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A Comparative Testing Study of Fire Extinguishing Agents for Shipboard Machinery Spaces

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

Engineering Research Branch
Mechanics Division

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U.S. NAVAL RESEARCH LABORATORY
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CONTENTS

ABSTRACT

Fire tests employing a 735 ft^2 bilge area covered with No. 2 diesel fuel within a simulated shipboard engine room structure were conducted. These tests were designed primarily to compare the effectiveness of the new "Light Water-Purple-K-Powder" system and the Type 5 protein foam presently used aboard ship. Other agents, such as "XL-6" protein foam, and carbon dioxide were tested. The effect of using these agents individually on a bilge fire, and also on a simulated 10 gpm fuel line rupture, spray fire, where a fire fighter was required to gain access inside the area and shut off the fuel valve near the fuel spray, was studied. The twinned use of "Light Water-PKP" as compared to Type 5 protein-PKP on the combined bilge and spray fire was also studied.

It was found for the bilge-fire-only fire condition that both the 6% and 25% "Light Water" foams exhibited a 2 or 3 to 1 superiority over the Type 5 and "XL-6" type protein foams with respect to application density (gal/ft^2) required for extinguishment.

The "Light Water" and protein foaming agents were found capable of controlling the spray fuel fire in its early stages (within 20 sec) to a sufficient degree allowing the fuel valve to be secured. The "Purple-K-Powder", when applied at 1.65 pounds per sec, was found to be the best agent for this particular application, requiring only a 2 sec discharge for complete spray fire control. Carbon dioxide was found not capable of controlling this fire.

For the combined agent tests, it was found that the 6% "Light Water" foam with 1.65 pps PKP applied required only 1/5 to 1/6 the amount of agent (12 gal "Light Water" soln, 7 lbs PKP) as compared to 6% protein foam with 1.65 pps PKP (64 gal protein soln, 12 lbs PKP) for securing the fuel valve and complete fuel fire extinguishment.

Purple-K-Powder, when used alone at the application rate of 4 pps, did not effectively control or extinguish this fire. Smoke and powder accumulation inside the structure presented a serious ingestion and visibility problem at these high powder discharge rates.

Type 5 protein foam also did not extinguish this fire. The bilge area fire was controlled, but no control was obtained over the spray fire after a two minute application.

PROBLEM STATUS

This is an interim report. Work on the problem is continuing.

AUTHORIZATION

NRL Problem C05-19

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INTRODUCTION AND BACKGROUND INFORMATION

Accidental fires of any type occurring aboard a Naval vessel are all serious incidents that require effective and immediate countermeasures. A most critical condition presents itself however, when flammable liquid fuels under pressure escape from piping arrangements and become ignited in the machinery spaces and boiler-engine room areas below decks. The ensuing quickly-developing, three dimensional fire is capable of completely crippling the control and power facilities of a ship.

Recently reported incidents involving such fires have included personnel fatalities because of difficulties of escape from such spaces when fires quickly become large and unmanageable with existing installed carbon dioxide fire fighting equipment. In some cases portable air foam devices are also available for first aid fire extinguishment in these spaces.

The advent of the new vapor-securing and fire extinguishing agent, "Light Water" with its combined agent system development using "Purple-K-Powder" dry chemical, Reference (1), appeared to offer a very promising solution to the problem of a quick, easily energized, single operator, fire extinguishment system for machinery space fires. A BuShips letter, Reference (2), containing this shipboard application proposal and others, whereby the new, highly efficient dual agent system might reduce fire problems aboard ship, initiated studies and tests in this direction at the U. S. Naval Research Laboratory.

A number of modeling tests were conducted in October of 1964 at NRL using mocked-up shipboard machinery space bilge fires in which a heat sink with a continuous oil spray was superimposed on the fuel surface fire. This yielded a three dimensional, continuously igniting JP-5 fuel fire. Quantitative measurements were not fully satisfactory during these fires because of the complete inability of ordinary air foam alone in the control of such a fire. Single operator application of the twinned "Purple-K-Powder", "Light Water" discharge controlled and extinguished this fire model in times varying from 18 to 40 seconds.

A number of test fires were conducted with satisfactory results during the summer and fall of 1965 omitting the use of difluorodichloromethane (Freon-12) gas as a blowing agent for the generation of "Light Water" foams. This was done relative to a need imposed by employment of this material in closed habitable spaces as given by BuShips letter, Reference (3).

The problem of adequately testing and evaluating new equipment or materials for shipboard fire fighting is made doubly difficult because of inaccuracies in the simulation of conditions surrounding a fire below decks of a vessel. A large number of controlling variables exist in such fires which defy duplication short of actual shipboard operation.

For these reasons, a decision was made by BuShips engineers that the existing full scale mock-up engine room structures used for ships personnel fire fighting instruction at the Naval Damage Control Training Center in Philadelphia should be employed for comparison testing with fires and fuels, duplicating as close as possible, the actual conditions of fire emergency which have occurred in shipboard incidents. The BuShips letter of Reference (4) contains a proposed fire test procedure which was adhered to as closely as possible in the tests reported by this report.

It was found during the test period that many of the procedures outlined by the above paper had to be modified. This is the usual case in such fire testing. Because of the influence of variables which can hardly be foreseen, many changes have to be made during the succession of fire tests in order that reliable data and information be obtained.

EXPERIMENTAL METHODS

Test Facilities

The simulated shipboard Engine Room located at the Naval Damage Control Training Center, Philadelphia, Pennsylvania was utilized for the experimental work. Figure 1 is a view of the starboard elevation of the simulated Engine Room. Hatches located at the top of this structure were used as ventilators having a total opening area of 70 ft^2. Figure 2 is a cut-away view of the interior of the Engine Room as seen from the forward door. The physical inside dimensions of this structure are 30 ft long by 35 ft wide by 22 ft high. The bilge area is sloped from the sides to a trough in the center for draining and flushing purposes. Interior structures are coated with a cement and asbestos mixture, mounted on cement covered brick supporting columns. Simulated condensers, turbines, and main reduction gear housings are located in the port section of the Engine Room. A steel structure simulating the main condenser and booster pump is located in the center of the room. Three other smaller steel structures are seen at the center aft section. The Engine Room is provided with door openings on each side. Portholes are provided on each side except for the aft side. Metal gratings with guard railings and walkways on the lower level connect all door openings except the port side.

The sloping sides of the bilge permitted adjustment of the extent of fire area by controlling the height of the water base on which the fuel was floated. For these tests the fire area was set at a width of 24.5 ft. This width, with the full length of 30 ft, created a fire of 735 ft^2. The fuel charge was 30 gal, which meant the fuel depth was 1/16" on top of the water. After each fire test the bilge area was either flushed down and refueled or additional make-up fuel was added to the remaining fuel. This fueling procedure was dependent on the nature of the fire test conducted and the extinguishing agent used.

In order to simulate the fuel line rupture used in some of the tests, a 1 in. dia. pipe fuel line, having a slit 3 in. from the end, was positioned inboard of the handrail near the forward door. It was mounted at a height of 30 in. above the fuel and the fan-shaped spray aimed downward at 45° from the horizontal (Fig. 2). An electric spark gap positioned at a height of 18 in. above the fuel and directly in line with the fuel spray was used as a source of immediate and constant fuel ignition. The 3/4" long spark was created by a 15,000 volt transformer. The fuel flow to the rupture was capable of being secured by a quarter-turn valve at the handrail inside the structure and also by a second valve located at the base of the 30 gal pressurized fuel supply tank outside the structure. Fig. 3 shows the fuel spray in operation with the shut-off valve visible in the upper left corner and the spark gap and leads visible behind the fuel spray. The rate of fuel flow was controlled by changing the pressure and the slot size. Fig. 4 gives the pressure-flow relationship for two different slit sizes.

A Chromel-Alumel thermocouple was positioned approximately 4 ft above the fuel surface to supply temperature data during the preburn period. It was connected to a direct temperature-indicating portable pyrometer located outside the structure.

Air temperatures during the tests were 50-60°F, with the water temperature considerably lower.

<u>Fuel Employed</u>

No. 2 diesel oil constituted the fuel used in these fires. Analysis of samples by the Closed Cup method showed the flash point to be 150°F.

<u>Extinguishing Agents and Equipment Used</u>

Two different protein foam forming concentrate liquids were used: namely, regular Type 5 and the new, dry chemical compatible "XL-6". Also two types of "Light Water" concentrates, 25% FC-183 and 6% FC-194, were used. The dry chemical agent used was "Purple-K-Powder" (potassium bicarbonate) conforming to MIL-E-22287, Reference (5). The carbon dioxide was from a Navy stock 50-lb cylinder.

Foam concentrates were proportioned into the water lines with the standard FP-180 "water motor" proportioner. The "Light Water" solutions were pre-mixed.

The protein solution foam maker was of a type newly introduced into shipboard use under MIL-N-12279 revised and to meet Plan, BuShips No. 810-1385959. Its nozzle body construction is similar to the Navy 2-1/2" and 3-1/2" FFF fog-foam nozzles, however, it is furnished with front end attachments different than those previously used in the Navy. The new devices are similar to Rockwood's commercial ones and consist of a 30 in. long, narrow-barreled stream shaper for straight stream foam application and a double-screen foam improver for close application. Nozzle hose connection is 1-1/2" and the flow rate is 60 gpm at 100 psi.

The "Light Water" solutions and "Purple-K-Powder" (high discharge rates) were dispensed from a self-contained pressurized system known as the Twinned Agent Unit (TAU), however, for these tests the Freon-12 gas, which is normally used as a blowing agent, was omitted. The "Light Water" foams were made by air aspiration at the nozzle exactly in the manner of protein foams.

This TAU is now employed as a standard aircraft fire-fighting system at naval air stations and is made in accordance with MilSpec MIL-E-23906A (WP), References (6) and (7). The unit consists of two spheres, each having an agent capacity of 400 lbs ("Light Water" volume; 48.5 gal). Pressurization is by means of separate nitrogen cylinders: a 220 cu ft cylinder for the PKP and a 110 cu ft cylinder for "Light Water". These spheres are connected to a 50 ft long twin hose terminating in two pistol grip nozzles mounted in a dual nozzle holder for one man trigger-controlled operation. A modified, 1-1/2" FFF nozzle with a double screen attachment was used with the "Light Water" solution. At a nozzle pressure of 120 psi, the flow rate was 50 gpm. The rate of discharge for the PKP averaged 4 lb/sec through an Ansul HF-35 nozzle.

When lower discharge rates of PKP were desired, a standard 30 lb capacity portable extinguisher having an average powder discharge rate of 1.65 lbs/sec was employed.

Carbon dioxide was employed from a 50 lb cylinder through a standard hose reel and standard discharge horn.

Agent application rates were as follows:

Protein foam: 60 gpm total; 0.082 gal/min/ft^2 bilge fire area
"Light Water": 50 gpm total; 0.058 gal/min/ft^2 bilge fire area
"Purple-K-Powder": 4 lbs/sec total; 0.0055 lbs/sec/ft^2 bilge fire area or 1.65 lbs/sec total from portable extinguisher
Carbon dioxide: 1.5 lbs/sec total (estimated)

Fire Observations

The copious quantities of smoke generated by each fire made any visual observations within the space extremely difficult. Under the test plan all side hatches, except the starboard one for entry of the fire party, were secured to simulate the restricted ventilation found on shipboard when the ventilation is shut down at the time of fires. Several observers were stationed outside at various small access openings to check on the progress of flame spread during the pre-burn period and progress of extinguishment during agent application.

Each ignition was primed with gasoline but the rate of spread of the fire was found to vary depending on the condition of the fuel (fresh or replenished), the temperature inside the structure, and the degree of gasoline priming. Therefore, to alleviate this problem, zero pre-burn time was taken as the time when it was visually observed that the entire area was involved in fire and the flames were at a height of 3 to 4 ft and a pre-burn time of 45 sec was allowed. The fire fighters also found it difficult to determine their fire extinguishment progress after the initial knockdown phase and therefore, the extinguishing agents were usually applied intermittently, allowing time for some smoke clearance to permit surveillance for lingering hidden fires. For each fire an attempt was made to enter the space as soon as possible to assess the degree of extinguishment and then record the time for complete extinguishment. In addition to the total elapsed time to complete extinguishment, observers clocked the exact times that each agent was actually being applied. From this data it was possible to calculate the rate of application of each agent and also the application density, the total amount of each agent required to extinguish all the fire area.

In fires in which the burning fuel spray was employed, the time was recorded when the fire fighter was able to reach the fuel supply cut-off valve and secure it.

EXPERIMENTAL RESULTS

Foam Characteristics

Some difficulty was encountered in obtaining a 6% protein concentrate solution using the FP-180 proportioner even when a second 60 gpm nozzle was connected to the discharge to step-up the throughput to 120 gpm. Analysis of the foam output with the stream shaper attached showed the following characteristics: Expansion 7.0, Drainage Time 4.2 min, and Concentration 4.5%.

The "Light Water" foams had an expansion of 10 with a drainage time of 1.5 to 2.0 minutes.

Extinguishment of Bilge Area Fire Only

The results of the fire tests where only the bilge area was on fire are summarized in Table I.

Extinguishment of Fuel Spray Fire Only

A series of tests was run to determine the effectiveness of the various agents in suppressing the intensity of the fuel spray fire to a stage where the fire fighter could secure the shut-off valve which was approximately one foot away from the fuel spray fire. In order to reduce the aggravating effect of a fire building up below, the bilge was flooded with foam prior to the spray ignition. The fuel spray did tend to push back the foam and generate a surface fire of about 20 ft^2 in area. This did not introduce a major problem unless the surface was allowed to increase to 50-100 ft^2 in area.

It was found that the foam spray patterns from the FFF nozzles with "Light Water" or protein foam were adequate to permit the fire fighter to approach and secure the valve at a fuel spray flow of 10 gpm and 120 psi pressure. The PKP output from a 30 lb extinguisher did a remarkable job of knocking the flames down when it was used in bursts of only 2 seconds. The CO_2 discharge was completely ineffective for this task.

When the fuel spray flow was increased to 15 gpm at 75 psi pressure, it proved to be beyond the capability of the liquid agents and even the 30 lb PKP unit.

Extinguishment of Combined Bilge and Fuel Spray Fire

In this series, a full bilge fire was combined with a 10 gpm fuel spray fire into one big fire problem. The planned approach was to have one fire fighter knock-down the bilge fire to where the second fire fighter could enter with a portable extinguisher, suppress the spray fire, and secure the fuel spray valve. The first fire fighter then went on to extinguish the remaining bilge fire. The data on times for conducting these operations and the quantities of agents required are given in Table II, for the various agents tried.

DISCUSSION

Extinguishment of Fires

The results given in Table I show that the four agents used were all capable of extinguishing and securing the bilge fire at application rates as low as 0.06 gpm/ft^2. The quantities of agent used in extinguishment were low, ranging from about 0.03 to 0.06 gal/ft^2, when compared to quantities normally used in gasoline fires. This is a reflection of the relatively high flash point fuel in the bilge.

Differences between the two protein concentrates, Type 5 and "XL", were slight and believed to be within the limits of experimental error. On this test it would be said they were both the same in performance. Likewise the two "Light Water" concentrates appeared to be equal in performance. The introduction of a new, inexperienced nozzleman did raise one set of values for 6% FC-194,however.

Despite the fact that the protein foams were added at a 20% higher rate than the "Light Water" foams, the latter could put out the fire in about half the time and use less than half the quantity of agent. In addition to gaining information as to the performance of the different agents employed on these bilge fires, the fire crews, timers and observers had the opportunity to get acquainted with the equipment and procedures for the more important tests which followed.

When the 10 gpm fuel spray fires were approached with the foam spray nozzles only it was surprising to find that the fire could be suppressed to permit personnel to gain access to and secure the fuel valve. Agents such as foams usually exhibit little control on a vertical type liquid fire, especially if it is from a pressure leak. The fuel valve could be secured only when the fire was limited almost to the fuel spray pattern itself. If the spray operated for longer than a 20 sec time period, a bilge fire also developed and the area became too hot to approach.

The excellent three-dimensional fire killing capability of "Purple-K-Powder" makes it the best agent for use on fuel spray type hazards. This high degree of efficiency was brought out during these tests. The first fires were approached using the handline nozzle with its 4 lbs/sec PKP discharge rate. It was immediately evident that this amount of powder being discharged in this space created an untenable environment for the fire party as well as the fire. Breathing without masks was impossible and visibility was cut down to zero. By going to the 30 lb portable extinguisher with its 50% lower discharge rate, the fire party could operate within the space. The extinguisher did an excellent job of holding down the 10 gpm spray fire with intermittent bursts of about 2 seconds duration. The cloud of powder hanging in the air produced a lingering flame suppression and spray reignition would not occur from the spark until the cloud drifted away. Of course, it was not possible to extinguish the fuel spray fire permanently because of the constant reignition source present in the spark gap.

In general, the spark gap served very well in supplying an ignition source to simulate a hot metal surface such as a high pressure steam line or boiler head at a temperature higher than the ignition point of a fuel contacting it in spray form. The problems encountered with the spark gap were concerned with high voltage leakage in the lines resulting from fire and water damage.

In order to establish the limiting size of fuel spray which could be handled with the portable PKP extinguisher, the fuel spray flow was increased to 15 gpm by using a wider slot. The 30 lb extinguisher could not extinguish this size spray fire so the limiting flow was assumed to be between 10 and 15 gpm. In actual practice the shape and direction of a rupture would probably play an important role in the flow rate which could be handled. Certainly a jet going upward and impinging on the overhead and creating an umbrella pattern would be more difficult than was the test fire.

The switch in dry chemical application rate required a modification to the test procedure because one fire fighter could no longer handle both the liquid agent and the dry chemical agent. A second fire fighter was necessary to man the small portable extinguisher. The time schedule of these tests did not allow for revamping the dry chemical system to install a smaller flow nozzle on the hoseline.

In the final test series, the "Twinned-Agent" concept was used on the combined 735 ft^2 bilge fire and 10 gpm fuel rupture spray fire. This test series was purposely run last to take advantage of the testing experience gained in the first two test series and the confidence and improved operator technique noted in the fire fighting operation.

The objective of these tests was to apply the primary foam agent until sufficient control of the bilge fire was obtained so that another operator could enter the area and knock down the spray fire with PKP, allowing a third man to secure the spray fuel valve. The operator applying the foam agent then continued agent application until the bilge fire was 100% extinguished.

Referring again to Table II, it is seen that Type 5 protein foam could not extinguish this combination bilge-fuel spray fire even with two minutes of continuous application. Furthermore, the fuel spray cut-off valve could not be reached and secured within this 2 min period because of the limited heat reduction achieved. This demonstrates the weakness of the foam-only protection system currently used in machinery spaces in combatting fuel line rupture fires. Type "XL" foam would not be expected to show improved performance in this area.

One extinguishment trial using 4 lbs/sec of PKP alone was made. The agent was applied for 60 seconds,at which time the fire party had to retreat because of breathing and visibility problems. A good knock-down was achieved but when the atmosphere cleared sufficiently to permit observation, it was found that numerous small fires still existed in the bilge from hot carbon particles and in shadowed locations. Extinguishment was completed through use of a wet agent. This test demonstrated the limitations of a dry chemical, three dimensional type agent on the test fire arrangement. The fuel spray shut-off valve could not be reached nor secured with PKP application alone.

The two runs made with Type 5 foam and PKP show a considerable difference between the amounts of foam applied. In the first fire the nozzleman reported he was getting clear water instead of foam solution at the nozzle for some time at the beginning of the application. If correct, and operation of the proportioner was erratic, perhaps the second fire test should be taken as the most representative for purposes of comparison.

The problems incurred with high application rates of PKP in confined spaces can be demonstrated by comparing the data from fires where two rates of PKP were used in conjunction with 6% FC-194 (Table II). In the first run where PKP was applied at 4 pps, 72 lbs of powder and 23 gals of "Light Water" were required. The second test using the 1.65 pps PKP rate required only 7 lbs of powder and 11 gals of "Light Water" for the same fire. The much more efficient application of both agents in the latter case is attributed to a better visibility and less "overkill". The "seek and kill" technique can be seen to be important in instances where conservation of agent is necessary but it can also be seen that the total elapsed time for extinguishment was not greatly reduced.

Comparing Type 5 protein with 6% FC-194 (averaged values) when each was used with 1.6 pps of PKP (Table II), it can be concluded that the "Light Water" - PKP combination extinguished the fire with between one-fifth and one-sixth that amount of agent required by protein-PKP. The fuel spray valve was reached and secured in one-third the time. The solution application density for complete extinguishment for "Light Water" - PKP was 0.016 gal/ft^2. Amazingly fast fire knockdown and rapid spreading ability of "Light Water" foam explains its efficient operation.

It should also be pointed out again that this decided superiority of "Light Water" foam over protein foam was obtained even though the application rate (gpm/ft^2) was 20% higher for the protein foams. The flow rate from the "Light Water" nozzle was only 50 gpm, compared to 60 gpm for the protein foam nozzle. Thus, as noted previously in this report, the application rate for "Light Water" foam was 0.058 gpm/ft^2 and for protein foam it was 0.082 gpm/ft^2 using similar nozzles.

An ultimate design of an applicator for dry chemical and "Light Water" should feature a "twinned" approach which will allow one man to activate the system and do the fire fighting with a minimum time delay and thus hold fire damage to an irreducible minimum. Past experience with field military personnel has shown the application techniques needed for dry chemical - "Light Water" to be relatively foolproof and easily learned. For this reason one man on duty in the machinery space should be able to do a creditable job of fire fighting with this equipment, even though this is not one of his normal duties. Pistol grip agent flow control valves and a properly designed mounting of the nozzles should also permit the one man to secure a fuel control valve with one hand while still holding the nozzles with the other.

Foam-Dry Chemical Compatibility

The results of these fire tests have brought about a new perspective on the problem of foam-dry chemical compatibility for shipboard fires. First, it was found that the "XL" type protein foams offer only improved dry chemical breakdown resistance as their advantage.

Second, it was found that compatibility with the present Type 5 foam cannot be considered a problem of any significance because of a combination of specialized shipboard conditions. One, the supply of foam making materials, Type 5 foam concentrate, is almost inexhaustible; two, any discharge of dry chemical must be restrained to a low flow rate within closed, interior spaces; and three, the fuels encountered are in the high flash point class.

The water available to a ship makes it possible to continue pumping for long periods, if necessary, and in this way overcome the effects of any foam breakdown from dry chemical which might have been applied. The fact that the dry chemical discharge rate must be held down to permit fire fighters to see and breathe, minimizes foam destruction because of the low ratio of amounts of dry chemical to volumes of foam. The biggest danger resulting from non-compatibility in a dry chemical-foam fire fighting system lies in the breakdown of the foam covering over the fuel and allowing reflashing of areas previously extinguished. These may actually endanger the personal safety of the fire fighters and may result in loss of the fire. However, when the fuels being extinguished have flash points of 125°F and upward, such as diesel fuel, JP-5, and black oils, reflashing is virtually nonexistent even in areas where the foam covering is completely gone. This set of conditions found on shipboard is in sharp contrast to that found in land aircraft fire fighting and rescue. In the latter instance, compatibility is still of importance because the supply of water carried is severely limited, the rates of dry chemical application from turrets or handlines can be very high, and the fuels may be of a low flash point nature.

In the light of the above discussion it is believed that there is no justifiable requirement for a new type of foam concentrate with the properties of "XL", except where specialized conditions outside those cited above exist..

"Light Water" Film Persistence

It should be mentioned that a very interesting surface film fuel protection phenomenon was demonstrated during the test with "Light Water".

Following the conclusion of each of the fire tests using "Light Water", with or without concurrent application of "Purple-K-Powder", it was found that the diesel fuel area could not be reignited, even by the customary surface priming of the fuel area with gasoline. The gasoline primed area would burn only in small patches and soon be self-extinguished by virtue of the water film spreading action of the perfluorocarbon surface active agents contained in the "Light Water" material. Even after draining and disposal of all pre-fired fuel, it was necessary to carefully wash down all bulkheads and surrounding areas with copious amounts of water and use fresh fuel if fuel ignition was to be accomplished.

CONCLUSIONS

A combined application of potassium bicarbonate type dry chemical, PKP, and Type 5 protein foam extinguished the 735 sq ft bilge fire area in the machinery space in 32 seconds, permitting approach to the valve controlling a pressurized fuel spray of 10 gpm which impinged on a constant ignition point within the space. A total of 64 gallons of foam solution were used for this action, along with 12 lbs of PKP.

The above fire problem required an average extinguishment time of only 21 seconds when combined application of PKP and "Light Water" was used. Only 12 gallons of "Light Water" solution and 7 lbs of PKP were required, giving a five to one ratio of advance in extinguishing efficiency over ordinary foam quantities.

Neither "Light Water", PKP, nor protein foam when used singly were capable of conquering the combined bilge-fuel spray fire. "Light Water" or protein foam alone could extinguish the bilge fire or permit approach to the fuel spray fire when there was no bilge fire. "Light Water" was two to three times as efficient as protein foam in extinguishing the bilge fire.

A discharge rate of 4 pps of PKP within a compartment creates a zero visibility condition and makes breathing impossible. A maximum allowable rate of 2 pps is suggested.

A PKP discharge rate of 1.65 pps from a 30 lb portable extinguisher is adequate to allow approach and extinguishment of a 10 gpm pressured fuel leak provided it is not accompanied by a spill fire underneath larger than 50 ft^2 in area.

The "XL" type of protein foam concentrate did not offer any advantage over the regular Type 5 material, from the point of view of speed of extinguishment at equal rates of application.

Dry chemical-foam compatibility did not present any problem under the shipboard conditions used in these tests when PKP and Type 5 concentrate were employed.

RECOMMENDATIONS

It is recommended that BuShips adopt a dual agent concept consisting of a portable discharge system of "Light Water" and "Purple-K-Powder" for rapid, improved extinguishment of fuel fires in shipboard engine room spaces.

It is also recommended that a self-contained, quick-operating system be designed for the purpose, consisting of approximately 50 gals of "Light Water" solution, 150 lbs of PKP discharging at rates no more than 2 lbs/sec with a single-operator "Tommy gun" type dual application nozzle connected to a live, charged, dual hose reel.

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Appreciation is also due Robert B. McCann and others of BuShips Code 432, for their strong and active support.

Mr. Charles S. Butler of NRL was an important member of the team conducting the fire tests.

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6. Military Specification MIL-E-23906A (WP), "Extinguisher, Fire, Twinned Unit ("Light Water"-Dry Chemical), Skid Mounted, 800 Pound Capacity, 30 Dec 1964

7. Military Specification MIL-F-23905A(WP), "Fire Extinguishing Agent, "Light Water" Liquid Concentrate", 26 Mar 1965

TABLE I

Quantities of Agents Required for Extinguishment of Bilge Fire

Foaming Agent	Applic. Rate Tot. (gpm)	Applic. Rate Fire Area gpm/ft²	Agent Applic. Time(sec)	Total Exting. Time (Elaps.) (sec)	Amt. Agent Used (gal)	Applic. Density (gal/ft²)
Type 5 Protein	60	0.082	105(1)	114	105	0.143
			63(2)	53	63	0.072
			40	45	40	0.054
			43	49	43	0.059
"XL-6" Protein	60	0.082	40(3)	45	40	0.063
			49	55	49	0.067
"Light Water" 25% FC-183	50	0.058	20	25	17	0.023
			23	28	19	0.026
"Light Water" 6% FC-194	50	0.058	32(4)	42	27	0.037
			27	27	22.5	.031

(1) For the first 22 sec, water only was applied because of faulty proportioner operation.

(2) Only 80% bilge area aflame when agent first applied.

(3) Only 85% fire involvement - 100 ft² in special metal enclosed area used for CO_2 fires, was not afire.

(4) New operator - used different technique - expended extra 10 sec agent combatting flicker fires at supporting column.

TABLE II

Quantities of Agents Required for Combined Bilge and Fuel Spray Fires

Agents	Application Rates				Applic. Times		Total Agent Used			Tot. Elap time for Ext. (sec)	Time to Secure Valve (sec)	Soln Applic. Density (gal/ft²)
	Total		Fire Area		Soln (sec)	PKP (sec)	Soln (gal)	PKP (lbs)	Combined Wt. (lbs)			
	(gpm)	(lbs/sec)	(gpm/ft²)	(pps/ft²)								
Type 5 Protein[1]	60	---	0.082	----	(120)[2]	---	(120)	---	(1000)	not ext.	not secured	(0.164)
"Purple-K-Powder"	---	4	---	0.0055	---	(60)	----	(240)	(240)	not ext.	not secured	(0.342 lbs/ft²)
Type 5 + PKP	60	1.65	0.082	----	110	7	110	12	927	110	40	0.150
					64	7	64	12	556	64	32	0.087
"Light Water" (6% FC194) + PKP	50	4	0.058	0.0055	28	18	23	72	264	28	18	0.031
		1.65	0.058	----	13	4	11	7	100	25	20	0.015
					14	4	12	7	107	16	10	0.016
					16	4	13	7	115	22	10	0.018

(1) Used with stream shaper
(2) Values in parenthesis indicate no extinguishment

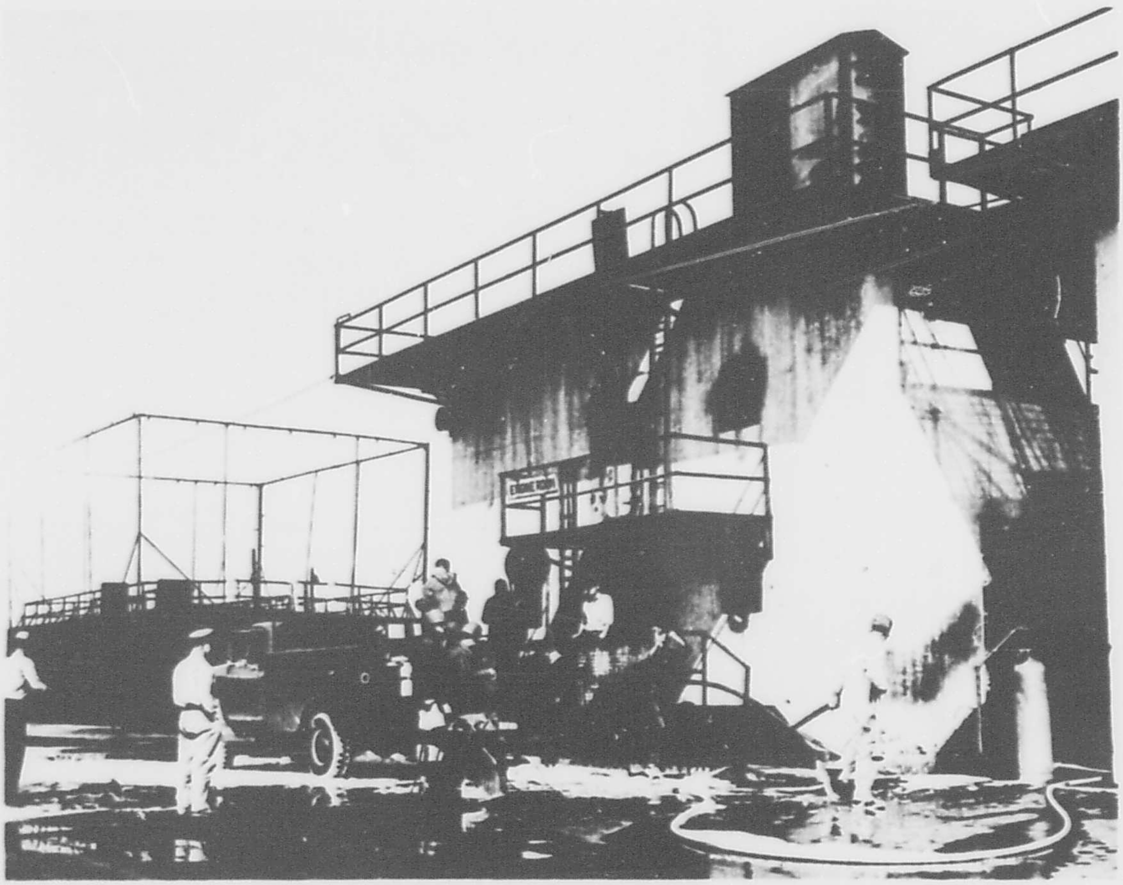

Fig. 1 - Exterior view of engine room structure

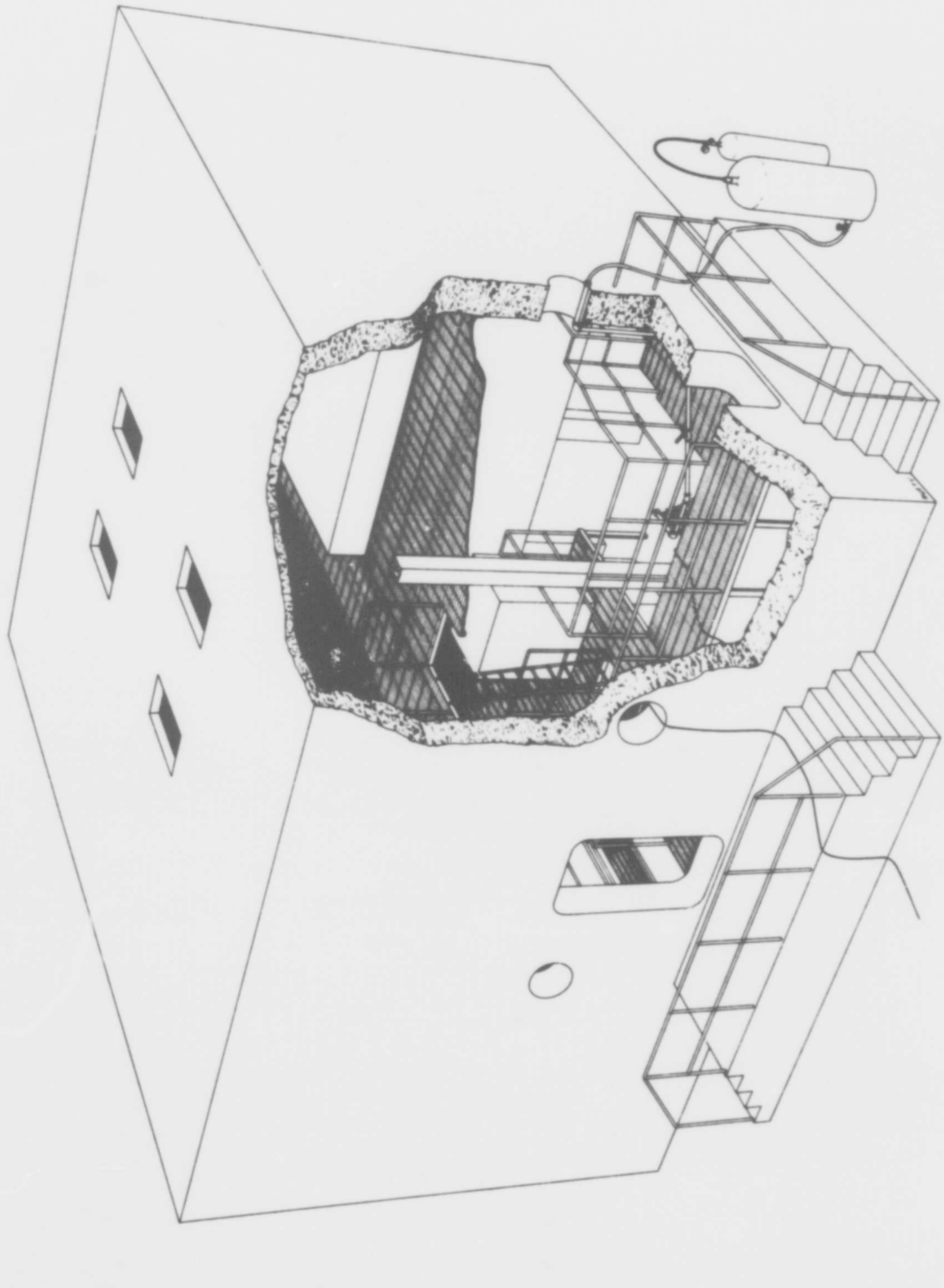

Fig. 2 - Cutaway view of engine room interior

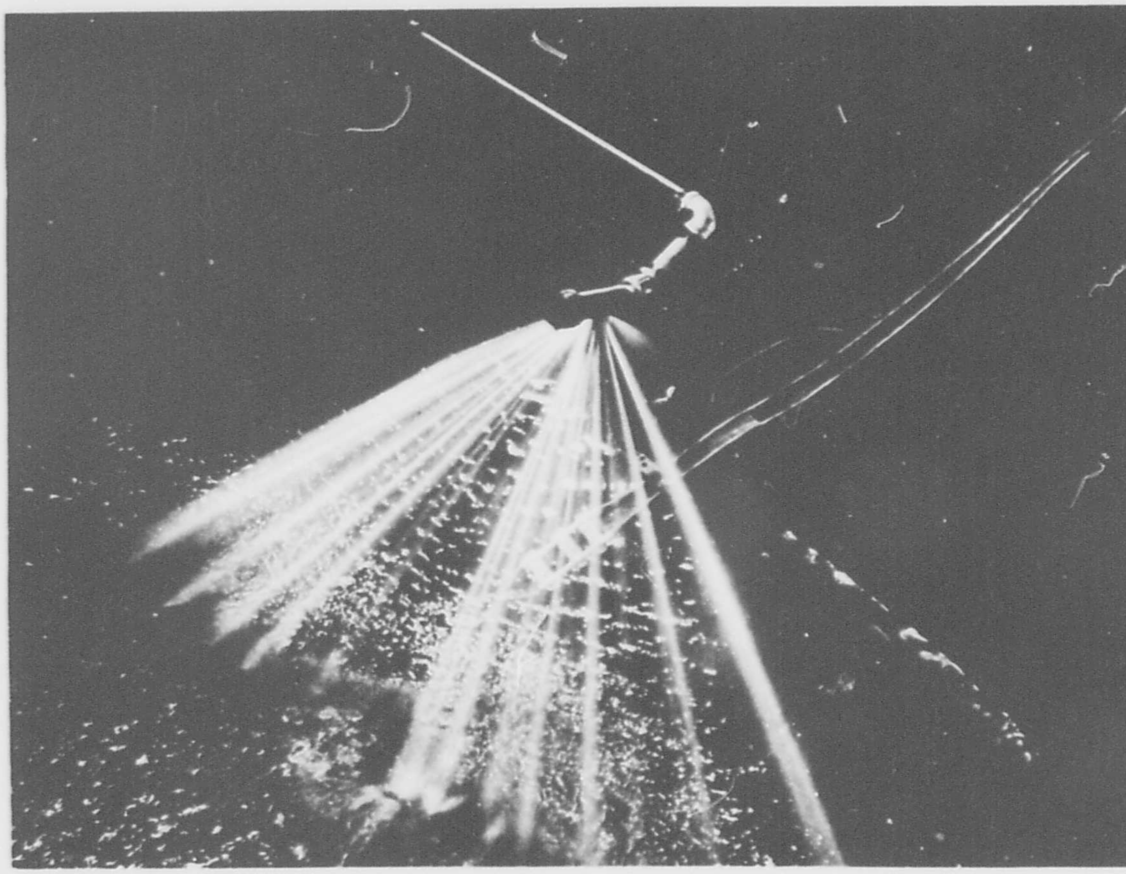

Fig. 3 - Fuel spray showing shut-off valve and spark gap igniter

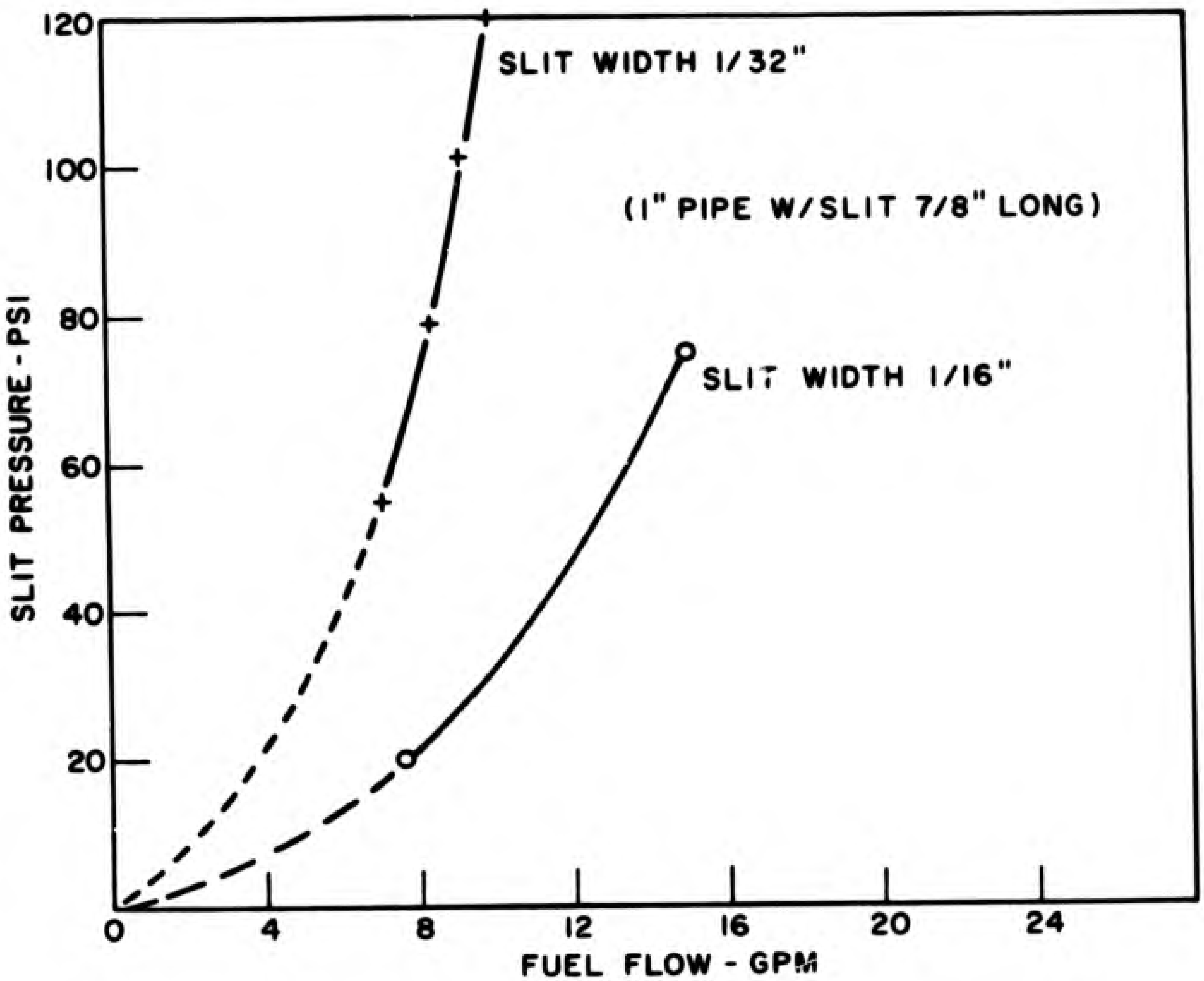

Fig. 4 - Simulated fuel line rupture - rates of flow (diesel fuel)