AD-A061 090 NATIONAL AVIATION FACILITIES EXPERIMENTAL CENTER ATL--ETC F/G 13/12
FULL-SCALE FIRE MODELING TESTS OF A COMPACT RAPID RESPONSE FOAM--ETC(U)
OCT 78 G B GEYER, L M NERI, C H URBAN

UNCLASSIFIED FAA-NA-78-24 FAA/RD-78/105 NL

1 OF 1
ADA
061090

END
DATE
FILMED
2-79
DDC

Report No. FAA-RD-78-105

LEVEL II

75th ANNIVERSARY OF POWERED FLIGHT 1903-1978

FULL-SCALE FIRE MODELING TESTS OF A COMPACT RAPID RESPONSE FOAM AND DRY CHEMICAL POWDER DISPENSING SYSTEM

George B. Geyer
Lawerence M. Neri
Charles H. Urban

DEPARTMENT OF TRANSPORTATION UNITED STATES OF AMERICA

OCTOBER 1978

FINAL REPORT

Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161.

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Systems Research & Development Service
Washington, D.C. 20590

NOTICE

(18) FAA/RD (19) 78/105

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FAA-RD-78-105		

4. Title and Subtitle	5. Report Date
(6) FULL-SCALE FIRE MODELING TESTS OF A COMPACT RAPID RESPONSE FOAM AND DRY CHEMICAL POWDER DISPENSING SYSTEM	(11) Oct[redacted] 1978
	6. Performing Organization Code
	8. Performing Organization Report No.
7. Author(s): (10) George B. Geyer, Lawrence M. Neri, [redacted] Charles H. Urban	(14) FAA-NA-78-24
9. Performing Organization Name and Address: Federal Aviation Administration, National Aviation Facilities Experimental Center, Atlantic City, New Jersey 08405	10. Work Unit No. (TRAIS)
	11. Contract or Grant No. 081-431-100
12. Sponsoring Agency Name and Address: U.S. Department of Transportation, Federal Aviation Administration, Systems Research and Development Service, Washington, D.C. 20590	13. Type of Report and Period Covered: (9) Final Rept. July 1975 - August 1976
	14. Sponsoring Agency Code

15. Supplementary Notes

(12) 82 p.

16. Abstract

The purpose of this study was to establish the firefighting capability of a rapid firefighting system of the dual-agent type capable of dispensing Aqueous-Film-Forming-Foam (AFFF) or dry chemical powder, either singly or in combination. Fire control times were determined for three 6-percent and two 3-percent-type AFFF agents and five dry chemical powders on 35- and 82.4-foot-diameter Jet A fuel fires at nominal discharge rates of 3.5 and 7.0 pounds per second.

Foam ground patterns were developed for the five AFFF agents, and the effective throw range of each of the five dry chemical powders was determined.

A means was developed for estimating the response time of a rapid fire-intervention vehicle to attend to any part of the operational area of an airport in a hypothetical aircraft accident situation. The methodology was based upon the results obtained by conducting a series of segmented time trials of basic maneuvers, the sum of which closely approximated the actual vehicle response time.

Experiments tend to indicate that the Twinned Agent Unit (TAU) would be capable of extinguishing the practical critical fire area associated with U.S. Index A aircraft within 120 seconds.

17. Key Words	18. Distribution Statement
Liquid Fuel Fires Supression of Aircraft Fires Aircraft Ground Crash Fires Crash Fire Environment Firefighting Vehicles	Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	67	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

240 550

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

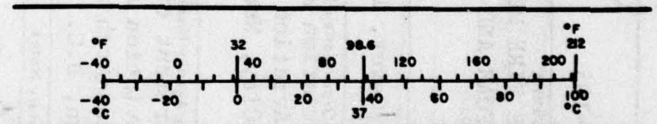


TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

LIST OF TABLES

INTRODUCTION

PURPOSE.

The project objective was to establish the firefighting capabilities of a rapid fire-intervention system employing newly developed aqueous-film-forming-foam (AFFF) agents and dry chemical powders (A listing of firefighting agent manufacturers is found in appendix A.), either singly or in combination, and to determine their potential value as applicable to aircraft ground fire suppression and rescue operations.

BACKGROUND.

The continually expanding operation of advanced commercial and military aircraft at high-density airports establishes the requirements for a rapid fire-intervention system capable of a minimum "transit time" to any part of an airport movement area. The connotation of the term "rapid fire-intervention system" is that the extinguishing system shall be self-contained (skid or wheel mounted) and potentially capable of high mobility. "Response time" is considered the elapsed time between the receipt of the initial fire alert call to the rescue and firefighting service and the first effective intervention at the accident by a rescue and firefighting vehicle.

The requirement for a rapid fire-intervention system is based upon experimental data which indicate that the melting time of an air carrier aircraft aluminum fuselage skin is approximately 40 seconds (reference 1) when exposed to flame impingement from a free-burning fuel spill fire. It is, therefore, evident that rapid fire-intervention is mandatory to control and/or extinguish incipient fires if a catastrophic conflagration is to be avoided.

The fire extinguishing characteristics of mechanical foams and dry chemical powders make these agents complementary for combined use on aircraft fuel spill fires. The dry chemical powder provides rapid flame knockdown of pool and three-dimensional fires with potential extinguishment if supplied at an adequate discharge rate over an adequate time period, but it does not provide protection of the hot fuel surface from possible reignition.

In contrast, mechanical foam has the capability of providing an efficient fuel vapor securing blanket after fire extinguishment, but it may be relatively time consuming when applied at low application rates. Therefore, a combined agent attack using dry chemical powder to effect rapid flame knockdown and foam to progressively blanket and secure the fuel surface has outstanding possibilities for the control and extinguishment of very complex aircraft fire configurations. Early attempts to exploit this concept were generally met with varying degrees of success because of the inherent incompatibility between protein foams and the then current dry chemical powders which resulted in a very rapid deterioration of the foam blanket.

A major technological advance was accomplished by the Naval Research Laboratory under the direction of Dr. R. L. Tuve in March 1964, with the development of a synthetic perfluorinated surfactant firefighting foam which virtually eliminated the incompatibility between mechanical foam and dry chemical powders.

The first research prototype dual-agent discharge system employing AFFF and Purple K powder (reference 3) was designed by the United States (U.S.) Naval Research Laboratory and delivered to the Naval Air Station (NAS) at Pensacola, Florida. As a consequence of its construction and the use of both dry chemical powder and AFFF, it was called a "Twinned Agent Unit" (TAU).

SCOPE.

A means was developed for estimating the response time of a firefighting vehicle to any part of the operational area of an airport in a hypothetical aircraft accident situation. The methodology employed was based upon a series of segmented time trials of basic maneuvers, the sum of which would equal the actual vehicle response time.

The firefighting effectiveness of the agent dispensing systems was evaluated in terms of the fire control and extinguishing times using five AFFF agents (three 6-percent (reference 2) and two 3-percent types) and five dry chemical powders employed both singly and in combination on 35- and 82.4-foot-diameter pool Jet A fuel fires. The larger diameter fires (5,333 square feet) approximate the practical critical fire area (5,527 square feet) established for Index A aircraft in Federal Aviation Administration (FAA) Advisory Circular (AC) No. 150/5210-6B.

The single-agent discharge rates employed with the foam solutions and dry chemical powders were approximately 3.5 and 7.0 pounds per second. While the combined foam and powder discharge rates were 7.0 and 14.0 pounds per second.

In a separate series of experiments, the effective discharge range of each dry chemical powder was determined at the maximum discharge rate of which the equipment was capable.

The quality of foam delivered by the dual-agent system using each AFFF agent was evaluated in terms of the 25-percent solution drainage time, foam expansion ratio, and the change in foam viscosity as a function of time after formation.

To extend the operating environmental conditions of the TAU to subfreezing temperatures, a series of laboratory and standard fire tests was conducted using a freezing point depressant in the AFFF premixed solution.

An estimate of the cost of extinguishing the 35-foot-diameter (962 square foot) Jet A fuel fire using foam and dry chemical powder both singly and in combination is also provided as a means of estimating the cost effectiveness of the single as opposed to the dual-agent application during fire control and extinguishing operations.

DISCUSSION

DESCRIPTION OF THE TAU RAPID RESPONSE VEHICLE.

BASIC CONSTRUCTION OF THE TAU. The principal components of the TAU are skid-mounted as shown in figure 1a. The firefighting agent-dispensing system comprised two metal spheres, one capable of containing 200 gallons of AFFF solution, and the second 450 pounds of potassium bicarbonate-base (Purple K) dry chemical powder. These agents may be dispensed either singly or in combination through two twinned hand-operated nozzles connected to a dual 100-foot-long hoseline shown in figure 1d. Both agents are expelled from the spheres by nitrogen gas maintained at a pressure between 230 and 250 pounds per square inch gauge (psig).

This basic unit may be mounted on a four-wheel over-the-road trailer as shown in figure 1b or on a small truck. Provision is also made for transporting the unit by helicopter.

When the firefighting system is trailer-mounted, a hydraulic cylinder integral with the coupling mechanism (figure 1c), which may be either a ball-and-socket, or pintle eye, provides adequate breaking of the trailer for positive control during operation at high speeds.

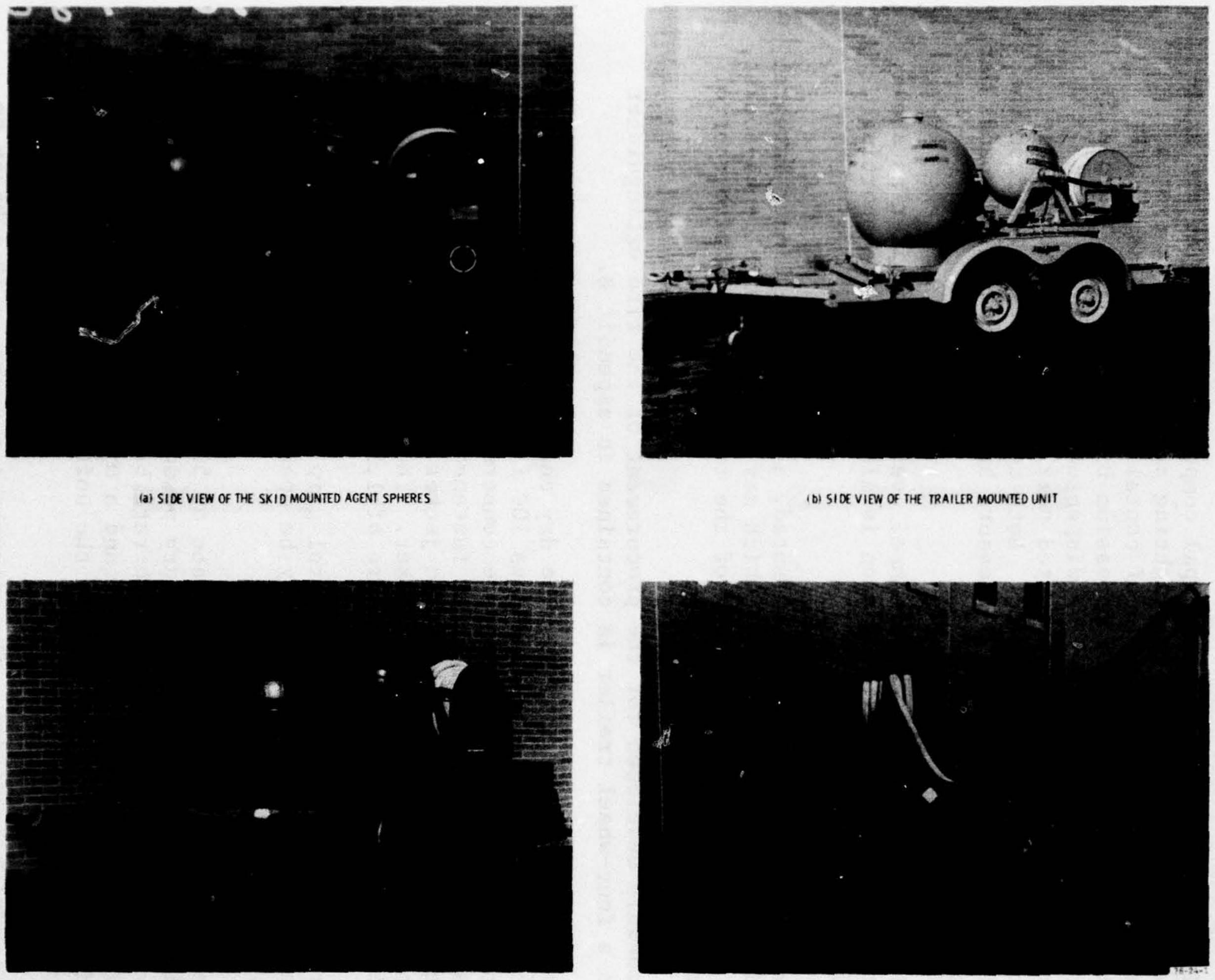
The complete schedule developed for the procurement of the fire extinguisher unit mounted on a four-wheel trailer is contained in appendix B.

HOSE REEL AND AGENT-DISPENSING NOZZLE. The dry chemical powder and AFFF solution are dispensed through twinned-handlines 100 feet long and secured on a manual rewind hose reel. The handlines are constructed of noncollapsible three-braided synthetic rubber-lined hoses fastened together with a woven polyester jacket. The strands of the woven jacket are prevented from raveling by a neoprene band bonded to the outer jacket. The hoses have a working pressure of 300 psig and a bursting pressure of 1,500 psig.

The foam and dry powder nozzles have a pistol grip and are close coupled by means of a yoke (figure 2) so that each may be operated individually or simultaneously.

The AFFF nozzle has a solution discharge rate of 50 gallons per minute (gal/min) and a minimum range of 35 feet. The dry powder nozzle is similar in design to the foam nozzle with a nominal discharge rate between 6 and 7.5 pounds per second, depending upon the powder density, and a minimum effective range of 45 feet. A suitable holder is provided on the unit for securing the nozzle when not in use.

Under ambient operating conditions, the nitrogen gas pressure is subject to temperature-oriented variations. To estimate the pressure corrections to be applied to the gauge readings for changes in temperature above or below 70° Fahrenheit (F), the chart provided in appendix C is employed.



(a) SIDE VIEW OF THE SKID MOUNTED AGENT SPHERES

(b) SIDE VIEW OF THE TRAILER MOUNTED UNIT

(c) FRONT VIEW OF THE TRAILER MOUNTED UNIT

(d) REAR VIEW OF THE TRAILER MOUNTED UNIT

FIGURE 1. CONFIGURATION OF THE TWINNED AGENT RAPID RESPONSE VEHICLE

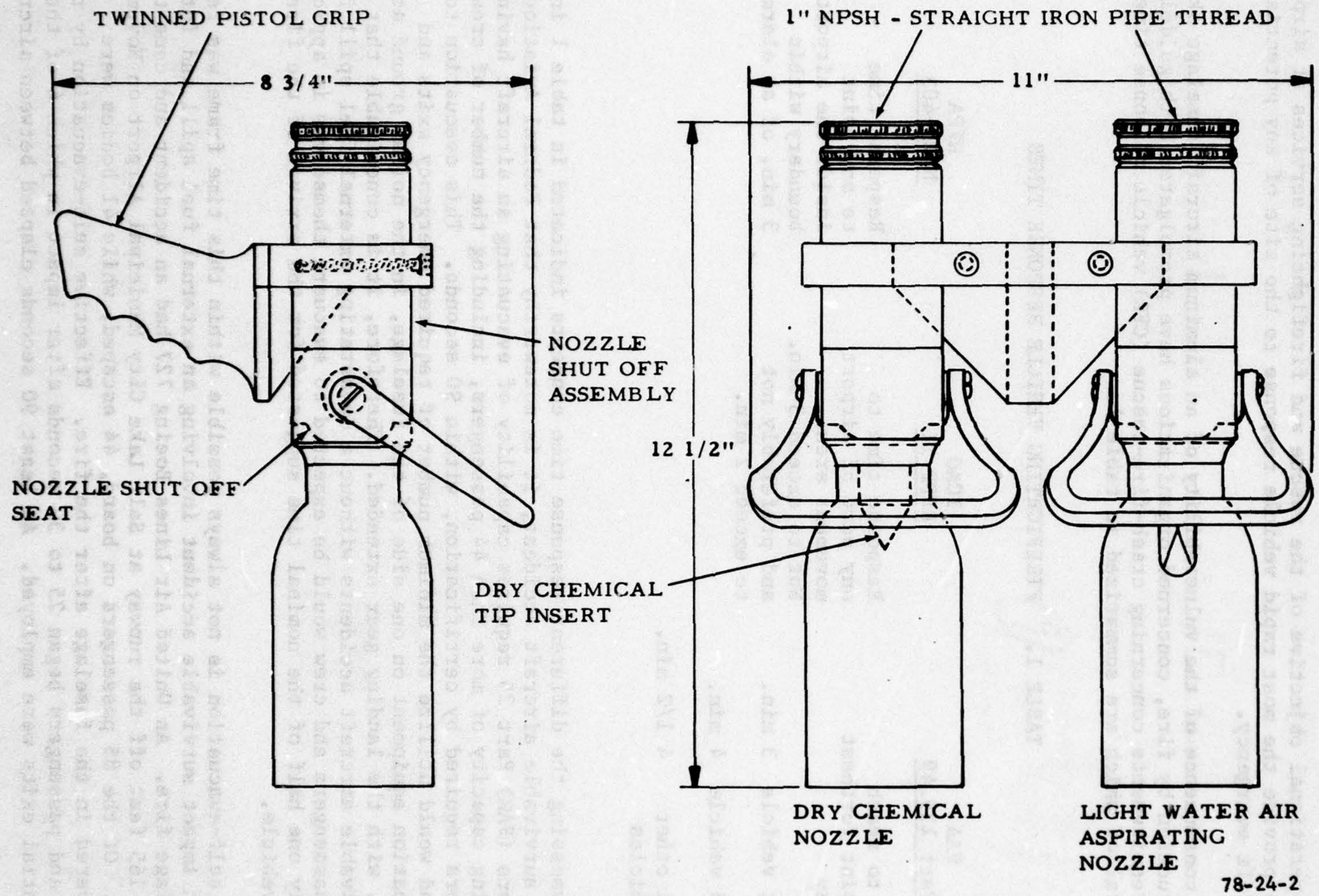


FIGURE 2. TWINNED AGENT HANDLINE NOZZLES

SIGNIFICANCE OF THE CRASH-FIRE-RESCUE RESPONSE TIME.

The operational objective of the rescue and firefighting services at airports is to provide the most rapid vehicle response to the site of any potential aircraft emergency.

As a consequence of the vulnerability of an aluminum aircraft fuselage skin to destruction by fire, concerned organizations have promulgated both guidelines and requirements concerning crash-fire-rescue (CFR) vehicle response times, several of which are summarized in table 1.

TABLE 1. FIREFIGHTING VEHICLE RESPONSE TIMES

FAA FAR Part 139.49	ICAO RFFP II	NFPA NFPA-403
Time to reach midpoint furthest runway 1st vehicle 3 min. 2nd vehicle 4 min. All other vehicles 4 1/2 min.	Response time to any part of airport movement area. Not to exceed 3 min. and preferably not to exceed 2 min.	Response time to any point inside the airport boundary within 3 min. of an alarm.

In assessing the different response time concepts indicated in table 1 in terms of a survivable aircraft accident, it is noteworthy that Federal Aviation Regulations (FAR) Part 25 requires capability of evacuating an aircraft having a seating capacity of more than 44 passengers, including the number of crew members required by certification, within 90 seconds. This evacuation to ground would utilize the minimum number of required emergency exits and evacuation equipment on one side of the fuselage, in the normal ground attitude, with the landing gear extended. Therefore, it is conceivable that in survivable aircraft accidents without a devastating external fuel spill fire, the passengers and crew would be expected to evacuate themselves in approximately one half of the nominal time suggested for the arrival of the first CFR vehicle.

That self-evacuation is not always possible within this time frame was revealed in an impact survivable accident involving an external fuel spill and interior fuselage fire. An United Air Lines Boeing 727 had an accident and came to rest 165 feet off the runway at Salt Lake City Municipal Airport on November 11, 1965. Of the 85 passengers on board, 44 escaped, while 41 bodies were recovered in the fuselage after the fire. Effective self-evacuation by the crew and passengers began 25 to 30 seconds after impact in which 6 of the 7 potential exits were employed. At least 90 seconds elapsed between aircraft impact and the escape of the majority of the passengers. An analysis of the firefighting activities indicated that the first fire truck arrived at the accident site about 3.5 minutes after impact, and no one was observed to escape after the arrival of the firefighting equipment with the exception of three survivors (a stewardess and two male passengers) trapped in the tail section, who were rescued by the CFR crews 25 minutes after impact.

These data tend to indicate the interrelationship between the CFR response times presented in table 1 and passenger evacuation time in one complex survivable aircraft accident. To have made a significant contribution toward expediting crew and passenger evacuation in this particular accident, it is conjectured that the CFR response time would have had to have been accomplished in less than 2 minutes after the aircraft came to rest. This accident involved a serious interior cabin fuel fire which resulted from a breach in the fuselage integrity, and it strongly emphasizes the need for a rapid response by the CFR services.

PERFORMANCE CHARACTERISTICS OF THE TAU CFR VEHICLE.

TAU SEGMENTED TIME TRIAL. To develop a methodology for estimating the potential minimum response time of the TAU (FAR Part 139.49 First Vehicle) CFR vehicle to any part of the operational area of an airport, a series of time trials was conducted on the National Aviation Facilities Experimental Center (NAFEC) airport shown in figure 3 in which the firefighting unit was towed by an eight-cylinder Chrysler station wagon. The equipment was provided with a Tracktest® fifth wheel (reference 4) as shown in figure 4. The instrument panel within the towing vehicle is presented in figure 5. These instruments provided operational data concerning speed, time, and the distance traveled during the time trials. From these data, a series of three profiles was constructed showing the performance characteristics of the equipment.

The profile in figure 6 shows the deceleration rate as a function of time, while figure 7 presents the deceleration rate in terms of the distance traveled by the vehicle. Figure 8 presents data showing the equipment acceleration time and the distance traveled in terms of the velocity. Two additional time trials included a determination of the speed and distance traveled in executing a 45° and 90° turn. The results of these tests are presented in figure 9. From these data, it was possible to estimate the vehicle response time to any given part of the operational area of the NAFEC airport.

The basic unit operations performed in these time trials are summarized in table 2.

The application of the segmented time trial data for estimating the vehicle response time is illustrated by the following example.

In a hypothetical, undeclared incident/accident situation in which the aircraft was disabled at the midpoint of runway 13-31 (figure 10), the calculated transit time for the TAU CFR vehicle was 77 seconds (table 3) exclusive of the time required to connect the TAU trailer to the towing vehicle. The actual measured transit time for the TAU CFR vehicle traveling over the same route was

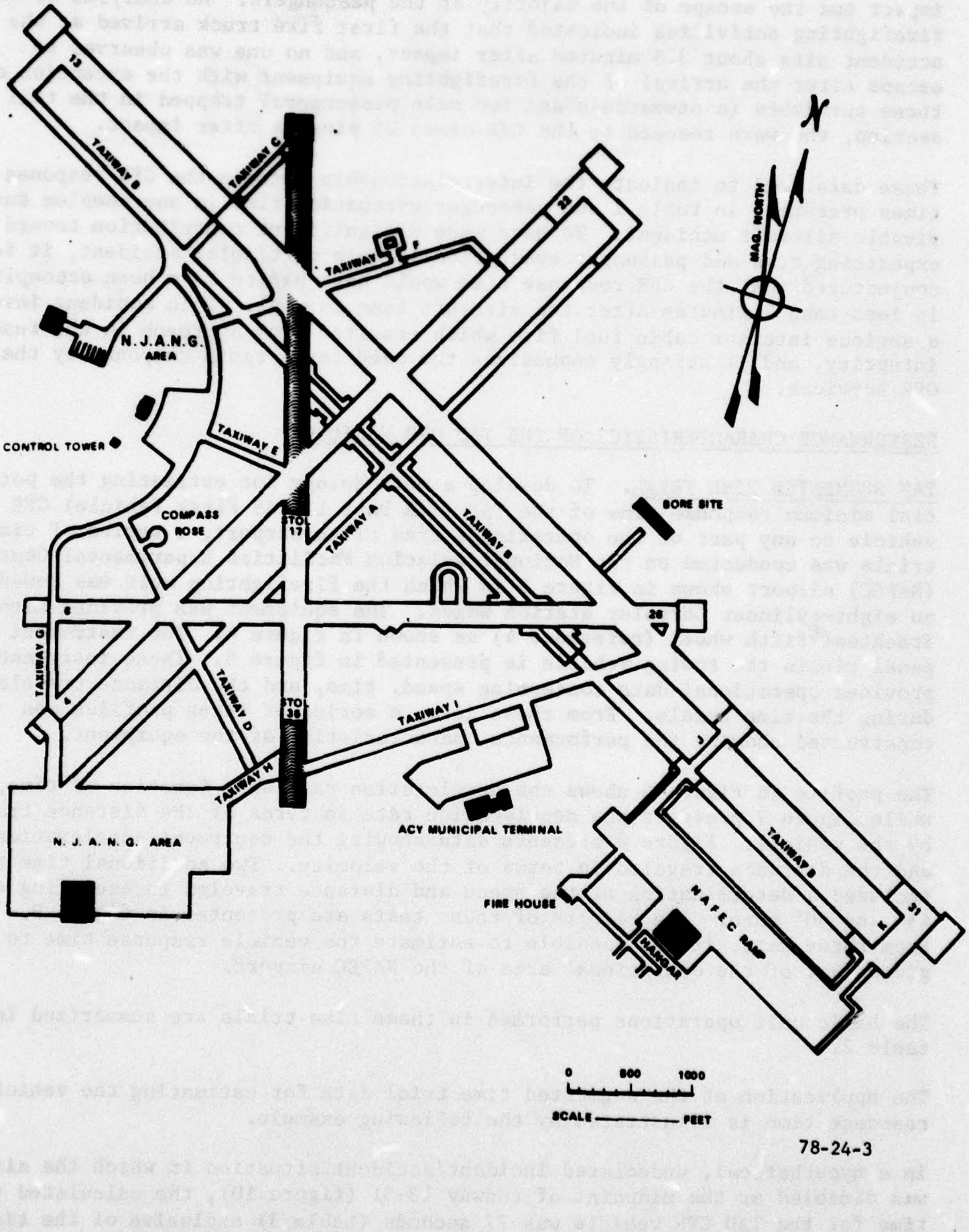


FIGURE 3. NAFEC/ATLANTIC CITY AIRPORT, ATLANTIC CITY, NEW JERSEY

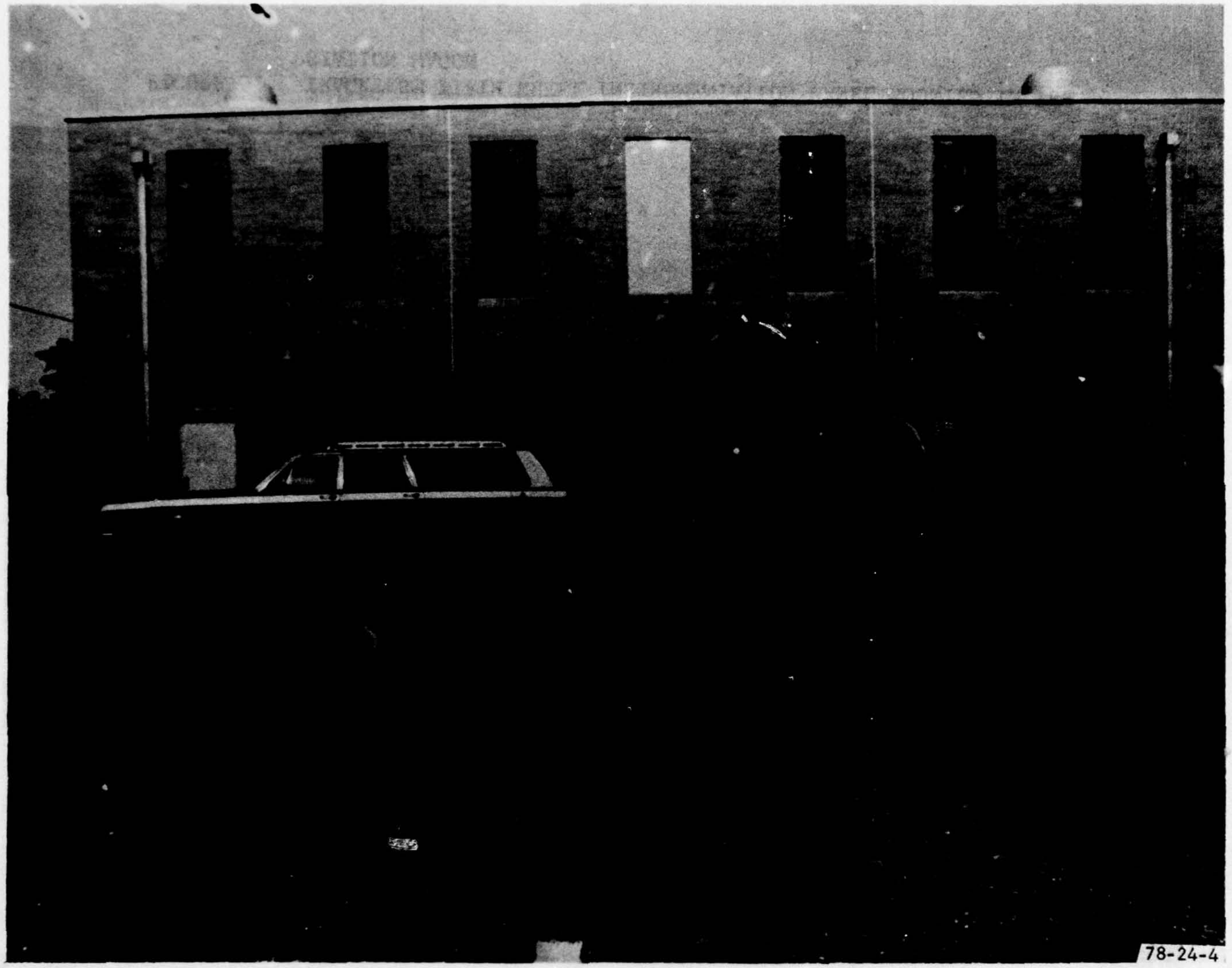


FIGURE 4. THE TAU WITH THE TRACKTEST FIFTH WHEEL MOUNTED IN THE REAR, BEING TOWED BY THE STATION WAGON

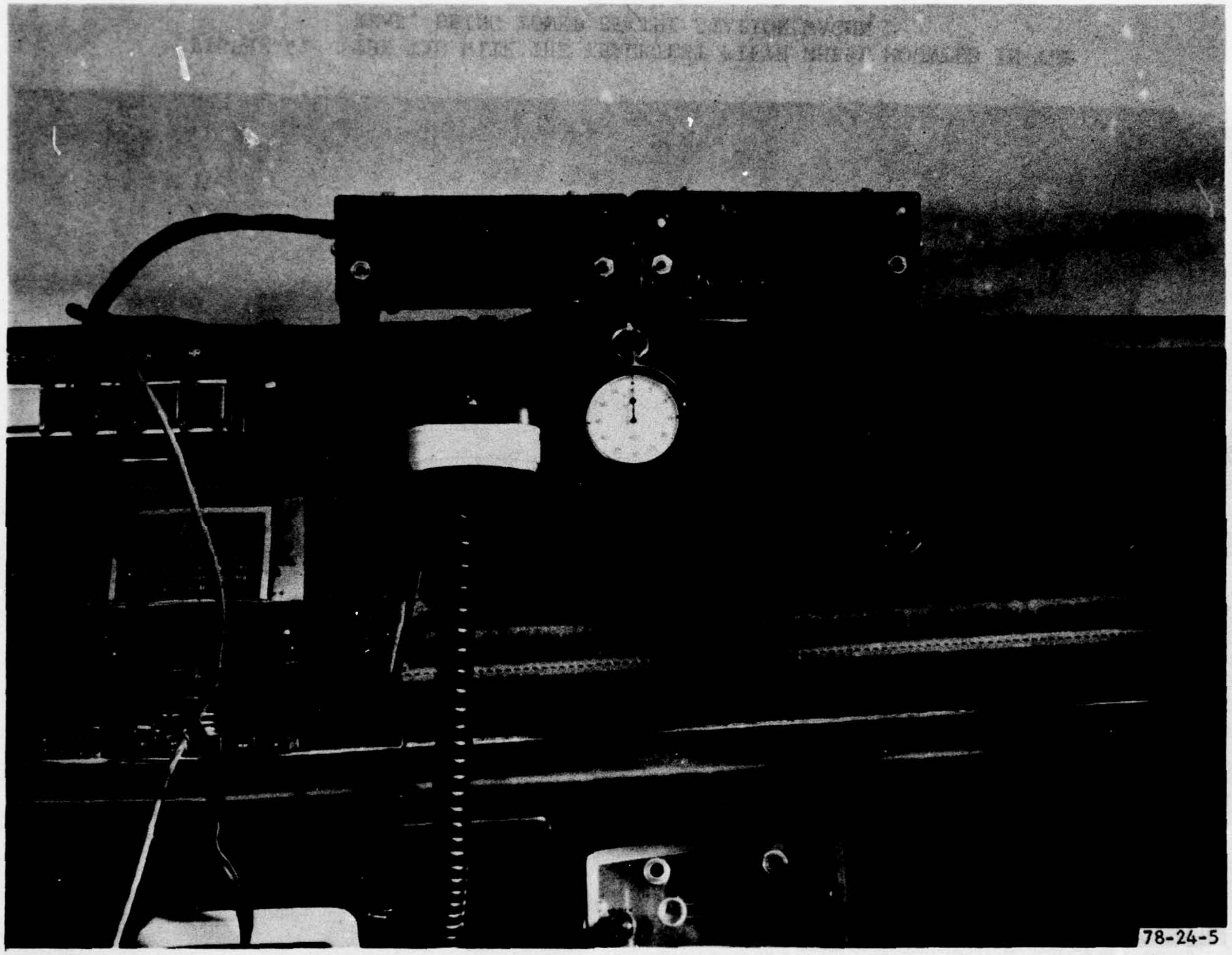


FIGURE 5. TRACKTEST FIFTH WHEEL INSTRUMENTATION PANEL MOUNTED IN THE STATION WAGON

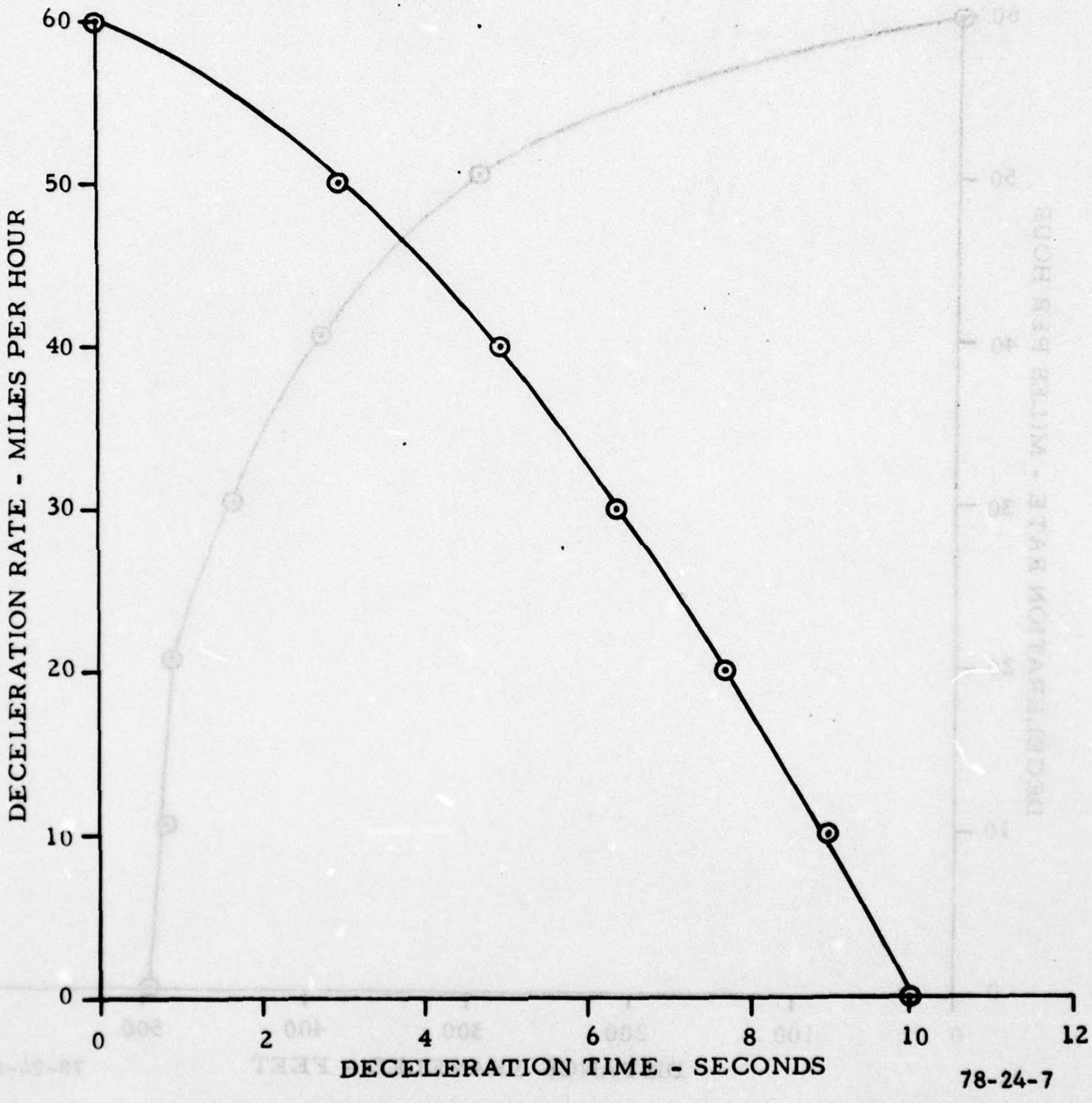


FIGURE 6. DECELERATION RATE OF THE CHRYSLER STATION WAGON AND TAU VERSUS DECELERATION TIME

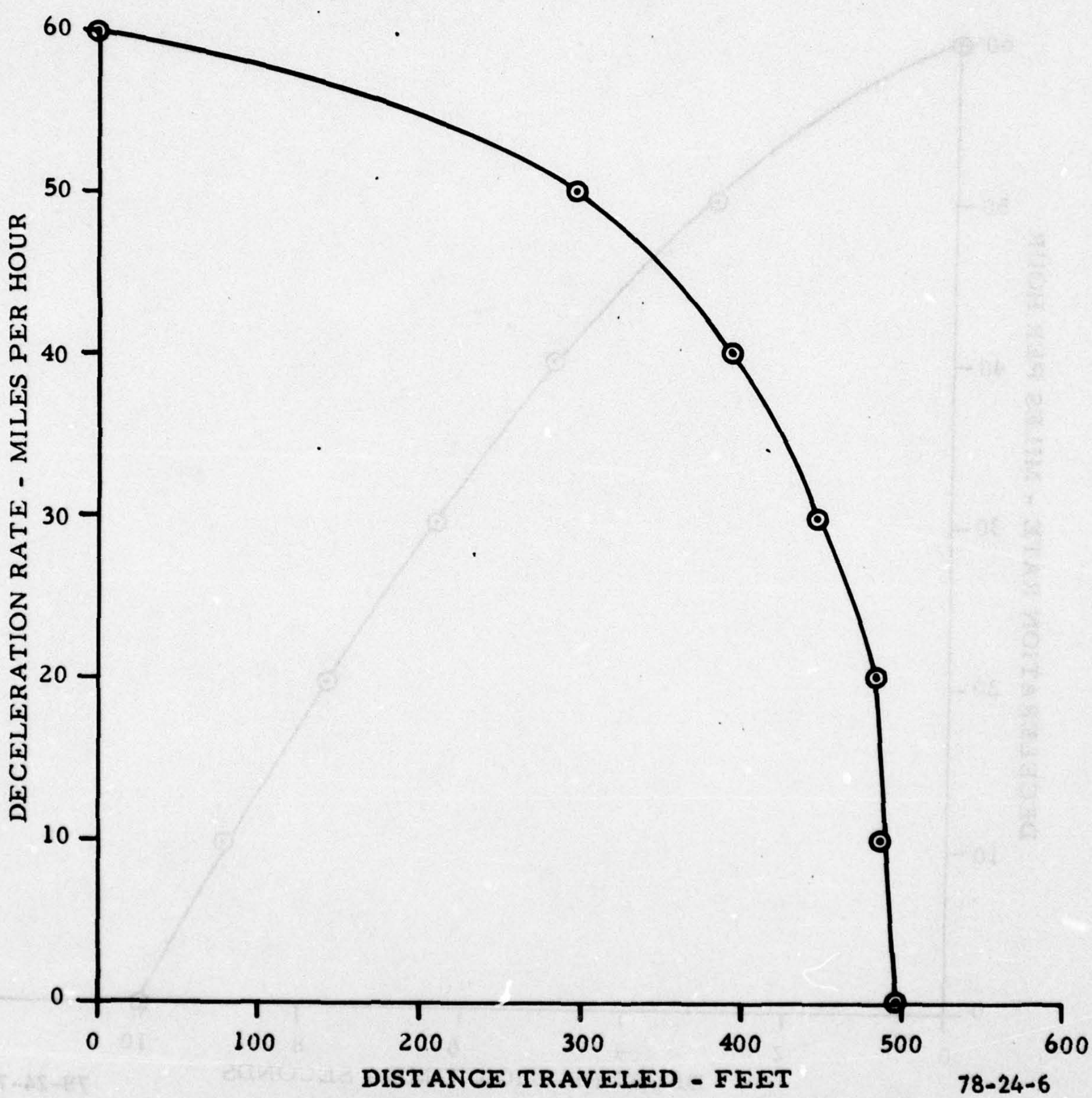


FIGURE 7. DECELERATION RATE OF THE CHRYSLER STATION WAGON AND TAU VERSUS DISTANCE TRAVELED

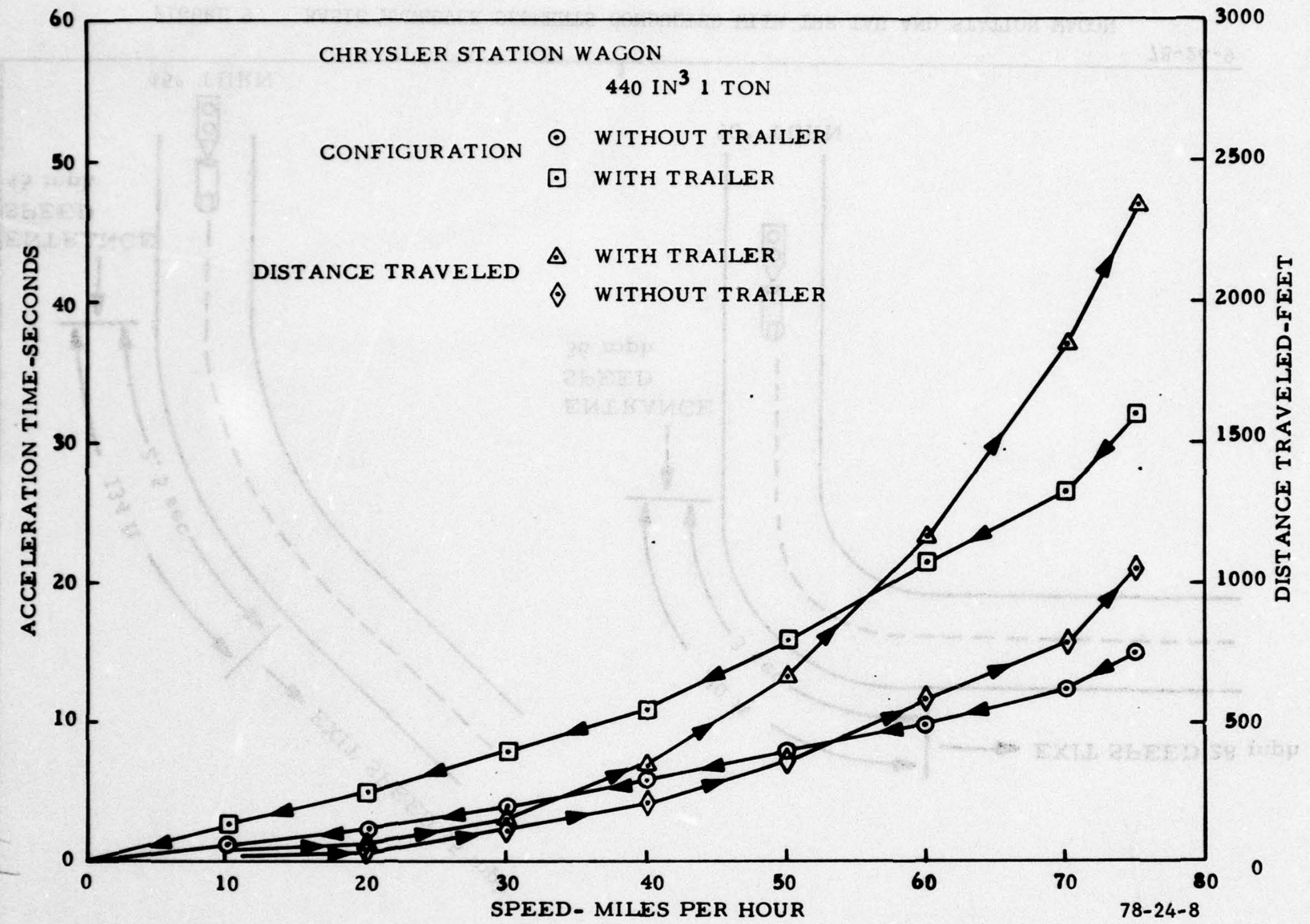


FIGURE 8. ACCELERATION RATES OF THE CHRYSLER STATION WAGON ALONE AND WITH THE TAU ON STRAIGHT, LEVEL PAVEMENT

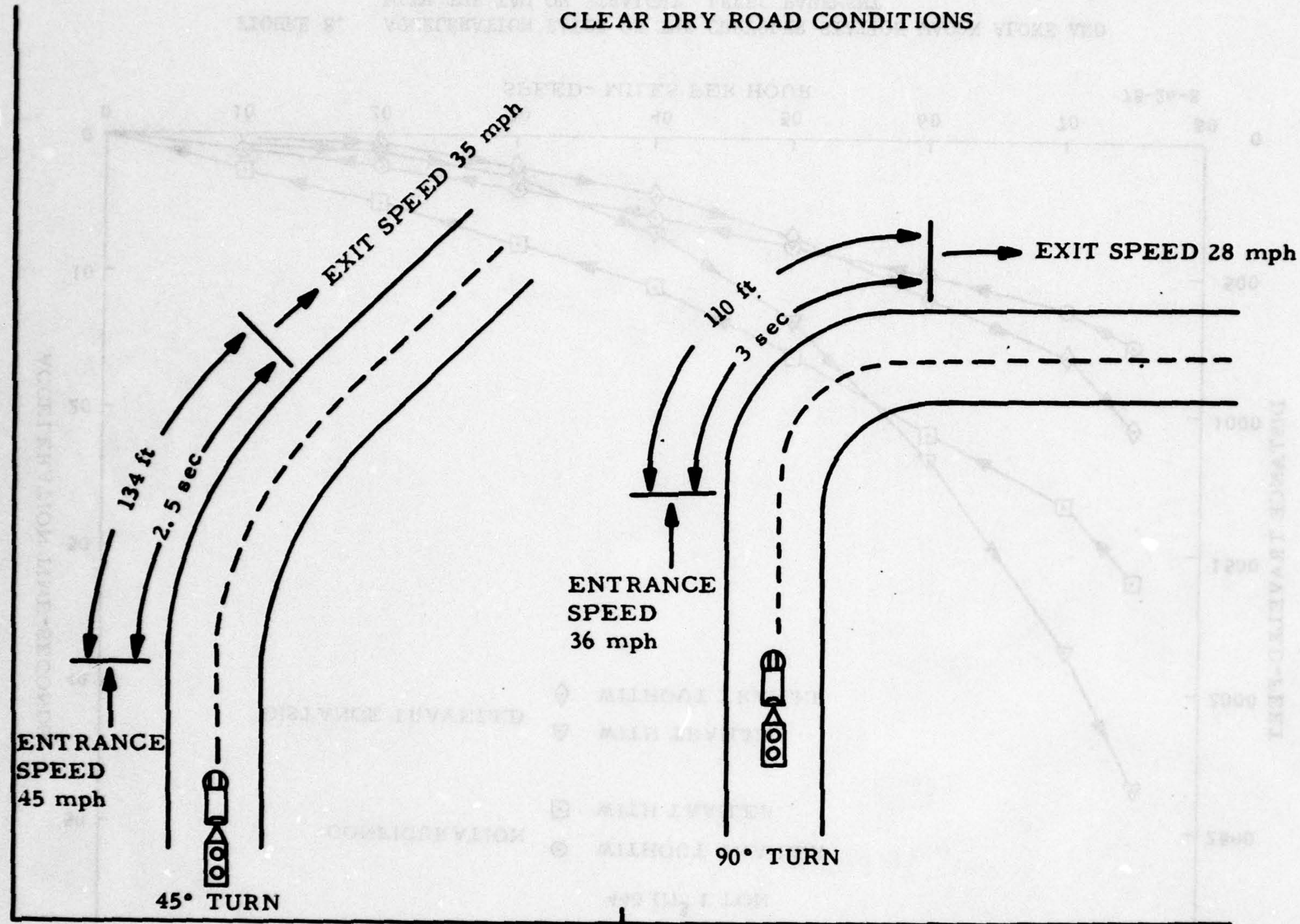


FIGURE 9. BASIC MANEUVER SEGMENTS CONDUCTED WITH THE TAU AND STATION WAGON

78 seconds which was in excellent agreement with the calculated transit time of 77 seconds.

TABLE 2. TAU OPERATION TIME TRIALS

TAU Towing Vehicle	Time to Deploy Hose (sec)	Time to Couple the TAU (sec)	Acceleration Time 0 to 60 mi/h (sec)	Deceleration Time 60 to 0 mi/h (sec)	Time to Execute Turns 45° (sec)	Time to Execute Turns 90° (sec)
Station Wagon	35	42	22	10	2.5	3

TABLE 3. TAU VEHICLE TRANSIT TIME OVER THE AIRPORT CERTIFICATION ROUTE AT NAFEC

Start at Fire Station	Speed (mi/h)	Distance Traveled (feet)	Time (Seconds)
Acceleration	0 to 57	1,020	19.5
Deceleration	57 to 36	285	4.4
90° Turn	36 to 30	110	2.9
Acceleration	30 to 60	1,000	13.5
Cruise	60	1,690	19.1
Deceleration	60 to 40	390	5.0
90° Turn	40 to 30	110	2.8
Acceleration	30 to 43	227	4.2
Deceleration	43 to 0	128	5.6
Totals		5,010	77.0

These time trials were performed by experienced equipment operators and are considered to be consistent with the performance to be anticipated from trained firefighting personnel.

Although the firefighting effectiveness of the rapid response vehicle may be of paramount importance if a devastating fuel spill fire is to be brought

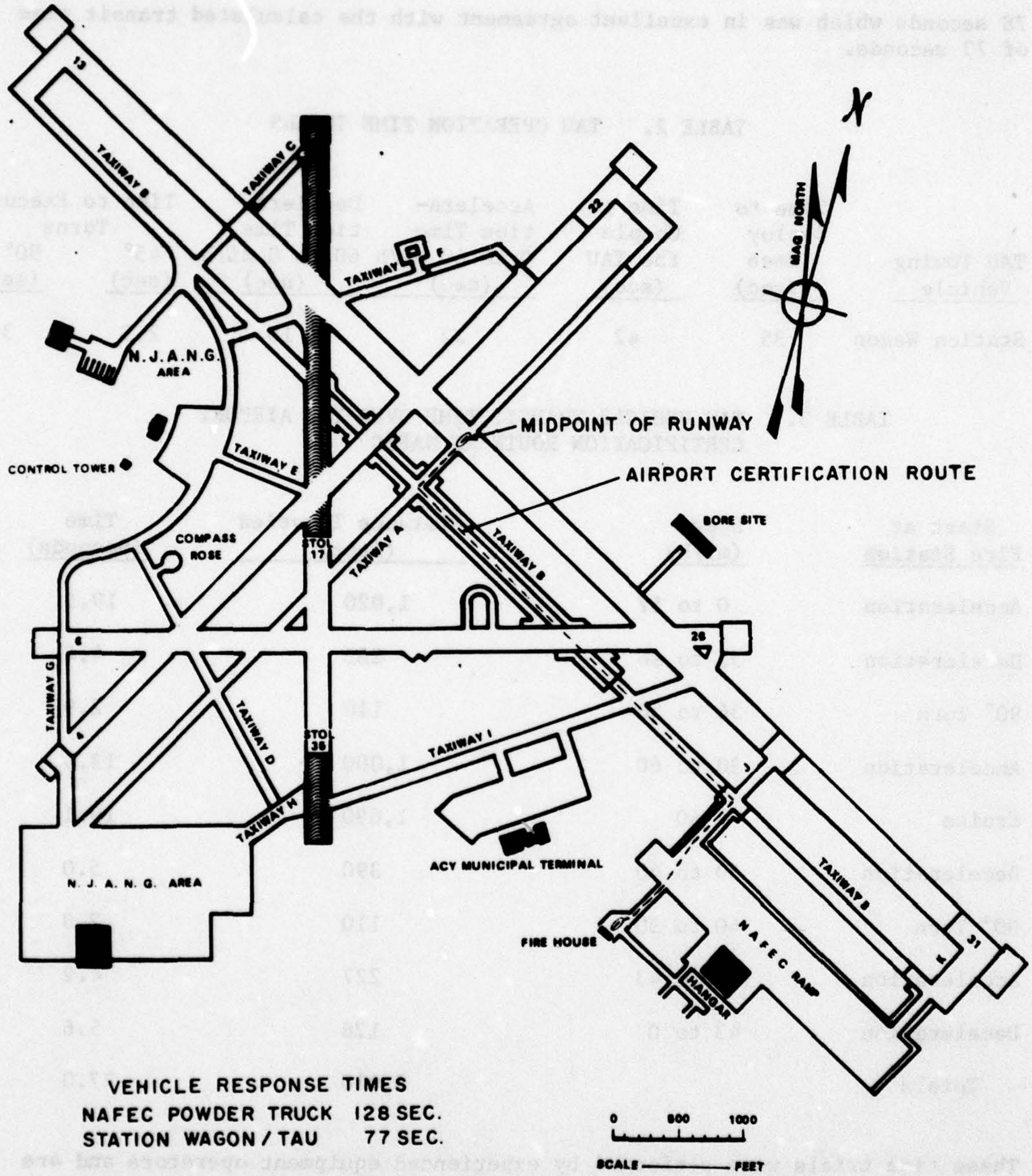


FIGURE 10. NAFEC/ATLANTIC CITY AIRPORT SHOWING THE VEHICLE RESPONSE ROUTE FOR AIRPORT CERTIFICATION (FROM THE FIRE HOUSE TO THE MIDPOINT OF THE MOST DISTANT RUNWAY)

rapidly under control or prevented from developing, it remains the responsibility of the primary foam truck(s) to consolidate the gains made by the rapid response vehicle and extinguish the fire. Therefore, the acceleration times for the primary firefighting foam trucks (second foam vehicles FAR Part 139.49) are of equal significance. The vehicle response times shown in table 4 were taken from the NFPA pamphlet indicated in reference 5. These data present the maximum times permitted the truck to accelerate from 0 to 50 miles per hour (mi/h) for seven different classes of vehicles ranging in weight from 16,000 to 75,000 pounds and above.

TABLE 4. VEHICLE ACCELERATION TIMES FROM 0 TO 50 MILES PER HOUR

Class	Water Capacity (Gallons)	Gross Vehicle Weight Range (Pounds)	Acceleration (Time 0-50) mi/h (Seconds)
1	500	16,000-24,999	30
2	1,000	25,000-31,999	35
3	1,500	32,000-46,999	40
4	2,000	39,000-57,999	45
5	2,500	52,000-64,999	45
6	3,000	58,000-74,999	50
7	3,000 Plus	Over 75,000	50

However, improvements in truck design and construction have been accomplished recently, such as those incorporated in the "Pathfinder" airport crash truck (reference 6), which have reduced the actual acceleration time significantly. The "Pathfinder" is in NFPA Class 7 with a gross weight of 82,000 pounds and an acceleration from 0 to 50 mi/h in 39 seconds, with cruising speeds up to 60 mi/h.

TURNING DIAMETER OF THE STATION WAGON AND TRAILER. The turning diameter of CFR vehicles is significant, since it is, in fact, a measure of the potential mobility of the equipment in the close quarters which may be encountered in major aircraft accidents.

The wall-to-wall turning diameter (reference 7) is intended to measure the space which will completely contain a vehicle as it is being turned. It is, therefore, the diameter of the smallest circle which can be described by the outermost point on the vehicle as it negotiates a 360° right or left turn. The wall-to-wall turning diameter of the Chrysler station wagon and TAU trailer was determined to be 48 feet.

EVALUATION OF THE TAU SYSTEMS.

EVALUATION OF THE FOAM AGENTS. The physical characteristics of the expanded foams produced by the three 6-percent and two 3-percent AFFF agents when discharged at solution rates of 25 and 50 gal/min are presented in table 5. The quality of AFFF was determined in terms of the expansion ratio and 25-percent solution drainage time, in accordance with NFPA methods (reference 5).

TABLE 5. QUALITY OF AFFF DISPENSED BY THE TAU

AFFF Agent	% Conc.	25% Solution Drainage Time (Min: Sec)	Foam Expansion Ratio	Foam Viscosity-Dynes/cm² Time (Minutes) 1	2	3	4
FOAM SOLUTION DISCHARGE RATE 50 Gal/Min							
FC-206	6	3:52	8.4:1	47.4	59.2	68.1	74.0
AER-O-WATER 6	6	3:06	6.1:1	41.4	56.2	59.2	68.1
LORCON	6	3:27	6.4:1	41.4	53.3	62.2	65.1
FC-203	3	4:00	8.1:1	47.4	59.2	71.0	77.0
AER-O-WATER 3	3	3:11	8.0:1	44.4	56.2	65.1	71.0
FOAM SOLUTION DISCHARGE RATE 25 Gal/Min							
FC-206	6	4:38	11.2:1	53.3	65.1	74.0	82.9
AER-O-WATER 6	6	4:24	6.5:1	47.4	59.2	68.1	77.0
LORCON	6	3:47	6.9:1	41.4	56.2	65.1	74.0
FC-203	3	5:30	10.2:1	53.3	56.1	79.9	88.8
AER-O-WATER 3	3	4:22	10.0:1	50.3	62.2	77.0	85.8

A third physical property of firefighting foams not included as a requirement in current federal and military specifications is viscosity. The instrument employed in measuring the foam viscosity in these experiments is shown in appendix D. Essentially, the instrument components comprise a constant-speed rotating torsion wire and vane which may be adjusted to shear a sample of foam held in a special container. The dimension of foam viscosity determined by this method is dynes per square centimeter (dynes/cm^2).

The data presented in table 5 showing the foam quality obtained at solution discharge rates of 25 and 50 gal/min indicate that there is a trend for the average 25-percent solution drainage time, expansion ratio, and foam viscosity to increase at the lower discharge rate. The physical characteristics of the foam produced by the TAU are in general agreement with those recommended by the NFPA (reference 5). However, the 25-percent solution drainage times and viscosities are somewhat below the values suggested by the International Civil Aviation Organization (ICAO) (reference 8).

The relationship between the physical properties and the fire-extinguishing effectiveness of AFFF is not as well defined as that required of protein-type foams. This situation maintains, since the actual fire-extinguishing and securing medium is the aqueous film which floats on the fuel surface rather than the foam body itself. However, the degree of protection afforded by AFFF after fire extinguishment is, in general, a function of the quantity of residual foam floating on the fuel surface which, in effect, serves as a reservoir for renewing the aqueous film as it drains from the film/fuel interface. A detailed treatment of this phenomenon is presented in reference 9.

EFFECTS OF AGING ON PREMIXED SOLUTIONS OF THE AFFF AGENTS. The potentially prolonged storage to which the premixed AFFF solutions may be subjected when stored in the TAU between operations was considered worthy of consideration. Accordingly, the hydrolytic behavior of each agent was assessed in terms of the sediment produced during storage over a 9-week period at ambient room temperatures. Also assessed were any associated variations in foam quality resulting from the aging cycle.

The test procedure adopted was to prepare solutions of each AFFF agent of the proper concentration and allow them to age for 9 weeks in the laboratory, after which they were centrifuged and the sediment determined in accordance with the procedure established in reference 10 for the foam liquid concentrates. The effects of solution aging on foam quality were determined in accordance with reference 9 and the results summarized in table 6.

TABLE 6. THE EFFECTS PRODUCED BY THE AGING OF PREMIXED SOLUTIONS OF THE AFFF AGENTS UPON FOAM QUALITY

Foam Agent	Concentration	Before Aging			After Aging 9 Weeks		
AFFF	Percent	Sediment Percent	Foam Expansion Ratio	25% Solution Drainage Time (Min: Sec)	Sediment Percent	Foam Expansion Ratio	25% Solution Drainage Time (Min: Sec)
FC-206	6	0	19.5:1	9:14	<0.05	17.9:1	6:55
AER-O-WATER 6	6	<0.05	19.0:1	7:50	<0.05	19.3:1	7:18
LORCON	6	0.07	17.3:1	6:28	0.18 *	25.6:1	5:07
FC-203	3	0	21.3:1	9:55	<0.05	19.7:1	9:05
AER-O-WATER 3	3	<0.05	17.5:1	7:16	<0.10 *	17.4:1	8:14

* Minor hydrolysis apparent

From these data, it is apparent that of the five agents tested, two showed measurable hydrolytic-tendencies but no significant variation in the foam expansion ratio or 25-percent solution drainage times. The precipitated solids present in the LORCON® and AER-O-WATER® 3 solutions were light textured and readily dispersible under mild shaking. Therefore, it is anticipated that no interference in the operation of the foam system on the TAU would derive through the use of these agents.

<u>LOW-TEMPERATURE OPERATION OF THE TAU</u>. To extend the operational capability of the TAU to subfreezing environmental conditions, two series of experiments were performed using ethylene glycol as the freezing-point depressant in the AFFF premixed solutions. The first series concerned the laboratory evaluation of the physical properties of the foam produced from premixed solutions containing various ratios of ethylene glycol and water, while the second series provided information on the fire extinguishing effectiveness of these depressed freezing point solutions on 100-square-foot Jet A fuel fires at a solution rate of 0.06 gal/min per square foot.

The results of the laboratory foam quality experiments employing both the 3- and 6-percent AFFF agents are presented in table 7. In these experiments, foam quality was evaluated in terms of the expansion ratio and 25-percent solution drainage time for each of the five depressed freezing point solutions, which permits a direct comparison to be made with the neat AFFF solutions. These data indicate that the foam expansion ratio of both the 3- and 6-percent agents tends to increase or decrease in a random manner as a function of the agent and ethylene glycol concentration.

In contrast, the 25-percent solution drainage times demonstrate a uniform upward trend as the ethylene glycol concentration is increased from 0 to 28 percent. The impact of the higher solution drainage times would be to reduce the rate of spread of the aqueous fluorocarbon film across the fuel surface, thereby increasing the fire control and extinguishing times.

The stability of the low freezing point solutions of the AFFF agents during storage was of concern because of the potential increase in hydrolytic tendencies which could result from the addition of ethylene glycol. Accordingly, solutions of each agent containing 28 percent by volume of ethylene glycol were aged for 9 weeks at ambient room temperature. The solutions were examined for any increased evidence of hydrolysis as well as changes in the physical properties of the expanded foam. The results of these aging experiments are summarized in table 8.

A comparison of the quantity of sediment initially developed during the preparation of the AFFF solutions showed no significant tendency to increase during the 9-week storage period. The relatively high concentration of sediment initially produced by the LORCON agent was of a very light texture and readily dispersible upon mild shaking. It also exhibited no tendence to increase with age. However, the effect of this precipitate upon foam quality is reflected by a reduction in the foam expansion ratio and 25-percent solution drainage time.

TABLE 7. LABORATORY TESTS USING ETHYLENE GLYCOL AS THE AFFF SOLUTION FREEZING POINT DEPRESSANT

Percent Ethylene Glycol by Volume		0		9.2		13.8		18.3		23.0		28.0	
Specific Gravity		1.000		1.013		1.019		1.026		1.032		1.040	
Freezing Point °F		32.0		25.6		22.0		17.8		12.8		6.8	
AFFF Agent	% Conc.	Expan. Ratio	25% Drain Time (Min: Sec)	Expan. Ratio	25% Drain Time (Min: Sec)	Expan. Ratio	25% Drain Time (Min: Sec)	Expan. Ratio	25% Drain Time (Min: Sec)	Expan. Ratio	25% Drain Time (Min: Sec)	Expan. Ratio	25% Drain Time (Min: Sec)
FC-206	6	19.51	9:14	16.99	9:32	17.57	10:19	17.69	10:37	16.85	12:34	16.36	13:10
AER-O-WATER 6	6	18.92	6:50	19.66	7:39	20.74	9:00	20.71	10:11	19.89	10:53	19.91	12:29
LORCON	6	18.31	5:28	19.69	6:38	22.71	8:01	20.53	8:36	20.56	8:47	20.90	9:53
FC-203	3	21.30	9:55	19.31	11:02	20.39	14:36	19.61	16:42	19.23	18:42	18.28	19:03
AER-O-WATER	3	17.54	7:16	17.23	10:17	10.11	12:21	18.40	13:41	17.41	15:09	17.22	17:04

TABLE 8. THE EFFECTS PRODUCED BY THE AGING OF ETHYLENE GLYCOL PREMIXED SOLUTIONS OF THE AFFF AGENTS UPON FOAM QUALITY

Foam Agents		Ethylene Glycol 28 Percent Freezing Point	Before Aging			After Aging 9 Weeks		
AFFF	Concentration (Percent)	(°F)	Sediment %	Foam Expansion Ratio	25% Solution Drainage Time (Min: Sec)	Sediment %	Foam Expansion Ratio	25% Solution Drainage Time (Min: Sec)
FC-206	6	6.8	0.025	16.4:1	13:10	0.03	17.2:1	18:22
AER-O-WATER 6	6	6.8	0.02	19.9:1	12:29	0.02	17.4:1	14:14
LORCON	6	6.8	0.45	20.9:1	9:53	0.45	12.2:1	5:01
FC-203	3	6.8	0.025	18.3:1	19:03	0.025	17.1:1	19:56
AER-O-WATER 3	3	6.8	0.04	17.2:1	17:04	0.06	16.9:1	19:55

The results of these laboratory experiments, with the exception of the LORCON AFFF, demonstrate the essential integrity of the reduced freezing point solutions to maintain for storage periods of up to 9 weeks with no anticipated variations in equipment operation and little or no deterioration in foam quality.

The effect of ethylene glycol on the relative fire control and extinguishing times of two AFFF agents at three selected solution concentrations may be drawn from the data presented in table 9. These experiments were conducted in nominal conformance with the standard fire test procedure presented in Federal Specification O-F555C (reference 10) (appendix E) in which FC-206 and FC-203 were substituted for protein foam. The results show a general increase in the fire control and extinguishing times for both the 3- and 6-percent AFFF agents as the ethylene glycol content was increased from 9.2 to 28 percent. However, even at the higher concentrations of ethylene glycol all of the fire performance criteria of the standard test were met. This tends to corroborate the previously predicted increase based upon the laboratory 25-percent solution drainage time experiments. Therefore, under environmental conditions requiring the operation of the TAU at below freezing temperatures, ethylene glycol may be considered to be an acceptable freezing point depressant within the concentration limits evaluated.

FOAM THROW RANGE OF THE TAU. In order to establish the most effective fire-fighting techniques to be employed during the full-scale fire modeling experiments using the TAU's foam-dispensing system, it was expedient to know

TABLE 9. AFFF FIRE TESTS USING ETHYLENE GLYCOL AS A SOLUTION FREEZING POINT DEPRESSANT

	AFFF AGENTS							
	6% Type FC-206				3% Type FC-203			
	Test 1	Test 2	Test 3	Test 4	Test 1	Test 2	Test 3	Test 4
Ethylene Glycol (%)	0	9.2	18.3	28.0	0	9.2	18.3	28.0
Ambient Air Temperature °F	81	72	65	63	75	72	68	62
Wind Velocity (mph)	4-6	7-8	5-6	5-7	4-6	7-8	6-7	4-5
Foam Expansion Ratio	9.4:1	7.1:1	8.4:1	7.2:1	11:1	6.5:1	7.4:1	7.5:1
25-Percent Solution Drainage Time (Min: Sec)	2:20	5:00	5:30	7:38	3:00	5:04	5:03	7:21
Fire Control Time (Min: Sec)	0:38	0:40	0:55	1:10	0:41	0:42	1:00	1:01
Fire Extinguishing Time (Min: Sec)	1:15	1:40	1:35	1:50	1:11	1:42	1:37	1:36
Foam Sealability Test	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Foam Burnback Test	Self Exting.	Self Exting.	Self Exting.	Self Exting.	Self Exting.	Self Exting.	Self Exting.	Self Exting.
Foam Depth (Inches)	4.0	3.5	4.5	5.5	3.0	3.0	3.5	3.75

the effective throw range and the approximate area of the ground pattern covered. These parameters would, in part, be used to establish the rate of traverse and the nozzle elevation that the firefighter would employ during the fire control and extinguishment of the Jet A pool fires. The foam patterns produced by each of the five AFFF agents during a 30-second discharge were determined in accordance with the procedure presented in NFPA No. 412 (reference 5). The average foam patterns developed during these experiments using the two 3-percent and three 6-percent agents at solution discharge rates of 25 and 50 gal/min are presented in figure 11. A photograph of the testbed configuration and the stand used to support the nozzle during foam discharge is presented in figure 12.

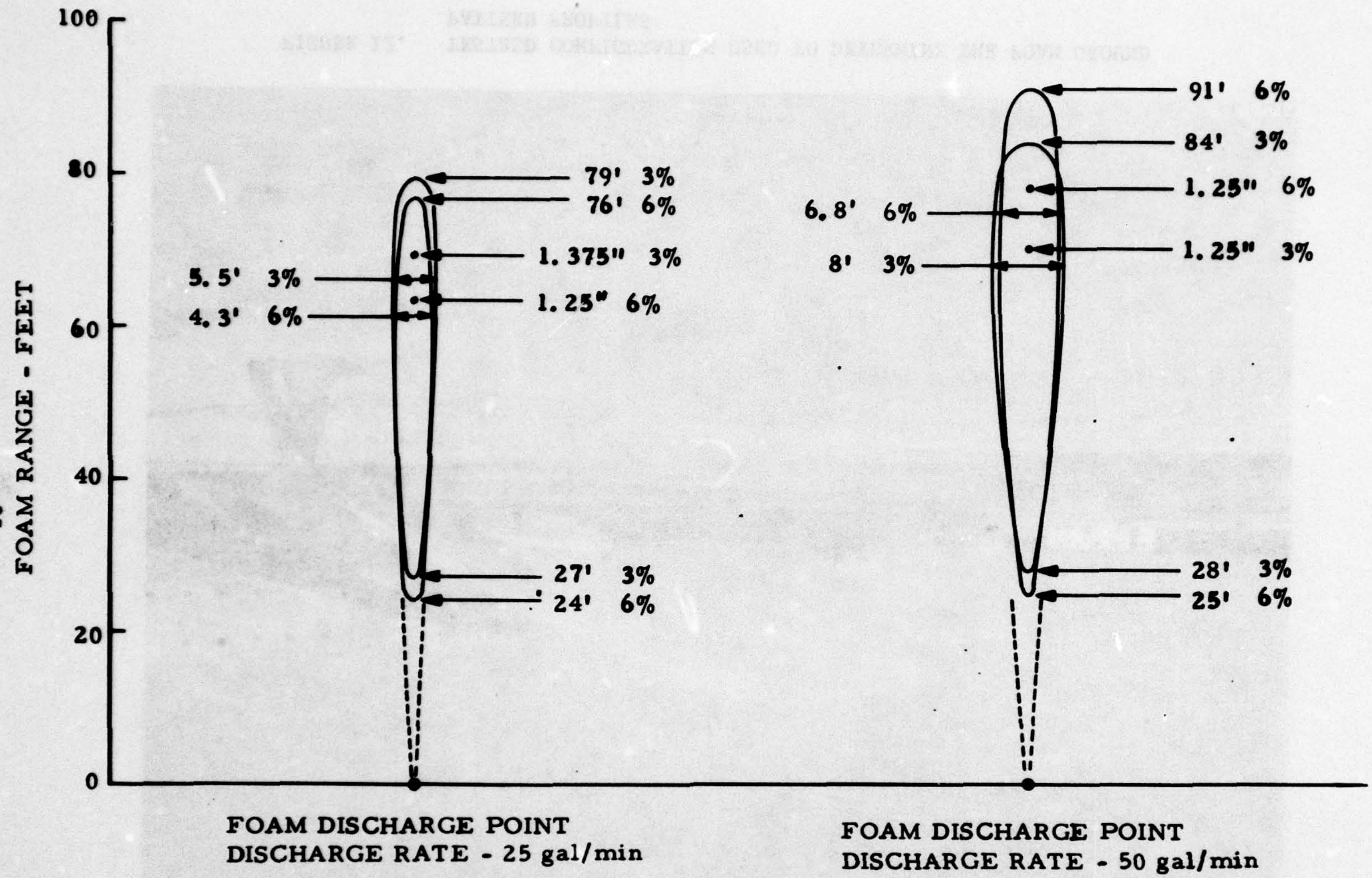
A performance analysis of the three 6-percent agents when they were discharged over the testbed at 50 gal/min shows a foam throw range from 87 to 94 feet long and from 5.0 to 9.25 feet wide. The maximum foam depth within these patterns varied from 1.0 to 1.5 inches among the different agents.

To provide information on the effect of solution discharge rate on the foam ground pattern configurations, a second series of experiments was conducted using the 6-percent agents at 25 gal/min, which was 50 percent of the maximum designed capacity of the TAU. Under these conditions the foam throw range varied from 74 to 80 feet long and from 4 to 5 feet wide with a maximum foam depth from 0.75 to 1.50 inches.

A comparison of the average dimensions of the foam ground patterns produced by the 6-percent agents shows an average increase in throw range of approximately 19.7 percent and 58.1 percent in width when the solution discharge rate was increased from 25 to 50 gal/min. However, the average maximum foam depth within the foam patterns was essentially the same at both discharge rates.

The average foam ground patterns developed for the two 3-percent agents at solution discharge rates of 25 and 50 gal/min are superimposed over the profiles of the 6-percent agents in figure 11. These data indicate that at a discharge rate of 50 gal/min, the average foam throw range was approximately 6.3 percent greater than at 25 gal/min, while the pattern width increased by approximately 45.5 percent and the foam depth decreased by 9 percent.

A comparison of the average ground patterns produced by the 3- and 6-percent AFFF agents at both 25 and 50 gal/min was considered significant because the increasing acceptance of the 3-percent agents as a consequence of their favorable economic advantage and lower storage requirement over the 6-percent agents. The test results showed the average foam throw pattern at 50 gal/min to be approximately 7.7 percent shorter and 17.6 percent wider for the 3-percent than for the 6-percent agents. When the foam solution discharge rate was reduced to 25 gal/min the 3-percent agents showed a slightly longer average throw range (3.9 percent) than the 6-percent agents. However, the average width of the foam pattern was approximately 28 percent wider for the 3-percent agents, while the average maximum foam depth within the patterns was approximately 10 percent deeper for the 3-percent than the 6-percent agents.



78-24-11

FIGURE 11. AVERAGE DIMENSIONS OF THE FOAM GROUND PATTERNS PRODUCED BY THE 3- AND 6-PERCENT AFFF AGENTS AT SOLUTION RATES OF 25 AND 50 GALLONS PER MINUTE

FIGURE 12. TESTBED CONFIGURATION USED TO DETERMINE THE FOAM GROUND PATTERN PROFILES

EFFECTIVE POWDER THROW RANGE OF THE TAU. To obtain the optimum firefighting performance with the TAU's dry chemical powder dispensing system, it is expedient to know the relative effective throw range of each candidate powder. An assessment of the effective fire extinguishing distance was made by discharging each powder through the TAU nozzle from a fixed position 32 inches above and parallel with the ground as shown in figure 13a.

The fire-extinguishing experiments were conducted by discharging the dry chemical powder over a fixed grid comprising 39 rectangular steel pans 9 inches wide by 14 inches long and 1.5 inches deep distributed in the array indicated in figure 14. The tests were performed by filling each pan to the brim with Jet A aviation fuel and discharging the dry chemical powder over the flaming grid from a threshold distance of 60 feet as shown in figure 13b.

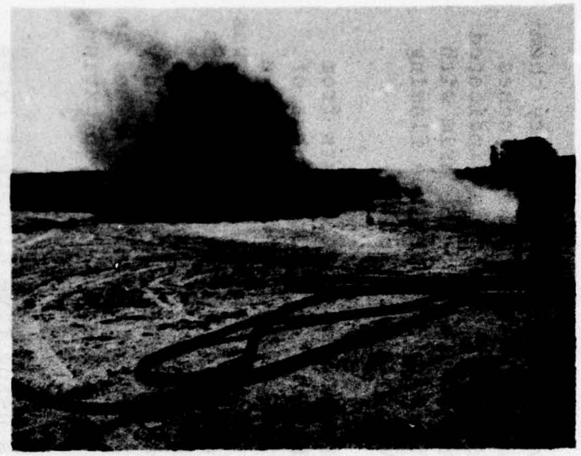
In practice, dry chemical powder is usually discharged in short bursts from handline nozzles to permit the firefighters to observe the effectiveness of the powder, thereby conserving the agent after fire extinguishment has been achieved. To implement this methodology in the test procedure, the powder was discharged in consecutive bursts of 15-seconds duration, until the sphere was empty (figure 13c). Assessing the effect of each powder discharge was accomplished by recording the number of fuel pans extinguished (figure 13d). The effective extinguishing range for each powder discharge was established as that distance from the point of discharge to the most distant fuel pan extinguished.

The results of the powder throw range experiments using five different types of dry chemical are summarized in table 10, along with other pertinent information of value in assessing the effective throw range of the powder dispensing system. In this regard, it is considered important to emphasize that these experiments were not designed to establish the fire extinguishing effectiveness of each individual powder per se. Therefore, no attempt was made to normalize the powder discharge rate. The weight of the charge in the container was a function of the specific density of each individual powder.

As a consequence of these experiments, it is apparent that the total number of fire pans extinguished by each powder during four consecutive bursts was not a common function of either the total quantity of powder available, the maximum effective throw range, the area of the powder ground pattern, nor of the powder discharge rate. Due to the absence of any definitive correlation between the physical distribution of the dry chemical powders and their observed fire extinguishing characteristics, it is expedient to include a brief chemical interpretation of the observed differences.

The fire extinguishing test data presented in table 10 closely correlate the results of experiments discussed in reference 9. Variations in the fire-extinguishing effectiveness demonstrated by the dry chemical powders were attributed to the flame chain-breaking mechanism that may vary significantly between the several heterogeneous flame inhibitors. These flame inhibitors are comprised principally of alkali and ammonium salts which provide the active moieties required to inhibit flaming combustion. The effect of chemical composition on the fire-extinguishing effectiveness of the dry chemical

(a) DRY CHEMICAL POWDER NOZZLE MOUNTED IN A FIXED POSITION ON THE TEST STAND



(b) PAN CONFIGURATION PRIOR TO POWDER DISCHARGE

(c) INTIAL POWDER DISCHARGE

(d) PARTIAL EXTINGUISHMENT OF THE FIRE PANS AFTER POWDER DISCHARGE

FIGURE 13. DRY CHEMICAL POWDER DISCHARGE RANGE TESTBED

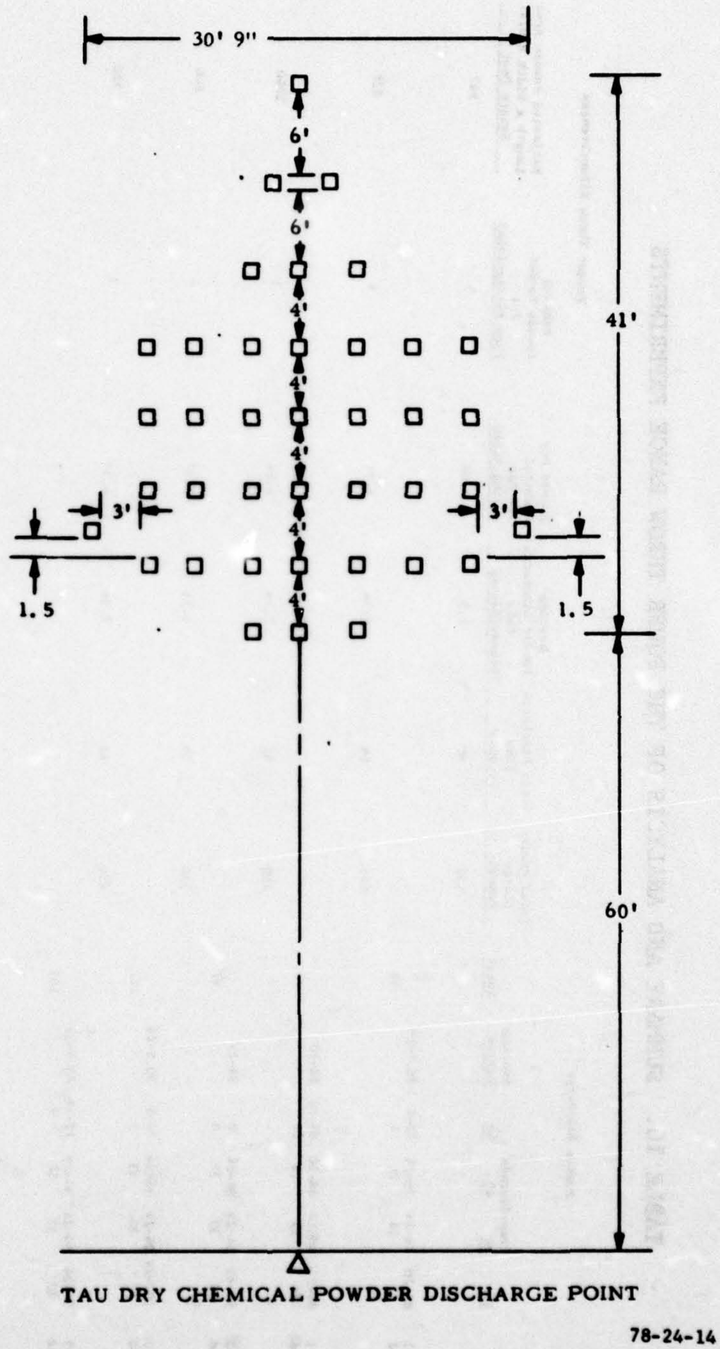


FIGURE 14. FIRE-PAN CONFIGURATION FOR EVALUATING THE DRY CHEMICAL POWDER DISCHARGE RANGE

TABLE 10. SUMMARY AND ANALYSIS OF THE POWER THROW RANGE EXPERIMENTS

Agents	Powder Discharge: Time-Seconds 15	30	45	60	Average Values	Total	Total Powder Charge Pounds	Total Discharge Time Seconds	Average Powder Discharge Rate Pounds/Second	Powder Throw Effectiveness: Pounds Dry Chemical Per Pan Extinguished	Ranking Pounds Powder Per Pans Extinguished	Estimated Powder Area Length x Width x 0.47 Square Feet
Sodium Bicarbonate							450	60	7.5	8.04	5	647
Throw Range												
Length-width (ft)	82-20	76-24	76-24	72-4	76.5-18							
Pans Extinguished	17	14	21	4		56						
Monoammonium Phosphate							445	66	6.74	5.71	4	827
Throw Range												
Length-width (ft)	88-24	88-16	88-20	88-20	88-20							
Pans Extinguished	26	13	18	21		78						
Super K							450	61	7.38	4.64	3	1060
Throw Range												
Length-width (ft)	94-24	94-24	94-24	0	94-24							
Pans Extinguished	30	32	35	0		97						
Monnex							330	54	6.11	3.27	1	846
Throw Range												
Length-width (ft)	102-24	94-24	94-24	72-8	90.5-20							
Pans Extinguished	35	30	33	3		101						
Purple K							450	62	7.26	4.37	2	920
Throw Range												
Length-width (ft)	94-24	94-24	94-24	72-16	88.5-22							
Pans Extinguished	30	32	32	9		103						

powders is graphically presented in figure 15. These profiles identify two groups of powders based upon the number of fire pans extinguished during each of four consecutive 15-second bursts of dry chemical during the powder throw range experiments. The most effective agents in this regard are the three containing the potassium moiety (Monnex® is a urea-potassium complex, reference 9), while the two less effective powders contain either the sodium or ammonium moieties. Although the TAU system is nominally capable of discharging powder over a period of 60 seconds, it is apparent from figure 15 that the most effective discharge time period for four of the agents occurred within the first 45 seconds, after which their effectiveness rapidly diminished. However, in contrast to this general trend, the monoammonium phosphate-base powder extinguished 21 fire pans during the fourth burst, which was 12 more than the next highest ranking agent (Purple K extinguished 9 pans).

The monoammonium phosphate-base powder is unique among the dry chemicals in that it is capable of extinguishing class A, B, and C fires (reference 11, Multipurpose type), all of which may be directly or indirectly associated with aircraft accidents involving fire. Accordingly, the selection of any dry chemical powder as an ancillary agent in aircraft firefighting operations should take into consideration the specific purpose for which the agent is intended.

The basic data developed during the powder discharge experiments may be summarized in terms of the number of pounds of each dry chemical required to extinguish one fire pan. These values are presented in table 10 and lead to the following ranking in decreasing order of effectiveness; Monnex, Purple K, Super K,® monoammonium phosphate (multipurpose), and sodium bicarbonate. This order of effectiveness was in general corroborated by subsequent full-scale fire modeling experiments conducted during the course of this project on 35-foot-diameter Jet A fuel fires.

COMPATIBILITY OF AFFF 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 will be either completely extinguished and the environment allowed to cool 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 12) 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

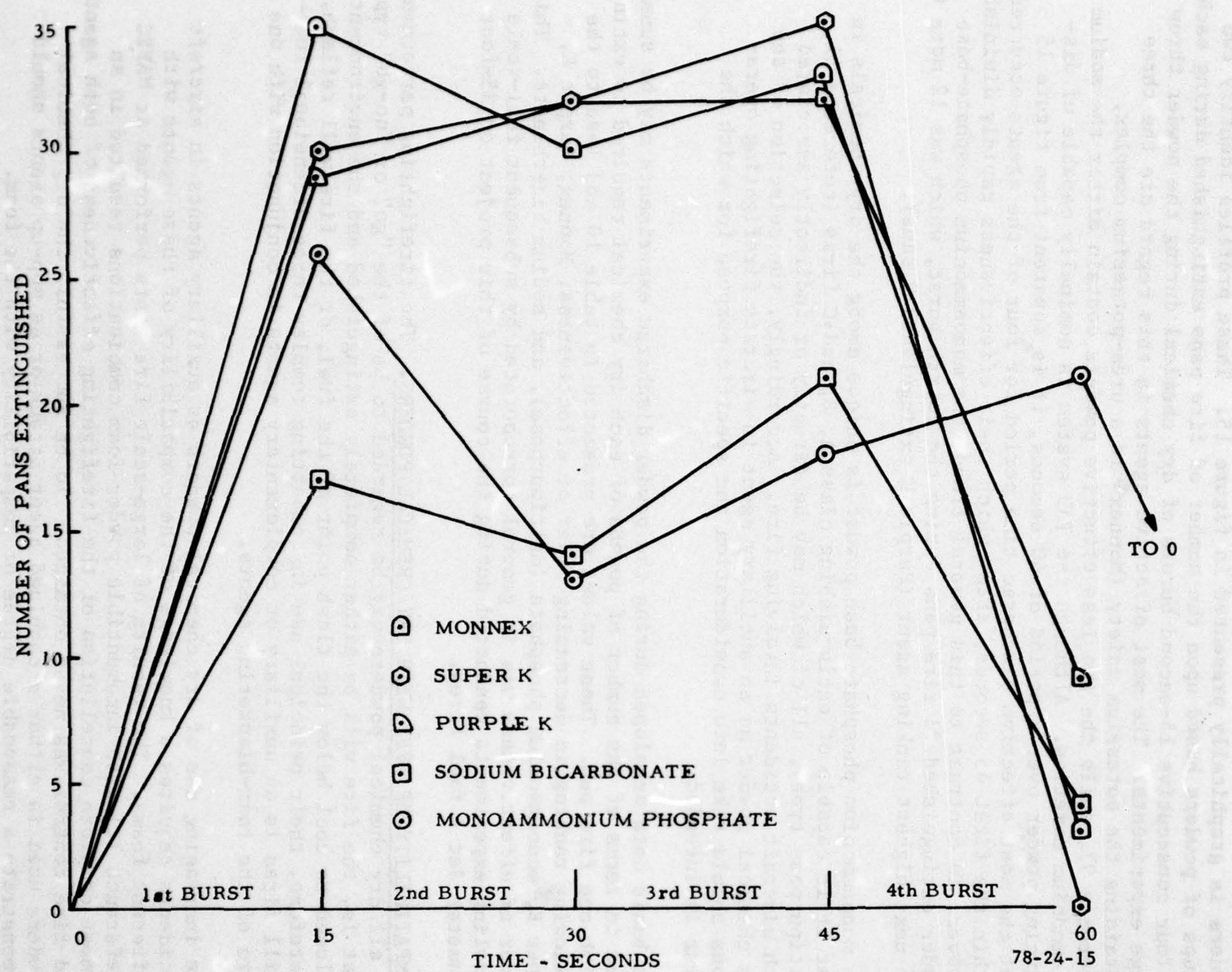


FIGURE 15. NUMBER OF FIRE-PANS EXTINGUISHED IN 15-SECOND CONSECUTIVE BURSTS OF DRY CHEMICAL POWDER

using the same agents under actual full-scale crash fire conditions. The laboratory test outlined in appendix F 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 to attempt to simulate the most severe conditions which might be realized under actual crash firefighting conditions 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 milliliters (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 powder in crash-fire situations.

The results obtained using the procedure contained in appendix F and five different AFFF agents with five different dry chemical powders are presented in table 11. These data indicate that all combinations of AFFF and dry chemical powder when mixed in the presence of Jet A fuel meet the minimum solution drainage time requirements established in the test procedure. In general, the presence of fuel in the system tends to produce a slight decrease in the foam solution drainage time, with the exception of sodium bicarbonate, and Monnex to a lesser degree, in which cases the presence of Jet A fuel tends to have a stabilizing effect on the foam. The foam solution drainage times developed in table 11 provide adequate laboratory data for estimating the foam blanket stability of each combination of agents under conditions of severe turbulation encountered during a combined agent attack on large free-burning pool fires. These experiments are considered significant in that they serve to confirm and emphasize the fact that the compatibility between powder, foam, and fuel is one of degree and, therefore, worthy of consideration when establishing full-scale firefighting procedures and training techniques.

FULL-SCALE FIRE MODELING EXPERIMENTS.

FIRE TEST FACILITY AND TEST METHODS. The fire testbed comprised a 200-foot-diameter fire pit with a soil-cement base covered by a 12-inch layer of clay-like soil. Within this area, two concentric pools were constructed, the smaller of which was 35 feet and the larger 82.4 feet in diameter. By removing the intervening dike it was possible to change from one pool size to the next larger with minimum delay. A three-dimensional fire was maintained in the center of the pools by directing a solid stream of Jet A fuel from a 1/4-inch diameter stainless steel tube at a height of 4-feet vertically downward into the center of the pool.

Uniform environmental burning conditions were maintained by allowing a minimum preburn time of 45 seconds or until maximum radiation intensity was obtained, which was determined from the radiometer data, before foam or dry chemical powder application was started. The Jet A fuel charge to the fire pools was a minimum of 0.36 gallons per square foot of surface area.

41

TABLE 11. COMPATIBILITY OF AFFF WITH DRY CHEMICAL POWDERS IN THE PRESENCE AND ABSENCE OF JET A FUEL

		Time to Collect 25 ml of Drained Solution (Min: Sec)													
	Solution Concentration	Purple K		Super K		Sodium Bicarbonate		CDC*Sodium Bicarbonate		Monnex		Mono-ammonium Phosphate		Fuel and Foam	Foam Alone
AFFF Agents	%	Fuel	No Fuel	Fuel	No Fuel	Fuel	No Fuel	Fuel	No Fuel	Fuel	No Fuel	Fuel	No Fuel		
FC-206	6	3:30	3:45	3:50	3:35	3:15	3:38	3:15	2:55	3:05	3:15	3:10	3:20	5:45	4:50
AER-O-WATER 6	6	3:15	3:15	2:50	3:35	4:00	3:37	3:34	3:24	4:00	3:50	3:00	3:50	6:05	5:20
LORCON	6	3:13	2:50	2:30	2:45	3:40	2:37	2:23	2:10	3:10	2:40	3:15	2:30	4:10	4:15
FC-203	3	3:55	4:00	3:40	3:50	4:45	3:30	3:58	3:26	3:55	4:40	3:20	4:50	8:00	6:15
AER-O-WATER 3	3	2:30	3:00	2:30	2:40	3:45	2:47	2:30	2:28	3:20	2:40	3:13	3:30	5:55	6:55

*CDC - compatible dry chemical

The fire control time obtained for each experiment was monitored by two radiometers distributed as indicated schematically in figure 16. The heat sensors A and B were elevated on steel poles 8 feet above ground level on the diameter at right angles to the wind direction and remained in position throughout the test. Thermal data were documented by two pen recorders equipped with event markers. A more detailed description of the instrumentation employed to monitor the experiments is presented in appendix G.

Photographic coverage of each fire test was provided in accordance with the procedure presented in appendix H.

During the evaluation of the firefighting capabilities of the TAU, an extensive series of experiments was conducted using the 3- and 6-percent AFFF agents and five dry chemical powders, both singly and in combination on 962 and 5,333 square foot Jet A fuel fires. To illustrate the type of data obtained from the instrumentation equipment, one test was selected from each series of experiments which was considered to be characteristic of that class of firefighting agents.

FIRE TESTS WITH AFFF'S. The first experiment with AFFF was conducted using FC-206 on a 35-foot-diameter Jet A pool fire at a solution discharge rate of 50 gal/min (7 pounds per second). Foam was dispensed from the twinned handline nozzle along the upwind rim of the pit from an initial distance of approximately 20 feet using a swinging side-to-side motion. As the surface of the fuel was progressively secured by foam, the firefighter advanced to within 5 feet of the fire pit. The typical fire-extinguishing technique employed to dispense AFFF is shown in figure 17. In this experiment, control of the fire was achieved in approximately 9 seconds and extinguished in 12 seconds as indicated by the profiles presented in figure 18. During the course of the normal extinguishing procedure, the 3-dimensional fire in the center of the pit was also extinguished.

Table 12 presents a summary of the full-scale fire-modeling experiments employing the 3- and 6-percent AFFF agents at solution application rates of 0.052, 0.026, and 0.0094 gal/min per square foot. These data tend to indicate the serious time penalty incurred in obtaining fire control and extinguishment by drastically reducing the solution application rate. When the rate was reduced from 0.052 to 0.026 gal/min per square foot, the average fire control and extinguishing times were approximately doubled. However, when the solution rate was reduced from 0.052 to 0.0094 gal/min, the average fire control time rose from 9.6 to 78.4 seconds. Therefore, at very low solution application rates, the use of foam tends to be time consuming and wasteful of the agent. In general, the 3- and 6-percent AFFF agents demonstrated equal effectiveness in terms of their fire control times. The widest divergence in their values maintained at the lower application densities. However, even at these relatively low values, good average correlation was achieved.

From the standpoint of firefighting effectiveness, the TAU was demonstrated to be capable of extinguishing 5,333 square feet of burning Jet A fuel in from 93 to 120 seconds, depending upon the AFFF agent employed, with a reserve in foam discharge of 2.5 and 2.0 minutes, respectively.

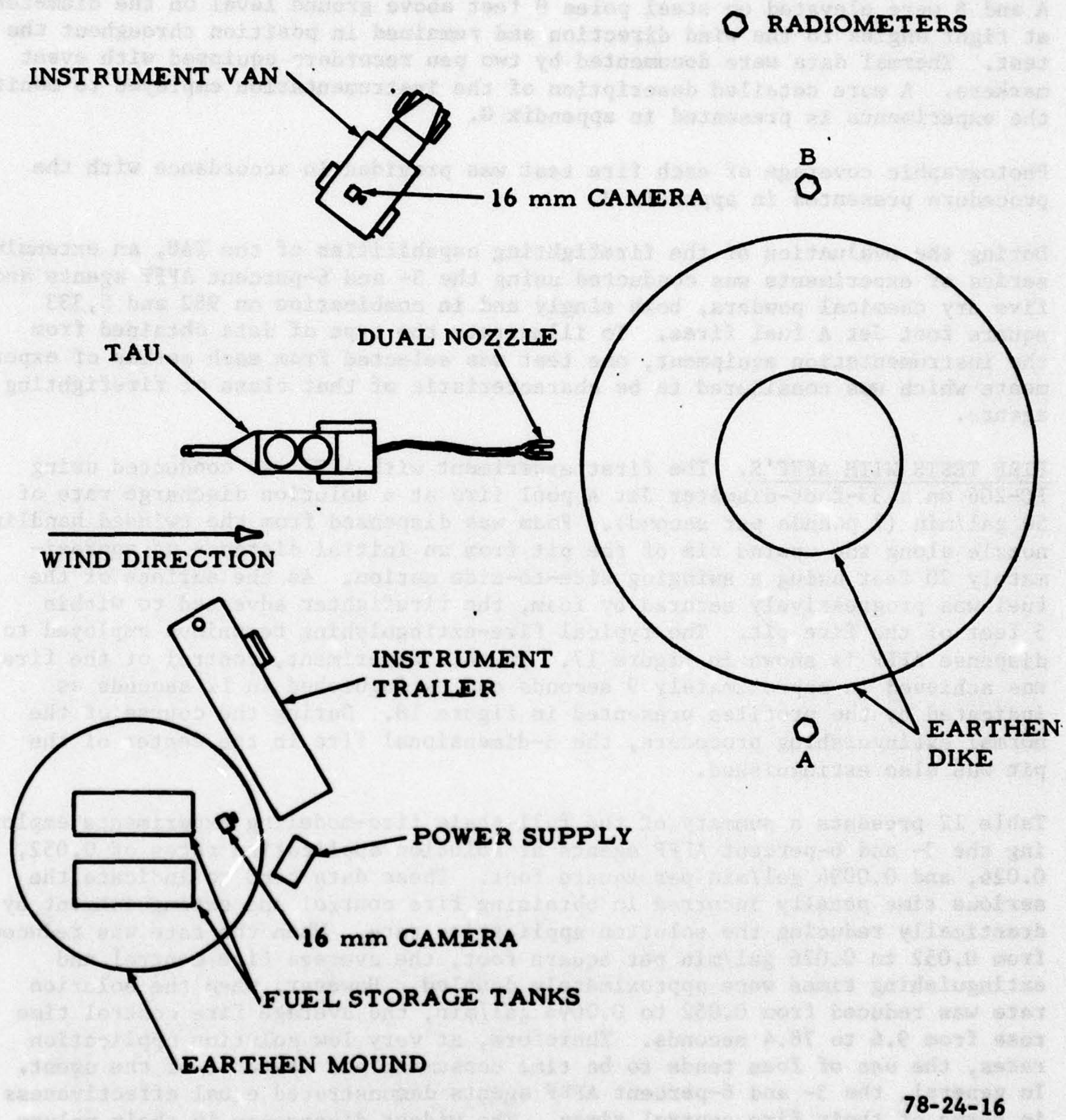


FIGURE 16. PLAN VIEW OF THE FIRE TESTBED SHOWING THE RADIOMETER AND CAMERA LOCATIONS (NOT TO SCALE)

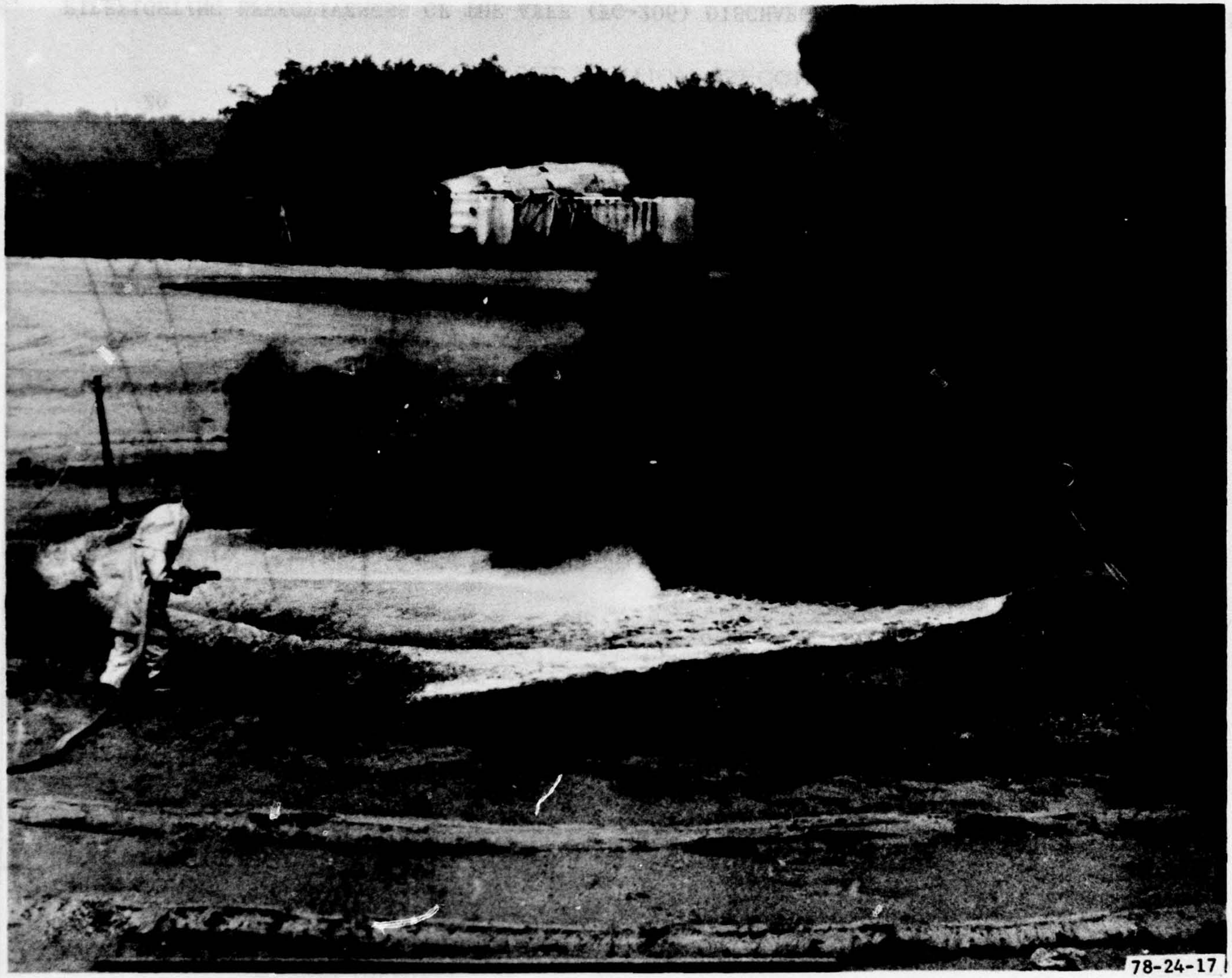


FIGURE 17. FIREFIGHTER DISPENSING AFFF ON THE 35-FOOT-DIAMETER FIRE PIT

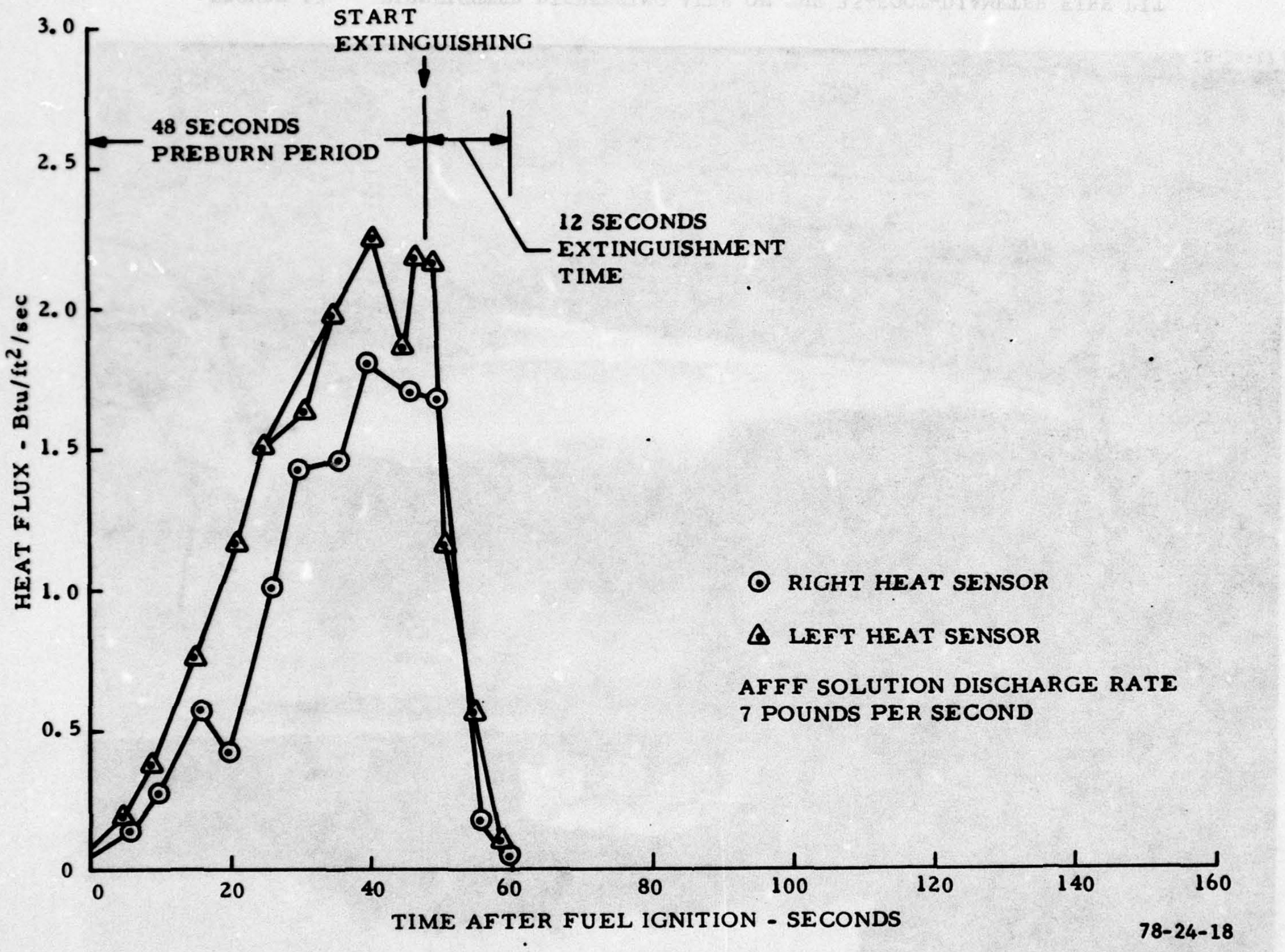


FIGURE 18. FIREFIGHTING EFFECTIVENESS OF THE AFFF (FC-206) DISCHARGE ON THE 35-FOOT-DIAMETER FIRE PIT

TABLE 12. AFFF TEST RESULTS

Firefighting Agents (AFFF)	AFFF Concentration (%)	Fire Pit Diameter (ft)	Fire Pit Area (ft^2)	Foam Sol. Discharge Rate (gal/min)	Foam Sol. Application Rate ($gal/min/ft^2$)	Fire Control Time (sec)	Fire Extinguishing Time (sec)
FC-206	6	35	962	50	0.052	9	12
AER-O-WATER 6	6	35	962	50	0.052	9	12
LORCON AFFF	6	35	962	50	0.052	11	15
FC-203	3	35	962	50	0.052	9	13
AER-O-WATER 3	3	35	962	50	0.052	10	14
FC-206	6	35	962	25	0.026	16	24
AER-O-WATER 6	6	35	962	25	0.026	17	26
LORCON AFFF	6	35	962	25	0.026	17	27
FC-203	3	35	962	25	0.026	13	18
AER-O-WATER 3	3	35	962	25	0.026	19	26
FC-206	6	82.4	5333	50	0.0094	66	120
AER-O-WATER 6	6	82.4	5333	50	0.0094	87	93
LORCON AFFF	6	82.4	5333	50	0.0094	77	128
FC-203	3	82.4	5333	50	0.0094	69	93
AER-O-WATER 3	3	82.4	5333	50	0.0094	93	99

These performance characteristics tend to indicate that the TAU, using foam alone, would be capable of extinguishing the practical critical fire area of 5,527 square feet associated with U.S. index A aircraft (reference 13) within 96.5 to 124 seconds with a reserve agent supply for 2.39 to 1.94 minutes of additional foam discharge.

FIRE TESTS WITH DRY CHEMICAL POWDERS. The first fire test in this series was performed on a 35-foot-diameter (962 square feet) water-base pool containing 350 gallons of Jet A aviation fuel. Purple K powder was discharged at the rate of approximately 7.3 pounds per second from the twinned handline nozzle. At the conclusion of the 68-second preburn period, which was the time required for the fuel surface to become completely involved in flame, the powder was discharged in a continuous stream from the handline nozzle held about 3 feet above ground level and approximately 20 feet from the upwind rim of the fire pit. During discharge, the powder stream was directed at the base of the flames using a sweeping side-to-side motion. The characteristic, enormous surge in radiant energy which always accompanies the initial discharge of dry chemical powder on large free-burning pool fires is dramatically caught in figure 19. The large flame front to which this firefighter is being exposed, at this time, was estimated to be in excess of 2,100° F. Therefore, suitable protective clothing must be provided for firefighters when dry chemical powders are being employed to combat large pool fires at close range.

The fire performance characteristics of Purple K in this particular experiment are indicated by the thermal profiles presented in figure 20. These data indicate that the fire was nominally brought under control within 12 seconds after powder discharge and maintained for approximately 66 seconds with intermittent bursts of powder, after which a serious flashback occurred. Continued intermittent bursts of Purple K were barely able to regain and maintain fire control for an additional period of 26 seconds, during which time the powder was becoming depleted and a major flashback occurred that required extinguishing with AFFF.

The profiles presented in figure 20 indicate that fire control was maintained for approximately 92 seconds. The general firefighting performance demonstrated in this experiment was subsequently found to be characteristic of all powder tests in which the fire was not actually extinguished within the first 15 to 20 seconds after discharge.

The results of the fire tests conducted with five dry chemical powders on the 962-square-foot Jet A pool fires at discharge rates from 3.5 to 7.5 pounds per second are summarized in table 13. Purple K and Monnex each controlled and extinguished the fire in two out of three separate attempts. Super K was successful in controlling and extinguishing the fire in one out of three experiments, while sodium bicarbonate and monoammonium phosphate were incapable of extinguishing any of the fires. All of the dry chemical powders failed to either control or extinguish any of the fires at a discharge rate of 3.5 pounds per second. From these data, it is evident that the 35-foot-diameter fire was adequate to assess the firefighting effectiveness of these agents.

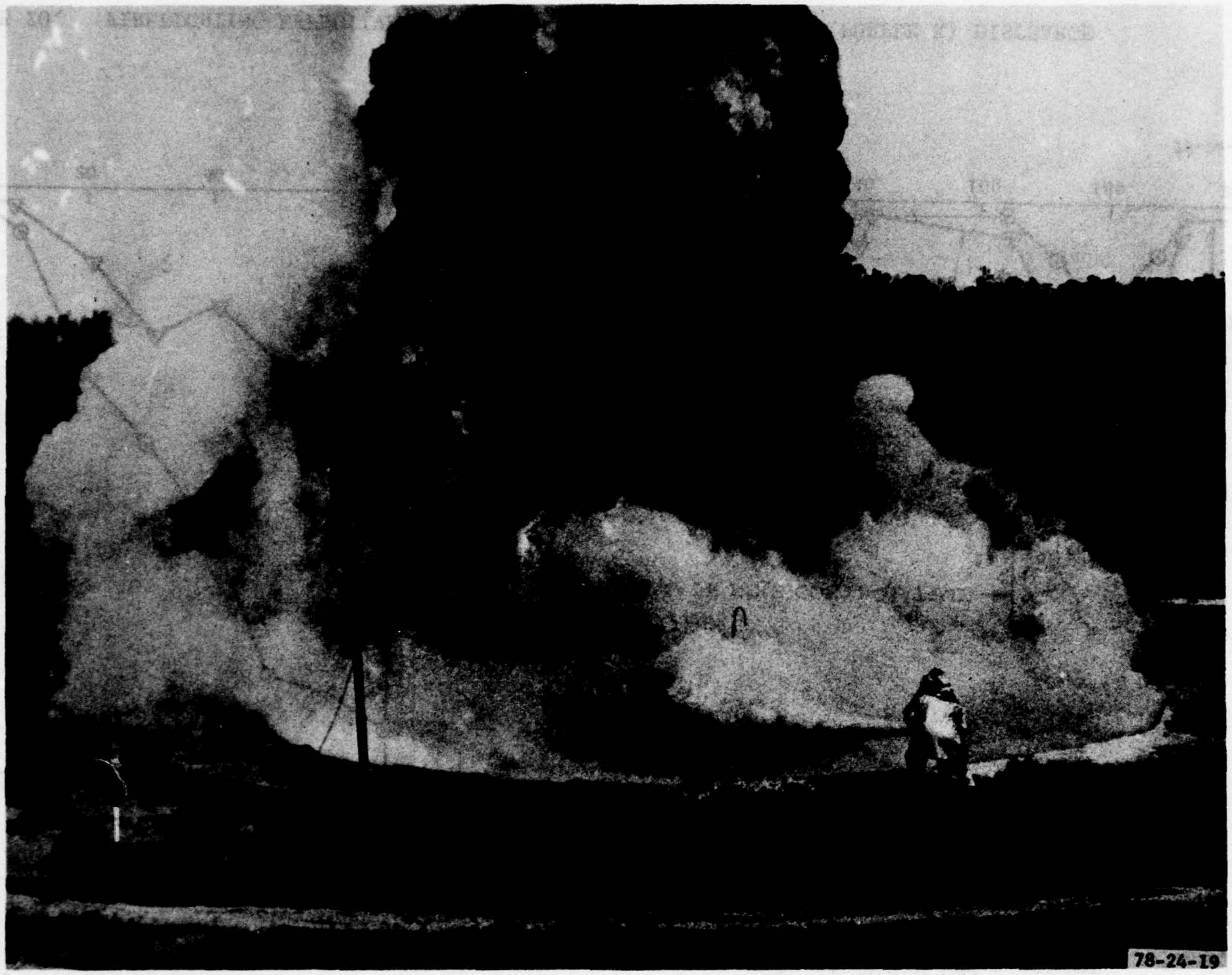


FIGURE 19. FIREFIGHTER DISPENSING DRY CHEMICAL POWDER (PURPLE K) ON THE 35-FOOT-DIAMETER FIRE PIT

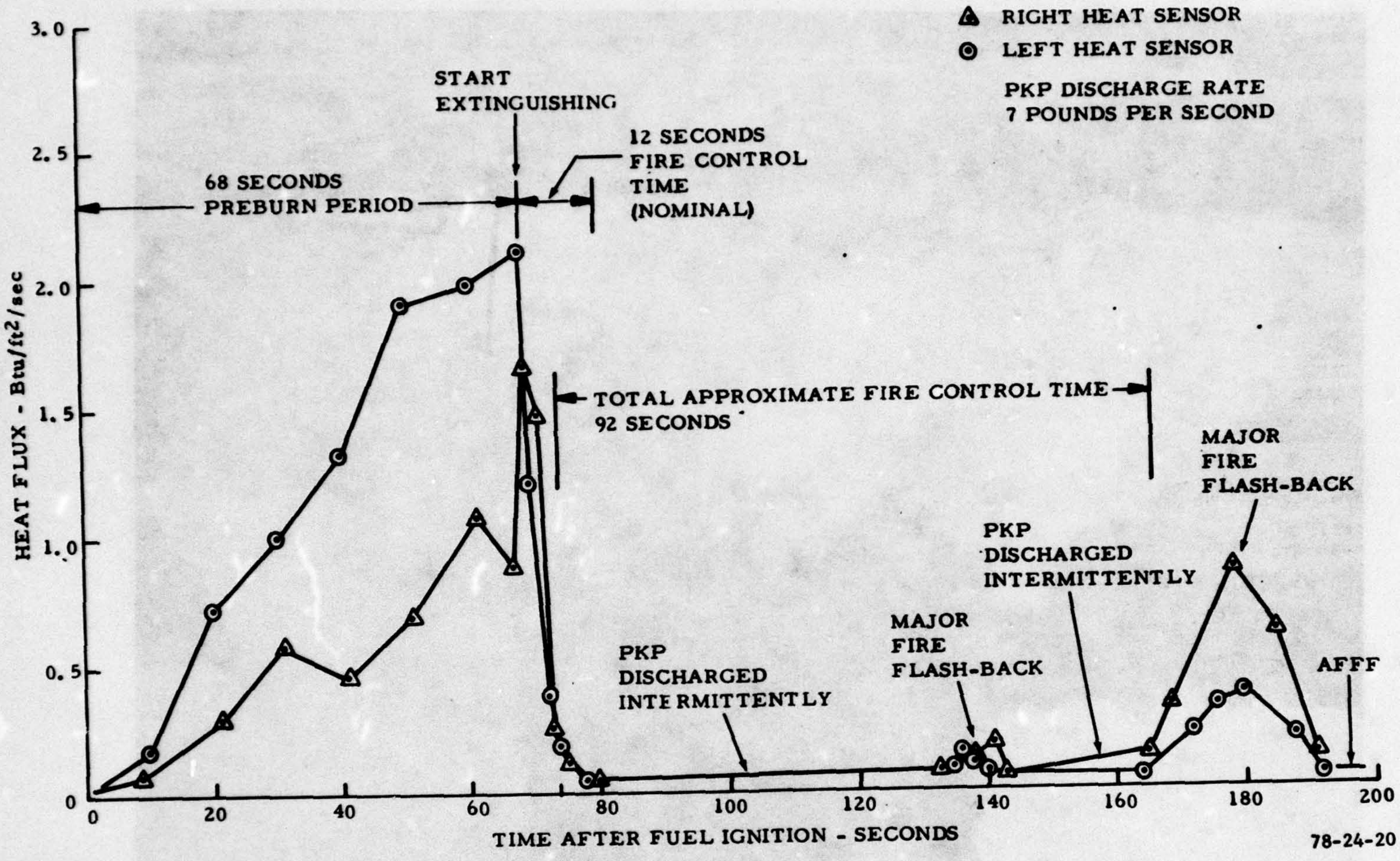


FIGURE 20. FIREFIGHTING EFFECTIVENESS OF THE DRY CHEMICAL POWDER (PURPLE K) DISCHARGE

TABLE 13. DRY CHEMICAL POWDER FIRE TEST RESULTS

Agents	Composition	Fire Pit Diameter (ft)	Fire Pit Area (ft^2)	Powder Discharge Rate (lb/sec)	Powder Application Rate ($lb/ft^2/sec$)	Fire Control Time (sec)	Fire Extinguishing Time (sec)
Purple K	Potassium	35	962	7.26	0.0076	7	13
	Bicarbonate	35	962	7.26	0.0076	8	14
		35	962	7.26	0.0076	12	NE(2)
		35	962	3.5	0.0037	NC(1)	NE
Monnex	Urea-	35	962	6.11	0.0064	8	15
	Bicarbonate	35	962	6.11	0.0064	9	15
		35	962	6.11	0.0064	9	NE
		35	962	3.5	0.0037	NC	NE
Super K	Potassium	35	962	7.38	0.0077	9	NE
	Chloride	35	962	7.38	0.0077	10	NE
		35	962	7.38	0.0077	9	15
		35	962	3.5	0.0037	NC	NE
Sodium	Sodium	35	962	7.50	0.0078	9	NE
Bicarbonate	Bicarbonate	35	962	7.50	0.0078	10	NE
		35	962	7.50	0.0078	13	NE
		35	962	3.5	0.0037	NC	NE
ABC Powder	Monoammonium	35	962	6.74	0.0070	14	NE
(Multipurpose)	Phosphate	35	962	6.74	0.0070	10	NE
		35	962	6.74	0.0070	13	NE
		35	962	3.5	0.0037	NC	NE

(1) NC - no control
(2) NE - not extinguished

The results of this series of experiments tend to emphasize the "go" or "no go" characteristics of fire extinguishment by means of dry chemical powder, since all of the agents were capable of achieving control of the fire at discharge rates from 6.11 to 7.5 pounds per second. Only three actually achieved extinguishment before the powder was exhausted.

<u>FIRE TESTS USING AFFF AND PURPLE K POWDER IN COMBINATION</u>. The third and last experiment in this series of basic fire tests was conducted with the twinned-agent-dispensing system on the same testbed configuration as that employed in the previous tests.

The objective of this experiment was to develop data for estimating the potential fire-extinguishing equivalency between a dual-agent foam-powder dispensing system as opposed to an equal discharge rate of each individual component of that system. This was accomplished by reducing the discharge rate of both the AFFF and dry chemical powder to 3.5 pounds per second, thereby providing a combined average agent discharge of approximately 7.0 pounds per second which was the maximum rate of the equipment employing the agents individually.

All of the combined agent application experiments were started at a distance of 20 feet upwind of the fire pit by first opening the AFFF nozzle followed as rapidly as possible by the powder nozzle. As the fuel surface was secured by foam and the radiant energy from the fire plume reduced by the powder discharge, the firefighter approached to within 5 feet of the rim of the fire pit. A typical dual-agent discharge of AFFF and dry chemical powder is shown in figure 21.

The thermal profiles developed during the first experiment showing the fire control and extinguishing times are presented in figure 22. These data indicate that under the combined agent discharge, the fire was controlled in 7 seconds and both the pool and 3-dimensional fires were extinguished within 13 seconds after the initial attack.

The results of the first three basic fire-extinguishing experiments using AFFF and Purple K powder, both singly and in combination, at approximately equal application rates are summarized in table 14. These data tend to indicate that the equivalency ratio between AFFF and Purple K powder is approximately 1 to 1 by weight in these experiments. The "go" or "no go" fire-extinguishing characteristics of dry chemical powder is also apparent as well as the "supporting-role" played by the foam discharge in obtaining extinguishment when using the dual-agent system. The mechanism whereby this is accomplished is through the fuel vapor securing action of the AFFF which reduces the effective fuel-burning area to within the fire-extinguishing capability of the dry chemical powder. Under these experimental conditions, the total weight of the combined agents discharged was the controlling factor in achieving fire control and extinguishment, and there is no indication of foam-powder synergism, since the fires were extinguished within the same general time frame. However, it is apparent from a consideration of all of the experimental data that the actual equivalency ratio between the AFFF agents and dry chemical powders may vary as a function of the fire-extinguishing effectiveness of each individual component of the dual-agent system.

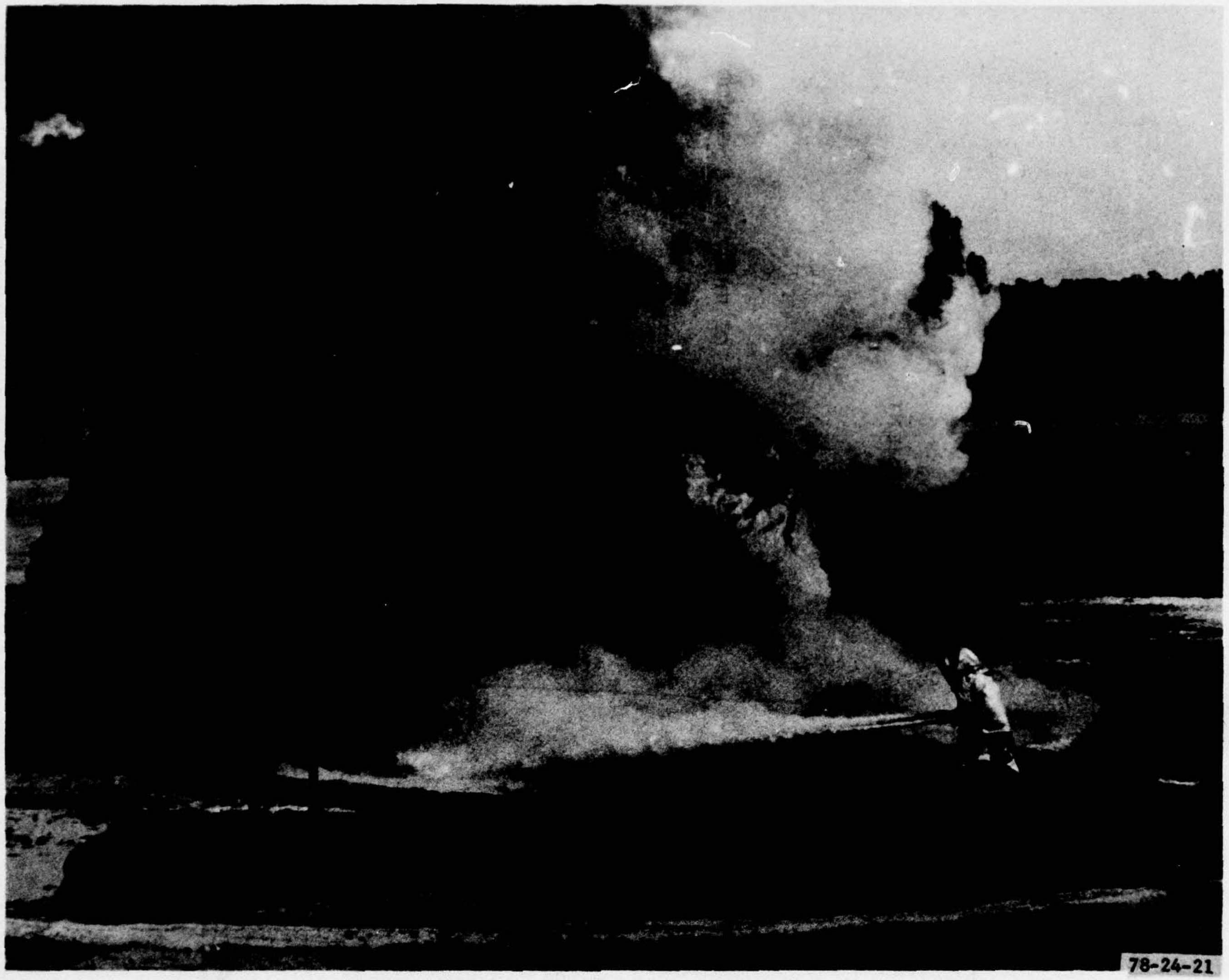


FIGURE 21. FIREFIGHTER EMPLOYING THE DUAL-AGENT (AFFF AND DRY CHEMICAL POWDER) DISPENSING SYSTEM ON THE 35-FOOT-DIAMETER FIRE PIT

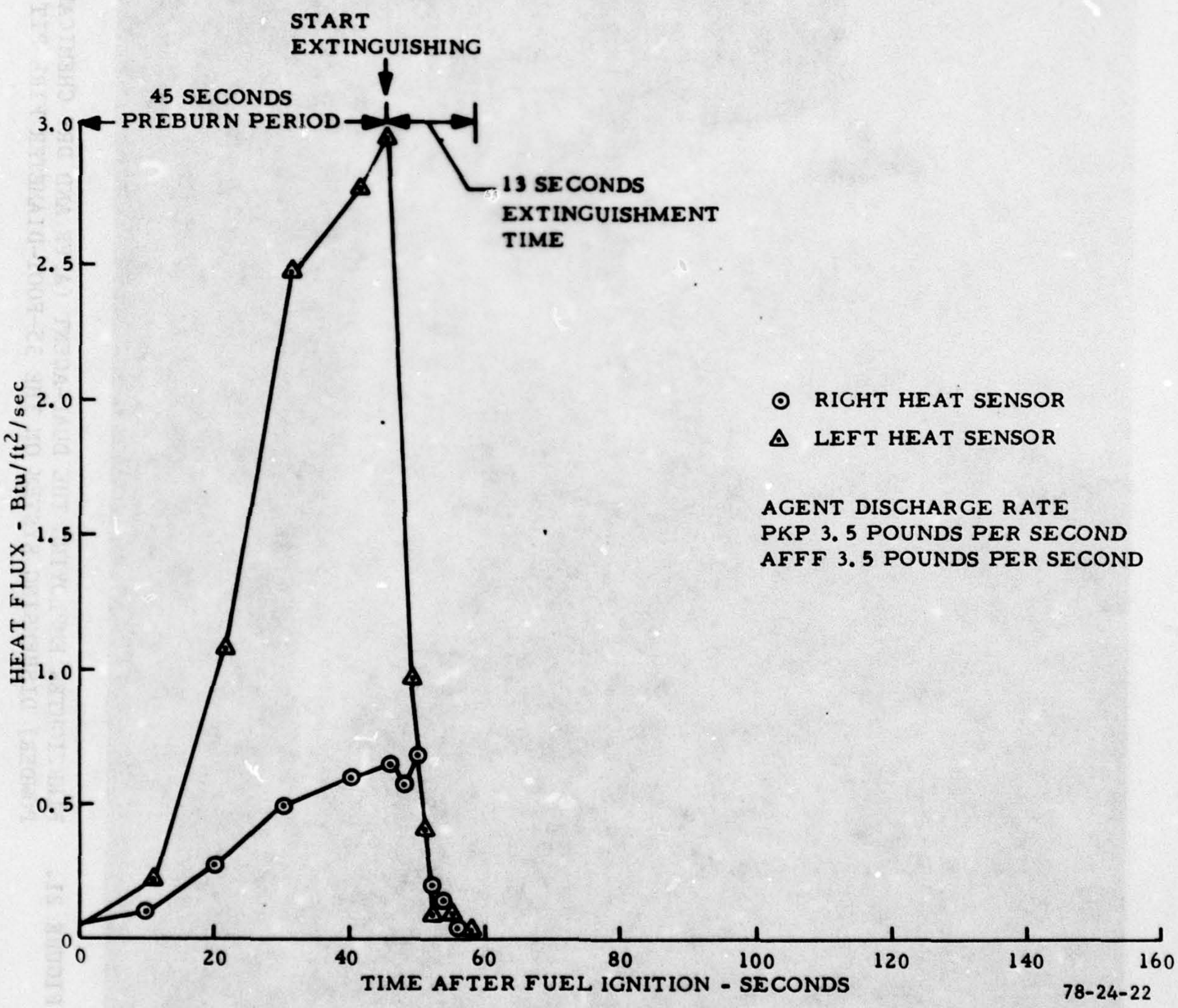


FIGURE 22. FIREFIGHTING EFFECTIVENESS OF THE COMBINED AFFF AND PURPLE K POWDER DISCHARGE

TABLE 14. FIREFIGHTING EFFECTIVENESS OF AFFF AND PURPLE K POWDER SINGLY AND IN COMBINATION

Fire-Fighting Agents	Fire Size (ft^2)	Agent Discharge Rate (lb/sec)	Agent Application Rate (lb/sec/ft^2)	Agent Application Density (lb/ft^2 at Cont.)	Agent Application Density (lb/ft^2 at Ext.)	Fire Control Time (sec)	Extinguishing Time (sec)	Comments
PKP	962	7.26	0.0076	0.0906	-	12	Not Extinguished	
AFFF	962	7	0.0073	0.066	0.087	9	12	(.052 gal/min/ft^2)
PKP and AFFF	962	3.5 3.5	0.0073	0.051	0.095	7	13	PKP and AFFF were compatible

A summary of the results obtained using the combined agent discharge on 35- and 82.4-foot-diamter fires is presented in table 15. These data tend to emphasize the significance of total agent application rate in terms of fire control and extinguishing times. The most rapid fire control and extinguishment was obtained in these experiments at a combined agent application rate of 0.0072 pounds per second per square foot. When the combined rate was reduced from 0.0072 to 0.0027 pounds per second per square foot the fire control and extinguishing times increased by a factor of 10 in some experiments. From these data, it is apparent that as the application rate tends to approach the threshold value for a particular fire configuration, the firefighting effectiveness of the dispensing system decreases in terms of the fire extinguishing time and economy of the agents.

COST OF OPERATING THE TAU. As a consequence of the relatively large number of agents tested during the evaluation of the TAU, a question arose concerning the actual cost of fire extinguishment using foam and powder, both singly and in combination. Accordingly, an estimate of the cost to extinguish the 35-foot-diameter fire employing both types of agents is indicated by the selected examples extracted from tables 12 through 15 and presented in appendix I. These estimated fire-extinguishing costs are based upon the price of the agents during the experimental program and exclude the cost of the nitrogen gas propellent.

The estimated cost (appendix I) of extinguishing the 35-foot-diameter Jet A fuel fire with either the 3- or 6-percent types of AFFF were essentially equivalent, with an average value of $5.85. This relatively low cost derives

TABLE 15. COMBINED AFFF AND DRY CHEMICAL POWDER FIRE TEST RESULTS

Combined Agents AFFF/Powder	AFFF Concentration (%)	Fire Pit Diameter (ft)	Fire Pit Area (ft^2)	Foam Sol. Discharge Rate (gal/min)	Powder Discharge Rate (lb/sec)	Foam Sol. Application Rate (gal/min/ft^2)	Powder Application Rate (lb/sec-ft^2)	Fire Control Time (sec)	Fire Extinguishing Time (sec)
FC-206/PKP	6	35	962	25	3.5	0.026	0.0036	7	13
AER-O-WATER-6/PKP	6	35	962	25	3.5	0.026	0.0036	10	16
FC-203/PKP	3	35	962	25	3.5	0.026	0.0036	9	14
AER-O-WATER-3/PKP	3	35	962	25	3.5	0.026	0.0036	9	13
FC-206/Monnex 6	6	35	962	25	3.5	0.026	0.0036	7	11
AER-O-WATER-6/Monnex	6	35	962	25	3.5	0.026	0.0036	8	13
FC-203/Monnex	3	35	962	25	3.5	0.026	0.0036	8	11
AER-O-WATER-3/Monnex	3	35	962	25	3.5	0.026	0.0036	9	13
FC-206/PKP	6	82.4	5333	50	7.26	0.0094	0.0014	99	112
AER-O-WATER-6/PKP	6	82.4	5333	50	7.26	0.0094	0.0014	75	100
LORCON/PKP	6	82.4	5333	50	7.26	0.0094	0.0014	87	129
FC-203/PKP	3	82.4	5333	50	7.26	0.0094	0.0014	82	114
AER-O-WATER-3/PKP	3	82.4	5333	50	7.26	0.0094	0.0014	94	146
FC-206/Monnex	6	82.4	5333	50	6.11	0.0094	0.0012	77	95
AER-O-WATER-6/Monnex	6	82.4	5333	50	6.11	0.0094	0.0012	93	107
LORCON/Monnex	6	82.4	5333	50	6.11	0.0094	0.0012	78	136
FC-203/Monnex	3	82.4	5333	50	6.11	0.0094	0.0012	89	120
AER-O-WATER-3/Monnex	3	82.4	5333	50	6.11	0.0094	0.0012	82	105

principally from the effectiveness of the firefighting agents and the highly competitive prices among the various brands of AFFF.

In contrast with the foam agents, the dry chemical powders show a relatively wide variation in the cost ($30.00; $59.80; $83.11) of extinguishing the 35-foot-diameter fire pit as well as a significant difference in the extinguishing frequency achieved. The principal reason for this wide variation in cost lies in the large difference in the basic price of the raw materials and the subsequent processing costs. In practice, the final overall cost is a function of the firefighting effectiveness of each agent which determines the total quantity of powder required to achieve fire extinguishment.

The estimated cost to extinguish the 35-foot-diameter fire using the combined AFFF/powder discharge was determined for both the 3- and 6-percent type foam agents in combination with Purple K powder. In these experiments, each agent was discharged at 3.5 pounds per second. The estimated cost to extinguish the Jet A fire using both systems was $37.50 for AER-O-WATER 6/Purple K combination and $30.00 for the AER-O-WATER 3/Purple K system. From a consideration of the fire-extinguishing data presented in appendix I, it is apparent that no major synergism is maintained between AFFF and Purple K powder in these experiments and that the total overall cost closely approximates that attributable to each individual agent.

From the standpoint of cost/effectiveness, the most economical as well as efficient use of the TAU would be to initially secure the fuel surface with foam while conserving the dry chemical powder to extinguish any three-dimensional fires and to mop up relatively small isolated or inaccessible peripheral fires. However, in all complex situations, the fire-extinguishing procedures lie within the province of the firefighter, and his judicious use of the TAU should be based upon adequate training, experience, and sound judgment.

THE CONCEPT OF FIREFIGHTING EQUIVALENCY BETWEEN AFFF AND DRY CHEMICAL POWDERS.

In every aircraft accident involving a severe fire, there exists a requirement for auxiliary agents which are capable of extinguishing three-dimensional and/or running-fuel fires. The dry chemical powders have assumed a prominent position in this regard in recent years, and their use is increasing rapidly. When foam and powder are used at the same time to control and extinguish complex aircraft fires, the problem arises as to the role each plays in the operation. Therefore, to provide a better understanding of the requirements for foam and powder in the overall fire-rescue mission, there is a need to know the approximate firefighting equivalency of dry chemical powder in terms of the foam solution discharge. Although dry chemical powder does not have any fuel vapor-securing properties of its own, it does provide a means for rapidly reducing the radiant energy and of disrupting the thermal updrafts from the fire plume which may aid in the establishment of the foam blanket and facilitate an approach to the fire.

Accordingly, cognizant organizations have developed and promulgated both regulations (FAR Part 139) and recommendations (ICAO, NFPA, and AC No. 150/5210-6B) for the compliance and guidance of concerned users of airport CFR equipment.

Under the FAR 139.49 concerning the substitution of dry chemicals, the ratio of 2.8 pounds per gallon of water may be substituted for up to 30 percent of the water specified for protein foam, thereby providing a 1 to 2.98 ratio of powder-to-foam solution on a weight basis.

The ICAO panel at its second meeting (reference 8) agreed to recommend that, for substitution purposes, 2.2 pounds of dry chemical powder might be considered to be equivalent to 0.26 gallons (2.17 pounds) of water for foam production and that the discharge rate would be the same as for foam, thereby establishing a 1 to 1 ratio of powder-to-foam by weight.

The National Fire Protection Association in NFPA No. 403 (reference 14) also recommends a substitution of 8 pounds of dry chemical powder for 1 gallon (8.345 pounds) of the water required for foam production, thereby providing an approximate 1 to 1 ratio between powder and foam to be applicable where permitted.

In FAA AC No. 150/5210-6B, 8 pounds of dry chemical powder (sodium bicarbonate base) are considered equivalent to 1 gallon of the water required for protein foam production. However, AC No. 150/5210-12 recognizes the superior fire-extinguishing effectiveness of the potassium bicarbonate base powders (Purple K) by permitting a substitution of only 7 pounds of these agents to 1 gallon of water, which is in nominal accord with the experimental data developed during the full-scale fire modeling experiments.

As a consequence of the experimental data developed during the full-scale fire tests using powder and AFFF, both singly and in combination, it is evident that a direct point-by-point comparison of the firefighting equivalency between foam and dry chemical powder is basically unrealistic because of the different physical states of the agents. However, from the standpoint of fire-extinguishing effectiveness alone on class B (Jet A) fuel fires within the capability of the dry chemical powder, the nominal equivalency between AFFF and the dry chemical powders as a class of agents, was shown, by experiment, to be approximately 1 to 1, by weight, when dispensed from the TAU's handline system. Notwithstanding, many complex aircraft accidents involve three-dimensional fires in which fuel pours from broken lines or tanks and over sloping terrain. Under these conditions, foam cannot be employed effectively alone, and dry chemical powder becomes the ancillary agent of choice as a consequence of its unique three-dimensional firefighting capability.

From these considerations, it is apparent that, in complex aircraft accidents involving fuel-spill fires, two different basic types of fire-extinguishing agents are required; i.e., foam, to control and secure the static two-dimensional class B fires, and a three-dimensional agent such as dry chemical powder to extinguish the dynamic, dripping, or flowing-fuel fires. The means for implementing these fundamental concepts are inherent in the design and construction of the TAU.

SUMMARY OF RESULTS

The results obtained from the evaluation of the TAU as a rapid response fire-fighting vehicle in laboratory experiments and full-scale fire modeling tests on 35- and 82.4-foot-diameter Jet A fuel fires are:

1. The transit time of the TAU/station wagon combination calculated by means of segmented time trials over the certification route (firehouse to the mid-point of the furthest runway) on the NAFEC airport was 77 seconds. The accuracy of this test procedure was validated by conducting a demonstration run over the same course which required a total time of 78 seconds.

2. The turning diameter of the Chrysler station wagon and TAU trailer combination was 48 feet.

3. The foam expansion ratios produced by the TAU using both the 3- and 6-percent type agents varied from 6.1:1 to 8.4:1, and the 25-percent solution drainage time varied between 3.1 minutes and 4.0 minutes.

4. The foam expansion ratios produced by the 3- and 6-percent AFFF premixed solutions in laboratory experiments both before and after a 9-week aging cycle varied between 17.3:1 and 25.6:1, with corresponding 25-percent solution drainage times varying between 5.1 minutes and 9.6 minutes.

5. Premixed solutions of one 3- and one 6-percent AFFF agent containing from 9.2 to 28 percent of ethylene glycol by volume demonstrated fire control times between 0.66 and 1.2 minutes and corresponding fire extinguishing times between 1.2 and 1.8 minutes when discharged at the rate of 6 gal/min on 100-square-foot Jet A fuel fires.

6. The average area of the foam ground patterns produced by the 6-percent AFFF agents at a discharge rate of 50 gal/min was approximately 85 percent greater than at 25 gal/min.

7. The estimated area of the foam ground patterns produced by the 3-percent agents discharged at 50 gal/min was approximately 54 percent greater than at 25 gal/min.

8. A comparison of the foam areas produced by the 3- and 6-percent AFFF agents indicates that the 3-percent liquids produce a 4.5-percent larger area at 50 gal/min and a 25-percent greater area at 25 gal/min than the 6-percent agents at equal solution discharge rates.

9. All of the AFFF agents (3- and 6-percent types) achieved fire control and extinguishment of the 35-and 82.4-foot-diamter Jet A fuel fire and provided an effective vapor-securing film/foam over the hot fuel surface which resisted repeated attempts to reignite.

10. The compatibility between AFFF and dry chemical powder when evaluated in accordance with the procedure presented in appendix F demonstrated that the

time required to collect 25 ml of foam solution was in excess of the 2-minute minimum requirement for all combinations of foam and powder.

11. The fire-extinguishing effectiveness of the dry chemical powder in terms of the number of fire pans extinguished in the TAU powder throw range experiments varied between 56 to 103 for the different agents.

12. A comparison of the fire-extinguishing effectiveness of dry chemical powder in terms of the average quantity of agent required to extinguish one fire pan varied from 3.27 to 8.04 pounds among the five agents.

13. A comparison of the average fire control times obtained using the 3- and 6-percent AFFF agents at solution application rates of 0.0072, 0.0036, and 0.0013 pounds per second per square foot demonstrated that the individual fire control times were of the same order of magnitude at each application rate.

14. Full-scale fire modeling experiments conducted with the TAU at maximum discharge rates using each of the five dry chemical powders on 35-foot-diameter Jet A fuel fires indicated Purple K and Monnex to be capable of extinguishing the fire in two out of three attempts, and Super K in one out of three attempts, while sodium bicarbonate and monoammonium phosphate were incapable of extinguishing any of the fires.

15. All of the dry chemical powders failed to control or extinguish any of the 35-foot-diameter Jet A fuel fires at a discharge rate of 3.5 pounds per second.

16. Although the dry chemical powders were capable of very rapid fire control and extinguishment of both the two-and three-dimensional fires at specific application densities which were characteristic of each agent, they did not provide vapor securing protection over the fuel surface which was therefore subject to reignition.

17. The combined application of AFFF and dry chemical powder when discharged at equal parts by weight and at an application rate of approximately 0.0072 pounds per square foot per second provided average fire control (8.4 seconds) and extinguishing times (13.0 seconds) of the same order of magnitude as each individual component of that system at the same discharge rate.

18. The approximate cost of firefighting agents required to extinguish the 35-foot-diameter Jet A fuel fire with AFFF varied from $5.33 to $6.25 and from $30.00 to $83.11 using dry chemical powder, depending upon the agent price while the cost of the dual-agent discharge varied between $37.50 and $30.00 employing AER-O-WATER 6 and AER-O-WATER 3, respectively, in combination with Purple K powder.

CONCLUSIONS

Based upon the results of tests conducted during the performance evaluation of the TAU, it is concluded that:

1. The transit times of CFR vehicles over the operational portions of an airport may be satisfactorily estimated by employing the segmented time trial methodology.

2. The quality of foam produced by the two 3-percent and three 6-percent AFFF agents in terms of the expansion ratio and 25-percent solution drainage time was in nominal agreement with the recommendations of the NFPA No. 412 (reference 5).

3. Premixed solutions of the AFFF agents may be stored at ambient room temperatures (65° to 70° F) for a minimum of 9 weeks without impairing the quality of foam produced or its firefighting effectiveness.

4. Premixed solutions of both a 3- and 6-percent type AFFF agent containing from 9.2 to 28 percent of ethylene glycol by volume showed no significant reduction in stability, foam quality, or fire-extinguishing effectiveness when tested at 0.06 gal/min per square foot on Jet A fuel fires.

5. Ethylene glycol is an effective freezing point depressant for premixed solutions of the AFFF agents and may be employed at concentrations up to 28 percent by volume.

6. The 3- and 6-percent type AFFF agents were equally effective in producing a fuel vapor securing aqueous-film/foam blanket over the Jet A fuel surface after fire extinguishment.

7. All of the 3- and 6-percent type AFFF agents were determined to be compatible with each of the five dry chemical powders in laboratory experiments conducted in the presence of Jet A fuel (appendix F).

8. The fire-extinguishing effectiveness of the dry chemical powders in terms of the number of fire pans extinguished in the powder throw range experiments indicates the following ranking of the agents in decreasing order of effectiveness: Purple K, Monnex, Super K, monammonium phosphate, and sodium bicarbonate.

9. A comparison of the fire-extinguishing effectiveness of the dry chemical powders in terms of the average quantity of agent required to extinguish one fire pan during the powder throw range experiments, indicates the following ranking in decreasing order of effectiveness: Monnex, Purple K, Super K, monoammonium phosphate, and sodium bicarbonate.

10. The 3- and 6-percent AFFF agents demonstrated equal firefighting effectiveness as classes of agents, in terms of their fire control times on the 35- and 82.4-foot-diameter Jet A fuel fires.

11. Dry chemical powders are incapable of providing a fuel vapor securing cover over a Jet A fuel surface after fire extinguishment.

12. No significant synergistic behavior was apparent between the dry chemical powders and AFFF agents in terms of firefighting effectiveness when these agents were discharged at equal rates by weight from the TAU handline nozzle.

13. The cost of extinguishing Jet A fuel fires of equal size was greater for the dry chemical powders than for the AFFF agents at approximately equal application rates.

RECOMMENDATIONS

Based upon the results obtained during the performance evaluation of the TAU, it is recommended that:

1. The methodology developed for determining the transit time of the TAU on the NAFEC airport be utilized to calculate the transit times of all CFR vehicles to all operational segments of the airport and those potential accident-prone areas off the pavements.

2. The equivalency between AFFF and dry chemical powders in terms of their firefighting effectiveness on 35-foot-diameter Jet A fuel fires using the TAU be considered approximately 1 to 1 on a weight basis when employing Monnex, Purple K, and Super K.

3. When employing the twinned foam and dry chemical dispensing system, AFFF be utilized as the principal firefighting agent on class B pool fires and that the dry chemical powder be conserved to extinguish three-dimensional and flowing fuel fires where required.

4. The premixed AFFF solutions employed in the operation of the TAU use either the 3- or 6-percent type agents at the required concentration by volume.

REFERENCES

1. Geyer, G. B., Effect of Ground Crash Fire on Aircraft Fuselage Integrity, Systems Research and Development Service, Federal Aviation Administration, National Aviation Facilities Experimental Center, Atlantic City, New Jersey, FAA-RD-69-46, December 1969

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

3. Military Specification MIL-F-24385 (Amendment 5) Fire Extinguishing Agent Aqueous Film Forming Foam (AFFF) Liquid Concentrate Six Percent for Fresh and Sea Water, April 25, 1967.

4. Tracktest Fifth Wheel, Laboratory Equipment Corporation, 156 East Harrison Street, Mooresville, Indiana, 46158.

5. Evaluating Foam Fire Equipment, Aircraft Rescue and Firefighting Vehicles, National Fire Protection Association, NFPA No. 412, 1974.

6. Geyer, G. B., Neri, L. M., and Urban, C. H., Evaluation of a High-Capacity, Firefighting Foam-Dispensing System, U.S. Department of Transportation, Federal Aviation Administration, Systems Research and Development Service, Report No. FAA-RD-74-204.

7. Aircraft Rescue and Firefighting Vehicles, National Fire Protection Association, NFPA No. 414, 1975.

8. Rescue and Firefighting Panel, International Civil Aviation Organization, Doc. 9036, RFFP/11, June 1972.

9. Geyer, G. B., Evaluation of Aircraft Ground Firefighting Agents and Techniques, National Aviation Facilities Experimental Center, FAA-RD-71-57, and Tri-Service System Program Office for Aircraft Ground Fire Suppression and Rescue, SMF, AGFSRS71-1.

10. Federal Specification O-F-555C, Foam Liquid, Fire Extinguishing Mechanical, January 3, 1969.

11. Underwriters' Laboratories, Inc., 207 East Ohio Street, Chicago, Illinois, 60611.

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

13. Advisory Circular AC No. 150/5210-6B, Department of Transportation, Federal Aviation Administration, January 26, 1973.

14. Aircraft Rescue and Firefighting Services at Airports, National Fire Protection Association, NEPA No. 403, 1974.

APPENDIX A

FIREFIGHTING AGENT MANUFACTURERS

<u>AFFF Manufacturers</u>

Laurentian Concentrates Ltd.
Minnesota Mining & Mfg. (3M) Co.
National Foam System, Inc.

<u>Dry Chemical Powder Manufacturers</u>

ICI Americas, Inc.
Pyro Chemicals Inc.
The Ansul Company

APPENDIX B

SCHEDULE

FIRE EXTINGUISHER UNIT
WITH
FOUR-WHEEL TRAILER

The Contractor shall furnish one (1) Fire Extinguisher Unit and one (1) Four Wheel Trailer and meet all of the following requirements.

REQUIREMENTS

FIRE EXTINGUISHER UNIT: (1 EA.)

Parts and Materials. Parts and materials shall be as specified herein. Parts and materials not specified shall be of the best quality and entirely suitable for the purpose intended with adequate strength for safety and reliability and shall be corrosion resistant.

Metals. All metal parts shall be of corrosion resistant material or treated in a manner to render them adequately resistant to corrosion. Dissimilar metals shall not be used in intimate contact with each other, unless they have been suitabley protected against electrolytic corrosion.

Nonmetallic Materials. Nonmetallic materials which will be adversely affected by continued use with fire extinguishing agents specified herein shall not be used.

Design and Construction. This fire extinguisher shall be a twin-agent type using fire extinguishing agents and charge as follows:

(a) AFFF 6-percent type conforming to MIL-F24385.

(b) AFFF 3-percent type.

(c) Potassium bicarbonate dry chemical conforming to O-D 1407.

(d) Sodium bicarbonate dry chemical conforming to O-F-371.

(e) Multipurpose phosphate dry chemical conforming to O-D-1380.

(f) Potassium bicarbonate urea compound dry chemical.

(g) Potassium chloride dry chemical.

The fire extinguisher shall be skid-mounted and shall be designed and constructed to permit easy inspection, operation, and recharging and shall consist of an AFFF agent tank, a dry chemical agent tank, nitrogen cylinders, piping, pressure regulators, discharge hoses and nozzles, hose reel and other equipment specified herein. The fire extinguisher shall be designed primarily to utilize the potassium bicarbonate dry chemical specified in (c) above, but shall also be capable of utilizing the dry chemical agents specified in (d) through (g) above without changing any of the mechanical components.

Twin-Agent Operating Principle. The AFFF solution and the dry chemical agent shall be stored unpresurrized in individual tanks. The expellant energy required to apply the agents shall be provided by nitrogen under pressure. When in use, nitrogen flow from the cylinders shall enter the agent tanks, pressurizing the active AFFF solution and simultaneously fluidizing and pressurizing the dry chemical agent. The agents distribution system shall begin at the outlets of both agent tanks and shall consist of a twin passage hose terminating in twin hand-operated valves and nozzles for controlling the agents' flow and direction. As the valves are opened, either individually or simultaneously, the agents shall flow from the pressurized tanks through the hose and from the nozzles.

AFFF Agent Tank,. The AFFF agent tank shall have a capacity of not less than 200 gallons. It shall be designed and constructed in accordance with the ASME Code for Pressure Vessels, Part UG of Division 1 of Section VIII and shall be National Board stamped as suitable for use at 250 pounds-force per square inch (lbf/in^2) working pressure in temperature ranges of -20°F to +130°F. It shall be constructed of carbon steel lined with coal tar epoxy or equal compatible with AFFF and salt or fresh water solutions. A reseating pressure-relief valve meeting the requirements of UG-125 through UG-134 of the ASME Pressure Vessel Code, set to operate at 275 lbf/in^2 (110 percent of operating pressure) shall be provided. It shall be capable of venting from the void volume of the tank at the maximum possible gas flow into the tank. A readily accessible 4-inch diameter fill opening shall be provided in compliance with UG-36 through UG-46 of the ASME Pressure Vessel Code. It shall be located in a position which allows the liquid level to be measured with a direct reading dipstick. The agent outlet opening in the tank shall be no smaller in size than the internal diameter of the discharge hose. Valving shall be provided to route the nitrogen supply directly to the hose line inlet, bypassing the AFFF agent tank, in order to purge the hose line of residual solution. A vent line with a "Quarter-turn" valve shall be provided on the top of the tank to permit"blowdown" to insure zero pressure in the tank prior to opening the long handled fill cap.

A temperature relief valve set for 212°F shall be installed in the tank positioned so that it will be in contact with the AFFF solution until the tank is empty. Provision shall be made for draining the tank for storage.

Dipstick and Funnel. A direct-reading dipstick and a funnel suitable for filling the AFFF tank shall be provided.

Dry Chemical Agent Tank. The dry chemical agent tank shall be capable of containing at least 450 pounds of "freshfill" (untamped) potassium bicarbonate dry chemical agent. The tank shall be designed and fabricated in accordance with Part UG of Division 1 of Section VIII of the ASME Code for Pressure Vessels for working pressure of 250 lbf/in^2 and shall be National Board stamped. It shall be suitable for use in the temperature range of -20°F to +130°F. A reseating pressure relief valve satisfying Parts UG-125 through UG-134 of the ASME Pressure Vessel Code, capable of relieving 275 lbf/in^2 (110 percent of design pressure), shall be provided. This relief valve shall be mounted to vent the void volume above the agent level at the maximum gas flow into the tank. A readily accessible fill opening at least 4 inches in diameter shall be provided in compliance with UG-36 through UG-46 of the ASME Pressure Vessel Code. A nitrogen distribution system shall be provided to fluidize, pressurize, and discharge the dry chemical agent at a flow of at least 6 pounds per second. Valving shall be provided to route the nitrogen supply directly to the hose inlet, bypassing the dry chemical tank, in order to purge the hose of residual dry chemical and prevent hose packing. A vent line shall be provided in the top of the tank for "blowdown" purposes to insure zero pressure in the tank before opening the fill cap. This vent line shall exhaust into the dry chemical hose inlet.

Fill Caps. The fill caps of both the AFFF and dry chemical agent tanks shall be provided with rubber gaskets and safety vent holes so that each cap is pressure-vented while at least three and one-half threads are still engaged. The fill cap arrangement shall be such that the female threads and handles are part of the cap.

Nitrogen Cylinders. A nitrogen gas cylinder(s) shall be provided for each of the two agent tanks. The cylinders shall be of sufficient capacity to completely discharge the agents (at the rated delivery rates) and purge all lines of residual agents. These cylinders shall be mounted on racks. The cylinders shall be of shatter-proof construction. Pressure gages (0-4000 lbf/in^2) for indicating the cylinder gas pressure and quick-opening lever operated valves requiring only 90° rotation of the lever to release the nitrogen gas shall be provided. These quick operating valves shall be capable of being easily reset manually. Mounting racks for these cylinders shall provide for positioning of the cylinders in the horizontal position with the quick-opening valves at the operating end of the unit.

Nitrogen Pressure Regulators. Two pressure regulators shall be provided (one for each agent tank). Pressure regulation shall be designed to automatically reduce the high pressure gas cylinder pressure and maintain the expellant gas pressure at 230 to 250 lbf/in^2, i.e., at or below the designed operating pressures of the agent tanks. The gas flow rate of the regulators and the gas distribution system of both tanks shall reach a pressure level of 80 percent of the operating pressure within 10 seconds after cylinder valve is opened.

The regulators shall be sealed after final adjustment. In normal operation, gas from the nitrogen cylinders shall pass through the regulators, test valves, check valves, agent tanks, hose reel and handlines, and shall be controlled at the handline nozzles.

Discharge Hoses. The handline shall be constructed of two noncollapsible, 3-braid neoprene lined and jacketed hoses 100 feet long. Both hoses shall have not less than 1-inch inside diameter and shall be fastened together with a smooth, abrasion-resistant woven polyester jacket running the full length of the hoseline. Strands of woven jacket shall be prevented from raveling by bonding a 1-7/8-inch-wide neoprene band to the outer jacket. The handline shall have a nominal working pressure of up to 400 lbf/in^2 and a bursting pressure of 1500 lbf/in^2. The material used must not be adversely affected by long exposure to the chemical agents.

Nozzles. The dry chemical and AFFF nozzles shall be close-coupled so that the nozzles may be easily operated and directed by one man. The nozzles shall be individually or simultaneously operated by an operator wearing firefighting protective clothing. Nozzles shall be mounted in a manner to prevent interference with either discharge stream. The nozzle assembly shall be of nonferrous construction, such as anodized aluminum, stainless steel, or chrome plated brass. Nozzles shall offer no obstruction to the flow in the passage ways, when the shutoff handles are rotated 90° from the full-off to the full-open position. the dry chemical nozzle tip shall give a semidispersed pattern at flow rates up to 6 pounds per second. The effective reach shall be 40 to 50 feet when the wind is less than 5 miles per hour (mi/h). The AFFF nozzle tip shall provide an effective reach of 45 to 50 feet, a 12-foot pattern width,and a foam expansion ratio of five to one when used with 6-percent AFFF solution. Range and pattern shall be determined with a minimum 100-lbf/in^2 inlet pressure, nozzle inclination of 15° above horizontal, and a nominal flow rate of 50 gallons per minute. The expansion ratio shall be measured as defined in NFPA Pamphlet No. 412. A suitable nozzle mount shall be provided on the extinguisher for holding nozzles when not in operation.

Hose Reel. One manual rewind twin hose reel shall be provided for both dry chemical agent and AFFF agent discharge hoses. It shall provide for easy one man rapid pay-out and takeup storage of 100 feet of twin hose. Normal flow through the nozzle is required when any portion of 100-foot hose is withdrawn from the reel.

Piping. Piping shall be designed to accommodate the flow rates specified herein without excessive friction losses. The piping system design shall inherently prevent loosening of joints and rupturing of pipes or connections under shock and vibration loads. No black or galvanized iron shall be used in contact with the AFFF agent. Potential galvanic corrosion points shall be eliminated by proper choice of materials.

Valves. Check valves shall be provided in the nitrogen supply system to prevent backflow of the extinguishing agents into the pressure regulators. Some means such as valves or rupture discs, shall be used to prevent the agents from entering the hose lines until pressurization occurs. All valves used in the control of the dry chemical agents must be suitable for use with the agents in 3.3. These valves shall be designed to withstand,without failure, 125 continuous "ON/OFF cycles during a nominal 5 pounds per second dry chemical agent flow. All valves shall have a size no less than the inside diameter of the connecting piping or hoses and shall be the "one-quarter" turn type. All valves shall be designed and installed to facilitate maintenance and replacement. All valves which will come in contact with the AFFF agent during normal operation shall be designed to show no signs of binding or seat deterioration after immersion in a 6-percent AFFF agent for 40 hours at a temperature of $100^{o} \pm 10^{o}$F.

Castings and Forgings. All castings shall be free from blowholes, porosity, hard-spots, shrinkage, defects, cracks, or other defects. Forgings shall be free from scale, inclusions, mismatching and other defects which might affect the structural strength. Strength, and other essentail physical and chemical properties of the castings and forgings, shall be adequate to meet the performance requirements specified herein.

Skid-Mounting Frame. The skid-mounting frame shall be constructed of electrically welded structural steel designed to withstand rough usage and shall permit forklift or crane (helicopter) lifting. The skid shall be provided with at least four lifting eyes to anchor the fire extinguisher to a truck bed or aircraft floor and to facilitate lifting or towing. The shipping weight and center-of gravity location shall be marked along each axis for both the charged and uncharged condition. The skid shall be provided with openings to insert forklift tines. Each opening shall be 3 inches by 12 inches. The distance between openings shall be 34 inches measured inside to inside. The openings shall be located so that the center of gravity of the fire extinguisher falls approximately midway between centers of the forklift openings.

Static Electricity. A static wire of sufficient size to ground both nozzles to the unit and to prevent shocks caused by agent flow through the lines or nozzles shall be provided in the handline assembly.

Safety Devices. The fire extinguisher shall be quipped with safety devices to adequately protect all hazards incident to their operation.

Interchangeability. All parts having the same manufacturer's part number shall be functionally and dimensionally interchangeable.

Maintainability. All subsystems, assemblies, and components shall be designed and assembled to afford maximum operational readiness with a minimum of preventive and corrective maintenance. Adjustments shall be readily accomplished by operating personnel without the need of special training or special tools. All components subject to wearout, deterioration, breakage, or loss of adjustment shall be readily accessible for replacement, repair, or adjustment. Nitrogen cylinder replacement and agent recharging operations shall be accomplished from the ground with a minimum of repiping or disassembling of components. Servicing from the bottom shall be avoided. There shall be no preventive maintenance requirement for servicing the dry chemical agent storage system to prevent compaction of the powder. The design of the dry chemical agent distribution system shall inherently provide the means for overcoming compacting problems without any manual operation.

<u>Performance.</u> The fire extinguisher shall be capable of the following performance characteristics:

<u>Operational Capability.</u> The fire extinguisher shall be capable of achieving 80 percent of the operating pressure through the gas regulators and gas distribution system within 10 seconds after the nitrogen cylinder valves have been opened.

<u>Dimensions.</u> The dimensions of the skid-mounted fire extinguisher shall not exceed 50 inches wide, 120 inches long and 60 inches high.

<u>Weight</u>. The weight of the skid-mounted fire extinguisher, fully charged, shall not exceed 5,500 pounds.

<u>Treatment and painting.</u> All ferrous metal surfaces which do not possess a resistance to corrosion (including framing, dry chemical agent tank,AFFF agent tank, hose reel, and piping) shall be protected with an inorganic zinc coating. This method shall consist of a white metal sandblasting, a spray application of inorganic zinc coating with maximum of 3 to 5 mils dry film thickness followed by epoxy base primer with maximum of 1.2 to 1.8 mils dry film thickness. A color coat shall be applied. This color coat shall be "fire truck yellow" gloss. Any aluminum surfaces shall be treated in accordance with MIL-T-704. They shall not be sandblasted and shall be coated with zinc-chromate primer before applying the epoxy base color coat. Finish thickness on the aluminum surfaces shall not exceed 3 to 5 mils dry film thickness. All stainless steel surfaces shall be etched (passitated) with a nitric acid solution, throughly rinsed with water, and prime coated with zinc-chromate primer prior to application of epoxy base color coating.

<u>Marking</u>. All plates, instruction and identification, shall be permanently mounted on the fire extinguisher at the rear so that they may be easily read by personnel intending to operate the fire extinguisher.

<u>Identification bands</u>. Two bands of reflectorized adhesive tape shall be attached to each agent tank. Each band shall be 2 inches wide with a minimum of 3 inches separation between bands. The AFFF agent tank shall bear the legend "AFFF" in black letters. The bands on the dry chemical tank shall bear the legend "DRY CHEMICAL" in black letters.

<u>Instruction Plates</u>. Instruction plates shall be provided showing the following

(a) Complete and detailed activation instructions.

(b) Shutdown and maintenance instructions.

(c) Instructions concerning when and how to replace the nitrogen cylinders.

(d) Refilling table and instructions for all agents showing quantities required to refill tanks when compared with quantity of agent remaining in the tanks.

Workmanship. This extinguisher shall be free from irregularities, defects, or foreign matter which could adversely affect safety, performance, reliability or durability. Safety devices shall be provided in accordance with manufacturing practices used in the production of this type of equipment.

QUALITY ASSURANCE PROVISIONS

Responsibility for Inspection. The supplier is responsible for the performance of all inspection requirements as specified herein. The supplier may use his own or any other facilities suitable for the performance of the inspection requirements specified herein. The purchaser reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure supplies and services conform to prescribed requirements.

Examination. The fire extinguisher shall be examined to determine compliance with requirements specified herein. Particular attention should be given, but not limited to, the following:

(a) Overall weight

(b) Dimensions

(c) Hose size and lenghts

(d) Arrangement of valves, regulators, gages, plumbing vents

(e) Type of materials and finishes

(f) Color

(g) Legibility and correctness of marking

(h) Tiedown and lifting means

(i) Agent tank certifications

(j) Freedom of valve operation

(k) Ease of refilling agent tanks and replacing nitrogen cylinders

(i) Completeness, including caps, funnel and dipstick

(n) Free unreeling and rewinding of discharge hose

(o) Complete drainage of all liquids

Tests.

Tank Pressure Test. The AFFF and dry chemical agent tanks shall be pressure tested. Relief valves shall be gagged and openings not related to this test shall be plugged. The tanks shall be pressurized to 150 percent of the 250 lbf/in^2 design operating pressure. The pressure shall be held for 15 minutes at both 130°F and -20°F. There shall be no evidence of leakage, permanent distortion or other defect.

Hose and Coupling Assembly Pressure Test. The dry chemical and AFFF discharge hoses and the hose reel and coupling assembly shall be hydrostatically tested to 600 lbf/in^2 pressure for 5 minutes. There shall be no evidence of leakage, permanent distortion or other defects.

High Pressure Piping and Fitting Assemblies Pressure Test. The high pressure piping and fitting assemblies shall be hydraulically tested to 4,000 lbf/in^2 for 1 minute. There shall be no leakage or other defects.

Operating Tests.

Pressurization. It shall take no more than 10 seconds for the nitrogen cylinders to develop 80 percent of the design operating pressure in each agent tank after valves have been fully opened. The pressure measurements shall be made with direct reading test gages located near fill openings of the tanks.

Pressure Relief. The pressure relief valves shall be tested to assure that each does not permit the controlled pressure to build beyond 275 lbf/in^2, i.e., 110 percent of the designed operating pressure capacity of the tank. Each relief valve shall be tested to assure that it allows full nitrogen flow when relieving. Test gages shall be installed at the fill openings of the tanks.

Temperature Relief. The temperature relief device installed on the AFFF agent tank shall be tested to assure that it relieves at a temperature greater than 190° but less than 212°F.

Intermittent Discharge. The fully charged and pressurized extinguisher shall be discharged in 5 seconds on and 5 seconds off alternating bursts until both agents have been exhausted. The design shall be rejected unless the discharge is free at all times and at least 90 percent of the dry chemical capacity has been discharged.

Operating Characteristics. Both agent tanks shall be charged and pressurized to their design operating pressures and capacities. The tests shall be conducted at ambient temperatures of 65°F to 80°F at less than 5-mi/h wind velocity. The nozzles shall be pointed about 15° above horizontal at a height of 4 feet above the ground. When tested in accordance with NFPA Pamphlet No. 412, the rate of discharge of the AFFF solution shall be at least 45 gal/min. The foam produced shall have a minimum expansion ratio of at least five and a minimum 25 percent drainage time of 1 minute when measured as described in section 422 and Appendix A sections A-220, A-230, and A-240 of NFPA Pamphlet No. 412. The AFFF nozzle ground pattern shall produce a maximum reach of 45 to 50 feet and a nominal width of 12 feet when the nozzle inlet pressure is 100 lbf/in^2. The rate of discharge of the dry chemical agent shall be at least 6 pounds per second and provide an effective reach of the powder stream of 40 to 50 feet with wind less than 5 mi/h. A maximum of 90 percent of the dry powder agent shall be discharged at an overall average rate of not less than 6 pounds per second.

Plumbing and Nozzle Leakage. The shutoff valves or nozzles shall effectively prevent the leakage of gas, dry chemical, and AFFF during this test. In this test, the fire extinguisher is to be charged with the exact rated capacities of expellent gas, dry chemical, and AFFF active solution and operated intermittently by opening and closing the dry chemical and AFFF discharge valves or nozzles for a period of 5 seconds "open" and allowed to sit for 30 minutes "closed". Upon being opened again and being held open until the end of discharge is reached, the total amount of dry chemical discharge shall be not less than 90 percent of the original charge. There shall be no evidence of leaks during this test cycle.

Test Results. To verify that all tests herein have been performed, and that results meet the criteria set forth, a copy of each test result shall be delivered with the Unit/Trailer.

TRAILER: (1 EACH)

A four-wheel trailer suitable in weight, design, and tire size to permit efficient hauling of the Fire Extinguisher Unit herein shall be furnished.

The trailer shall be delivered complete with framing, mounting provisions for the self-contained unit, tail and stop lights, license plate bracket, electrical plug attachment for the towing vehicle, pintle eye, and four wheel hydraulic brakes.

Specification Availability

1. The specifications shown in Items (a) through (f) under "Design and construction", and the MIL Spec. indicated under "Treatment and painting" are available from NAFEC, if required.

2. The American Society of Mechanical Engineers (ASME) and National Fire Protection Association (NFPA) literature is available as follows:

ASME MATERIAL:

American Society of Mechanical Engineers
345 E. 47th Street
New York, New York

NFPA MATERIAL:

National Fire Protection Association
60 Batterymarch Street
Boston, Massachusetts

APPENDIX C

NITROGEN PRESSURE VERSUS TEMPERATURE CHART
(BASE POINT 2,400 PSIG @ 70° F)

Temperature (°F)	Pressure Corrections for Gage Reading
110°	Subtract 217 PSIG
100°	Subtract 164 PSIG
90°	Subtract 110 PSIG
80°	Subtract 53 PSIG
70°	0
60°	Add 59 PSIG
50°	Add 108 PSIG
40°	Add 170 PSIG
30°	Add 227 PSIG
20°	Add 286 PSIG
10°	Add 344 PSIG
0°	Add 402 PSIG
-10°	Add 460 PSIG
-20°	Add 523 PSIG

NOTE: For temperatures above 110° F subtract 53 PSIG more from gage pressure for every 10° F. For temperatures below -20° F add 53 PSIG more to gage pressure for every 10° F.

EXAMPLE: Gage pressure reading is 1,900 PSIG. Temperature is 90° F.
1,900 gage pressure reading
- 110 figure on chart for 90° F
1,790 corrected pressure reading (cylinder need not be replaced).

APPENDIX D

METHOD OF DETERMINING FOAM VISCOSITY

Foam viscosity was determined by employing the viscometer shown in figure D-1. 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 spherical 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 disc 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 immersed in the foam to its uppermost edge. The dimension of foam viscosity determined by this method is dynes per square centimeter.

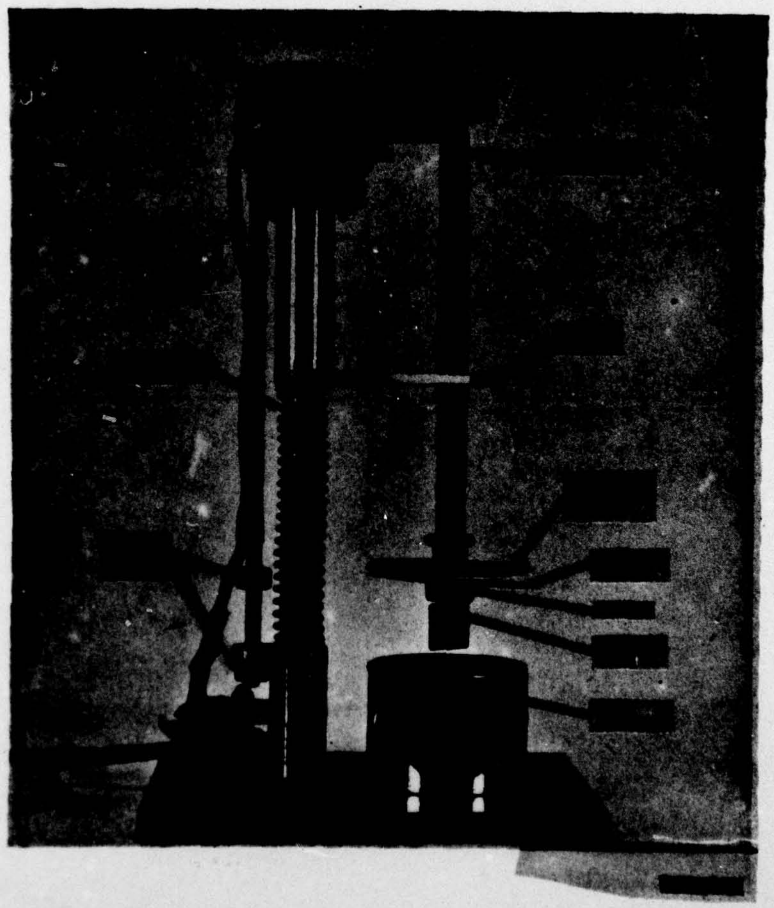


FIGURE D-1. FOAM VISCOMETER

APPENDIX E

SMALL-SCALE FIRE TEST PROCEDURE FOR COMPARING THE EFFECTIVENESS OF AFFF SOLUTIONS CONTAINING VARYING AMOUNTS OF ETHYLENE GLYCOL

Objective

The purpose of this test is to provide data for assessing the relative fire-extinguishing effectiveness of the AFFF agents when premixed with aqueous solutions containing various amounts of ethylene glycol added as a freezing point depressant.

Test Procedure

The test method employed is a modification of that required under section 3.13 (Fire 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-square by 3-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 required 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 allow 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 within 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, starting 10 minutes after foam application was concluded without touching or penetrating the surface. 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 Jet A fuel was then lowered into the opening level with the interface between the fuel and the foam blanket. The container and surrounding fuel was then permitted to burn for 5 minutes after which the burnback area was determined.

The effectiveness of the foam agents is judged on the basis of achieving fire control within 4 minutes or less, fire extinguishment within 5 minutes or less with a maximum burnback area of 20 inches square.

APPENDIX F

LABORATORY FOAM-POWDER COMPATIBILITY TEST

This test method is a modification of that required in reference 2 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° ± 2° 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 rpm for exactly 2 minutes. During the mixing process, the bowl is made to rotate at approximately 1 rps. 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 3/8 inch 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° 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 seconds 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 powder.

APPENDIX G

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 $\pm$1.5 millivolts (mV) at 15 Btu/ft^2/s. The angle of view was 120°. Each unit was provided with a calibration curve by the manufacturer.

APPENDIX H

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 testbed. 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 during the entire time required to obtain fire control and extinguishment and for a minimum period of 2 minutes thereafter.

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 testbed 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.

APPENDIX I

TAU OPERATING COSTS

APPROXIMATE COST TO EXTINGUISH THE 35-FOOT-DIAMETER FIRE PIT WITH THE TAU USING DRY CHEMICAL POWDER AND AFFF SINGLY AND IN COMBINATION

Dry Chemical Powder

Agent	Extinguishing Frequency	Average Fire-Extinguishing Time (Sec.)	Agent Cost (Dollars)
Super K	1 of 3	15.0	30.00
Purple K	2 of 3	13.5	59.80
Monnex	2 of 3	15.0	83.11

Aqueous-Film-Forming Foam
(6-Percent Agents)

Agent	Fire-Extinguishing Time (Sec.)	Agent Cost (Dollars)
FC-206	12	6.22
AER-O-WATER 6	12	5.37
LORCON AFFF	15	6.25
(3-Percent Agents)		
FC-203	13	6.05
AER-O-WATER 3	14	5.33
Combined AFFF and Dry Chemical Powder		
AER-O-WATER 6 Purple K	16	37.50
AER-O-WATER 3 Purple K	13	30.00