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TD 825

AD-A160 874

**Technical Document 825**
July 1985

# TOXICITY OF AQUEOUS FILMFORMING FOAMS TO MARINE ORGANISMS: LITERATURE REVIEW AND BIOLOGICAL ASSESSMENT

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## ADMINISTRATIVE INFORMATION

The work described herein was performed by the Environmental Sciences Division, Code 52, Naval Ocean Systems Center, for the Naval Facilities Engineering Command (Code 032), Marine Environmental Quality Assessment Program.

Released by
P.F. Seligman, Head
Marine Environment Branch

Under authority of
S. Yamamoto, Head
Environmental Sciences
Division

JG

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

AD-A160 874

# REPORT DOCUMENTATION PAGE

| | |
|---|---|
| 1a REPORT SECURITY CLASSIFICATION<br>UNCLASSIFIED | 1b RESTRICTIVE MARKINGS |
| 2a SECURITY CLASSIFICATION AUTHORITY | 3 DISTRIBUTION/AVAILABILITY OF REPORT<br>Approved for public release; distribution unlimited. |
| 2b DECLASSIFICATION/DOWNGRADING SCHEDULE | |
| 4 PERFORMING ORGANIZATION REPORT NUMBER(S)<br>NOSC TD 825 | 5 MONITORING ORGANIZATION REPORT NUMBER(S) |
| 6a NAME OF PERFORMING ORGANIZATION<br>Naval Ocean Systems Center | 6b OFFICE SYMBOL (If applicable)<br>Code 522 |
| 6c ADDRESS (City, State and ZIP Code)<br>San Diego, CA 92152-5000 | 7b ADDRESS (City, State and ZIP Code) |
| 8a NAME OF FUNDING/SPONSORING ORGANIZATION<br>Naval Facilities Engineering Command | 8b OFFICE SYMBOL (If applicable)<br>NFAC-03 |
| 8c ADDRESS (City, State and ZIP Code)<br>Alexandria, VA 22332 | 9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER |

| 10 SOURCE OF FUNDING NUMBERS | | | |
|---|---|---|---|
| PROGRAM ELEMENT NO | PROJECT NO | TASK NO | Agency Accession |
| 63721N | Y0817 | ME65 | DN288 604 |

11 TITLE (Include Security Classification)

TOXICITY OF AQUEOUS FILMFORMING FOAMS TO MARINE ORGANISMS: LITERATURE REVIEW AND BIOLOGICAL ASSESSMENT

12 PERSONAL AUTHOR(S)

S.M. Salazar

| 13a TYPE OF REPORT | 13b TIME COVERED | 14 DATE OF REPORT (Year, Month, Day) | 15 PAGE COUNT |
|---|---|---|---|
| Final | FROM Oct 82 TO Oct 82 | July 1985 | 38 |

16 SUPPLEMENTARY NOTATION

| 17 COSATI CODES | | | 18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number) |
|---|---|---|---|
| FIELD | GROUP | SUB-GROUP | Aqueous filmforming foams<br>Toxicity |
| | | | |
| | | | |

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

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.

CONTD PG

| 20 DISTRIBUTION/AVAILABILITY OF ABSTRACT | 21 ABSTRACT SECURITY CLASSIFICATION |
|---|---|
| ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT ☐ DTIC USERS | UNCLASSIFIED |

| 22a NAME OF RESPONSIBLE INDIVIDUAL | 22b TELEPHONE (Include Area Code) | 22c OFFICE SYMBOL |
|---|---|---|
| S.M. Salazar | (619) 225-2559 | Code 522 |

DD FORM 1473, 84 JAN

83 APR EDITION MAY BE USED UNTIL EXHAUSTED
ALL OTHER EDITIONS ARE OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

# 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 are produced by only a few different manufacturers under the guidelines and specifications given in MIL-F-24385C (Military Specification, 1981). Approximately 1 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).

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.

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.

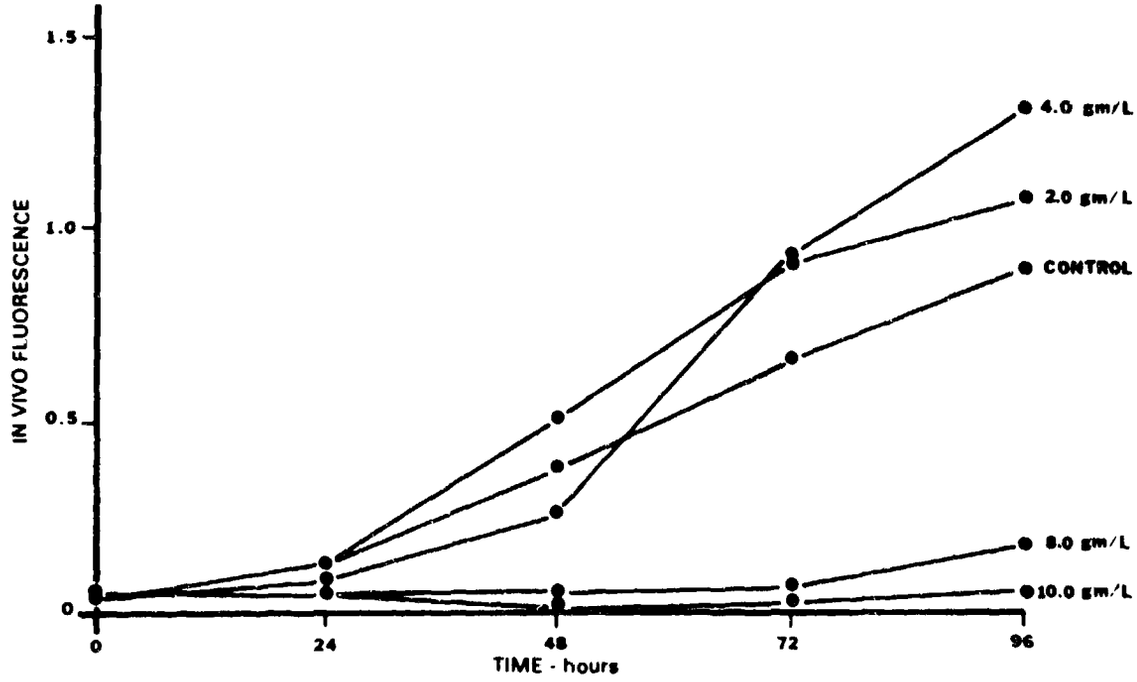


**Figure 1. Effects of AFFF on the in vivo fluorescence of *Dunaliella* during the 96-hour exposure period.**

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.

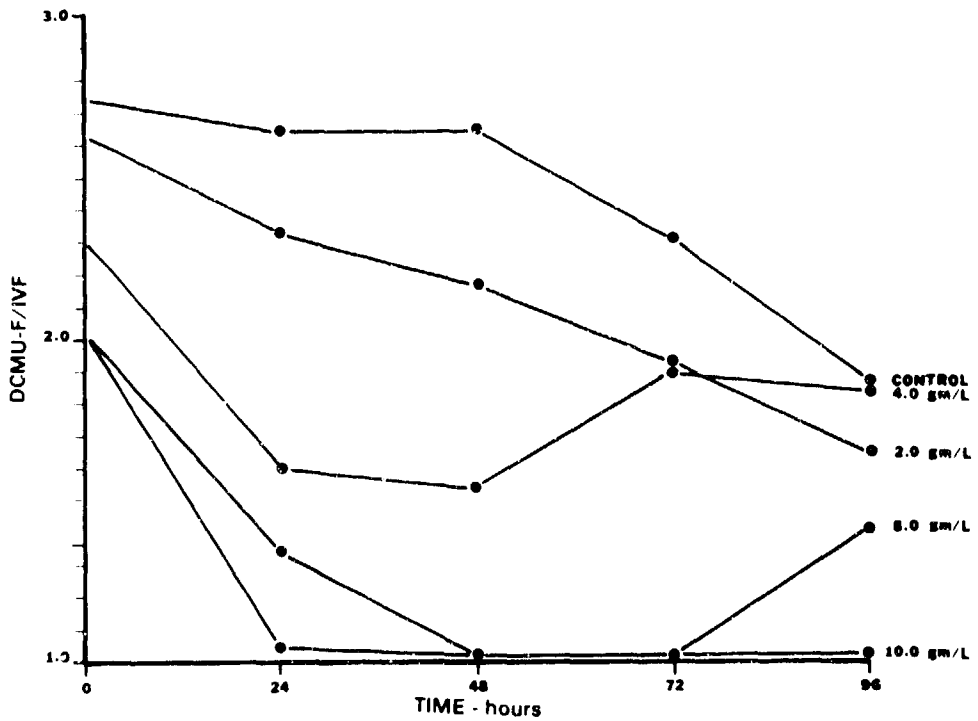


**Figure 2. Effects of the FC-780B AFFF on the ratio of DCMU-fluorescence to in vivo fluorescence for *Dunaliella* during the 96-hour exposure period.**

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<br>Control = 4.0 | Control ≠ 8.0 gm/l<br>Control ≠ 10.0 |
| 24 Hours | Control = 2.0 gm/l | Control ≠ 4.0 gm/l<br>Control ≠ 8.0<br>Control ≠ 10.0 |
| 48 Hours | Control = 2.0 gm/l | Control ≠ 4.0 gm/l<br>Control ≠ 8.0<br>Control ≠ 10.0 |
| 72 Hours | Control = 2.0 gm/l<br>Control = 4.0 | Control ≠ 8.0 gm/l<br>Control ≠ 10.0 |
| 96 Hours | Control = 2.0 gm/l<br>Control = 4.0 | Control ≠ 8.0 gm/l<br>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.

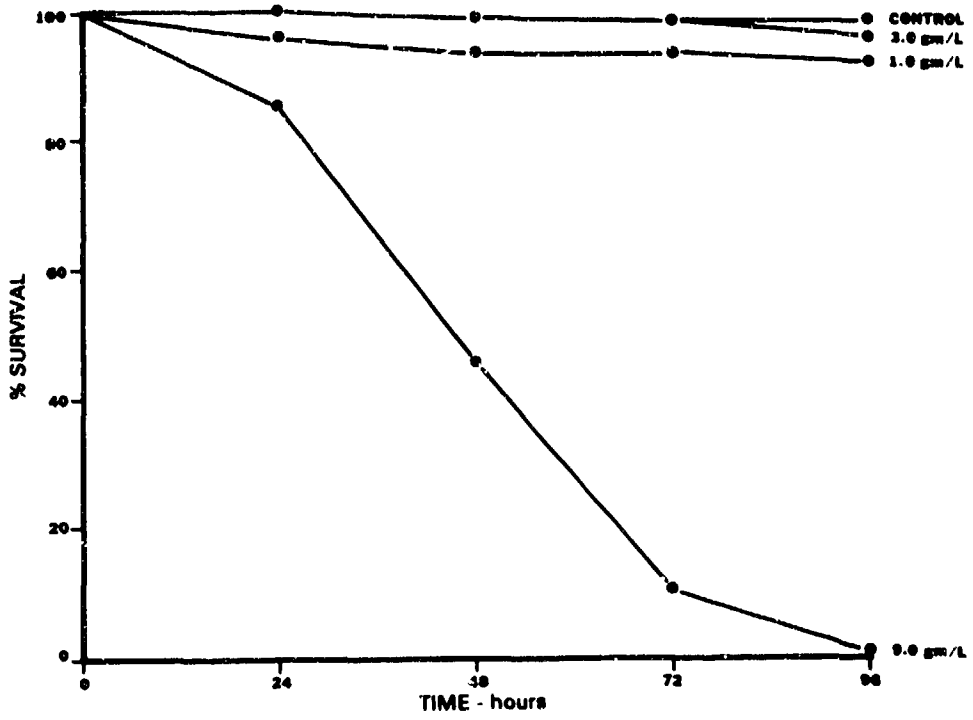


**Figure 3. Effects of the FC-780B AFFF on the survival rate of *Artemia salina* during the 96-hour exposure period.**

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

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

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 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*.







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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 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 |







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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 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.







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# 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-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<br>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<br>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 |







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# Product Environmental Data

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**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

(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 |







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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-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.







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# Product Environmental Data

3M

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**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

(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.







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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

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







Form 14705-B PWO

# 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.

# 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

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 ≥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/l) |
| [redacted] (*Fundulus heteroclitus*) | [redacted] | (3,400-4,600 mg/l) |

2/9/81 (Supersedes 1/8/80) Page 1 of 2

Date:





Form 14705-C PWO

# 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:





Form 14705-C PWO

# 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

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







Form 14705-C PWO

# 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 $\leq$25 mg/l (1 gallon of FC-203C concentrate in $\geq$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







Form 14705-C PWO

# Product Environmental Data

3M

**Environmental Laboratory**
**Environmental Engineering and Pollution Control**
900 Bush Avenue
PO Box 33331
St. Paul, MN 55133
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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

3M

**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] | /l |
| (Fundulus heteroclitus) | |

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 |