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Full-Scale Fire Modeling Test Studies of "Light Water" and Protein Type Foams

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Henry B. Peterson, Edwin J. Jablonski, Raymond R. Neill, Richard L. Gipe, and Richard L. Tuve

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13. ABSTRACT

A comprehensive study has been made of the fire-control and extinguishing effectiveness of "Light Water" and protein type foams on full-scale fires of the type associated with aircraft accidents. Most tests were conducted with a Navy MB-5 aircraft fire-rescue vehicle utilizing a 250-gpm-solution-capacity foam pump as the foam-making device for both agents. For comparative and evaluative purposes, some testing was done using an experimental O6X vehicle which carried 2500 lb of Purple-K dry chemical and 300 gal of Light Water solution and had dually rigged roof turrets discharging 32 lb/sec of P-K-P and 180 gpm of solution. An air aspirating nozzle and a specially designed nozzle using Refrigerant-12 as a blowing agent were interchanged and used to produce Light Water foams of different physical properties. Both the Light Water and protein foam liquid concentrates used were of the 6-percent type.

Avgas and JP-5 were used as test fuels on fire test areas, containing a simulated fuselage, ranging in size from 450 ft^2 to 9000 ft^2. In all tests, avgas fires were more difficult to control and extinguish than JP-5. For the avgas fires, Light Water required about a 50-percent higher application density than for JP-5 fires. The increase for protein ranged from 35 to 200 percent.

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The margin of superiority of Light Water over protein foam was found to be as high as 3 to 1 for control as determined by radiometer and visual measurements of avgas fires and as high as 1.5 to 1 for control of JP-5 fires. Complete fire extinguishment was achieved with application densities as low as 0.026 gal/ft^2 of Light Water on JP-5 and 0.035 gal/ft^2 on avgas, while protein required 0.043 gal/ft^2 and 0.085 gal/ft^2 respectively.

The dual-agent fire-fighting concept, wherein equal quantities of Light Water and P-K-P dry chemical were discharged from a twin turret, showed no advantage over the use of Light Water foam alone in gaining control of the large-scale fires.

The new 6-percent Light Water concentrate was effectively used in both the MB-5 vehicle foam-pump system and the air-aspirating type foam maker as well as with Refrigerant-12.

The laboratory-scale, indoor fires consistently required about three times the application density to extinguish than the comparable outdoor fires, when run with JP-5 and avgas fuels, and protein and Light Water foam agents. The relative difficulty in extinguishing the two fuels was inconsistent between the small-scale and large-scale tests.

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H. B. Peterson, E. J. Jablonski, R. R. Neill, R. L. Gipe, and R. L. Tuve

Engineering Research Branch
Mechanics Division

August 15, 1967

NAVAL RESEARCH LABORATORY
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PROBLEM STATUS

This is a final report on one phase of the problem; work on the problem is continuing.

AUTHORIZATION

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FULL-SCALE FIRE MODELING TEST STUDIES OF "LIGHT WATER" AND PROTEIN TYPE FOAMS

INTRODUCTION

Progress in the Use of Fluorocarbon Surfactants ("Light Water") for Fire Extinguishment

The development of a new fuel vapor-securing agent, called "Light Water" by its discoverers, suitable for the extinguishment of hydrocarbon liquid fuels was reported by NRL in 1964 (1). At that time special equipment had been designed and was under procurement to enable this new material to be employed for fire-extinguishment purposes at Naval air activities by station fire-fighting personnel, usually enlisted military men. A research prototype fire-fighting unit was delivered in September 1964 to NAS Pensacola, where it was evaluated under field conditions by the crash crew in cooperation with Naval Research Laboratory representatives.

The device used in these tests was the Twinned-Agent Unit (abbreviated as TAU), designed by NRL and fabricated by industry (Fig. 1). It consists of two equally sized aluminum spheres 28 in. in diameter, two gas cylinders, a refrigerant container, and a dual hose line with nozzles. One sphere holds 400 lb of Purple-K, potassium bicarbonate type dry chemical, and the other 48 gal of Light Water active solution. Dry chemical is expelled by nitrogen gas from a 220-ft^3 cylinder, while the solution and refrigerant are expelled by nitrogen pressure from a 110-ft^3 cylinder. Each system can be operated independently of the other. A hose basket mounted above the spheres holds the 100-ft-long discharge hose in a position for ready "pay-out." The dual-nozzle mounting

Fig. 1 - The TAU (twinned agent unit), shown dismounted for a better view of the components, is normally carried on a one-ton rated 4 x 4 vehicle

Fig. 2 - A close-up of the dual nozzle with finger-tip control valves. Light Water is on the operators left side.

and the pistol-grip shut-off valves are pictured in Fig. 2. The unit fully charged with agents weighs 1560 lb and is skid mounted to facilitate installation in the bed of a 4 × 4 pick-up type vehicle with utility cabinets, as illustrated in Fig. 3.

During the test period at Pensacola, 14 different modeling fires were extinguished in diked pits and on grassy areas with both jet fuels and avgas. In most instances old fuselages were present and served as an objective for the rescue man to attain. In some fires large wooden stakes were set in the ground to simulate trees, and stacked wooden pallets presented additional Class A fire loading. In some tests, piles of magnesium chips were used to add a Class D metal fire problem. Rescue times to reach a dummy in the fuselage varied from 7 sec in the case of a 1200-ft^2 fire to 20 sec in a 2700-ft^2 fire. All fires were extinguished with the material carried in the TAU, and reignition protection of the fuel was judged to be very good after extinguishment. The most effective technique developed was to split the fire quickly down the center to the fuselage, using both agents to carve out a safe rescue path; then, after rescue had been made, fires on each side were handled in sequence. (These fires were designed to simulate the problems of the Naval air training field, small trainer aircraft with one or two occupants.) The results of these tests were summarized in a sound-track motion picture report (2).

Subsequent to the highly successful tests at Pensacola, 40 additional units were procured from the manufacturer of the prototype and distributed to Naval Air Stations. The

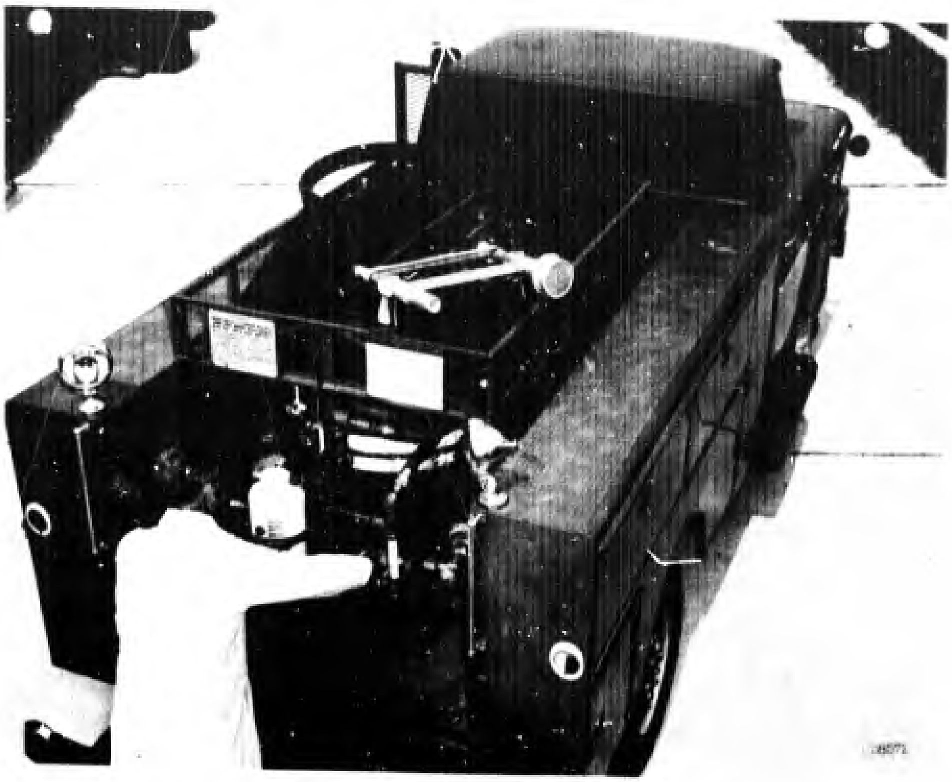


Fig. 3 - TAU as mounted in vehicle and showing the operating position for actuating the systems

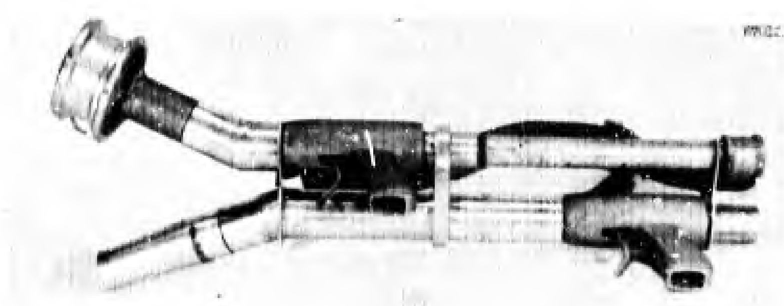


Fig. 4 - An experimental side-by-side rigging of the handline nozzle and valves, with an over-the-shoulder strap for ease in carrying

TAU replaced the 400-lb air-transportable Purple-K units previously used. Although the units were purchased with nozzle arrangements as illustrated in Fig. 2, several other designs have been constructed. One of these, shown in Fig. 4, is a side-by-side model with a shoulder strap to facilitate its support, while the side-by-side model of Fig. 5 is of a compact mounting type.

Reports from the field received by the Bureau of Naval Weapons in 1965 indicated the need for some method of fire extinguishment which could be transported by helicopter and applied while it was still airborne. Bases had been encountering fires involving aircraft in terrain that was completely inaccessible to wheeled vehicles. This situation

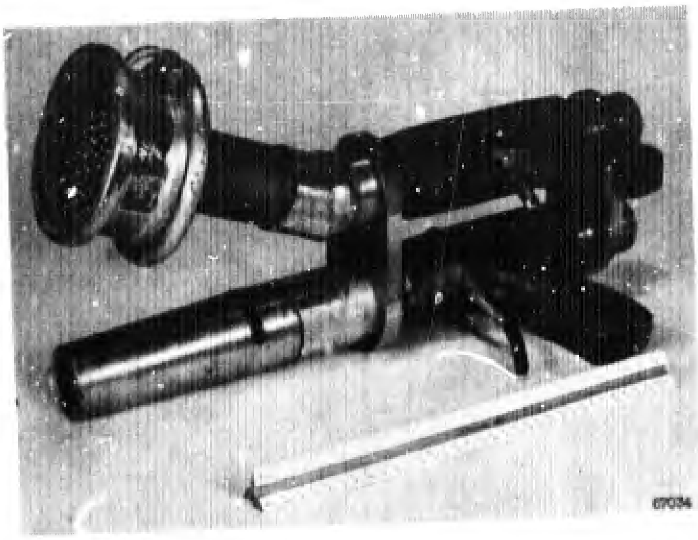


Fig. 5 - A second experimental side-by-side rigging featuring shorter length and lighter weight

appeared to be ideal for some type of application of Light Water because of its high fire-extinguishment efficiency on a weight basis. Simulated experiments were initiated on the fire-test field using a 5000-cfm axial-flow blower mounted on a stand with the output stream of air directed downward onto a diked fuel 100 ft^2 in area. Spray nozzles near the blower outlet permitted the introduction of Light Water agents into the air blast. It was found that 1 gal of Light Water solution discharged from ordinary spray nozzles could completely secure a small JP-5 fuel fire within a few seconds and provide a protective foam covering over the fuel surface. Recommendations were then made to the Navy Department for conducting additional work using helicopters on large fires.

Helicopter testing was initiated in July 1965 at the Naval Air Station, Miramar, California, where an aircraft was available and also a pilot with considerable previous experience in using helicopter rotor downwash for suppressing flames for aircraft rescue purposes. A 60-gal-capacity liquid tank was mounted inside the UH-2A's cargo space with a nitrogen cylinder to propel the solution. The two discharge nozzles were mounted on booms projecting forward and below the nose of the ship. The pilot was provided with pushbutton control over the nozzle flow by means of a switch operating an electrically actuated solenoid valve located at the tank. After extinguishing a series of fires in the 700 to 900 ft^2 size using JP-4 and JP-5 as fuels, it was concluded that a foamier type of Light Water discharge would offer improved efficiency, so the two spray nozzles were replaced with a single fog-foam nozzle of 50-gpm capacity. This nozzle has a double screen covering the impinging jet discharge, serving to create impact and turbulence and thereby produce a watery foam. Its location in the downwash was such that the foam discharge was swept directly downward and into ground contact with very little, if any, foam being lost by wind turbulence from the rotor blast.

The final mounting of the nozzle on the helicopter was outward and downward on the pilot's side (Fig. 6). This arrangement enabled the pilot to observe the foam discharge pattern and the rescue team below him simultaneously and thus effectively protect them while they entered and worked around the burning, disabled aircraft. The excellent maneuverability of the helicopter permitted pin-point application of the agent. After rescue operations had been completed, the pilot proceeded to extinguish the remaining fire. It was found that his most effective operating altitude was between 20 and 30 ft. Figure 7 illustrates the typical knock-down and hold-back of flames while the dummy was being "rescued." Before the helicopter had moved in, the fuselage had been

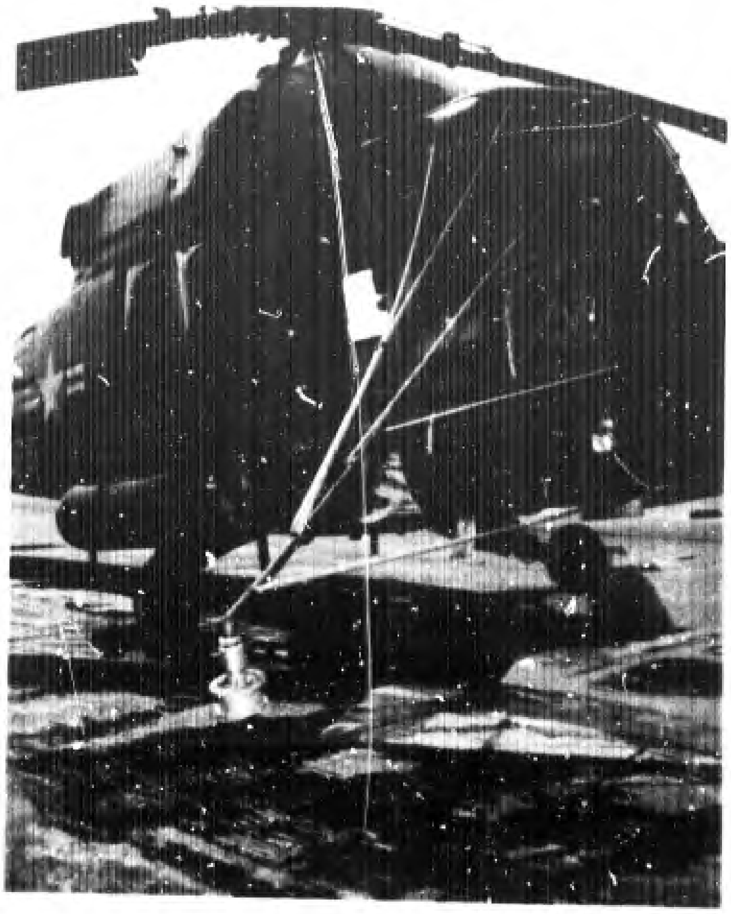


Fig. 6 - The single fog-foam nozzle for discharge of Light Water, mounted within view of the helicopter pilot while airborne

completely encircled by fire. The fire areas were 40 by 60 ft (2400 ft^2) and were fueled with 200 to 300 gal of mixed JP-5 and avgas, and each fire contained an aircraft complete with wings, but with the landing gear retracted so it was lying on its belly. Despite the excellent maneuverability of the helicopter, it was usually not possible to obtain 100-percent fire extinguishment because of persistent ground fires under the low-lying wings, or fires inside the aircraft. However, the securing ability of the Light Water prevented these isolated fires from creating any difficulties in the rescue operations. Rescue paths to the fuselage were available in an average of 10 sec and the "rescue" completed in 25 to 35 sec. One control, or "blank," run was made by the helicopter without the use of the Light Water in order to compare the effect of downwash alone toward creating a tenable rescue path. When this was done under similar fire conditions it was found that a rescue path could not be established and held, and that the helicopter and its pilot were subjected to considerable danger from heat while trying to hover in an effective position.

A complete motion-picture record made of the fire tests conducted in the program served as summary and report of the work (3). It definitely established that Light Water was capable of use as a fire-extinguishing agent without the accompanying use of dry chemical. Also established for the first time was a method of attacking a fire and making a rescue without the necessity for the helicopter to land equipment and men within a hose-length distance of the fire. In the test operations at Miramar, the rescue personnel lowered

Fig. 7 - Helicopter hovering at optimum location to protect personnel with downwash while they are working in the cockpit area

themselves from the helicopter by a rappeling technique using the "Sky Genie," a mechanical snubbing device. Thus, the operation features much more flexibility than other previous helicopter-borne systems because it does not require actual touchdown by the helicopter at any time at any particular spot.

In 1960, very much prior to the introduction of Light Water as a securing agent, NRL had been interested in the determination of the capabilities of dry chemical discharge at high rates from turret nozzles. Such a project required facilities beyond those available at the Laboratory, and an invitation for proposals on a development project were issued. The Ansul Company received a research contract in 1961 to design and fire test dry chemical nozzles discharging up to 200 lb/sec, with the objective of establishing the maximum size gasoline spill fire extinguishable with each flow rate and the optimum or more efficient flow rate, based on square feet extinguished per pound of powder. An experimental dry chemical system of 4000-lb capacity was mounted on a vehicle test bed, and tests were made on large circular spill areas. The results, however, were disappointing because of the extremely low efficiency of the high-rate dry chemical discharge and the persistent fuel-vapor flashback problem. In April 1964 a contract change was initiated by NRL to remove part of the dry chemical capacity of the test unit and replace it with Light Water, to create a dual-agent system, similar in concept to an oversized TAU. This system was mounted on a reused military Cardox CO_2 truck, the O-6, and the remodeled version was named the "O6X". It carried 2500 lb of Purple-K dry chemical and 300 gal of Light Water solution and had dually rigged roof turrets discharging 32 lb/sec of P-K-P and 180 gpm of solution. The Light Water was the 25-percent FC-183 type, and Refrigerant-12 was used as a blowing agent. Tests conducted by the contractor demonstrated that gasoline fires 100 ft in diameter (8000 ft^2) could be extinguished with this dual system.

Working with the TAU, the O6X truck system, and the helicopter on gasoline spill fires, it was soon realized that Light Water possessed an extremely fast flame knockdown ability by itself and in many instances was equivalent to that achievable by Purple-K-Powder dry chemical applied at the same rate by weight. This fact led to the need to obtain data which might broaden applications for the new agent.

Patent Status

A patent application covering the use of the fluorocarbon surfactant materials, commonly referred to as "Light Water," was filed on Sept. 4, 1963, by R.L. Tuve and E.J. Jablonski as assignors to the United States of America as represented by the Secretary of the Navy. The patent was granted on June 28, 1966, as No. 3,258,423, entitled "Method of Extinguishing Liquid Hydrocarbon Fires." It is the current policy of the Navy that the new materials and methods described in the patent belongs to the people of the United States and is for their use without cost, and therefore no organization may use this material to its exclusive gain.

The teachings of this patent include the employment of the "Twinned Agent" concept of application of the two agents, Light Water and potassium bicarbonate dry chemical discharges, simultaneously from dual, trigger-valve-controlled nozzles capable of one-man operation. Laboratory and field tests had shown the added merits of this arrangement in fire-extinguishment efficiency.

The patent revealed for the first time a description of the fluorocarbon types used in making Light Water concentrate. They are quaternary nitrogen compounds with an intermediate amidopolymethylene linkage in the molecular structure, as typified by the following compounds:

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

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

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

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

Another compound found useful in the mixture is a sulfonamido aliphatic acid salt of the type represented by this formula:

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

In order to make water solutions of the above fluorinated compounds fully effective as synthetic fire-fighting foaming agents, the patent discloses that polyethylene polymers of the water-soluble type are necessary to provide flame and mechanical stability to the final foam bubble. Polymer molecular weight ranges having 2000 to 4000 times that of ethylene oxide function best for this requirement.

Formulation and Other Developments

The original work done at NRL led to a carefully constructed mixture of synthetic surface-active materials dissolved in requisite amounts of water. This mixture was a concentrate and was employed in fire-fighting equipment by dilution of the concentrate with more water at its point of use. Because of viscosity and ease of mixing requirements, this early concentrate formula was adjusted so that three volumes of water were needed to dilute each volume of concentrate to arrive at the correct final solution necessary for making Light Water foam. It was thus a 25-percent concentrate. Military procurement specification standards were drawn up for this solution (4).

Customarily, ordinary fire-fighting foam forming concentrates of the protein type are supplied in a liquid concentrate foam such that 94 volumes of water are needed for every six volumes of concentrate to make the final foam-forming solution. These protein concentrates are called 6 percent. Obviously they represent a considerable saving in amounts of material when compared to material such as a 25-percent concentrate.

One of the early efforts at improving the usefulness of Light Water was concerned with reconstruction of the formula of the concentrate so that only 6 percent of a strongly concentrated liquid was needed for obtaining fully effective fire-fighting results. Viscosity characteristics of the liquid would have to be similar to other 6-percent foam-forming concentrates if existing proportioning equipment were to be employed with Light Water.

It will be noted that all the initial applications of Light Water to field fire-fighting problems involved the use of Refrigerant-12, difluorodichloromethane, for purposes of properly expanding the Light Water active solution into a properly formed foam. This gas acted as a "blowing agent," so that the foam-application nozzle did not have to be particularly designed to perform air-mixing and foam-making operations on the solution. Proper aspiration of air by venturi action at a nozzle introduces serious design problems which very often interfere with the optimum pattern of foam discharge.

One of the important objectives of the 1964 to 1966 period was concerned with the search for methods and materials which would allow omission of Refrigerant-12 from the system without suffering compromises in the inherent fire-fighting efficiency of Light Water. Early in 1966 the commercial source for Light Water concentrate had developed a new material capable of producing fully effective foam from existing equipment utilizing only six volumes of the concentrate in 94 volumes of water and completely omitting the need for Refrigerant-12. Small-scale tests in the laboratory justified these claims, but full-scale field tests were needed.

The current MIL Specification for 6-percent Light Water concentrate is given in Appendix A.

The Need for Full-Scale Modeling Tests

The progressive development of new concepts in fire-extinguishment systems seems to arrive inevitably at a point where laboratory-scale testing and fire modeling becomes inadequate to justify complete field application. Because of the complete variability of fire situations in actual practice, every individual with responsibilities for fire protection seeks to improve his confidence level concerning a new system by accumulation of evidence concerning the performance of a candidate under field conditions of full-scale fire test. This requirement oftentimes results in an outcome less than that desired, because of the unknown contributions of the uncontrolled variables encountered in field tests.

The prospect of increased usefulness of Light Water in the spring of 1966 brought about the need for enlarged tests for application to fire-extinguishing situations in which protein-type foam concentrates had been previously satisfactorily used. With larger scale tests in mind, a comprehensive series of full-scale fire-modeling tests were designed utilizing a foam pump as a foam-making device on an MB vehicle, and the aforementioned O6X high-discharge-rate "Twinned Agent" vehicle. Fire department personnel at the Miramar Naval Air Station, San Diego, California, volunteered their large outdoor fire-test facilities and cooperative manpower assistance.

It can readily be appreciated that a comparison of Light Water capabilities against protein foam capabilities involved many possible combinations of Light Water application, and thus a complex series of tests. Much of this comparative testing had been done on small and intermediate-size fires, but actual data were still needed from large, full-scale fires in the open. Application rates were to be held as nearly the same as possible for all agents and techniques. The variations of Light Water selected for these tests were:

1. Potassium bicarbonate dry chemical and Light Water "blown" with Refrigerant-12 in twinned, high-flow discharge

2. Light Water "blown" with Refrigerant-12

3. Light Water from a foam pump

4. Light Water from an air aspirating foam nozzle.

Test Criteria

As with most problems as complex as the aircraft rescue and fire-fighting one, there are several criteria which can be selected in making a choice of one material over another. The establishment of "control time" of the fire is certainly a primary objective and may be used as one basic criterion. Here a certain level of thermal radiation, percentage diminishment of fire radiation, or percentage of fire area extinguished is selected as representing "control." The time elapsed from start of application of agent until control is judged to be accomplished is recorded as fire-control time. A second criterion is the determination of the minimum critical application rate required for an agent, and its corollary value, the minimum amount of agent per unit of fire area, to control and/or extinguish the fire. The latter concept has always played an important role in the work of NRL in developing and evaluating agents. By comparing data obtained from a series of graduated fire sizes, it is possible to extrapolate to fires of other sizes with a certain degree of confidence.

In addition to the dispatch with which the fire surrounding an aircraft is extinguished, another item of importance is the degree of "permanence" of the extinguishment. The "burnback resistance," or rate of blanket burn-off, has always been held to be important in the eyes of the fire engineers concerned, because they have always presupposed that no aircraft fire will be totally extinguished. Because of the possibilities of exhausting the supply of extinguishing agents on the vehicles, unquenchable magnesium fires, inaccessible fires, or unseen fires, a source of ignition is always assumed present. Thus, it is required that the fuel-blanketing cover of foam contain these remaining fires for an adequate length of time to permit the fire fighters to accomplish their life-saving mission. The residual fire-containment time is important assuming that no more agent of any type is available for further application. Obviously, the best form of burnback protection is to completely extinguish all fires, leaving no sources of fire to burn back.

No one has really ever tried to define what minimum level of burnback resistance is required for good practice. The NFPA Pamphlet 412 (5), presents one procedure for determining the burnback characteristics of both new and aged foams, but it does not give any guidance as to definite minimum acceptable levels of performance. The whole subject has become more important of late with the introduction of high-capacity dry chemical turrets and Light Water for aircraft fire fighting, because these two agents have properties quite different from the older, more familiar protein foam.

Previously, when protein foam was the chief agent for extinguishing aircraft fires, the burnback resistance or rate of foam-blanket burn-off was a common denominator in all applications. It is still true that the stability or rate of water dropout (measured as 25-percent drainage time) from protein foams greatly influences its ability to resist heat, and the burnback characteristics of protein foams can vary considerably, depending on how they were made (expansion and drainage-time properties). However, these differences are small in comparison to the wide differences between types of agents. At one end of the scale is dry chemical, which has practically a zero burnback resistance, and at the other end is protein foam, which has in general the longest burnback resistance. The decision of what agent is "best" is rendered difficult, when it is realized that the highly sought property of quick fire control has been in an opposite relationship; i.e., dry chemical is very fast and protein foam very slow. Some compromise then must be sought between speed of extinguishment and speed of burnback. It was planned to gather data on the relative burnback characteristics of the agents to be tried at Miramar in order to assist in arriving at the best compromise point for the chosen purpose.

Eliminating the Human Element During Testing

In conducting a series of test fires involving fires of large size, the problem of the human element always must be considered, because of the variable of fire-fighter technique. His methods improve with experience, and he can never do exactly the same thing twice. All this is true even providing one can be so fortunate as to always have the same personnel, a rare occurrence indeed.

Two subseries of tests were made at Miramar in an effort to divorce the human role and isolate the action of the agents. In the first runs the fire area was shaped exactly to conform with the outline of the MB-5 turret ground pattern, making it unnecessary to move the turret to cover the surface. The foam system was run just long enough to achieve the desired degree of radiation reduction. The second series was meant to introduce a dynamic concept, but still divorcing the human variable of placement of agent by moving a nozzle. A larger fire area whose depth coincided with the near and far points of the turret ground pattern was set up and the vehicle driven alongside the fire as it discharged foam. The vehicle speed, and thus the agent application per square foot, was closely controlled by monitoring the vehicle drive-shaft speed by means of an electronic counter.

Scaling Comparisons of Smaller Scale Tests and Other Tests

A considerable number of smaller scale tests have been performed using the same agents as planned for Miramar, and accurate data were available as to minimum application rates, minimum amounts of material required to extinguish, and burnback characteristics. The greatest amount of data were available from a 6-ft-diameter indoor fire test (28 ft^2) with lesser amounts of data from 20 × 20 ft fires (400 ft^2) and 40-ft-diameter fires (1250 ft^2). These data plus those from Miramar presented a good opportunity to observe scaling factors and construct a base for extrapolation to even larger fire areas.

In addition to the smaller fires for comparative data, other large-scale fire-test programs have been conducted by the Federal Aviation Agency at the National Aviation Facilities Experimental Center in Atlantic City and the Fire Research Station at Stansted Airfield in England. The latter program was aimed primarily toward determining optimum foam properties (in the manner of work reported in 1952 in NRL Memo. Rept. 92), but three large-scale test plans conducted almost concurrently offered a unique chance to observe results from three independent sources.

TEST FACILITIES

Equipment

An MB-5 aircraft fire and rescue vehicle, USN No. 71-01052, was used in all tests requiring the foam-pump system. This vehicle had been converted from its original configuration to one of a gas-turbine engine prime mover with a drive train which permitted independent vehicle operation while using the foam-pump system. The unit's characteristics had been thoroughly checked out during its experimental development program. These were reported in NRL Report 6309 (6). The turret discharge rate was 250 gpm of 6-percent protein foam solution or 6-percent Light Water solution. A handline with a aspirating foam-maker nozzle of 30 gpm flow was available, as was a dry chemical handline of a nominal 4 pps flow (150 lb total capacity).

Foam analyses were made on the output of the MB-5 in accordance with the procedures of Ref. 5 with the following results:

	Expansion	Drain Time (min)	Concentration (percent)
Turret Nozzle - Protein Foam	11.8	34	6.0
Turret Nozzle - Light Water	8.4	3	5.5
Handline Nozzle - Protein Foam	9.0	6.9	7.0
Handline Nozzle - Light Water	7.0	1.5	7.0

The difference in the foam quality between protein and Light Water made in the same equipment is evident. Earlier experimentation with added baffles at the foam-pump outlet had increased the internal pump mixing pressure from 10 psi to 40 psi; however, the increase in expansion and drainage time was very small, and the MB-5 foam system as used at Miramar was the standard system as employed in all MB-5's. Figure 8 shows the vehicle with the forward-mounted discharge nozzle.

The O6X vehicle used was an experimental device of special design built strictly as an extension of the much smaller Twinned Agent Unit. The twin turret discharges approximately equal rates by weight of Purple-K-Powder (P-K-P) and Light Water: 32 pounds per second of P-K-P; 180 gpm (25 pounds per second) Light Water. The Light Water foam was blown by Refrigerant-12 in order to make a more stable foam, but analysis of the output showed it to be only of expansion seven and drainage time of about one minute. In addition to the twin turret, with individual shut-off valves for each agent, there were two twin handlines, each being identical to the handline from the TAU: P-K-P rate 4 pps and Light Water 50 gpm. Total agent capacity of the vehicle was 2500 lb P-K-P and 300 gal of premixed Light Water solution. Figure 9 is an overall view of the right-hand side of the O6X. The P-K-P container can be seen at the rear of the top deck; the Refrigerant container is the light-colored vertical tank in the forward side compartment. Both P-K-P and Light Water were expelled by nitrogen gas pressure provided from a bank of high-pressure cylinders visible in the rear, side-compartment. Figure 10 is a head-on view of the vehicle, showing the mounting of the twin turret. Figure 11 shows the turret from topside, with the yoke handle and the individual valve controls. Figure 12 is a close-up, head-on view of the two turret nozzles. The P-K-P nozzle on the right is essentially a conventional straight-bore nozzle, while the Light Water nozzle was made as a perforated baffle design in an effort to achieve good foam mixing plus a good stream pattern. Considerable effort was devoted toward achieving some degree of matching discharge patterns between the two outlets. Figure 13 shows the twin handline nozzle and the live reel for hose stowage. The Refrigerant-12 storage tank is again visible.

Fig. 8 - MB-5 Class aircraft fire and rescue vehicle converted to use with a gas turbine engine and new drive train, allowing vehicle movement while pumping foam

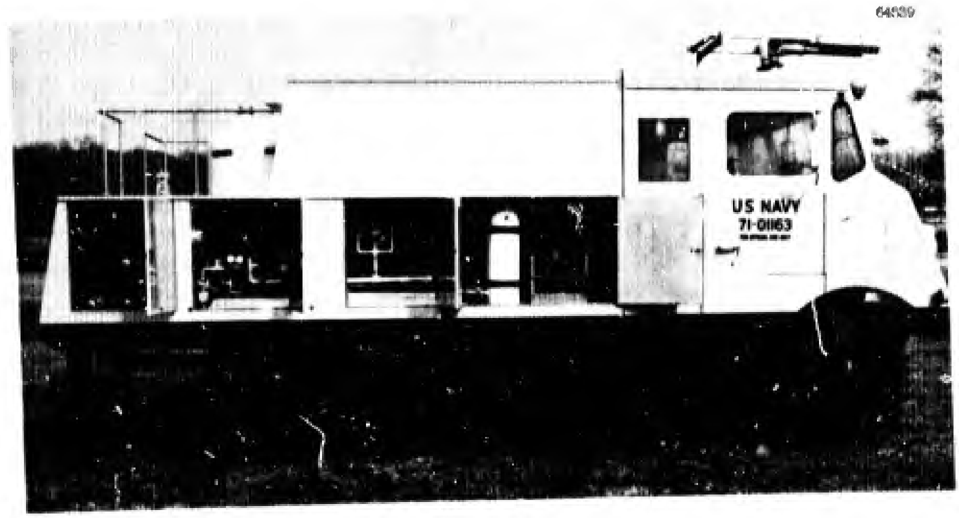


Fig. 9 - O6X experimental vehicle, having a total agent capacity of 2500 lb P-K-P and 300 gal of premixed Light Water solution

Fig. 10 - Front view of O6X experimental vehicle, showing mounting of the twinned-agent turret

The requirements for a device for applying the Light Water in air-aspirated form were for a high-drainage-time foam maker discharging a dispersed pattern with a flow capacity of 180 gpm with 100 psi pressure. These requirements were to permit use of the nozzle on the O6X turret mounting, where it could be supplied with a premix solution and match the flow rate of the nozzle which used the Refrigerant-12. The nozzle unit finally selected as being closest to meeting the requirements was an experimental one. It was built as a conventional, long-barreled foam nozzle and provided with two movable deflectors at the outlet to form a flat, fish-tail-shaped pattern when desired. The actual flow rate was 187 gpm at 100 psi pressure. Operating with Light Water solution, the foam expansion produced was 7.8 and the drainage time 0.5 min.

Materials

The protein foam concentrate used in all tests was that meeting Federal Specification O-F-555b and was taken from Naval supply system stocks.

The Light Water concentrate was a 6-percent type designated as FC-194, manufactured by the 3M Co. of St. Paul, Minnesota. The particular liquids used came from manufacturing lots 13 and 14. It was charged into the MB-5 concentrate tank and used in the proportioning system exactly in the manner of the protein concentrate without vehicle modifications. In fact, the Light Water and protein concentrates were constantly being interchanged to accommodate the testing pattern of agents.

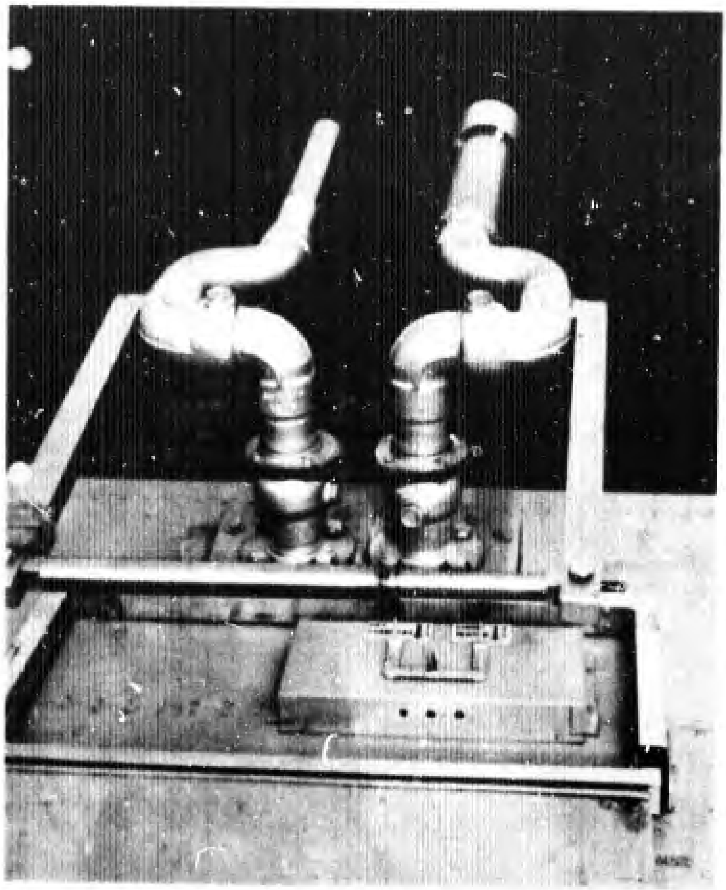


Fig. 11 - Topside view of twinned-agent turret assembly, with a yoke handle and individual agent valve controls on the O6X experimental vehicle

The jet fuel used was the military grade JP-5, NATO symbol F-44. Chemical and physical requirements for this fuel are given in Military Specification MIL-J-5624F. This fuel grade is classified as being of the high-flashpoint, kerosene type and is required to have a flash point no lower than 140°F. Minimum initial boiling point is 400°F, and maximum distillation end point 550°F.

The gasoline fuel used was aviation gasoline of the 115/145 grade. Chemical and physical requirements for this fuel are given in Military Specification MIL-G-5572D. All military avgas grades have the same properties, except for the antiknock ratings, and the dye and lead content. The initial 10 percent of volume must boil below 167°F, and the end point of distillation maximum temperature is 338°F. Reid vapor pressure is between 5.5 and 7.0 psi at 100°F.

The burning rate of kerosene type jet fuels from large spill areas is approximately 0.08 gal/ft^2/min (7). This is equivalent to burning 0.128 in. of depth per minute. In fuel-burning studies made at NRL this rate has been confirmed; however, it takes a preburn time of several minutes to reach this rate. Avgas burns at a slightly higher rate, 0.095 gal/min/ft^2 (0.152 in./min), and significantly it reaches this rate immediately upon ignition. Amounts of fuel for the Miramar fires were chosen to provide a full-intensity fire of approximately three to four minutes, with extra fuel allowance made for imperfect leveling of the fuel bed. It was desired to minimize the water layer beneath the fuel, so fuel was used to do some of the leveling. A full water bed beneath the fuel

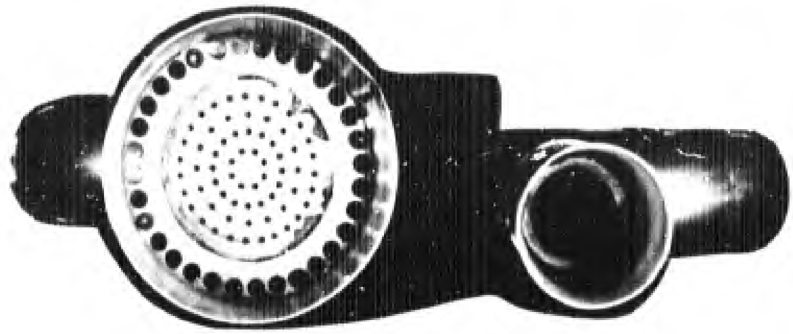


Fig. 12 - Close-up view of the two turret nozzles mounted on the O6X experimental vehicle. The 180-gpm Light Water nozzle has the perforated plate, and the 32-pps P-K-P nozzle has a straight through bore.

Fig. 13 - The twinned-agent, one-man handline nozzle assembly with live hose reel shown mounted on side of O6X experimental vehicle

makes it subject to easy surface displacement by wind and agent application. The fueling schedule for the various size fires is given in Table 1.

Fuel temperatures at time of ignition varied from 80° to 99°F. Water temperatures in the tanks of the MB-5 varied from 76° to 83°F. Air temperatures varied from 70° to 84°F. Weather conditions in the San Diego area in July are almost ideal, with constantly clear skies, moderate temperatures, and fairly consistent wind direction at a moderate five knots velocity after 1000 hours.

Table 1
Fueling Characteristics of Large Area Fires

Fire Diam. (ft)	Fire Area (ft^2)	Fuel Volume (gal)	Fuel Density (gal/ft^2)	Avg. Fuel Depth (in.)
30	700	300	0.425	0.68
42.5	1400	500	0.358	0.57
75	4400	1400	0.320	0.51
106	9000	3800	0.422	0.68

Test Site

A large working area was graded as level as possible on a heavy clay site. Once this soil had been thoroughly wetted with water it became impervious to permeation by the fuels. The individual fire pits were made within this working area as desired by raising earthen dikes about four inches high. After each dike had been completed, the interior area was further leveled and smoothed by the firemen using shovels and large squeegee boards. Sand was added as fill material as required for the low spots revealed by flooding with water. At the conclusion of each test, the foam-fuel residue was flushed from the pit toward a drainage ditch at one edge. Further use of squeegee boards insured a clean pit before fueling for the succeeding test.

In order to provide as much comparability as possible between the data at Miramar and that from FAA tests, an obstacle of a similar type was placed in the center of the pit (7). This obstacle introduced a source of hot metal and also created a shadowed area for flames and a bare fuel surface. The obstacle was formed by welding nine steel 55-gal drums end to end in the form of a cross lying horizontally. With the exception of the first tests, which were designed to eliminate the human element, all fires were run on circular areas with the obstacle. Figure 14 is an overall view of a typical test arrangement.

Fig. 14 - Overall view of a typical test site arrangement. Nine steel 55-gal drums welded together in the form of a cross were used as an obstacle in the center of the test area. The timing clock is located in the foreground. The radiometer set-up is shown at the near right edge of the test area.

Instrumentation

In providing the instrumentation for the Miramar tests, it was again planned to work along the lines of the FAA arrangement. Their previous test program had proven the Heat Technology Laboratory radiometers to be satisfactory for large-scale fire testing, and two similar radiometers were purchased from the same source for the Miramar tests.* This model has a sapphire window to protect the sensor and is constructed to read radiant energy and not convective heat input. Connections were made to the rear of the instrument to provide a gas purge supply to flush the front of the window and prevent it from becoming sooted-up, and to provide a cooling water supply for the heat sink. The radiometer had an electrical output signal of 10 mV when exposed to a radiation flux of 30 Btu/ft^2/sec. Each unit had a conical field of view of 90 degrees, and for each fire they were positioned 9 ft above the ground and aimed toward the fire pattern so as to fill the cone of reception with the flames insofar as possible. Figure 15 is a close-up view of the radiometer and its mounting on a pipe stand.

A second type of radiometer was also used during the tests. This unit, a Honeywell "Radiamatic," was of the thermopile type with a lens system to provide a narrow-angle field. This latter feature enabled it to be located a great distance back from the fire and thus eliminate many of the problems of running electrical leads and other services into the fire zone.

A portable wind speed and direction station capable of transmitting appropriate electrical signals to a dc recorder was set up near the fire. The two elements are shown in Fig. 16. A continuous record of wind velocity and direction was made throughout each fire test.

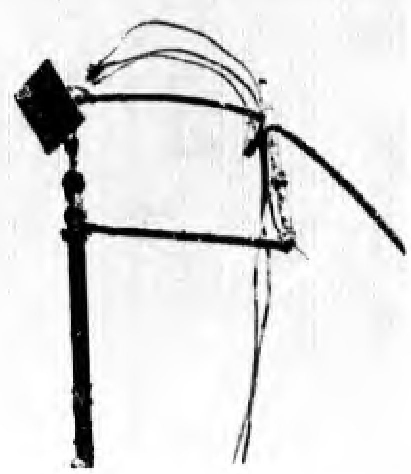


Fig. 15 - Close-up view of the radiometer and its pipe-stand mounting Pick-up unit required gas purging for window and water cooling of heat sink.

Fig. 16 - Overall view of portable wind-speed and direction instrumentation which fed into master recorder

The outputs of all primary elements of the instruments were fed into appropriate amplifiers and then into a Honeywell "Visicorder" multichannel oscillograph. The adjustment provided through the amplifiers made it possible to obtain full chart-width

*Heat Technology Laboratory, Inc., Huntsville, Alabama; model GRW 3072 PT.

deflection for each signal for the level being received on each transducer. For example, the maximum signal of the radiometer was 10 mV output for a radiation level of 30 Btu/ft^2/sec, but the maximum radiation output of a freely burning spill fire is only about 3 Btu/ft^2/sec, or 3 mV output. By increasing the gain in the amplifier, the tracing on the recorder chart could be moved all the way across the six-inch chart width for this amount of radiation flux. This step made for maximum ease and accuracy in reading out the results of each test. Chart speed during the fires was 1 in./sec. Six channels were recorded simultaneously during the fires: wind direction, wind speed, fuel temperature and the three radiometers outputs. The instrumentation center as set up in a trailer is shown in Fig. 17. A typical section of Visicorder chart with the six traces is shown in Fig. 18.

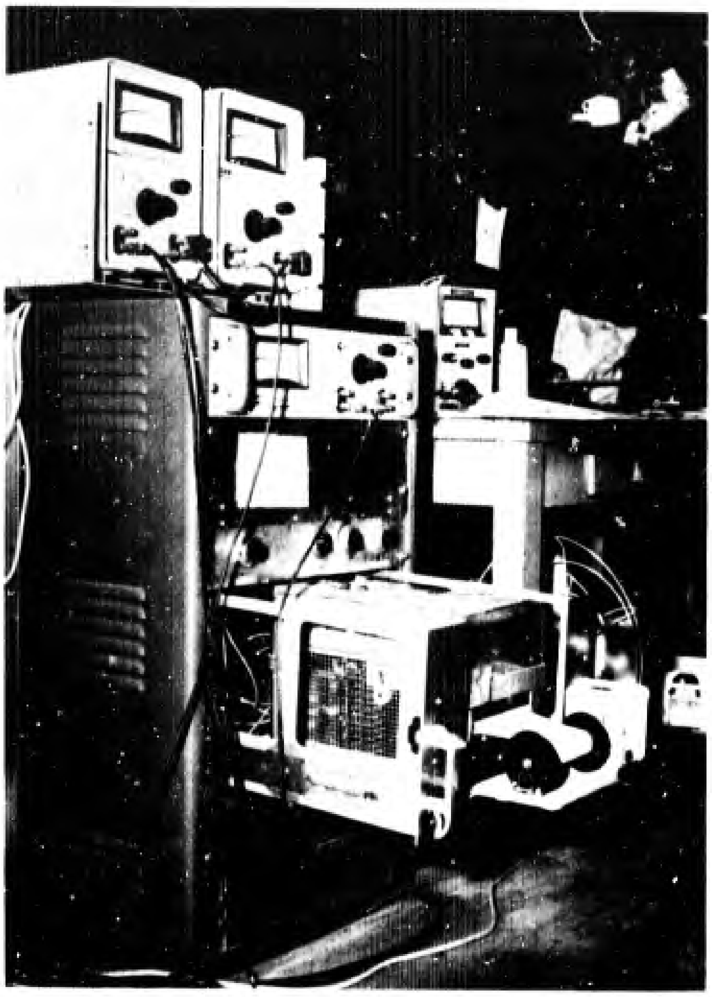
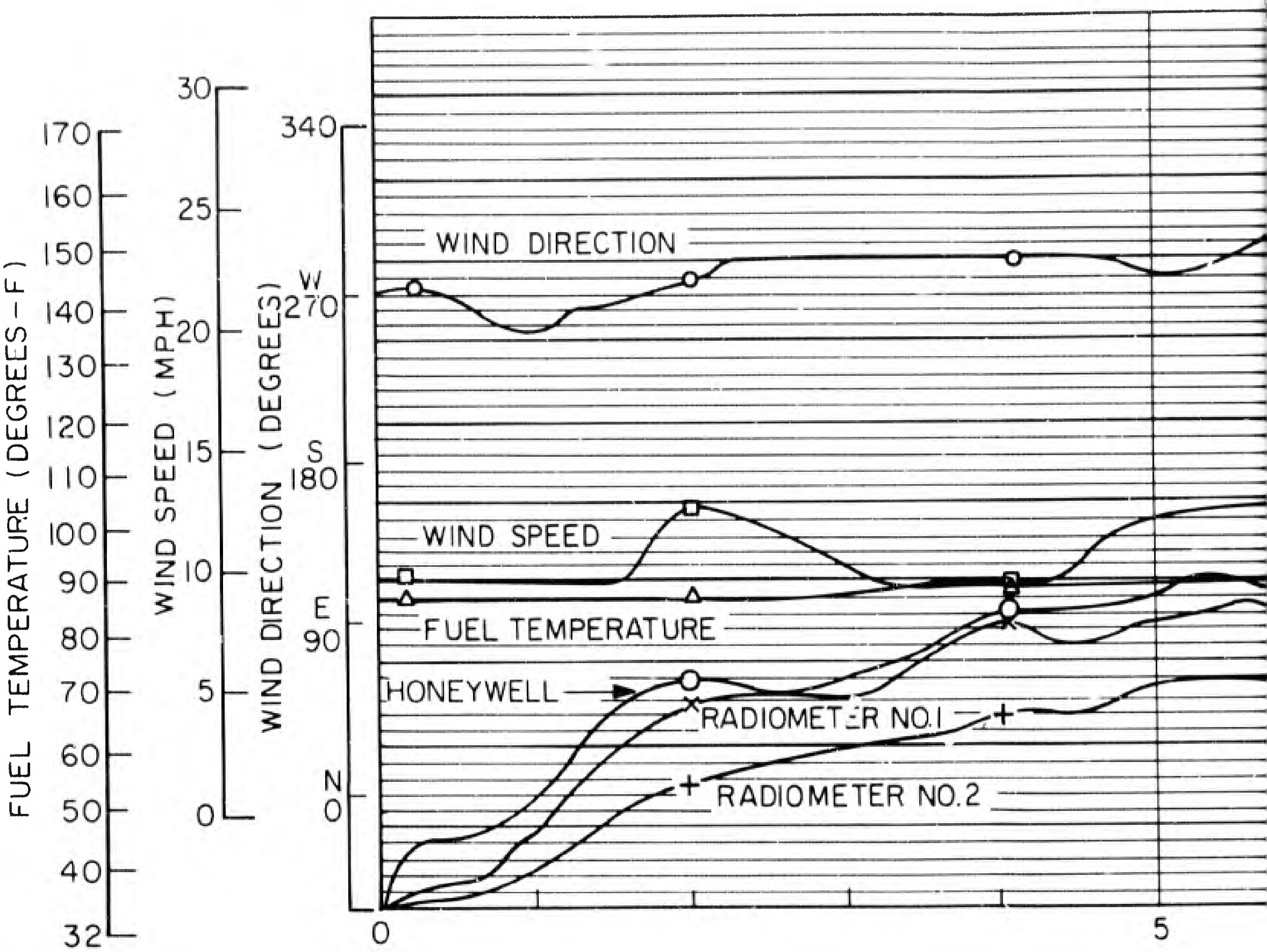


Fig. 17 - The instrumentation center, mounted in a trailer near the fire test area

Photographic Coverage

A 16-mm motion picture camera was located on an elevated platform in order to obtain a continuous photographic coverage of each fire. The camera was electrically driven and used 400-ft film magazines. A zoom lens made it possible to include full-width fire coverage at the start of each extinguishment and still obtain close-up details of areas of special interest as the extinguishing process progressed. The camera was usually



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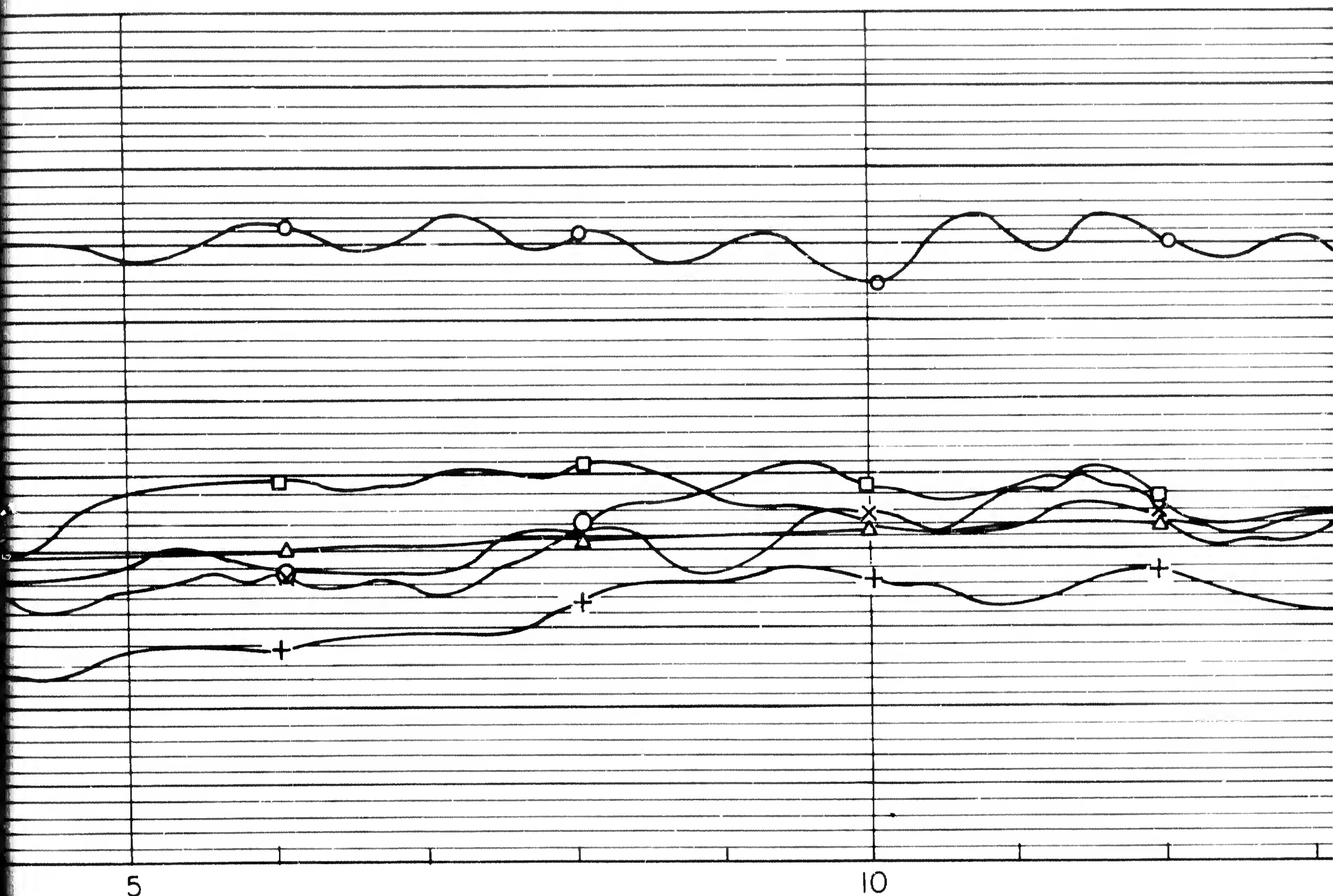

Fig. 18 - Reproduction of data recording obtained on Visicorder oscill
and Honeywell radiometer - smalle

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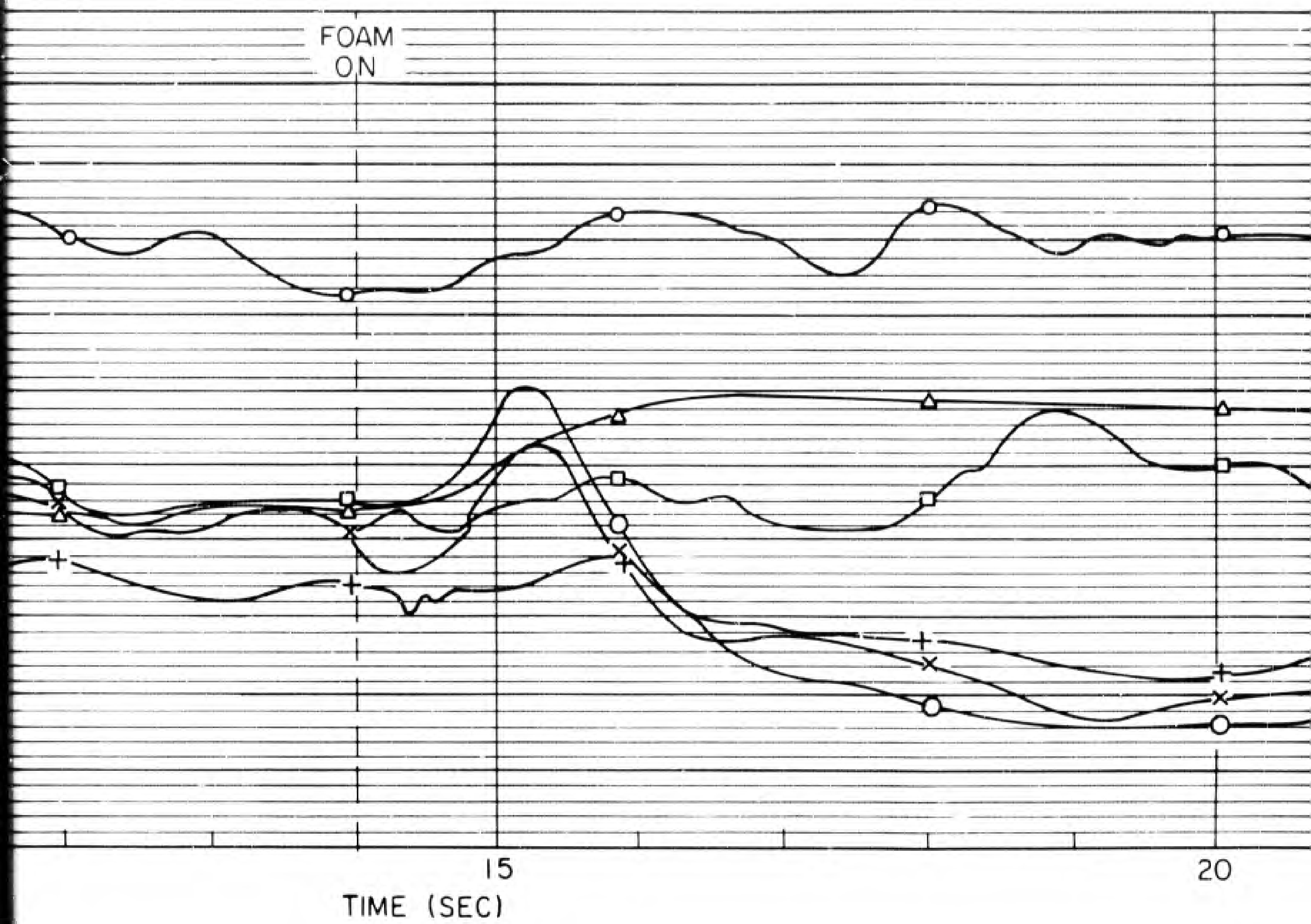

d on Visicorder oscillograph: Fuel temperature - smallest scale division equals 2.66°F; radiometers 1 and 2,
l radiometer - smallest scale division equals 0.06 in V, or 0.16 Btu/ft²/sec

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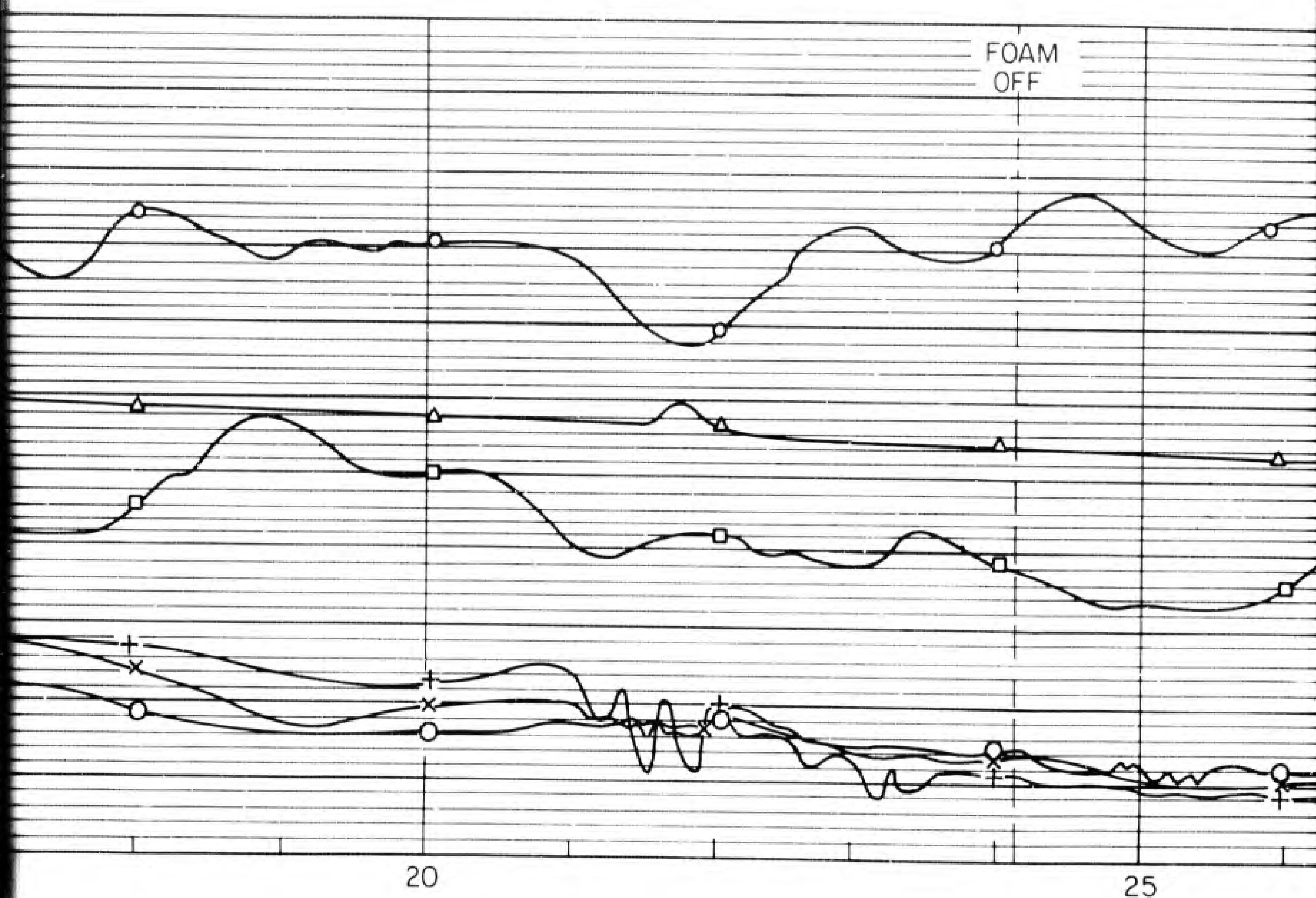

2.66°F; radiometers 1 and 2,

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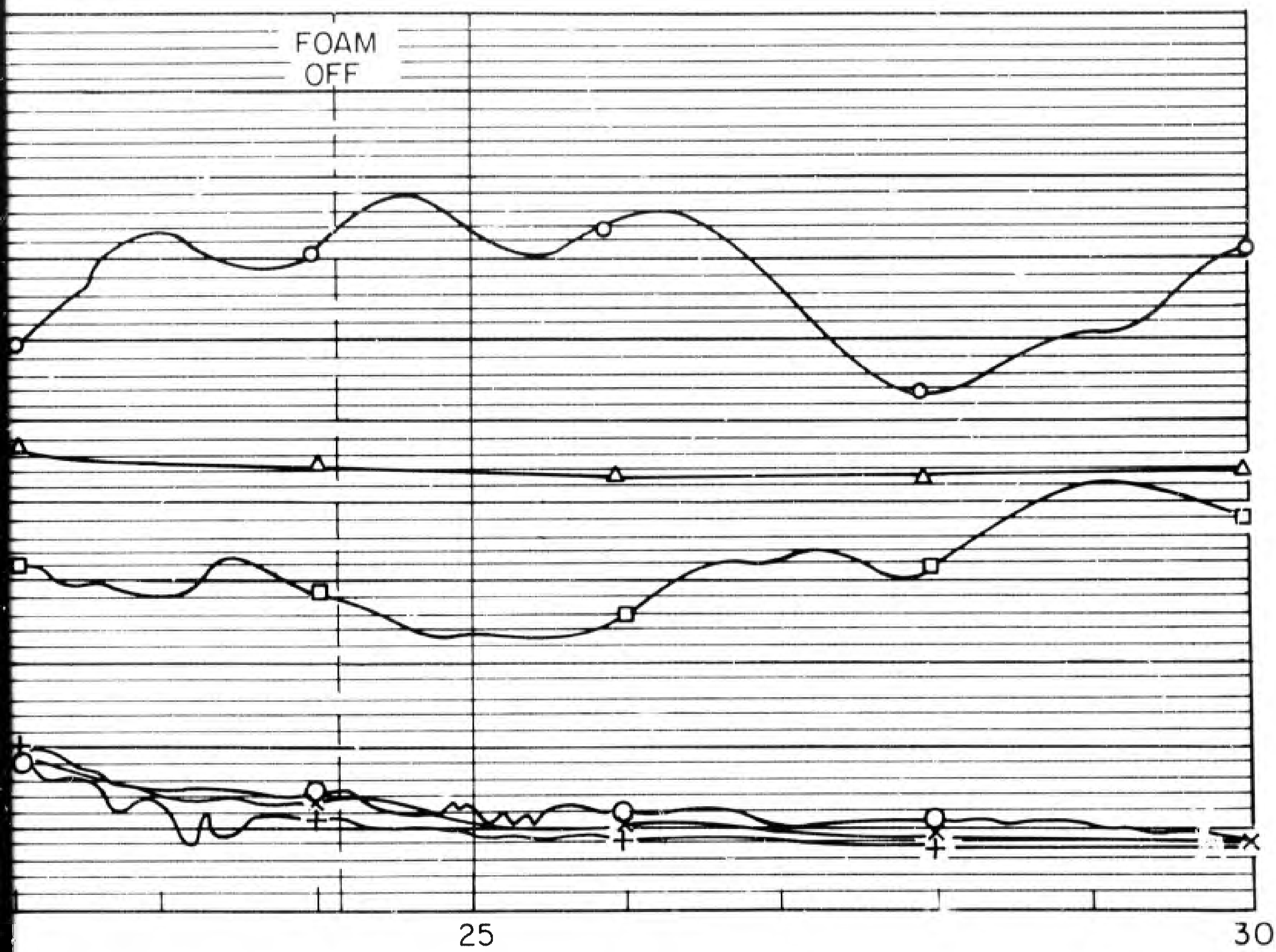

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located about 45 degrees off the upwind point of the fire area to minimize obscuration from both the smoke and the fire-fighting vehicle. The timer was kept within the field of view during the extinguishment and as much as possible during all other periods.

A 70-mm Hulser still camera was located adjacent to the movie camera, where it could be started by the same operator. This camera automatically shoots a series of still pictures on a 100-ft-long roll of film at predetermined timed intervals. For these tests the exposures were made every two seconds.

All photographic recording was done with color film. The motion picture film was Ektachrome Commercial and the still film Ektacolor S.

Visual Observation

An observer with a portable tape recorder made a tape record of all events during each fire test. During extinguishment, he made running estimates of the amount of fire area extinguished, using the master timer or a stop watch synchronized to the same time base. At the conclusion of each fire the comments of other participants in the test were also recorded.

Timer

The perennial problem of getting a readable time scale on the photographic record was solved for these tests by purchasing an electrical digital timer and scoreboard as used for sports events. The 18-in.-tall digits, configured with light bulbs, read out time by seconds to a total of 60 minutes. A second cluster of similar lighted digits, normally used for indicating score, was utilized to indicate the fire-test number. The time could be started, stopped, and reset, and the test number set by means of a portable, remote-control box on a 200-ft-long cable. The large size of the numbers made it possible to locate the timer a safe distance back from the heat of fire and still be readable in the field of view of the cameras.

The procedures for starting the clock for zero time varied somewhat over the testing period. When using avgas as a fuel, the spread of flame was very rapid. There was no appreciable lag between ignition, and full fire intensity and the clock was started upon ignition. However, with the jet fuel the flame spread was very slow, and the preburn time period was started only after the entire pit was aflame. In some of the jet-fuel fires the clock was started at ignition, and some on 100-percent flame coverage. All timing of events for all observers and instrumentation was based on this master timer.

FIRE-TEST DATA

Small-Scale Fires

The smallest scale fire tests run for the purpose of obtaining data for Light Water have been done on an indoor 28-ft^2 steel pan, 6 ft in diameter, and 4 in. in depth. The foam applied was from a special air-aspirating nozzle with a liquid-flow capacity of 2.0 gpm at 100 psig nozzle pressure. It was one of a type designed by National Foam System Inc. to simulate the standard 6-gpm test nozzle used for protein foam in Federal Specification O-F-555, in order to permit foam testing on a smaller scale. The straight stream discharge from the nozzle was directed across the fire pan against a low backboard and allowed to flow back across the fuel surface in the same manner as in the 10 × 10 ft specification test. This type of foam application intentionally did not represent the spray application normally used in aircraft fire fighting, because it was desired to have a fire test which would reflect wider usage than just aircraft fires. The single-point application was considered to be less efficient than a spray application, based on the amount of agent required to extinguish.

During the application of foam to the fire, an observer made visual estimates as to the rate of extinguishment. (Accumulation of smoke within the enclosure, where ventilation was restricted to reduce wind variables, precluded the use of thermal radiation devices.) Agent application continued at the 0.07-gpm/ft^2 rate until the flames had been completely extinguished. This procedure generated data for evaluating separately the fire knock-down ability, as well as the ability to fuse into a tight fuel covering and seal against hot metal. After extinguishment, an 8-in.-diameter metal pan containing burning gasoline was placed in the center of the 6-ft pan. The time at which fire spread outward over 20 percent of the originally foam-covered fuel was used as a measure of burnback resistance. Because the time required to burn the foam off was in part dependent on the amount of foam required to extinguish the fire, a factor was also computed which gave the minutes of burnback resistance obtainable through application of one gallon of water per square foot of fuel surface. Using the above criteria, many experimental formulations of Light Water were compared to protein foams for their fire performance and dry chemical compatibility.

A summary of averaged values for those tests which were related to those conducted at Miramar on a basis of fuel and agent are given in Table 2:

Table 2
Comparative Performance of Agents on 28 ft^2 Indoor
JP-5 and Gasoline Fires

Fuel	Agent (6% solution)	Water Req'd. to Exting. (gal/ft^2)	Relative fire "Knock-down"*	Burnback Factor (min/gal/ft^2)	Burnback Time (min)
Gas	FC-194	0.130	14	60	8
	Protein	0.286	34	63	18
JP-5	FC-194	0.073	14	110	8
	Protein	0.20	27	115	22

*The relative fire "knock-down" values were determined by first plotting a curve of percentage of fire area remaining against time and then measuring the area under the curve with the aid of a planimeter. The number is the total area in square inches.

Stationary Single Ground Pattern

A short preliminary discharge of foam from the MB-5 turret in its full-spray position elevated 30 degrees above the horizontal served to define the dike location for a maximum size fire area without the necessity of moving the turret. This step was designed to eliminate the human influence and technique of turret manipulation. The fire area was roughly elliptical in shape, with a longitudinal axis of 30 ft and a cross axis of 18 ft, 14 ft distant from the turret. The total fire area was 450 ft^2, which with the turret-flow rate of 250 gpm, resulted in an application rate of 0.56 gpm/ft^2, a relatively high rate. Agent was applied in each case until the fire was judged to be extinguished. The average results, based on at least two fires for each condition, are summarized in Table 3:

Table 3
Comparative Performance of Agents on Single Ground Pattern Fires, 450 ft^2, Application Rate 0.56 gpm/ft^2

Fuel	Agent	Water Density Req'd for Extinguishment (gal/ft^2)
Avgas	Light Water Foam Protein Foam	0.050 0.125
JP-5	Light Water Foam Protein Foam	0.028 0.088

Moving Double Pattern

The second phase of the "dehumanized" fire testing involved making a long, rectangular fire area whose width was the same as the length of the turret pattern used in the previous single pattern test, 30 ft. The length of the new area was 36 ft, twice the width of the previous single pattern. By driving the MB-5 alongside this area while directing the turret out at 90 degrees to the path of travel, the fire could be extinguished in a progressive and dynamic manner, but still free from the element of variable human technique. The forward speed of the vehicle controlled the density of application, and a maximum speed was determined which would just extinguish the area as the foam pattern swept past. The results of these tests are given in Table 4:

Table 4
Comparative Performance of Agents Discharged From a Moving MB-5, 1080 ft^2 Fire Area

Fuel	Agent (6% solution)	Vehicle Speed (ft/sec)	Water Density Req'd for Extinguishment (gal/ft^2)
Avgas	FC-194 Protein	3.0 1.5	0.070 0.142
JP-5	FC-194 Protein	6.8 2.3	0.031 0.093

Large Area Fires

The sizes for the large fires were chosen to provide a wide range of agent application rates, because the inflexibility of the equipment would not permit a varied application rate on a single size fire. It was desired to study the effect of application rate on the amount of agent required for control and extinguishment of the fire, as well as the time it took to control the fire. The areas were selected to approximately double in area, (or halve the application rate) for each step. Tests were continued until it was judged that the maximum area had been reached for the agent application rate and amount of agent available.

The first step toward reducing the data from the fire tests was to convert the millivolt values on the original oscillograph recordings into units of radiation, temperature, etc. A section of original chart from a typical test is shown in Fig. 18.

Variations in wind and other outdoor conditions apparently caused differences in the intensity of radiation before start of agent application. It was believed that the best technique to handle this situation would be to normalize the values for each fire. By this

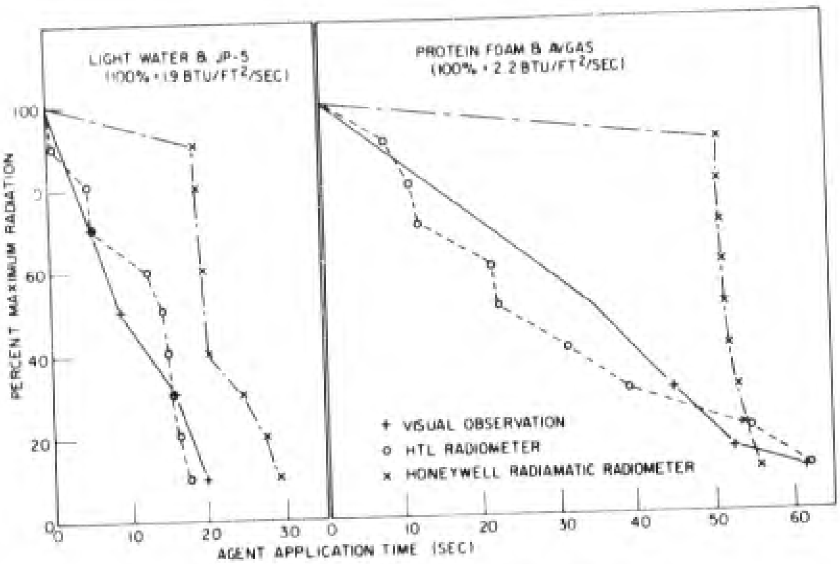

Fig. 19 - Data output from typical test fires, 75 ft diameter, 4400 ft^2

process the extinguishment or decrease in radiation is based on a percentage of the maximum radiation observed at the start of agent application. Control time was then arbitrarily selected as being the time required to attain a level of 10 percent of the maximum radiation level for that particular fire. This is in contrast to a procedure in which control time is chosen to be an arbitrary level of thermal radiation, such as 0.2 Btu/ft^2/sec, regardless of the radiation level observed at the onset of agent application. In order to establish a physiological frame of reference for the thermal radiation level of 0.2 Btu/ft^2/sec, it has been reported that this value mav be tolerated in normal street clothing for about 50 sec before extreme pain would be experienced. After about 200 sec third degree burns would result on the unprotected portions of skin (8).

Figure 19 illustrates and compares the radiation-reduction curves observed from two test fires by the three different types of different sensors; these were typical of the remainder of the tests. A wind-direction change, during an early fire test one of the HTL radiometer was immersed in flames for a period long enough to burn off the electrical connections and render it useless for the remainder of the program.

We have always held that the seriousness of a fire was a function of its size in terms of area. In other words, if a fire originally 100 ft^2 in area was reduced to an area of 10 ft^2 by application of foam, then 90 percent of the fire was extinguished. Theoretically, it is supposed that the thermal radiation emitted would also be proportional to the area of fire. No well-defined attempt has been made to verify this supposition. One instrumentation problem arises, and that is that a fire of Class B nature consists only of visible flame, but a radiometer does not discriminate between thermal radiation from flames, hot metal, earth, or any warm background, and thus ambiguity is introduced into radiometer readouts. Several other observations at Miramar led to questioning the placing of absolute reliance on radiometers. Two of these involved the preburn time between ignition and start of agent application. Originally it was planned to follow the radiation build-up following ignition and apply agent 30 sec after the radiation leveled off at a constant value, indicating full fire. It was found, however, that the radiometer was indicating an equilibrium fire condition even before the fueled area was fully aflame. Also, the radiometers were reading equilibrium fire conditions within about 30 sec of ignition, long before the burning rate could have reached its steady state with JP-5.

A study of the motion-picture record and the time-lapse photographs also revealed that the radiometer readings could be misleading at times as to the amount of fire remaining during extinguishment. An example of this fault was found in test 37. In this instance the diameter of the pit was 75 ft, corresponding to an area of 4400 ft^2. The control point, or 10 percent of initial fire, therefore, would have been a fire of 440 ft^2. A photograph taken at the exact time the radiometer reading indicated 10 percent fire is shown as Fig. 20. Obviously, this fire was not 440 ft^2 in size.

It was concluded that the most significant value for 90-percent control time was one arrived at by making a judgment based on radiometer value, visual observation, motion pictures, and photographic record. In by far of the majority of cases this method presented no problem, because all methods were in good agreement. Only in a few isolated cases was either the radiometer or visual method found to have wide variation. A similar composite best value was also arrived at for fire-extinguishment time. This latter figure called for more judgment than selecting the control time, because a variety of techniques and agents were experimented with to extinguish the fire once control had been established. Table 5 summarizes the data derived from the large area fires.

Fire Tests Using Light Water and Purple-K-Powder Applied Simultaneously

The fire test made on the 75-ft-diameter area indicated poor total range and narrow pattern spread of foam from the Light Water turret nozzle on the O6X vehicle. For this reason the final combined-agent test was conducted using the Light Water turret on the MB-5 vehicle in combination with the dry chemical turret nozzle on the O6X, with the two vehicles pulled up alongside each other at the edge of the fire. The two turret operators attempted to work to best advantage with each other in progressively extinguishing an avgas fire. The following results were obtained:

	LW	PKP
Agent Discharge Rate:	250 gpm	32 lb/sec
Application Rate:	0.056 gal/min/ft^2	0.0073 lb/sec/ft^2
Application Time, sec:	48	26
Control Time, sec:	20	20
Exting. Time, sec:	48	48
Total Agent Used, Control:	0.019 gal/ft^2	0.15 lb/ft^2
Exting.:	0.045	0.19
Combined Total Agent Used, Control:	0.308 lb/ft^2	
Exting.:	0.565 lb/ft^2	

"Burnback" Resistance of Agent to Reignition

No formal procedure for quantitatively evaluating the "burnback" of the two foaming agents was evolved during the test period. The wide variations in the size and location of fires remaining after turret application of agent made it impractical to use a "natural" starting point for a burnback test. At the conclusion of each fire involving Light Water, the fuel surface was probed with a torch to determine the resistance of the foam blanket to ignition, and subsequently the rate of spread of fire across or into the blanket was evaluated by qualitative observation.

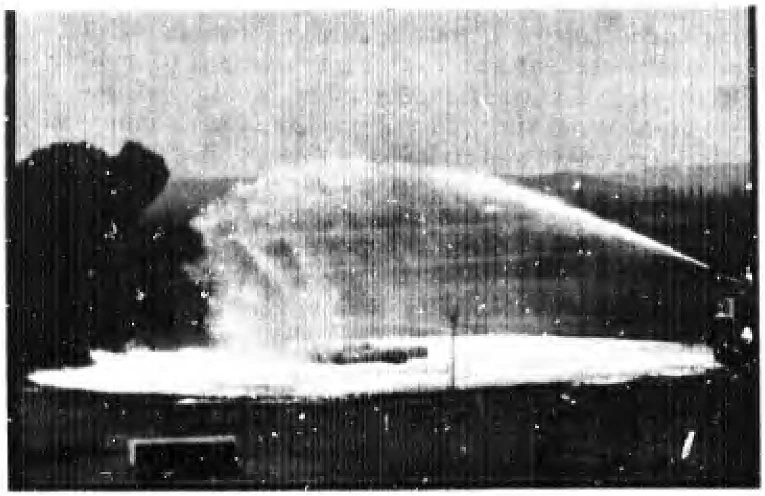

Fig. 20 - Progress of fire extinguishment—at this point a visual estimate of percent remaining fire was 3 percent (130 ft^2), while the radiation level indicated by the radiometer was 10 percent (440 ft^2).

Table 5
Control and Extinguishment Times for Large Area Fires

Fire Size		Agent	Application Rate	Fuel	Control Time	Exting. Time	Amount of Agent	
Diam. (ft)	Area (ft^2)		(gal/min/ft^2)		(sec)	(sec)	Control (gal/ft^2)	Exting. (gal/ft^2)
30	700	LW	0.36	Avgas	9	11	0.053	0.065
		Prot	0.36	Avgas	12	22	0.071	0.240
		LW	0.36	JP-5	6	9	0.035	0.047
		Prot	0.36	JP-5	9	14	0.053	0.083
42.5	1400	Prot	0.177	JP-5	12	(1)	0.035	(1)
		LW	0.177	JP-5	8	(1)	0.024	(1)
		LW	0.177	JP-5	9	15	0.027	0.044
		Prot	0.177	JP-5	10	15	0.029	0.044
		Prot	0.177	Avgas	22	46	0.065	0.135
		LW	0.177	Avgas	14	20	0.041	0.059
75	4400	LW	0.057	JP-5	18	29	0.017	0.026
		Prot	0.057	JP-5	25	55	0.024	0.052
		LW	0.057	Avgas	19	37	0.018	0.035
		Prot	0.057	Avgas	57	90	0.054	0.085
		LW	0.043(2)	JP-5	44	65	0.030	0.044
		LW	0.041(3)	Avgas	38	65	0.026	0.044
106	9000	LW	0.028	JP-5	37	75	0.017	0.035
		Prot	0.028	JP-5	42	90	0.020	0.043
		LW	0.021(2)	JP-5	46	91	0.016	0.031

Notes:
1. Unorthodox technique for extinguishing did not produce comparable results.
2. Rockwood aspirating nozzle.
3. O6X nozzle with Refrigerant-12.

DISCUSSION

Small-Scale Fire Results

Examining the results of the small-scale fire data shown in Table 2, it is first seen that Light Water had the same fire "knockdown" characteristic, or speed of initial fire suppression, on gasoline, 14, that it did on JP-5. However, nearly twice the amount of Light Water agent, 0.073 to 0.13 gal/ft^2, was required to achieve complete extinguishment of the lower-flashpoint gasoline. This increase occurred because of the difficulty in extinguishing the small, isolated, flickering fires which persisted around the hot metal sides of the pan. This is characteristic of low-flash point fuels. The burnback times for Light Water were the same on both fuels (eight minutes), but the burnback factor was considerably higher with JP-5, 110 compared to 60, because much less water had been applied.

Protein foam both knocked down and extinguished the JP-5 fire somewhat more easily than the gasoline fire but not with as large differences as were found with Light Water. Apparently the fuel volatility was not as influential in the case of protein foam. The burnback factor with JP-5 (115) was twice that on gasoline (63).

In comparing the two fuels on all three criteria of fire knockdown, extinguishment, and burnback, it was judged that the JP-5 was an easier fuel to cope with than gasoline. The greatest difference was in burnback and the least difference in fire knockdown.

In comparing the two agents, it may be seen that Light Water had twice the fire-knockdown capability (14 to 27), and three times in density the advantage over protein (0.073 to 0.20 gal/ft^2), in extinguishing the fire when used on JP-5 fuel. When using gasoline as the fuel, the knockdown capability advantage remained at twice as fast for Light Water; however, the comparative density advantage in extinguishing decreased from 3 to 1 for JP-5 to 2 to 1 for gasoline. The Light Water and protein foam were equal in burnback factor on both fuels, although the burnback times were considerably longer for the protein foam. By way of summary, then, in small-scale fire tests, Light Water was found to be twice or more as effective as protein foam. It was also concluded that Light Water did not demonstrate any greater weakness than protein foam in forming a fuel-vapor-tight seal against the hot metal sides of the test pan.

Stationary Single Ground Pattern, Field Fire Tests

The water-application densities required to extinguish these fires were summarized in Table 3. It is seen that almost twice as much Light Water was required to extinguish the fire when using avgas as the fuel as when using JP-5, whereas protein foam required about 30 percent more. Comparing agents, Light Water had a 3-to-1 superiority over protein on JP-5 and a 2.5-to-1 superiority on avgas in application density.

Although the ratios of superiority of Light Water over protein foam were preserved in moving up in fire area from the small-scale 28 ft^2 fire to the 450 ft^2 fire, the agent application density requirements were reduced to approximately 40 percent. The turret spray pattern of agent application in the larger fire was undoubtedly more efficient than the straight stream used in the small test fire, but it was surprising that the "mass action" of the larger fire did not more than offset this factor. The metal pan used in the small-scale fire was probably an additional factor in increasing the agent requirement.

Moving-Pattern Fire Results, Field Fire Tests

The water-density values for extinguishing the moving-pattern fires are summarized in Table 4. Here again the Light Water showed a 2-to-1 superiority over protein foam on avgas and a 3-to-1 superiority on JP-5 fuel. Thus, the relative ratios were preserved exactly from the 28 ft^2 fire, an extension in fire area of 40 times.

All water-application-density requirements were up slightly from those of the stationary ground-pattern fires, possibly because of some wastage at the ends of the fire area.

Large-Area Field Fire Tests

Some explanation is necessary in order to appreciate fully the values presented in Table 5. The "control" data were obtained, as explained previously, by arriving at a 90-percent-extinguished figure by radiometers, visual observation, and/or photographic coverage. (In almost all test fires the 90-percent-extinguished level represented a radiation level of 0.2 Btu/ft^2/sec.) This degree of fire extinguishment was obtained solely through manipulation of the agent from the vehicle turret to the operator's best ability. The vehicle was not moved once it had taken its position and agent application commenced, although the vehicle had the capability of moving and pumping simultaneously.

When 99-100-percent of the fire had been extinguished, the turret was shut down and the 30-gpm foam handline, the 4 lb/sec Purple-K handline, or a 30-lb Purple-K portable extinguisher were brought into play in varied combinations and sequences to extinguish the remaining fire. The exact techniques used varied from fire to fire, according to the desires of the fire fighters and the whim of the test directors to "experiment." In general the secondary means were quite adequate and much more conserving of agent than prolonged turret usage in the "mop-up" phases of fire extinguishment. Usually the amount of agent used for the mop-up was insignificant and was not calculated into the application density for extinguishment. However, in at least one instance, where protein foam was being used on avgas, complete extinguishment was difficult to achieve, and an significant volume of foam was required from the handline. Continued mixing and burning of fuel and foam is a basic problem with protein foam and especially with avgas.

Purple-K was found to be an effective and efficient clean-up or secondary agent, although in some instances a compatibility situation can develop when protein base foam is used as the primary agent.

The values from Table 5 summarizing the large-area tests have been plotted in several different ways in order to make the comparison of agents and fuels easier. Figures 21 and 22 afford a comparison of the two agents, Light Water and protein foam, in establishing control of the fires involving JP-5 and avgas fuels respectively. In both figures isogram lines have been drawn in to indicate the multiple relative values for Light Water. For example, in Fig. 21, the isogram labeled "150 percent Light Water" denotes 150 percent of the actual Light Water application density values (50 percent more agent) required to attain 90-percent control of the fire. From the relative positions of the protein-foam curve and the 150-percent Light Water isogram, it is seen the protein foam required slightly under 50 percent more agent on JP-5 fuel at all application rates used.

From Fig. 21 it is immediately evident that as the rate of application was reduced (through the use of increasing fire areas), the application densities of agent required were also reduced for both agents. This again is somewhat surprising, as it is normally expected that the larger fires would require more agent per unit area.

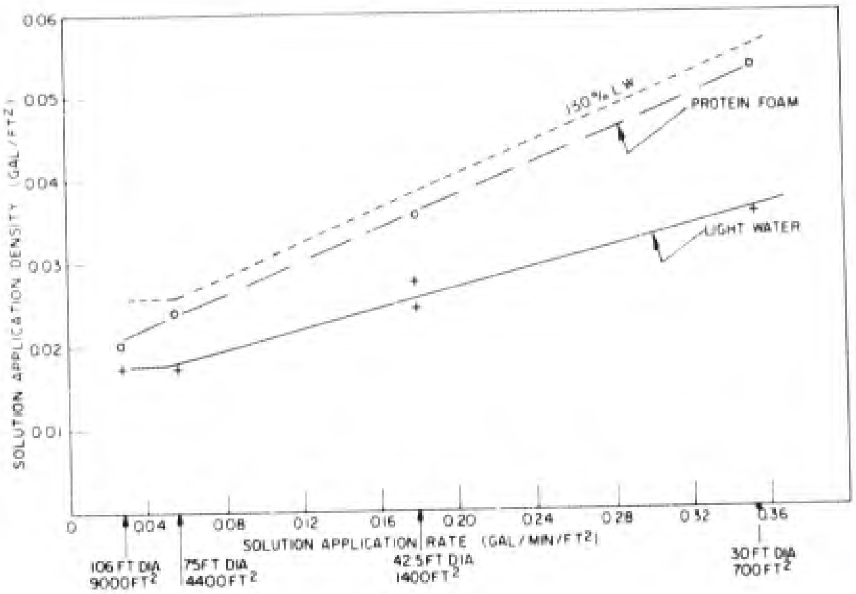

Fig. 21 - Water application density required for fire control with varied application rates on JP-5 fuel

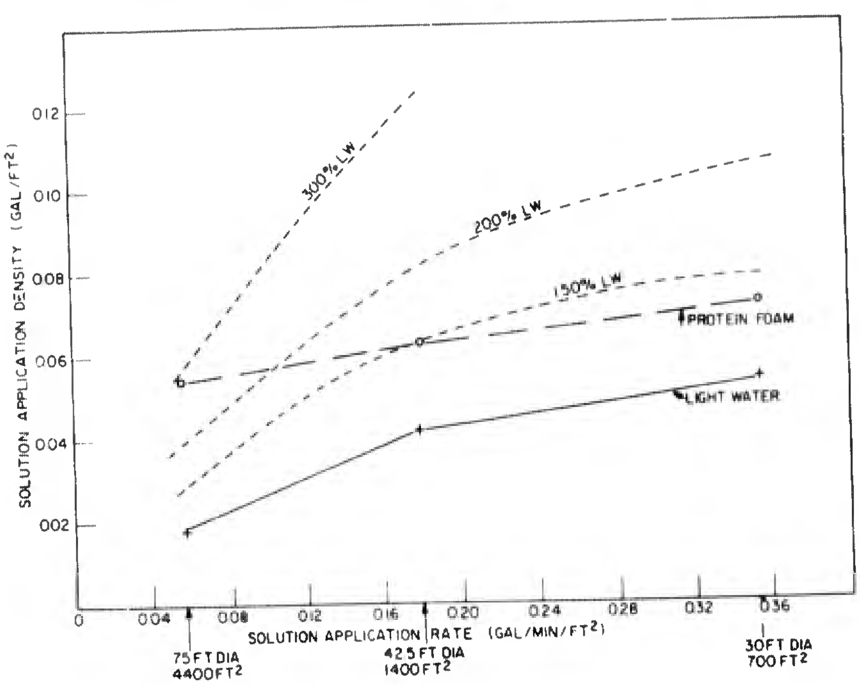

Fig. 22 - Water application density required for fire control with varied application rates on avgas fuel

Referring to Fig. 22, where results on avgas are plotted, it may be observed that the application densities for protein foam did not drop appreciably with the lower application rates. For this reason, the superiority of Light Water over protein gradually increased, so that it required three times as much protein foam to attain fire control at an application rate of 0.057 gal/min/ft^2.

Figure 23 compares the water-application densities of protein foam and Light Water that were required to extinguish the JP-5 test fires. The relationships here are rather irregular; however, in general, protein required about 50 percent more agent, which is the same ratio as for 90-percent fire control previously shown in Fig. 21. In Fig. 24

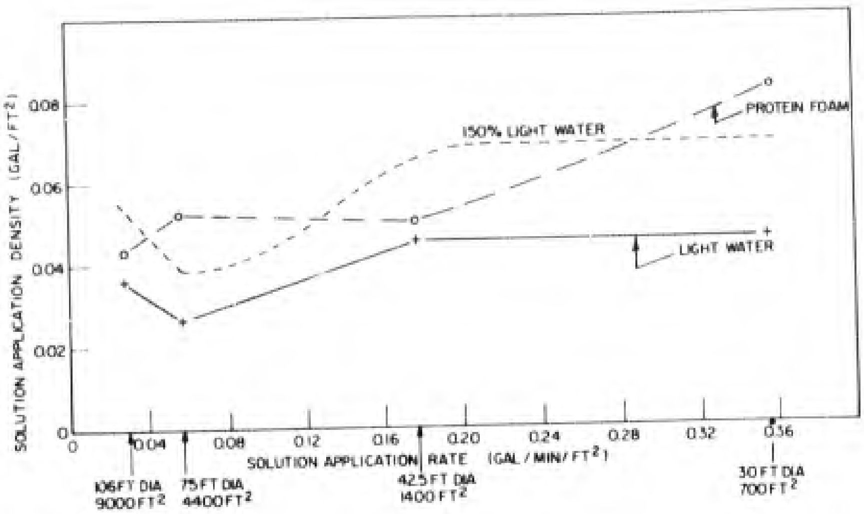

Fig. 23 - Water application density required for fire extinguishment with varied application rates on JP-5 fuel

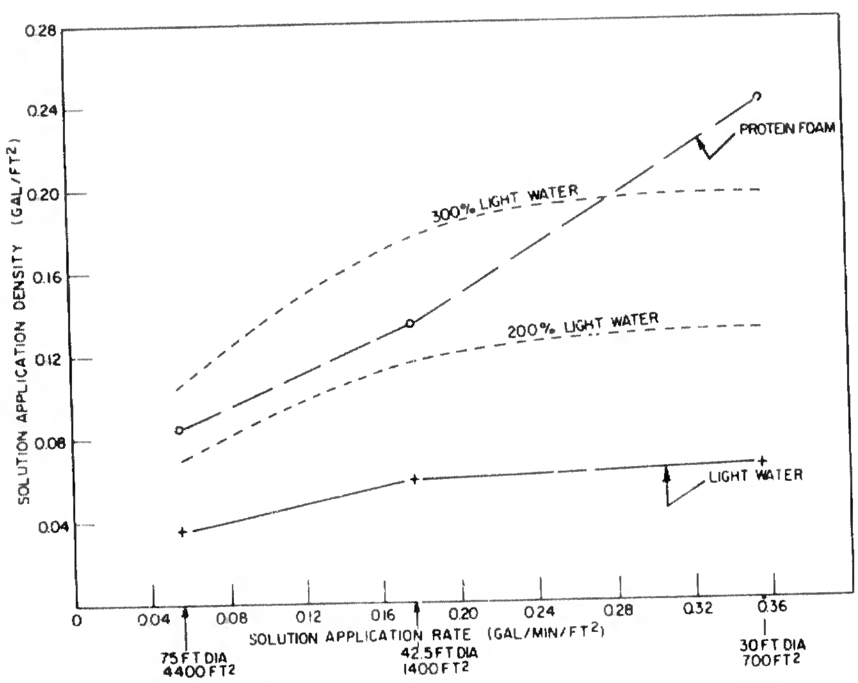

Fig. 24 - Water application density required for fire extinguishment with varied application rates on avgas

comparable values are given for extinguishing avgas fuel fires. Here protein foam was found to require approximately 250 to 350 percent additional water densities than Light Water.

In summary, then, protein foam was found to require water-application densities 50-percent higher than Light Water to control and to extinguish JP-5 fuel fires. When avgas was used as the fuel, protein foam was found to require water-application densities 40 to 300 percent higher than Light Water to control and 250 to 350 percent greater to extinguish. The wide range of variation found with avgas occurs with different rates of application.

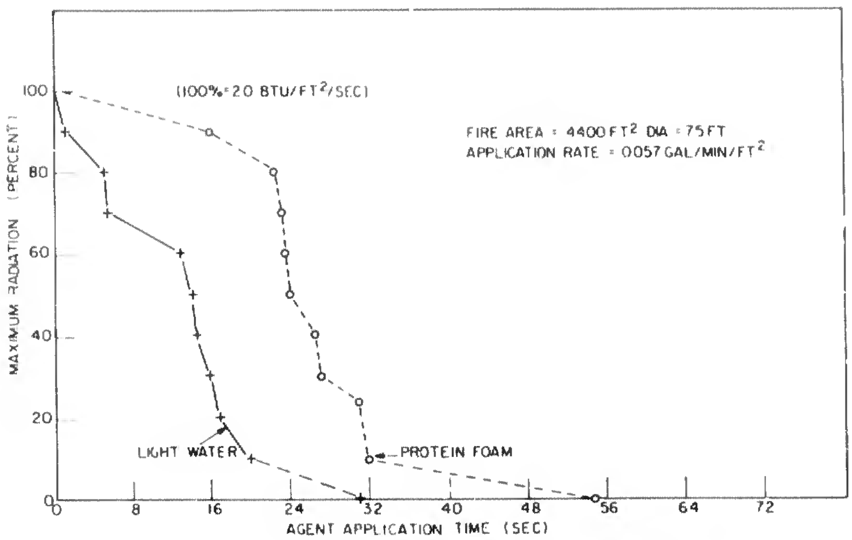

Fig. 25 - Thermal radiation during extinguishment of JP-5 fire by HTL radiometer

Comparing Extinguishment Processes of the Agents Tested

In the observation of fires during their extinguishment, it was obvious that the diminution of flame followed different characteristics. The arbitrary selection of a single point at which a certain reduced radiation level is achieved, such as 0.2 Btu/ft²/sec, 10 percent of the maximum, or some other value, may well represent the time at which rescue proceedings can be safely started. However, the total quantity of thermal radiation generated up to this point is also important to the integrity of the aircraft and its contents. This total quantity is the product of multiplying time by radiation intensity. This is informally referred to as "rate of fire knockdown."

Figure 25 traces the thermal radiation levels recorded by an HTL radiometer during the application of agents to two 4400-ft² JP-5 fires. The vertical scale is given in terms of percent of the maximum radiation intensity recorded before agent application was started. It is seen that the radiation was cut off much more sharply upon the application of Light Water, and when it had achieved a radiation reduction down to 10 percent (0.2 Btu/ft²/sec), protein foam had only achieved an 85-percent level. By determining the areas under such curves with a planimeter, the total radiation emitted during agent application may be expressed and the relative effectiveness of the two agents calculated from the ratio of thermal outputs. From Fig. 25, the thermal output from the fire extinguished with protein foam was 2.2 times that for Light Water. When the agents were compared for effectiveness on a basis of time required to achieve 90-percent fire control, the protein foam required 1.6 times the time of agent application time for Light Water. Thus, the Light Water may be said to have achieved better radiation control than would be indicated by simply considering the time for attaining the single point of 90-percent fire control.

The complete extinguishment times are also noted on the curve, although they were not established by the radiometer but rather by visual observation. On the basis of extinguishing time, the protein foam required 1.7 times as long as the application of Light Water.

The rate of diminution of radiation is seen to decrease rapidly after the 10-percent level had been reached and a disproportionate amount of agent, 60 to 70 percent of that required to extinguish the first 90 percent of fire, was required to complete extinguishment

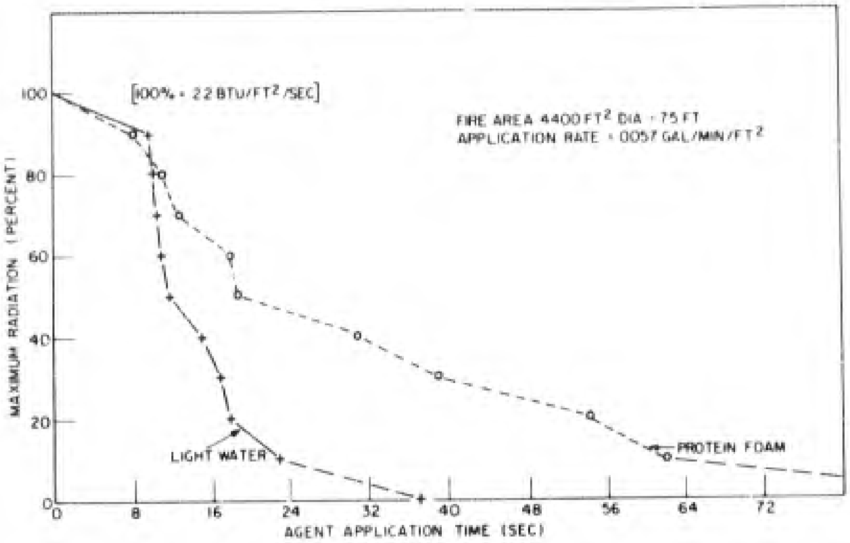

Fig. 26 - Thermal radiation during extinguishment of avgas fire by HTL radiometer

of the last 10 percent of fire. Expressed in another way, 30 to 40 percent of the agent was applied in extinguishing the last 10 percent of the fire. The use of agent from the turret becomes very inefficient toward the end and serves mainly to agitate the fuel and foam rather than form a coherent, sealing blanket.

Comparable radiation-reduction curves for two avgas fires are given in Fig. 26. In this particular test the total heat release down to 90-percent fire control with protein foam was 2.0 times that for Light Water. The agent application time to the 90-percent fire-control point for protein foam was 2.7 times that for Light Water, and agent application time to complete extinguishment for protein foam was 2.4 times that for Light Water. Again, approximately 40 percent of the agent applied was used to extinguish the final 10 percent of fire area.

The Role of Fuel

Data from Table 5 have been extracted and plotted in Figs. 27, 28, 29, and 30, with isograms for a closer examination of the role of fuel in the large circular area fires. Figure 27 shows the application densities of water with protein foam required to achieve 90-percent fire control, and it may be observed that the avgas fuel took varied additional amounts of agent over JP-5.

The amount of agent that avgas required increased from 135 percent of that for JP-5 as the application rate was reduced and the test became more severe, until at the lowest application rate 225 percent was required. A different type of relationship occurred when these tests were repeated with Light Water, as shown in Fig. 28. Here avgas took only about 150 percent more agent than JP-5, and this difference was almost independent of the application rate.

A similar pair of curves is given by Figs. 29 and 30, which are based on the fire-extinguishing time rather than the 90-percent control time. First, it should be observed that the Light Water agent, as also shown previously, was less affected by the more volatile gasoline and required less additional agent than the protein foam did. Secondly, it is seen that the percentage increase with protein foam agent is greater at the higher application rates. This, of course, is just the opposite of the effect noted with 90-percent fire control shown by Fig. 27.

In summary, it may be said Light Water required approximately a 50-percent higher application density to control or to extinguish avgas than JP-5, regardless of the application rate. Protein required a minimum of 50-percent higher application density and up to 200 percent more, depending on the conditions. Achieving complete fire extinguishment was always accomplished with Light Water with lesser additional amounts of application. This is attributable to its highly oleophobic nature.

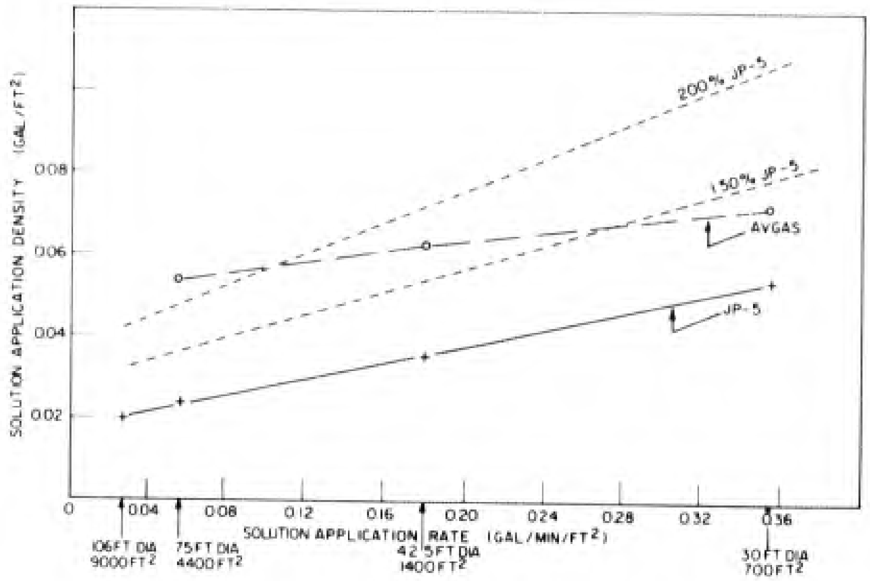

Fig. 27 - Water application density required for fire control with protein foam on avgas and JP-5 fuels

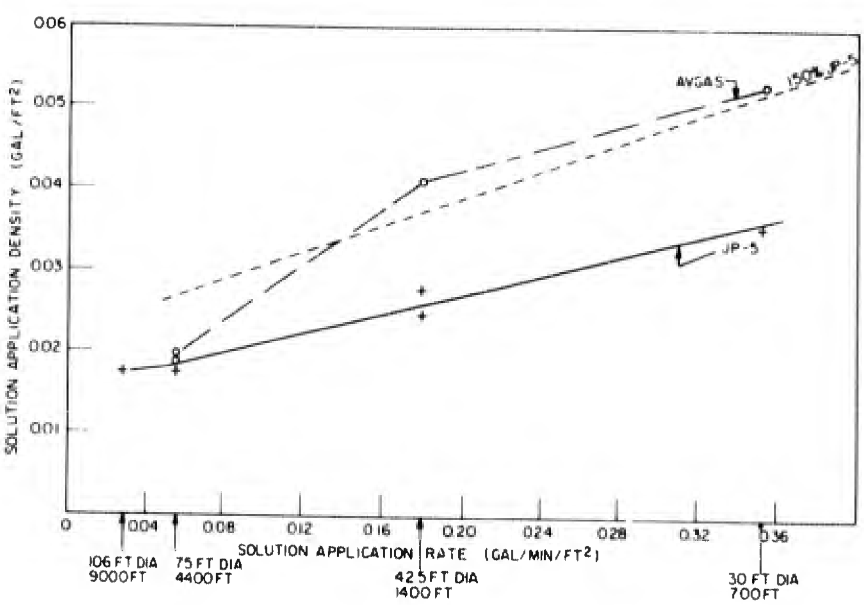

Fig. 28 - Water application density required for fire control with Light Water on avgas and JP-5 fuels

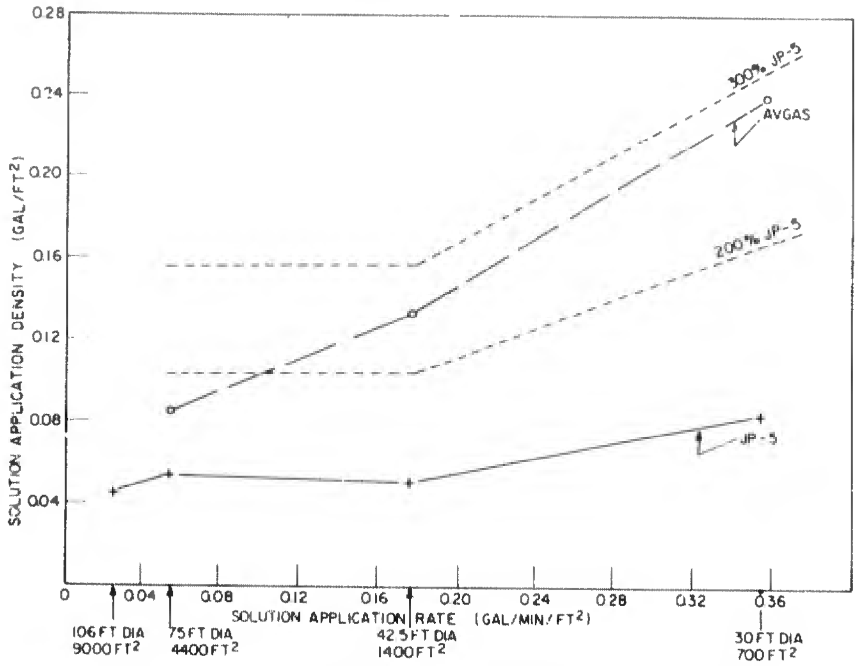

Fig. 29 - Water application density required for fire extinguishment with protein foam on avgas and JP-5 fuel

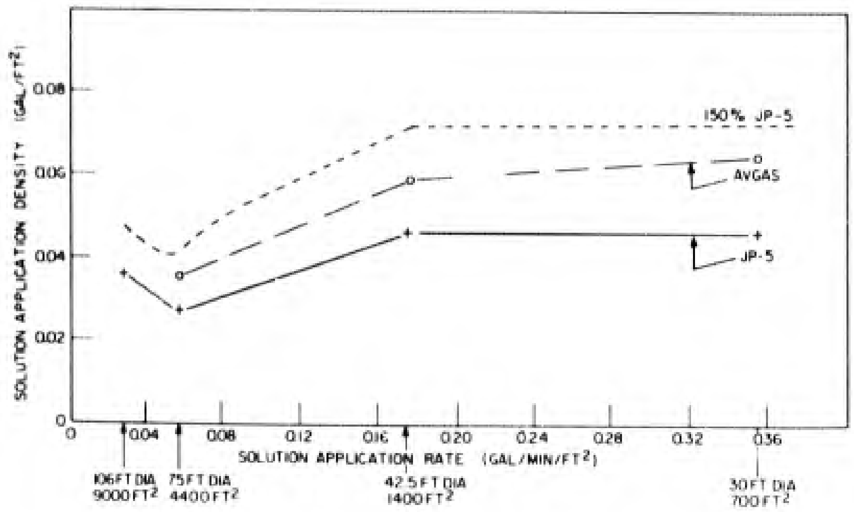

Fig. 30 - Water application density required for fire extinguishment with Light Water on avgas and JP-5 fuels

At this point it is of interest to go back and compare these differences in fuels with those observed in the previous tests. It was found in the small-scale indoor test, the single-pattern test, and the moving-pattern test that all held the ratio of twice as much protein foam required as Light Water on gasoline, and three times as much protein as Light Water on JP-5 for extinguishment. The large circular fire tests materially altered these ratios (Figs. 23 and 24); protein required 2.5 to 3.5 times the amount of Light Water on gasoline, and only 1.5 times on JP-5. The cause of this reversal, wherein Light Water went from the greater advantage on JP-5 to a greater advantage on avgas, is not evident, but it does weaken the feeling of confidence in the earlier and smaller-scale tests. The size of the fire area, on the other hand, is not the only factor involved, because there was a considerable overlap; the moving-pattern test involved 1000 ft^2, while the smallest outdoor area test involved 700 ft^2, and the reversal was very pronounced between these two test areas.

Relationship of Water Application Rate and Application Density

All through the history of the work done on fire-fighting foams, as well as other agents, for that matter, minimum application density has been a criterion for expressing the efficacy of an agent. Here, the agent which requires the least material to extinguish a unit area of fire is taken to be the best. In order to properly interpret the application-density results, it is essential that the rate of application per unit area also be stated. High application rates mask inherent differences in agents, hence the most significant resolution between agents is obtained at the application rates at which the agent is just on the edge of being capable of fire extinguishment.

Theoretically, as the rate of agent application is lowered, the application density to obtain fire control is increased because the agent is subject to more exposure and thus destruction from the heat. Finally, a point is reached at which the agent is destroyed as fast as it is being added, and fire control is impossible no matter how high the application density ultimately provided. Just above this application rate is the minimum critical rate. If a higher application rate is used, the application density becomes lower; however, a point is soon approached at which the agent is being wasted, because it cannot be distributed rapidly enough, and "overkill" results. Beyond this the application density continues to rise. This creates a characteristic "U" shaped curve, the bottom of which describes the most efficient (using minimum amount of agent) rate at which to add agent. Outside of fixed fire-fighting systems for fixed-area hazards, this point cannot be designed for. In aircraft fire fighting, for example, the size of the fuel area varies widely and one never knows just where on the application-rate curve his particular application rate will occur. Certainly, he hopes it will be above the minimum critical rate.

The application rate-application density curves have been plotted in Figs. 21, 22, 23 and 24, showing data for both 90-percent fire control and complete fire extinguishment. In all figures, except for one point in Fig. 23, and this is believed to be an experimental error, there was no indication in these tests that the application rate every reached the minimum critical. This is true even though the application rates reached as low as 0.028 gal/min/ft^2, by normal standards a very low value. Thus, one of the main objectives of the program was not satisfactorily achieved, that of determining the minimum critical rates of protein foam and Light Water on large-scale fires.

The foregoing data are of benefit in providing guidance in establishing adequate airport fire protection, using foam equipment of this design. Once the magnitude of aircraft fuel spill area has been established from fuel loadings and other factors, the total rate of agent application sufficient to extinguish the fire can be calculated. The minimum application rate might indeed be less. However, the time element must also be taken into consideration. Designing to the minimum critical application rate, or even the efficient application rate, may prolong the time for fire control and extinguishment perhaps past the point of successful personnel rescue from aircraft.

Consideration of the time element can best be accomplished by plotting the data from Table 5 in the form of time versus application rate. The pair of curves in Fig. 31 are for the 90-percent fire-control time of protein foam and Light Water, run on avgas fuel. In Fig. 32 there are two pairs of curves given, one for the two agents and one for the two fuels, based on complete extinguishment times.

The arrangement of data in Figs. 31 and 32, with time of control or extinguishment plotted as a function of application rate, appears to throw a different light on the subject of critical application rate. We now have a feeling of alarm at the precipitous rise in control and extinguishing times at low application rates. From the trend of these curves it appears that the minimum critical application has almost been reached. The curves of Figs. 21-24, on the contrary, exhibited no such rise, and gave no suggestion that the minimum critical application rate was near at hand.

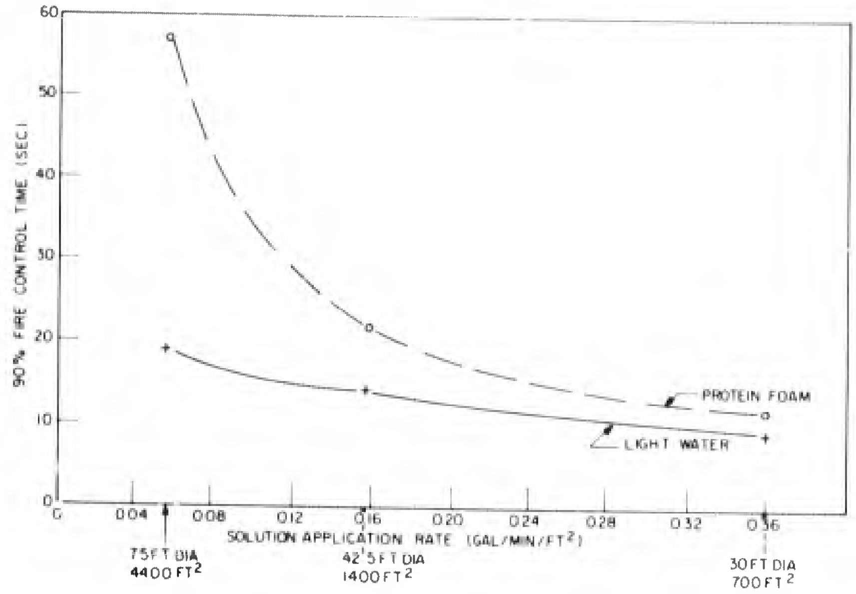

Fig. 31 - Ninety-percent fire-control time as a function of application rate on avgas

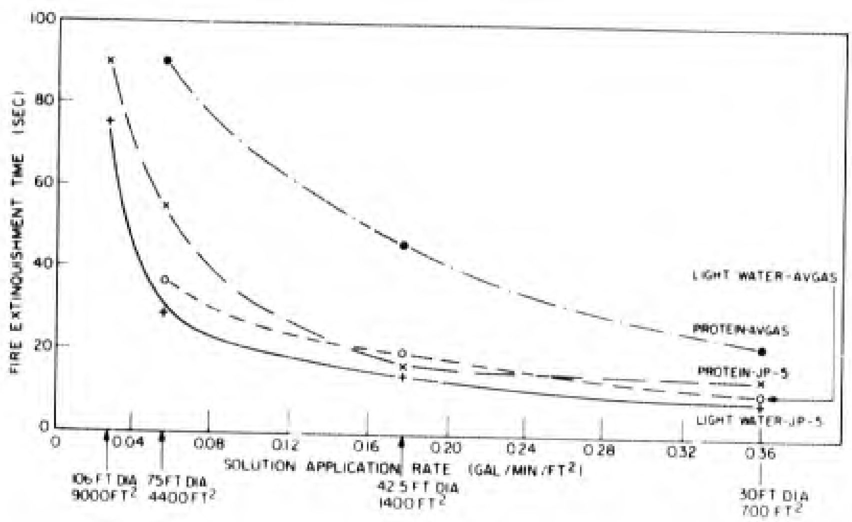

Fig. 32 - Fire-extinguishment time as a function of application rate on avgas and JP-5

In a comparison of Light Water with protein foam, the behavior at application rates approaching the minimum critical one is particularly significant if one is concerned with very large fires or with the maximum size fire that can be successfully attacked with given equipment. Then the sustained margin of superiority of Light Water over protein foam, 3 to 1 for control of avgas fire and 2 to 1 for extinguishment of JP-5, takes on striking importance.

It also should be noted that relatively high application rates were reached before any appreciable leveling off in times takes place. In the case of 90-percent fire-control time, it can be seen that an application rate approaching 0.24 gal/min/ft^2 was required. For fire areas of any magnitude, attaining this rate would present a considerable problem with respect to the logistics of getting sufficient water to the scene and discharging it rapidly enough.

For example, the absolute minimum fuel areas which must be secured in connection with aircraft incidents have been estimated by the NFPA Future Planning and Programs Subcommittee (Aviation Fire and Rescue Committee) to be on the order of 8500 ft^2 for a 727 aircraft and 13,500 ft^2 for a "stretched" DC-8. (This includes fuselage length plus 25 ft on each side of fuselage.) In order to gain rapid fire control an application rate of 0.24 gal/min/ft^2 would require total flows 2000 and 3300 gal/min from the responding equipment.

Indoor Tests and Outdoor Tests

The application densities recorded for extinguishment of the large fire areas ranged down to 0.026 and 0.036 gal/ft^2 for Light Water on JP-5 and avgas respectively, and 0.043 and 0.084 gal/ft^2 for protein foam on JP-5 and avgas respectively. In general, these values would be considered low, especially for low application rates. Fire-extinguishing application densities from the small-scale indoor tests (Table 2) and application densities taken from Figs. 23 and 24 for the same application rate for the large area fires are summarized in Table 6.

Table 6
Application Density for Fire Extinguishment at Application Rate 0.07 gal/min/ft^2

Area	Agent 6% Solution	Fuel	Density (gal/ft^2)	Density Ratio (28/3500)
28 ft^2 indoor 3500 ft^2*	FC-194	gas Avgas	0.130 0.038	3.4
28 ft^2 indoor 3500 ft^2	FC-194	JP-5 JP-5	0.073 0.029	2.5
28 ft^2 indoor 3500 ft^2	Protein foam	gas Avgas	0.286 0.09	3.2
28 ft^2 indoor 3500 ft^2	Protein foam	JP-5 JP-5	0.20 0.052	3.8

*No actual fires were conducted on this size area. The density values were taken from the curves, which in effect were interpolated to the desired application rate of 0.07 gal/min/ft^2.

The small-scale indoor test application densities indicate that the indoor test is a much more severe procedure, because of the consistently higher amounts of agent required to extinguish the fire. As the ratios in the last column show, however, the relationships were quite uniform for both agents on both fuels, except for the Light Water on JP-5, which dropped off somewhat. These data are taken to mean that the indoor test is a good representation of actual aircraft fire-fighting practice; however, a coefficient is necessary to obtain absolute values for application densities. The indoor fire test was not designed specifically to simulate aircraft fire fighting, but rather an approach to "across-the-board" use of protein foam. It is easily conceivable that the test could be modified by using a spray application technique, metal-side cooling, etc., to obtain application densities equivalent to those found in the large fires. In any event the data from the large fires will serve as a much-needed basis for the development of future scaled-down aircraft fire testing.

The ratios for amounts of agent required for extinguishment of gasoline as compared to JP-5 fuel on the small indoor fires and the large outdoor fires were as follows:

		Light Water	Protein Foam
Indoor	gas/JP-5	1.8	1.4
Outdoor	gas/JP-5	1.3	1.7

These ratios were based on the same application rate for both indoor and outdoor fires. From the variations of application densities versus application rate, these ratios might shift considerably. The ratios cited here are reasonably consistent, but they do show the same interesting inversion that Light Water requires relatively more agent on gasoline when testing indoors, and protein foam requires relatively more agent when testing outdoors.

Dual-Agent Extinguishing

The results from the test wherein Light Water and Purple-K dry chemical were applied simultaneously in approximately equal quantities by weight from turrets used 0.019 gal/ft^2 of Light Water to control the 75-ft-diameter (4400 ft^2) gasoline fire and 0.045 gal/ft^2 to extinguish. In addition, 0.15 lb/ft^2 and 0.19 lb/ft^2 of Purple-K were used. In a comparable fire using the Light Water by itself, the control density was 0.018 gal/ft^2, and the extinguishing density was 0.035 gal/ft^2. Thus, it was concluded that the dry chemical in this test had no beneficial effect in lowering the control time or in reducing the amount of Light Water required, even though the total amount (by weight) of agent materials added per unit area was doubled until 90-percent fire control had been established.

If the dual-agent technique using the Purple-K could not improve fire-fighting performance with gasoline as a fuel, it is reasoned that there would likewise be no effect with lower-volatility, higher-flash-point fuels. This fact, coupled with the greatly increased complexity of a large-capacity dual-system vehicle, does not make an attractive proposition. It does not appear on earlier work as well as that at Miramar that the present Twinned Agent Unit should be scaled up in size; rather, larger quantities of Light Water should be teamed with lesser amounts of dry chemical and not discharged from unitized type nozzles. Dry chemical appears to be best suited for the tasks of extinguishing three-dimensional fires and extinguishing small, isolated fires from 4 lb/sec handlines or portable extinguishers.

Light Water and dry chemical agents are completely compatible and, therefore, no foam breakdown problems were encountered in the dual agent tests. Also serving to alleviate the compatibility problem is the wider usage of the kerosene type jet fuels. With low-volatility, high-flash-point fuel a "leaky" foam covering, such as a noncompatible dry chemical-protein foam tends to create, is not the hazard and problem that it is with gasoline-type fuels.

Light-Water Foam Makers

One of the original objectives of the Miramar tests was to determine the efficacy of Light Water as generated and applied from several different devices. The basic reference was taken to be Light Water blown with a refrigerant gas to form a stable foam using the system on the O6X vehicle. Compared to this were to be Light Water from the foam-pump system and Light Water from the aspirating foam nozzle. Because of last-minute changes in the test plan, foams were not run on a common fuel, and as a result a complete comparison was not possible. Also, the flow rates of the three units were slightly different, which requires an adjustment in directly comparing time values. A summary using the most appropriate results is given in Table 7.

Table 7
Comparison of Light Water Performance in Three Foam Makers

	Fuel	Application Rate (gal/min/ft^2)	Time		Amount of Agent	
			Cont. (sec)	Exting. (sec)	Control (gal/ft^2)	Exting. (gal/ft^2)
O6X and Refrig.-12	Avgas	0.041	38	65	0.026	0.044
MB-5 Pump	Avgas	0.057	19	37	0.018	0.035
Air Aspirated	JP-5	0.021	46	91	0.016	0.031
MB-5 Pump	JP-5	0.028	37	75	0.017	0.035

In comparing the refrigerant-blown foam with the pump foam on avgas, it can be seen that the times for 90-percent fire control and fire extinguishment were higher for the blown foam than would normally be attributed to the lower application rate alone. The application densities were 20 to 30 percent lower for the pump foam. On the basis of these results, it was judged that the Light Water product as made and discharged from the foam-pump system on the MB-5 was equivalent to or better than Light Water solution blown with refrigerant from the turret nozzle of the O6X.

In comparing the aspirated Light Water foam with that from the foam pump, both control and extinguishing times were longer, but at these very low application rates the lower application rate for aspirated Light Water could fully account for them. The application densities for the aspirated product for both control and extinguishment were slightly less than for the foam-pump product.

Although the tests showed aspirated and foam-pumped Light Water foams to be equal to refrigerant-blown foam, further development work is needed on nozzle design. Fire-fighting techniques were hampered by the lack of range and pattern adjustment with the aspirating nozzle. This handicap was understandable, since it was being employed in a manner for which it was never intended. The Cardox turret stream was also restricted in its performance, because the volume of foam was only about half its designed flow. An easily variable discharge pattern through a wide range of patterns is a must for good, effective fire fighting. The fact that Light Water worked as well as it did in the variety of equipment used is an indication of its great potential.

Other Large-Scale Fire Tests

Early in 1966 the FAA initiated an aircraft fire-extinguishing study to examine the role of application rate and the comparative action of a few selected agents other than Federal specification protein foam (7). The experimental work was done at the National Aviation Facilities Experimental Center (NAFEC) in Atlantic City, New Jersey. Since their experimental arrangements were similar to those at Miramar, it would be expected that comparable data would result. Therefore, it is of interest to look at some of their early data presented in May 1966 at the NFPA Aviation Seminar (9).

The foam-making equipment used at NAFEC was more versatile than that used at Miramar, and with multiple vehicles available they were able to run different foam-application rates on each of several fire-area sizes. It was found in their tests, as at Miramar, that the larger fires could be controlled with less agent than smaller fires, when using the same unit-area application rate. For this reason it is not possible to compare directly the data for application rates without considering the actual fire size involved. Thus, the number of comparable data points from Miramar are more or less limited to one point each on the NAFEC 40 ft diameter fires. These points are summarized in Table 8. It is believed that the absolute radiation levels used for determination of Control Time permit a direct comparison between sites.

Table 8
Comparisons of Miramar and NAFEC Fire Data

Site	Fire Size (ft)	Fire Size (ft^2)	Agent	Fuel	Application Rate ($gal/min/ft^2$)	Control Time (sec)	Application Density (gal/ft^2)
NAFEC	40	1250	Protein	Jet A	0.166	38	0.114
Miramar	42.5	1400	Protein	JP-5	0.177	11	0.03
Miramar	42.5	1400	FC-194	JP-5	0.177	8	0.024

Examination of the values in the table shows a considerable increase, 3.8 times, in the amount of protein foam required between Miramar and NAFEC to control the test fire. This increase is believed to be because of the differences in the systems used in making and applying the agent. The foam-pump system makes a higher expansion foam which, by virtue of its lower density, impacts the fuel with less momentum, resulting in less splashing and fuel contamination. The wide, extremely diffused pattern from the turret provides large simultaneous area coverage and also contributes to a soft, highly effective application. Other factors, of course, could enter into these comparisons, and a final resolution cannot be made until the two foam systems are run side by side. The application densities for protein foam at NAFEC were 4.5 and 5.5 times those found at Miramar for Light Water.

The results of the large-scale fire tests by the Fire Research Station in Great Britain have not yet been published. Their unofficial values for control of kerosene-type jet fuel with protein foam indicate even higher application densities than NAFEC, using an 875-ft^2 fire area.

The Miramar application densities for protein foam on avgas were much lower than those reported from Danish tests conducted at Kastrup Airport in Copenhagen by the Comit'e Technique International de Prevention and Extinction du Feu. Their results on 4300-ft^2 fires with an application rate of 0.13 $gal/min/ft^2$ showed an application density of 0.26 gal/ft^2 for fire extinguishment. A quite comparable test at Miramar showed an application density of only 0.085 gal/ft^2.

Additional Comments on Fuels

Subsequent to the completion of the Miramar fires, the differences in fuels have been examined further in the laboratory. In order to gather additional information a series of indoor fire tests using both Light Water and protein foam was conducted on JP-4, JP-5, avgas, and motor gas. The validity of the results of the comparisons obtained are somewhat overshadowed by the findings on this subject discussed earlier in this report; however, the following relationships were found:

	Protein Foam	Light Water
Motor gas	100	100
Avgas	108	115
JP-4	191	134
JP-5	143	176

Each column is based on a value of one hundred for motor gas, and the numbers higher than 100 indicate the relative increased area which could be extinguished by a fixed volume of agent. For both agents it is seen motor gas was the most difficult to extinguish, followed closely by avgas. With the jet fuels there was an interesting difference: Protein foam was more effective on JP-4 than on JP-5.

The relative fire "knockdown ability" of the two agents on the same fuels is as follows:

	Protein Foam	Light Water
Motor gas	100	100
Avgas	97	96
JP-4	75	124
JP-5	79	108

These values indicate the total outputs of thermal radiation released from the fire until the radiation level had been reduced by 90 percent of maximum, all relative to motor-gas fuel, which was assigned a value of 100. For protein foam, the motor-gas fire was the most difficult to knock down, followed closely by avgas, and then somewhat easier were both jet fuels. For Light Water, the two jet fuels were the most difficult to knock down and the gasolines the easiest. Somewhere then, between the occurrence of 90-percent knockdown and complete extinguishment, the jet fuels went from harder to easier to cope with when using Light Water. With protein foam the jet fuels were easier to control and extinguish than motor gas.

It should be pointed out that JP-4 is a variable product in respect to its flash point. No limits for this property are given in the MIL specification, and it may vary anywhere from the flash point of gasoline to that of JP-5. Any test work using JP-4 should be done with this in mind, and the significant characteristics should be stated in the test results. The flash point of the JP-4 used in the small-scale tests cited above was 66°F. It is not known at this time what other specific properties of the fuels affect the extinguishing actions of foam, but there do appear to be other considerations. Also, care must be exercised in the event that more than one source or batch of JP-4 fuel is involved in a test program, to insure a consistent product is being used in all experiments.

Concurrent with the fire-extinguishing studies on the different fuels, additional data were taken on the burning rates and fuel-layer temperature profiles. These results will be covered in a separate report at a later date.

Overall Test Comments

On the whole, the test plan and arrangements worked out very satisfactorily, and the final results obtained are believed to be significant and representative. Several comments are offered for those who may be in the planning stages for similar projects. First, the fire areas should be kept large enough not only to keep the application rates down to realistic large-fire rates, but also to incorporate a feel for maximum turret effective range. Second, the use of a water base should be avoided, if at all possible. Wind forces will peel back an amazing depth of fuel floated fully on water, and then too, the force of the agent application stream readily pushes fuel away. Without a water underlayer, however, leveling of a large area can be difficult and time consuming. At Miramar water was used only as a guide in leveling, and then was removed as completely as possible, leaving a mud base impervious to fuel seepage and resistant to fuel motion. Third, all common aircraft fuels should be used for a limited number of tests, in order to obtain data for transposing the results of the main test fuel to other fuels.

Perhaps the biggest gap in the Miramar results lies in the area of data on burnback protection. Some type of instrumented test procedure is badly needed to provide such data. This test is very difficult to implement, because this characteristic of foam coverings is highly sensitive to wind velocity, and results are almost impossible to duplicate from test to test, to say nothing of day to day and month to month.

Quantitative burnback relationships were not established at Miramar, but it was observed that Light Water was not as good as protein foam in this respect. Inasmuch as no burnback resistance time limits have been established, it will remain to be determined through actual field usage whether Light Water provides adequate working protection. The quality of Light Water foam, referring to its expansion and drainage time, have been shown in small-scale tests to play an important role in burnback protection; however, this has not been similarly evaluated on a large scale. Since considerable differences were found between the expansion and drainage-time values for Light Water foams from the various foam makers used, it would be expected that the foam product from the foam-pump system would have given superior burnback protection compared to the other Light Water Foams tried.

CONCLUSIONS

Light Water made from a 6-percent concentrate is a highly effective agent for the extinguishment of large, full-scale fires of avgas, JP-5, and other aircraft fuels. When applied to similar fires at similar rates, Light Water will establish fire control and fire extinguishment faster than will protein foams.

Light Water may be effectively used in the present foam-pump systems on MB-1 and MB-5 vehicles, or in long barrel aspirating type foam makers, however, the limitations in output pattern of the currently available aspirating nozzles restrict their potential capability. This is true for all foams, protein or Light Water types.

Protein foam is made and applied in a well dispersed pattern from a foam pump system is almost four times as effective as protein foam applied from aspirating nozzles with their "harder" stream characteristics.

A single large fire test using equal quantities of Light Water and Purple-K dry chemical from turrets indicated little advantage under this test condition was gained by the use of the dual agent technique over the same amount of Light Water used by itself. Purple-K-Powder was found to be very valuable, however, as a secondary agent applied by means of handlines and/or portable extinguishers. No compatibility problem exists between Purple-K and Light Water.

Additional study is required in order to establish a better relationship between thermal radiation as determined by instruments and physiological reactions.

The application density of agents required per unit area of burning surface to control and to extinguish decreased with larger fire areas, approaching the minimum critical application rate. This was true for both Light Water and protein foam. Ninety-percent fire control (about 0.2 Btu/ft^2/sec) at low application rates could be obtained with 0.02 gal/ft^2 of protein foam on JP-5 and 0.05 gal/ft^2 on avgas; Light Water required 0.017 and 0.02 gal/ft^2 respectively. Complete fire extinguishment was achieved with 0.043 gal/ft^2 of protein foam on JP-5 and 0.085 gal/ft^2 on avgas; Light Water foam required 0.026 and 0.035 gal/ft^2 respectively.

Minimum critical application rates were not precisely determined, but were estimated to be approximately 0.02 gal/min/ft^2. The fire-control times for protein foam on avgas fires begin to rise rapidly with application rates below 0.36 gal/min/ft^2; for Light Water, below 0.06 gal/min/ft^2.

RECOMMENDATIONS

It is recommended that a program be instituted to introduce Light Water into field service by replacing the protein concentrate presently used in MB-5 vehicles with Light Water. This step will provide much greater protection with the same equipment operational data to guide the future course of Light Water and vehicle design also needed in the Navy.

It is also recommended that improved aspirating foam makers with better foam quality and better dispersed stream patterns, be sought for the more effective application of Light Water and protein foams.

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MIL-F-23905B(AS)

25 April 1967

Superseding
MIL-F-23905A(WP)
26 March 1965

MILITARY SPECIFICATION

FIRE EXTINGUISHING AGENT, "LIGHT WATER"
LIQUID CONCENTRATE, (6 PERCENT)

This specification has been approved by the Naval Air Systems Command, Department of the Navy

1. SCOPE

1.1 This specification covers the requirements for one type and grade of "Light Water" liquid concentrate fire extinguishing agent consisting of non-toxic fluorocarbon surfactants and appropriate foam stabilizers. The material shall be suitable for use in conjunction with potassium dry chemical fire extinguishing agent in suitably designed "twinned" equipment and in suitably designed foam-forming devices. The liquid concentrate shall be diluted or proportioned by suitably designed equipment for use in concentrations of six parts concentrate to ninety-four parts water by volume.

2. APPLICABLE DOCUMENTS

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

SPECIFICATIONS

Federal

PPP-B-601	Box, Wood, Cleated-Plywood
PPP-B-621	Box, Wood, Nailed and Lock-Corner
PPP-P-704	Pails, Shipping, One through Twelve Gallons

FSC 4210

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Military

MIL-F-22287	Fire Extinguishing Agent, Potassium Dry Chemical

STANDARDS

Military

MIL-STD-105	Sampling Procedures and Tables for Inspection by Attributes
MIL-STD-129	Marking for Shipment and Storage
MIL-STD-147	Palletized Unit Loads, 40" x 48" 4-Way Partial and 4-Way Pallets

(When requesting specifications, standards and publications refer to both the title and number. Copies of this specification and applicable specifications may be obtained upon application to the Commanding Officer, Naval Supply Depot (CDI), 5801 Tabor Avenue, Philadelphia, Pennsylvania 19120).

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

American Society for Testing and Materials

ASTM-D445-61	Test for Kinematic Viscosity
ASTM-D-1298-55	Test for Specific Gravity of Petroleum Liquids, Hydrometer Method
ASTM-D1331-56	Tests for Surface and Interfacial Tension of Solutions of Surface Active Agents

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

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3. REQUIREMENTS

3.1 Preproduction - The fire extinguishing agent, "Light Water" liquid concentrate furnished under this specification shall be a product which has been inspected and passed the preproduction inspection specified herein.

3.2 Data requirements - No data is required by this specification (other than reports accompanying samples submitted for preproduction testing), or by applicable documents referenced in Section 2, unless specified in the contract or order. (see 6.2).

3.3 Chemical and physical requirements - The "Light Water" liquid concentrate shall conform to the requirements of Table I when tested as specified therein. The material shall consist of non-toxic fluorocarbon surfactants, and shall not give off toxic vapors when subjected to intense heat.

3.4 Performance requirements -

3.4.1 Foamability - The solution of "Light Water" concentrate in water (six parts concentrate to ninety-four parts water by volume) shall produce a foam possessing an expansion with a limit of 7.0 minimum and a 25 percent drainage time of 2-1/2 minutes minimum value when tested as specified in 4.5.7.

3.4.2 Film formation and sealability - The foam produced by the sample shall spread over the surface of the fuel when tested as specified in 4.5.8 and result in a surface from which no sustained ignition of fuel vapors can be detected.

TABLE I

CHEMICAL AND PHYSICAL REQUIREMENTS

Requirement	Limits/Value	Test Paragraph
Specific Gravity at 25° ± 3°C (77 ± 5°F), minimum	1.075	4.5.1
Viscosity in centistokes at 25 ± 0.5°C (77 ± 1°F)	50-150	4.5.2
Viscosity in centistokes at 4.4 ± 0.5°C (40 ± 1°F) maximum	300	4.5.2
Refractive Index (n25/D)	1.3750 - 1.3850	4.5.3
pH value 25 ± 3°C (77 ± 5°F minimum	4.2	4.5.4
Surface tension, dynes per centimeter at 25 ± 3°C (77 ± 5°F), maximum	20.0	4.5.5

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TABLE I (Continued)

CHEMICAL AND PHYSICAL REQUIREMENTS

Requirement	Limits/Value	Test Paragraph
Nitrogen Content, percent	0.30 - 0.40	4.5.6
Color Identification, maximum	light amber	visual
Foamability:		
Expansion, minimum	7.	4.5.7
Drainage time, mim'mum minutes	2.5	4.5.7

4. QUALITY ASSURANCE PROVISIONS

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

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

(a) Preproduction Inspection (4.3)

(b) Quality Conformance Inspection (4.4)

4.3 Preproduction inspection - Preproduction inspection shall consist of all the inspection of this specification.

4.3.1 Sampling for preproduction inspection -

4.3.1.1 Unless otherwise specified, as soon as practicable after award of a contract or order, the contractor shall furnish preproduction samples for inspection to determine conformance with this specification. Quantity production shall be withheld until the preproduction sample has been pronounced satisfactory by the Government. When a contractor is in continuous production of these items from contract to contract, submission of further preproduction samples may be waived at the discretion of the Contracting Officer. The approval of preproduction samples or the waiving of the preproduction inspection shall not relieve the contractor of his obligation to submit samples for quality conformance inspection.

4.3.1.2 The preproduction sample shall consist of 5-gallons of the material furnished in a sealed container. The sample shall be inspected as specified herein and in accordance with the contract or order. Each sample shall be accompanied by the results of all specification tests (see 6.2).

4.4 Quality conformance inspection - Quality conformance inspection shall consist of all the tests of this specification as described under "Test Methods" (4.5), and the examination of filled containers (4.4.2).

4.4.1 Sampling -

4.4.1.1 Inspection Lot - All material manufactured as one batch and offered for delivery at one time shall be considered a lot for purposes of quality conformance inspection.

4.4.1.2 Lot acceptance test samples - From each lot of material offered for acceptance under contract, four filled 5-gallon containers shall be selected at random. A composite sample, sufficient in size for test purposes, shall be made up by drawing equal portions from the containers and immediately placed in a dry, air and water tight container and forwarded to a testing laboratory satisfactory to the procuring agency. The composite sample shall be subjected to all the tests as described under "Test Methods". (4.5).

4.4.2 Examination of filled containers - A random sample of filled containers shall be selected from each lot in accordance with MIL-STD-105 at inspection level I, and acceptable quality level (AQL) equal to 2.5 percent defective to verify compliance with all stipulations of this specification regarding fill, closure, packaging, packing, marking and other requirements not involving tests. Containers shall be examined for defects of the container and the closure, for evidence of leakage, and for unsatisfactory markings; each sample filled container shall also be weighed to determine the amount of the contents. Any container in the sample having one or more defects or under required fill shall be rejected, and if the number of defective containers in any sample exceeds the acceptance number for the appropriate sampling plan of MIL-STD-105, the lot represented by the sample shall be rejected.

4.5 Test Methods -

4.5.1 Specific Gravity - The specific gravity of the liquid concentrate shall be determined in accordance with ASTM Method D-1298-55.

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4.5.2 Viscosity - The viscosity of the liquid concentrate shall be determined in accordance with ASTM Method D-445-61 using a capillary viscometer of appropriate size number at 25°C. (77 ± 1°F.) and at 4.4°C. (40 ± 1°F.).

4.5.3 Refractive Index - An Abbe refractometer shall be used to determine the refractive index of the sample. Standard testing procedures for this instrument shall apply.

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

4.5.5 Surface tension - The surface tension of a solution of 1cc of the liquid concentrate in 370cc of distilled water shall be determined in a Cenco DuNuoy tensiometer in accordance with ASTM Method 1331-56 and until the readings come to an equilibrium (approximately 30 minutes).

4.5.6 Nitrogen Content - A modified sealed tube Kjeldahl digestion and titration method shall be used to determine the nitrogen content of the liquid concentrate. (Reference Analytical Chemistry, Volume 23, pp 363, 1951).

4.5.7 Foamability - An Ansul Company (Marinette, Wisconsin) portable extinguisher, Model WF-2-1/2, (or similar) of the stored pressure type is modified for this test. The discharge hose and nozzle are replaced by the following assembly in 1/4" pipe size: A nipple 2-1/2" in length, a tee fitted with a calibrated 200 psi gage, a 1/4" to 3/4" bushing, and finally a special foam-producing nozzle. This air-aspirating nozzle (or similar), available as a laboratory testing item from National Foam System, Inc., West Chester, Pennsylvania, should have a flow rated at 2.00 gpm ± .10 gpm at 100 psig delivery pressure.

First, in the procedure to test foam concentrates for expansion and drainage, the extinguisher container is charged with one gallon of premixed solution at 70°F. in the required quantities. The discharge assembly is then coupled to the extinguisher. Using compressed air or nitrogen, the unit is pressurized to 110 psig.

The unit is held with the nozzle 3 ft. from the ground and at a distance of 10 ft. from a foam collecting board. The latter is constructed at an angle of 45° to the horizontal and has a V-shaped trough to direct the run-off foam into a standard 1-liter glass graduate centered below the trough exit.

The discharge valve is depressed and the foam stream directed to one side of the collector. When the installed discharge gage registers 105 psi the foam stream is directed to impinge on the stand backboard at its center point. Discharge is continued in this manner until the foam fills the cylinder. The protruding top of the foam column in the graduate is then struck off level and a stopwatch is started.

The expansion value is defined as the ratio of the final foam volume to original foam solution volume before air addition. The foam filled graduate is weighed to the nearest gram and the expansion calculated from the following expression.

$$\text{Expansion} = \frac{\text{(graduate total volume in ml.)}}{\text{(Full weight minus empty weight in grams)}}$$

At one minute intervals from the stopwatch starting point, the total volume of solution drained from the foam column is recorded. Sufficient readings should be taken to insure that more than one-fourth of the solution in the foam sample has drained. The 25% drainage volume is calculated from:

$$\text{25\% Volume} = \frac{\text{(Full weight minus empty weight in grams)}}{4}$$

The time required to collect this drainage volume shall be reported as the 25% drainage time.

This test shall be run three times on the one gallon charge. Repressurize unit each time to 110 psi. The reported expansion and drainage time values will be averages of the three tests.

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

A stainless steel Graduated Measure of 1,000 ml capacity (4-1/2" dia., 5" deep) (Cole-Parmer Co., Chicago Illinois, or similar) is fitted at the top edge with two small metal clips protruding 1/8" into the opening. They serve to restrain an 80 mesh conical screen of stainless steel (5" in height by 4-3/4" in diameter) from floating out of the container during the test. A Waring Automatic Blender, or similar, is used as the test foam maker. (at 70 ± 5°F.).

First, 600 ml of 98% cyclohexane are placed into the Graduated Measure. 100 ml of the active solution to be tested are formed for 10 seconds at low speed in the Blender. 200 ml of this foam are poured onto the fuel surface. The screen is then inserted into the Measure and clipped firmly into place, and a stopwatch is started. A small portion of foam bubbles will be forced through the screen mesh but the dominant surface area will appear bare.

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

4.6 Rejection criteria - When any lot acceptance test sample fails to meet any of the test requirements of this specification or when the number of defective filled containers exceeds the acceptance number as specified in 4.4.2, the lot represented by the sample shall be rejected.

5. PREPARATION FOR DELIVERY

5.1 Preservation and packaging -

5.1.1 Level A -

5.1.1.1 Cleaning, drying and preservative application - Not applicable.

5.1.1.2 Unit packaging - Unit packaging of the liquid concentrate fire extinguishing agent shall be furnished in 5-gallon containers in accordance with specification PPP-P-704A, Type 1, Class 1 except that the interior coating shall be a uniform double coating of Bradley-Vrooman Series 46, epon-phenolic resin. The closure shall be a snap-on cap type with a protective metal band as described in paragraph 3.3 of PPP-P-704A.

5.1.2 Level B - Not applicable.

5.1.3 Level C -

5.1.3.1 Unit packaging - Unit packaging of the liquid concentrate fire extinguishing agent shall be in accordance with 5.1.1.2.

5.2 Packing -

5.2.1 Level A -

5.2.1.1 Exterior Containers - Unless otherwise specified, material packaged in accordance with 5.1.1.2 shall be shipped without exterior packing. When specified by the procuring activity, pails shall be packed in wood boxes in accordance with specification PPP-B-601, overseas type, or PPP-B-621, Class 2 (weight limit not to exceed 200 lbs) or palletized in accordance with Specification MIL-STD-147, load type III.

5.2.2 Level B - Not applicable.

5.2.3 Level C - The liquid concentrate fire extinguishing agent packaged in accordance with 5.1.3.1 shall be packed to afford protection against damage during shipment from the supply source to the first receiving activity for immediate use. Containers shall comply with Consolidated Freight Classification Rules or other common carrier regulations applicable to the mode of transportation.

5.3 Marking -

5.3.1 Special Markings - Two identical instructions for use and caution label markings as listed below shall be applied to each container so that the markings are located diametrically opposite on the container side. The labels shall be applied in such a manner that water immersion of the container, or normal handling will not impair the legibility of the marking.

Instructions for use: Fire extinguishing agent "Light Water" liquid concentrate is a non-toxic, non-corrosive, fluorocarbon surfactant mixture for use in specially designed equipment which generates "Light Water" (Lt H_2O) foam for firefighting purposes in foam-forming devices or in conjunction with "twinned" potassium bicarbonate dry chemical equipment. This concentrate is to be diluted for use with clean fresh water in volume proportions of 6 gallons concentrate to 94 gallons water. This may be done by premix in the final storage container or by suitably designed flow proportioning equipment.

Caution: Do not store below 32°F. (0°C) for ready use. Do not mix with any other liquids except as noted in the instructions for use.

5.3.2 Normal markings - In addition to the markings required by contract or order, unit packages, and shipping containers shall be marked in accordance with the requirement of MIL-STD-129.

6. NOTES

6.1 Intended use - Foams produced from "Light Water" diluted concentrates are intended for use as fire extinguishing agents or in conjunction with dry chemical extinguishing type agents for the purpose of eliminating flashbacks and preventing reignition of flammable hydrocarbon fuels.

6.2 Ordering data - Procurement documents should specify the following:

a. Title, number and date of this specification
b. Quantity
c. Level of packaging and packing required (see 5.1 and 5.2)
d. Whether preproduction inspection is required (see 4.3.1.1)
e. Where preproduction inspection is to be conducted when required (see 4.3.1.2).