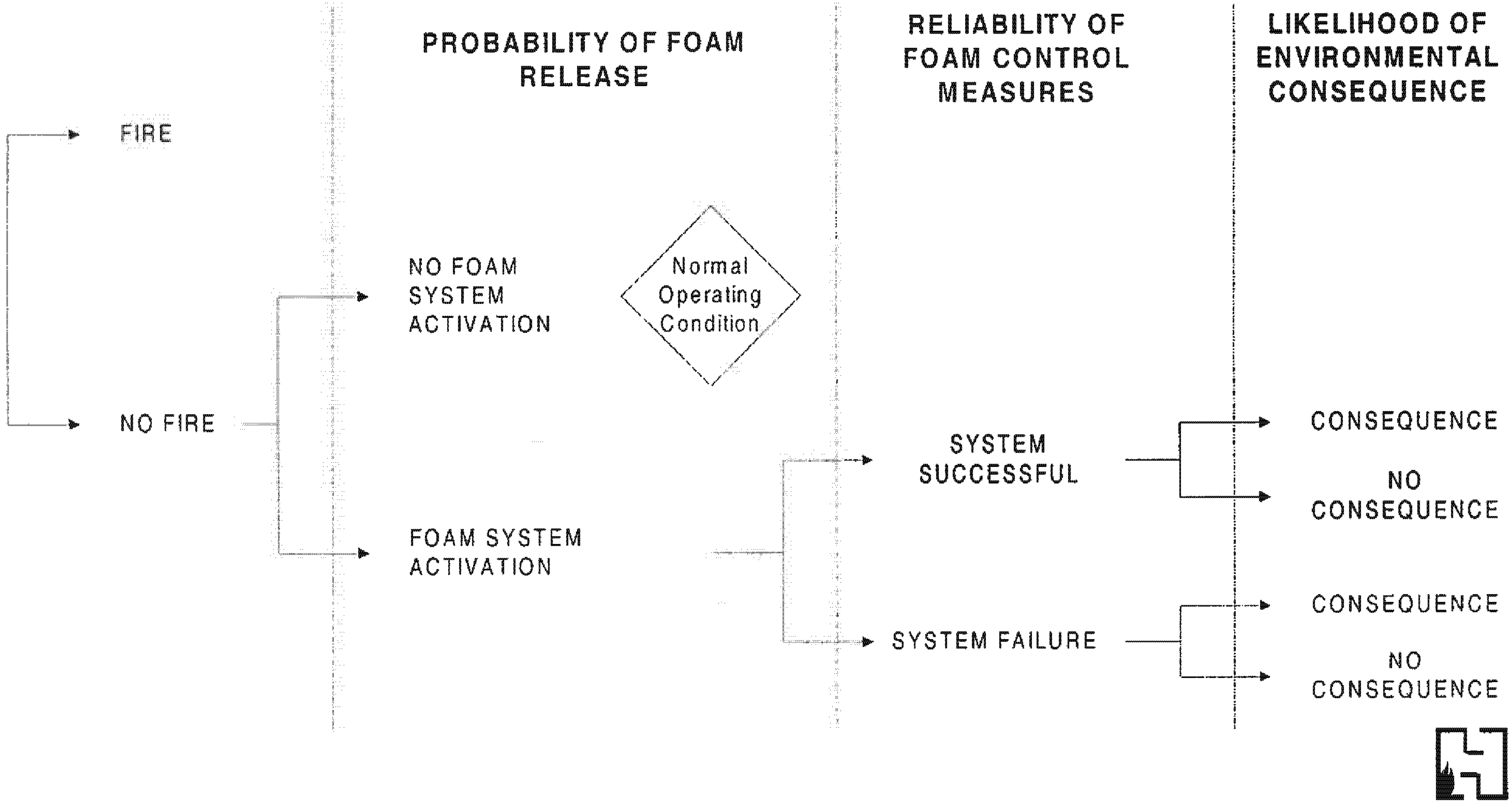
Hangar - Floor Drains → Diversion —Normal Operation→ Sanitary Sewer

Diversion — AFFF Release → Unlined Ditch/Pond → Percolation & Evaporation

Occasional C

Probability Estimation

Environmental Consequence



PROBABILITY OF FOAM RELEASE

RELIABILITY OF FOAM CONTROL MEASURES

LIKELIHOOD OF ENVIRONMENTAL CONSEQUENCE

FIRE

NO FIRE

NO FOAM SYSTEM ACTIVATION

Normal Operating Condition

FOAM SYSTEM ACTIVATION

SYSTEM SUCCESSFUL

SYSTEM FAILURE

CONSEQUENCE

NO CONSEQUENCE

CONSEQUENCE

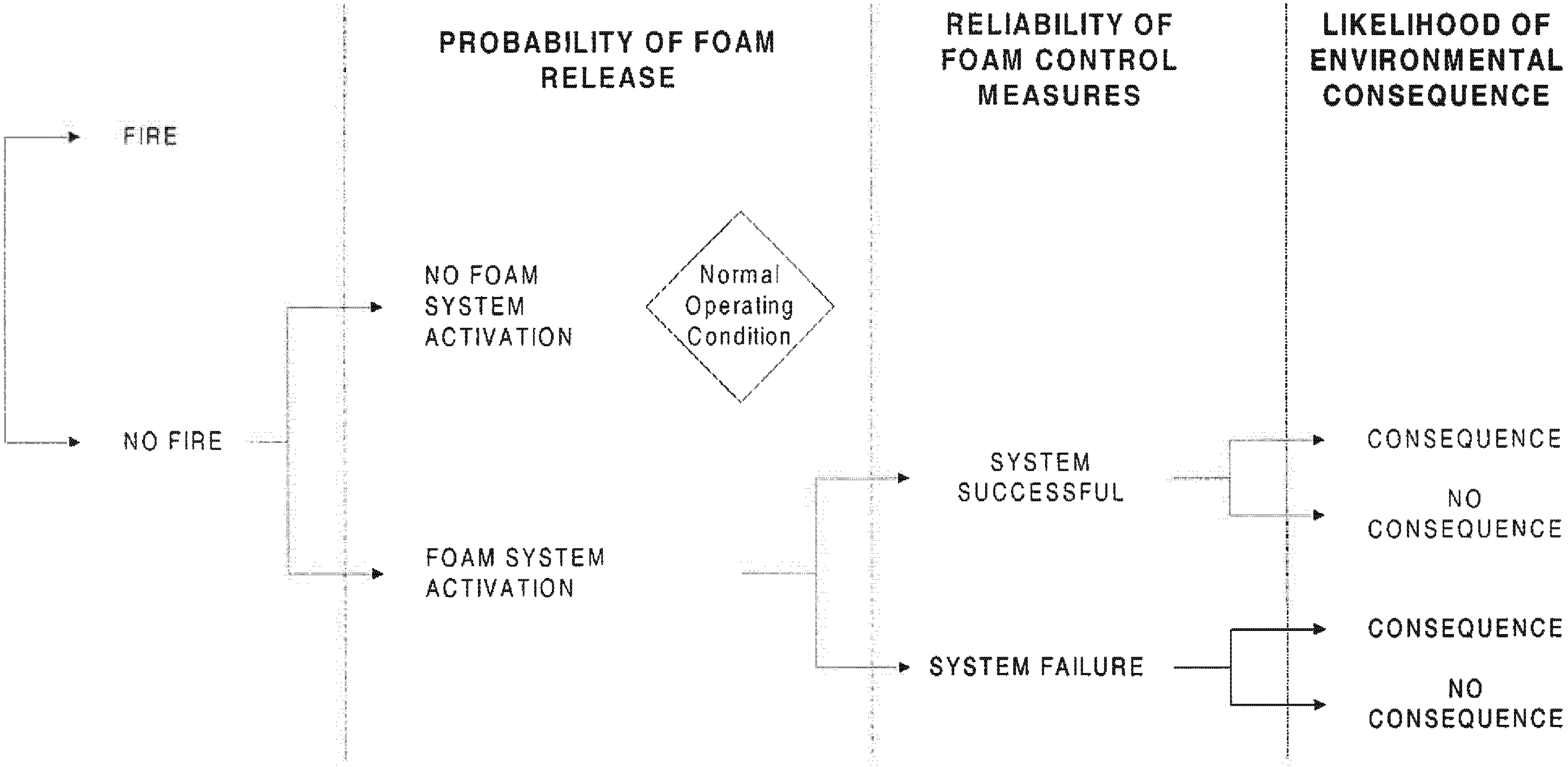
NO CONSEQUENCE

Probability Estimation
Environmental Consequence

Successful Foam Control (Risk By Media)				
	AIR	**Sensitive Body of Water**	**Soil Ground Water**	**Wastewater Treatment Plant**
1. Sanitary sewer, WWTP	Remote	Frequent	Improbable	Frequent
2. Plugged, Storm Sewer	Remote	Improbable	Improbable	Improbable
3. Unlined Pond, Percolates	Remote	Remote	Remote	Improbable
Unsuccessful Foam Control (Risk By Media)				
	AIR	**Sensitive Body of Water**	**Soil Ground Water**	**Wastewater Treatment Plant**
1. Sanitary sewer, WWTP	Remote	Frequent	Remote	Frequent
2. Plugged, Storm Sewer	Remote	Occasional	Remote	Occasional
3. Unlined Pond, Percolates	Remote	Occasional	Occasional	Occasional

Probability Estimation

Environmental Consequence



PROBABILITY OF FOAM RELEASE

RELIABILITY OF FOAM CONTROL MEASURES

LIKELIHOOD OF ENVIRONMENTAL CONSEQUENCE

FIRE

NO FIRE

NO FOAM SYSTEM ACTIVATION

Normal Operating Condition

FOAM SYSTEM ACTIVATION

SYSTEM SUCCESSFUL

SYSTEM FAILURE

CONSEQUENCE

NO CONSEQUENCE

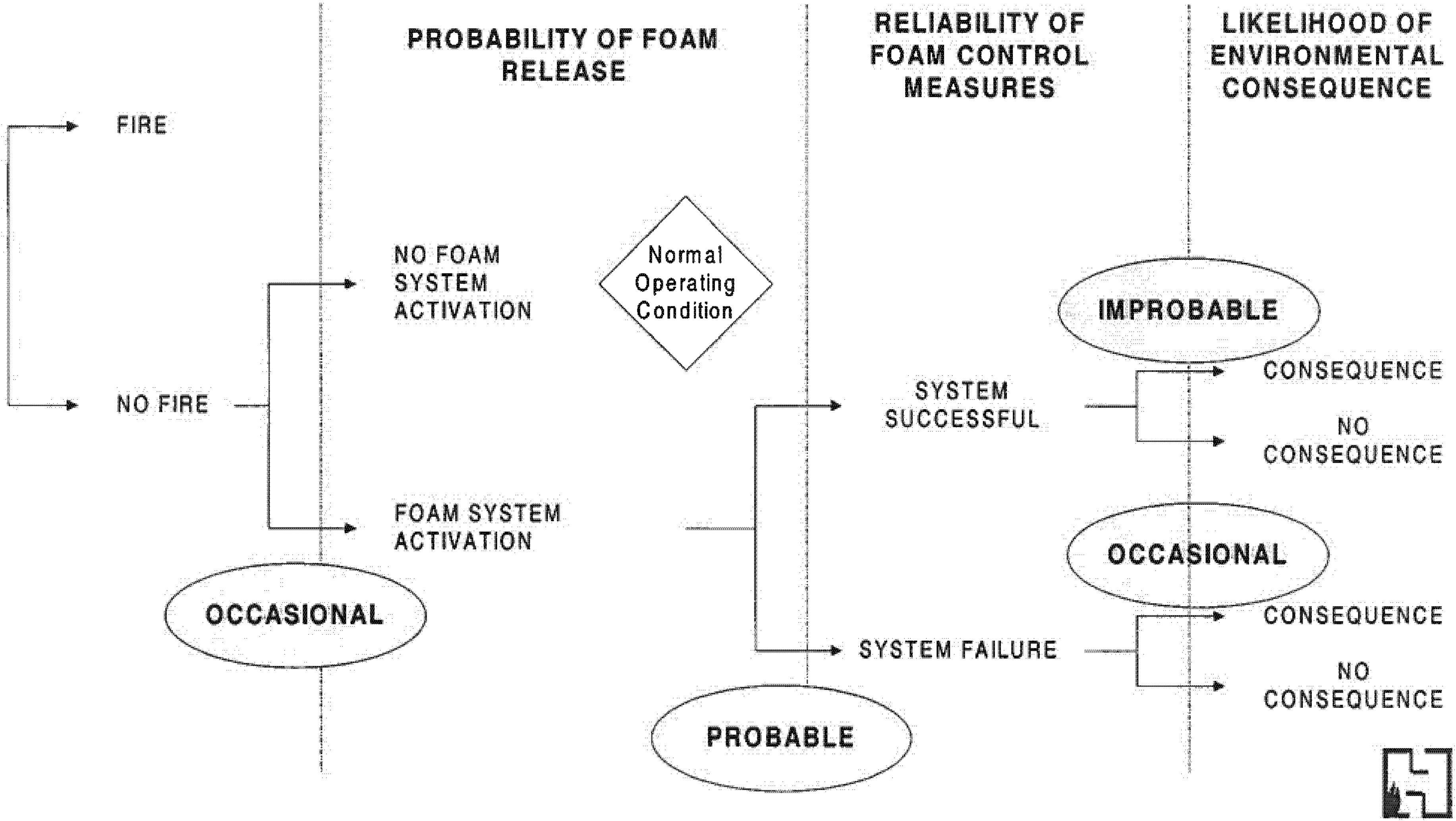
CONSEQUENCE

NO CONSEQUENCE

Probability Estimation

Environmental Consequences

Option 2: Plugged storm sewer Sensitive body of water



PROBABILITY OF FOAM RELEASE

RELIABILITY OF FOAM CONTROL MEASURES

LIKELIHOOD OF ENVIRONMENTAL CONSEQUENCE

FIRE

NO FIRE

NO FOAM SYSTEM ACTIVATION

Normal Operating Condition

FOAM SYSTEM ACTIVATION

OCCASIONAL

SYSTEM SUCCESSFUL

SYSTEM FAILURE

PROBABLE

IMPROBABLE

CONSEQUENCE

NO CONSEQUENCE

OCCASIONAL

CONSEQUENCE

NO CONSEQUENCE

Probability Estimation

Frequency Estimation		Suggested Range
A	FREQUENT	$X > 10^{-1}$
B	PROBABLE	$10^{-1} > X > 10^{-2}$
C	OCCASIONAL	$10^{-2} > X > 10^{-3}$
D	REMOTE	$10^{-3} > X > 10^{-6}$
E	IMPROBABLE	$10^{-6} > X$

Probability Estimation
Environmental Consequence

	AIR	Sensitive Body of Water	Soil Ground Water	Wastewater Treatment Plant
1. Sanitary sewer, WWTP	E	C	E	C
2. Plugged, Storm Sewer	E	D	E	D
3. Unlined Pond, Percolates	E	E	E	E

Consequence Estimation
Severity of Environmental Impact

Air	Negligible/Marginal*
Sensitive Body of Water	Marginal
Soil Ground Water	Marginal
WWTP	Critical

*Air becomes marginal if foam in WWTP

Risk Assessment & Acceptance

CATEGORY FREQUENCY	1 CATASTROPHIC	2 CRITICAL	3 MARGINAL	4 NEGLIGIBLE
A – FREQUENT	1A	2A	3A	
B – PROBABLE	1B	2B	3B	
C – OCCASIONAL	1C	2C	3C	4C
D – REMOTE	1D	2D		4D
E - IMPROBABLE				4E

UNACCEPTABLE:	1A, 1B, 1C, 2A, 2B, 3A
UNDESIRABLE:	1D, 2C, 2D, 3B, 3C
ACCEPTABLE WITH REVIEW:	
ACCEPTABLE WITHOUT REVIEW:	4C, 4D, 4E

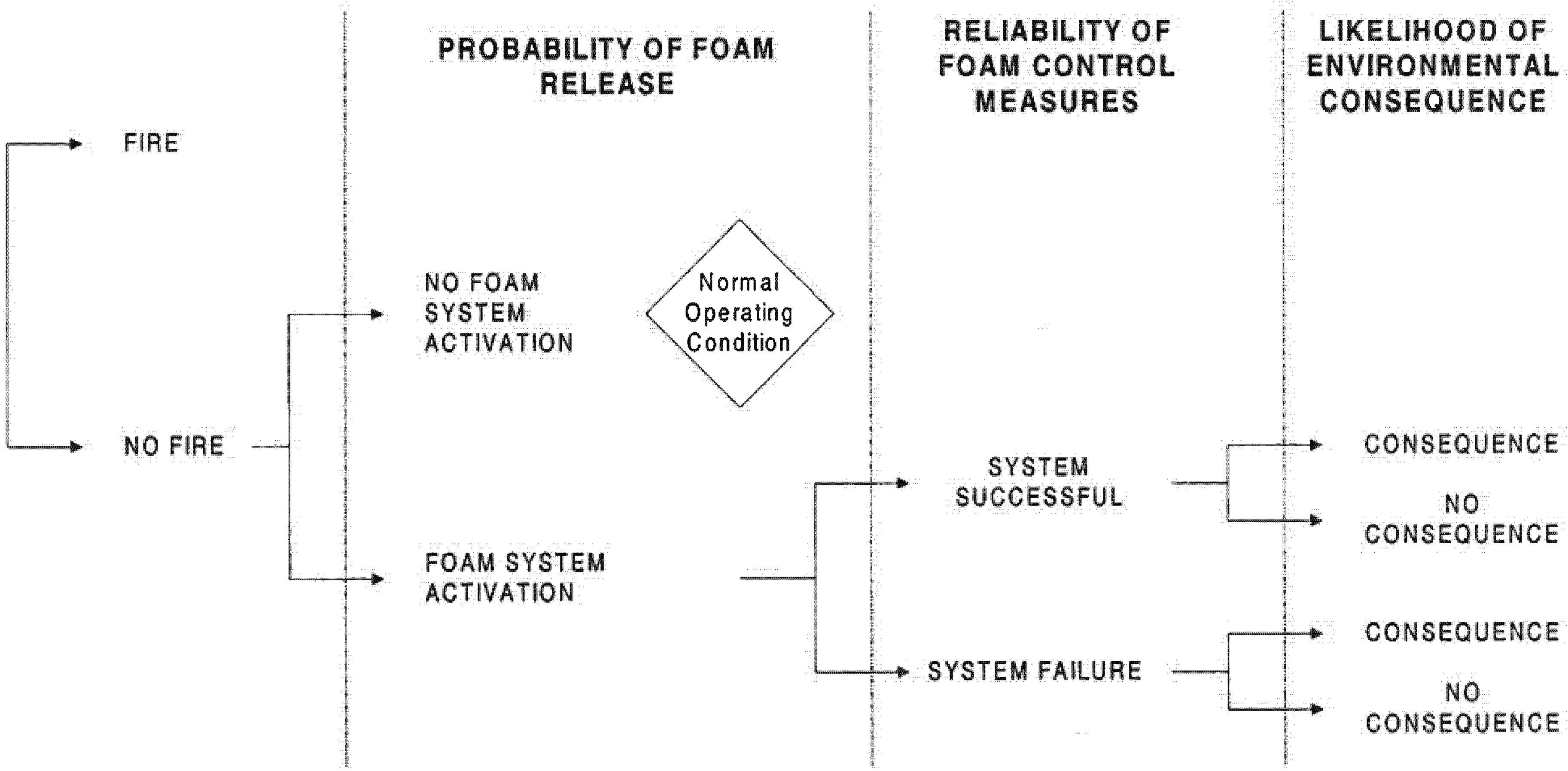
Risk Assessment

Environmental Consequence

	AIR	Sensitive Body of Water	Soil Ground Water	Wastewater Treatment Plant
1. Sanitary sewer, WWTP		3C		2C
2. Plugged, Storm Sewer	4E			2D
3. Unlined Pond, Percolates	4E			

Probability Estimation

Foam System Activation



PROBABILITY OF FOAM RELEASE

RELIABILITY OF FOAM CONTROL MEASURES

LIKELIHOOD OF ENVIRONMENTAL CONSEQUENCE

FIRE

NO FIRE

NO FOAM SYSTEM ACTIVATION

Normal Operating Condition

FOAM SYSTEM ACTIVATION

SYSTEM SUCCESSFUL

SYSTEM FAILURE

CONSEQUENCE

NO CONSEQUENCE

CONSEQUENCE

NO CONSEQUENCE

Probability Estimation

Foam System Testing

- Should foam control systems be used for testing?
- Foam system activation becomes probable
- Reliability improved as testing supervised

Risk Assessment
Environmental Consequence

For Foam Testing

	AIR	Sensitive Body of Water	Soil Ground Water	Wastewater Treatment Plant
1. Sanitary sewer, WWTP		3B		2B
2. Plugged, Storm Sewer	4D			2D
3. Unlined Pond, Percolates	4D			

For Accidental Release

	AIR	Sensitive Body of Water	Soil Ground Water	Wastewater Treatment Plant
1. Sanitary sewer, WWTP		3C		2C
2. Plugged, Storm Sewer	4E			2D
3. Unlined Pond, Percolates	4E			

Risk Assessment

Environmental Consequence

	AIR	Sensitive Body of Water	Soil Ground Water	Wastewater Treatment Plant
1. Sanitary sewer, WWTP		3C		2C
2. Segregated Storm Sewer	4E	3C		
3. Plugged, Storm Sewer	4E			2D
4. Pavement, Plugged Storm Sewer/drains	4E			
5. Pavement, Plugged Combined Sewer/drains	4E			2D
6. Pavement, Combined Sewer WWTP		3C		2C
7. Pavement, Storm Sewer	4E	3C		
8. Unlined Pond, Percolates	4E			
9. Lined Pond, Pump Off-Site	4E			
10 Lined Pond, evaporate	4E			
11. Lined Pond, Meter WWTP				2D
12. Lined Pond, Meter Storm Sewer	4E	3C		2D
13. Lined Pond, Degrade WWTP				2D
14. Lined Pond, Degrade Storm Sewer	4E			2D
15. Tank, Pump Off-Site	4E			
16. Tank, Meter WWTP				2D
17. Tank Meter Storm Sewer	4E	3C		2D
18. Tank, Degrade WWTP				2D
19. Tank, Degrade Storm Sewer	4E			2D

Costs

- Single module, 16 minutes of foam discharge
- Costs options we have identified are in the $0–200K range
- More stringent control criteria can lead to much greater costs
- However risk of an environmental consequence is not reduced

APPENDIX (13)

Presentation: “Summary of Shore Facility AFFF Management Breakout Session”

D. Verdonik
Hughes Associates, Inc.
Baltimore MD

Summary of Shore Facility AFFF Management Break-Out Session

Dan Verdonik

3 August 2000

Facility AFFF Management Working Group

- Decision to ‘formalize’ a Working Group
  - Develop Facility Policy for AFFF Management
    - Changed name from “Hangar” to “Facility” to reflect broader scope
    - Target for Completion: Approximately 6 months
  - Develop a draft DoDI
    - Staff Through Environmental Side of Services
    - Present to OSD
  - Next Meeting Scheduled for October 12
- Accepted-in-Principle the Risk Based Approach
  - Use as the Basis for the Policy
  - Need to Review Details and Back-up Information
  - Report will be Provided Prior to Next Meeting

Facility AFFF Management Working Group - Membership

Service	**Office**	**Name**
Navy	HQ NAVFAC	Joe Gott
Navy	HQ NAVFAC	Joe Simone
Navy	NAVFAC	Vincent Donnally
Navy	CNO N457C	Ms. Kathy Ellis
Navy	NAVAIR	Larry Wolf
Navy	HQ NAVFAC (Contractor Representative)	Kim DePaul Dawn Roderique
Army	USACE	Bob DiAngelo
Army	USACE	K.C. Kochhar
Army	ACSIM F&H	Bruce Park
Army	USACE/ACE	Billy Ray Scott
USAF	AFCESA	Fred Walker
USAF	HQ USAF ILEV	Jayant Shah
USMC	HQUSMC DCS/I&LFL	Michael Doherty
USMC	HQUSMC DCS/I&LFF	Kevin King

- Additional Members To Be Identified Prior to Next Meeting

APPENDIX (14)

Presentation: Summary of AFFF Environmental Breakout Session"

J. Hoover
Naval Air Warfare Center
China Lake CA

R. Darwin
Hughes Associates, Inc.
Baltimore MD

Summary
Of
AFFF Environmental Impact
Breakout Session

Naval Research Laboratory
3 August 2000

Dr. Jim Hoover
Head, Combustion Research Branch
NAWCWD China Lake

Robert Darwin
Senior Engineer
Hughes Associates, Inc.

Purpose of Breakout Session

Share Information on AFFF

- History, performance, chemical composition
- Environmental and human health impacts
- Regulations – current and future
- Replacement activity and status
- Future management strategy

(1) What current and future environmental regulations impact AFFF and why (data and policies)?

Current:

Different regulations affect different components of AFFF

Presentation by Bill Ruppert yesterday provided good summary

Except for UNDS, there are no definitive restrictions at present and no identified directives for change

Future:

Depends on future EPA assessment of AFFF as data is reviewed

(2) What data do we have (or lack) on the environmental impact of AFFF?

Lacking:

Component toxicity/BOD/Persistence (Fate)/Bio-accumulation

Accurate and appropriate dilution factors when AFFF discharged in open bodies of water

Predictive capability/data regarding releases for estimating potential environmental damage. Must consider where the release occurs (shore hangars, runways, unpaved ground, ship bilges, at sea, etc)

(3) What technology or products exist that could help reduce AFFF releases into our environment or mitigate the impact of those releases?

Depends on the type and location of the release

Reducing releases:
- Reduction in system tests, efficiency improvements
- Spill response/advance planning/preparedness

Mitigation:
- ASH (Air-sparged hydrocyclone)
- RO (Reverse osmosis)
- Biological/microbial systems

Education and Planning:
- DOD guidance/standards on prevention, clean-up and disposal, training, intentional discharges

(4) What technology or products could be applied to recycle or reuse AFFF?

Not considered to be feasible or cost effective (reformulation, losses, contamination)

(5) What alternatives to AFFF currently exist and how do they compare in effectiveness, cost, environmental impact, availability, etc ?

None meet performance specification (mil spec)

Development of an AFFF alternative was proposed as project under ONR Future Naval Capability Platform Protection Program

Potential SERDP statement of need

Some UK effort on environmentally friendly foam

(6) What related planning documents exist with other services or agencies?

UK is reportedly working on a standard definition of “biodegradability”

EPA presentation mentioned international dialog on AFFF PFOS issue

USAF needs included in draft NAVAIR ESH-Needs Assessment

(7) What follow-on strategies should be considered ?

Need accurate quantitative definition of the problem

- DOD inventory status
    - How much AFFF in DOD/where used/in-service and reserve stocks/concentrate types
- DOD AFFF discharges
    - How much released/consumed annually (training, system testing and maintenance, accidental discharges, research, fires)
- Review current DOD regs and policy

Need a definition of "environmentally friendly" (need "green" definition—what are acceptable thresholds from an environmental standpoint)

- Biodegradability
- BOD/COD
- Toxicity
- Persistence
- Bio-accumulation

Follow-On Strategies (con't)

Need for future research
- SBIR
- Goals for Universities
- ONR

Need to develop small scale screening tests

Develop "SNAP-equivalent" guidance

Need for "worst case" transition plan (short/mid/long term)

Information distribution to all levels (users, requirers, trainers, regulators, etc)

Develop AFFF detection capability (learn method used by 3M)

Define hazard protocols and appropriateness of AFFF (use and response)

Follow-On strategies (con't)

- Assess commercial state-of-the-art
  - CBD announcement
  - "Turkey shoot" of all available AFFF alternatives
  - Quantify performance, chemical and physical properties
  - Obtain EPA endorsement of screening tests

- Consider future mods to AFFF mil spec
  - Prioritze requirements
  - Consider trade-offs

- Establish formal AFFF working group
  - Info sharing
  - Formal charter
  - DOD primary advocate?
  - Future meetings/host/agenda topics

Summary
Of
AFFF Environmental Impact
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Need a definition of "environmentally friendly" (need "green" definition—what are acceptable thresholds from an environmental standpoint)

Biodegradability	Persistence
BOD/COD	Bio-accumulation
Toxicity	

Follow-On Strategies (con't)

Need for future research
- SBIR
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  - Info sharing
  - Formal charter
  - DOD primary advocate?
  - Future meetings/host/agenda topics

EPA Activities/Issues on Fluorosurfactants

Mary F. Dominiak
U.S. Environmental Protection Agency
DoD AFFF Workshop, Pentagon
March 16, 2001

Issues and Status

- Discovery of perfluorooctyl sulfonates (PFOS) in humans and wildlife worldwide.
- Concern: Data indicate PFOS chemicals are persistent, bioaccumulative, and toxic.
- 3M phasing out 90 PFOS chemicals by 2003; EPA proposed regulation to follow voluntary phaseout.
- EPA has concerns on related chemistries (PFOA, telomers); assessment and research are underway.
- PFOS, PFOA, and telomers are used in MilSpec AFFF products.

Status of PFOS Rulemaking

- EPA published Proposed Significant New Use Rule (SNUR) on 90 PFOS chemicals (65 FR 62319, 10/18/2000), consonant with 3M phaseout.
- Proposed SNUR is *not* a ban:
  - Would require companies to file notice with EPA 90 days before beginning new manufacture or import of listed PFOS chemicals. EPA could grant, deny, or impose conditions on intended use.
  - Would *not* affect continued use of stocks of chemicals obtained before the end of the phaseout period.
- Comment period extended to 1/1/2001.
- Public meeting 3/27/2001, Sheraton Crystal City.

Status of PFOS Rulemaking

- 25 comments filed.
- Most comments challenge legal basis of proposed SNUR; also request exemptions for specific uses of PFOS chemicals as being essential, low volume, and low exposure.
- Claimed essential uses include photoresists in semiconductor manufacture; aviation hydraulic fluids; and some photolithography.
- Comments currently under review.
- Public meeting on 3/27/2001 provides opportunity for clarification of comments.

Related Chemistry Concerns

- PFOA & telomer chemicals raise similar concerns:
  - Known persistence.
  - PFOA toxicity data in public literature.
  - Question: similar bioaccumulative potential?
  - Question: similar fate and transport?
  - Question: similar widespread exposure?
- EPA hazard assessment on PFOA underway; preliminary conclusions likely by June 2001.
- Telomer producers began voluntary testing in 2000; data to be available in 2002.
- Fluoropolymer manufacturers began additional testing on PFOA/APFO in 2001.

Future EPA Actions

- PFOS:
  - – Assess and respond to comments on proposed SNUR for 90 3M phaseout PFOS chemicals.
  - – Consider need/options for action on other PFOS chemicals.
- PFOA:
  - – Complete preliminary hazard assessment by June 2001.
  - – Assess new data as received.
  - – Identify needs/options for action.

Future EPA Actions

- Telomers:
  - Begin EPA review of existing data.
  - Review submissions from voluntary industry testing program in 2001-2002.
- International Activities:
  - Participate in initial assessment of PFOS by Organization for Economic Cooperation and Development; further action to be determined.

Future EPA Actions

- Regulatory actions available under the Toxic Substances Control Act include:
  - Testing requirements (section 4).
  - SNURs, new chemical reviews (section 5).
  - Manufacturing, use, disposal rules (section 6).
  - Information submission (section 8).
- TSCA uses an “unreasonable risk” standard balancing hazard, exposure, benefits, costs, availability of alternatives at time of proposal.

Future Actions

- Voluntary activity may be expected in lieu of or while regulatory activities are pending.
  - If assessments raise liability concerns, more companies may elect to discontinue chemicals.
  - New chemicals are being submitted to EPA for review as potential substitutes for PFOS/PFOA.
    - Presence of new chemical alternatives may affect TSCA “unreasonable risk” determinations.

AFFF Implications

- Current EPA activities would *not* restrict continued use of PFOS-based AFFF stocks obtained prior to the 12/31/2002 phaseout.
- Current EPA activities *would* prevent manufacture or import of PFOS after phaseout, *including* PFOS-based AFFF, *unless* 90-day notice filed and approved.

AFFF Implications

- Non-PFOS-based AFFF products formulated with PFOA or telomers *may be affected* by ongoing EPA reviews of these related chemistries, and *may be subject* to future regulatory or voluntary risk management actions.
  - Persistence is known: information on toxicity, bioaccumulative potential being assessed or collected.
  - Initial assessments will be completed in 2001-2002.
  - If undertaken, regulatory proceedings average 2-5 years.

AFFF Implications

- A program to seek, test, and consider long-range alternatives to current fluorosurfactant-based AFFF would be prudent.
  - Health and environmental concerns generally argue for a move away from persistent chemicals where possible.
  - Ongoing EPA activities provide a multi-year window for development, evaluation, and qualification of alternatives, while still allowing access to and use of stocks of currently accepted chemicals.

For Further Information

- Mary F. Dominiak, 202-260-7768, *dominiak.mary@epa.gov*
- Karen Lannon, 202-260-2797, *lannon.karen@epa.gov*
- For data CDs from PFOS file (AR-226), TSCA NCIC, 202-260-7099, Monday-Friday, noon to 16:00 Eastern time.
- To attend 3/27/2001 PFOS SNUR public meeting: Annette Washington, 202-260-3515, *washington.annette@epa.gov*

Chemical & Material Risk Management Directorate,
Office of the Under Secretary of Defense for Acquisition, Technology & Logistics

Chemical & Material Emerging Risk Alert

Aqueous Film Forming Foam (AFFF)

Some legacy AFFF formulations contain chemicals that present human health and environmental risks and require special handling and disposal.

What is AFFF?

AFFF is a fire suppressant used to extinguish flammable liquid fires such as fuel fires. The Department of Defense (DoD) uses AFFF in shipboard and shore facility fire suppression systems, fire fighting vehicles, and at fire training facilities. AFFF is purchased as a concentrate, typically referred to as “3%” or “6%” (Type 3 or Type 6, respectively) depending on its mixture ratio with water. AFFF used by the military must satisfy Military Specification MIL-F-24385F requirements.

What are PFOS and PFOA?

Perfluorooctane sulfonate (PFOS) is a long-chain perfluorinated compound (PFC) either present in legacy stocks of AFFF or a potential breakdown product of PFOS-based AFFF. Perfluorooctanoic acid (PFOA) is also a long-chain PFC. PFOA is not an ingredient in AFFF, but long-chain fluorotelomer-based AFFFs can break down to PFOA. PFOS, PFOA, and other long-chain perfluorinated compounds are found widespread at low levels in humans and the environment, bioaccumulate in the food chain, resist degradation, show evidence of toxicity in laboratory studies, and are the subject of increasing regulation worldwide.[1] Prior to 2000, most fluorosurfactants used in the AFFF military specification (mil spec) were PFOS-based which resulted in AFFF that contained PFOS or PFOS pre-cursors. During that time, AFFFs based on long-chain fluorotelomers were also available for mil spec use. Shortly after the manufacturing phase out announcement by 3M, Inc. of PFOS-based products in 2000, mil spec PFOS-based AFFFs were no longer available. The primary supply of AFFF then became fluorotelomer-based. Over the last several years, manufacturers of fluorotelomer AFFF have been replacing long-chain fluorosurfactants with short-chain fluorosurfactants. The PFCs in current fluorotelomer-based AFFF are shorter chain molecules and tend to be less bioaccumulative and toxic. Telomer-based AFFF does not contain PFOS but may contain trace amounts of PFOA.

PFOS-Based AFFF

How do I determine if I have PFOS-based AFFF?

Due to their long shelf lives, legacy AFFF, including PFOS-based AFFF concentrate, may still be present in your inventory. Through 2001, the DoD purchased AFFF from 3M and/or Ansul Inc. 3M supplied PFOS-based AFFF under the product name, 3M Light Water AFFF. Ansul supplied a telomer-based AFFF to the DoD.[2] If the product name and/or purchase date cannot be determined, a sample can be sent to an analytical laboratory to determine the presence or absence of PFOS. Users are advised to compare sampling costs and disposal costs. It may be more cost-effective to properly dispose of limited quantities of unknown PFOS content material rather than pay for sampling and analysis.

Can stockpiles of PFOS-based AFFF continue to be used?

Yes, PFOS-based AFFF can continue to be used in the United States; however, the discharge of wastewater containing AFFF can be regulated under the Clean Water Act. The potential liability from a release during

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use of PFOS-based AFFF should be weighed against the cost of disposal and resupply in determining whether to dispose of or maintain PFOS-based AFFF in your inventory.

How can I dispose of PFOS-based AFFF?

PFOS, PFOA and other perfluorinated acids are highly stable and generally recalcitrant to low energy forms of treatment (e.g. conventional wastewater systems). Industry recommendations for disposal of AFFF concentrate is by thermal destruction at a facility capable of handling halogenated waste or the equivalent. Contact your installation's environmental or hazardous waste management office for assistance.

What environmental risks may be associated with the historic storage, use and disposal of PFOS-based AFFF?

Although not allowed for use today, DoD has used unlined earthen areas/basins at many installations to support live firefighting training activities. These activities may have resulted in soil and groundwater contamination. AFFF releases also may have occurred at AFFF storage tanks and transport lines, accident/emergency response sites, and near facilities (e.g., aircraft hangers) with AFFF fire suppression systems.

As PFOS is subject to restrictions under certain international treaties, restrictions on the use and/or disposal exist in some countries. The European Union requires the removal of all PFOS-based AFFF from service by 27 June 2011.[3] In Europe, some Services may have specific policy on the management and disposal of PFOS-based AFFF and resupply of conforming AFFF.[4]

The U.S. Environmental Protection Agency (EPA) has developed Provisional Health Advisories (PHA) for PFOS (0.2 micrograms per liter [µg/L]) and PFOA (0.4 µg/L) to protect against potential risk from exposure to these chemicals in drinking water.[5] PHAs reflect reasonable, health-based hazard concentrations above which action should be taken to reduce exposure. State regulatory agencies (e.g., Minnesota, New Jersey, and North Carolina) also have established guidance or action levels for several PFCs in drinking water, groundwater, and soil.[6]

Very limited environmental sampling data exist for PFCs as they were not typically sampled for during site characterization. However, analytical results from sampling conducted at three DoD firefighting training areas showed concentrations of PFOS and PFOA in groundwater several orders of magnitude greater than the EPA PHA values.[2]

If records indicate your facility may have experienced AFFF leaks, spills or releases to the environment, refer to DoD Instruction 4517.18 for principles to follow in determining what site specific characterization, assessment, and risk management actions you should take.[7]

Currently, there are no *in situ* technologies and very limited *ex situ* options to treat soil or groundwater contaminated with PFCs. Thermal treatment is typically used for contaminated solids while granular activated carbon is the most effective water treatment method.[8] The DoD Strategic Environmental Research and Development Program is funding research to develop innovative treatment technologies for PFCs.[9]

Telomer-based AFFF

Do telomer-based AFFF concentrates meet DoD military specification requirements?

Current fluorotelomer-based AFFF concentrates that satisfy the requirements of Mil Spec MIL-F-24385F are listed in the DoD Qualified Products Database (QPD) (https://assist.daps.dla.mil/online/start/). In order to ensure that the AFFF you purchase meets MIL-F-24385F specifications, it must be listed in the DoD QPD. Because the QPD is updated periodically, the QPD should be checked before each AFFF purchase.

Do telomer-based AFFF concentrates meet current EPA standards? Will releases trigger cleanup requirements?

Manufacturers have developed new short-chain telomer-based AFFF formulations in coordination with EPA. EPA has approved over 100 pre-manufacture notices for new products that are based on C_6 telomer chemistry.[1] EPA considers the shorter chain compounds to have lower bioaccumulation potential and toxicity than the longer chain PFCs used in legacy AFFF. Fluorotelomer manufacturers can be contacted for advice on how best to distinguish the legacy long-chain telomer-based AFFF products from the newer short-chain telomer-based formulations.

A one-time release of telomer-based AFFF for emergency fire suppression would not be expected to result in levels of contamination requiring cleanup. However, uncontrolled repeated applications of AFFF at firefighting training areas could be expected to contaminate soil and groundwater and thus these activities need to be managed.

How can I control releases of AFFF in the future?

Follow applicable DoD and industry standards on the design, installation, and maintenance of foam systems, extinguishers, and firefighting training areas. DoD Unified Facilities Criteria (UFC), DoD Unified Facilities Guide Specifications, and Component-specific design documents contain relevant guidance. Provide for containment, treatment, and proper disposal of foam discharges through actions such as the use of double lined fire training pits and improved wastewater collection systems.

Minimize false discharges from fixed foam systems by using approved detection, actuation, and control systems as required by industry standards. Whenever operational situations allow, use non-fluorosurfactant training foams.

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Footnotes

[1] USEPA Long-Chain Perfluorinated Chemicals (PFCs) Action Plan. 30 December 2009. http://www.epa.gov/opptintr/existingchemicals/pubs/pfcs_action_plan1230_09.pdf.

[2] Schultz MM, Barofsky DF, Field JA. 2004. Quantitative Determination of Fluorotelomer Sulfonates in Groundwater by LC MS/MS (*and references herein*) 38:1828-1835.

[3] European Union Directive 2006/122/ECOF amending Annex 1 to Council Directive 76/769/EEC related to restrictions on the marketing and use of certain dangerous substances and preparations (perfluorooctane sulfonates). 12 December 2006.

[4] Headquarters United States Air Forces in Europe (USAFE) Policy for Management/Elimination of Aqueous Film Forming Foam containing Perfluorooctane Sulfonate (PFOS AFFF). October 2007.

[5] See USEPA–Perfluorooctanoic Acid (PFOA) and Fluorinated Telomers. http://www.epa.gov/opptintr/pfoa/pubs/pfoainfo.html#provisional.

[6] See http://www.pca.state.mn.us/index.php/waste/waste-and-cleanup/cleanup-programs-and-topics/topics/risk-based-site-evaluation-process-guidance-documents.html for SRV Spreadsheets; http://www.health.state.mn.us/divs/eh/risk/guidance/gw/table.html; http://www.state.nj.us/dep/watersupply/pfoa_dwguidance.pdf; http://h2o.enr.state.nc.us/csu/documents/15A2L-TANBOOK-1jan2010.pdf.

[7] DoD Instruction 4715.18. Emerging Contaminants (ECs). USD(AT&L). 11 June 2009.

[8] Water Treatment for PFOA and PFOS. Presented by Andrew S. Hartten, DuPont Corporate Remediation Group, at the PFOS and PFOA Science Presentation for EPA Office of Water. 16 October 2009. http://www.epa.gov/opptintr/pfoa/pubs/activities.html.

[9] See http://www.serdp.org/Program-Areas/Environmental-Restoration/Contaminated-Groundwater/Emerging-Issues.

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For more information about chemical and material risks, please visit us at http://www.denix.osd.mil/cmrmd/.

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June 17, 2016

MEMORANDUM FOR DEPUTY CHIEF OF NAVAL OPERATIONS
(FLEET READINESS AND LOGISTICS) (N4)
DEPUTY COMMANDANT OF THE MARINE CORPS
(INSTALLATIONS AND LOGISTICS)
DEPUTY COMMANDANT OF THE MARINE CORPS
(AVIATION)

SUBJECT: Aqueous Film Forming Foam (AFFF) Control, Removal, and Disposal

Ref: (a) DASN (E) Policy Memo, 21 Oct 2014
(b) ASD (EI&E) Policy Memo, 28 Jan 2016
(c) EPA Perfluorinated Chemical (PFC) Health Advisories, 19 May 2016

Perfluorinated compounds (PFCs)/per and polyfluoroalkyl substances (PFASs) are a suite of over 100 chemicals, several of which are of emerging public health concern to the Department of the Navy (DON), U.S. Environmental Protection Agency (EPA), state regulators, public water systems, and the general public. The most common DON activity that results in the release of PFC/PFAS to the environment is through the use of AFFF for testing, training, firefighting, and other emergency responses.

Reference (a) directed actions regarding two PFC/PFAS, perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA), at cleanup sites and in drinking water systems. In reference (b), ASD (EI&E) directed the DoD Components to issue Service-specific policies to prevent routine uncontrolled environmental releases of AFFF during maintenance, testing, and training activities, and remove and properly dispose of uninstalled PFOS containing AFFF drums and cans from local stored supplies (non-shipboard).

On 19 May 2016, the U.S. Environmental Protection Agency (EPA) issued reference (c) to provide lifetime drinking water health advisories for PFOS and PFOA, which are contained in older formulations of AFFF. The newest formulations of MILSPEC-compliant AFFF (i.e., products qualified since November 2015) may still contain trace quantities of PFOA.

DON intends to remove, dispose, and replace legacy AFFF that contains PFOS and/or PFOA once environmentally suitable substitutes are identified and certified to meet MILSPEC requirements. This policy directs the following actions be taken until suitable replacements are certified:

- Immediately cease the uncontrolled environmental release of AFFF for shoreside installations, with the exception of emergency responses. Installations should verify and ensure that the following activities have appropriate controls in place to prevent an environmental release: controlled outdoor training with AFFF; testing of firefighting and crash response vehicle AFFF systems; testing of hangar AFFF and other fixed systems. Where such non-emergency operations are deemed necessary, complete containment, capture, and proper disposal mechanisms and procedures must first be in place to the maximum extent practicable prior to conducting such actions to ensure no AFFF is released to the environment.

- Update and implement Navy and Marine Corps firefighting system requirements, as needed, to ensure fire and emergency service vehicles and equipment at DON installations and facilities are tested and certified in a manner that does not allow the release of AFFF to the environment.
- By the end of FY2017, remove and dispose of uninstalled PFOS-containing AFFF in drums and cans from local stored supplies for shore installations and ships to prevent future environmental releases.

The above actions are vitally important to ensure all personnel and their families who live or work on DON installations and facilities are protected from environmental contaminants and receive safe drinking water.

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