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① LEVEL II

COMPARATIVE EVALUATION OF FIREFIGHTING FOAM AGENTS

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AUGUST 1979

FINAL REPORT

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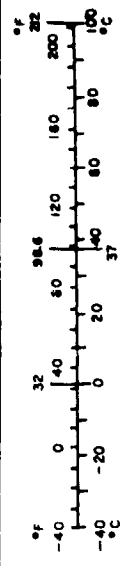
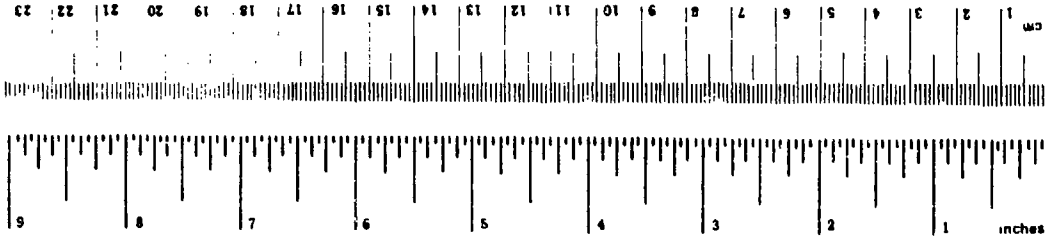
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<p>16. Abstract</p> <p>Information was obtained by conducting laboratory experiments and large-scale fire tests which were of value in estimating the fire extinguishing effectiveness of eight Aqueous-Film-Forming-Foams (AFFF), 11 fluoroprotein foams (FPF), and three protein foam (PF) agents.</p> <p>Large-scale fire tests were performed under fixed fire conditions employing air-aspirating and non-air-aspirating nozzles on 82.4-, 101-, and 143-foot diameter Jet A fuel fires. Experiments were performed with only one foam agent which was considered representative of each class.</p> <p>Experiments tend to validate the continuation of allowing a 30-percent reduction in the water requirement at certificated U.S. airports when AFFF is substituted for protein foam (Federal Aviation Regulation (FAR) Part 139.49) and to maintain a 1:1 equivalency ratio when fluoroprotein foam is substituted for protein foam. The data also tend to substantiate the validity of allowing an equivalent reduction in water requirements at airports when the 3-percent AFFF, FPF, and PF agents are substituted for the 6-percent agents within each class.</p>			
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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures				Approximate Conversions from Metric Measures			
Symbol	When You Know	Multiply by	To Find	Symbol	When You Know	Multiply by	To Find
LENGTH							
in	inches	2.5	centimeters	mm	millimeters	0.04	inches
ft	feet	30	centimeters	cm	centimeters	0.4	inches
yd	yards	0.9	meters	m	meters	3.3	feet
mi	miles	1.6	kilometers	km	kilometers	0.6	miles
AREA							
m ²	square inches	6.5	square centimeters	cm ²	square centimeters	0.16	square inches
ft ²	square feet	0.09	square meters	m ²	square meters	1.2	square yards
yd ²	square yards	0.8	square meters	km ²	square kilometers	0.4	square miles
mi ²	square miles	2.6	square kilometers	ha	hectares (10 000 m ²)	2.5	acres
MASS (weight)							
oz	ounces	28	grams	g	grams	0.036	ounces
lb	pounds (2000 lb)	0.45	kilograms	kg	kilograms	2.2	pounds
		0.9	tonnes	t	tonnes (1000 kg)	1.1	short tons
VOLUME							
sp	teaspoons	5	milliliters	ml	milliliters	0.03	fluid ounces
Tbsp	tablespoons	15	milliliters	l	liters	2.1	pints
fl oz	fluid ounces	30	milliliters	l	liters	1.06	quarts
c	cups	0.24	liters	l	liters	0.26	gallons
pt	pints	0.47	liters	m ³	cubic meters	35	cubic feet
qt	quarts	0.96	liters	m ³	cubic meters	1.3	cubic yards
gal	gallons	3.8	liters				
cu ft	cubic feet	0.03	cubic meters				
cu yd	cubic yards	0.76	cubic meters				
TEMPERATURE (exact)							
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature



* 1 in = 2.54 (exact). For other exact conversions and more data, see table in NBS Monograph 286, Units of Weights and Measures, Price \$2.25, SD Catalog No. C13.111.286.

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INTRODUCTION

PURPOSE.

The project objective was to study and test all currently available firefighting foam agents and to rank these agents in accordance with the method developed at the National Aviation Facilities Experimental Center (NAFEC) (appendix A) according to their potential value where applicable in the control and extinguishment of aircraft fuel ground fires.

BACKGROUND.

The development of larger commercial aircraft and the enormous increase in general aviation aircraft activities has emphasized the need for the most effective firefighting capabilities at certificated and general aviation airports. This goal can be achieved both efficiently and economically by employing the most effective firefighting agents and equipment combinations.

The principal fire extinguishing agents employed in aircraft fire protection are aqueous foams. The development and effective utilization of these agents involve many of the fundamental principles of chemistry and the surface and interfacial tension of liquid systems. As a consequence of the recent rapid advance made in firefighting technology, a periodic assessment of the impact of these new developments on aircraft fire protection is indicated.

DISCUSSION

COMPOSITION AND TYPES OF FIREFIGHTING FOAM AGENTS

PROTEIN FOAM AGENTS. There are two protein foam (PF) agents in general use in the United States, based primarily upon the differences in their use concentration. The 6-percent type and 3-percent type are recommended for proportioning with water to produce 6-percent and 3-percent solutions by volume.

The 6-percent agent is used by the Federal Government and procured under Federal Specification O-F-555C (reference 1). At present there is no Federal or military specification for procuring the 3-percent agent. However, it is recognized by the National Fire Protection Association (NFPA) and listed for commercial use by the Underwriters' Laboratories, Inc. (reference 2). Most of the 3-percent PF foam liquid is consumed by industry in the protection of hydrocarbon fuel storage tanks and related applications.

The definitive 3-percent and 6-percent PF liquid concentrates employed in the United States (U.S.) are not in common use on a world-wide basis.

AQUEOUS-FILM-FORMING FOAM. The recorded firefighting accomplishments of PF agents are long and impressive. However, the chemical advances in fluorine technology made significant improvements in mechanical foam

technology a reality. It had long been the goal of foam research chemists to develop new and improved products which would materially reduce the fire control and extinguishing times for complex class B fires.

This goal was finally achieved at the Naval Research Laboratory under the direction of Dr. R. L. Tuve. A very significant technical document appeared in March 1964, entitled "A New Vapor Securing Agent for Flammable Liquid Fire Extinguishment" authored by Tuve, Peterson, Jablonski, and Neil (reference 3). This document provided detailed information on the chemical and physical properties of a new class of mechanical firefighting foams based on proprietary products developed by the 3M Company.

The fluorochemicals provided by the 3M Company during these early efforts were derivatives of perfluorooctanoic acid produced by an electrolytic process in the Simons cell (reference 4). An important paper authored by R. A. Guenther and M. L. Vietor entitled "Surface Active Materials from Perfluorocarboxylic and Perfluorosulfonic Acids" appeared in 1962 (reference 5).

The aqueous-film-forming foam (AFFF) agents are currently available in both the 3-percent and 6-percent concentrations. The 6-percent type is procured by the Federal Government under a military specification, MIL-F-24385, Navy (reference 6).

The original composition of the AFFF firefighting foam liquid concentrates developed by the Naval Research Laboratory (NRL) comprised a

combination of one or more highly fluorinated surface-active agents in combination with foam stabilizers and pour point depressants or other additives (reference 7). In an effort to reduce the cost as well as to improve the fire extinguishing characteristics of AFFF agents certain modifications to this basic composition were developed by Arthur F. Ratzer in a paper presented at a technical meeting of concerned government agencies and manufacturers convened on Campabello Island, N. B. during August 11 through 13th, 1964, under the aegis of The Mearl Corporation. This new composition comprised a combination of hydrocarbon foaming agents and highly fluorinated surfactants which could be readily formulated to meet the optimum surface and interfacial tension requirements of the aqueous film to achieve the most rapid spread rate and stability on a liquid hydrocarbon surface. Previous studies conducted by Bernette and Zisman (reference 8) at the NRL demonstrated the synergistic surface tension-reducing effects produced upon water from mixtures of fluorinated alcohols with conventional hydrocarbon surfactants. These fundamental principles were subsequently incorporated in a U.S. Patent (reference 9) which discloses a fire extinguishing composition comprising a fluoroaliphatic surfactant and a fluorine-free surfactant. Presently, firefighting foam liquid concentrates incorporating these basic concepts are being produced on a world-wide basis.

FLUOROPROTEIN FOAMS. A logical offsprig of the development of AFFF was a combination of PF and the fluorocarbon surface-active agents.

This combination is called "fluoroprotein" foam (FPF), and the variable physical properties which can be achieved by different proportions of a protein hydrolyzate and fluorinated surfactants are indicated in figure 1.

In this diagram, the FPF agents are indicated as lying in a variable position between PF on the left and AFFF on the right. If a small quantity of a suitable fluorocarbon is added to protein foam, the resulting product may produce foam with excellent stability toward Purple-K powder (PKP) without the formation of an aqueous film on the surface of the hydrocarbon fuel. However, when increased quantities of suitable fluorocarbon surfactants are added to a protein hydrolyzate, the surface tension of the solution draining from the foam decreases until it reaches a point where it may spread across the surface of a liquid hydrocarbon. Under these conditions the generic term "fluoroprotein" foam would still apply, but the physical characteristics of the foam would approach and perhaps equal those of a true AFFF.

The FPF liquid concentrates were developed by the Naval Applied Science Laboratory (NASL) and industry specifically to achieve an acceptable degree of compatibility between PF and Purple-K powder from candidate formulations submitted principally by the National Foam System, Inc. This effort therefore recognized the basic incompatibility between the current 6-percent PF and Purple-K powder.

As a result of this work, a protein-type agent was developed which demonstrated a greatly improved compatibility with Purple-K powder. The FPF agents demonstrate complete conformance with the requirements of the Federal specification for PF, and in addition may display a high order of compatibility with Purple-K powder when evaluated in accordance with tests developed by the NASL (reference 10).

From the standpoint of chemical composition, the only difference between the FPF agents and those approved under the Federal Specification is the presence of a relatively small quantity, generally less than 1 percent by weight, of a perfluorinated surfactant.

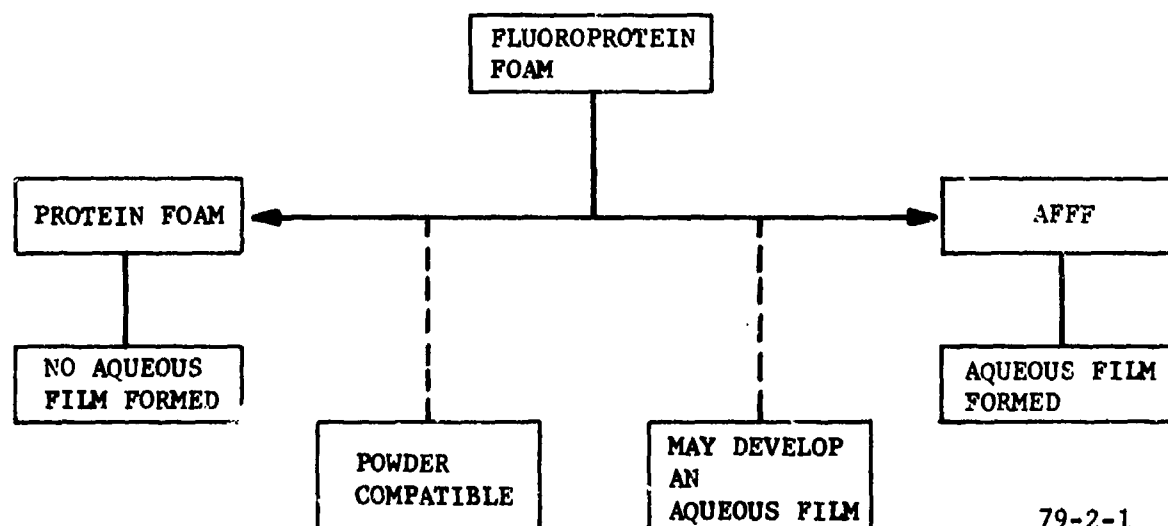


FIGURE 1. RELATIONSHIP OF FLUOROPROTEIN FOAM WITH PROTEIN FOAM AND AQUEOUS-FILM-FORMING FOAM (AFFF)

These fluorocarbons convey powder compatibility to PF through a physical rather than a chemical property. The fluorocarbon molecule is functionally double ended; that is, one end is hydrophilic, or water loving, and the other is hydrophobic and/or oleophobic; that is, water and oil hating.

The manner in which the fluorocarbon protects the protein foam from destruction by powder may be visualized by considering the way in which a drop of hydrocarbon fuel, such as JP-4 or gasoline, spontaneously spreads when placed on the surface of water. This same spreading phenomenon may be considered to occur when an aqueous protein-base foam is placed on the surface of a hydrocarbon fuel. That is, a very thin film of fuel, probably monomolecular in thickness, "climbs" or spreads up and across the foam surface. This hydrocarbon film in itself is not destructive to the foam. However, when Purple-K powder is present in the system, a synergistic foam-destructive mechanism is established between the powder and the fuel which causes a very rapid and progressive destruction of the foam body. When a fluorocarbon is present in the foamed solution, the surface tension of the aqueous phase is lowered from approximately 45 dynes/centimeter (cm) to approximately 34 dynes/cm in some formulations, and the fluorocarbon molecules are oriented in the foam wall in such a way that the fluorocarbon end is extended outward and forms an oleophobic or oil-repelling barrier at the interface between the foam and fuel. This interpretation of the phenomenon implies that the hydrocarbon film is no longer able to spread over the surface; therefore, the fuel parameter is excluded from

the foam-destructive mechanism involving Purple-K, fuel, and foam. This system is dynamic, however, and only a few seconds are required to establish the optimum foam-fuel interfacial equilibrium condition.

LABORATORY EVALUATION OF FOAM AGENTS.

PHYSICAL PROPERTIES OF AQUEOUS FLUOROCARBON FILMS PRODUCED BY THE AFFG AGENTS. The firefighting effectiveness of the foam produced by the perfluorinated surfactants is greatly enhanced by the aqueous fluorocarbon film which floats on the surface of hydrocarbon fuels as it drains from the foam blanket.

The mechanism whereby the fluorocarbon surfactants function as effective vapor securing agents is based upon their outstanding effect in reducing the surface tension of water and of their controllable oleophobic and hydrophilic properties. These properties provide a means for controlling the physical properties of water enabling it to float and spread across the surface of a hydrocarbon fuel even though it is more dense than the substrate. This unique property led to the term "light water" which appeared in several of the early military specifications defining the properties of this class of agents.

According to classical theory (reference 11) concerning the spreading of insoluble films on liquid surfaces, the following equation maintains:

$$SC = \gamma_0 - (\gamma_w + \gamma_i),$$

where: SC = spreading coefficient of the aqueous fluorocarbon solution,
 γ_0 = surface tension of the fuel,
 γ_w = surface tension of the aqueous film, and
 γ_i = interfacial tension between fuel and the aqueous film.

If the spreading coefficient has a value greater than zero (i.e., positive), the aqueous phase can spread spontaneously upon or "wet" the fuel. A coefficient below zero (i.e., negative) indicated that it cannot spread spontaneously. When the spreading coefficient is zero, the two liquids are miscible.

Although this equation is applicable to pure liquids, there is wide variation possible when aqueous fluorocarbon films spread on a hydrocarbon fuel because of the variable oleophobic and hydrophobic properties of the fluorocarbon moieties. Therefore, to assess the interrelationship between fire-fighting effectiveness and the surface activity of the aqueous films produced by the 3- and 6-percent AFFF agents, a study was conducted to determine the film spread rate of each agent as a function of its interfacial tension on Jet A aviation fuel (appendix B). The Jet A fuel employed in these and all subsequent laboratory experiments had a surface tension of 27.0 dynes/cm.

In an effort to obtain better insight into the aqueous film spreading phenomenon on hydrocarbon fuels four separate aliquot liquid fractions were taken of the solution as it drained from the foam body. The spreading coefficients obtained by this procedure using four different 6-percent AFFF solutions on Jet A fuel are summarized in table 1. From these data it is apparent that only one agent (Lorcon 6) showed a negative spreading coefficient indicating that the first aliquot liquid fraction which drained from the foam would not spread spontaneously on Jet A fuel. It is speculated that this behavior resulted from the temporary adsorption of the

active fluorocarbon moiety(s) within the body of the foam from which it was slowly released toward the end of the foam drainage cycle. However, this same agent produced relatively high spreading coefficient values for the unfoamed solution and of the third aliquot fraction which drained from the foam.

Similar experiments were performed using the three 3-percent AFFF agents, and the results are presented in table 2. A comparison of the film spreading coefficients obtained for the 3- and 6-percent type AFFF agents shows a strong similarity in pattern between the unfoamed solution and the three aliquot fractions of the drained foam liquid, with the exception of the anomalous performance of Lorcon 6. Based upon these data, it is apparent that all of the AFFF agents produce an aqueous fluorocarbon film capable of spontaneously spreading over the surface of Jet A fuel.

However, a second factor considered of equal significance in determining the firefighting effectiveness of the AFFF agents is the rate at which the aqueous fluorocarbon film spreads over the hydrocarbon fuel surface. To accomplish this objective, the apparatus shown in figure 2 was developed.

The film spread rate experiments were conducted by discharging 4 milliliters (ml) of solution down the inclined trough onto the surface of the Jet A fuel at the uniform rate of 0.10 ml/second and observing the distance traveled by the solution at appropriate time intervals. The film spread rates obtained for the unfoamed solution and each of the three aliquot foam drainage samples are presented in table 1 for the 6-percent agents and in table 2 for the 3-percent agents.

TABLE 1. SURFACE TENSION CHARACTERISTICS AND FILM SPREAD RATE OF THE 6-PERCENT AFFY AGENTS

Agent and Sample	Surface Tension of the Aqueous Film $\frac{\gamma_w}{(\text{dynes/cm})}$	Interfacial Tension between Fuel and the Aqueous Film $\frac{\gamma_1}{(\text{dynes/cm})}$	Spreading Coefficient of Aqueous Film $\frac{S C}{(\text{dynes/cm})}$	Film Spread Rate $\frac{(\text{cm/sec})}{(\text{cm/sec})}$
FC-206				
Not Foamed	15.20	5.20	6.90	1.26
1st Fraction	17.88	4.60	4.82	0.58
2nd Fraction	18.43	4.80	4.07	0.93
3rd Fraction	15.88	5.20	6.22	1.33
AFR-O-WATER 6				
Not Foamed	18.68	2.37	5.78	1.17
1st Fraction	17.95	2.33	6.55	0.10
2nd Fraction	17.95	2.43	6.45	0.28
3rd Fraction	17.05	2.10	7.68	1.22
ANSUL 6				
Not Foamed	18.0	2.20	6.80	1.00
1st Fraction	21.50	2.80	3.00	0.23
2nd Fraction	20.90	2.55	3.85	0.48
3rd Fraction	19.31	1.95	6.04	1.11
LORCON 6				
Not Foamed	17.50	1.70	7.80	0.54
1st Fraction	25.45	2.67	-1.12	0
2nd Fraction	24.28	2.53	0.19	0
3rd Fraction	18.58	2.27	5.15	0.14

Note: Surface Tension of Jet A Fuel = 27.0 dynes/cm.

TABLE 2. SURFACE TENSION CHARACTERISTICS AND FILM SPREAD RATE OF THE 3-PERCENT APFF AGENTS

Agent and Sample	Surface Tension of the Aqueous Film $\frac{\gamma_w}{\text{(dynes/cm)}}$	Interfacial Tension between Fuel and the Aqueous Film $\frac{\gamma_1}{\text{(dynes/cm)}}$	Spreading Coefficient of Aqueous Film $\frac{S}{C}$ (dynes/cm)	Film Spread Rate $\frac{\text{cm}}{\text{sec}}$
FC-203				
Not Foamed	16.37	4.53	6.10	1.04
1st Fraction	16.37	4.37	6.26	0.52
2nd Fraction	16.30	4.40	6.30	0.81
3rd Fraction	16.37	4.43	6.20	1.13
AER-O-WATER 3				
Not Foamed	19.20	1.77	6.03	1.08
1st Fraction	20.00	2.00	5.00	0.20
2nd Fraction	19.90	1.70	5.40	0.41
3rd Fraction	18.50	1.47	7.03	0.86
AER-O-WATER PLUS 3				
Not Foamed	19.33	1.23	6.44	1.10
1st Fraction	19.67	1.90	5.43	0.20
2nd Fraction	19.97	1.90	5.13	0.38
3rd Fraction	18.37	1.27	7.36	0.58

Note: Surface Tension of Jet A Fuel = 27.0 dynes/cm.

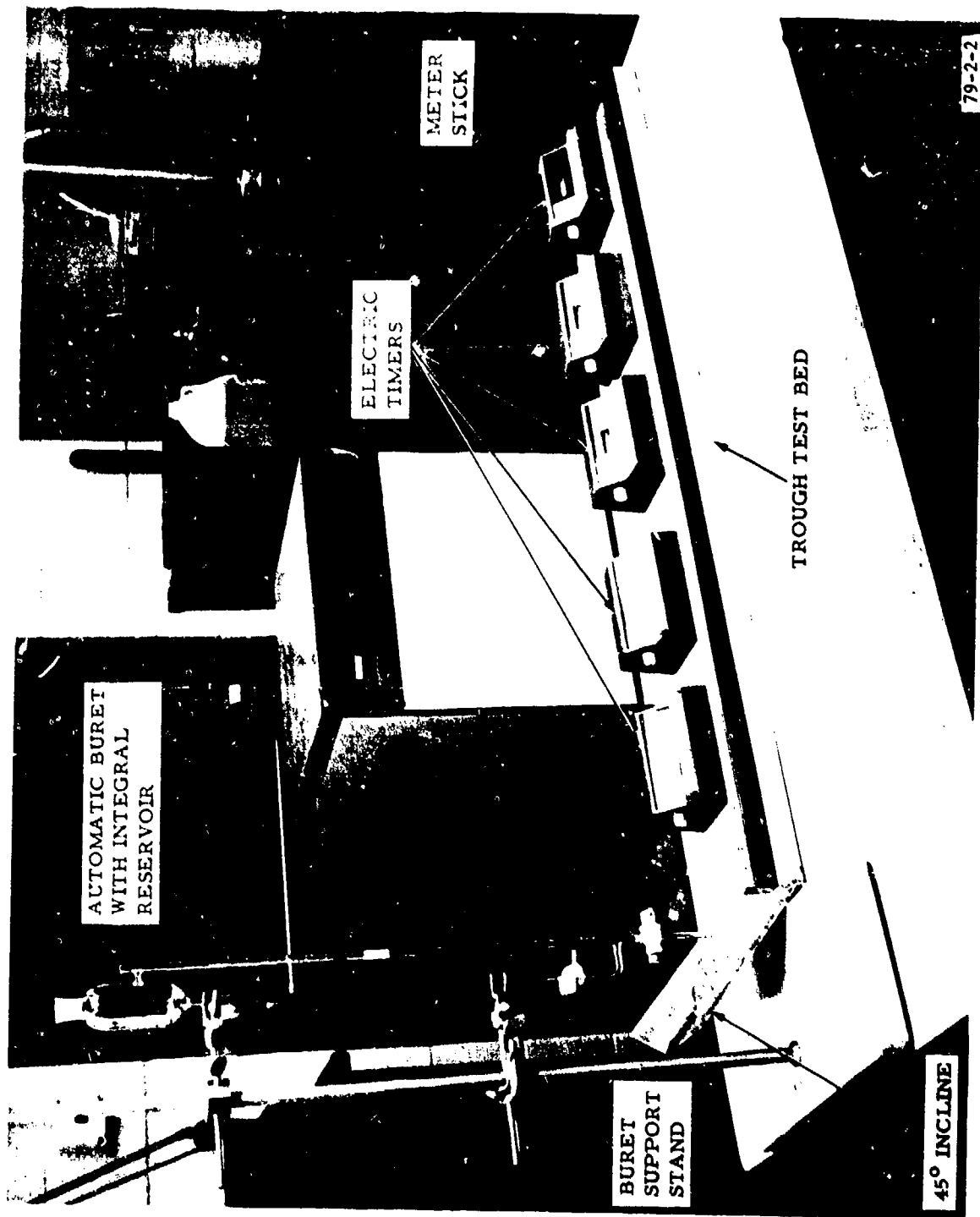


FIGURE 2. APPARATUS USED TO MEASURE FILM SPREAD RATE OF AFF AGENTS

For comparative purposes, these data are plotted in figures 3 and 4 for the 6-percent and 3-percent AFFF agents, respectively. A comparison of these profiles show similar trends for both the 3-percent (FC-203 and Aer-0-Water 3) and 6-percent (FC-206 and Aer-0-Water 6) agents. However, it is considered noteworthy that the film spread rate obtained with the third aliquot sample drained from FC-206 and Aer-0-Water 6 foams achieved the same film spread rate as the unfoamed solution. Therefore, these data tend to indicate that the foaming of an AFFF solution may retard the rate at which the aqueous film spreads over Jet A fuel. This phenomenon was, in fact, later demonstrated in large-scale fire tests in which the foam solution was discharged through a non-air-aspirating nozzle.

Visual evidence of the rate at which an aqueous fluorocarbon film (Aer-0-Water 6) spreads over Jet A fuel is illustrated by the sequential photographs presented in figure 5.

MUTUAL COMPATIBILITY BETWEEN FOAM LIQUID CONCENTRATES. The probability that firefighting foam agents produced by different manufacturers will be used concurrently in airport firefighting operations is increasing and requires that tests be performed to determine the effects upon the resulting composite liquid system if these agents are inadvertently mixed. Accelerated aging tests were therefore performed in nominal conformance with Federal Specification O-F-555C (reference 1) to determine the degree of compatibility between the different brands within each class of agents employed at the same usage concentration (i.e., either 3- or 6-percent by volume). A summary

of the manufacturers and the agents tested for compatibility within each class is presented in table 3.

Appendix C contains the results of the compatibility experiments conducted with binary mixtures at concentrations of 25, 50, and 75 percent by volume of each agent. From these data it is apparent that the four 6-percent AFFF agents demonstrated an acceptable degree of compatibility when evaluated in accordance with the test procedures established in appendix C for all liquid mixtures.

Although the 3-percent AFFF agents are not manufactured in accordance with a military specification, as are the 6-percent agents (reference 6), they also demonstrated excellent mutual compatibility in all of the laboratory experiments.

In contrast with the AFFF agents, the 6-percent FPF liquid concentrates showed a low order of compatibility in the accelerated aging cycle. Of the 10 binary combinations tested, only two showed a sediment of 0.25 percent (maximum allowable) or less in the aging experiments.

Similar results were obtained when combinations of the 3-percent fluoroprotein agents were subjected to the accelerated aging test. A total of six mixtures were tested of which only one combination produced a sediment of 0.25 percent or less by volume.

From these data it is evident that combinations of the fluoroprotein agents should be avoided if they are to be stored for any prolonged period of time. However, it does not necessarily preclude their being mixed when they are required for immediate use.

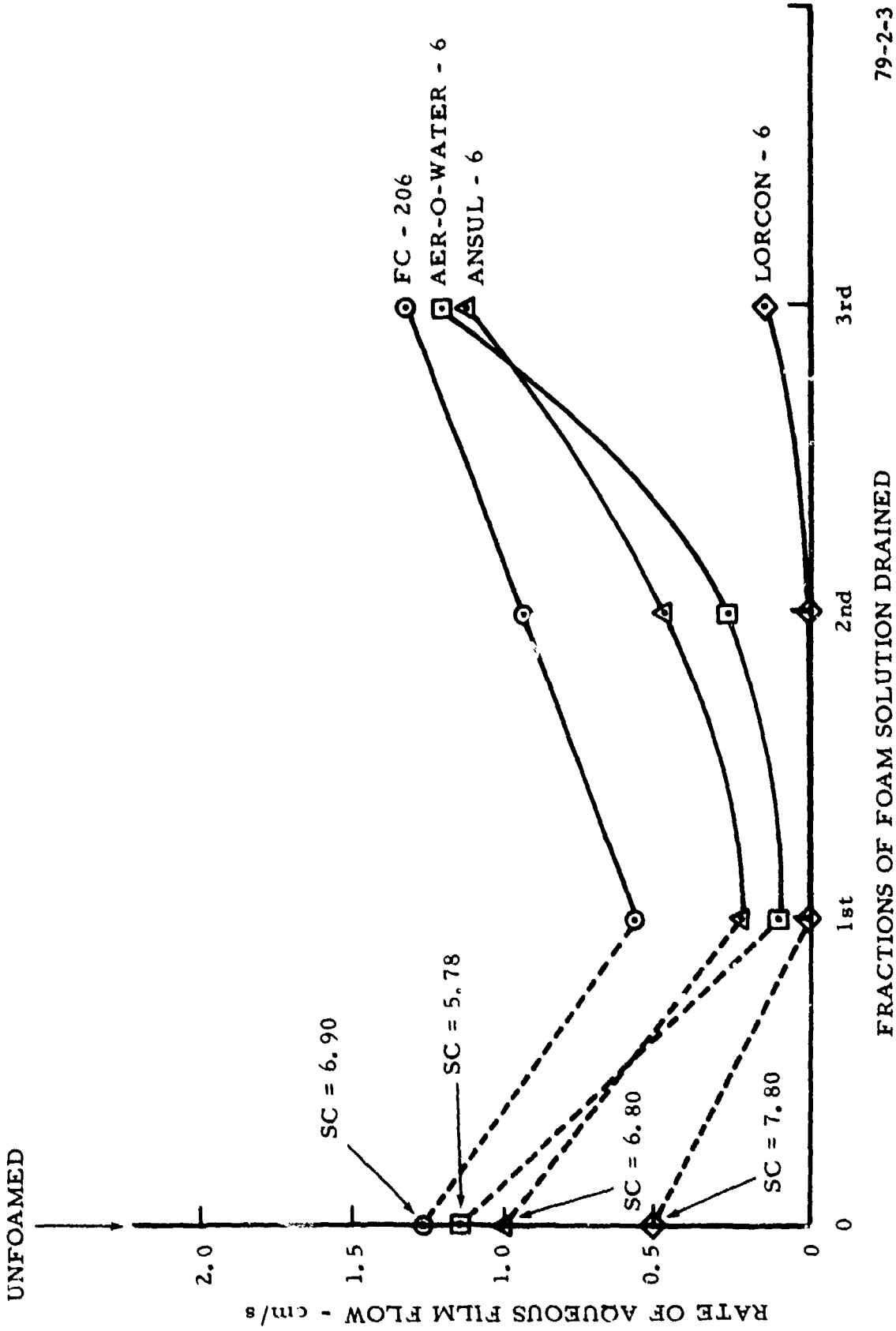
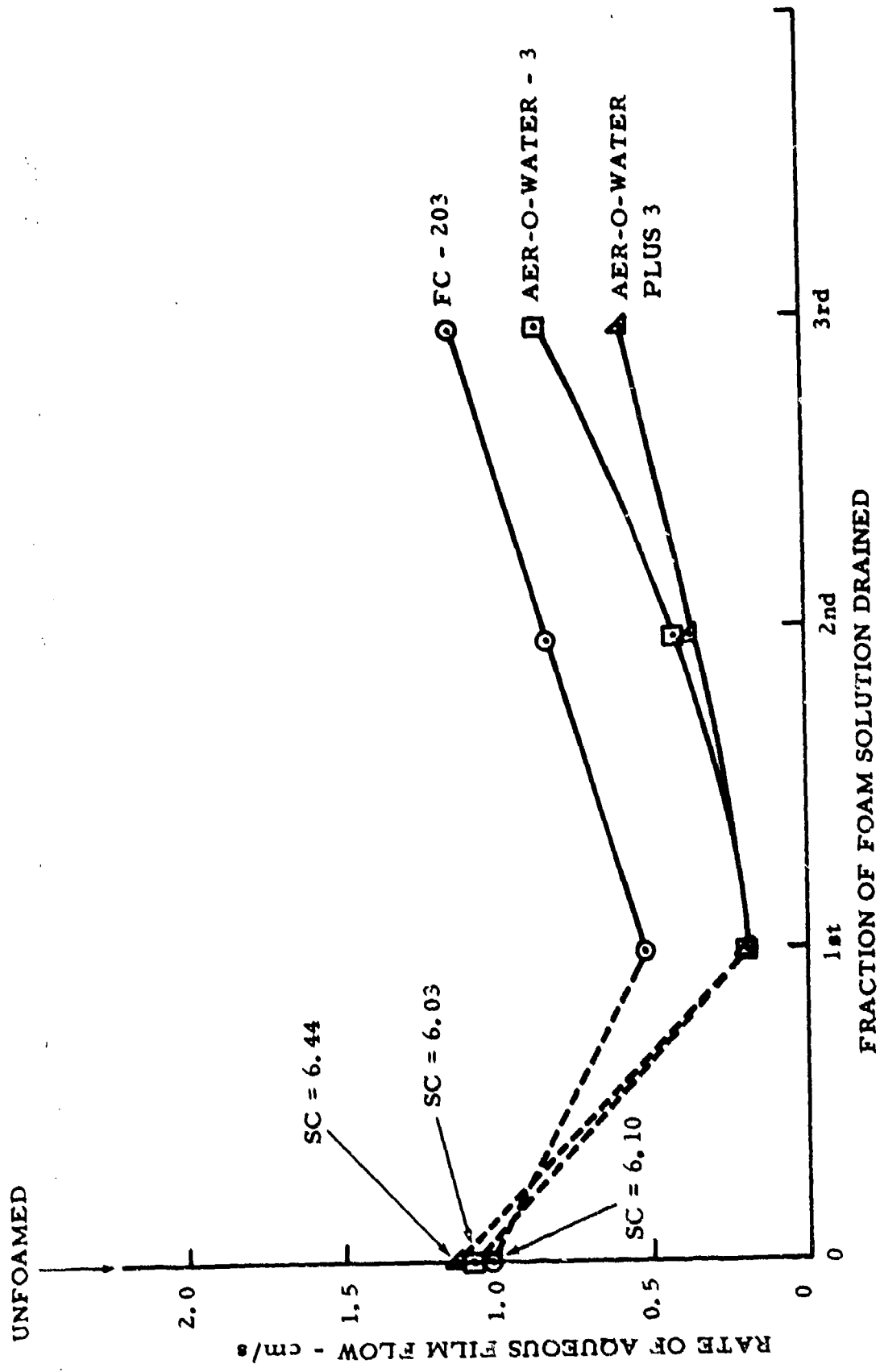


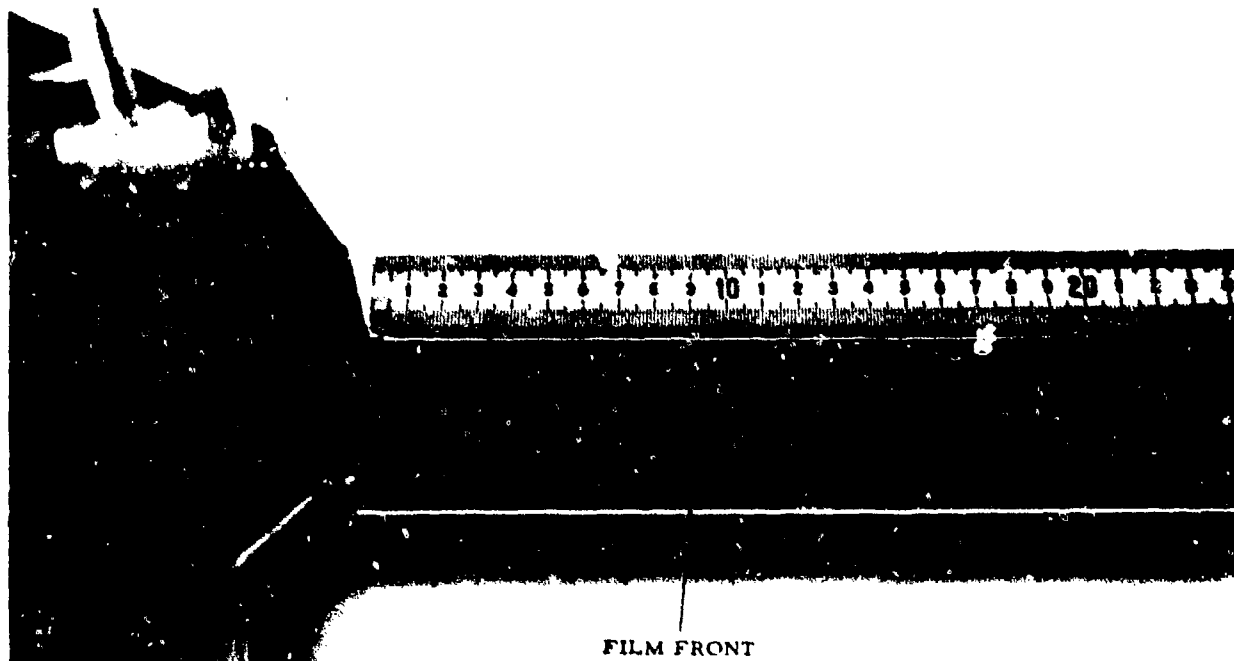
FIGURE 3. AQUEOUS FILM SPREAD RATE ON JET A FUEL FOR UNFOAMED AND FOAMED 6-PERCENT AFFF AGENTS

79-2-3

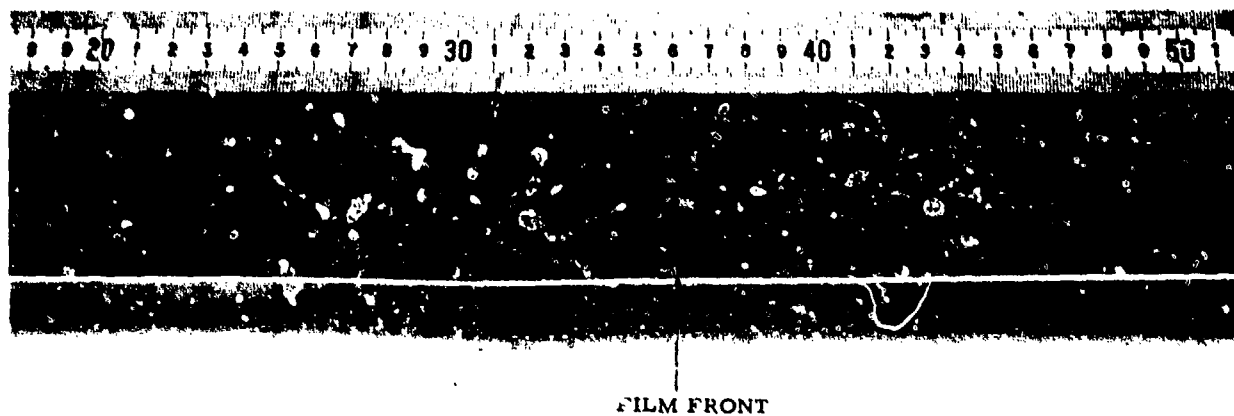


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FIGURE 4. AQUEOUS FILM SPREAD RATE ON JET A FUEL FOR UNFOAMED AND FOAMED 3-PERCENT AFFF AGENTS

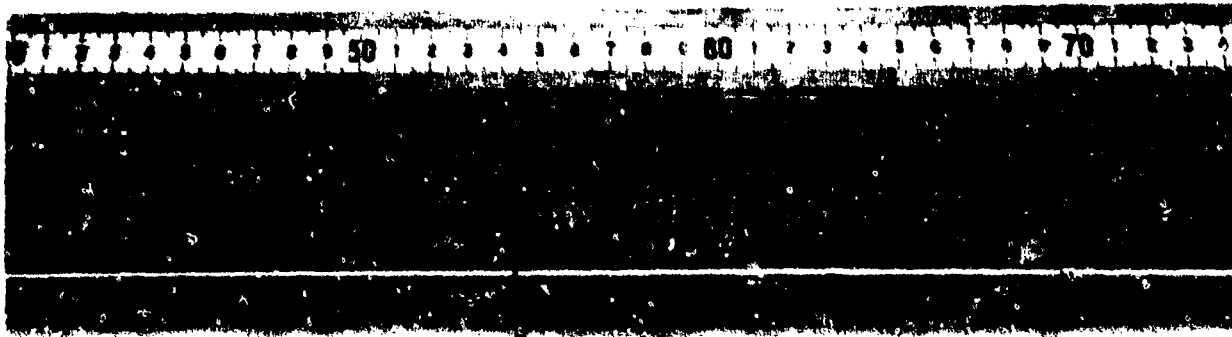


(a) FILM FRONT DISTANCE TRAVELED AT 2.8 SECONDS



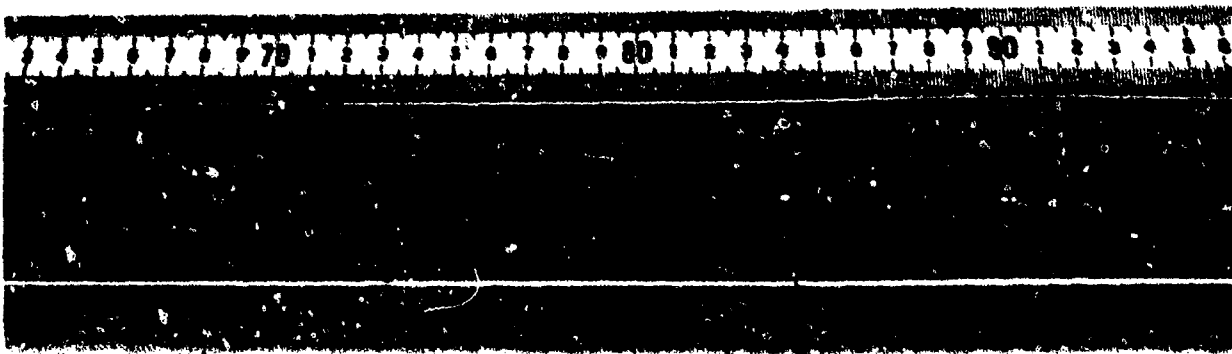
(b) FILM FRONT DISTANCE TRAVELED AT 13.1 SECONDS

FIGURE 5. FILM SPREAD RATE OF AN AQUEOUS FLUOROCARBON FILM
(AER-O-WATER 6) ON JET A FUEL (1 OF 2)



FILM FRONT

(c) FILM FRONT DISTANCE TRAVELED AT 25.9 SECONDS



FILM FRONT

(d) FILM FRONT DISTANCE TRAVELED AT 54.6 SECONDS

FIGURE 5. FILM SPREAD RATE OF AN AQUEOUS FLUOROCARBON FILM (AER-O-WATER 6) ON JET A FUEL (2 OF 2)

TABLE 3. CLASSES OF FIREFIGHTING FOAM AGENTS

MANUFACTURER	AFFF AGENTS		FLUOROPROTEIN FOAMS			PROTEIN FOAM	
	33 Type	62 Type	33 Type	Various 2 Type	65 Type	33 Type	62 Type
3 M COMPANY NATIONAL FOAM SYSTEM, INC.	FC-203 AER-O-WATER 3 AER-O-WATER Plus 3	FC-206 AER-O-WATER 6	AER-O-FOAM EL-3		AER-O-FOAM EL-6	AER-O-FOAM 3	
LAWRENTIAN CONCENTRATES Ltd.	LORCON 6	LORCON 6	LORCON FF-3		LORCON K LORCON FF		
THE ARSUL CO. PYRENE Co. Ltd.	ARSUL 6			PYRENEZ Plus F 4.52			
ARCUS FIRE ARMOUR CORPORATION			ARCUS FF-70	ARCUS FF-570 52			
NEARL CORPORATION MORRIS INTERNATIONAL Ltd.			NEARL 3	PROTECTOFOAM 42		NEARL 3	

These agents are generally made in accordance with Federal Specification O-P-132c (See reference 1 for details)

It is speculated that the reason for the low order of compatibility between the fluoroprotein agents as a class is the absence of a suitable specification to define pertinent requirements and thereby provide guidance during their manufacture. In this regard, reference 12 specifically emphasizes the fact that the mixing of protein, fluoroprotein, or AFFF liquid concentrates of different types or produced by different manufacturers shall not be permitted unless it has been established that they are mutually compatible under long-term storage conditions and that the mixture will not reduce the firefighting effectiveness of the equipment in which it is used.

Only one experiment was conducted using 3-percent PF liquids (Aer-0-Foam 3 and Mearl 3) in the accelerated aging tests. The results of this experiment showed that an acceptable degree of compatibility maintained between the agents, with sediment not exceeding 0.05 percent by volume after aging.

No compatibility experiments were conducted with the 6-percent PF agents because of the work previously accomplished with these agents (reference 13) and the fact that they are generally produced in conformance with the federal specification (reference 1) which requires mutual compatibility for approval.

COMPATIBILITY OF FIREFIGHTING FOAMS WITH DRY-CHEMICAL POWDERS. The firefighting performance of all dry-chemical powders may be regarded to be of the "go" or "no go" type. That is, the fire is either completely extinguished with the environment cooled below the flash point of the fuel, or the fire will reflash. Therefore, their

principal use in combatting complex three-dimensional fuel-spill fires is as auxiliary or complementary agents in conjunction with one or more of the foam-blanketing agents.

The increasing use of dry-chemical powders as auxiliary agents in aircraft accidents requires a knowledge of the compatibility of these agents with different foams. The results of large-scale fire tests performed at NAFEC (reference 14) with incompatible powder-foam combinations resulted in an almost complete cancellation of the firefighting effectiveness of both agents, and fire control was never obtained. To be successful the dry-chemical powders used in either a combined agent attack or as mop-up agents should demonstrate a reasonable degree of compatibility with the foam.

The compatibility between dry-chemical powders and different foams is usually one of degree rather than an absolute value. Therefore, laboratory tests designed to evaluate this property must be correlated with the results obtained using the same agents under actual full-scale crash fire conditions. The laboratory test outlined in appendix D contains the four parameters existent in all aircraft fire situations in which foam and powder are employed; i.e., fuel, heat, foam, and dry-chemical powder. The purpose of employing this test procedure, in which the materials are intimately mixed and exposed to intense thermal radiation, was an attempt to simulate the most severe conditions which might be realized under actual crash firefighting conditions and to avoid the ambiguity sometimes associated with interpreting the results of tests representative of some unknown intermediate degree of fire severity.

The results of experiments performed in accordance with this procedure using a variety of foam and dry-chemical agents indicated that if the time required to collect 25 ml of foam solution was 2.0 minutes (min) or more, an acceptable degree of compatibility would be obtained under conditions involving a high-degree of turbulence of the burning fuel, foam, and dry-chemical powder in crash-fire situations (references 13 and 15). The experimental results obtained using this test method and five different dry-chemical powders with each agent comprising the three classes of foams are summarized in table 4. The manufacturers of the dry-chemical powders are presented in appendix E.

From these data it is apparent that all of the 6- and 3-percent AFFF agents demonstrated an acceptable degree of compatibility with each of the five dry-chemical powders when tested in accordance with the procedure outlined in appendix D.

In contrast with the AFFF agents, 6 of the 10 fluoroprotein agents showed an acceptable degree of compatibility with Monnex[®] and compatible dry-chemical (CDC), while only four demonstrated acceptable compatibility with monomonium phosphate (ABC) powder. No compatibility was shown between any of the 10 fluoroprotein agents and Super K or Purple K powder (PKP). None of the five dry-chemical powders were compatible with either the 6- or 3-percent regular PF agents tested. As a consequence of these adverse results, a second series of experiments was conducted in an effort to identify the parameter responsible for the incompatibility between the PF and FPF agents and the dry-chemical powders.

Previous foam powder compatibility experiments conducted in nominal conformance with reference 16 indicated that the major parameter contributing to incompatibility was the fuel. Therefore, to assess the effect of the fuel parameter, a second series of experiments was conducted similarly to the first in which the fuel was omitted from the system.

The results of these experiments are summarized in table 5. From these data it is apparent that the compatibility between the PF and FPF type foam agents and dry-chemical powders showed marked improvement in the absence of fuel. However, it is obvious that any test method purporting to measure the compatibility between firefighting agents which are recommended for use either in combination or sequentially (reference 17) that does not take cognizance of the presence of fuel is unresponsive to the conditions maintaining in aircraft accidents involving fire. It was for this reason that the test procedure presented in appendix D was developed and determined to be reasonably consistent with the results obtained in full-scale outdoor fire tests. Therefore, the foam and dry-chemical powder compatibility data presented in table 4 are considered to more closely approximate the compatibility to be anticipated in aircraft accidents involving massive fuel spill fires.

COMPATIBILITY OF FIREFIGHTING FOAMS WITH VAPORIZING LIQUIDS (HALOGENATED HYDROCARBONS). The halogenated hydrocarbons are considered among the more stable of the organic compounds. Although all of the vaporizing agents employed in firefighting are chemically related, each member of the group has a different chemical structure resulting in different degrees of thermal

TABLE 4. COMPATIBILITY OF AFFF, FPF, AND PF AGENTS WITH DRY-CHEMICAL POWDERS AND JET A FUEL

Foam Agents	Solution Concentration Percent	FOAM SOLUTION DRAINAGE TIME FOR 25 ml min:sec										No Dry-Chemical Powders
		Super K	PKP	CDC	ABC	MONNEX	PKP	CDC	ABC	MONNEX		
AFFF												
FC-200	6	4:00	4:20	4:50	4:10	5:40						7:40
FC-206	6	3:50	3:30	3:15	3:10	3:05						5:45
AER-O-WATER 6	6	2:50	3:15	3:34	3:00	4:00						6:05
LORCON	6	2:30	3:13	2:23	3:15	3:10						4:10
ANSUL	6	3:40	3:15	2:39	4:04	3:35						5:50
FC-203	3	3:40	3:55	3:58	3:20	3:55						8:00
AER-O-WATER 3	3	2:30	2:30	2:30	3:13	3:20						5:55
AER-O-WATER PLUS 3	3	3:01	3:10	2:27	3:26	3:32						4:53
FPF												
AER-O-FOAM XL-6	6	0:01	0:02	2:04	0:02	3:01						3:15
LORCON K	6	0:15	0:50	1:37	2:50	3:10						5:10
LORCON FP	6	0:01	1:00	2:31	3:11	4:30						5:59
ANGUS FP-570	5	0:01	0:01	2:17	2:27	3:01						6:24
PYRENE PLUS F	4.5	0:01	0:01	2:12	0:50	2:18						3:33
PROTECTOFOAM	4	0:01	0:02	0:02	0:15	1:20						3:57
AER-O-FOAM XL-3	3	0:01	0:03	1:41	0:01	1:30						3:21
LORCON FP 3	3	0:05	1:15	2:30	2:20	4:45						4:51
ANGUS FP-70	3	0:01	0:01	1:57	0:01	1:07						3:31
MEARL	3	0:01	0:01	2:26	0:01	1:55						4:45
PF												
TYPE O-F-555C	6	0:01	0:01	1:12	0:01	1:05						3:55
AER-O-FOAM 3	3	0:01	0:01	0:02	0:01	0:02						3:27
MEARL	3	0:01	0:01	1:38	0:01	0:01						4:37

TABLE 5. COMPATIBILITY OF AFFF, FPF, AND PF AGENTS WITH DRY-CHEMICAL POWDERS (WITHOUT JET A FUEL)

FOAM SOLUTION DRAINAGE TIME FOR 25 ml
Min:Sec

<u>Foam Agents</u>	<u>Foam and Heat Alone</u>	<u>Super K</u>	<u>Foam, Powder, and Heat Dry-Chemical Powders</u>			
			<u>PKP</u>	<u>CDC</u>	<u>ABC</u>	<u>MONNEX</u>
<u>AFFF</u>						
FC-200	6:55	4:05	5:00	3:44	5:05	4:45
FC-206	4:50	3:35	3:45	2:55	3:20	3:15
AER-O-WATER 6	5:20	3:35	3:15	3:24	3:50	3:50
LORCON	4:15	2:45	2:50	2:10	2:30	2:40
ANSUL	5:20	5:20	6:18	2:19	5:20	5:20
FC-203	6:15	3:50	4:00	3:26	4:50	4:40
AER-O-WATER 3	6:55	2:40	3:00	2:28	3:30	2:40
AER-O-WATER PLUS 3	4:24	3:27	3:26	2:07	4:09	3:45
<u>FPF</u>						
AER-O-FOAM XL-6	4:10	3:00	2:05	2:06	4:40	4:00
LORCON K	7:05	4:45	3:15	2:37	4:15	4:40
LORCON FP	6:48	4:00	4:15	2:03	5:15	5:00
ANGUS FP-570	7:22	3:16	2:59	2:19	5:37	3:50
PYRENE PLUS F	4:38	3:16	3:15	3:04	5:07	4:28
PROTECTOFOAM	5:30	2:44	1:30	2:12	3:35	3:00
AER-O-FOAM XL-3	6:00	2:18	1:25	1:46	3:25	2:40
LORCON FP 3	5:10	1:48	4:20	2:21	4:00	4:15
ANGUS FP-70	4:59	2:15	2:01	2:00	4:52	4:35
MEARL	5:16	4:09	3:41	2:00	5:15	6:13
<u>PF</u>						
TYPE O-F-555C	6:15	3:08	1:35	1:56	3:45	4:20
AER-O-FOAM 3	5:25	2:14	0:20	1:33	2:15	2:55
MEARL	6:49	4:12	2:11	2:44	3:36	4:46

stability. The molecular stability of individual compounds is a function of the dissociation energies for the weakest bonds in the molecules; accordingly, the weaker the bond energy, the more readily thermal dissociation will be accomplished.

As a consequence of the low chemical reactivity of these agents at ambient temperatures and their very low water solubility, they are compatible with all preformed aqueous foams. In addition, the AFFF solutions were shown to be compatible with chlorobromomethane (CB) in reference 15, and in reference 3 the premixed AFFF solution was "blown" (foamed) with Freon 12 (dichlorodifluoromethane).

Although the pure vaporizing agents show an acceptable degree of compatibility with preformed foams, there may be some minor transient incompatibility with their pyrolysis products. An extensive series of tests conducted by ICI America under practical fire conditions using bromochlorodifluoromethane indicated that about 98 percent of the agent is volatilized in an unchanged condition. Analyses of the data available on the thermal decomposition products of the halogenated compounds indicates that these are quite similar for all of the agents. The products include principally the halogen-acid gases such as hydrogen fluoride, hydrogen chloride, hydrogen bromide, and to a lesser extent the free halogens (chlorine, bromine, but not fluorine) carbon monoxide and various analogs of phosgene (COCl_2) such as COFCl , COF_2 , COFBr , etc. All of which are highly toxic. It is these acidic pyrolysis products which could conceivably be incompatible with established blankets of preformed foams. However, because of the dynamic and highly turbulent environmental conditions inherent in

combatting large outdoor free-burning pool fires no significant incompatibility has been observed or reported when employing the vaporizing agents and aqueous foams either simultaneously or sequentially.

STABILITY OF PREFORMED FOAMS ON POLAR SOLVENTS. The primary hazard associated with aircraft firefighting is the large quantity of hydrocarbon fuel and oil carried. These petroleum products are insoluble in water and are sometimes referred to as nonpolar compounds, to differentiate them from the polar compounds or polar solvents which are either completely soluble or partially soluble in water. All other flammable liquids associated with the operation of the aircraft are extremely small by comparison. However, the large increase in cargo shipments of highly flammable polar solvents presents a potential hazard worthy of consideration by the Crash-Fire Rescue (CFR) services at airports in the future.

Regular AFFF, FPF, and PF agents are satisfactory for extinguishing/securing large aviation fuel fires at nominal application densities from 0.022 to 0.053 gallons per square foot (gal/ft^2) depending upon the fire conditions. However, these agents are not capable of securing large quantities of polar solvents existing in-depth at these application densities.

To effectively fight polar solvent fires of significant depth, a special class of extinguishing agents has been developed which are variously referred to as being of the "alcohol-type," "polar solvent type," or "all-purpose type." An example of the solution application rates recommended by one manufacturer using specially formulated foam agents (reference 18) to extinguish several different classes of

polar solvent fires is presented in appendix F. From these data, it is apparent that the solution application rates required to extinguish different polar solvent fires, even with these specially formulated agents, requires somewhat elevated solution application rates over those recommended for hydrocarbon fires. These data also emphasize the dependence of the foam solution application rate on the particular type of polar solvent fuel involved. Although the polar solvents carried as cargo pose a potential fire hazard the actual quantity and packaging requirements (reference 19) for shipment tend to reduce the hazard to within the capabilities of the CFR services using regular nonpolar fire extinguishing agents.

The polar solvent most frequently used onboard aircraft is methanol, either neat or in the form of its aqueous solutions. The quantity of neat methanol carried may vary from a few gallons to 45 gallons or more depending upon the configuration of the aircraft. Therefore, laboratory foam stability experiments were performed on neat methanol and its aqueous solutions in accordance with the experimental requirements outlined in appendix G.

In these experiments the volume of foam used (35.77 in^3) and the area of interfacial contact with the fuel (26.01 in^2) were held constant. These parameters were considered most representative of actual firefighting field conditions.

Because of the wide variation in the foaming characteristics of each class of agents the average foam expansion ratios varied as follows: AFFF, 18-20:1; FPF, 10-12:1; and PF, 8-10:1 by volume, which resulted in the following solution application

densities: AFFF, 0.042 gal/ft^2 ; FPF, 0.071 gal/ft^2 ; and PF, 0.084 gal/ft^2 . As a consequence of the relatively large volume of methanol employed in these experiments, the dilution caused by the liquid which drained from the foam was negligible.

The results of the foam stability experiments conducted with AFFF, FPF, and PF agents on neat methanol and aqueous solutions of 75, 50, and 25 percent by volume are summarized in table 6. These data tend to indicate that the rate at which the foams are destroyed decreases as the solution becomes more dilute and that the critical concentration required to delay the very rapid destruction of the foam lies somewhere between 25 and 50 percent by volume. The most stable foam blanket on methanol and its solutions were produced by the fluoroprotein foams (Aer-O-Foam XL-6, XL-3, Angus FP-70) and protein foams (Aero-O-Foam 3 and Mearl 3).

In these experiments, the estimated average foam solution application density varied between 0.071 and 0.084 gal/ft^2 when the foam was placed gently on the methanol surface. However, in actual practice, where these foams are normally applied from an air-aspirating nozzle, the application density would have to be increased by a factor of 2 to 3 to offset the deleterious effects produced by the turbulent action caused by this mode of discharge.

FOAM QUALITY DETERMINATIONS. After the completion of the laboratory experiments, a series of small-scale fire tests was scheduled employing the standard U.S. Navy (1-gal/min foam nozzle specified in reference 1. Prior to performing these experiments, the quality of foam produced by those agents, which were considered candidates for future evaluation, was determined.

TABLE 6. STABILITY OF PREFORMED FOAMS ON NEAT METHANOL AND ITS AQUEOUS SOLUTIONS

Foam Stability Min:Sec								
AFFF AGENTS								
Agent	FC-200	FC-206	AER-O-WATER 6	ANSUL	LORCON	AER-O-WATER 3	AER-O-WATER PLUS 3	FC-203
Solution Conc. (%)	<u>6</u>	<u>6</u>	<u>6</u>	<u>6</u>	<u>6</u>	<u>3</u>	<u>3</u>	<u>3</u>
Methanol Conc. Percent by Volume								
100	0:09	0:08	0:08	0:00	0:00	0:00	0:00	0:02
75	0:25	0:18	0:39	0:10	0:07	0:27	0:11	0:46
50	30:00	30:00	30:00	30:00	12:48	30:00	30:00	30:00
25	--	--	--	--	30:00	--	--	--
0	--	--	--	--	--	--	--	--

FLUOROPROTEIN FOAM AGENTS									
Agent	AER-O-FOAM		ANGUS		AER-O-FOAM		ANGUS		NEARL
	XL-6	LORCON K	LORCON FP	FP-570	Plus F	XL-3	FP-70	LORCON FP 3	
Solution Conc. (%)	<u>6</u>	<u>6</u>	<u>6</u>	<u>5</u>	<u>4.5</u>	<u>3</u>	<u>3</u>	<u>3</u>	<u>3</u>
Methanol Conc. Percent by Volume									
100	4:50	0:04	0:00	0:50	0:00	1:02	1:05	0:00	0:07
75	30:00	7:44	1:28	30:00	0:09	30:00	25:36	0:46	22:04
50	--	30:00	30:00	--	30:00	--	30:00	30:00	30:00
25	--	--	--	--	--	--	--	--	--
0	--	--	--	--	--	--	--	--	--

PROTEIN FOAM			
Agent	Federal Spec. O-7-555C	AER-O-FOAM	NEARL
Solution Conc. (%)	<u>6</u>	<u>3</u>	<u>3</u>
Methanol Conc. Percent by Volume			
100	0:08	0:59	0:06
75	19:45	30:00	30:00
50	30:00	--	--
25	--	--	--
0	--	--	--

The quality of AFFF, FPF, and PF agents was determined in terms of the expansion ratio and 25-percent solution drainage time, in accordance with NFPA methods (reference 12). A third physical property of fire-fighting foams not included as a requirement in current federal, military, or civil specifications is viscosity.

The instrument employed in measuring the foam viscosity in these experiments is shown in figure 6. Essentially, the instrument consists of a constant speed rotating torsion wire and vane which may be adjusted to shear a sample of foam held in a special container.

The torsion wire and vane are rotated by a geared motor in the head of the instrument. The torsion wire is enclosed in a brass tube on the downward facing spindle of the gear box. Attached to the lower end of this tube is an adjustable circular scale which is divided into 100 divisions. The vane is attached to the torsion wire which is also fitted with a steel disk of sufficient size to keep the wire taut. These components are arranged so that they can be moved vertically as a unit, and the sliding head is fitted with adjustable stops which can be preset so that when the head is depressed the vane is fully emersed in the foam to its uppermost edge.

The results of the foam quality experiments are presented in tables 7 through 9. These tables show foam quality data in terms of the foam expansion ratio and 25-percent solution drainage time for the candidate agents subsequently employed in the small-scale fire tests. However, only one agent

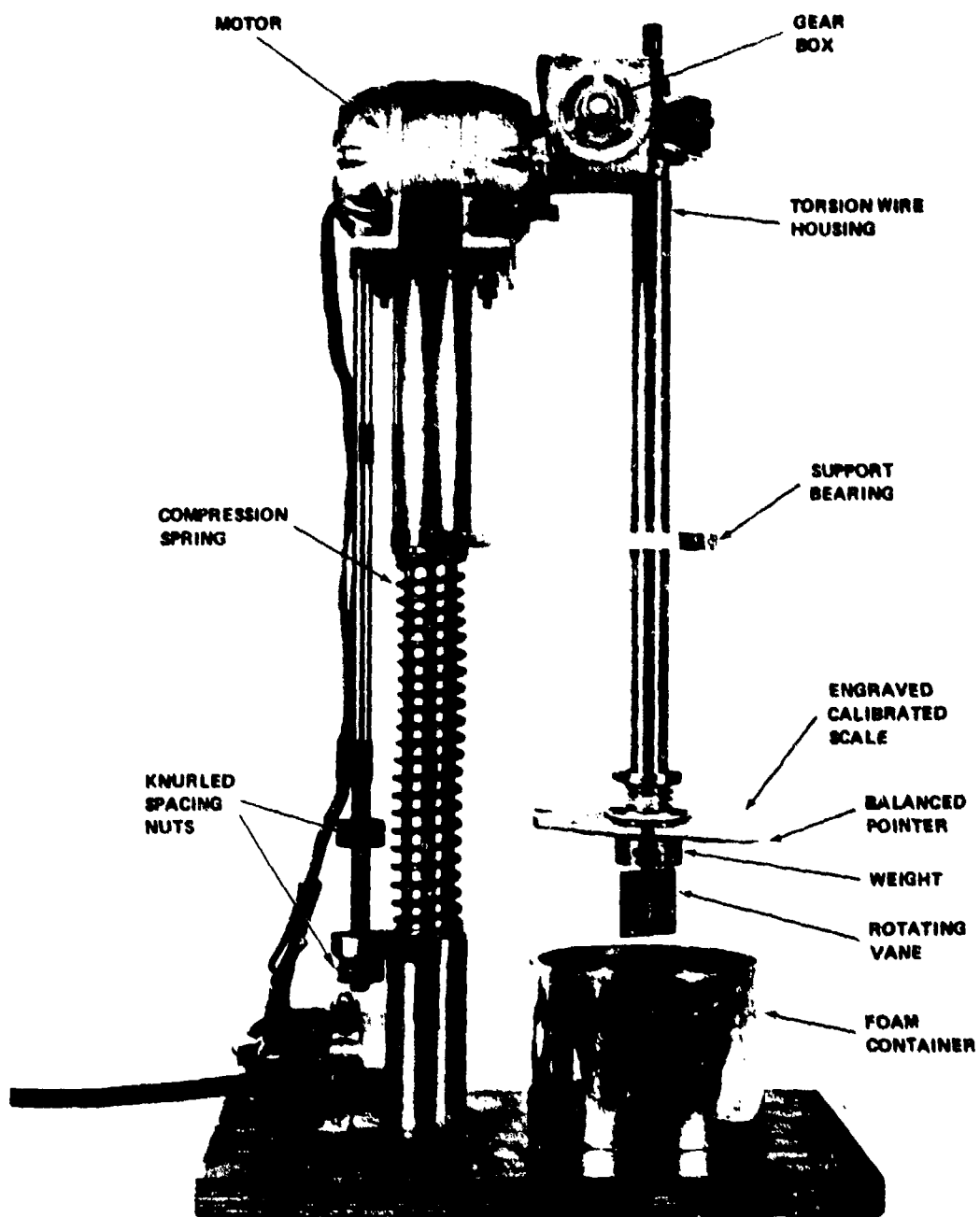
was selected from each class and type for detailed analysis of the change in foam viscosity as a function of time after formation. These data were considered of value in assessing foam fluidity, which is one of the principal properties defining fire control time. The increase in foam viscosity with time is indicated by the profiles presented in figure 7.

SMALL-SCALE FIRE EXTINGUISHING EXPERIMENTS.

COMPARATIVE EVALUATION OF FIREFIGHTING FOAMS ON 100-SQUARE-FOOT JET A FUEL FIRES. The foam equivalency ranking procedure presented in appendix A requires a determination of the relative fire extinguishing effectiveness of agents under a variety of environmental conditions encountered in actual aircraft accident situations. Therefore, a series of small-scale fire tests was developed based upon the fire requirements of Federal Specification O-F-555-C using the standard 6-gal/min foam nozzle. Experiments were conducted with the three classes of foam agents in accordance with the modified procedure presented in appendix H. The results of these experiments are summarized in tables 10 through 12.

Table 10 presents a summary of the data obtained using the 3- and 6-percent AFFF agents. These data show the average fire control and extinguishing times for both concentrations to be of the same order of magnitude, with the 3-percent showing a slight advantage over the 6-percent agents.

The data presented in table 11 indicate that all of the FPF agents passed the foam sealability and burnback requirements. However, the fire control and extinguishing times varied widely among the different FPF agents. In general



79-2-6
78-24-C-1

FIGURE 6. FOAM VISCOMETER

QUALITY OF AQUEOUS-FILM-FORMING FOAMS *

6-Percent Types

Foam Agent	Foam Expansion Ratio	25% Drainage Time - Min:Sec	Foam Viscosity (dynes/cm ²) Time After Formation			
			1 Min.	2 Min.	3 Min.	4 Min.
FC-200	9.2:1	3:15	--	--	--	--
FC-206	9.5:1	2:16	47.36	59.20	74.59	76.96
AER-O-WATER 6	8.3:1	2:45	--	--	--	--
LORCON AFFY	8.8:1	2:17	--	--	--	--
ANSUL	9.7:1	3:15	--	--	--	--

3-Percent Types

FC-203	10.3:1	2:51	33.15	53.28	56.83	61.57
AER-O-WATER 3	9.4:1	2:10	--	--	--	--
AER-O-WATER PLUS 3	11.7:1	2:45	--	--	--	--

* Federal Specification O-P-555C Standard Foam Nozzle

TABLE 8. QUALITY OF FLUOROPROTEIN FOAMS *

Foam Agent	Foam Expansion Ratio	25% Drainage Time - Min:Sec	6-Percent Types			
			1 Min.	2 Min.	3 Min.	4 Min.
AER-O-FOAM XL-6	8.8:1	3:44	224.96	260.48	296.00	331.52
LORCON K	9.6:1	3:50	--	--	--	--
LORCON FP	8.9:1	8:37	--	--	--	--

3-Percent Types						
AER-O-FOAM XL-3	6.1:1	1:08	106.56	201.28	272.32	337.44
ANGUS FP-70	6.4:1	3:44	--	--	--	--
LORCON FP-3	6.4:1	4:11	--	--	--	--
MEAKL	6.1:1	2:56	--	--	--	--

Various Concentration Types						
ANGUS FP-570 5%	7.1:1	5:08	--	--	--	--
TYRENE PLUS F 4.5%	6.3:1	3:19	--	--	--	--
PROTECTOFOAM 4%	5.8:1	0:48	--	--	--	--

* Federal Specification O-P-555C Standard Foam Nozzle

TABLE 9. QUALITY OF PROTEIN FOAMS *

Foam Agent	Solution Concentration Percent	Foam Expansion Ratio	25% Drainage Time - Min:Sec	Foam Viscosity (dynes/cm ²)			
				1 Min.	2 Min.	3 Min.	4 Min.
TYPE O-F-555C	6	8.4:1	3:17	248.64	307.84	307.04	390.72
AER-O-FOAM 3	3	6.0:1	1:15	148.00	224.96	278.24	319.68
MEARL	3	6.1:1	3:45	--	--	--	--

* Federal Specification O-Y-555C Standard Foam Nozzle

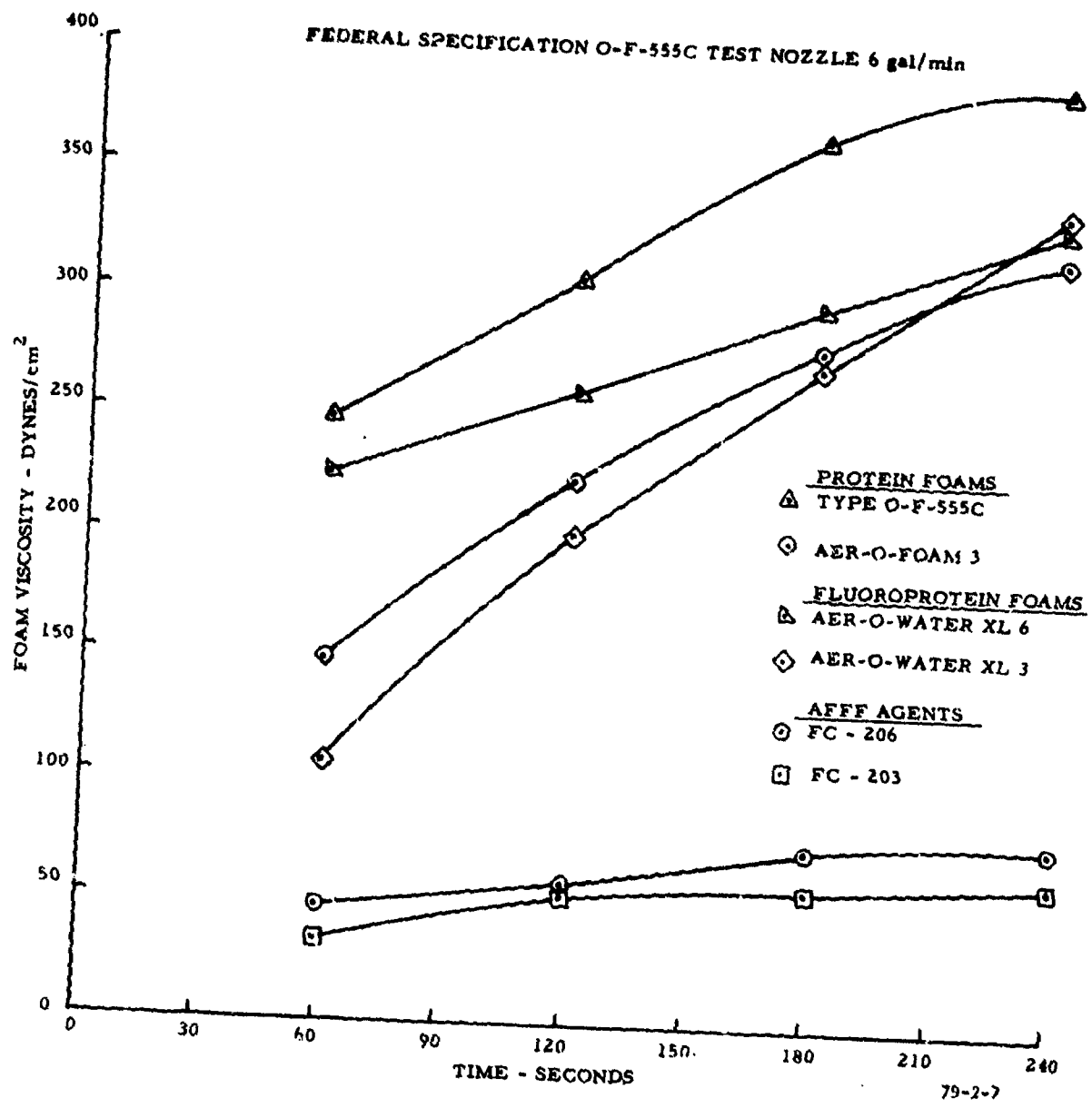


FIGURE 7. VARIATION OF FOAM VISCOSITY WITH TIME AFTER FORMATION

TABLE 10. FIREFIGHTING EFFECTIVENESS OF AFFF AGENTS ON 100-SQUARE-FOOT FIRES

Test Agent	FC 200		AER-O-WATER 6		LORCON AFFF		AER-O-WATER 3		AER-O-WATER PLUS 3	
	AFFF	AFFF	AFFF	AFFF	AFFF	AFFF	AFFF	AFFF	AFFF	AFFF
Class of Agent	6	6	6	6	6	6	6	3	3	3
Concentration-%	78	84	77	73	64	75	92	78	78	78
Ambient Air Temperature-°F	6	4-6	10	5	3-4	4	6-8	4	4	4
Wind Velocity mph	0:45	0:32	0:45	0:45	0:54	0:40	0:45	0:38	0:38	0:38
Fire Control Time-Min:Sec	1:30	1:15	1:40	1:45	1:50	1:00	1:17	1:22	1:22	1:22
Fire Exting. Time-Min:Sec	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Sealability Test	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Burnback Test	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
	Self-Exting.	Self-Exting.	Self-Exting.	Self-Exting.	Self-Exting.	Self-Exting.	Self-Exting.	Self-Exting.	Self-Exting.	Self-Exting.

TABLE 11. FIREFIGHTING EFFECTIVENESS OF FPF AGENTS ON 100-SQUARE-FOOT FIRES

Foam Agent	LORCON FP		AER-O-FOAM XL-6		LORCON K		ARCUS FP-570		FIRENE FLAB F		PROTECTO FOAM		AER-O-FOAM XL-3		LORCON FP J		ARCUS FP-70		MELARL	
	FPF	FPF	FPF	FPF	FPF	FPF	FPF	FPF	FPF	FPF	FPF	FPF	FPF	FPF	FPF	FPF	FPF	FPF	FPF	FPF
Class of Agent	FPF	FPF	FPF	FPF	FPF	FPF	FPF	FPF	FPF	FPF	FPF	FPF	FPF	FPF	FPF	FPF	FPF	FPF	FPF	FPF
Concentration-%	6	6	6	6	6	6	5	4.5	4	4	4	3	3	3	3	3	3	3	3	3
Ambient Air Temperature-°F	85	78	77	77	86	86	82	86	77	77	77	75	75	85	85	86	86	86	86	86
Wind Velocity mph	4-6	1	2-4	2-4	0-2	0-2	4-6	0-2	2-4	2-4	2-4	2	2	2-4	2-4	0-2	0-2	0-2	0-2	0-2
Fire Control Time-Min:Sec	1:00	1:15	1:15	1:20	0:55	0:55	1:20	1:37	1:50	1:50	1:50	1:37	1:37	3:20	3:20	0:57	0:57	0:57	0:57	0:57
Fire Exting. Time-Min:Sec	1:30	2:53	2:40	1:59	1:43	1:43	1:59	2:51	3:10	3:10	3:10	2:51	2:51	3:52	3:52	1:30	1:30	1:30	1:30	1:30
Scalability Test	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Burnback Test	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass

the average fire control and extinguishing times for the 6-percent agents were lower than for the 3-percent foams, while those for the 4-, 4.5-, and 5-percent agents were found to lie between these extremes.

The results of experiments conducted with one 6-percent and two 3-percent PF agents are summarized in table 12. These data indicate that all PF agents passed the sealability and burnback requirements and that neither class of agents demonstrated a significant advantage in the fire control and extinguishing times over the other.

This experimental procedure demonstrated the adequacy of AFFF, FPF, and PF agents to meet the minimum requirements for compliance with the federal specification at a foam solution application rate of 0.06 gal/min/ft². However, the 3- and 6-percent AFFF agents exhibited the fastest fire control and extinguishing times of all agents tested.

EFFECT OF SOLUTION TEMPERATURE ON FOAM QUALITY AND FIRE EXTINGUISHING EFFECTIVENESS OF FOAM AGENTS.

The effect of the ambient air temperature upon foam production under simulated crash fire conditions has not been extensively investigated because of the logistics problems inherent in conducting full-scale fire tests under extremely low-temperature conditions. However, it was evident in one series of experiments (reference 13) conducted at temperatures from 18° to 20° Fahrenheit (F), that the ambient air temperature was of minor importance in determining the fire control time, probably, in part, because of the temperature-moderating influence produced by the intense thermal radiation on the environment during

foam application. In general, the temperature of the water and foam liquid was determined to be more influential than the ambient air temperature in establishing the foam quality produced by any particular foam-dispensing system.

The results of small-scale (100-square-foot) fire tests and foam quality experiments conducted at solution temperatures of 35° F and 125° F with AFFF and those agents based upon protein hydrolyzates are summarized in table 13. The general trend among all foams was for the expansion ratio to increase (figure 8) and the 25-percent solution drainage time to decrease (figure 9) as the solution temperature was increased from 35° F to 125° F. The effect of these diverse trends in foam quality upon fire control time is indicated in figure 10 for the different classes of agents. From these profiles it is apparent that the firefighting effectiveness of the AFFF's tends to increase as the solution temperature is increased, while the proteinaceous agents required a longer time for fire control at the higher solution temperatures. One interpretation of the improved firefighting effectiveness of the AFFF agents concerns the more rapid release of the aqueous perfluorinated surfactant film (figure 5) from the foam body at elevated solution temperatures, which is the predominant factor defining rapid fire control by these agents.

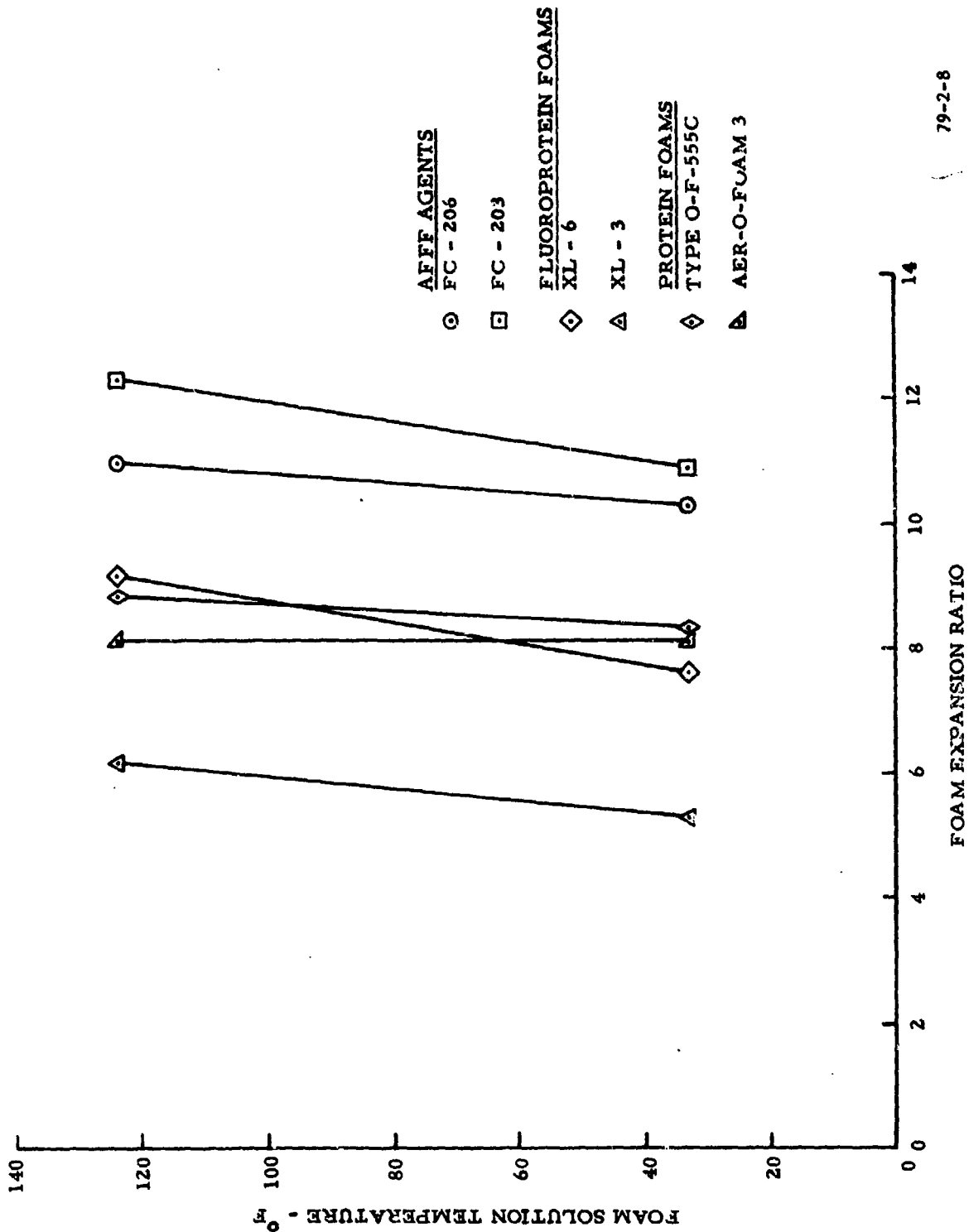
However, since no aqueous film is produced by the protein-base agents, the predominant factor defining firefighting effectiveness is foam quality, which is indicated in figure 9 to rapidly deteriorate through the loss of liquid as it drains from the foam body at elevated solution temperatures. The extended fire control time is further

TABLE 12. FIREFIGHTING EFFECTIVENESS OF PF AGENTS ON 100-SQUARE-FOOT FIRES

<u>Foam Agent</u>	<u>TYPE</u> <u>O-F-555C</u>	<u>AER-O-FOAM</u> <u>3</u>	<u>MEARL</u>
Class of Agent	PF	PF	PF
Concentration-%	6	3	3
Ambient Air Temperature-°F	80	78	74
Wind Velocity mph	0-3	2	2-9
Fire Control Time-Min:Sec	0:55	1:00	0:46
Fire Exting. Time-Min:Sec	2:27	3:00	1:42
Sealability Test	Pass	Pass	Pass
Burnback Test	Pass	Pass	Pass

TABLE 13. EFFECT OF SOLUTION TEMPERATURE ON THE FIREFIGHTING EFFECTIVENESS OF AFFF, FPF, AND PF AGENTS ON 100-SQUARE-FOOT FIRES USING THE 6-GAL/MIN NOZZLE

Foam Agent	EFFECTS OF TEMPERATURE											
	35° F						125° F					
	FC-206	FC-203	KL-6	KL-3	O-F-555C	TYPE	FC-206	FC-203	KL-6	KL-3	O-F-555C	TYPE
Foam Type	AFFF	AFFF	FPF	FPF	PF	PF	AFFF	AFFF	FPF	FPF	PF	PF
Concentration-%	6	3	6	3	6	3	6	3	6	3	6	3
Foam Expansion Ratio	10.3:1	10.9:1	7.7:1	5.4:1	8.4:1	8.2:1	11.0:1	12.3:1	9.2:1	6.3:1	8.9:1	8.2:1
25% Solution Drainage Time Min:Sec	5:14	4:40	5:30	2:25	6:23	8:50	2:37	3:45	2:47	2:15	3:21	2:04
Wind Velocity mph	2-4	2-4	4-6	4-6	2-4	0-2	2-3	2-3	1-3	1-3	2-3	5-7
Ambient Air Temperature-°F	63	62	60	60	60	60	78	80	78	75	79	71
Fire Control Time-Min:Sec	0:37	0:38	0:55	1:35	0:58	1:06	0:25	0:27	1:30	1:40	1:18	1:38
Fire Extng. Time-Min:Sec	0:53	1:00	1:20	3:40	2:22	2:40	1:05	1:05	2:25	3:15	2:55	3:50
Foam Application Time-Min:Sec	5:00	5:00	5:00	5:00	5:00	5:00	5:00	5:00	5:00	5:00	5:00	5:00
Foam Depth Inch	3.75	3.25	3.0	2.0	3.0	3.0	6.5	7.0	4.5	3.25	3.75	3.5
Foam Burnback Test	Pass Self-Extng.	Pass Self-Extng.	Pass	Pass	Pass	Pass	Pass Self-Extng.	Pass Self-Extng.	Pass	Pass	Pass	Pass



79-2-8

FIGURE 8. EFFECT OF FOAM SOLUTION TEMPERATURE ON THE FOAM EXPANSION RATIO

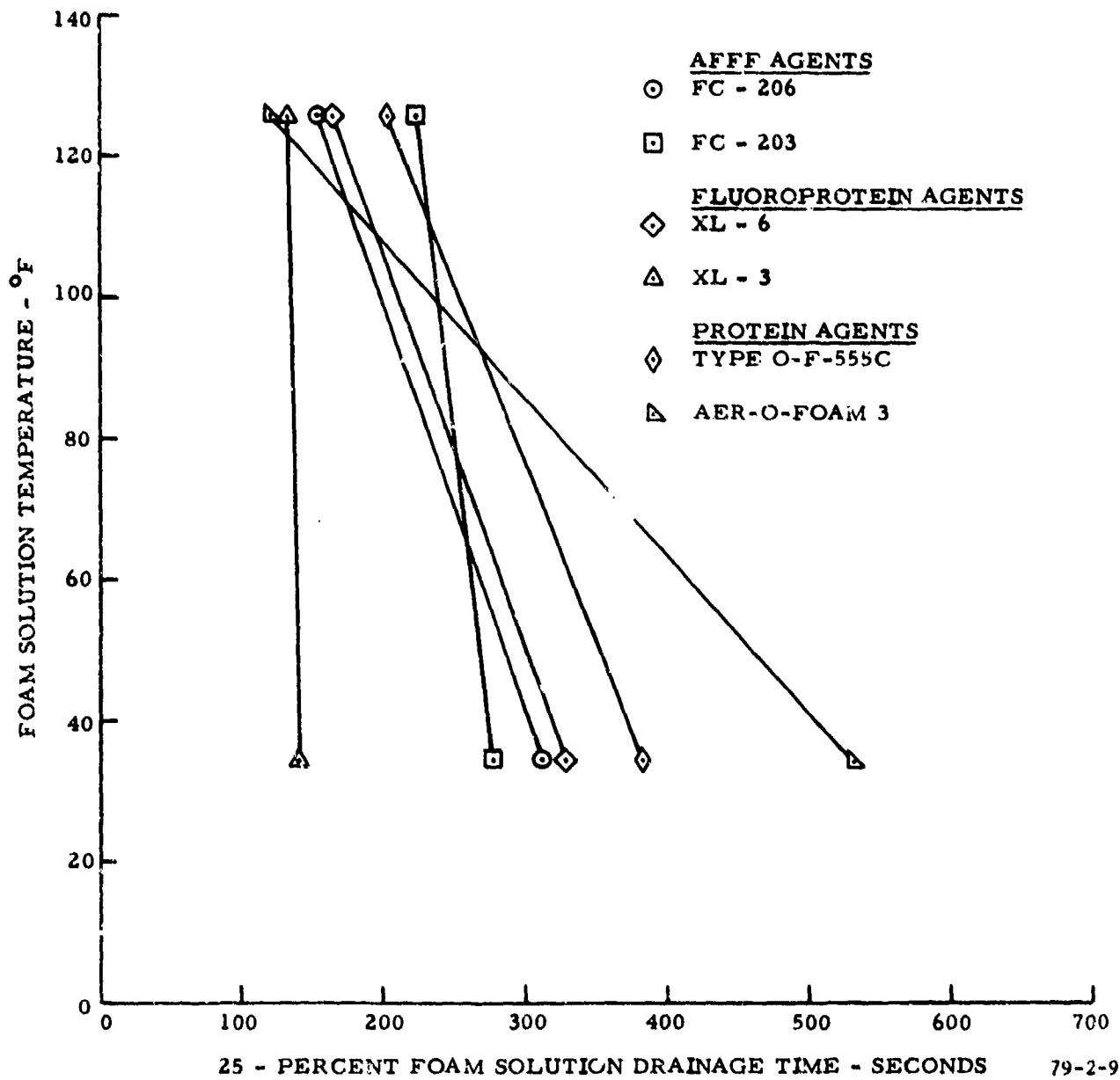
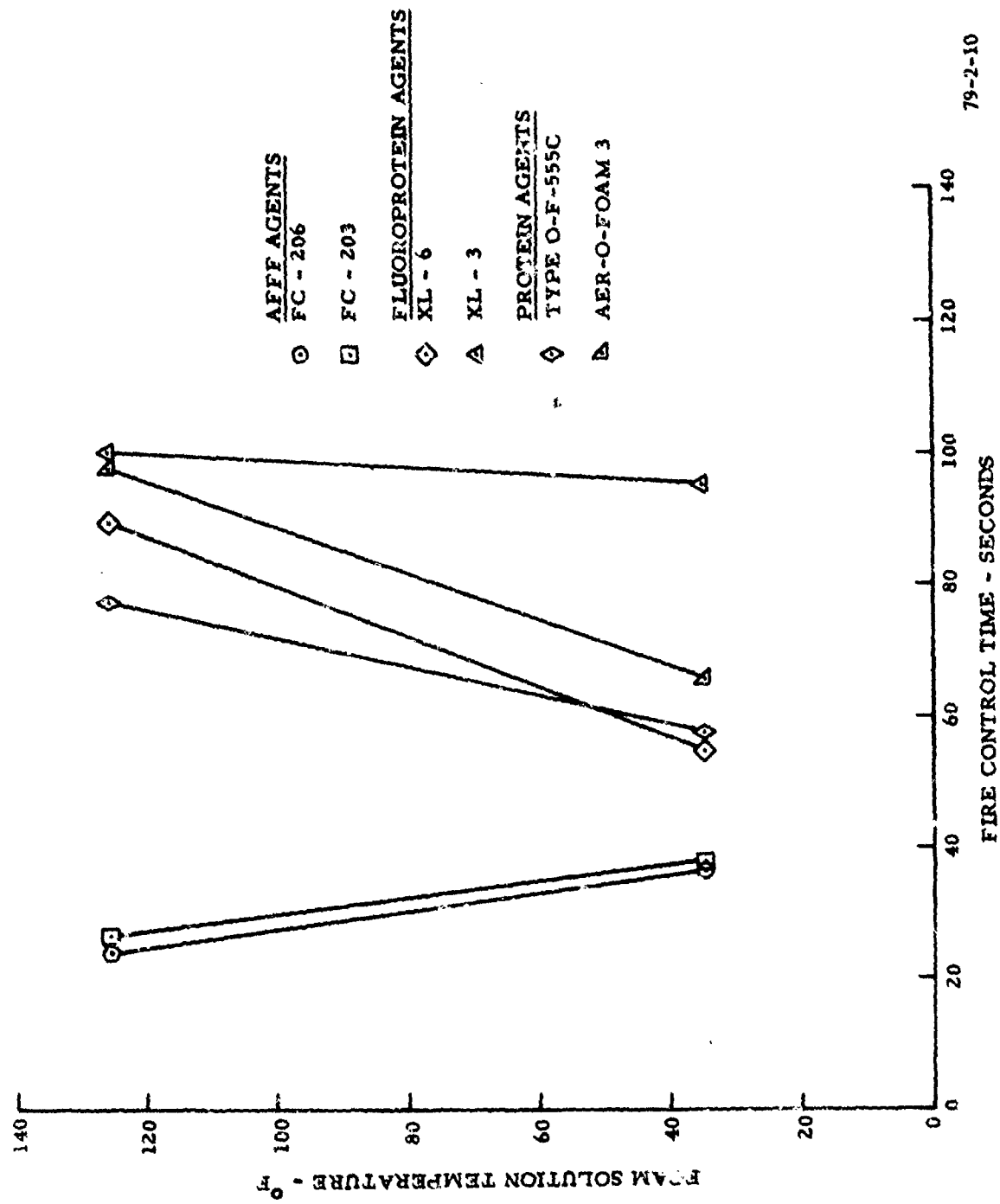


FIGURE 9. EFFECT OF FOAM SOLUTION TEMPERATURE ON THE 25-PERCENT SOLUTION DRAINAGE TIME



79-2-10

FIGURE 10. EFFECT OF FOAM SOLUTION TEMPERATURE ON FIRE CONTROL TIME

augmented by an increase in the foam expansion ratio, as indicated in figure 8, which, in the case of low-expansion protein-type foam agents, is accompanied by a rise in foam viscosity (reference 9). As the foam viscosity increases, the fluidity decreases, and the foam may become more difficult and time-consuming to distribute uniformly over a burning fuel surface. Therefore, excessively high or low water temperatures are to be avoided to obtain optimum firefighting foam quality, particularly with regard to the protein-base agents.

EFFECT OF WATER HARDNESS ON THE FIRE-EXTINGUISHING EFFECTIVENESS OF FOAM AGENTS. With respect to hardness, waters may be roughly classified as soft, less than 50 parts per million (ppm); moderately hard, 50 to 100 ppm; and hard, above 100 ppm.

Water hardness derives principally from the presence of the calcium and magnesium cations and to the chloride, sulfate, carbonate, and bicarbonate anions which are dissolved in various amounts as they contact different geologic formations and are subsequently exposed to local environmental conditions. A determination of the water hardness at a number of airport locations throughout the United States indicated that the hardness varied from approximately 3 ppm to 410 ppm (reference 13). As a consequence of this finding, it was decided to conduct the evaluation of agents at 18 ppm, which is the approximate hardness of water at NAPEC, and at 470 ppm, which is roughly equivalent to one-half the hardness of coastal sea water.

Since it is known that various quantities and combinations of contaminating ionic moieties could have a degrading effect upon firefighting effectiveness, it was considered expedient to identify any adverse reactions caused by water hardness by conducting a series of laboratory foam quality experiments and small-scale outdoor fire tests.

The results of the foam quality experiments conducted with each class of agents at water hardness levels of 18 ppm and 470 ppm are summarized in table 14. Only one agent was selected from each class in an effort to identify any general trends concerning the effects of water hardness on foam quality.

The profiles presented in figure 11 show a decrease in the foam expansion ratio for increasing water hardness with the exception of AER-O-Water 3 which increased and XL-16 which remained unchanged, while figure 12 shows a general decrease in the 25-percent solution drainage time for all classes of agents with an increase in water hardness. The slope of the curves constructed for the AFFF agents indicate that the foam solution drainage rates increase with increasing water hardness, thereby, releasing the fluorocarbon film more rapidly from the foam body. Therefore, it is apparent that both elevated solution temperatures and an increase in the water hardness accelerate the release of the aqueous fluorocarbon film from AFFF.

The effect of water hardness on firefighting effectiveness was determined by selecting one representative 3- and one 6-percent agent from each class and conducting tests

TABLE 14. EFFECT OF WATER HARDNESS ON THE FIRE-EXTINGUISHING EFFECTIVENESS OF AFFF, FPF, AND PF AGENTS

Foam Agent	WATER HARDNESS											
	18 PPM						470 PPM					
	FC-206	FC-203	XL-6	XL-3	TYPE O-P-55SC	AER-O-FOAM 3	FC-206	FC-203	XL-6	XL-3	TYPE O-P-55SC	AER-O-FOAM 3
Foam Type	AFFF	AFFF	FPF	FPF	PF	PF	AFFF	AFFF	FPF	FPF	PF	PF
Concentration-%	6	3	6	3	6	3	6	3	6	3	6	3
Foam Expansion Ratio	9.5:1	10.3:1	8.8:1	6.2:1	8.6:1	7.5:1	5.9:1	8.0:1	6.1:1	8.1:1	8.0:1	8.0:1
25% Solution Drainage Time Min:Sec	3:16	2:51	3:44	1:14	3:40	1:45	1:49	2:18	3:27	0:53	2:45	1:40
Wind Velocity mph	4-6	2-4	0-2	8-10	3-5	2-4	0-1	2-3	8-10	2-3	2-4	2-4
Ambient Air Temperature-°F	84	75	78	70	72	78	80	75	75	86	85	85
Fire Control Time-Min:Sec	0:32	0:40	1:15	1:31	1:48	1:06	0:22	0:42	0:56	Failed	1:35	1:20
Fire Exting. Time-Min:Sec	1:08	1:05	2:41	2:55	2:48	2:50	0:59	1:21	2:05	Failed	3:21	2:35
Foam Application Time-Min:Sec	5:00	5:00	5:00	5:00	5:00	5:00	5:00	5:00	5:00	5:00	5:00	5:00
Foam Depth Inch	4.0	4.0	3.5	1.5	4.0	3.5	3.5	4.0	3.5	—	4.0	4.5
Foam Overback Test	Pass Self-Exting.	Pass Self-Exting.	Pass	Pass	Pass	Pass	Pass Self-Exting.	Pass Self-Exting.	Pass	—	Pass	Pass

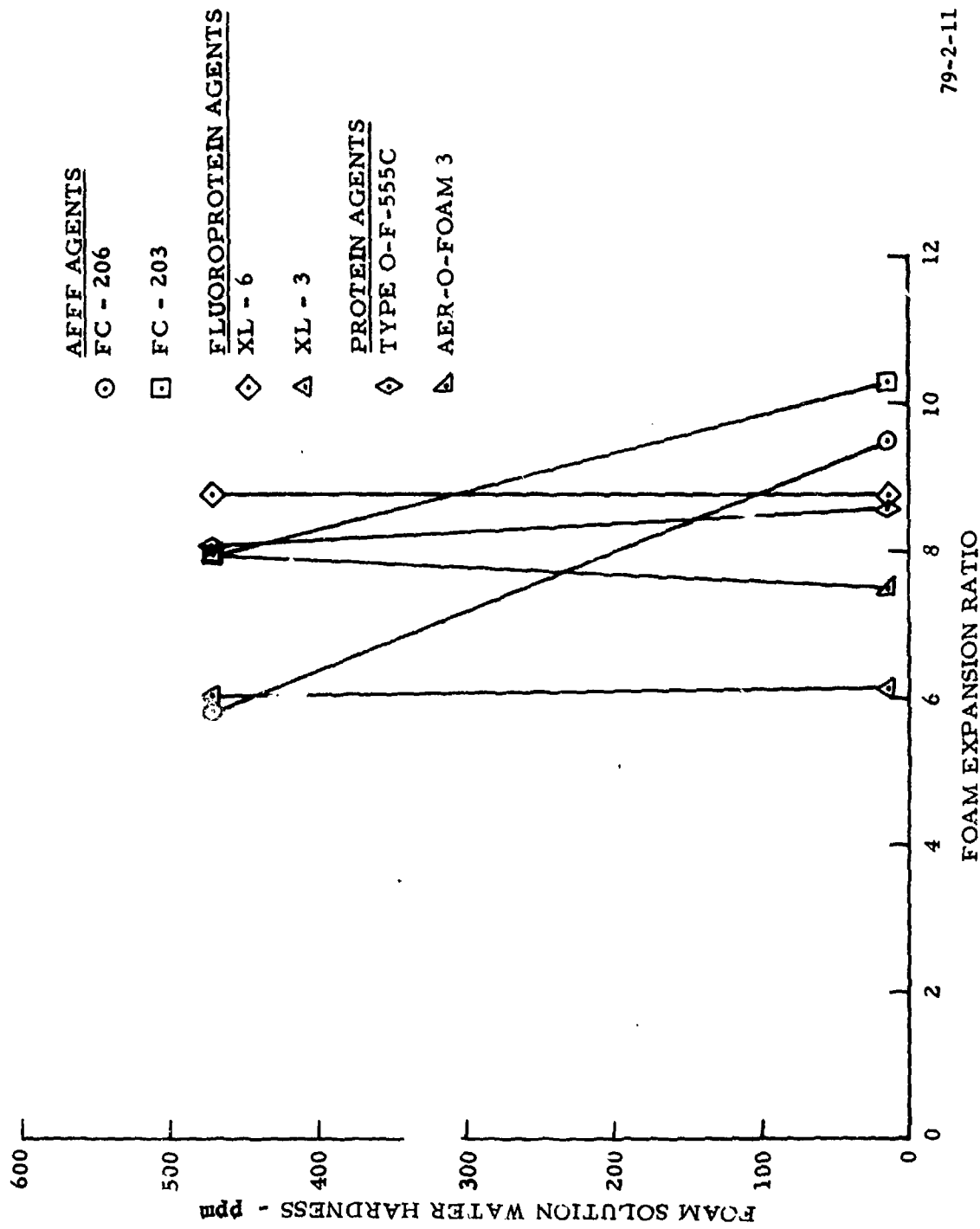


FIGURE 11. EFFECT OF SOLUTION WATER HARDNESS ON THE FOAM EXPANSION RATIO

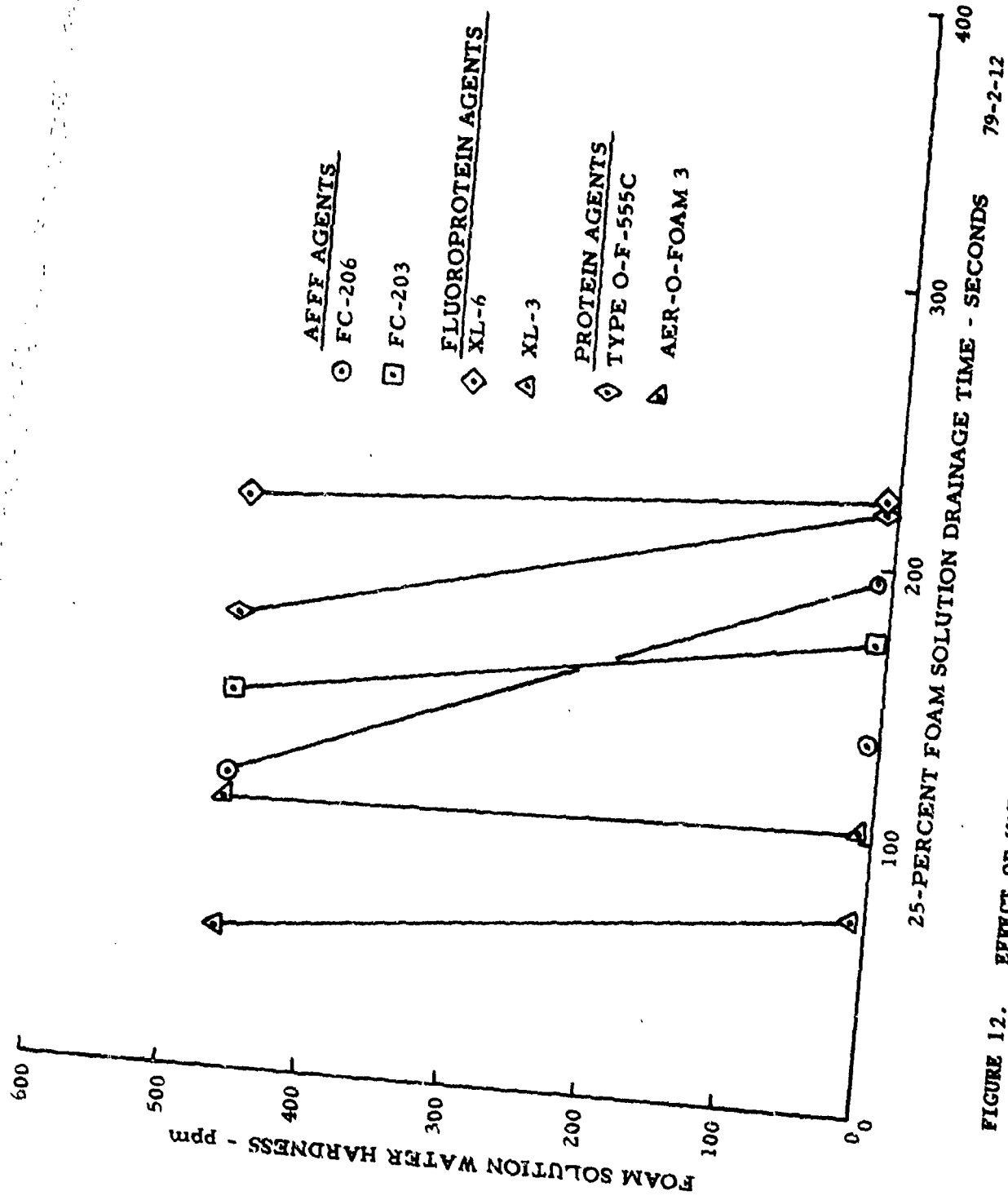


FIGURE 12. EFFECT OF WATER HARDNESS ON 25-PERCENT SOLUTION DRAINAGE TIME
79-2-12

in the 100-square-foot test tank (reference 1). The results of these experiments are summarized by the profiles presented in figure 13. The fire performance of these agents tends to suggest that their individual effectiveness is strongly influenced by water hardness in the fire environment. However, it is noteworthy that all of the 6-percent types demonstrated shorter and all of the 3-percent types longer fire control times with hard water regardless of their class.

THERMAL STABILITY OF FOAMS ON JET A FUEL FIRES. The relative thermal stability of mechanical foam blankets was determined for AFFF, FPF, and PF agents by modifying the fire test procedure required in reference 1 to include a source of thermal radiation and flame impingement on the established foam blankets. Foam blanket stability was determined as a function of the time required for fuel reignition to occur as a consequence of the thermal disintegration of the foam blanket. A description of the equipment and test method is presented in appendix I.

In these experiments, 6-percent PF conforming to the federal specification (reference 1) was chosen as a frame of reference for comparing the foam blanket stability with that obtained for other agents.

The results of the fire tests are presented in tables 15 through 17. From the data presented in table 15 for the 3- and 6-percent AFFF agents, it is evident that fire control was achieved with all foams within 37 to 47 seconds. At the conclusion of the 10 minute foam application period, the residual blankets varied from 5.75 to 10 inches in depth. In general, the correlation between foam

depth and fuel reignition times are good. However, foam quality in terms of heat resistance also appears to be significant, as evidenced by FC-206 which produced a 7-inch-deep foam blanket that resisted fuel reignition for 9.5 minutes, which was the longest for any of the AFFF agents. The generally longer fire extinguishing times required by the 3-percent over the 6-percent AFFF agents is attributable in part to the higher viscosity of the 3-percent foams.

The fire test results obtained with the FPF agents are summarized in table 16. These data display a rather broad range of fire control and extinguishing times among the various commercially available products. The quality of foam produced by the different agents also varied widely, especially in terms of the 25-percent drainage time which ranged from 55 seconds to 6 minutes. It is noteworthy, however, that the thermal stability of the resulting foam blanket, in terms of the fuel reignition time, was 10 minutes or more for all foams with the exception of Aer-O-Foam XL-3 which required 5.5 minutes. These results tend to indicate that the overall effectiveness of the FPF agents may be more closely associated with the oleophobic properties of the expanded foam conveyed by the fluorinated surfactant than to the purely mechanical properties of the foam. However, none of the FPF agents displayed any significant tendency to produce a spreading aqueous film upon the surface of Jet A fuel.

The results of the fuel reignition experiments performed with one 6-percent and two 3-percent PF agents are presented in table 17. These data indicate that the PF agents provided rapid fire control and extinguishment of the Jet A fires which

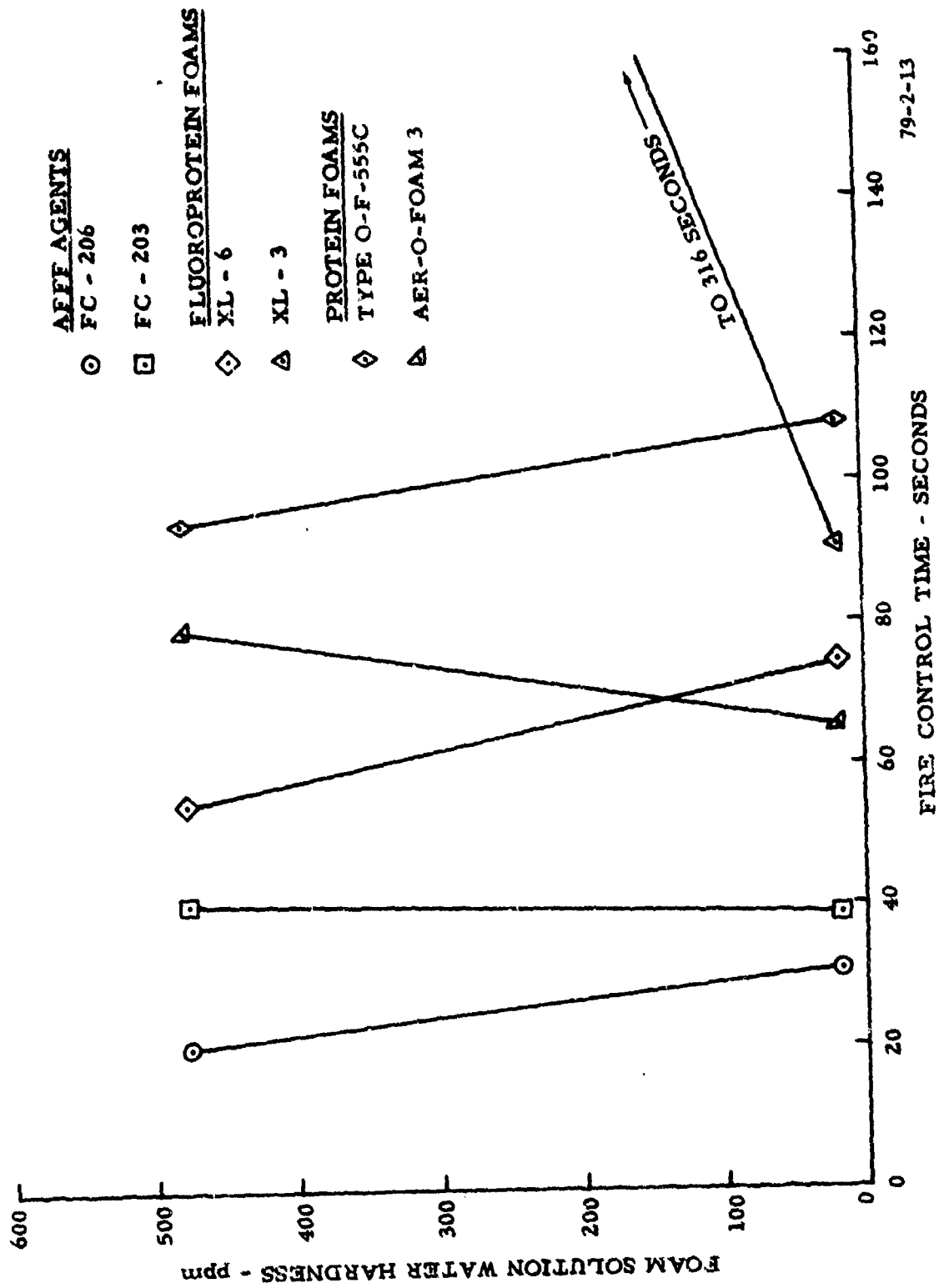


FIGURE 13. EFFECT OF SOLUTION WATER HARDNESS ON FIRE CONTROL TIME

TABLE 15. THERMAL STABILITY OF FOAM BLANKETS PRODUCED BY AFFF AGENTS

<u>Foam Agent</u>	<u>FC 206</u>	<u>AER-O-WATER 6</u>	<u>LORCOM AFFF</u>	<u>ANSUL</u>	<u>FC 203</u>	<u>AER-O-WATER 3</u>	<u>AER-O-WATER PLUS 3</u>
Class of Agent	AFFF	AFFF	AFFF	AFFF	AFFF	AFFF	AFFF
Concentration-%	6	6	6	6	3	3	3
Ambient Air Temperature-°F	54	73	59	65	61	70	58
Wind Velocity mph	2-6	8	0-2	3-7	4-6	5-7	0-3
Fire Control Time-Min:Sec	0:40	0:40	0:40	0:47	0:37	0:45	0:42
Fire Exting. Time-Min:Sec	1:20	1:50	1:20	1:20	2:15	2:15	1:20
Foam Depth Inch	7	5.75	7	10	7	7.75	12
Reignition Time-Min:Sec	9:30	5:15	7:53	9:15	8:00	7:56	5:15

TABLE 16. THERMAL STABILITY OF FOAM BLANKETS PRODUCED BY PFF AGENTS

FOAM AGENT	AER-O-FOAM XL-6		LORCON K		LORCON FF		AMCWS FP-570		FIREZE PLUS F		PROTECTO FOAM		AER-O-FOAM XL-3		HEARL		AMCWS FP-70		LORCON FF 3	
	PFF	FFF	PFF	FFF	PFF	FFF	PFF	FFF	PFF	FFF	PFF	FFF	PFF	FFF	PFF	FFF	PFF	FFF	PFF	FFF
Concentration - %	6	6	6	6	6	6	5	5	4.5	4	4	4	3	3	3	3	3	3	3	3
Ambient Air Temperature - °F	58	66	66	66	58	58	60	60	69	69	54	54	65	65	60	60	70	70	62	62
Wind Velocity mph	10	8-10	8-10	8-10	6-6	6-6	5-8	5-8	2-5	2-5	6-8	6-8	8	8	0-3	0-3	0-5	0-5	0-3	0-3
Fire Control Time - Min:Sec	1:45	1:50	1:50	1:50	0:46	0:46	0:62	0:62	0:58	0:58	1:30	1:30	2:57	2:57	1:12	1:12	0:50	0:50	1:07	1:07
Fire Exting. Time - Min:Sec	8:20	7:10	7:10	7:10	1:37	1:37	1:42	1:42	1:42	1:42	4:40	4:40	8:30	8:30	1:57	1:57	2:10	2:10	3:00	3:00
Foam Depth Inch	6.5	7.75	7.75	7.75	8.0	8.0	7.5	7.5	9.0	9.0	4.5	4.5	2.0	2.0	9.25	9.25	6.75	6.75	9.0	9.0
Reignition Time - Min:Sec	10:43	10:05	10:05	10:05	16:10	16:10	12:56	12:56	10:30	10:30	10:00	10:00	5:30	5:30	15:33	15:33	10:00	10:00	13:15	13:15

TABLE 17. THERMAL STABILITY OF FOAM BLANKETS PRODUCED BY PF AGENTS

<u>FOAM AGENT</u>	<u>TYPE O-F-555C</u>	<u>AER-O-FOAM 3</u>	<u>NEARL</u>
Class of Agent	PF	PF	PF
Concentration - %	6	3	3
Ambient Air Temperature - °F	55	54	69
Wind Velocity mph	10	10	6-8
Fire Control Time - Min:Sec	1:15	1:20	0:46
Fire Exting. Time - Min:Sec	3:00	2:30	3:40
Foam Depth Inch	7.75	6.0	10.0
Reignition Time - Min:Sec	13:15	8:03	13:18

resulted in a heavy cohesive blanket over the fuel surface after foam discharge. The foam produced by the 6-percent agent was the most thermally resistant to radiant energy as evidenced by its lower deterioration rate. The rate at which the foam blanket produced by the two 3-percent agents deteriorated was essentially identical. However, the 3-percent Mearl foam provided protection equivalent to that of the 6-percent foam because of its greater depth.

A comparison of the fire control and extinguishing times obtained with AFFF and PF illustrates the very rapid fire control times that are characteristic of the AFFF agents. It was observed during these tests that fire control, and particularly the fire-extinguishment time, was a function of foam fluidity. The drum obstruction in the center of the tank required the foam to flow around the back of the obstacle, and the more viscous foams produced a V-shaped opening in this area which required a massive buildup of foam to close. This condition was most evident with PF.

Although there was wide variation between individual agents within each class, a comparison of the thermal resistance of the fire-fighting foams, based upon their disintegration rates, tends to indicate the following ranking order from most to least stable: FPF 6-percent > FPF 3-percent > PF 6-percent > PF 3-percent > AFFF 6-percent > AFFF 3-percent. It is noteworthy that this ranking order is not representative of the fire-fighting effectiveness of these agents but only of the stability of established blankets of these foams to prevent reignition after fire extinguishment.

The wide variation in the results of experiments conducted with FPF agents manufactured and distributed on a world-wide basis, strongly suggests the requirement for a specification to provide basic guidelines for manufacturers in formulating these agents to achieve their maximum effectiveness for use in the CFR services.

THE EFFECT OF WATER SPRAY ON ESTABLISHED BLANKETS OF AFFF, FPF, AND PF FOAM. A study of the relative effect of water-spray on established blankets of firefighting foams was considered necessary to provide information which would be useful in estimating the disruptive effect that could be caused by heavy rain or by water discharge from firefighting equipment.

A small-scale water-spray test procedure was developed based upon the 100-square-foot fire test tank and 6-gal/min foam nozzle required in the federal specification (reference 1).

The procedure required that the 100-square-foot test tank be filled to a depth of 12 inches with water upon which 100 gallons of Jet A fuel were floated. The fuel was then ignited and allowed to burn for 60 seconds, after which foam was discharged onto the fire for a period of 5 minutes, and the times required to obtain control and extinguishment were recorded. In these experiments, the fire control time was judged to be the time required for 90 percent of the fuel surface to be covered by foam, and the fire extinguishment time was recorded as the total elapsed time until all flames were extinguished within the tank. The foam blanket sealability was evaluated for a period of 1 minute by continually passing a lighted torch held 1/2 inch above the surface in accordance with the requirement of the federal specification. At the conclusion of the

1-minute torching period, the water-sprinkler system was activated and allowed to discharge for 30 seconds, after which the system was deactivated and the torch passed over the remaining foam blanket for 1 minute in an attempt to ignite any escaping fuel vapors. This entire process was repeated until permanent ignition of the fuel occurred. The number of successful water-spray cycles completed was considered a measure of the foam blanket stability.

The results of the water-spray tests using AFFF are presented in table 18 and for the FPF and PF agents in tables 19 and 20, respectively.

A bar chart relating the foam blanket stability of each agent tested is presented in figure 14, where the number of spray cycles obtained, before blanket failure occurred, is plotted on the ordinate. A comparison of these test results shows that the number of spray cycles completed by FPF, as a class of agents, significantly exceeded that of either AFFF or PF. These data also indicate that the use concentration (agent type) of the agents within a specific class is not a major contributing factor in determining the resistance of an established foam blanket to destruction by water spray, with the exception of PF. The water-spray resistance demonstrated by FPF appears to be the result of a synergistic reaction between the perfluorinated surfactants and protein hydrolyzates which produce a foam significantly superior to either of the components individually.

EFFECT OF TERRAIN ON THE CONTROL AND EXTINGUISHMENT OF JET A FUEL FIRES BY FOAM. Previous tests conducted at NAFEC comparing the fire control

and extinguishment times for different foam agents were performed on large water-base pool fires. In these experiments, a water substrate was used under the fuel to adjust the level of the liquid surface and prevent the intrusion of islands through the surface. Although this procedure led to the establishment of uniform fire test conditions, it was not necessarily representative of aircraft crash-fire conditions. Therefore, to establish a more valid basis for the estimation of foam blanket stability, a series of small-scale experiments was performed on three different types of terrain using AFFF, FPF, and PF. A description of the fire test procedure and the equipment employed in these experiments is contained in appendix J. The types of terrain employed to evaluate foam stability included sand, traprock, simulated tree-studded sod, and a standard water-base pool fire for comparison of the fire control and extinguishment times. In these tests, the primary objectives were to evaluate the stability of the foam in contact with the burning fuel-soaked surfaces and to estimate the rate of flow of foam across the various simulated terrains. A steel backboard, requiring foam stream impingement before draining into the fire pit, was used to expose the foams to the most severe environmental conditions possible. Foam was dispensed at a solution rate of 0.06 gal/min/ft² for all tests, which approximates the threshold value for PF. The effect of these different terrains upon the fire control and extinguishment times for Jet A fuel fires employing representative members of the three classes of firefighting foams are presented in tables 21 through 23.

From the data presented in table 24, it is apparent that all of the foam

TABLE 18. EFFECT OF WATER SPRAY ON AFFF BLANKETS

FOAM AGENT	FC	AER-O-	LORCON	AMSUL	FC	AER-O-	AER-O-
	205	WATER 6	AFFF	AFFF	203	WATER 3	WATER PLUS 3
Class of Agent	AFFF	AFFF	AFFF	AFFF	AFFF	AFFF	AFFF
Concentration - %	6	6	6	6	3	3	3
Ambient Air Temperature - °F	78	77	76	58*	75	79	59
Wind Velocity - mph	0-3	0-2	2-4	4-6	4-6	0	2-7
Avg. Fire Control Time (2 Tests) - Min:Sec	0:45	0:44	0:47	0:48	0:42	0:37	0:41
Avg. Fire Exting. Time (2 Tests) - Min:Sec	1:25	1:26	1:40	1:42	1:22	1:12	1:16
Avg. Foam Depth (2 Tests) - Inch	4	3.5	3.5	3.1	4	4.5	5.5
Avg. Water-Spray Cycles Completed (2 Tests)	5	6	4	6	7.5	9	6

TABLE 19. EFFECT OF WATER SPRAY ON FPF BLANKETS

FOAM AGENT	AER-O-FOAM XL-6		LOXCON K		LOXCON FP		AMCUS FP-570		FYRENE PLUS F		PROTECTO FOAM		AER-O-FOAM XL-3		LOXCON FP-3		AMCUS FP-70		HEADL
	FPF		FPF		FPF		FPF		FPF		FPF		FPF		FPF		FPF		
Class of Agent	6		6		6		5		4.5		4		3		3		3		FPF
Concentration - %	74		74		64		72		78		61		70		70		68		FPF
Ambient Air Temperature - °F	8-10		2-6		2-7		2-6		5-7		2-4		8-10		2-6		1-7		FPF
Wind Velocity - mph	1:05		0:51		1:03		0:42		0:58		1:25		1:25		1:06		0:51		FPF
Avg. Fire Control Time (2 Tests) - Min:Sec	2:42		2:20		1:24		1:22		2:15		2:40		2:57		2:25		1:49		FPF
Avg. Fire Exting. Time (2 Tests) - Min:Sec	3		3.5		4.3		3.0		2.4		1.5		1.5		3.1		3.3		FPF
Avg. Foam Depth (2 Tests) - Inch	21		32		49		50.5		12.5		7		13		28.5		28.5		FPF
Avg. Water-Spray Cycles Completed (2 Tests)																			FPF

TABLE 20. EFFECT OF WATER SPRAY ON PF BLANKETS

<u>FOAM AGENT</u>	<u>TYPE</u> <u>O-F-555C</u>	<u>AER-O-FOAM</u> <u>3</u>	<u>MEARL</u>
Class of Agent	PF	PF	PF
Concentration - %	6	3	3
Ambient Air Temperature - °F	71	78	30
Wind Velocity - mph	6-10	2-4	0-5
Avg. Fire Control Time (2 Tests) - Min:Sec	1:12	1:12	0:57
Avg. Fire Exting. Time (2 Tests) - Min:Sec	2:55	2:52	1:57
Avg. Foam Depth (2 Tests) - Inch	2.75	3.5	2.4
Avg. Water Spray Cycles Completed (2 Tests)	13	9	3

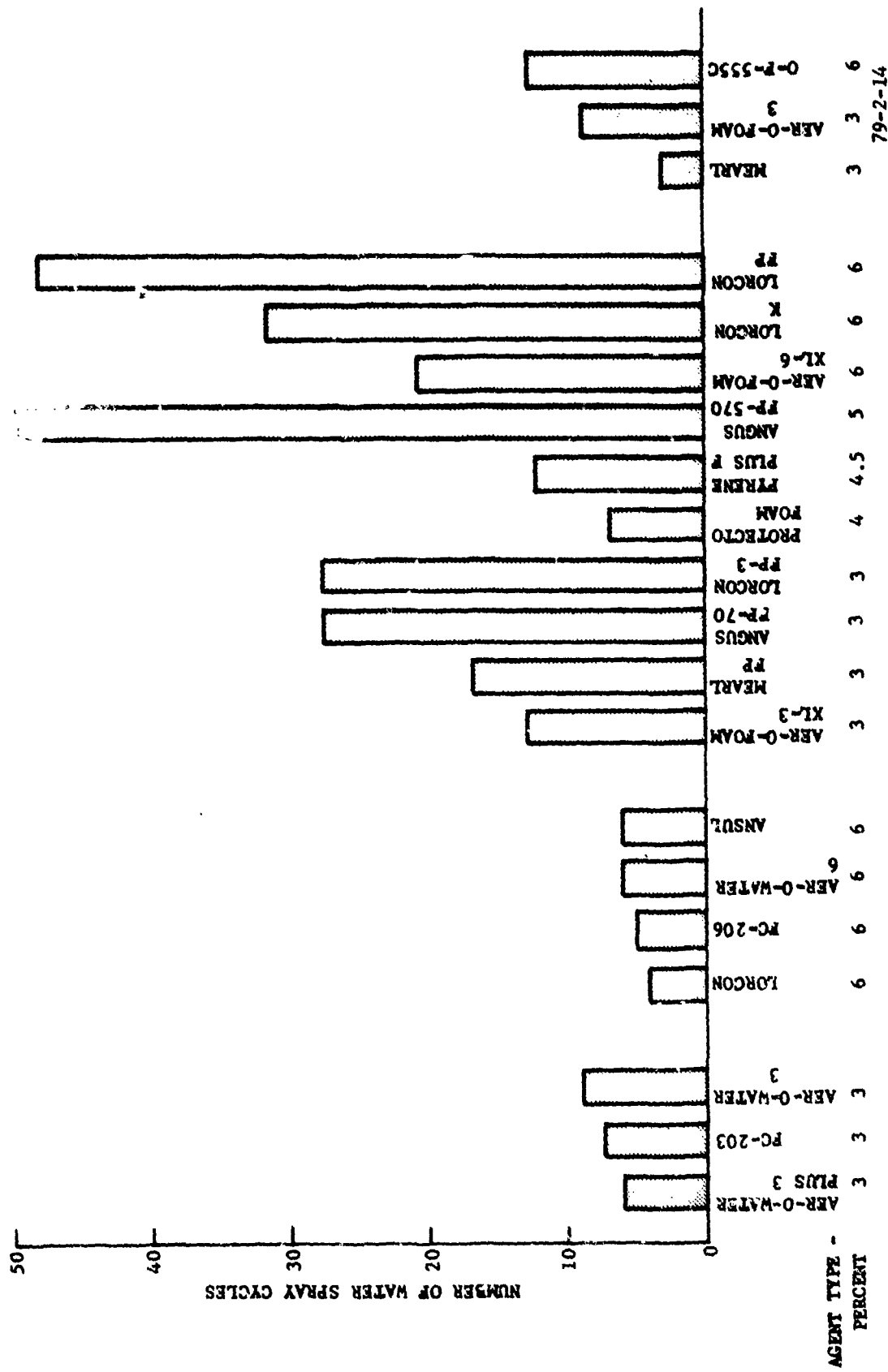


FIGURE 14. THE STABILITY OF FIREFIGHTING FOAMS IN TERMS OF WATER-SPRAY CYCLES

TABLE 21. EFFECT OF A SIMULATED TREE-STUDDED SOD ON THE CONTROL AND
EXTINGUISHMENT OF JET A FUEL FIRES

Agent	AFFF AGENTS		FLUOROPROTEIN AGENTS		PROTEIN AGENTS	
	FC-206	FC-203	XL-6	XL-3	TYPE O-F-555C	AER-O-FOAM 3
Concentration %	6	3	6	3	6	3
Fire Preburn Time (Min:Sec)	1:45	1:45	1:30	2:30	2:30	2:30
Wind Velocity (mph)	4-8	8-10	6-8	6-8	6-8	6-8
Ambient Air Temperature (°F)	65	65	69	69	65	65
Fire Control Time (Min:Sec)	9:45	Failed	14:15	Failed	Failed	Failed
Fire Exting. Time (Min:Sec)	14:38	Failed	Failed	Failed	Failed	Failed
Total Foam Application Time (Min:Sec)	14:38	15:00	15:00	15:00	15:00	15:00

TABLE 22. EFFECT OF SAND TERRAIN ON THE CONTROL AND
EXTINGUISHMENT OF JET A FUEL FIRES

Agent	AFFF AGENTS		FLUOROPROTEIN AGENTS		PROTEIN AGENTS	
	FC-206	FC-203	XL-6	XL-3	Type O-F-555C	AER-O-FOAM 3
Concentration %	6	3	6	3	6	3
Fire Preburn Time (Min:Sec)	1:00	1:00	1:00	1:00	1:00	1:00
Wind Velocity (mph)	2-3	3-6	8-10	8-10	8-10	8-10
Ambient Air Temperature (°F)	68	71	70	70	70	70
Fire Control Time (Min:Sec)	2:20	2:25	8:52	8:20	10:12	8:50
Fire Exting. Time (Min:Sec)	4:50	3:30	12:15	10:20	13:12	10:20
Total Foam Application Time (Min:Sec)	4:50	3:30	12:15	10:20	13:12	10:20

TABLE 23. EFFECT OF TRAPROCK TERRAIN ON THE CONTROL AND EXTINGUISHMENT OF JET A FUEL FIRES

Agent	AFFP AGENTS		FLUOROPROTEIN AGENTS		PROTEIN AGENTS	
	<u>FC-206</u>	<u>FC-203</u>	<u>XL-6</u>	<u>XL-3</u>	Type <u>O-F-555C</u>	<u>AER-O-FOAM</u>
Concentration %	6	3	6	3	6	3
Fire Preburn Time (Min:Sec)	1:00	1:00	1:00	1:00	1:00	1:00
Wind Velocity (mph)	4-6	2-3	2-4	2-3	2-3	2-3
Ambient Air Temperature (°F)	67	69	67	68	68	68
Fire Control Time (Min:Sec)	4:40	4:40	6:45	12:15	11:10	11:25
Fire Exting. Time (Min:Sec)	7:50	6:00	10:12	14:30	13:40	14:40
Total Foam Application Time (Min:Sec)	7:50	6:00	10:12	14:30	13:40	14:40

TABLE 24. FIRE CONTROL AND EXTINGUISHING TIMES OF WATER-BASE JET A FUEL FIRES

Agent	AFFF AGENTS		FLUOROPROTEIN AGENTS		PROTEIN AGENTS	
	FC-206	FC-203	XL-6	XL-3	Type O-F-555C	AER-O-FOAM
Concentration %	6	3	6	3	6	3
Fire Preburn Time (Min:Sec)	1:00	1:00	1:00	1:00	1:00	1:00
Wind Velocity (mph)	2-3	3-6	2-3	2-3	4-6	3-5
Ambient Air Temperature (°F)	72	74	70	68	67	71
Fire Control Time (Min:Sec)	0:58	0:59	1:15	1:27	1:15	1:20
Fire Exting. Time (Min:Sec)	1:27	1:45	2:38	2:40	2:45	2:40
Total Foam Application Time (Min:Sec)	1:27	1:45	2:38	2:40	2:45	2:40

agents met the nominal fire control and extinguishing times established in reference 1 for PF. However, none of the foam agents met the 4-minute control and 5-minute extinguishing times required in the federal specification when discharged on any of the other simulated terrains, with the exception of the AFFF agents on the sandy terrain.

The data presented in tables 21 through 23 show that of the three terrains tested the simulated tree-studded sod posed the most complex fire situation, since it comprised both class B and three-dimensional class A fires. By contrast, the sandy terrain Jet A fire was the least difficult to extinguish, followed in complexity by the traprock fire configuration. These results therefore tend to emphasize the importance of the physical properties of the foam, in terms of expansion ratio and foam viscosity to provide a rapidly spreading vapor-securing blanket over the fire hazard.

The results of these tests also suggest that fire control and extinguishment times obtained under simple pool fire conditions may not be adequate to accurately define the actual requirements with regard to the solution application density necessary and the time required to achieve fire control and extinguishment when different natural surface structures are involved. These facts were confirmed by previous full-scale fire tests using B-47 aircraft (reference 13) which emphasized the fact that other parameters are involved in aircraft firefighting than those encountered in simple, pool fire experiments. The aircraft configuration and its position relative to the wind direction and the type of terrain

are among the factors which may affect the fire control time.

LARGE-SCALE FIRE EXTINGUISHING EXPERIMENTS.

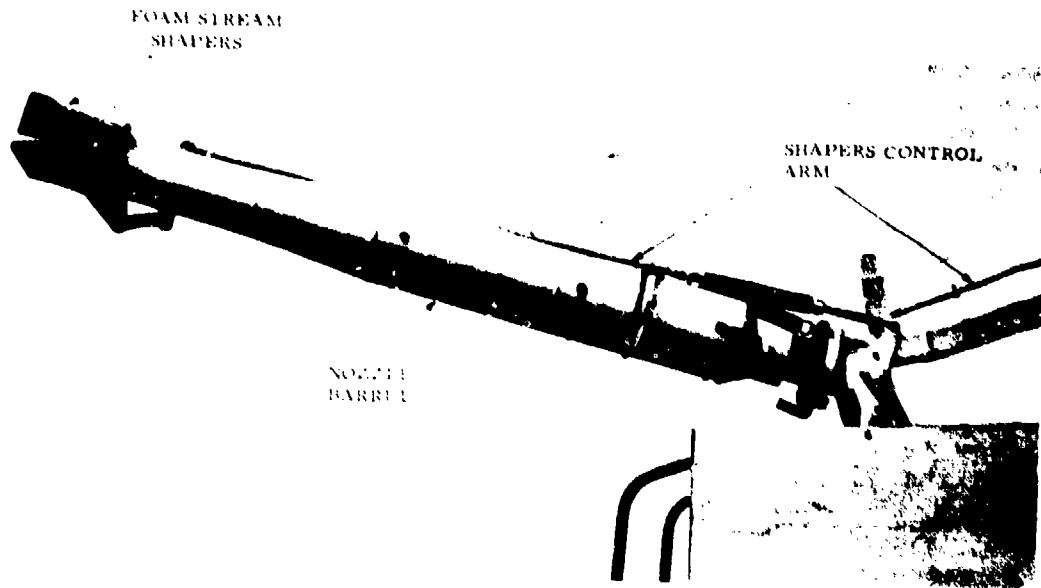
FULL-SCALE FOAM DISPENSING EQUIPMENT.

Two different turret nozzles were employed in the large-scale fire-modeling experiments. One (figure 15 a and b) was an air-aspirating single-barrel unit with a nominal solution discharge rate of 800 gal/min at 250 pounds per square inch (lb/in²) at the pump. This nozzle was capable of imparting high energy to the foam solution by creating a condition of high shear and turbulence to the foam during passage through the barrel. Foam shapers at the end of the barrel were capable of changing the foam pattern from straight stream to the fully dispersed pattern in a continuous manner.

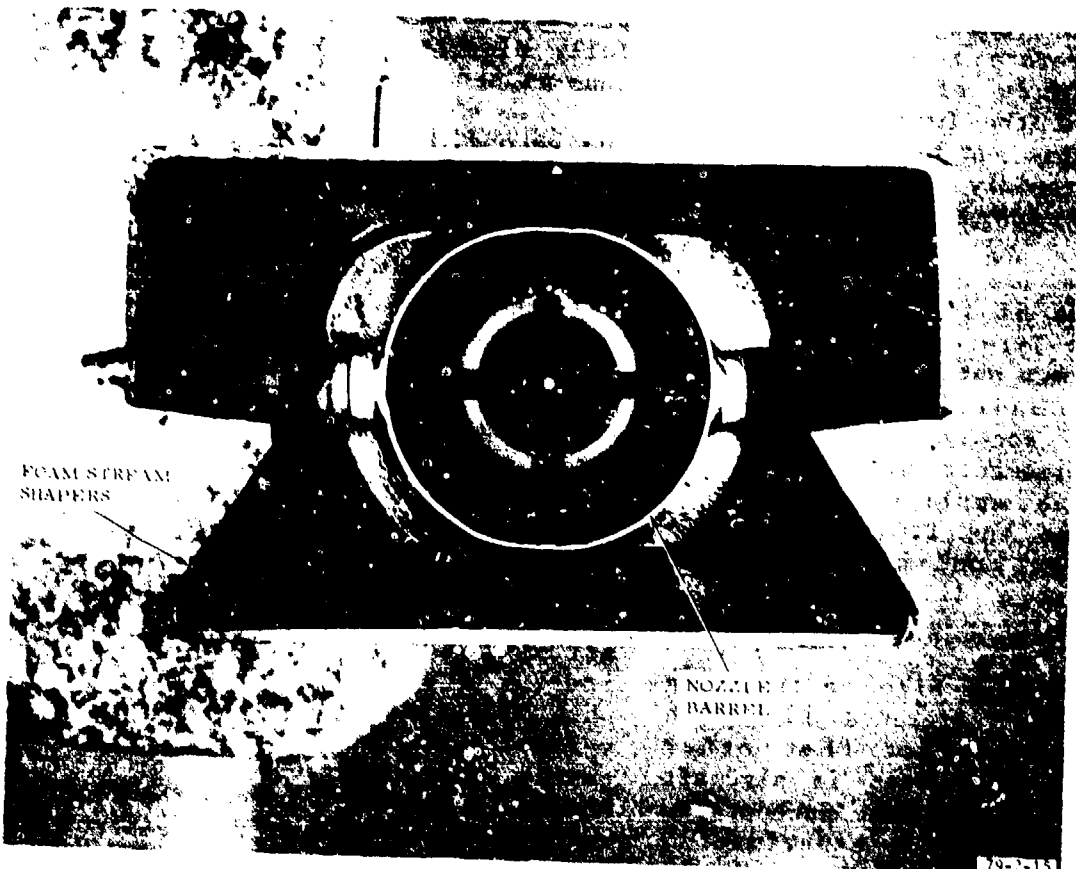
The second nozzle (figure 16 a and b) was a non-air-aspirating single-barrel unit comprising a discharge tube and a stacked deluge tip with a 1.5-inch orifice capable of discharging foam solution at the rate of 800 gal/min. Foam shapers were adapted to the end of the nozzle which were capable of varying the discharge from straight stream to a fully dispersed pattern.

Figures 16 and 18 through 21 show the foam ground patterns produced by the 3- and 6-percent AFFF, FPF, and PF agents when dispensed in the straight stream and fully dispersed modes. These patterns are of value when adjusting the initial foam dispersion pattern and for estimating the nozzle elevation required after each successive traverse across the fire pit to achieve the minimum fire control and extinguishing times.

The quality of foam produced by the 800-gal/min turret nozzles is

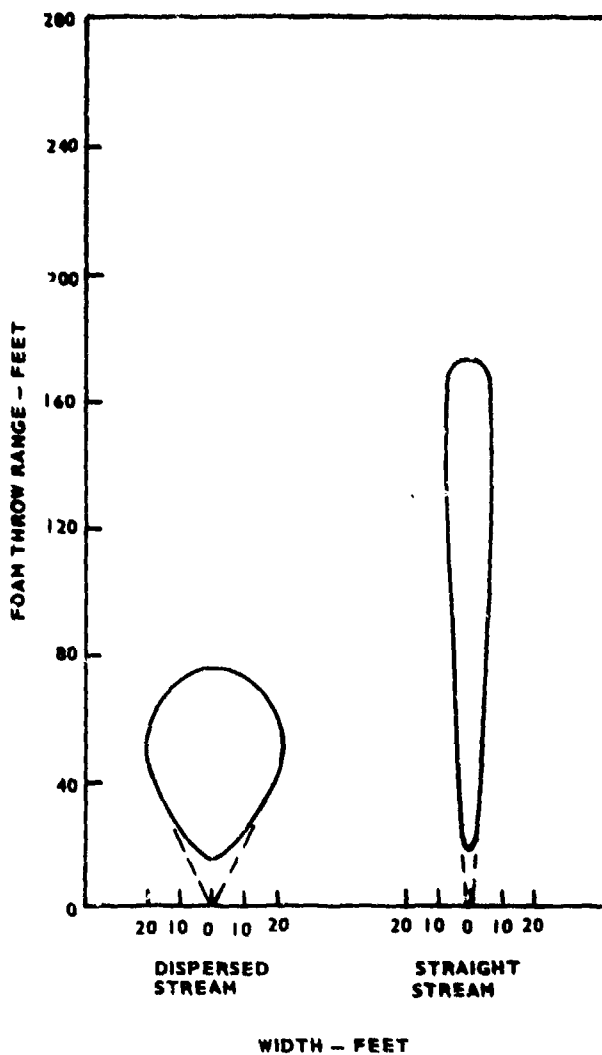


(a) PROFILE VIEW

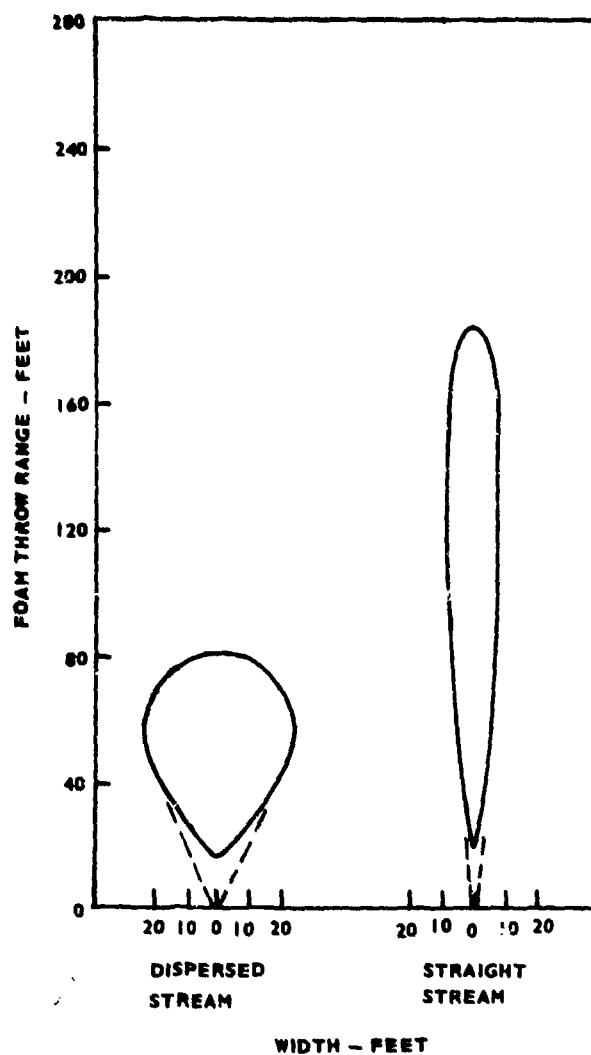


(b) FRONT VIEW

FIGURE 15. GENERAL CONFIGURATION OF THE AIR-ASPIRATING FOAM NOZZLE

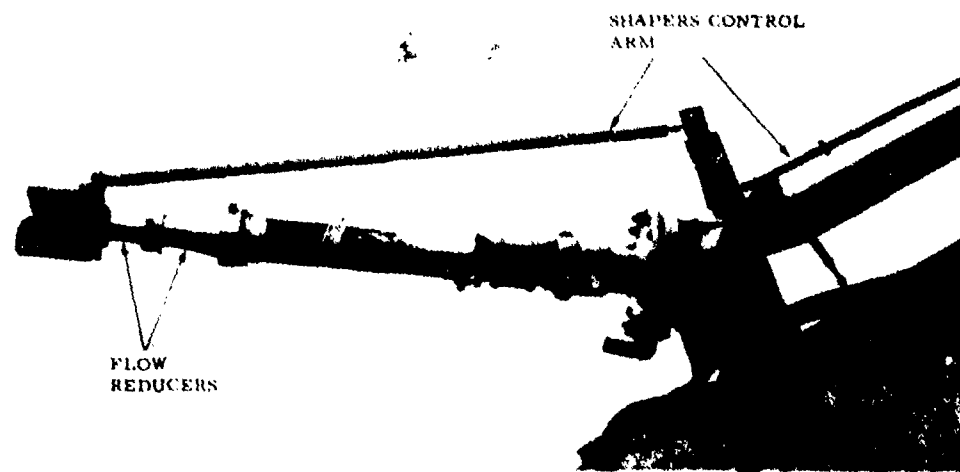


(A) FOAM GROUND PATTERNS FOR THE 6-PERCENT AFFF AGENTS

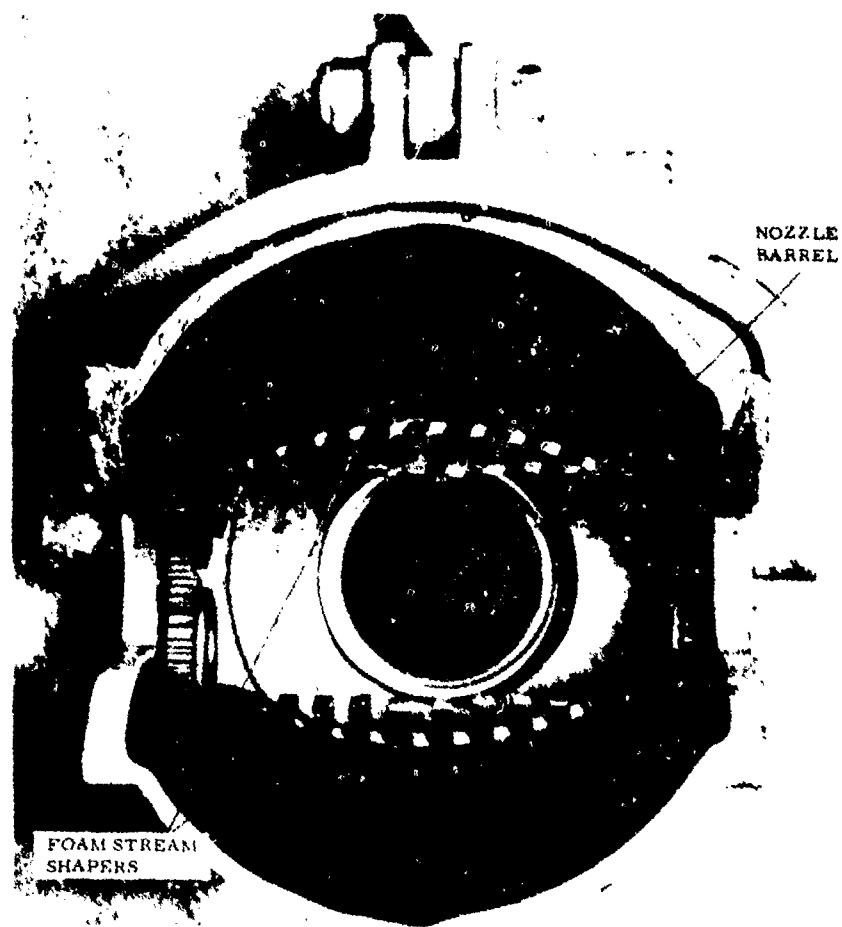


(B) FOAM GROUND PATTERNS FOR THE 3-PERCENT AFFF AGENTS 79-2-16

FIGURE 16. FOAM GROUND PATTERNS PRODUCED WITH AFFF AT 800 GAL/MIN USING THE AIR-ASPIRATING FOAM NOZZLE



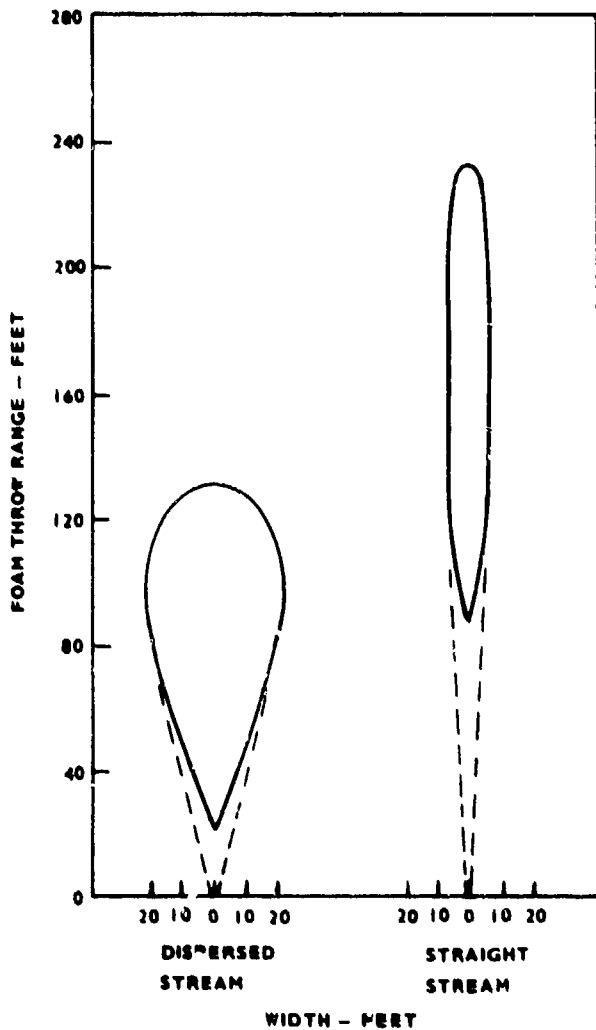
(a) PROFILE VIEW



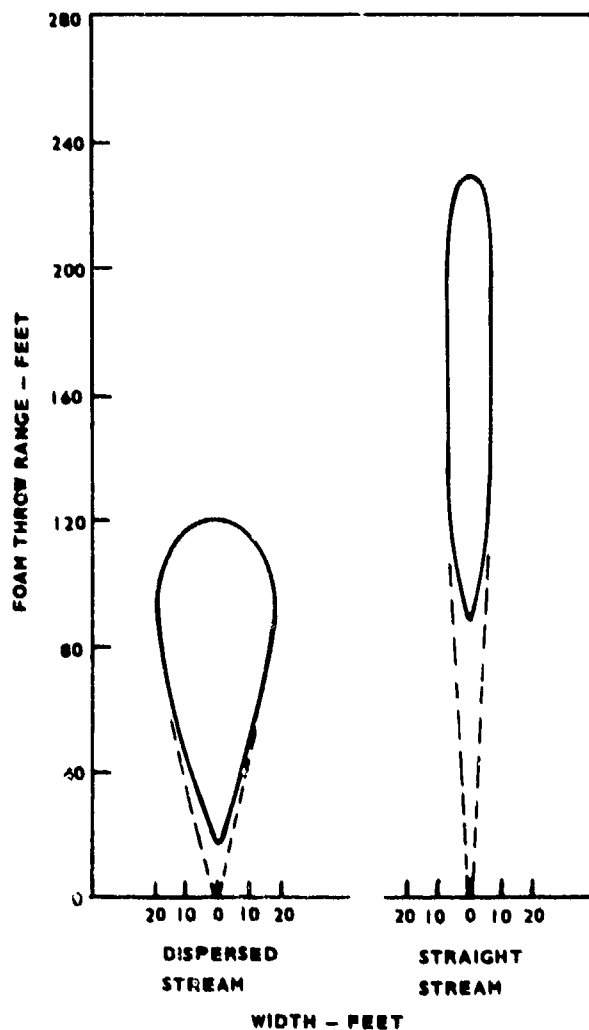
(b) FRONT VIEW

79-2-17

FIGURE 17. GENERAL CONFIGURATION OF THE NON-AIR-ASPIRATING WATER NOZZLE



(A) FOAM GROUND PATTERNS FOR THE 6-PERCENT AFFF AGENTS



(B) FOAM GROUND PATTERNS FOR THE 3-PERCENT AFFF AGENTS 79-2-18

FIGURE 18. FOAM GROUND PATTERNS PRODUCED WITH AFFF AT 800 CAL/MIN USING THE NON-AIR-ASPIRATING WATER NOZZLE

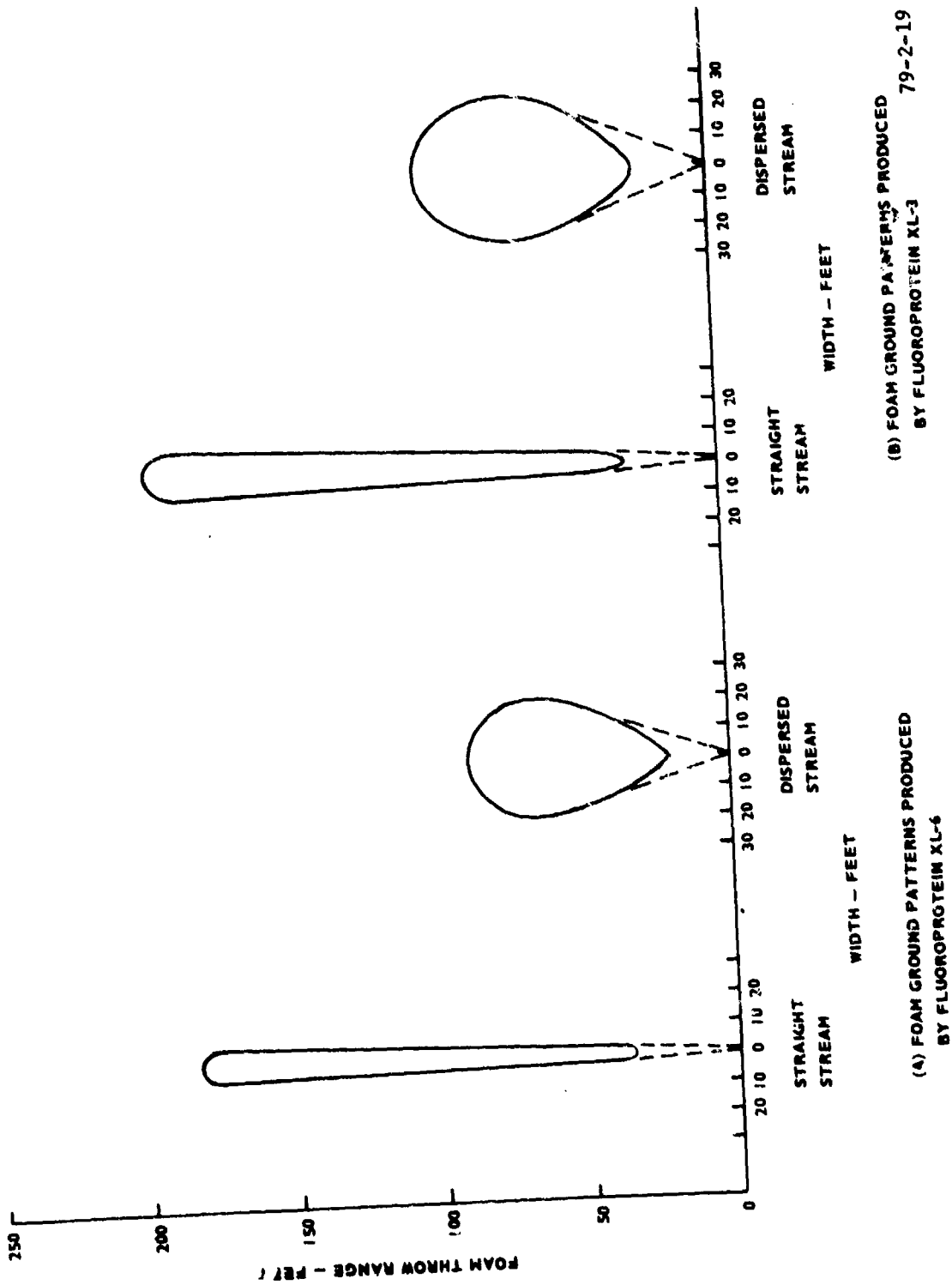
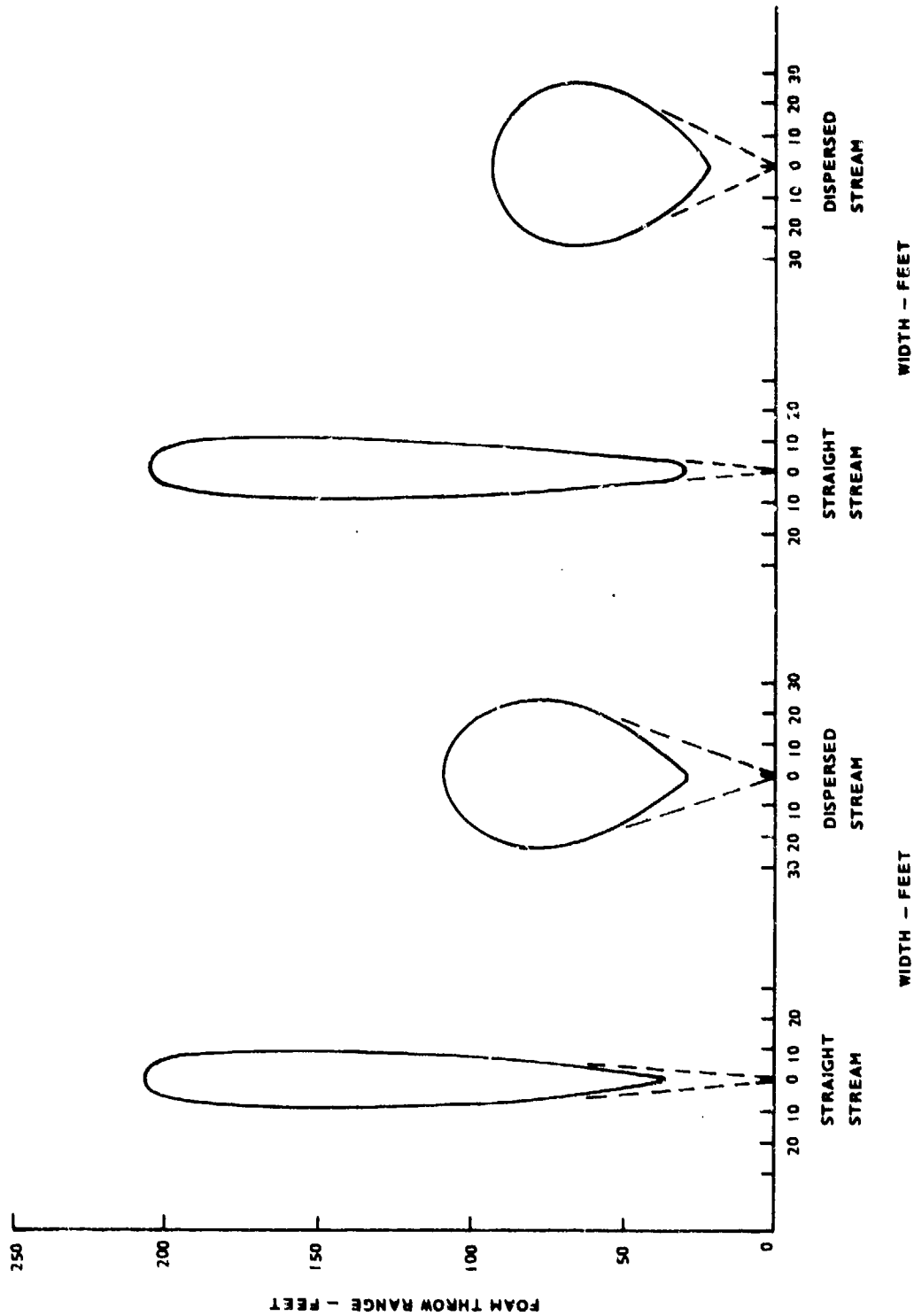
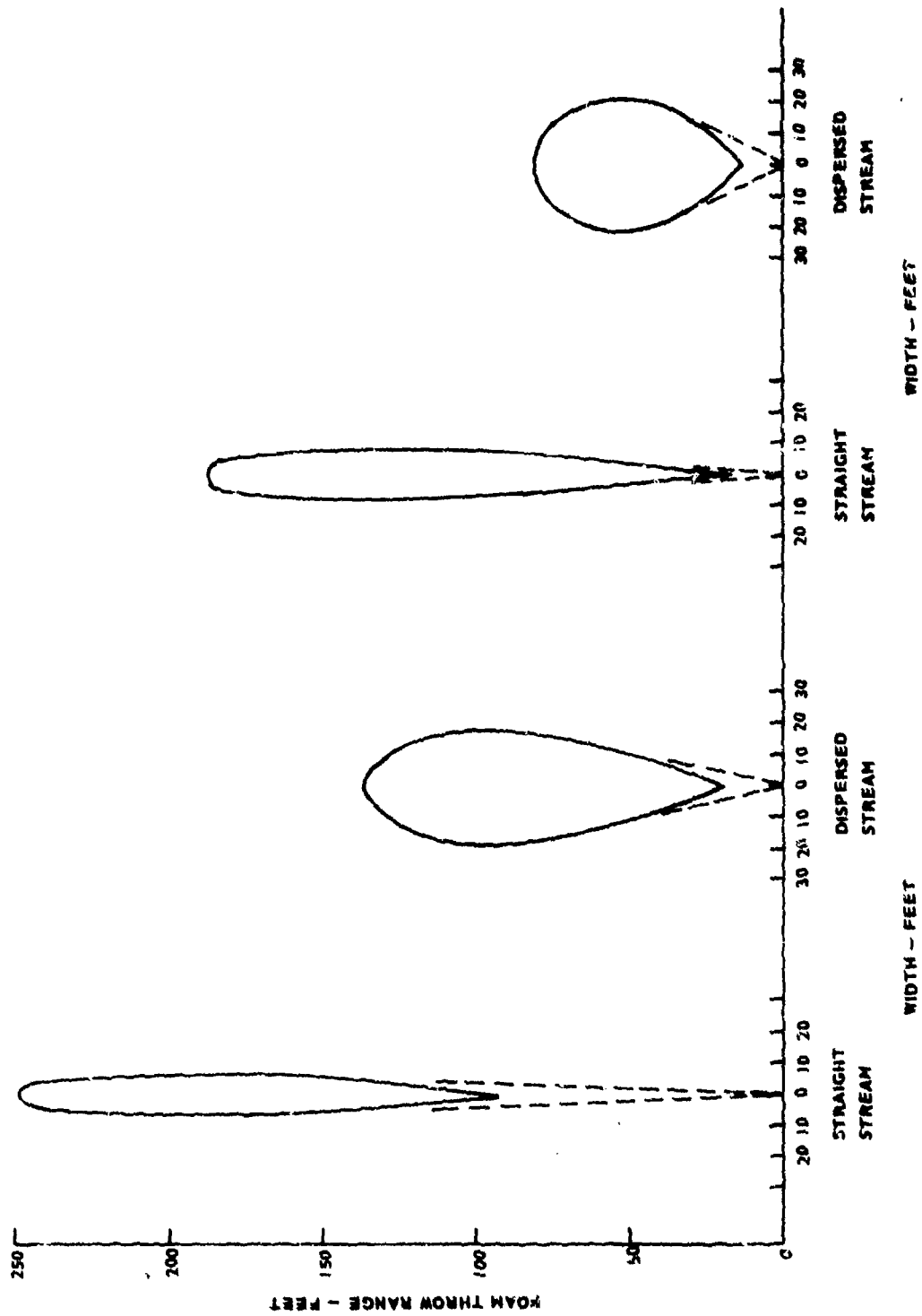


FIGURE 19. COMPARISON OF THE FOAM GROUND PATTERNS PRODUCED BY THE FLUOROPROTEIN AGENTS XL-6 AND XL-3 AT SOLUTION RATES OF 800 GAL/MIN AT 250 PSIG FROM THE AIR-ASPIRATING FOAM NOZZLE



(A) FOAM GROUND PATTERNS PRODUCED BY 6 PERCENT PROTEIN FOAM (O-F-555C)
 (B) FOAM GROUND PATTERNS PRODUCED BY 3 PERCENT FOAM AER-0-FOAM 3 79-2-20

FIGURE 20. COMPARISON OF THE FOAM GROUND PATTERNS PRODUCED BY THE 3-PERCENT AND 6-PERCENT PROTEIN AGENTS AT SOLUTION RATES OF 800 GAL/MIN AT 250 PSIG FROM THE AIR-ASPIRATING FOAM NOZZLE



(A) FOAM GROUND PATTERNS PRODUCED BY THE WATER NOZZLE

(B) FOAM GROUND PATTERNS PRODUCED BY THE FOAM NOZZLE

79-2-21

FIGURE 21. COMPARISON OF THE FOAM GROUND PATTERNS PRODUCED BY THE NON-AIR-ASPIRATING WATER NOZZLE AND THE AIR-ASPIRATING FOAM NOZZLE AT 800 GAL/MIN USING AFFF (FC-206)

summarized in table 25 in terms of the foam expansion ratio, 25-percent solution drainage time, and foam viscosity. However, there was insufficient foam produced by the non-air-aspirating nozzle to evaluate foam viscosity. The increase in foam viscosity as a function of time after formation is indicated by the profiles presented in figure 22.

FIRE TEST FACILITY AND TEST METHODS.

The fire test environment employed in these experiments is schematically and pictorially presented in figure 23. The test bed comprised a 200-foot-diameter pit constructed with a 12-inch-thick soil cement base and a polyvinyl chloride membrane embedded 6-inches below the surface to serve as a fuel and water barrier. Within this area, fires were confined in concentric pools of 22.4, 101, and 143 feet in diameter. The two innermost pools were constructed of 9- and 13-inch-high concrete dikes, and the outermost by an 18-inch-high earthen dike. By employing this configuration, it was possible to change from one fire size to the next larger by the addition of the water substrate to the proper pool.

The fixed fire conditions incorporated a cruciform cluster of seven 55-gallon steel drums as an obstacle factor in the center of the fire pools. This served as a heat sink in support of a three-dimensional fire situation which was sustained by a spray of fuel from a 2-foot-high, 1/4-inch-diameter stainless steel tube. Fuel tanks fed the burn area by gravity through an underground network of pipes.

The instrumentation employed in monitoring the progress of fire control is shown in figure 23 b and

described in appendix K. Heat sensors were located at the pool perimeter on the diameter and at right angles to the wind direction. Thermal data were recorded on instruments within a specially prepared trailer. Motion pictures for documentation and data analysis of each test was obtained at locations on the top of two specially designed vans (appendix L).

Uniform fire test conditions were maintained throughout the testing program by allowing a minimum preburn time of 30 seconds at maximum radiation intensity prior to initiating fire control action. The connotation of the terms, preburn time and control time, as defined by the test parameters, is illustrated by the idealized profiles in figure 24, where heat flux versus time after ignition is plotted to illustrate the type of thermal radiation data obtained from the fire-monitoring system. It will be noted that after the fuel was ignited, the heat flux slowly rose until a maximum radiation level was reached, under the existing conditions, and maintained for a minimum of 30 seconds prior to the start of foam discharge. This period of maximum radiation intensity before foam application is defined as the preburn time; in this case, 45 seconds. Fire control is defined as the elapsed time between the initiation of the extinguishing operation to that time when the heat flux, as measured by the radiometers, was reduced to 0.20 British Thermal Units (BTU)/ft²-s. In these experiments, the fire control time was recorded as the major test parameter defining fire performance, because it was more consistently reproducible than the fire extinguishing time.

FIRE EXTINGUISHING EFFECTIVENESS OF AFFF, FPF, AND PF AGENTS. The purpose of the large-scale fire extinguishing

TABLE 25. QUALITY OF FOAM PRODUCED BY THE 800-GAL/MIN TURRET NOZZLES

Class	Agent	AIR-ASPIRATING FOAM NOZZLE				Foam Viscosity (dynes/cm ²)		
		Solution Concentration (%)	Foam Expansion Ratio	25% Drainage Time (Min:Sec)	1 Min.	2 Min.	3 Min.	4 Min.
AFFF	FC-206	6	9.5:1	3:45	35.52	53.28	59.20	77.00
	FC-203	3	10.9:1	3:35	23.76	29.80	53.30	71.04
FFF	XL-6	6	8.6:1	10:14	236.80	254.60	284.20	313.80
	XL-3	3	6.75:1	3:48	213.10	284.20	355.20	390.70
FF	O-F-555C	6	10.5:1	9:42	290.10	331.50	378.90	461.80
	Aer-O-Foam 3	3	7.9:1	4:21	195.60	235.00	278.20	319.70
AFFF	FC-206	6	3.5:1	0:40				Not Determinable
	FC-203	3	3.5:1	0:40				Not Determinable

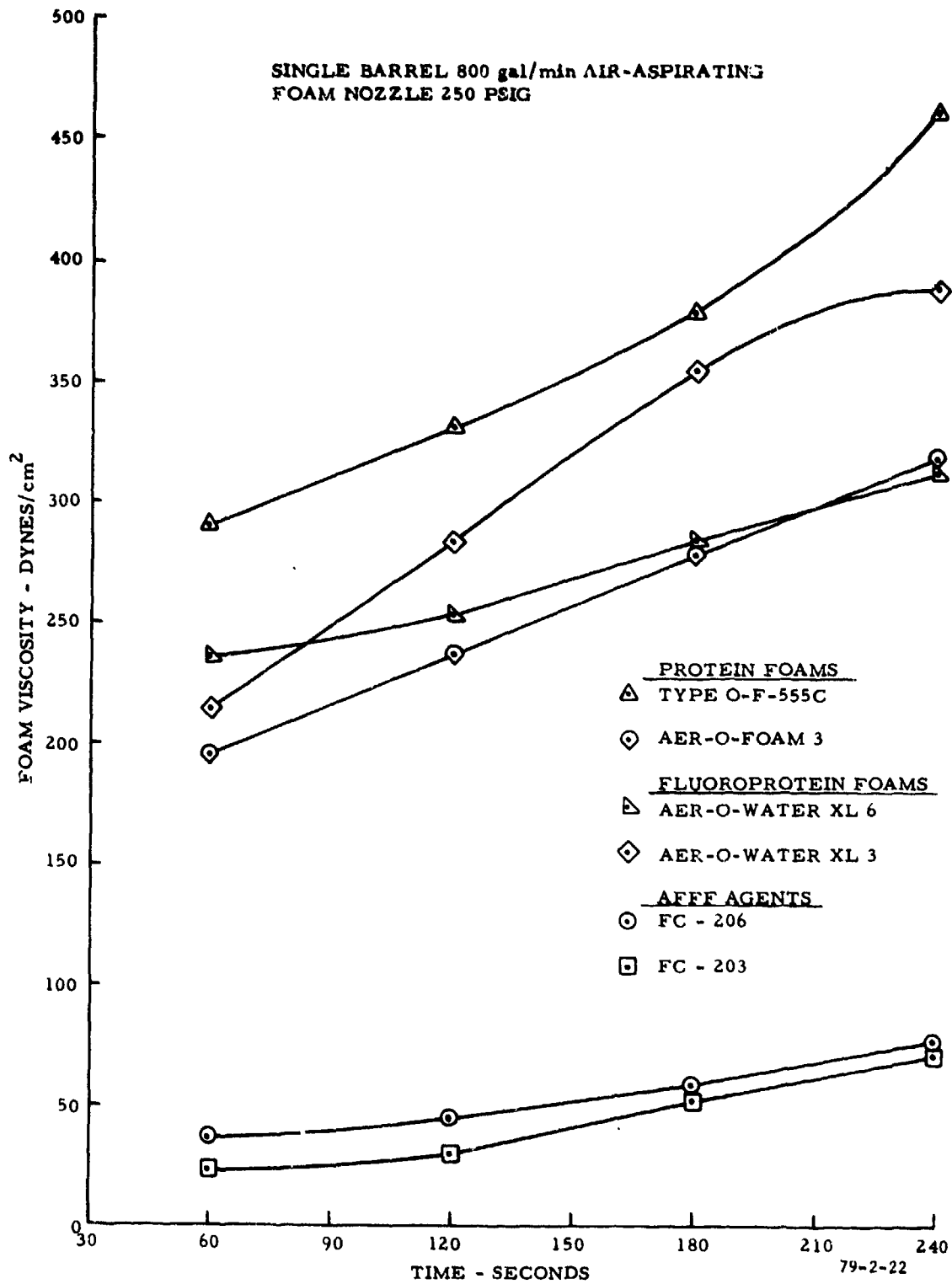
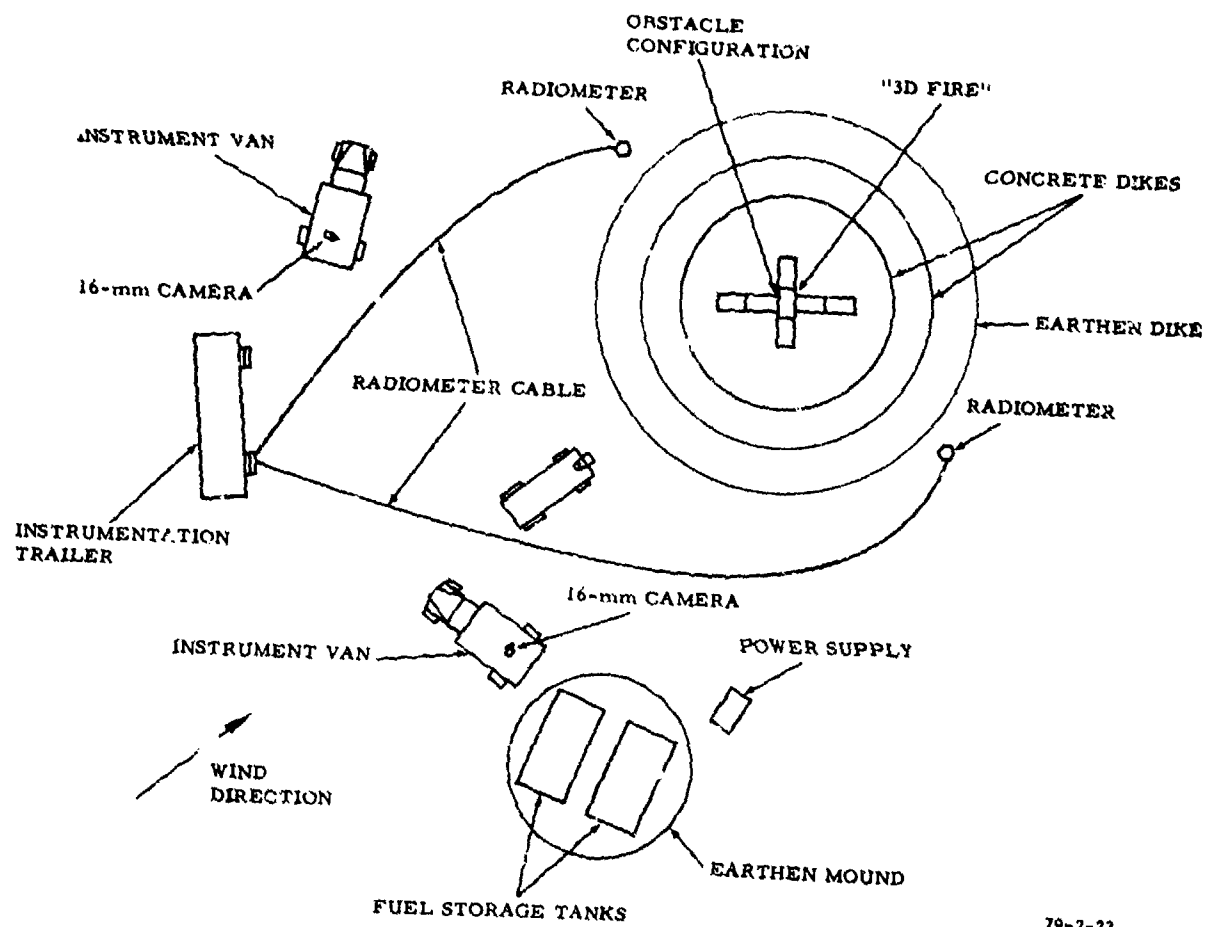


FIGURE 22. VARIATION OF FOAM VISCOSITY WITH TIME AFTER FORMATION



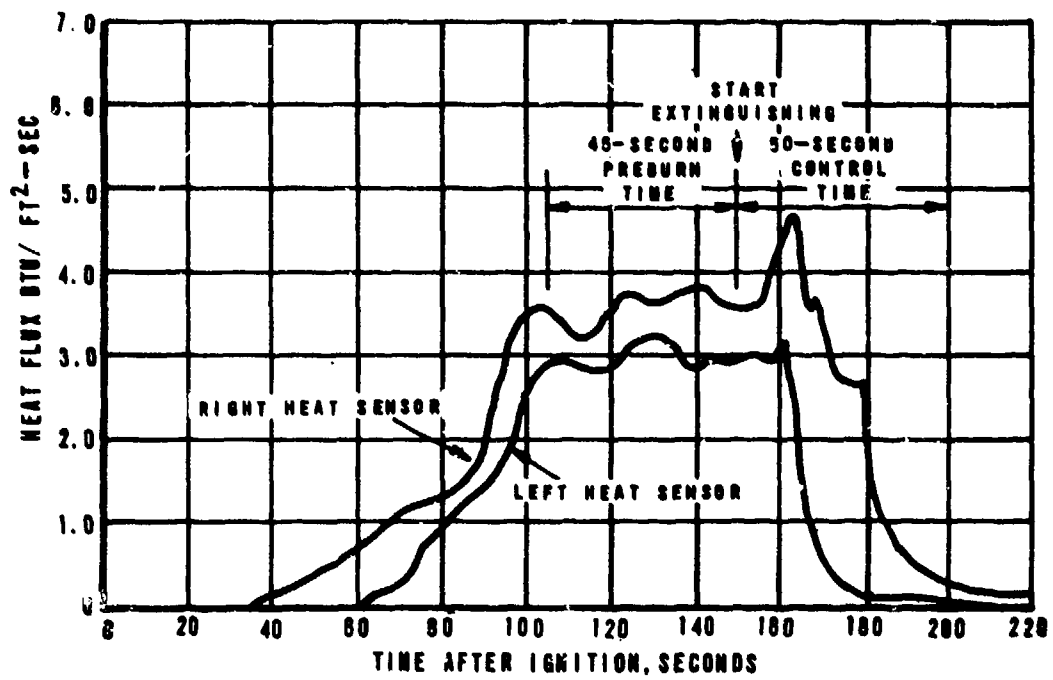
(a) PICTORIAL VIEW



79-2-23

(b) SCHEMATIC VIEW

FIGURE 23. PICTORIAL AND SCHEMATIC PRESENTATION OF THE FIRE TEST FACILITY



79-2-24

FIGURE 24. TYPICAL TEST DATA SHOWING FIRE PREBURN AND FIRE CONTROL TIME

experiments was to establish the optimum foam solution application rates for both the 3- and 6-percent type AFFF, FPF, and PF agents on Jet A fuel fires using the 800-gal/min air-aspirating foam nozzle and the 800-gal/min non-air-aspirating water nozzle. One representative foam agent was selected from each class and type and tested at solution application rates of 0.05, 0.10, and 0.15 gal/min/ft².

The results obtained using the air-aspirating foam nozzle are summarized in table 26 and in 27 for the non-air-aspirating nozzle. These data are presented in figure 25, which shows the fire control time as a function of the foam solution application rate for each agent.

In general, these profiles identify two families of agents based upon their chemical composition; i.e., the AFFF, or synthetic agents and the proteinaceous agents derived principally from natural products. It is also evident from these experiments that the fire control times were consistently lower for the AFFF agents at all solution application rates.

A comparison of the profiles developed for the FPF and PF agents indicate that the average fire control time obtained with the two FPF agents was approximately 16 percent longer than for the PF agents at an application rate of 0.05 gal/min/ft². The estimated average fire control time demonstrated by all of the proteinaceous foams indicated an approximate increase of 76.8 percent over that obtained for the synthetic AFFF agents at 0.05 gal/min/ft². However, when the solution application rate was increased from 0.05 to 0.10 gal/min/ft², the average difference in fire

control time between the proteinaceous and synthetic agents was reduced to approximately 27.3 percent. From these experiments, it is apparent that the AFFF agents are significantly more effective than the proteinaceous foams at a solution application rate of 0.05 gal/min/ft² and that all of the agents tend to reach a minimum fire control time at an application rate of 0.10 gal/min/ft².

The profiles in figure 26 were constructed to show the relationship between the foam application rate and the residual application density after fire control had been obtained. From these data it is evident that, as the solution application rate was reduced (by increasing the fire area), the application density of the AFFF agents required to achieve fire control was also reduced.

In contrast, the profiles developed for the proteinaceous agents show a reduction in the amount of agent required as the application rate was decreased from 0.15 to 0.10 gal/min/ft² but then to increase as the application rate was further reduced to 0.05 gal/min/ft². One explanation for this anomalous performance is that these agents are being employed below their critical application, or threshold rate, which nominally lies between 0.055 and 0.060 gal/min/ft². (The term threshold or critical solution application rate may be defined as the minimum rate at which a foam agent can provide a continuous and progressive securing action toward achieving fire control and extinguishment of class B fires.)

The results of these experiments tend to indicate that the fire extinguishing effectiveness of the FPF and PF agents decreases rapidly below 0.10 gal/min/ft² and that the AFFF agents tend to reach an optimum solution application density

TABLE 26. LARGE-SCALE FOAM APPLICATION EXPERIMENTS EMPLOYING THE 800-GAL/MIN AIR-ASPIRATING FOAM NOZZLE

Foam Agents	Solution Concentration (%)	Fire Pit Diameter (feet)	AFFF AGENTS			Fire Control Time (sec)	Solution Application Rate (gal/min/ft ²)	Solution Application Density (gal/ft ²)
			Fire Pit Area (ft ²)	Jet A Fuel (gal)				
FC-203	3	82.4	5,333	1,500	17	0.15	0.0425	
FC-203	3	101	8,000	2,400	17	0.10	0.0283	
FC-203	3	143	16,000	5,000	30	0.05	0.0250	
FC-206	6	82.4	5,333	1,500	16	0.15	0.0399	
FC-206	6	101	8,000	2,400	16	0.10	0.0266	
FC-206	6	143	16,000	5,000	26.5	0.05	0.0218	
<u>FFP AGENTS</u>								
XL-3	3	82.4	5,333	1,500	20	0.15	0.0500	
XL-3	3	101	8,000	2,400	22	0.10	0.0366	
XL-3	3	143	16,000	5,000	52	0.05	0.0435	
XL-6	6	82.4	5,333	1,500	20	0.15	0.0500	
XL-6	6	101	8,000	2,400	20	0.10	0.0333	
XL-6	6	143	16,000	5,000	56	0.05	0.0467	
<u>PF AGENTS</u>								
Aer-O-Foam 3	3	82.4	5,333	1,500	20	0.15	0.0500	
Aer-O-Foam 3	3	101	8,000	2,400	20	0.10	0.0333	
Aer-O-Foam 3	3	143	16,000	5,000	43	0.05	0.0358	
TYPE O-F-555C	6	82.4	5,333	1,500	21	0.15	0.0525	
TYPE O-F-555C	6	101	8,000	2,400	21	0.10	0.0350	
TYPE O-F-555C	6	143	16,000	5,000	50	0.05	0.0418	

TABLE 27. LARGE-SCALE FOAM APPLICATION EXPERIMENTS EMPLOYING THE 800-GAL/MIN NON-AIR-ASPIRATING WATER NOZZLE

AFFF AGENTS

Foam Agents	Solution Concentration (%)	Fire Pit Diameter (feet)	Fire Pit Area (ft ²)	Jet A Fuel (gal)	Fire Control Time (sec)	Solution Application Rate (gal/min/ft ²)	Solution Application Density (gal/ft ²)
FC-203	3	101	8,000	2,400	16	0.10	0.0266
FC-203	3	143	16,000	5,000	25	0.05	0.0210
FC-206	6	101	8,000	2,400	15.5	0.10	0.026
FC-206	6	143	16,000	5,000	22	0.05	0.018

AIR-ASPIRATING
FOAM NOZZLE

AFFF

◇ FC - 203

□ FC - 206

FLUOROPROTEIN

△ XL - 3

○ XL - 6

PROTEIN FOAM

△ AER-0-FOAM 3

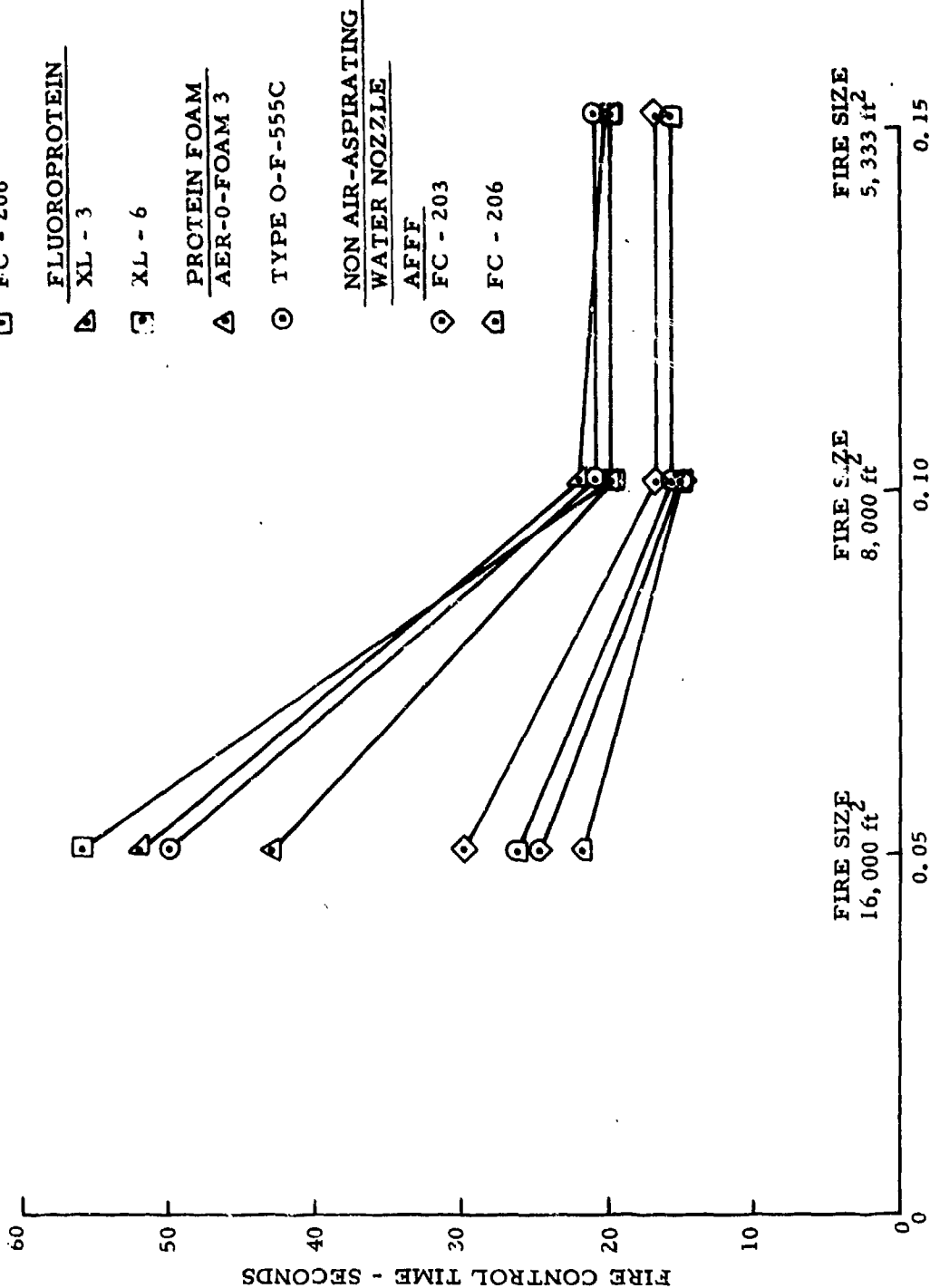
○ TYPE O-F-555C

NON AIR-ASPIRATING
WATER NOZZLE

AFFF

◇ FC - 203

□ FC - 206



FOAM SOLUTION APPLICATION RATE - gal/min / ft² 79-2-25
 FIRE CONTROL TIME AS A FUNCTION OF SOLUTION APPLICATION RATE FOR AFFF,
 FLUOROPROTEIN, AND PROTEIN FOAMS FOR JET A FUEL FIRES

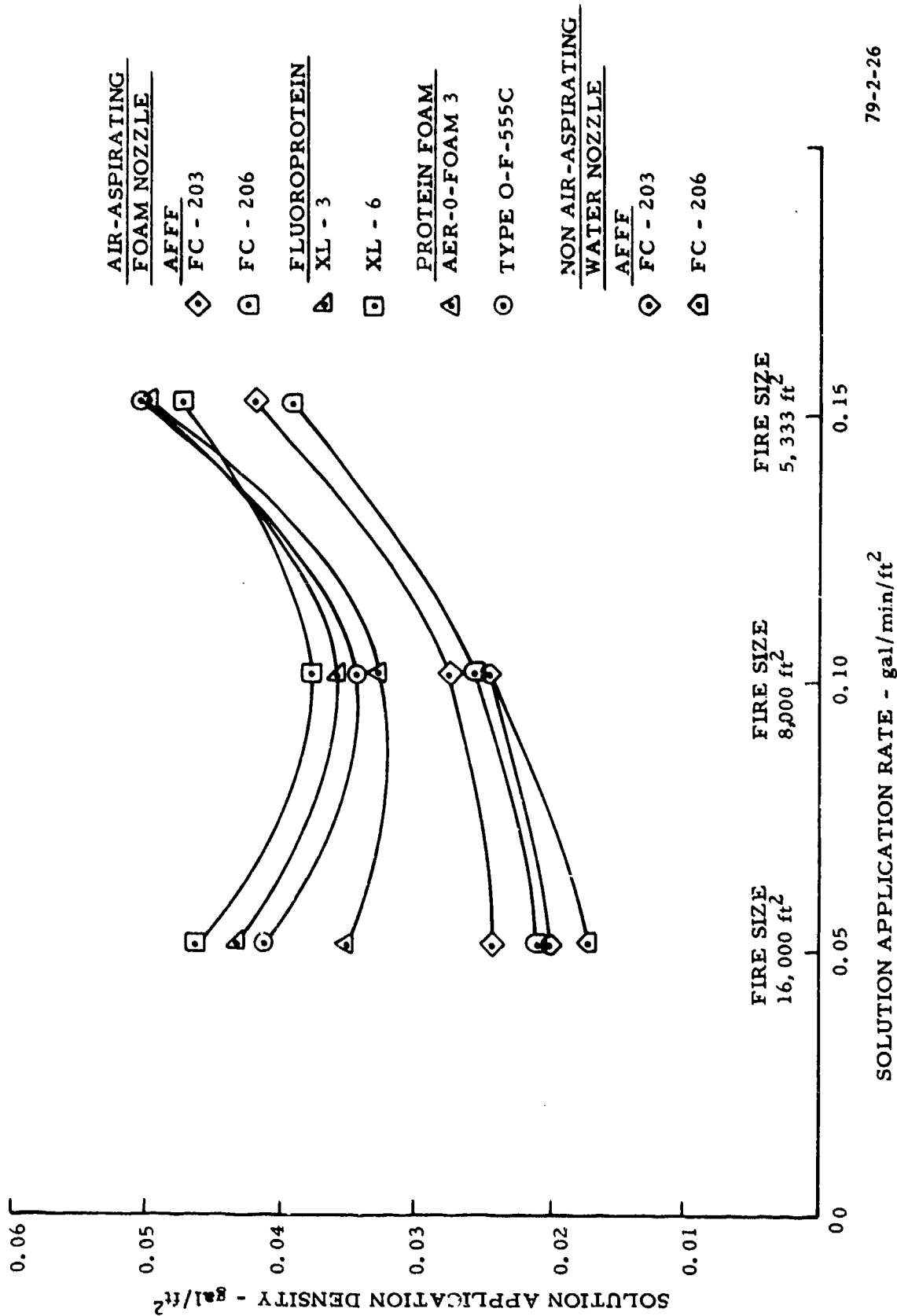


FIGURE 26. FOAM SOLUTION APPLICATION DENSITY REQUIRED FOR FIRE CONTROL OF JET A FUEL FIRES WITH AFFF, FLUOROPROTEIN, AND PROTEIN FOAMS

79-2-26

between 0.022 and 0.025 gal/ft² (0.05 gal/min/ft²). Based upon the test procedures and agents employed in these experiments it is evident that no reduction in the fire control time or solution application occurred through the use of FPF over the PF agents.

The results of experiments conducted with the 800 gal/min non-air-aspirating nozzle are presented graphically in figures 25 and 26. These profiles indicate that a shorter fire control time was required at discharge rates of 0.05 and 0.10 gal/min/ft², which resulted in a lower solution application density. However, after fire control and extinguishment had been obtained, less than 25 percent of the fuel surface had been secured by foam, although there was evidence of the presence of an aqueous fluorocarbon film.

These experiments suggest the potential advantages of a prototype nozzle incorporating the long-throw-range characteristic of the non-air-aspirating nozzle with the air-aspirating capability of the foam nozzle which could be controlled by the turret operator to produce the required foam quality in a continuous manner.

EFFECTIVENESS RATING OF FIREFIGHTING FOAMS.

Considerable emphasis is being placed upon the cost of fire protection at airports, which is, in fact, the primary reason for considering the new and more effective foam agents, even though they may be more expensive. However, any potential increase in the cost of agents to obtain control of a given fire situation must be balanced against

the potential economies realized from a reduction in hardware and manpower, which may constitute a substantial and continuing economy.

As a consequence of a contractual effort supported by the U.S. Air Force and the FAA-NAFEC (reference 13) sufficient data were developed to permit a ranking of AFFF and PF in overall effectiveness. The method developed is presented in appendix A and was subsequently submitted by the U.S. delegate to the International Civil Aviation Organization (ICAO) during the second meeting of the Rescue and Fire Fighting Panel in June of 1972.

In this ranking procedure, the overall effectiveness of firefighting foams is based upon a point system (appendix A) with a maximum or perfect score of 400 points being possible. There are 10 major parameters, each of which was assigned a point value that was considered representative of its relative importance in the proper functioning of the agent under field conditions. It will be noted that items 4 and 6 are subdivided into pertinent components, each of which contributes to the total value of that item.

The estimated values shown in appendix A for AFFF and PF under each parameter are based upon laboratory experiments and the results of small- and large-scale fire tests. This ranking system permitted a reduction of approximately 30 percent in the water requirements in firefighting operations when AFFF is substituted for PF. Subsequently, concerned organizations such as the ICAO and NFPA recommended a reduction of one-third in the water requirement when AFFF is substituted for PF and, in Federal Aviation Regulation (FAR) Part 139.49, a reduction of 30 percent is permitted at U.S. certificated airports (reference 19).

As a consequence of the large increase in the use of the 3-percent foam agents at U.S. airports and the ready availability of numerous FPF agents, the ranking method employed in appendix A was expanded in table 28 to include these newer agents. From a comparison of the grand totals developed for each class and type of agent, it is apparent that no significant change in the original ranking of the 6-percent AFFF and PF agents occurred. The data also show that the values obtained for the 3- and 6-percent AFFF and protein foams were essentially equivalent. However, there was no improvement in the overall ranking of the 3- and 6-percent FPF agents over the corresponding PF agents. This was due in part to the very low order of compatibility between the FPF agents as a class and the dry-chemical powders. In addition the FPF liquid concentrates of the same type demonstrated a very low order of mutual compatibility when mixed.

The results of this ranking procedure tend to confirm the validity of allowing a 30-percent reduction in the water requirement at certificated airports when either the 3- or 6-percent type AFFF agents are used to replace PF agents. The data further indicate that when either the 3- or 6-percent type FPF agents are substituted for similar types of PF agents, the total water requirement for foam production should remain the same.

SUMMARY OF RESULTS

The results obtained from laboratory and large-scale fire tests employing AFFF, FPF, and PF on 82.4, 101, and 143 feet in diameter Jet A fuel fires are:

1. Only the 3- and 6-percent type AFFF agents produced aqueous fluorocarbon films which spread across the Jet A fuel.

2. When the 3- and 6-percent type AFFF and PF liquid concentrates were mixed in proportions of 25, 50, and 75 percent by volume and subjected to accelerated aging, the sediment produced was less than 0.10 percent by volume. Under identical conditions, the 3- and 6-percent FPF agents produced sediment in excess of 0.10 percent by volume.

3. Laboratory foam-powder compatibility experiments indicated that all combinations of 3- and 6-percent AFFF with five dry-chemical powders showed 25-ml solution drainage times of 2 minutes or more. None of the FPF or PF agents demonstrated 25 ml drainage of 2 minutes or more with all powders.

4. All of the AFFF, FPF, and PF agents when tested in accordance with the fire requirements of Federal Specification O-F-555C demonstrated fire control times of less than 4 minutes and fire extinguishing times under 5 minutes.

5. In small-scale fire tests conducted with AFFF, FPF, and PF agents the effect of elevated solution temperatures was to decrease the fire control time for the AFFF agents and to increase the control time for FPF and PF agents.

6. In small-scale fire tests, the effect of permanent water hardness of 470 ppm demonstrated a reduction in the fire control times for FC-206, XL-6, and 6-percent PF (Hearl) and an increase in the fire control times of FC-203 and Aer-O-Water 3. Fire control could not be obtained using FPF XL-3 within the test duration time (5 minutes).

TABLE 28. FOAM RATING SYSTEM

	AFFF			PF			FFF		
	32	62	62	32	62	62	32	62	62
1. Fire Control Time	100	100	52.5	50	47	52.5			
2. Fire Extinguishing Time	80	80	30	30	25	25			
3. Foam Blanket Stability	33	31	43	50	48	49			
a) Disruption by Wind									
b) Stability Under Thermal Radiation									
c) Stability Under Water Spray									
d) Wicking Action (Jet A)									
e) Burnback Rate									
Subtotal			31	43	50	48			49
4. Effect of Terrain on Fire Control Time	45			45	40	45			
5. Training Level Required (Ease of Application)	40			30	35	35			
6. Competibility of Agents	30			20	12	15			
a) Foam/Powder									
b) Halocarbons/Foams									
c) Competibility Between Liquid Concentrates Within Each Class (Binary Mixtures)									
Subtotal			30	20	12	15			
7. Foam Stream Range	25	25	25	25	25	25			
8. Foam Liquid Concentrate Storage Life (12-Month Period)	10	10	10	10	10	10			
9. Effect of Temperature on Foam Quality	10	10	7	9	9	8			
10. Effect of Water Hardness on Foam Quality and Firefighting Effectiveness	10	7	10	5	10	0			
Grand Total	360	374	267.5	279	251	274.5			

62 AFFF/PF 1:1.34 62 AFFF/FFF 1:1.37
 32 AFFF/PF 1:1.35 32 AFFF/FFF 1:1.43

7. In small-scale fire tests the thermal disintegration of established blankets of AFFF varied from 0.0158 in/sec for the 6 percent to 0.023 in/sec for the 3-percent agents. The thermal disintegration rate of FPF agents varied from 0.0033 to 0.0096 in/sec for the 6- and 3-percent agents, respectively. The 6- and 3-percent PF agents demonstrated a thermal decomposition rate from 0.0098 to 0.0125 in/sec, respectively.

8. Small-scale fire tests conducted to determine the resistance of established foam blankets to destruction in terms of the number of water-spray cycles survived indicates an average of 5.2 for the 6-percent and 7.3 for the 3-percent AFFF agents. The number of water-spray cycles sustained by the 6- and 3-percent FPF agents varied from 3.4 to 21.5, respectively. The 6-percent PF blanket survived 13 water-spray cycles and the 3-percent agents an average of 6 cycles.

9. The small-scale fire tests conducted in which Jet A fuel was spilled on different types of terrain, indicated that only the 6-percent AFFF (FC-206) was successful in extinguishing fires in tree-studded sod. However, both the 3- and 6-percent AFFF, FPF, and PF agents extinguished fires on sandy and traprock terrains which required from 2.33 minutes for 6-percent AFFF (FC-206) to 14.66 minutes for 3-percent PF, respectively.

10. Large-scale fire tests conducted on Jet A fuel fires at solution application rates of 0.05, 0.10, and 0.15 gal/min/ft² using both 3- and 6-percent type AFFF, FPF, and PF agents indicated that the optimum

application rate was 0.10 gal/min/ft². However, when the solution application rate of the 3- and 6-percent type AFFF agents was reduced to 0.05 gal/min/ft² (50 percent), the fire control time was increased by approximately 65 percent.

11. Based upon a rating system with a maximum or perfect score of 400 points, the relative values obtained for each foam agent were: AFFF 3-percent 360, 6-percent 374; FPF agents 3-percent 251, 6-percent 274.5; and PF 3-percent 267.5, 6-percent 279.

CONCLUSIONS

Based upon the results of tests conducted during the evaluation of the foam firefighting agents, it is concluded that:

1. The spreading coefficient of the aqueous fluorocarbon films calculated in accordance with the laboratory procedures outlined was greater than zero for both the 3- and 6-percent AFFF agents, indicating that the AFFF solution was capable of spreading freely upon the surface of Jet A fuel.

2. The AFFF and protein foam (PF) liquid concentrates, as individual classes of agents, demonstrated an acceptable degree of mutual compatibility when subjected to the accelerated aging test requirements.

3. The 3- and 6-percent fluoroprotein foam (FPF) liquid concentrates demonstrated an unacceptable degree of compatibility as a class when subjected to the accelerated aging test requirements.

4. All of the AFFF, FPF, and PF agents met the minimum fire test requirements of Federal Specification O-F-555C at a solution application rate of 0.06 gal/min/ft².

5. Water hardness has a significant but variable effect upon the fire control and extinguishing times of the AFFF, FPF, and PF agents at a solution application rate of 0.06 gal/min/ft² on Jet A fuel fires.

6. The thermal resistivity of firefighting foams as classes of agents indicate the following ranking order from the most to least effective: FPF 6-percent > FPF 3-percent > PF 6-percent > PF 3-percent > AFFF 6-percent > AFFF 3-percent.

7. The resistance of firefighting foams to destruction in terms of the number of water-spray cycles survived indicates the following ranking order from the most to least effective: FPF 6-percent > FPF 3-percent > PF 6-percent > AFFF 3-percent > PF 3-percent > AFFF 6-percent.

8. Aviation fuel (Jet A) spill fires in wooded or on grass-covered sod are more difficult to extinguish with foam than those on sandy or rock-covered terrain.

9. The optimum solution application rate for all classes and types of foam agents on large-scale Jet A fuel fires was 0.10 gal/min/ft²; however, the 3- and 6-percent AFFF agents were more effective at a solution rate of 0.05 gal/min/ft² than the FPF or PF agents.

10. Based upon the results obtained from the foam rating system, the AFFF as a class of agents (3- and 6-percent types) show an overall average improvement of 34.5 percent over the PF agents (3- and 6-percent types) and an advantage of 40 percent over the FPF (3- and 6-percent types).

RECOMMENDATIONS

Based upon the results obtained during the evaluation of foam firefighting agents, it is recommended that:

1. The mutual compatibility between all foam liquid concentrates be unequivocally established before they are mixed in any proportion for bulk storage.

2. The fire-extinguishing effectiveness of all foam agents be established before they are selected for use in those areas where excessively hard or brackish water may be employed in foam firefighting vehicles.

3. The 3- and 6-percent type AFFF's should be considered the agents of choice for use in combatting aviation fuel spill fires in those areas within or adjacent to an airport containing trees/shrubs or grass-covered sod.

4. A minimum foam solution application rate of 0.10 gal/min/ft² be employed when using FPF and PF agents to control large-scale Jet A fuel fires.

5. A minimum foam solution application rate of 0.05 gal/min/ft² be employed to extinguish large-scale Jet A fuel fires with AFFF agents (3- or 6-percent types).

6. The 30-percent reduction in the water requirement at U.S. certificated airports be continued when the AFFF agents (3- or 6-percent type) are substituted for PF agents (3- or 6-percent type) and that FPF

(3- or 6-percent types) and PF agents be considered equivalent in terms of their total water requirement at U.S. airports.

7. Guidelines be established by the FAA/NAFEC, in collaboration with industry, defining the physical properties of the FPF (3- and 6-percent types) liquid concentrates and the quality and firefighting effectiveness of the foam produced, for inclusion in an FAA Advisory Circular.

REFERENCES

1. Federal Specification O-F-555C, Foam Liquid, Fire Extinguishing Mechanical, January 3, 1969.
2. Air Foam Equipment and Liquid Concentrates, Underwriter's Laboratories, Inc., UL 162, 1969.
3. Tuve, R. L., Peterson, H. B., Jablonski, E. J., and Neill, R. R., A New Vapor-Securing Agent for Flammable Liquid Fire Extinguishment, NRL Report 6057, AD435612, March 13, 1964.
4. Simons, J. H., Electrochemical Process for Making Fluorine Containing Carbon Compounds, U.S. Patent No. 2,519,983, August 22, 1950.
5. Guenther, R. A. and Vietor, M. L., Surface Active Materials from Perfluorocarboxylic and Perfluorosulfonic Acid, I and EC Product Research and Development, Vol. 1, September 1962.
6. Military Specification MIL-F-24385 (Navy), Fire Extinguishing Agent, Aqueous-Film-Forming-Foam (AFFF) Liquid Concentrate Six Percent for Fresh and Sea Water, November 1969, and Interim Amendments dated February 17, 1972.
7. Tuve, R. L. and Jablonski, E. J., Method of Extinguishing Liquid Hydrocarbon Fires, U.S. Patent No. 3,258,423, June 28, 1966.
8. Bernette, M. K. and Zisman, W. A., Synergistic Surface Tension Effects From Mixtures of Fluorinated Alcohols with Conventional Wetting Agents, U.S. Naval Research Laboratory, Washington, D.C., August 30, 1960.
9. Francen, V. L., Fire Extinguishing Composition Comprising a Fluoroaliphatic Surfactant and Fluorine-Free Surfactant, U.S. Patent No. 3,562,156, February 9, 1971.
10. Wilder, I., Development of a Foam Compatible with Dry Powder, Naval Applied Science Lab., Project 9300-55, Technical Memorandum No. 3, SF-020-03-03, Task 0605, April 25, 1966.
11. Harkins, W. D., The Physical Chemistry of Surface Films, Reinhold Publishing Corporation, 1952.
12. NFPA No. 412, Evaluating Foam Fire Equipment Aircraft, Rescue and Firefighting Vehicles, National Fire Protection Association, Boston, Massachusetts, 1974.
13. Geyer, G. B., Evaluation of Aircraft Ground Firefighting Agents and Techniques, National Aviation Facilities Experimental Center, FAA-RD-71-57, FAA-NA-72-20, and Tri-Service System Program Office for Aircraft Ground Fire Suppression and Rescue, SMF, AGFSRS 71-1, February 1972.

14. Geyer, G. B., Foam and Dry Chemical Application Experiments, Federal Aviation Administration, Systems Research and Development Service, FAA-RD-68-55, December 1968.

15. Geyer, G. B., Firefighting Effectiveness of Aqueous-Film-Forming-Foam (AFFF) Agents, Prepared for DOD Aircraft Ground Fire Suppression and Rescue Unit, Wright-Paterson Air Force Base, Ohio ADS-TR-73-13, April 1973.

16. Federal Specification O-D-1407, Dry Chemical Fire Extinguishing Potassium Bicarbonate, August 9, 1972.

17. NFPA No. 403, Aircraft Rescue and Firefighting Services at Airports, National Fire Protection Association, Boston, Massachusetts, 1974.

18. National Foam System, Inc., Lionville, Pennsylvania, 19353.

19. Federal Aviation Regulations, Part 139 Certification and Operations; Land Airports Serving CAB-Certificated Air Carriers, December 1974.

20. Fisher Model 215 Autotensiomat Surface Tension Analyzer, Catalog No. 14-811, Fisher Scientific Co., Pittsburgh Pa. 15219.

APPENDIX A
FOAM RATING SYSTEM

TABLE A-1. FOAM EFFECTIVENESS RATING BASED UPON A FIRE CONTROL TIME OF 1:2 FOR AFFF TO PROTEIN FOAM. OVERALL ADVANTAGE RATIO PROTEIN FOAM/AFFF (1.0:1.3).

FOAM RATING SYSTEM

	Assigned Ratings		Maximum Rating																					
	AFFF	PF																						
1. Fire Control Time	100	50	100																					
2. Fire Extinguishing Time	80	30	80																					
3. Foam Blanket Stability	27	50	50																					
	<table border="1"> <thead> <tr> <th></th> <th>AFFF</th> <th>PF</th> </tr> </thead> <tbody> <tr> <td>a) Disruption by Wind</td> <td>8</td> <td>10</td> </tr> <tr> <td>b) Stability Under Thermal Radiation</td> <td>6</td> <td>10</td> </tr> <tr> <td>c) Stability Under Water Spray</td> <td>8</td> <td>10</td> </tr> <tr> <td>d) Wicking Action</td> <td>0</td> <td>10</td> </tr> <tr> <td>e) Burnback Rate</td> <td>5</td> <td>10</td> </tr> <tr> <td>Subtotal</td> <td>27</td> <td>50</td> </tr> </tbody> </table>			AFFF	PF	a) Disruption by Wind	8	10	b) Stability Under Thermal Radiation	6	10	c) Stability Under Water Spray	8	10	d) Wicking Action	0	10	e) Burnback Rate	5	10	Subtotal	27	50	
	AFFF	PF																						
a) Disruption by Wind	8	10																						
b) Stability Under Thermal Radiation	6	10																						
c) Stability Under Water Spray	8	10																						
d) Wicking Action	0	10																						
e) Burnback Rate	5	10																						
Subtotal	27	50																						
4. Effect of Terrain on Fire Control Time	38	45	45																					
5. Training Level Required (Ease of Application)	40	30	40																					
6. Compatibility of Agents	30	24	30																					
	<table border="1"> <thead> <tr> <th></th> <th>AFFF</th> <th>PF</th> </tr> </thead> <tbody> <tr> <td>a) Foam/Powder</td> <td>10</td> <td>8</td> </tr> <tr> <td>b) Halocarbons/Foams</td> <td>10</td> <td>10</td> </tr> <tr> <td>c) Between Qualified Product List Liquid Concentrates (Binary Mixtures)</td> <td>10</td> <td>6</td> </tr> <tr> <td>Subtotal</td> <td>30</td> <td>24</td> </tr> </tbody> </table>			AFFF	PF	a) Foam/Powder	10	8	b) Halocarbons/Foams	10	10	c) Between Qualified Product List Liquid Concentrates (Binary Mixtures)	10	6	Subtotal	30	24							
	AFFF	PF																						
a) Foam/Powder	10	8																						
b) Halocarbons/Foams	10	10																						
c) Between Qualified Product List Liquid Concentrates (Binary Mixtures)	10	6																						
Subtotal	30	24																						
7. Foam Stream Range	25	25	25																					
8. Foam Liquid Concentrate Storage Life (12-Month Period)	8	10	10																					
9. Effects of Temperature on Foam Quality	10	9	10																					
10. Effect of Water Hardness on Foam Quality and Firefighting Effectiveness	8	10	10																					
Grand Total	366	283	400																					

APPENDIX B

METHODS EMPLOYED TO DETERMINE SURFACE AND INTERFACIAL TENSION OF SOLUTIONS OF AFFF AGENTS ON A HYDROCARBON SUBSTRATE

The following experimental procedures were developed to determine the surface and interfacial tension and the film spread rate of solutions of the AFFF agents on Jet A fuel before foaming and of three equal sequential fractions of the solution which drained from the foam during aging.

PREPARATION OF SAMPLES.

Samples of the candidate AFFF agents are prepared by mixing the proper quantity (3- or 6-percent by volume) of the liquid concentrate with distilled water maintained at $70^{\circ} \pm 2^{\circ}$ F. A 200-milliliter (ml) sample of the experimental solution is poured into the large bowl of a kitchen mixer (Sunbeam Mixmaster Model 12C or equivalent) and beaten at a speed of 870 revolutions per minute (r/min) for exactly 3 minutes. During the mixing process, the bowl is made to rotate at approximately one revolution per second (r/s). After completion of the mixing cycle, the foam in the bowl is removed with a spatula and placed in the standard 1,400-ml foam container (reference 12) and screeded off, level with the rim. The foam container is then placed on a special stand having a slope downward of 1-inch per 12-inches toward the front. The solution samples draining from the foam are collected in 100-ml graduated cylinders by means of the drain cock provided under the front of the container. By this procedure three consecutive aliquot

samples of the solution draining from the foam were collected.

DETERMINATION OF THE SURFACE AND INTERFACIAL TENSION BETWEEN THE AFFF SOLUTIONS AND JET A FUEL.

The "Fisher Autotensionat" surface tension analyzer (reference 20) was employed to measure the surface tension of Jet A fuel and solutions of the AFFF agents as well as the interfacial tension between these two liquids.

The surface tension of individual samples of the AFFF solutions and Jet A fuel were determined at $70^{\circ} \pm 2^{\circ}$ F. Measurements were recorded on a Servo II, Model L1102S, No. 2 pen recorder in accordance with the equipment manufacturer's requirements (reference 20). All surface tension measurements were made using a du Nouy ring withdrawal rate of 0.05 in/min and a recorder chart speed of 1 in/min. A 5-minute stabilization period was allowed before each measurement was taken.

Determinations of the interfacial tension between the AFFF agents and Jet A fuel were performed by placing 35 ml of the AFFF solution in a 100-ml beaker and submerging the du Nouy ring well beneath the surface after which 35 ml of Jet A fuel was gently floated on the surface of the aqueous solution. At the conclusion of the 5-minute stabilization period at $70^{\circ} \pm 2^{\circ}$ F, the interfacial tension was measured in accordance with the manufacturers' specification (reference 20).

APPENDIX C

LABORATORY DETERMINATION OF THE COMPATIBILITY BETWEEN FIREFIGHTING FOAM LIQUID CONCENTRATES

Firefighting foam agents are generally procured on the basis of class, type, and cost. Therefore, the probability that agents produced by different manufacturers may be subject to mixing in various proportions during storage is increasing. Accordingly, a series of laboratory experiments was conducted to assess the projected storage life of mixtures of the three classes of foam agents employed at the two principal use concentrations (3 and 6 percent by volume).

The major parameters defining foam liquid compatibility were considered to include the pH value, the kinematic viscosity and the percentage of sediment in the liquid both before and after the aging cycle. The quality of foam produced by the various combinations of liquid concentrates was determined as a function of the expansion ratio and 25-percent solution drainage time.

The pH value of the solution was determined potentiometrically by means of a pH meter equipped with a glass and suitable reference electrode. Kinematic viscosity determinations were conducted in accordance with American Society for Testing and Materials (ASTM) method D-445-65 at $40^{\circ} \pm 0.1^{\circ}$ F for the AFFF agents and at $32^{\circ} \pm 0.1^{\circ}$ F

for both the protein foam (PF) and fluoroprotein foam (FPF) agents. The high temperature stability (accelerated aging tests) of the foam liquid concentrates was determined in accordance with Federal Specification O-F-555C under 3.10.2 High Temperature Stability, 149° F (65° C) and 4.7.5 Sedimentation.

The quality of foam produced by the aged foam liquids was determined by beating a 200-ml aqueous sample of the candidate agent of the proper concentration in the large bowl of a mixer (Sunbeam Mixmaster Model 12C or equivalent) at a speed of 870 revolutions per minute for 3 minutes, after which the foam was removed from the bowl and the expansion ratio and 25-percent solution drainage times were determined in accordance with NFPA No. 412 (reference 12).

The results of the foam liquid compatibility experiments are summarized for the 6-percent AFFF agents in tables C-1 and C-2 and in table C-3 for the 3-percent agents. The data indicating the compatibility between the 4.5-, 5-, and 6-percent FPF agents are presented in tables C-4 through C-7 and in tables C-8 and C-9 for the 3-percent agents. The compatibility between the two 3-percent PF liquids is indicated by the data in table C-10.

TABLE C-1. COMPATIBILITY BETWEEN 6-PERCENT AFFF LIQUID CONCENTRATES
IN ACCELERATED AGING TESTS

<u>Foam Agents</u>	<u>Foam Liquid Mixtures Percent By Volume</u>				
	0	25	50	75	100
FC-206	0	25	50	75	100
AER-O-WATER 6	100	75	50	25	0
pH (not aged) @ 75° F	7.21	--	--	--	7.80
Viscosity* (not aged)	3.81	--	--	--	4.08
Sediment % (aged)	<0.05	<0.05	<0.05	<0.05	<0.05
pH (aged) @ 75° F	7.22	7.25	7.30	7.33	7.48
Viscosity* (aged)	3.64	3.59	3.50	3.66	3.62
Foam Expansion Ratio	18.84	20.35	20.74	20.59	19.53
Foam Drainage Time 25% (min:sec)	6:50	7:24	8:00	7:46	7:32
AER-O-WATER 6	0	25	50	75	100
LORCON 6	100	75	50	25	0
pH (not aged) @ 75° F	6.61	--	--	--	7.21
Viscosity* (not aged)	6.64	--	--	--	3.81
Sediment % (aged)	<0.05	<0.05	<0.05	<0.05	<0.05
pH (aged) @ 75° F	6.78	6.83	6.99	7.13	7.22
Viscosity* (aged)	5.60	5.10	4.80	4.18	3.64
Foam Expansion Ratio	18.52	18.02	20.47	21.41	18.84
Foam Drainage Time 25% (min:sec)	6:13	6:16	7:36	7:50	6:50
FC-206	0	25	50	75	100
LORCON 6	100	75	50	25	0
pH (not aged) @ 75° F	6.61	--	--	--	7.8
Viscosity* (not aged)	6.64	--	--	--	4.08
Sediment % (aged)	<0.05	<0.05	<0.05	<0.05	<0.05
pH (aged) @ 75° F	6.78	6.88	6.93	7.16	7.48
Viscosity* (aged)	5.6	5.21	4.79	4.06	3.62
Foam Expansion Ratio	18.52	21.05	20.65	22.47	19.53
Foam Drainage Time 25% (min:sec)	6:13	7:00	6:40	7:40	7:32

* Kinematic Viscosity in centistokes at 40° F

TABLE C-2. COMPATIBILITY BETWEEN 6-PERCENT AFFF LIQUID CONCENTRATES
IN ACCELERATED AGING TESTS

<u>Foam Agents</u>	<u>Foam Liquid Mixtures Percent By Volume</u>				
	0	25	50	75	100
FC-206	0	25	50	75	100
ANSUL 6	100	75	50	25	0
pH (not aged) @ 75° F	8.2	--	--	--	7.8
Viscosity* (not aged)	4.16	--	--	--	4.08
Sediment % (aged)	<0.05	<0.05	<0.05	0	<0.05
pH (aged) @ 75° F	8.30	8.10	8.10	7.80	7.48
Viscosity* (aged)	4.28	4.36	4.85	4.19	3.62
Foam Expansion Ratio	16.85	18.35	18.92	20.23	19.53
Foam Drainage Time 25% (min:sec)	7:57	9:52	10:50	10:00	7:32
AER-O-WATER 6	0	25	50	75	100
ANSUL 6	100	75	50	25	0
pH (not aged) @ 75° F	8.2	--	--	--	7.21
Viscosity* (not aged)	4.16	--	--	--	3.81
Sediment % (aged)	<0.05	<0.05	<0.05	<0.05	<0.05
pH (aged) @ 75° F	8.30	7.90	7.90	7.85	7.22
Viscosity* (aged)	4.28	4.07	4.24	4.19	3.64
Foam Expansion Ratio	16.85	17.81	18.37	18.11	18.84
Foam Drainage Time 25% (min:sec)	7:57	8:41	9:20	7:43	6:50
LORCON 6	0	25	50	75	100
ANSUL 6	100	75	50	25	0
pH (not aged) @ 75° F	8.2	--	--	--	6.61
Viscosity* (not aged)	4.16	--	--	--	6.64
Sediment % (aged)	<0.05	<0.05	<0.05	<0.05	<0.05
pH (aged) @ 75° F	8.30	7.70	7.35	7.00	6.78
Viscosity* (aged)	4.28	4.61	5.08	5.73	5.60
Foam Expansion Ratio	16.85	17.65	17.50	17.07	18.52
Foam Drainage Time 25% (min:sec)	7:57	8:51	7:50	6:41	6:13

* Kinematic Viscosity in centistokes at 40° F

TABLE C-3. COMPATIBILITY BETWEEN 3-PERCENT AFFF LIQUID CONCENTRATES
IN ACCELERATED AGING TESTS

Foam Agents	Foam Liquid Mixtures Percent By Volume				
	0	25	50	75	100
FC-203					
AER-O-WATER 3	100	75	50	25	0
pH (not aged) @ 75° F	8.12	--	--	--	7.59
Viscosity* (not aged)	23.58	--	--	--	12.98
Sediment % (aged)	<0.05	<0.05	<0.05	0	<0.05
pH (aged) @ 75° F	8.31	8.25	8.19	8.01	7.68
Viscosity* (aged)	20.21	18.39	14.76	13.54	11.69
Foam Expansion Ratio	20.60	20.23	20.93	21.77	21.37
Foam Drainage Time	10:30	9:58	10:05	9:57	9:59
25% (min:sec)					
FC-203					
AER-O-WATER PLUS 3	100	75	50	25	0
pH (not aged) @ 75° F	8.11	--	--	--	7.59
Viscosity* (not aged)	49.06	--	--	--	12.98
Sediment % (aged)	<0.05	<0.05	<0.05	<0.05	<0.05
pH (aged) @ 75° F	8.28	8.10	8.00	7.90	7.68
Viscosity* (aged)	42.99	27.23	21.43	11.91	11.69
Foam Expansion Ratio	18.28	17.95	20.00	21.41	21.37
Foam Drainage Time	9:15	8:47	9:40	8:46	9:59
25% (min:sec)					
AER-O-WATER 3					
AER-O-WATER PLUS 3	100	75	50	25	0
pH (not aged) @ 75° F	8.11	--	--	--	8.12
Viscosity* (not aged)	49.06	--	--	--	23.58
Sediment % (aged)	<0.05	<0.05	<0.05	<0.05	<0.05
pH (aged) @ 75° F	8.28	8.20	8.20	8.20	8.31
Viscosity* (aged)	42.99	33.48	31.03	24.06	20.21
Foam Expansion Ratio	18.28	19.86	19.53	19.58	20.60
Foam Drainage Time	9:15	10:09	9:52	9:47	10:30
25% (min:sec)					

* Kinematic Viscosity in centistokes at 40° F

TABLE C-4. COMPATIBILITY BETWEEN 4.5-, 5-, AND 6-PERCENT FLUOROPROTEIN LIQUID CONCENTRATED IN ACCELERATED AGING TESTS

<u>Foam Agents</u>	<u>Foam Liquid Mixtures Percent By Volume</u>				
AER-O-FOAM XL-6	0	25	50	75	100
PYRENE Plus F	100	75	50	25	0
pH (not aged) @ 75° F	7.00	--	--	--	7.10
Viscosity* (not aged)	11.26	--	--	--	30.17
Sediment % (aged)	1.75	1.90	1.30	0.38	<0.05
pH (aged) @ 75° F	6.6	6.75	6.85	6.95	7.15
Viscosity* (aged)	12.99	14.86	21.28	28.22	41.13
Foam Expansion Ratio	13.42	14.00	12.01	12.50	11.20
Foam Drainage Time 25% (min:sec)	15:13	18:32	19:51	21:51	19:42
LORCON K	0	25	50	75	100
LANGUS FP-570	100	75	50	25	0
pH (not aged) @ 75° F	6.5	--	--	--	6.19
Viscosity* (not aged)	15.27	--	--	--	55.92
Sediment % (aged)	0.05	0.60	0.50	0.16	0.10
pH (aged) @ 75° F	6.55	6.40	6.30	6.25	6.20
Viscosity* (aged)	13.58	19.30	27.18	35.04	55.81
Foam Expansion Ratio	12.50	12.54	11.73	11.36	14.00
Foam Drainage Time 25% (min:sec)	22:37	23:48	19:55	18:09	28:27
LORCON K	0	25	50	75	100
LORCON FP	100	75	50	25	0
pH (not aged) @ 75° F	6.19	--	--	--	6.19
Viscosity* (not aged)	36.99	--	--	--	55.92
Sediment % (aged)	2.80	1.80	0.65	0.25	0.10
pH (aged) @ 75° F	6.10	6.10	6.10	6.10	6.20
Viscosity* (aged)	32.24	33.51	46.64	49.88	55.81
Foam Expansion Ratio	11.86	13.01	11.82	11.78	14.00
Foam Drainage Time 25% (min:sec)	19:02	22:34	23:21	28:52	28:27

* Kinematic Viscosity in centistokes at 32° F

TABLE C-5. COMPATIBILITY BETWEEN 4.5-, 5-, AND 6-PERCENT FLUOROPROTEIN LIQUID CONCENTRATED IN ACCELERATED AGING TESTS

<u>Foam Agents</u>	<u>Foam Liquid Mixtures Percent By Volume</u>				
AER-O-FOAM XL-6	0	25	50	75	100
ANGUS FP-570	100	75	50	25	0
pH (not aged) @ 75° F	6.50	--	--	--	7.10
Viscosity* (not aged)	15.27	--	--	--	30.17
Sediment % (aged)	0.05	0.13	0.15	0.14	<0.05
pH (aged) @ 75° F	6.55	6.78	6.90	7.00	7.15
Viscosity* (aged)	13.58	18.91	24.46	32.97	41.13
Foam Expansion Ratio	12.50	11.57	11.57	11.36	11.20
Foam Drainage Time 25% (min:sec)	22:37	20:40	15:32	20:48	19:42
AER-O-FOAM XL-6	0	25	50	75	100
LORCON K	100	75	50	25	0
pH (not aged) @ 75° F	6.19	--	--	--	7.10
Viscosity* (not aged)	55.92	--	--	--	30.17
Sediment % (aged)	0.10	0.15	0.07	0.05	<0.05
pH (aged) @ 75° F	6.20	6.50	6.74	6.99	7.15
Viscosity* (aged)	55.81	56.29	46.40	53.93	41.13
Foam Expansion Ratio	14.00	11.29	10.61	12.73	11.20
Foam Drainage Time 25% (min:sec)	28:27	25:36	12:15	23:03	19:42
AER-O-FOAM XL-6	0	25	50	75	100
LORCON FP	100	75	50	25	0
pH (not aged) @ 75° F	6.19	--	--	--	7.10
Viscosity* (not aged)	36.99	--	--	--	30.17
Sediment % (aged)	2.80	0.25	0.11	<0.05	<0.05
pH (aged) @ 75° F	6.10	6.55	6.78	6.99	7.15
Viscosity* (aged)	32.24	33.70	37.21	42.01	41.13
Foam Expansion Ratio	11.86	13.08	11.97	12.50	11.20
Foam Drainage Time 25% (min:sec)	19:02	26:31	16:49	21:37	19:42

* Kinematic Viscosity in centistokes at 32° F

TABLE C-6. COMPATIBILITY BETWEEN 4.5-, 5-, AND 6-PERCENT FLUOROPROTEIN LIQUID CONCENTRATED IN ACCELERATED AGING TESTS

<u>Foam Agents</u>	<u>Foam Liquid Mixtures Percent By Volume</u>				
	0	25	50	75	100
LORCON K	0	25	50	75	100
PYRENE Plus F	100	75	50	25	0
pH (not aged) @ 75° F	7.00	--	--	--	6.19
Viscosity* (not aged)	11.26	--	--	--	55.92
Sediment % (aged)	1.75	2.50	2.30	0.80	0.10
pH (aged) @ 75° F	6.60	6.45	6.30	6.15	6.20
Viscosity* (aged)	12.99	13.83	23.48	36.20	55.81
Foam Expansion Ratio	13.42	13.15	11.57	11.78	14.00
Foam Drainage Time 25% (min:sec)	15:13	17:28	16:10	18:26	28:27
LORCON FP	0	25	50	75	100
ANGUS FP-570	100	75	50	25	0
pH (not aged) @ 75° F	6.50	--	--	--	6.19
Viscosity* (not aged)	15.27	--	--	--	36.99
Sediment % (aged)	0.05	0.30	1.30	2.10	2.80
pH (aged) @ 75° F	6.55	6.35	6.30	6.20	6.10
Viscosity* (aged)	13.58	18.20	20.58	23.45	32.24
Foam Expansion Ratio	12.50	12.58	11.94	11.19	11.86
Foam Drainage Time 25% (min:sec)	22:37	22:40	16:11	20:23	19:02
LORCON FP	0	25	50	75	100
PYRENE Plus F	100	75	50	25	0
pH (not aged) @ 75° F	7.00	--	--	--	6.19
Viscosity* (not aged)	11.26	--	--	--	36.99
Sediment % (aged)	1.75	1.50	2.20	2.80	2.80
pH (aged) @ 75° F	6.60	6.48	6.35	6.28	6.10
Viscosity* (aged)	12.99	14.64	18.15	23.39	32.24
Foam Expansion Ratio	13.42	13.77	13.18	12.38	11.86
Foam Drainage Time 25% (min:sec)	15:13	18:33	22:01	22:30	19:02

* Kinematic Viscosity in centistokes at 32° F

TABLE C-7. COMPATIBILITY BETWEEN 4.5-, 5-, AND 6-PERCENT FLUOROPROTEIN LIQUID CONCENTRATED IN ACCELERATED AGING TESTS

<u>Foam Agents</u>	<u>Foam Liquid Mixtures Percent By Volume</u>				
PYRENE Plus F	0	25	50	75	100
ANGUS FP-570	100	75	50	25	0
pH (not aged) @ 75° F	6.50	--	--	--	7.00
Viscosity* (not aged)	15.27	--	--	--	11.27
Sediment % (aged)	0.05	0.35	0.75	1.10	1.75
pH (aged) @ 75° F	6.55	6.40	6.45	6.50	6.60
Viscosity* (aged)	13.58	13.82	13.47	14.05	12.99
Foam Expansion Ratio	12.50	12.90	13.26	14.23	13.42
Foam Drainage Time 25% (min:sec)	22:37	13:38	10:17	14:28	15:13

* Kinematic Viscosity in Centistokes at 32° F

TABLE C-8. COMPATIBILITY BETWEEN 3-PERCENT FLUOROPROTEIN LIQUID
CONCENTRATED IN ACCELERATED AGING TESTS

<u>Foam Agents</u>	<u>Foam Liquid Mixtures Percent By Volume</u>				
	0	25	50	75	100
AER-O-FOAM XL-3	0	25	50	75	100
ANGUS FP-70	100	75	50	25	0
pH (not aged) @ 75° F	6.8	--	--	--	6.65
Viscosity* (not aged)	69.18	--	--	--	106.42
Sediment % (aged)	<0.05	0.06	0.05	0.09	0.10
pH (aged) @ 75° F	6.85	6.75	6.70	6.70	6.70
Viscosity* (aged)	60.46	81.14	91.07	115.43	109.66
Foam Expansion Ratio	11.23	11.26	11.59	10.97	11.25
Foam Drainage Time 25% (min:sec)	13:18	15:57	14:08	17:11	22:34
AER-O-FOAM XL-3	0	25	50	75	100
MEARL	100	75	50	25	0
pH (not aged) @ 75° F	6.65	--	--	--	6.65
Viscosity* (not aged)	123.36	--	--	--	106.42
Sediment % (aged)	0.05	2.50	2.45	1.10	0.10
pH (aged) @ 75° F	6.62	6.68	6.70	6.72	6.70
Viscosity* (aged)	88.6	97.82	105.49	116.15	109.66
Foam Expansion Ratio	10.39	10.20	9.84	9.91	11.25
Foam Drainage Time 25% (min:sec)	20:35	16:04	19:53	14.45	22:34
AER-O-FOAM XL-3	0	25	50	75	100
LORCON FP 3	100	75	50	25	0
pH (not aged) @ 75° F	6.35	--	--	--	6.65
Viscosity* (not aged)	88.9	--	--	--	106.42
Sediment % (aged)	2.70	0.70	0.20	0.15	0.10
pH (aged) @ 75° F	6.42	6.50	6.62	6.68	6.70
Viscosity* (aged)	65.10	71.04	83.54	95.13	109.66
Foam Expansion Ratio	10.74	10.75	9.97	10.30	11.25
Foam Drainage Time 25% (min:sec)	14:20	14:07	10:56	10:18	22:34

* Kinematic Viscosity in centistokes at 32° F

TABLE C-9. COMPATIBILITY BETWEEN 3-PERCENT FLUOROPROTEIN LIQUID
CONCENTRATED IN ACCELERATED AGING TESTS

<u>Foam Agents</u>	<u>Foam Liquid Mixtures Percent By Volume</u>				
ANGUS FP-70	0	25	50	75	100
MEARL	100	75	50	25	0
pH (not aged) @ 75° F	6.65	--	--	--	6.80
Viscosity* (not aged)	123.36	--	--	--	69.18
Sediment % (aged)	0.05	3.60	2.40	1.20	<0.05
pH (aged) @ 75° F	6.62	6.71	6.72	6.75	6.85
Viscosity* (aged)	88.60	111.91	69.18	71.10	60.46
Foam Expansion Ratio	10.39	11.34	10.62	10.74	11.23
Foam Drainage Time 25% (min:sec)	20:35	15:37	15:00	12:15	13:18
ANGUS FP-70	0	25	50	75	100
LORCON FP 3	100	75	50	25	0
pH (not aged) @ 75° F	6.35	--	--	--	6.80
Viscosity* (not aged)	88.90	--	--	--	69.18
Sediment % (aged)	2.70	1.70	0.90	0.25	<0.05
pH (aged) @ 75° F	6.42	6.54	6.63	6.75	6.85
Viscosity* (aged)	65.10	64.64	62.10	55.84	60.46
Foam Expansion Ratio	10.74	10.08	10.51	10.99	11.23
Foam Drainage Time 25% (min:sec)	14:20	7:17	12:50	16:06	13:18
MEARL	0	25	50	75	100
LORCON FP 3	100	75	50	25	0
pH (not aged) @ 75° F	6.35	--	--	--	6.65
Viscosity* (not aged)	88.90	--	--	--	123.36
Sediment % (aged)	2.70	0.60	2.00	3.00	0.05
pH (aged) @ 75° F	6.42	6.51	6.55	6.60	6.62
Viscosity* (aged)	65.10	82.23	88.21	99.74	88.60
Foam Expansion Ratio	10.74	10.85	10.30	10.77	10.39
Foam Drainage Time 25% (min:sec)	14:20	10:50	8:26	7:40	20:35

* Kinematic Viscosity in centistokes at 32° F

TABLE C-10. COMPATIBILITY BETWEEN 3-PERCENT PROTEIN FOAM LIQUID
CONCENTRATES IN ACCELERATED AGING TESTS

<u>Foam Agents</u>	<u>Foam Liquid Mixtures Percent By Volume</u>				
AER-O-FOAM 3	0	25	50	75	100
MEARL	100	75	50	25	0
pH (not aged) @ 75° F	6.60	--	--	--	6.80
Viscosity* (not aged)	131.61	--	--	--	135.47
Sediment % (aged)	0.05	<0.05	<0.05	<0.05	<0.05
pH (aged) @ 75° F	6.50	6.60	6.70	6.80	6.90
Viscosity* (aged)	109.65	136.31	87.84	118.78	106.98
Foam Expansion Ratio	10.29	10.69	9.59	10.04	9.52
Foam Drainage Time 25% (min:sec)	18:44	22:57	12:34	18:56	12:24

* Kinematic Viscosity in centistokes at 32° F

APPENDIX D

LABORATORY FOAM-POWDER COMPATIBILITY TEST

This test method is a modification of that required in reference 16 to determine the compatibility between Purple-K powder and protein foam, and is concerned primarily with the addition of the important parameter of fuel to the system. Combinations of foams and dry-chemical powders meeting the requirements of the modified test have shown an acceptable degree of compatibility in terms of foam blanket stability and depth in full-scale fire modeling experiments.

TEST PROCEDURE.

A sample of the experimental foam solution is prepared by mixing the proper quantity of foam liquid concentrate with the required volume of fresh water at $70^{\circ} \pm 2^{\circ}$ F. Two-hundred milliliters (ml) of this solution is poured into the large bowl of a kitchen-mixer (Sunbeam Mixmaster Model 12C or equivalent) and beaten at a speed of 870 r/min for exactly 2 minutes. During the mixing process, the bowl is made to rotate at approximately 1 r/s. At the end of the 2-minute foam-mixing cycle and with the mixer running, a 10-gram (g) ± 0.1 -g sample of the test powder is sprinkled onto the surface of the foam in the bowl and allowed to mix for an additional 30 seconds, after which a 15-ml sample of the test fuel is added and the mixing continued for another 30 seconds. The foam mixture remaining in the bowl is removed with the aid of a spatula into the standard foam

container and screeded-off level with the rim. The pan is then placed on a stand having a slope of 1 inch in 12 inches toward the front and constructed so that the top of the pan and the foam surface is $2 \frac{3}{8}$ inches below a radiating metal surface. The heat source consists of a 1,000-watt electrical hotplate with a 7-inch-diameter face (Edwin L. Wiegard Co., Pittsburgh, Pa., Model ROPH-100 or equivalent) mounted upside down over a 6 1/2-inch-diameter hole in a 1/2-inch-thick piece of transite. The temperature of the hotplate face is maintained at $1,000^{\circ}$ F by varying the current input with a Variac[®] transformer. To determine this temperature, it is convenient to use a thermocouple embedded in the hotplate. As the pan containing the foam is inserted, a sheet of transite 8-inches-square and 1/2-inch-thick is placed beneath the pan to insulate it from the hot stand. A 100-ml graduated cylinder is placed under the draw-off tube of the foam container, and the liquid draining from the foam is measured at 30-second intervals. From these data, the time required to collect 25 ml of solution is determined.

The results of experiments performed in accordance with this modified procedure using a variety of foam and dry-chemical agents indicated that if the time required to collect 25 ml of foam solution was 2.0 minutes or more, an acceptable degree of compatibility would be obtained under conditions involving a high degree of turbulence of the burning fuel, foam, and dry-chemical power.

APPENDIX E

DRY-CHEMICAL POWDER MANUFACTURERS

<u>Type Base Powder</u>	<u>Manufacturer</u>
Potassium Chloride (Super K)	Pyro Chemicals Inc., Boonton, New Jersey, USA
Potassium Bicarbonate (Purple-K Powder, PKP)	The Ansul Company, Marinette, Wisconsin, USA
Sodium Bicarbonate (Foam Compatible, CDC)	Chemical Concentrates Corporation, Fort Washington, Pennsylvania, USA
Monoammonium Phosphate (Multipurpose, ABC)	The Ansul Company, Marinette, Wisconsin, USA
Monnex	Imperial Chemical Industries America, Inc., Wilmington, Delaware, USA

APPENDIX F

**EXAMPLES OF TWO SPECIALIZED FIREFIGHTING FOAM AGENTS AND THE SOLUTION
APPLICATION RATES REQUIRED TO EXTINGUISH SOME OF THE MORE IMPORTANT
INDUSTRIAL POLAR (WATER SOLUBLE) CHEMICALS**

TABLE F-1. RECOMMENDED APPLICATION RATES FOR COMMON POLAR SOLVENT
FUELS RATES GIVEN IN GAL/MIN/FT² (L/MIN/M²)*

FLAMMABLE LIQUID	AERO-O-WATER PSL		AER-O-FOAM 99
	Nozzles, Monitors or Overhead Spray		Nozzles, Monitors or Overhead Spray-Spills of 1 inch or Less
	Proportioning @ 10% @ 6%		6% Proportioning Only
Alcohols			
Isopropanol (99%)	0.20 (8)	0.25 (10)	0.20 (8)
Methanol	.16 (6)	.20 (8)	.16 (6)
N-Propanol	.12 (5)	.16 (6)	.16 (6)
N-Butanol	.12 (5)	.16 (6)	.16 (6)
T-Butyl Alcohol	.30 (12)	.35 (14)	.25 (10)
Isodecanol	.10 (4)	.16 (6)	.16 (6)
Esters			
Ethyl Acetate	.10 (4)	.16 (6)	.16 (6)
N-Propyl Acetate	.10 (4)	.16 (6)	.16 (6)
Butyl Acetate	.10 (4)	.16 (6)	.20 (8)
Methyl Amyl Acetate	.10 (4)	.16 (6)	.16 (6)
Methyl Acrylate	.10 (4)	.16 (6)	.16 (6)
Ketones			
Acetone	.20 (8)	.25 (10)	.25 (10)
Methyl Ethyl Ketone	.20 (8)	.25 (10)	.20 (8)
Methyl Isobutyl Ketone	.10 (4)	.16 (6)	.25 (10)
Mixed Alcohol Solvents			
SDA — 1-200 PF	.16 (6)	.20 (8)	.20 (8)
SDA — 25-190°	.16 (6)	.20 (8)	.20 (8)
Jaysol — SDS	.20 (8)	.25 (10)	.20 (8)
Glycol Ether	.10 (4)	.16 (6)	.16 (6)
Propionaldehyde	.16 (6)	.20 (8)	.16 (6)
Hydrocarbons	.16 (6)	@ 6%	.16 (6) (All Spills)

* Extracted from National Foam System Inc. Engineering Manual

APPENDIX G

STABILITY OF PREFORMED FOAMS ON POLAR SOLVENTS

It is known that the preformed foams produced by AFFF, fluoroprotein and protein agents show a very low order of stability toward polar solvents. However, an estimate of the relative stability of the foams may be made by employing the following procedure:

OBJECTIVE.

The objective of the test is to determine the maximum residence time of a foam blanket on methanol-water mixtures of 100, 75, 50, 25 percent by volume.

TEST PROCEDURE.

A sample of the experimental foam solution is prepared by mixing the proper quantity of foam liquid concentrate with fresh water at $70^{\circ} \pm 2^{\circ}$ F. Two hundred milliliters (ml)

of this solution are poured into the large bowl of a kitchen mixer (Sunbeam Mixmaster Model 12C or equivalent) and beaten at a speed of 870 revolutions per minute (r/min) for exactly 3 minutes. During the mixing process, the bowl is made to rotate at approximately 1 revolution per second (r/s).

After mixing, the foam is immediately poured onto the surface of 600 ml of the test polar-solvent solution contained in a 6-inch-diameter crystallizing dish, and the foam is screeded-off level with the rim.

The stability of the foam is measured in terms of the elapsed time after the foam is screeded-off level with the rim of the dish to the time any portion of the liquid surface is exposed as a consequence of foam decomposition.

APPENDIX H
METHOD FOR EVALUATING THE FIRE EXTINGUISHING EFFECTIVENESS OF
FIREFIGHTING FOAM AGENTS

TEST PROCEDURE.

The test method used to compare the effectiveness of the extinguishing agents was a modification of the test required in section 3.13 (Foam Requirements) of Federal Specification O-F-555c. In this section of the specification the fire requirements are determined in terms of the fire performance, foam fluidity, foam blanket sealability, and the foam burnback resistance. The fire extinguishing tests were conducted in a 10-foot-deep test tank using a standard 6-gal/min foam nozzle as provided for in the federal specification under the quality assurance provisions.

The procedure requires that the 100-square-foot test tank be filled to a depth of 10.5 inches with water upon which 100 gallons of Jet A aviation fuel was floated. The fuel was then ignited and allowed a preburn time of 60 seconds after which foam was discharged across the tank to impinge in the approximate center of the downwind side for a period of 5 minutes, and the times required to obtain fire control and extinguishment were recorded. Fire control was judged to be the time required for 90 percent of the fuel surface to be covered by foam, and the fire extinguishment time was recorded as the total elapsed time until all flames were extinguished with the tank.

The fuel vapor sealability of the foam blanket was evaluated twice by means of a lighted torch after completion of the foam discharge. The first torching was made by passing the torch continuously for a period of 60 seconds over the blanket without touching or penetrating the surface starting 10 minutes after foam application was concluded. Fourteen minutes after completion of foam application, the torch was passed over the foam blanket for 1 minute with the torch touching but not penetrating the blanket by more than 1/2 inch.

Immediately following the completion of the sealability test, a modification of the standard burnback test was performed by cutting a hole 6 inches in diameter in the approximate center of the foam blanket. A metal container 6 inches in diameter and 6 inches deep containing burning JP-4 fuel was then lowered into the opening level with the interface between the fuel and foam blanket. The container and surrounding fuel was then permitted to burn for 5 minutes after which the burnback area was determined.

The compliance of foam agents with the federal specification is judged on the basis of achieving fire control within 4 minutes, fire extinguishment within 5 minutes, and a maximum burnback area of 20 inches square.

APPENDIX I
THE THERMAL STABILITY OF MECHANICAL FOAM BLANKETS

This section contains a description of the test procedure and equipment employed to evaluate the relative thermal stability of mechanical foam blankets.

TEST METHOD.

The test method is a variation of the standard fire tests procedure contained in the Federal specification (reference 1) of this report and was made by introducing a suitable source of flames and radiant heat into the fire test tank after the fire had been extinguished.

TEST EQUIPMENT.

The basic equipment comprised the fire test tank and standard 6-gal/min foam nozzle specified in reference 1.

A means of introducing a source of intense thermal radiation into the center of the 10-foot by 10-foot by 1-foot steel tank was made by erecting a 4-foot by 4-foot by 3/8-inch-thick steel plate in a horizontal position, 8 inches above a 17-inch-high section of a 55-gallon steel drum.

A profile view of the fire test bed is shown in figure 1-1.

FIRE TEST PROCEDURE.

The steel test tank was filled to a depth of 11 inches with water upon which 100 gallons of Jet A fuel was floated. The fuel was then ignited and given a preburn time of 60 seconds. Foam was discharged onto the fire for a total time of 10 minutes, and the time to obtain fire control and extinguishment were recorded. Fire control was judged to be the time required for 90 percent of the fuel surface to be covered by foam. The fire extinguishment time was recorded as the total elapsed time from the start of foam application until all flames were extinguished within the tank. At the conclusion of the 10-minute foam application time, 5 gallons of Jet A fuel were placed in the drum section in the center of the tank and ignited. The time required for the fuel outside the drum section to ignite was recorded as the reignition time and was considered to be a measure of the foam blanket stability.

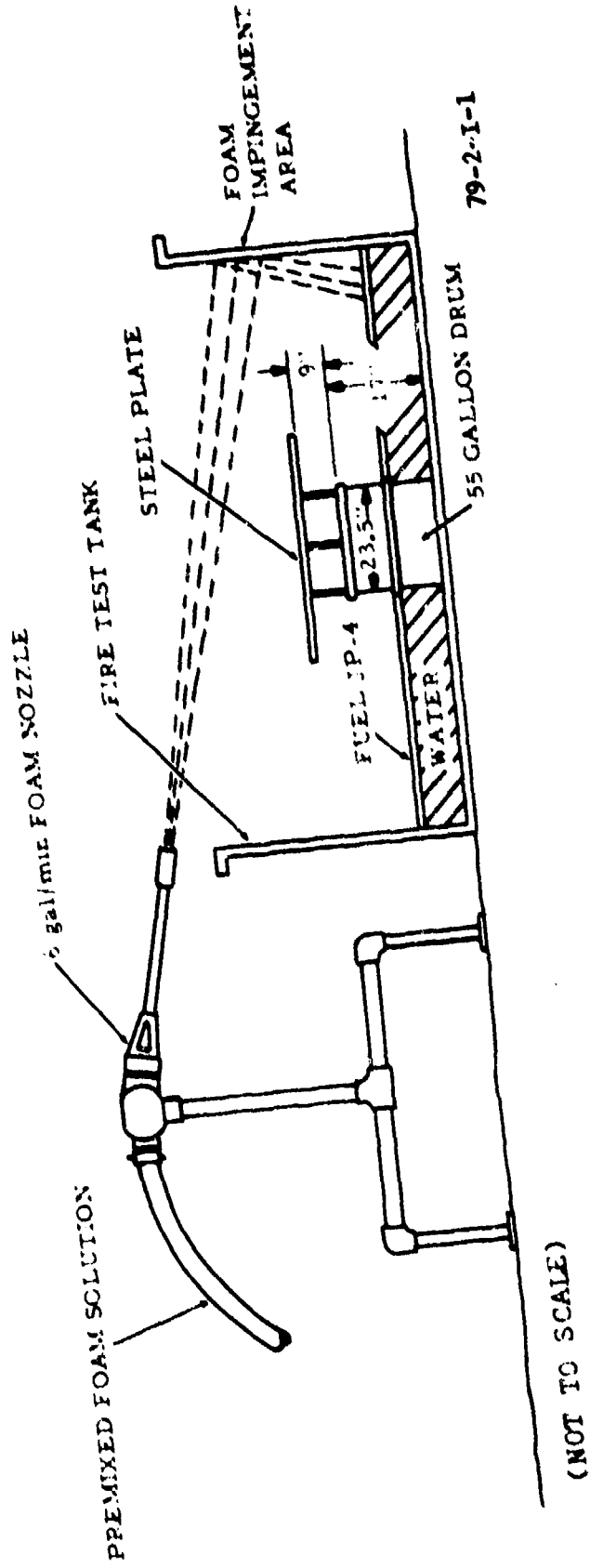


FIGURE I-1. PROFILE VIEW OF THE FIRE TEST BED TO DETERMINE THE THERMAL STABILITY OF MECHANICAL FOAM BLANKETS

APPENDIX J
THE EFFECT OF TERRAIN ON THE FIRE CONTROL AND EXTINGUISHMENT
TIMES FOR JET A FUEL FIRES

This section contains a description of the test procedure and equipment employed in a determination of the effects of different terrains on the fire control and extinguishment of Jet A fuel fires.

TEST METHOD.

This was a new test method, in which fire control and extinguishment tests were performed in 10-foot by 10-foot open pits. The terrains selected for evaluation were confined within this area by 12-inch-high earthen dikes.

Foam was dispensed from an air-aspirating nozzle positioned directly above the dike, on the upwind side of the fire pit, so as to impinge on a steel backboard on the opposite side and flow back over the burning area to extinguish the fire.

TEST EQUIPMENT AND FOAM AGENTS.

The mechanical equipment comprised the small-scale 6-gal/min mechanical foam nozzle described in reference 1 mounted on a suitable monitor stand and a 4-foot by 4-foot steel backboard and stand.

The agents evaluated by this procedure included AFFF, fluoro-protein, and protein foam of the 3- and 6-percent types. To assure accurate solution concentrations, all liquids were premixed with potable water in the required concentration.

TEST PROCEDURE.

Three square pits 1 foot by 10 feet by 10 feet were constructed within the 200-foot-diameter fire test bed. Each pit was filled with a different material to simulate a particular naturally occurring surface structure. These included (1) a 3-inch-thick layer of traprock to simulate a rocky terrain; (2) a 3-inch-thick layer of fine sand; and (3) grass-covered sod, studded symmetrically on 2-foot centers with 16 pine boards, 2 inches by 2 inches by 24 inches high, to simulate a woodland area.

Each pit was saturated uniformly with 100 gallons of Jet A fuel just prior to ignition. The basis for comparison was the time required to control and extinguish a pit of similar size wherein the Jet A fuel was floated on a water surface. A preburn time of 1 to 2 minutes was allowed before foam application was started, depending upon the type of terrain.

Foam was applied to the test pits by directing a solid stream from the upwind side of the fire so as to impinge on the center of a 4-foot by 4-foot steel backboard located on the downwind side of the pit. Foam was therefore required to flow back across the pit to effect fire extinguishment. The time necessary to obtain fire control and extinguishment was determined. Fire control was estimated to be the time required for 90 percent of the fire surface to be covered by foam.

Extinguishment time was recorded as the total elapsed time until all flames were extinguished.

Sufficient premixed foam solution was available for approximately 15 minutes

of foam discharge. Therefore, if the foam solution was exhausted before total fire extinguishment was obtained, only the time of total foam discharge was recorded.

**APPENDIX K
ELECTRONIC FIRE-MONITORING EQUIPMENT**

The instrumentation employed for the required parametric measurements consisted of radiometers and cameras. Thermal data were recorded on a Speed Servo 11, two-channel crossover potentiometer analog recorder, model L 1102S, manufactured by the Esterline Angus Instrument Corporation and was equipped with an event marker which was manually activated when foam was discharged.

Two heat flux transducers manufactured by Heat Technology Laboratory Inc., Model GRW 20-64D-SP, were mounted on steel poles and positioned on the diameter of the fire pits at right angles to the wind. These radiometers measured the radiant heat flux and were rated at 10 ± 1.5 millivolts (mV) at 15 Btu/ft²-sec. The angle of view was 120°. Each unit was provided with a calibration curve by the manufacturer.

APPENDIX L
PHOTOGRAPHIC TEST PLAN

Each full-scale outdoor fire-modeling experiment was monitored by two 16-mm Lo Cam motion picture instrumentation cameras, both equipped with a 15-mm lens exposing Ektachrome Commercial color film, type 7252, at 24 frames per second operated by one photographer each from fixed, elevated positions strategically located around the fire test bed. An elapsed-time clock, graduated in minutes and seconds, was within the line of sight of each camera. The experiments required the instrumentation cameras to start operating 0.5 minutes prior to fuel ignition and to continue running till the end of foam agent discharge.

Documentation coverage of the fire tests was provided from a 16-mm Arriflex motion picture camera

equipped with a 12-mm to 120-mm Angenieux zoom lens exposing Ektachrome Commercial color film, type 7252, at 24 frames per second. This camera was operated by one photographer from various positions around the fire test bed selected at his discretion.

One still photographer shot a minimum of six different exposures marking critical events before, during, and after each full-scale fire-modeling experiment using a 120-mm Mamiya RB-67 camera equipped with a 90-mm Mamiya/Sekor lens exposing Veri-Color II (VPS) roll film. The exposures provided 8- by 10-inch glossy color prints, 2- by 2-inch color slides, and 8- by 10-inch color viewgraphs of each full-scale fire-modeling experiment.