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INTERIM REPORT

Project No. 430-002-02X

FOAM AND DRY CHEMICAL APPLICATION EXPERIMENTS

DECEMBER 1968

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
National Aviation Facilities Experimental Center
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Prepared by:
GEORGE B. GEYER

for

SYSTEMS RESEARCH AND DEVELOPMENT SERVICE

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ABSTRACT

Full-scale tests were conducted under fixed fire conditions employing air-aspirating foam and dry powder dispensing equipment in which six different foam agents and three different dry chemical powders were evaluated, both alone and in combination. The time required to control circular pool fires of 40, 60, and 80 feet in diameter, containing an obstacle and a three-dimensional fire, was determined.

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INTRODUCTION

Purpose

The project objective was to provide criteria which would be meaningful in determining adequate fire protection for airports with respect to type of agents, discharge rates, and quantities of agents required when used alone and in combination.

This Interim Report provides information concerning the relative effectiveness of foam and dry chemicals in controlling large aircraft fuel fires and the effect of agent discharge rate.

Background

Protein foam and dry chemical powder are the primary fire control and extinguishing agents currently employed in airport fire-fighting equipment. The total capacity and discharge rates of these vehicles have increased over the years to keep abreast of the increased size of aircraft carrying more passengers and greater quantities of fuel. However, with the development of even larger aircraft, such as the Supersonic Transport, the Lockheed C-5A, and the Boeing 747, this approach to achieving adequate fire protection is becoming untenable. Therefore, it has become mandatory to evaluate all currently available fire-fighting agents to determine the most effective one(s) to minimize the size and cost of vehicular ground equipment.

The Federal Aviation Administration (FAA) and the National Fire Protection Association (NFPA) have published tables, as have others, of suggested minimum fire protection requirements for airports (References 1 and 2). These recommendations are based upon the use of an empirical formula which relates the total aircraft movements, maximum passenger capacity, and maximum fuel loading. Although this approach to the overall fire protection effort is a useful interim measure, it is equally necessary to be able to define more precisely, by mathematical methods, the time available to obtain fire control (as determined by the fire resistance of the aircraft) for any potential incident involving a known aircraft and the type and quantity of fuel aboard.

A recent effort directed toward developing a better understanding of the aircraft fire environment was conducted by the FAA at the National Aviation Facilities Experimental Center (NAFEC) (Reference 3). Full-scale fire tests were conducted on a Boeing C-97 aircraft which yielded information on the time available to escape or survive an aircraft crash fire. The values obtained were influenced by the type of fire condition employed; namely, continued spilling and spread of fuel and fire subsequent to ignition of small pre-wetted areas.

The information which must be made available to define adequate fire protection for airports is:

1. The total response and transit time required for the fire-fighting equipment to reach the most remote section and crash suspect portion of land in the immediate vicinity of the airport.

2. The time required to control various sizes of representative crash fires with respect to agents, discharge rates, and total quantities of agents.

3. Survival time of aircraft occupants under fire conditions as a function of the type of aircraft involved.

This report provides information and test results pertaining to Item 2 and the final report provides information on Items 1 and 3.

The table provided in Appendix 1 shows the foam solution discharge rates and the corresponding application rates as a function of the three fire pit diameters employed in this study.

DISCUSSION

Test Procedures and Results

General: The idealized goal of this investigation was to determine which agent or combination of agents was capable of providing the most rapid fire control time with adequate vapor suppression and fire-securing action in any given aircraft incident. The basic approach to meeting these objectives was to measure the time required to control liquid fuel fires of various sizes as a function of foam discharge rate, type of foam agent, and type of aircraft fuel involved. Fire tests were conducted in which foam and dry chemicals were used alone and in combination.

With the cooperation of the Bureau of National Capital Airports, 12 fire tests were conducted at Dulles International Airport to make use of their high discharge rate foam trucks. Six tests were conducted at 2000 gallons per minute (gal/min) (two trucks) and six tests at 2600 gal/min (three trucks).

The fire test environment used is schematically and pictorially presented in Figure 1. Fires were confined in circular diked areas which could be extended to diameters of 40, 60, and 80 feet. Sufficient water was placed in the pool area to present a smooth surface and prevent islands from intruding into the fuel surface. The fixed fire conditions incorporated a cluster of 55-gallon steel drums as an obstacle factor in the center of the pool fire. This acted as a heat sink in support of a three-dimensional fire situation which was sustained by a spray of fuel from a 4-foot high, 1/4-inch-diameter stainless steel tube. The fuel tanks fed the burn area by gravity through an underground network of pipes.

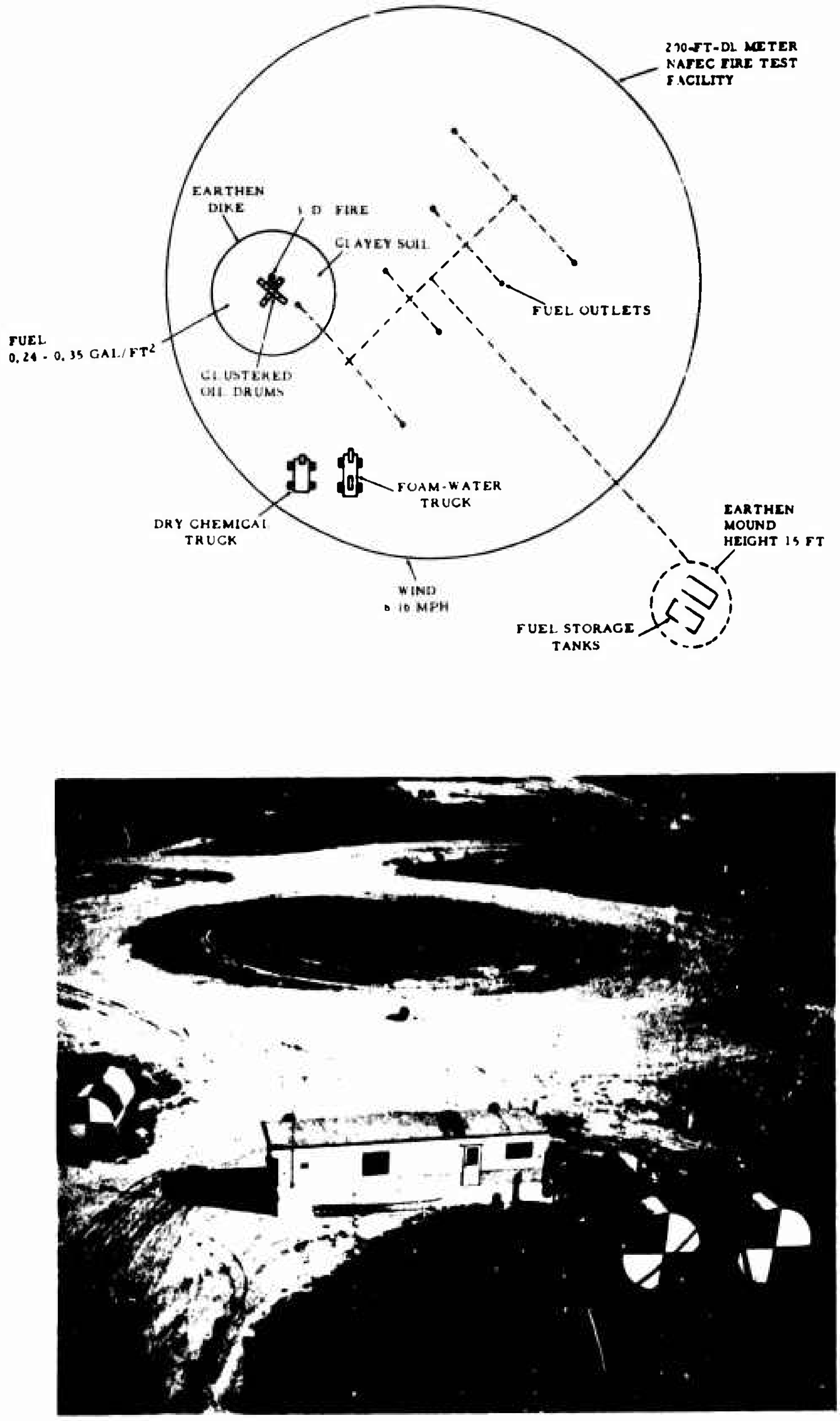


FIG. 1 SCHEMATIC AND PICTORIAL PRESENTATION OF FIRE TEST ENVIRONMENT

Three types of aircraft fuels, namely, aviation gasoline, Jet A, and JP-4, were used at densities of 0.24 to 0.35 gallon persquare foot (gal/ft^2). This amount was determined to be sufficient to maintain a burning rate at a maximum intensity for a period of 3 to 4 minutes. Properties of the fuel used are further defined in Appendix 2.

The instrumentation employed in monitoring the fire test performance is shown in Figure 2 and described in Appendix 3. Heat sensors were located at the pool perimeter on the diameter and at right angles to the wind direction. Thermal data were recorded on instruments within a specially prepared van. Motion pictures of each test were obtained for documentation and data analysis from locations on top of the van and on the mound containing the fuel storage tanks.

Uniform fire test conditions were maintained throughout the testing program by allowing a minimum of a 30-second preburn time at maximum fire intensity prior to initiating fire control action. The connotation of the terms preburn time and control time, as defined by the test parameters, is illustrated by the idealized curve in Figure 3 where heat flux versus time after ignition is plotted to show the type of thermal radiation data obtained from the fire-monitoring system. It will be noted that after the fuel was ignited, the heat flux slowly rose until a maximum radiation level was reached and was maintained for a minimum of 30 seconds. This period of maximum radiation intensity, before fire extinguishment action was initiated, is defined as preburn time; in this case, 45 seconds. Fire control time is defined as the elapsed time between the initiation of the extinguishing operation to that time when the heat flux, as measured by the radiometers, was reduced to 0.20 Btu/ft^2-sec. These various phases of a typical fire test are presented pictorially in Appendix 4.

<u>Foam Agents:</u>

<u>Protein Foam</u> - The first series of tests was conducted to determine the optimum solution application rate required to obtain fire control when employing protein foam on 40-, 60-, and 80-foot diameter Jet A pool fires and to establish a frame of reference for comparing the new foam agents. The discharge rate using protein foam was varied from 200 to 2600 gal/min which required as many as three foam trucks, operating jointly, to simulate a single discharge point and to achieve the higher discharge rates. The fire-fighting equipment used is described in Appendix 5.

The foam produced by all vehicles was of the air-aspirated type and produced foam patterns and foam quality in nominal conformance with FAA (Reference 4) and NFPA (Reference [illegible]) recommendations when employing protein foam liquid (Reference 6).

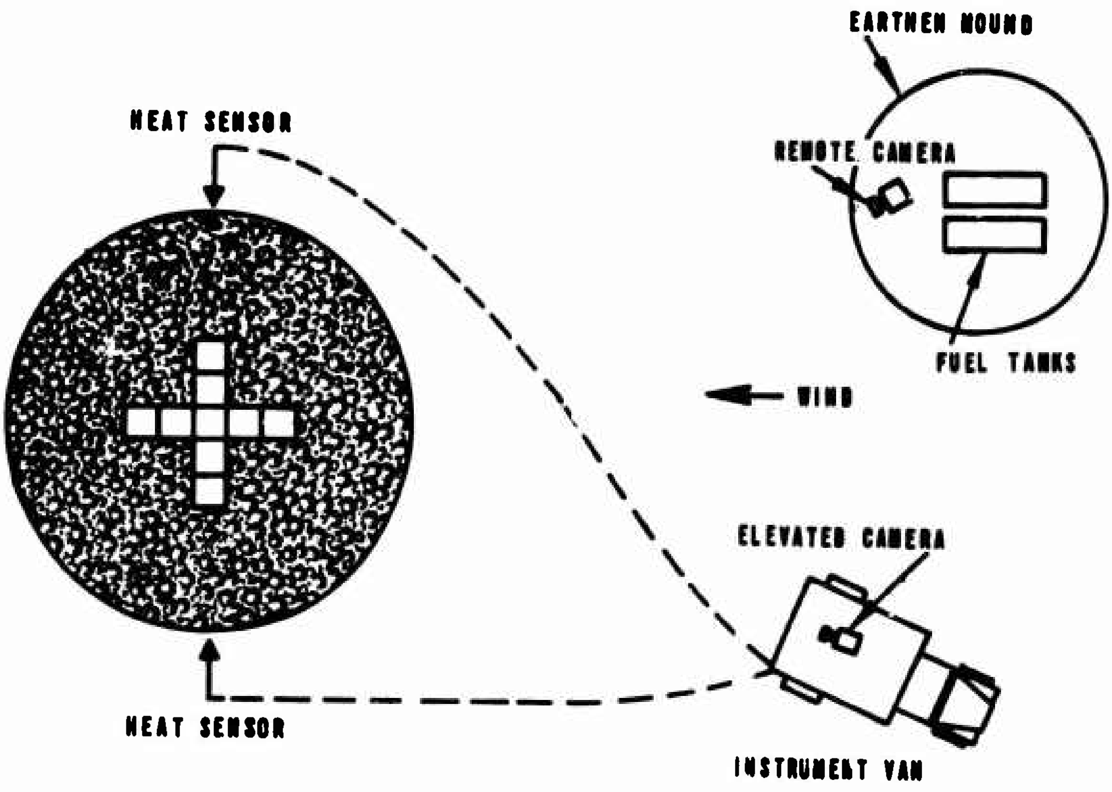


FIG. 2 INSTRUMENTATION FOR TESTS

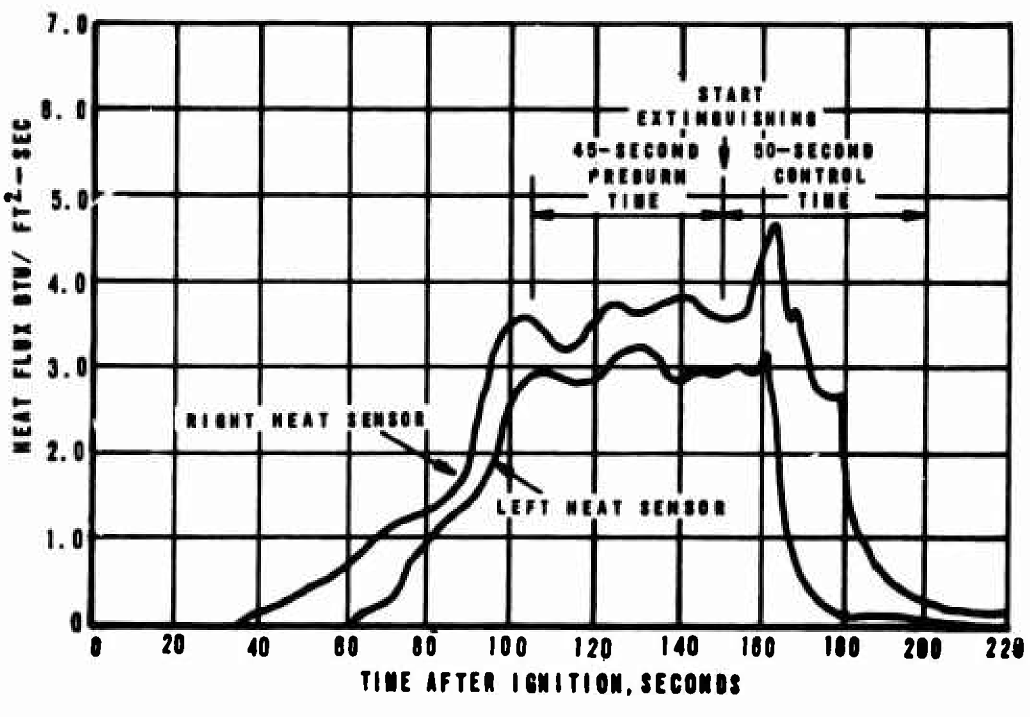


FIG. 3 TYPICAL TEST DATA

Foam liquid was premixed with water to obtain a concentration of 6 percent by volume in the tests conducted at NAFEC, while those performed at Dulles International Airport used the crash truck liquid proportioning system and the concentration varied from 6 to 8 percent by volume. The data obtained from this series of tests not only present the results of a series of controlled fire conditions, but also represent a practical fire-fighting exercise because the foam trucks and crews were periodically rotated at NAFEC while the tests conducted at Dulles International Airport employed their own equipment and personnel.

Fire control time data from all protein foam fire tests employing Jet A fuel are presented graphically in Figure 4 in which the fire control time is plotted as a function of the solution application rate. The general contour of the plot shows that at solution application rates below 0.20 gal/min-ft^2, fire control time becomes erratic. This is believed to have been due to variations in application techniques, minor differences in equipment, and variable wind conditions which become significant factors when the solution application rate is at or below the minimum critical application value for the system. At solution application rates over 0.50 gal/min-ft^2, the fire was completely overwhelmed and the time required to mechanically distribute the foam became the controlling factor defining fire control time. Therefore, solution application rates in these borderline areas are inefficient and wasteful. The optimum solution application rate lies in the elbow of the curve at approximately 0.35 gal/min-ft^2 for these test conditions.

The term optimum is used in a general sense to indicate a solution application rate below which a significant increase in control time occurred and above which little reduction in control time was obtained.

Before a meaningful comparison of the fire performance characteristics of the new foam agents could be established, it was essential to determine the relative foam destructive influence exerted by three of the most common types of aircraft fuels on protein foam.

The curves developed in Figure 5 show the time required to control a 40-foot-diameter pool fire with protein foam using aviation gas, Jet A and JP-4 fuels. At a solution discharge rate of 700 gal/min (0.56 gal/min-ft^2), fire control was obtained for all fuels in approximately 16 seconds. However, as the solution application rate was reduced, the greater foam destructiveness of JP-4 and aviation gas over Jet A to protein foam was apparent.

The practical importance of the variation in fire control time with pool fire size is considered in Figure 6. These curves may be employed to estimate the solution discharge rate required to control spill fires of various sizes within a predetermined time interval. This

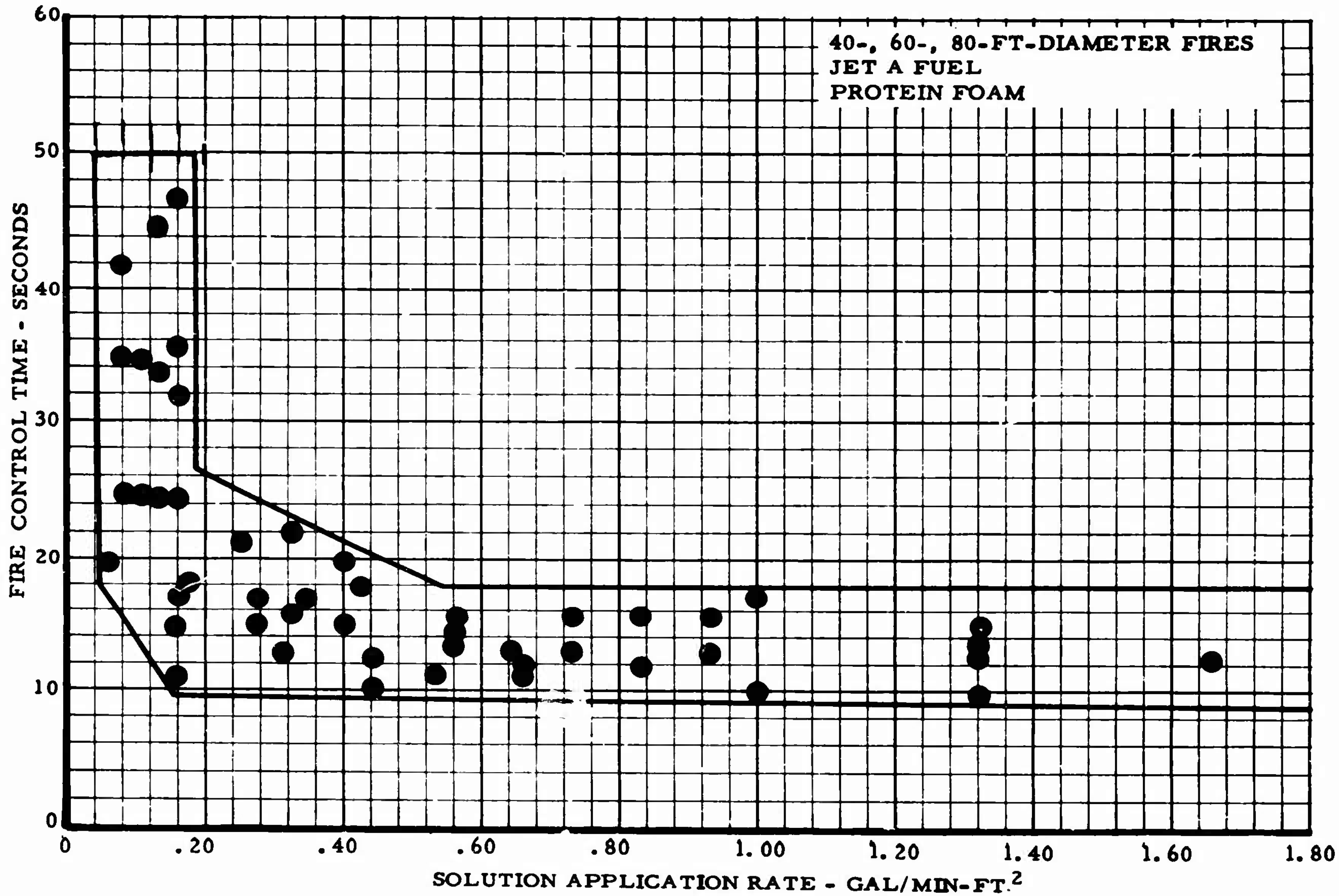


FIG. 4 FIRE CONTROL TIME DATA ON VARIOUS SIZE JET A FUEL FIRES USING PROTEIN FOAM AT DIFFERENT SOLUTION DISCHARGE RATES

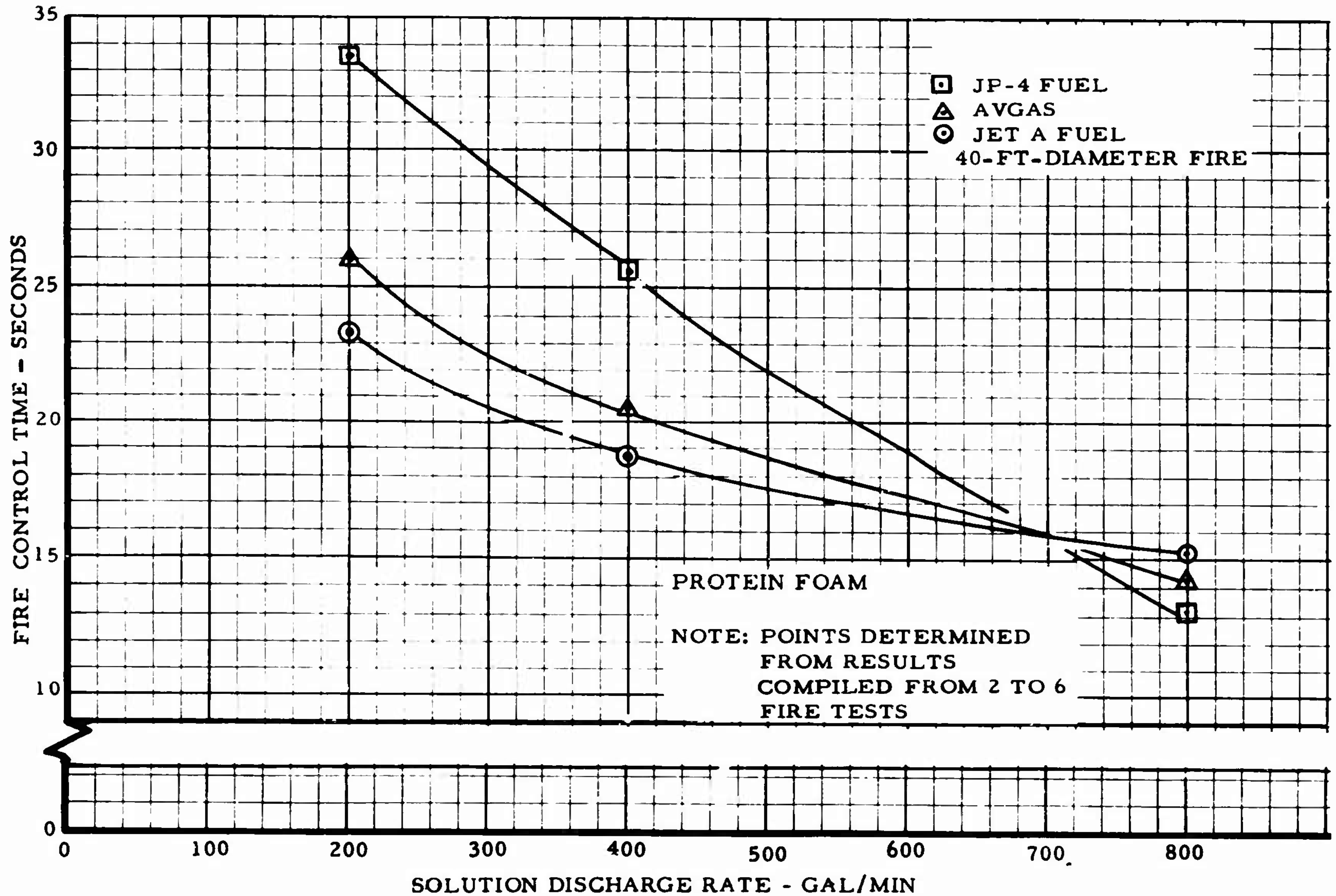


FIG. 5 THE EFFECT OF FUEL TYPE ON FIRE CONTROL TIME

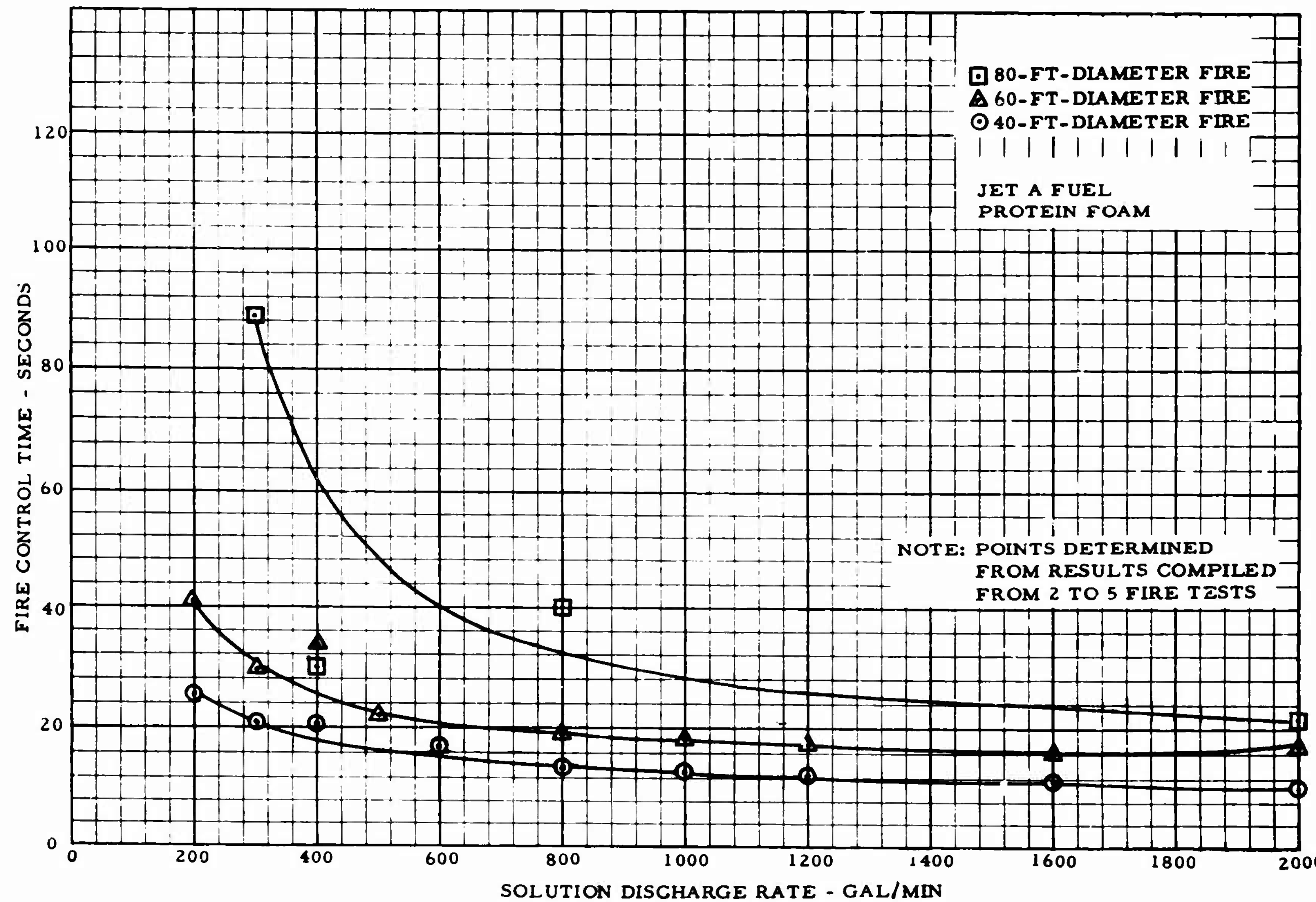


FIG. 6 THE VARIATION IN FIRE CONTROL TIME WITH POOL FIRE SIZE

is an important factor in establishing the fire-fighting hardware requirements for airports. For example, if it has been determined that a 60-foot-diameter spill fire must be controlled in 25 seconds to assure occupant survival in a particular aircraft incident, a solution discharge rate of 425 gal/min would be adequate. However, if the spill were 80 feet in diameter, a discharge rate of approximately 1400 gal/min would be required to obtain fire control in the same 25 second period.

<u>"Fluoroprotein" Foam Agents</u> - After having established the performance characteristics of the regular protein foam for the various fixed fire situation, attention was directed toward correlating this information with data obtained for the newer agents. One new class of fire-fighting foam compounds included three proprietary brands (Reference 7) of compatible dry chemical (CDC) protein base liquids. These products were reported to be in nominal conformance with Federal Specification O-F-555b by the manufacturers and will be referred to as "Fluoroproteins" throughout the remainder of this document. The "Fluoroprotein" agents were developed through a joint effort by the U. S. Naval Applied Science Laboratory (Reference 8) and industry. Fire tests were conducted on 40- and 60-foot-diameter fires, using JP-4 and Jet A fuels and at solution discharge rates of 200, 400, and 800 gal/min.

The fire control time obtained with the "Fluoroprotein" agents for the 40-foot-diameter Jet A fuel fires and presented in Figure 7 is for a single test at each discharge rate and is meaningful only in the performance trend which is established. These data show that an appreciable variation in the fire control time exists between the several agents within the "Fluoroprotein" class. When a comparison of the "average" fire control time for the "Fluoroprotein" foams as a "class" of agents was made at the optimum solution application rate established for regular protein foam of 0.35 gal/min-ft^2, the estimated reduction in fire control time was 15 to 20 percent.

With an increase in the fire diameter from 40 to 60 feet and the substitution of JP-4 for Jet A, there was no general reduction in the fire control time when employing the "Fluoroprotein" agents over regular protein foam.

Figure 8 presents curves defining the fire control time as a function of the solution application rate for the "Fluoroprotein" agents and regular protein foam on a 60-foot JP-4 fuel fire. A comparison of these data with those in Figure 7 reveals that a substantial increase in the fire control time is required for all agents under the more severe fire conditions.

Since the quality of foam produced by the "Fluoroprotein" agents and regular protein foam is similar, the fire-fighting techniques employed in aircraft incidents are the same. In general, the fully dispersed stream should be employed whenever possible and the foam applied on the burning hazard surface as gently as is practicable.

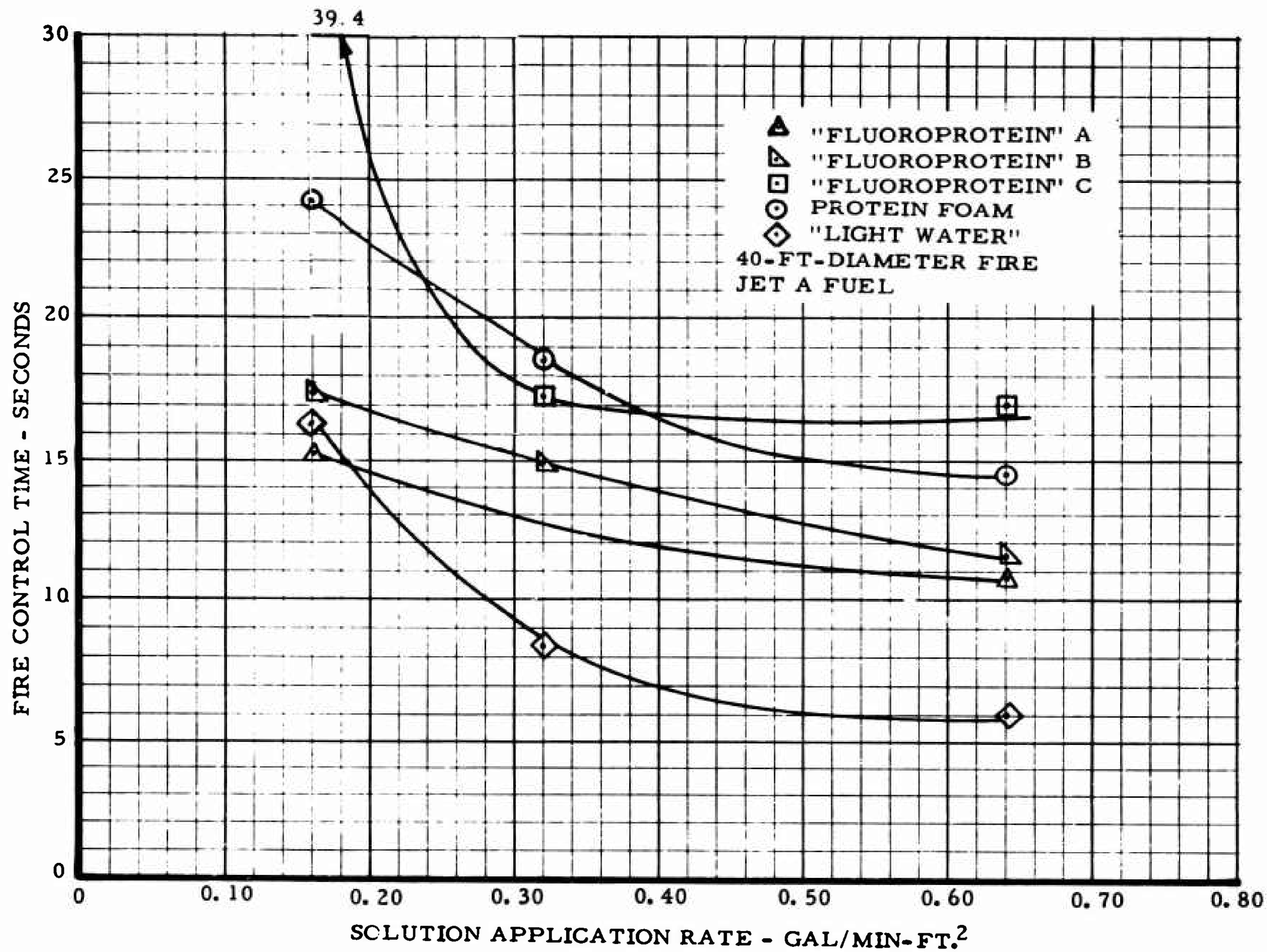


FIG. 7 FIRE CONTROL TIME DATA OF THE "FLUOROPROTEIN" AGENTS, "LIGHT WATER" AND PROTEIN FOAM ON 40-FOOT-DIAMETER JET A FIRES

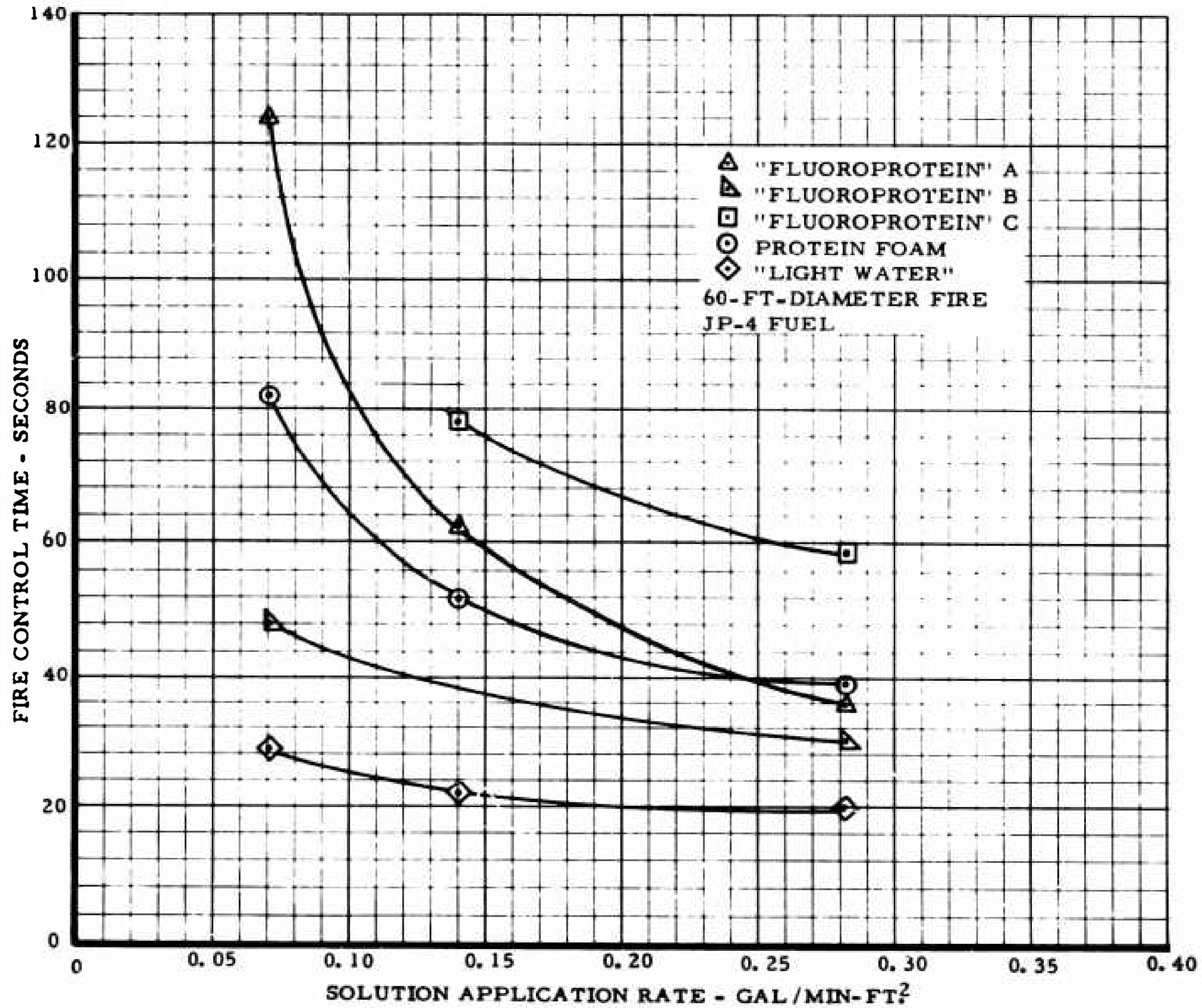


FIG. 8 FIRE CONTROL TIME DATA OF THE "FLUOROPROTEIN" AGENTS, "LIGHT WATER," AND PROTEIN FOAM ON 60-FOOT-DIAMETER JP-4 FIRES

A comparison of the fire-fighting performance of protein foam and the "Fluoroprotein" foams may also be made from data presented graphically in Figure 9 for a 40-foot-diameter Jet A fuel fire at three different solution application rates. The curves show the number of square feet of fire area that can be controlled (independent of time) for each gallon of foam solution applied at solution discharge rates of 200, 400, and 800 gal/min. Data points are included for the "Fluoroprotein" agents for comparison with the curves for protein foam and "Light Water." A detailed consideration of the performance characteristics of "Light Water" will be considered later in this report. The "Fluoroprotein" foam liquid concentrates supplied by manufacturers A and B show a sharp increase in the number of square feet of fire surface which can be controlled for each gallon of foam solution applied as the application rate is decreased from 0.32 to 0.16 gal/min-ft^2, while that supplied by manufacturer C shows close conformance to regular protein foam throughout the entire solution application range.

"Light Water" - "Light Water" was developed by the U. S. Naval Research Laboratory (Reference 9) and industry and is manufactured in conformance with a Military Specification (Reference 10). The foam liquid concentrate is designated as FC-194 by the manufacturer (Reference 11) and was used premixed at a concentration of 6 percent by volume and evaluated at solution discharge rated of 60, 200, 400, and 800 gal/min on 40- and 60-foot-diameter Jet A and JP-4 fuel fires. The fire control characteristics of "Light Water" foam on a 40-foot-diameter Jet A pool fire are presented in Figure 7 together with that obtained for regular protein foam and the "Fluoroprotein" foams for comparison. From these curves, it will be noted that "Light Water" gave the most rapid fire control of all agents tested at a solution application rate above 0.20 gal/min-ft^2; "Light Water" and the "Fluoroprotein" foams from manufacturers A and B gave approximately equal fire control time; while that supplied by manufacturer C performed much like regular protein foam.

A comparison of the fire control time curves for "Light Water" in Figures 7 and 8 shows that a significant increase in time is required for the 60-foot-diameter JP-4 fuel fire over that required for the 40-foot Jet A fire at equal solution application rates.

High Expansion Foam - High expansion foam (Reference 12) was produced in specially designed hydraulically-operated equipment by driving a high volume airstream through a metal grid which was continually sprayed with a foam solution. Large flexible ducts were used to conduct the foam to the perimeter of the fire on the upwind side. The equipment is pictured in Appendix 5, Figures 5.3 and 5.4.

This foam had an estimated expansion ratio of 500:1 and was evaluated at solution discharge rates of 100, 135, 300, and 500 gal/min on 60-foot-diameter JP-4 fuel fires. Foam expansion is defined as the reciprocal of the density.

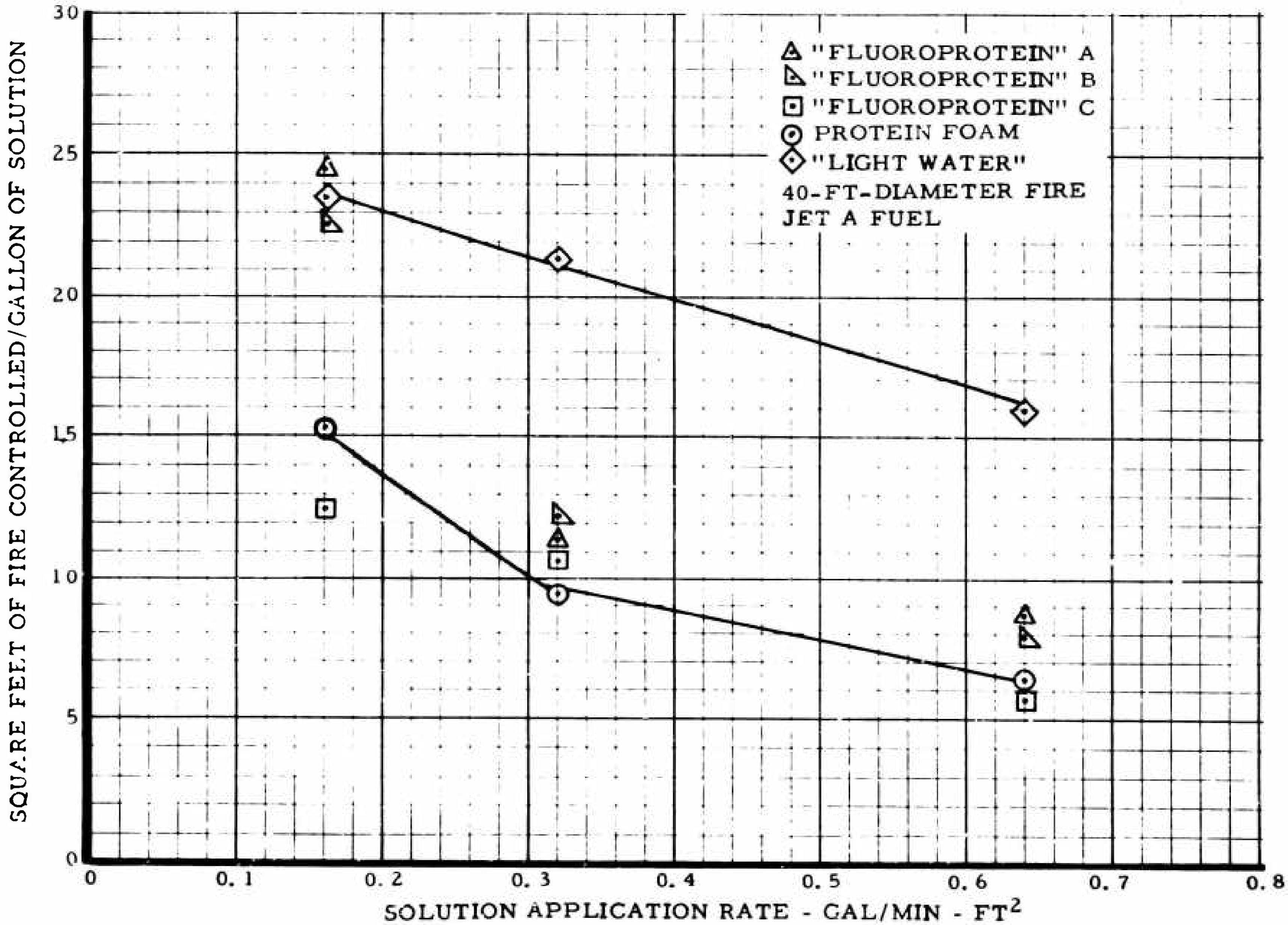


FIG. 9 THE NUMBER OF SQUARE FEET OF FIRE CONTROLLED PER GALLON OF SOLUTION FOR VARIOUS AGENTS ON A 40-FOOT-DIAMETER JET A FUEL FIRE

The curve presented in Figure 10 shows the optimum solution application rate for these particular high expansion foam units to be approximately 0.055 gal/min-ft^2. At this rate, approximately 20 square feet of fuel surface was controlled for each gallon of solution applied. At the conclusion of foam application, the foam blanket was found to vary in depth from 2 to 4 feet and to possess a limited vapor-securing ability.

Dry Chemical Powders: Dry chemical application was provided by one high capacity truck, described in Appendix 5, at discharge rates which were varied from 23.2 to 65.6 pounds per second (lbs/sec) using CDC (Reference 13) and Purple-K powder (P-K-P) (Reference 14). Neither agent was found to be capable of extinguishing the 40-foot-diameter Jet A pool fire. This result, at the high powder discharge rates employed in these tests, was attributed to the presence of the large heat sink and the three-dimensional fire.

Compatible Dry Chemical Powder - The fire control data obtained for CDC on the 40-foot-diameter Jet A pool fire are contained in Table I. The variation in heat flux determined for these tests is presented graphically in Figure 11. From these profiles, it will be noted that the fire control time, as defined by the test conditions, was longer in Test No. 43 than in Tests Nos. 44A and 45. However, the actual powder discharge rate of 23.2 lbs/sec required to maintain fire control was adequate in Test No. 43. Therefore, in aircraft incidents in which actual fire extinguishment is unlikely or impossible, powder should be applied at the minimum application rate consistent with achieving and maintaining fire control until an adequate vapor-securing blanket of foam is established. No reduction in the total time required to establish an adequate vapor-securing foam blanket would be realized by increasing the powder discharge rate above this minimum value.

TABLE I

FIRE TEST CONDITIONS AND RESULTS USING COMPATIBLE DRY CHEMICAL

Test No.	Ambient Temp. (°F)	Wind Velocity (mph)	Fire Diameter (ft)	Type Fuel	Fuel Quantity (gal)	Preburn Time (sec)	Powder Discharge Rate (lbs/sec)	Time Applied (sec)	Quantity Applied (lb)	Fire Control Time (sec)
43	85	12	40	Jet A	350	67.4	23.2	93.6	2170	24.9
44A	85	10	40	Jet A	350	51.2	65.6	13.1	860	12.5
45	85	8	40	Jet A	600	81.3	62.3	6.1	380	5.0

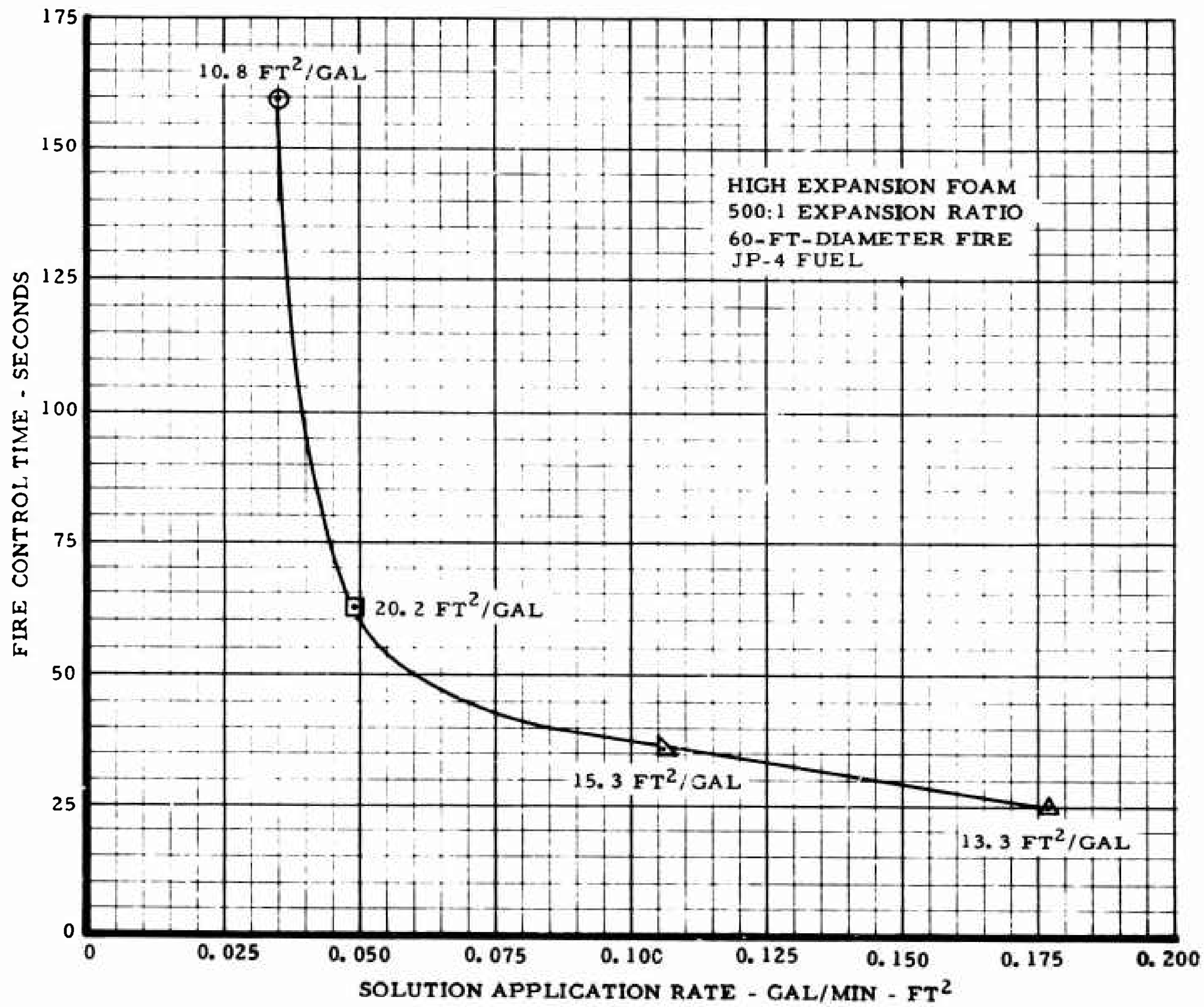


FIG. 10 FIRE CONTROL TIME DATA FOR HIGH EXPANSION FOAM ON 60-FOOT-DIAMETER JP-4 FUEL FIRES

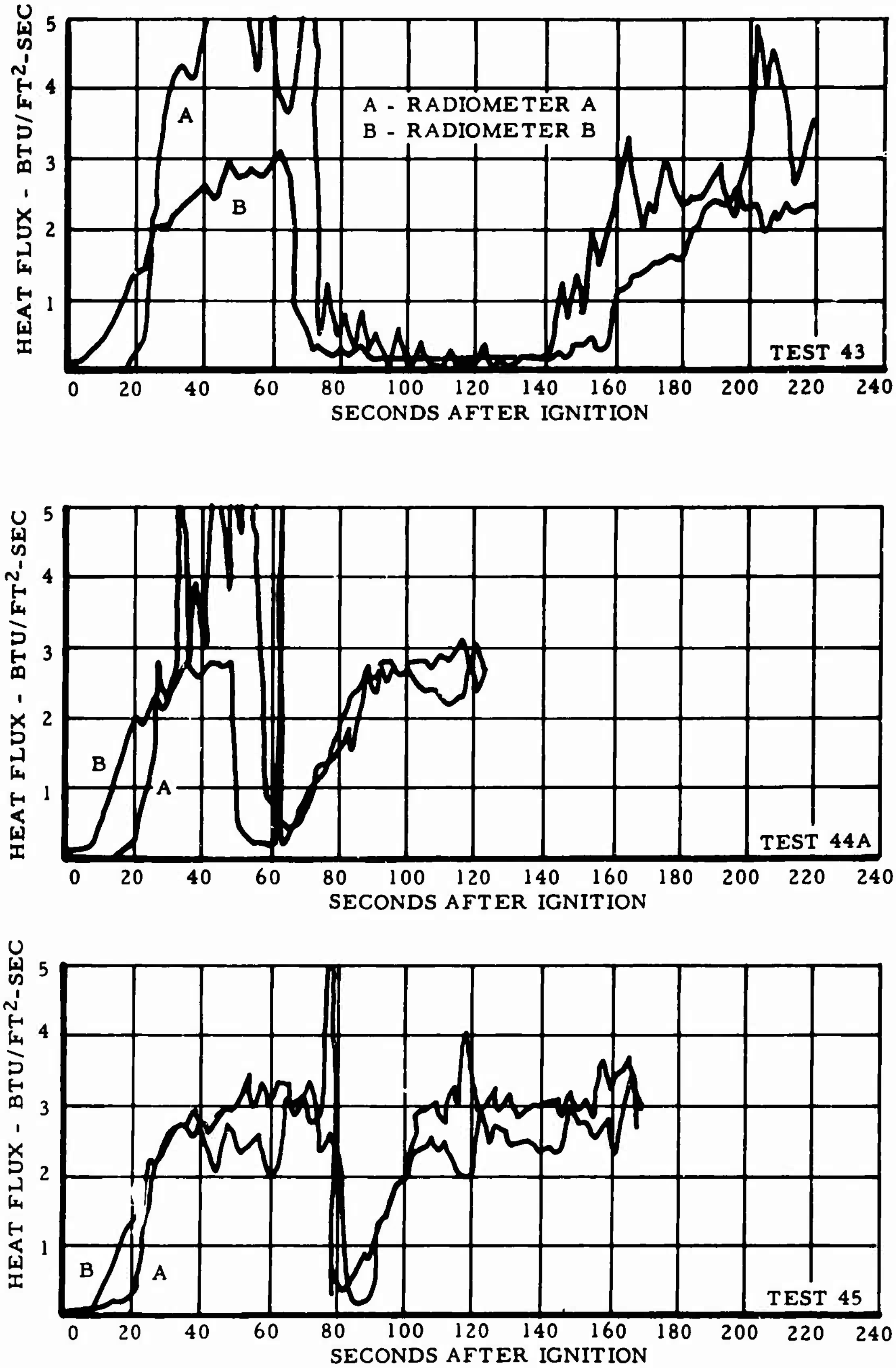


FIG. 11 THERMAL RADIATION DATA FROM COMPATIBLE DRY CHEMICAL POWDER TESTS ON 40-FOOT-DIAMETER JET A FUEL FIRES

Purple-K Powder - The time required to control the 40-foot-diameter Jet A pool fire using P-K-P at several discharge rates is presented in Table II and the thermal profiles in Figure 12. The heat flux in Test No. 57 was never reduced to the required 0.20 Btu/ft^2-sec used to define the fire control time. This was determined from an analysis of the photographic instrumentation to be caused by a faulty application technique in the presence of adverse wind conditions.

TABLE II

FIRE TEST CONDITIONS AND RESULTS USING PURPLE-K POWDER

Test No.	Ambient Temp. (°F)	Wind Velocity (mph)	Fire Diameter (ft)	Type Fuel	Fuel Quantity (gal)	Preburn Time (sec)	Powder Discharge Rate (lbs/sec)	Time Applied (sec)	Quantity Applied (lb)	Fire Control Time (sec)
55	87	7	40	Jet A	350	82.6	29.5	19.8	585	13.4
56	85	7	40	Jet A	350	74.6	44.6	16.7	745	15.7
57	81	7	40	Jet A	350	78.4	60.5	19.0	1150	----

A potentially serious hazard, in addition to those usually present in large-scale fire testing, was encountered when dry chemical powder was discharged at high velocity into a 60-foot-diameter JP-4 pool fire burning at maximum intensity. This took the form of a large fire ball which developed at the pool perimeter where the flame and dry chemical fronts converged. The momentary release of radiant energy from this mass of flame and powder was so intense that it cracked the plastic face piece in the fireman's helmet, melted the plastic headlights, and blistered the paint on the dry chemical truck which was located 30 feet from the pool perimeter on the upwind side of the fire (Appendix 6). This phenomenon was observed on numerous occasions and is considered to warrant investigation to determine the magnitude of the increased radiation hazard involved when dry chemicals or other agents are employed at sufficiently high discharge rates on large pool fires to produce a massive disturbance in the flame front.

Combined Agent Application:

Protein Foam and Compatible Dry Chemical - The data presented thus far have compared the fire control performance for the various types of foam agents and dry chemical powders when employed alone. Consideration will now be given to the results of tests in which foam was employed as a vapor-securing agent while dry chemical was being used as a flame depressant.

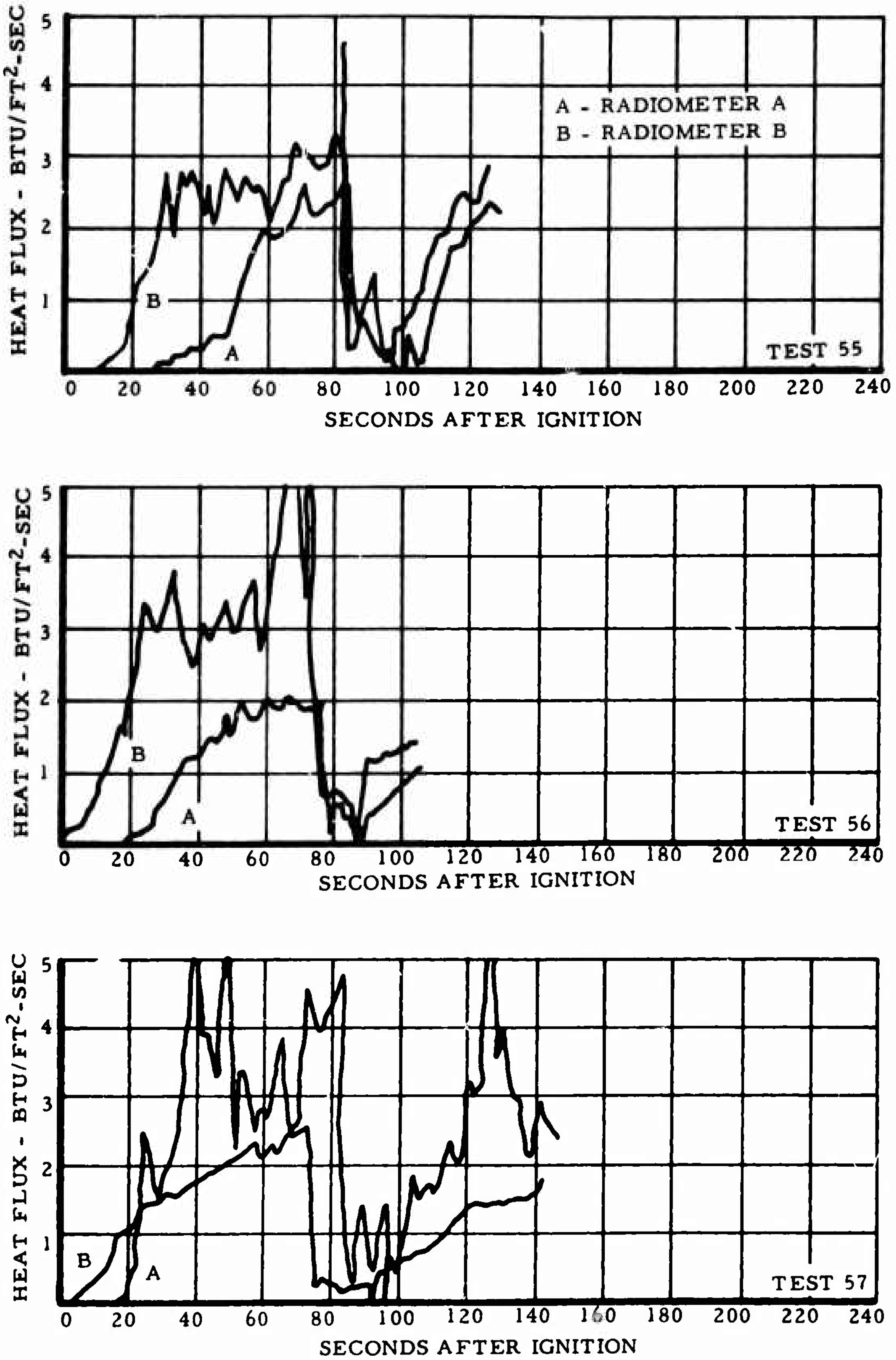


FIG. 12 THERMAL RADIATION DATA FROM PURPLE-K POWDER TESTS ON 40-FOOT-DIAMETER JET A FUEL FIRES

The curves in Figure 13 were developed from fire control data for protein foam alone and in combination with CDC on a 40-foot-diameter Jet A fuel pool fire.

A constant CDC discharge rate of 30 lbs/sec was maintained in all tests while the discharge rate of the protein foam was varied from 200 to 400 and 800 gal/min. It is evident from the curves that an appreciable reduction in the fire control time can be achieved through the use of a combined agent attack, especially at the lower solution application rates. These systems showed good foam powder compatibility at all foam discharge rates and a stable protein foam blanket was established on the fuel surface.

"Fluoroprotein" Foam Agents and Purple-K Powder - The rapid fire control time that can be obtained through the combined application of "Fluoroprotein" foam and P-K-P on a 40-foot-diameter Jet A pool fire is presented as individual points in Figure 14. The curves are included for comparison of the fire control times which were obtained with foam alone under similar test conditions. Purple-K powder was discharged at a uniform rate of 45 lbs/sec while the foam discharge was varied from 200 to 400 and 800 gal/min. The agents proved to be very effective when used in combination, although after fire control was obtained, the residual foam blanket showed less stability and covered less area than the blanket established by foam alone. A visual estimate of the foam blanket stability using "Fluoroprotein" foam alone and "Fluoroprotein" foam in combination with P-K-P may be made by comparing the photographs in Figure 15.

The curves presented in Figure 16 show the effect upon the fire control time when P-K-P is discharged at the rate of 30 lbs/sec in combination with the "Fluoroprotein" agents at three different solution discharge rates on a 60-foot-diameter JP-4 fuel fire. When these curves are compared with the points in Figure 14, it will be noted that the fire control time is increased substantially under the more severe fire conditions.

The effect upon fire control time of a combined agent application of "Fluoroprotein" foam and P-K-P on a 60-foot-diameter JP-4 fuel fire may be established through a comparison of the curves in Figures 8 and 16. These data show that although adequate foam powder compatibility exists between the "Fluoroprotein" foam and P-K-P, no reduction in fire control time will be obtained through their combined application. Therefore, P-K-P may be employed in situations where very rapid flame knockdown is necessary or for use as a mop-up agent after fire control has been established with foam.

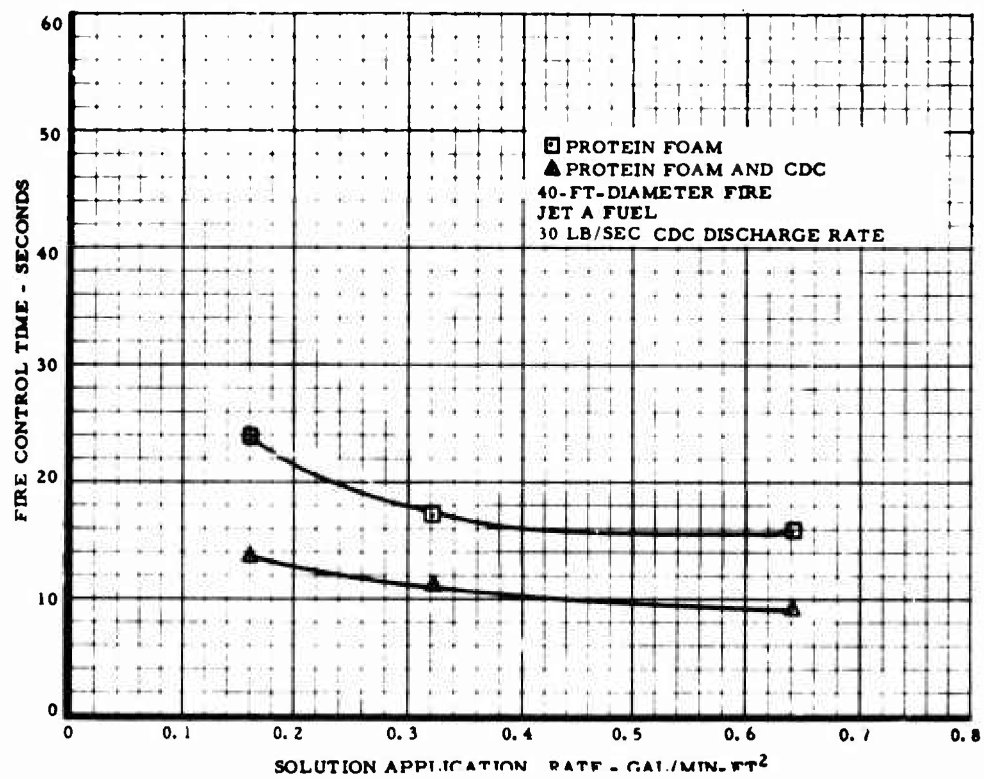


FIG. 13 COMPARATIVE DATA OF PROTEIN FOAM WHEN USED ALONE AND IN COMBINATION WITH CDC POWDER ON 40-FOOT-DIAMETER JET A FUEL FIRES

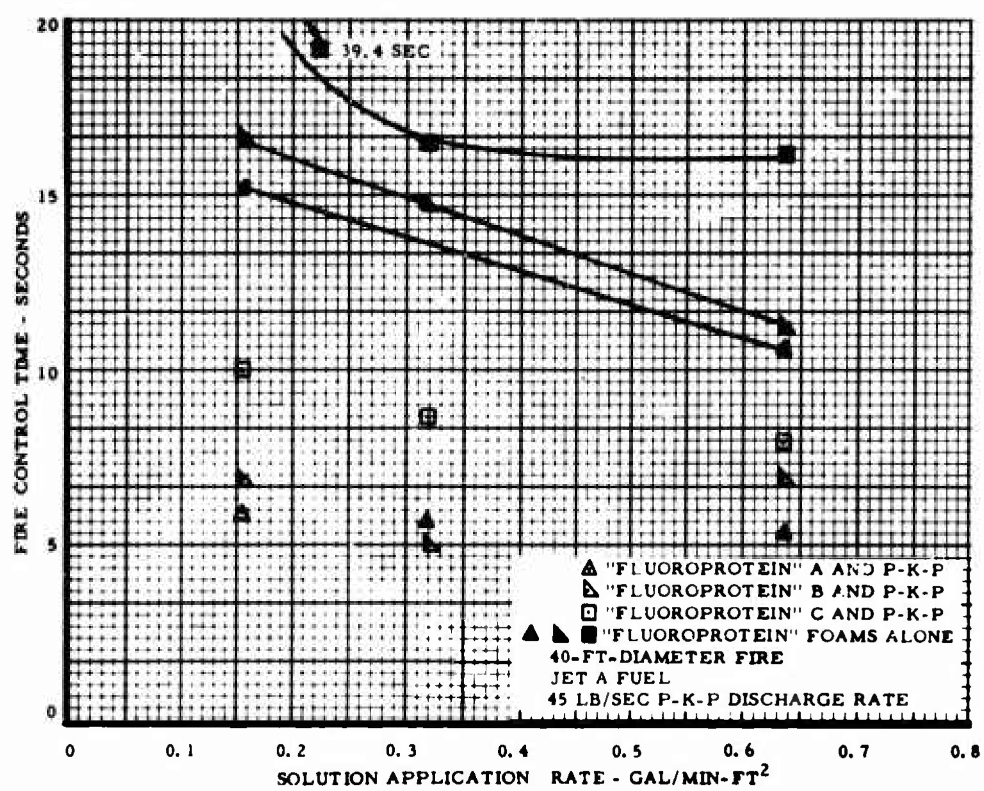
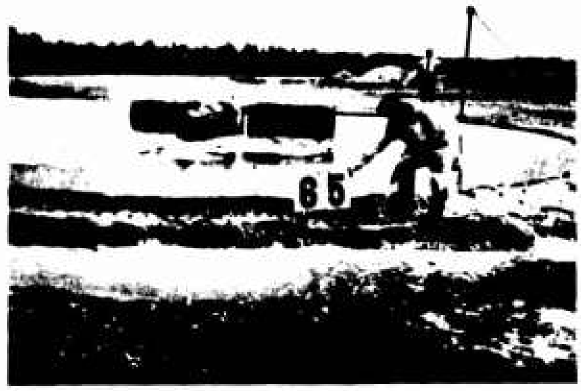


FIG. 14 COMPARATIVE DATA OF "FLUOROPROTEIN" FOAMS WHEN USED ALONE AND IN COMBINATION WITH PURPLE-K POWDER ON 40-FOOT-DIAMETER JET A FUEL FIRES

(1) "FLUOROPROTEIN" FOAM ALONE
FOAM DISCHARGE RATE - 400 GAL/MIN



(2) "FLUOROPROTEIN" FOAM AND PURPLE-K-POWDER
FOAM DISCHARGE RATE - 400 GAL/MIN
PURPLE-K DISCHARGE RATE - 50 LB/SEC

(3) "FLUOROPROTEIN" FOAM ALONE
FOAM DISCHARGE RATE - 200 GAL/MIN

(4) "FLUOROPROTEIN" FOAM AND PURPLE-K-POWDER
FOAM DISCHARGE RATE - 200 GAL/MIN
PURPLE-K DISCHARGE RATE - 50 LB/SEC

FIG. 15 COMPARISON OF THE FOAM BLANKETS PRODUCED BY "FLUOROPROTEIN" FOAM ALONE AND WHEN USED IN COMBINATION WITH PURPLE-K POWDER ON A 40-FOOT-DIAMETER JET A FUEL FIRE

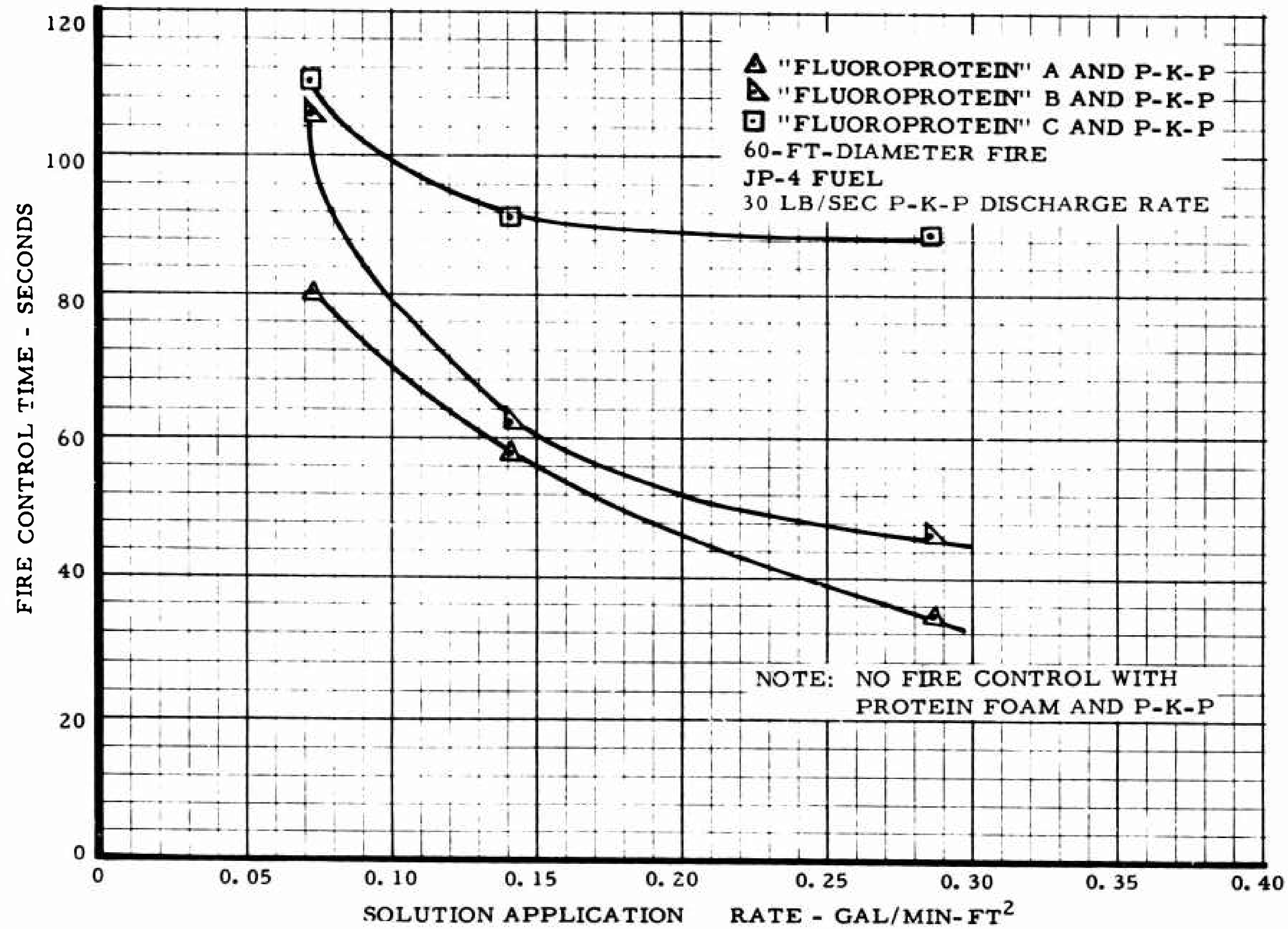


FIG. 16 COMPARATIVE DATA OF "FLUOROPROTEIN" FOAMS WHEN USED IN COMBINATION WITH PURPLE-K POWDER ON 60-FOOT-DIAMETER JP-4 FUEL FIRES

Protein Foam and Purple-K Powder - Three tests were conducted on a 60-foot-diameter JP-4 fuel fire. Handlines were employed to discharge P-K-P at a rate of 7.5 lbs/sec. One handline was used in the first test and two handlines were used in the second and third tests. The solution discharge rates of the protein foam were 200, 200, and 400 gal/min, respectively. Fire control was not obtained in any of the tests. (See note on Figure 16.) Thermal profiles similar to those developed in Figures 11 and 12 as well as the instrumentation photography showed that protein foam could not form a fuel vapor-securing blanket in contact with P-K-P since it is rapidly decomposed under these conditions.

"Light Water" and Purple-K Powder - Preliminary tests employing "Light Water" alone and in combination with P-K-P were conducted on 40-foot-diameter Jet A pool fires. The curve in Figure 17 shows the fire control time required for "Light Water" alone at solution discharge rates of 200, 400, and 800 gal/min. The data obtained from three exploratory tests are plotted to show the reduction in fire control time which was obtained when P-K-P was employed at 30 and 52 lbs/sec in combination with "Light Water."

After the general performance of the combined agents was established, the next effort was directed toward obtaining fire control information under more severe fire conditions.

The curves presented in Figure 18 compare the fire control time at three differenct solution application rates for "Light Water" alone and in combination with P-K-P on a 60-foot-diameter JP-4 fuel fire. Purple-K powder was discharged at a uniform rate of 80 lbs/sec while the "Light Water" discharge rate was varied from 200 to 400 and 800 gal/min.

The data indicate that a reduction in fire control time may be obtained through the simultaneous application of "Light Water" and P-K-P at the higher solution discharge rates. However, as the weight ratio of "Light Water" to P-K-P is reduced, the time required to control the fire was greatly increased. This is believed to have resulted from the "Light Water" foam being carried along with the high velocity powder discharge, thus not being effectively applied to the fire area.

From these data and those obtained from previous dry chemical powder tests, it is evident that there exists an optimum foam powder discharge ratio when these agents are used in combination. Wide divergence from this value would tend to result in a loss of efficiency and a waste of agent(s). The optimum value of the foam powder ratio for the system under consideration is of the order of 10 to 12 pounds of P-K-P for each gallon of "Light Water" solution discharged. The foam powder ratio is most meaningful in defining the operational requirements of twinned hand-operated equipment or of vehicles equipped to deliver a simultaneous discharge of powder and foam.

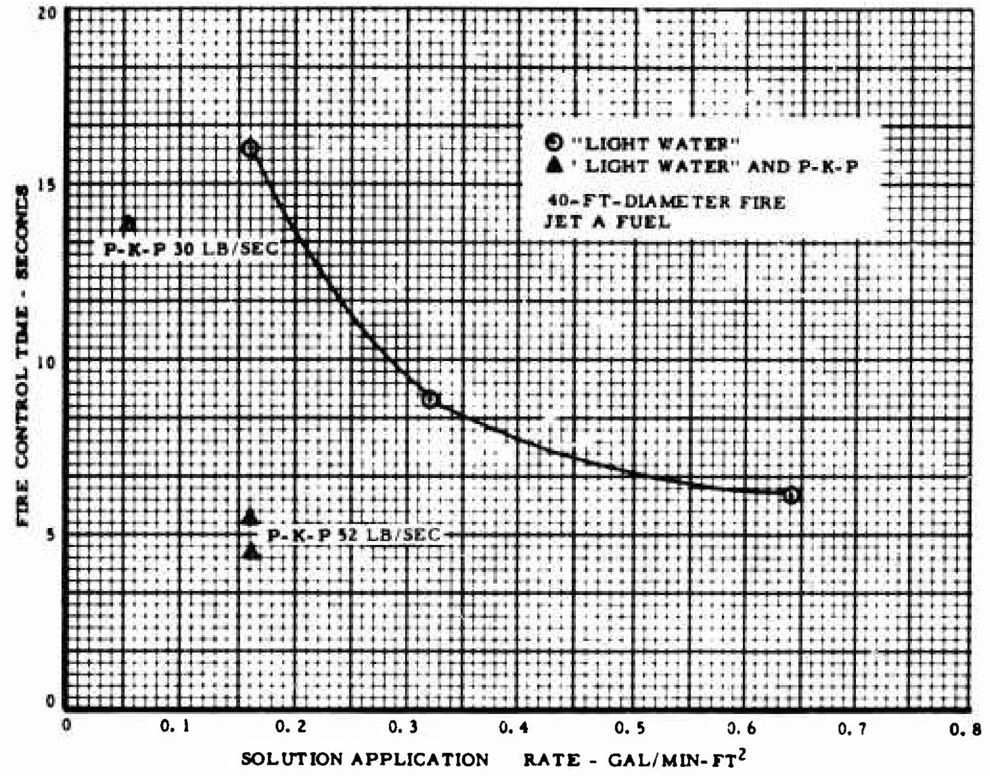


FIG. 17 COMPARATIVE DATA OF "LIGHT WATER" WHEN USED ALONE AND IN COMBINATION WITH PURPLE-K POWDER ON 40-FOOT-DIAMETER JET A FUEL FIRES

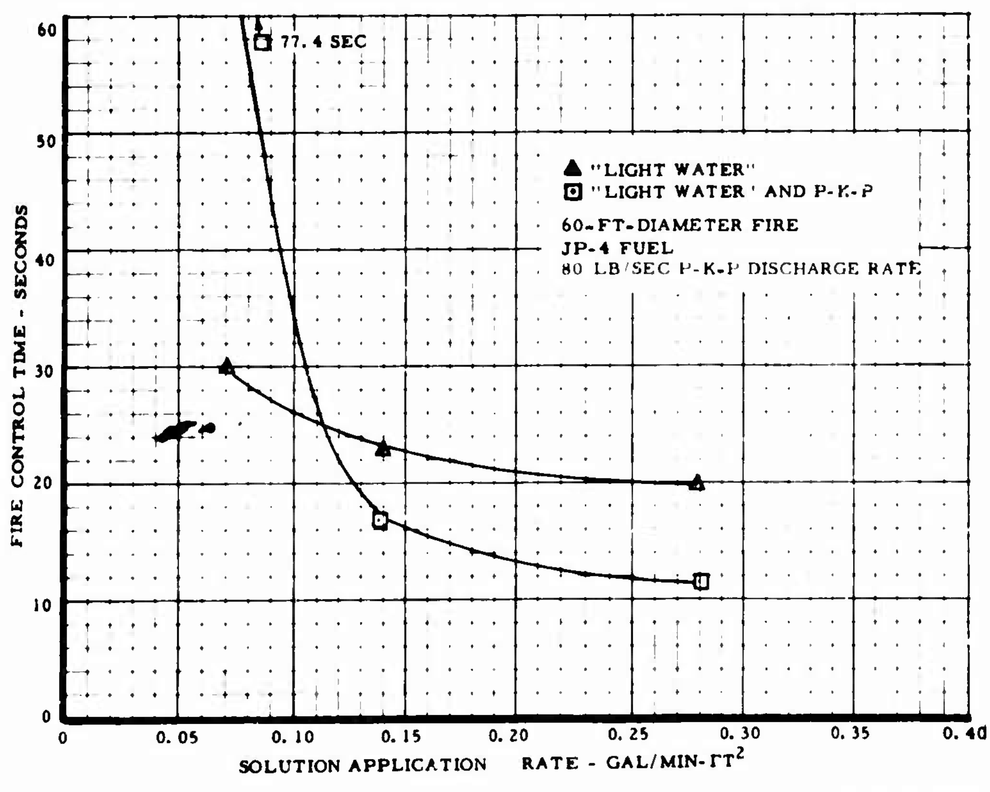


FIG. 18 COMPARATIVE DATA OF "LIGHT WATER" WHEN USED ALONE AND IN COMBINATION WITH PURPLE-K POWDER ON 60-FOOT-DIAMETER JP-4 FUEL FIRES

Protein Foam and Compatible Potassium Base Powder - The data thus far presented have shown the advances made toward achieving greater foam powder compatibility by modifying the protein base foam liquids. Figure 19 illustrates the powder compatibility which has been achieved with regular protein foam by modifying the dry chemical composition. Tests were conducted in which a new foam compatible potassium base powder (Reference 15) and protein foam were used in combination on a 60-foot-diameter JP-4 fuel fire. The results of these tests are plotted on the same graph with the data obtained for P-K-P and the "Fluoroprotein" foams for convenience in comparing the fire control times. The solid line in Figure 19 shows the fire control time as a function of solution application rate when protein foam is used in combination with the compatible potassium base powder and the dashed lines for "Fluoroprotein" foams and P-K-P. The powder in all tests was discharged at a uniform rate of 30 lbs/sec. Although tests were conducted only at solution discharge rates of 200 and 400 gal/min, there is evidence that the foam powder compatibility between the two systems is of the same order of magnitude.

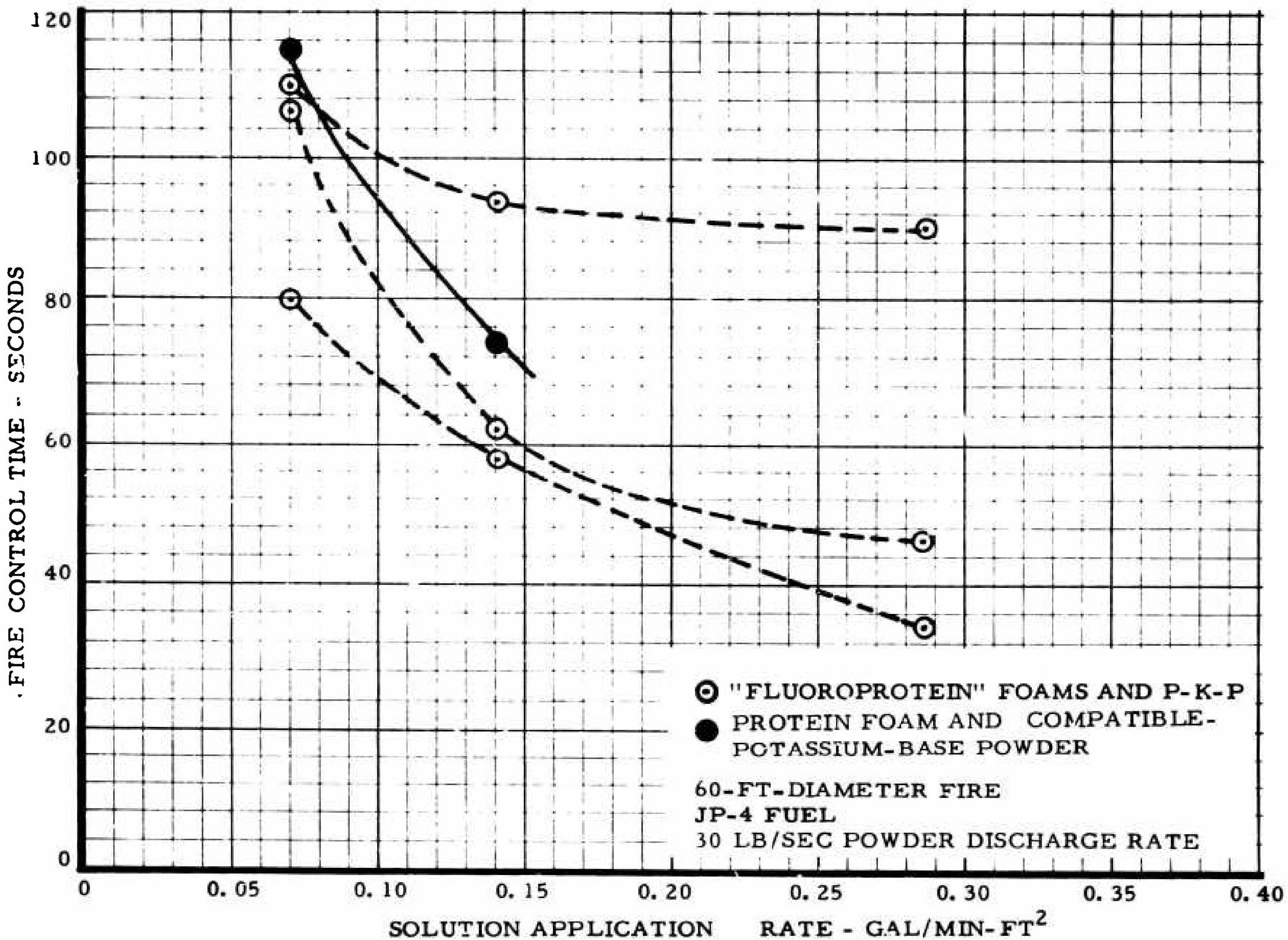


FIG. 19 COMPARATIVE DATA OF PROTEIN FOAM AND COMPATIBLE POTASSIUM BASE POWDER WITH "FLUOROPROTEIN" FOAMS AND PURPLE-K POWDER ON 60-FOOT-DIAMETER JP-4 FUEL FIRES

SUMMARY OF RESULTS

The results obtained during the foam and dry chemical application experiments conducted under fixed fire conditions are:

1. The time required to control Jet A pool fires when employing protein foam in air-aspirating equipment of the type used in the tests and when simulating a single point of discharge was a function of solution application rate. Rates in excess of approximately 0.35 gal/min-ft^2 resulted in no significant reduction in control time. Lower rates resulted in a significant increase in fire control times.

2. For 40-foot-diameter pool fires and solution discharge rates of less than 700 gal/min, JP-4 fuel fires required larger foam quantities for equivalent control times as compared to aviation gasoline and Jet A fuel fires.

3. The three new "Fluoroprotein" foam agents, when considered as a class, produced a small reduction in the fire control time over that required for protein foam on 40-foot-diameter Jet A pool fires. When compared at a solution application rate of 0.35 gal/min-ft^2, the "Fluoroprotein" foams produced control times from 0 to 30 percent (average of 15 to 20 percent) less than the control time achieved with protein foam.

4. "Light Water" may be used in air-aspirating equipment and gave the most rapid fire control time of any vapor-securing agent tested and, in this regard, it was indicated to be from two to three times as effective as protein foam in terms of control time depending upon the test condition.

5. The optimum solution application rate for high expansion foam with an estimated expansion ratio of 500:1 was determined to be 0.055 gal/min-ft^2 on a 60-foot-diameter JP-4 fuel fire. This provided a control time of approximately 55 seconds. The above application rate gave control of approximately 20 square feet of fire area for each gallon of solution discharge. After fire extinguishment, the established foam blanket was highly vulnerable to disruption by the wind.

6. Compatible dry chemical powder and purple-K powder discharged on 40-foot-diameter three-dimensional Jet A fires provided rapid reduction in the radiant energy from the fire plume at discharge rates ranging from 25 to 65 lbs/sec; however, the fires could not be extinguished by the use of the powders alone.

7. The discharge of CDC at a uniform rate of 30 lb/sec in combination with regular protein foam at solution application rates from 0.17 gal/min-ft^2 to 0.64 gal/min-ft^2 showed a reduction of approximately 40 percent in fire control times for 40-foot-diameter JP-4 fuel fires.

8. Purple-K powder and protein foam, when used in combination on a 60-foot-diameter JP-4 fuel fire, were incapable of controlling the fire.

9. Fire control time obtained with the combined use of compatible potassium base powder and protein foam on JP-4 fuel fires was comparable to that obtained by using the "Fluoroprotein" foam and P-K-P combination. Protein foam and compatible potassium base powder when employed in a combined agent application on JP-4 fuel fires may not produce any significant reduction in fire control time over the foam alone.

10. Purple-K powder and "Light Water" demonstrated excellent compatibility under all test conditions. A significant reduction in the fire control time was obtained by the combined application of P-K-P at a uniform rate of 80 lb/sec and "Light Water" at solution application rates from approximately 0.14 to 0.28 gal/min-ft^2. However, no definitive reduction in fire control time was obtained by the combined agent discharge of "Light Water" at solution application rates from 0.07 to 0.14 gal/min ft^2 over foam alone on 60-foot-diameter JP-4 fuel pool fires.

11. Purple-K powder and "Fluoroprotein" foam when employed in a combined agent application on JP-4 fuel fires may not produce any significant reduction in fire control time over the foam alone.

CONCLUSIONS

Based on the results of the foam and dry chemical application experiments, it is concluded that:

1. The optimum solution application rate for obtainging rapid fire control employing protein foam in air-aspirating equipment of the type used in the tests on Jet A pool fires up to 80 feet in diameter is approximately 0.35 gal/min-ft^2.

2. JP-4 and aviation gasoline fires are more destructive to protein foam than Jet A fuel.

3. The "Fluoroprotein" agents, when considered as a class, and regular protein foam have essentially equivalent fire-fighting capability in controlling 40-foot-diameter Jet A fuel fires.

4. "Light Water" employed alone results in a significant reduction in the fire control time compared with that of protein foam under similar pool fire conditions and can be used with air-aspirating equipment.

5. High expansion foam is capable of obtaining rapid control and extinguishment of aviation fuel fires at low solution application densities but its vulnerability to wind and limited vapor-securing characteristics restrict its use as a crash fire-fighting agent.

6. Dry chemical powders used alone in combating crash fires may result in very rapid reduction in thermal radiation but do not provide the fuel vapor-securing action required to prevent flashback.

7. A significant reduction in the control time of JP-4 fuel fires can be obtained by the combined agent discharge of CDC and regular protein foam.

8. Protein foam and P-K-P when used in a combined agent discharge on Jet A fuel fires are incompatible.

9. Compatible potassium base powder and protein foam demonstrate an acceptable degree of compatibility and may be employed in a simultaneous discharge on JP-4 fuel fires. The degree of compatibility between these agents is of the same order of magnitude as that which exists between the "Fluoroprotein" foams and P-K-P.

10. Purple-K powder and "Light Water" may be employed in combination on JP-4 and Jet A fuel fires to achieve a reduction in the fire control time.

RECOMMENDATIONS

Based on the foam and dry chemical application experiments, it is recommended that:

1. A system for evaluating fire control and extinguishing requirements employing protein foam in terms of pool fire area should utilize a solution application rate of 0.35 gal/min-ft^2. This rating value is applicable to Jet A fuel fires up to 80 feet in diameter.

2. JP-4 aircraft fuel be employed to establish fire test conditions ot maximum severity.

3. The "Fluoroprotein" agents when considered as a class of agents be employed at a rate and in a manner similar to that used for protein foam.

4. "Light Water" be employed at solution application rates from one-half to one-third of those established for protein foam on 40-foot-diameter Jet A and 60-foot-diameter JP-4 fuel pool fires.

5. High expansion foam in its present state of development not be employed as the primary fuel vapor-securing agent in large aircraft accidents involving fire.

6. When employing dry chemical powders, consideration should be given to the potential hazard of flame flashback and the momentary increase in thermal radiation. To secure exposed fuel surfaces from reflash during powder application, a foam vapor-securing agent should be employed.

7. Protein foam and CDC be considered as paired agents for the combined agent discharge on JP-4 fuel fires.

8. Protein foam and P-K-P not be employed in a combined agent discharge on JP-4 fuel fires and that the P-K-P not be used as a mopup agent around established protein foam blankets.

9. Compatible potassium base powder and protein foam be considered as paired agents in combined agent application on JP-4 fuel fires.

10. "Light Water" and P-K-P be considered as paired agents for use on Jet A and JP-4 fuel fires in all proportions and combinations.

11. Full-scale fire tests be conducted employing the same foam agents evaluated under this project to determine the optimum foam quality, with regard to increased expansion ratios and longer 25 percent drainage times, necessary to achieve the most rapid fire control time.

12. Additional tests be performed to establish the ability of a foam to produce an adequate fuel vapor-securing barrier under adverse weather conditions involving heavy rain, hail, and snow and high discharge waterfog streams.

13. Improved methods be developed to provide better dispersed foam patterns and the most effective means for their distribution.

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14. Spec. MIL-F-22287A (WEP) of November 1962, Fire Extinguishing Agent, Potassium Dry Chemical.

15. Chemical Concentrates Corporation, Fort Washington, Pennsylvania.

ACKNOWLEDGEMENTS

Appreciation is expressed to Chief Paul P. Benarick and to Captain Linwood Robertson and the members of the Fire Department for their cooperation and proficiency in the prosecution of that portion of the fire test program conducted at Dulles International Airport.

APPENDIX 1

FOAM SOLUTION DISCHARGE RATES

APPENDIX 1 TABLE I

FOAM SOLUTION DISCHARGE RATES AND THE CORRESPONDING APPLICATION RATES AS A FUNCTION OF FIRE PIT SIZE

GALLONS PER MINUTE PER SQUARE FOOT													
Pit Diam. (ft.)	Pit Area (ft^2)	GALLONS PER MINUTE											
		200	400	600	800	1000	1200	1400	1600	1800	2000	2200	2400
40	1256	.159	.318	.477	.636	.795	.954	1.113	1.272	1.431	1.592	1.749	1.908
60	2826	.070	.140	.210	.280	.350	.420	.490	.560	.630	.700	.778	.849
80	5024	.039	.078	.117	.156	.195	.234	.273	.312	.351	.390	.429	.468

APPENDIX 2

PROPERTIES OF FUELS

APPENDIX 2

PROPERTIES OF FUELS

The jet fuel employed in the fire test program was in conformance with Military Specification MIL-J-5624F and the aviation gasoline was grade 115/145 conforming to Military Specification MIL-G-5572D. Other significant fuel-burning characteristics not included in the above specifications are contained in the following tables:

TABLE I

Estimated Properties of Typical U. S. Fuels*

	Aviation Gasoline	JP-4	Jet A
Flash Point, min (°F)	-40	-20	110
Reid Vapor Pressure (psi)	6.5	2.7	0.1
Approximate Flammability Limits (°F)	-40 to -20	-20 to +60	110 to 150

TABLE II

Flame Spread on Fuel Surfaces*

Conditions	Fuel	Rate of Flame Spread
Liquid below 0°F	Jet A JP-4	Same, less than 50 ft/min
Liquid above 0°F but below 120°F	Jet A JP-4	Slowly 100 to 700 ft/min
Liquid above 180°F	Jet A JP-4	Same rate of spread (over 700 ft/min)

*Coordinating Research Council, Inc., "Aviation Fuel Safety" (CRC Project No. CA-37-64), June 1964.

TABLE III

ESTIMATED FUEL BURNING RATE
(Large Shallow Pool Fires)

	Aviation Gasoline	Fuel JP-4	Jet A
lb/ft^2-min	0.600	0.584	0.546

The fuel-burning rates presented in Table III are approximate values obtained under ambient weather conditions where the average temperature was 70°F and the wind velocity was 4 to 6 mph. Note should be taken of the fact that these rates may be expected to vary appreciably with wind velocity. In general, a decrease in the burning rate will result from an increase in wind velocity; conversely, an increase in the burning rate will result as the wind velocity is decreased.

APPENDIX 3

INSTRUMENTATION FOR FIRE TESTS

APPENDIX 3

INSTRUMENTATION FOR FIRE TESTS

General

The instruments employed for the required parametric measurements consisted of radiometers and cameras. Recording instruments consisted of two potentiometer recorders manufactured by the Bristol Company, Dynamaster Model No. 760, with two pens each and equipped with event markers which were manually actuated when foam or dry chemical was discharged. Since data were to be collected at Dulles International Airport, as well as at NAFEC, a mobile van was suitably equipped to house the recorders and a gasoline-powered 115 volt AC generator.

Radiometers

Two Heat Technology Laboratory, Inc., Model GRW20-64P-SP, heat flux transducers were mounted on 9-foot-high stands and positioned at the perimeter of the fire pool on the diameter at right angles to the wind direction. These heat sensors were water-cooled and purged with nitrogen gas. They measured the radiant heat flux and were rated at 10 $\pm$1.5 millivolts (mV) at 15 Btu/ft^2-sec. Each unit was provided with a calibration curve by the manufacturer. The angle of view was 120 degrees. Cooling water was supplied to the unit at the rate of 0.1 gal/min from a pressurized reservoir located at the base of each stand.

Photographic Recording

Two 16-mm motion picture cameras, loaded with Kodachrome II color film and operating at 24 frames per second, were employed to provide for visual analysis of the fire test performance. An electric clock with a face diameter of 24 inches was placed in the line of sight of one 16-mm camera during each test. The arrangement was not completely satisfactory, however, due to poor visibility during some of the tests. Therefore, the clock was not relied upon as a primary timing device. Additional photographic coverage was obtained on a Maurer KB10 A camera, using 70-mm black and white film, exposing 1 frame per second. Numerous random black and white still shots were taken at various critical phases of the fire-fighting operation and of the final foam blanket.

APPENDIX 4

CRITICAL PHASES OF A TYPICAL FIRE TEST

(1) IGNITION

(2) PREBURN

(3) START EXTINGUISHMENT

(4) EXTINGUISHMENT OPERATION

(5) FIRE CONTROL

(6) FOAM BLANKET

FIG. 4. 1 CRITICAL PHASES OF A TYPICAL FIRE TEST

APPENDIX 5

FIRE-FIGHTING EQUIPMENT

APPENDIX 5

FIRE-FIGHTING EQUIPMENT

Foam Equipment

Equipment at NAFEC: The ground fire-fighting equipment employed by the NAFEC Crash Rescue Section comprised two water foam trucks and one nurse truck (water tanker/pumper). A stationary 500-gallon capacity tank on the fire test site was used to supply additional water. The water foam trucks were Model CPS manufactured by the Walter Motor Truck Company. Each of these units had a water capacity of 1500 gallons and a foam liquid concentrate capacity of 300 gallons. The foam turret was double-barreled and designed to deliver 800 gal/min of a foam solution water or water fog, at 225 lb/in^2. The turret was so valved that the discharge could be restricted through the use of a single barrel to 400 gal/min. When a lower discharge rate was required, a modified tip was substituted in the barrel to deliver foam solution at 200 gal/min.

The nurse truck was a Model PFUL 635801 manufactured by the Walter Company. It had a capacity of 3000 gallons of water and was capable of pumping at a rate of 1000 gal/min.

Equipment at Dulles International Airport: With the cooperation of the Bureau of National Capital Airports, 17 fire tests were conducted at Dulles Airport to make use of their high capacity foam trucks. The equipment was similar to that at NAFEC and could be adapted to discharge foam solution at 500, 1000, 1600, 2000, and 2600 gal/min, which required three trucks at the highest rates. Foam was produced by proportioning protein foam liquid concentrate at a concentration of 6 to 8 percent by volume.

Dry Chemical Equipment: The dry chemical fire-fighting equipment was a Fire Boss Model D-35 WF250P, crash-rescue vehicle manufactured by Fire Control Engineering Company, Fort Worth, Texas. The unit had a capacity of 3500 pounds of CDC which could be discharged from the turret at 150 lbs/sec for an effective distance of 150 feet. Two handlines had a discharge rate of 12 lbs/sec each with a range of [illegible] feet.

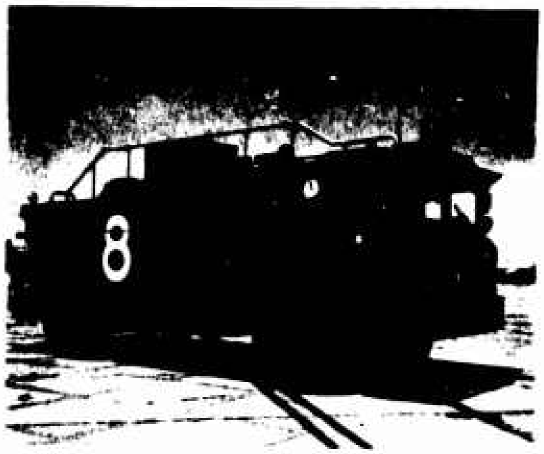

FIG. 5.1 NAFEC FOAM TRUCK

FIG. 5.2 DRY CHEMICAL TRUCK

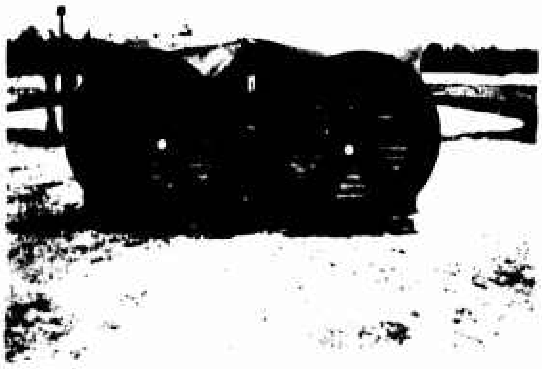

FIG. 5.3

HIGH EXPANSION FOAM EQUIPMENT

FIG. 5.4

HIGH-EXPANSION FOAM EQUIPMENT

APPENDIX 6

DAMAGE TO FIRE-FIGHTING EQUIPMENT

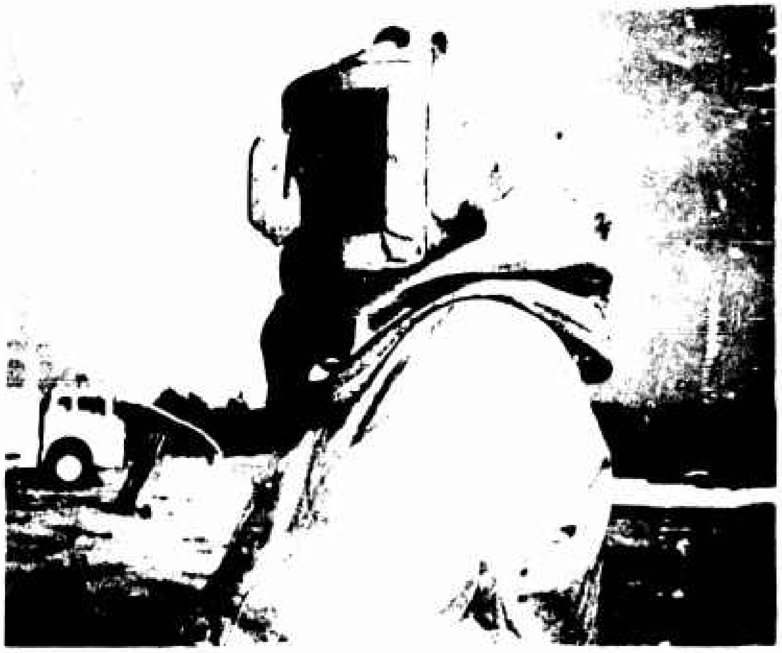

FIG. 6.1 DAMAGE SUSTAINED BY THE FIREMAN'S FACE MASK FROM THE INTENSE THERMAL RADIATION DEVELOPED AT THE FLAME FRONT BY A HIGH-VELOCITY DISCHARGE OF DRY CHEMICAL POWDER.

FIG. 6.2 DAMAGE TO THE DRY CHEMICAL TRUCK, WHICH WAS POSITIONED 30 FEET FROM THE FIRE POOL PERIMETER DURING THE SAME INCIDENT, INCLUDED BLISTERED POINT AND MELTED PARKING LIGHT LENSES.