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Supplement 1

Toxicity and Fire Hazards Associated With Shipboard Materials

Contributed Articles
From Invited Specialists
at

Naval Research Laboratory
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NAVAL RESEARCH LABORATORY
Washington, D.C.

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Supplementary Report On

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Prepared by Contributed Articles
from Invited Specialists at
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the Naval Weapons Laboratory, Dahlgren, Virginia,
and the Naval Applied Science Laboratory, Brooklyn, New York

Organized and Edited at the Request of the
Chief of Naval Research by Dr. W. A. Zisman, NRL, Washington, D.C.
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Section I. Introduction

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Origin and Purpose of This Report

1. This report is a supplement to NRL Memorandum Report 1816 of September 18, 1967, concerning "Toxicity and Fire Hazards Associated with Shipboard Materials." It was learned last September that the Naval Weapons Laboratory, Dahlgren, Virginia, and the Naval Applied Science Laboratory, Brooklyn, New York, had valuable research and development background as well as recommendations to contribute on the subject of toxicity and fire hazards on board naval ships. Rather than delay issuing Memorandum Report 1816, which was urgently needed, it was decided to issue a later supplementary report as rapidly as the new material could be assembled, edited, and reproduced. In addition, the subject of "Reticulated Foam," to be used for prevention of explosions in aircraft fuel tanks, is now unclassified, so it too is included in this report. The enclosed supplement is hereby submitted and thus completes the task assigned this Laboratory and the editor by the Chief of Naval Research in his memorandum of 3 August 1967.

2. The definitions of short-term, intermediate-term, and long-term recommendations used in this supplement are precisely those given in the Introduction, page 8, of Memorandum Report 1816, and therefore they will not be reproduced here.

3. We hope that the several state-of-the-art summaries and well-focused sets of recommendations included herein will prove helpful to the Navy in focusing its efforts as rapidly as possible to decrease the incidence and seriousness of fire on board naval ships.

Section II. Fire and Toxicity Hazards of Explosives and Propellants

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Introduction

1. Ranking high on the list of hazardous materials placed aboard the modern naval vessel are the explosives and propellants. Unless treated with extreme care these materials may not only cause a fire but may turn an otherwise minor incident into a major catastrophe. When ignited they produce heat, toxic vapors, pressures, and fragments which under uncontrolled conditions are detrimental to a ship's structure and personnel.

2. The explosives carried aboard the naval vessel are normally in a solid form. Until recent years propellants have also been in a solid form because of ease of packaging, relative safety in handling and readiness at the time of need. Liquid propellants for naval use were first considered after World War II. As initially conceived, their use would have required stowage in bulk with transfer to the employing ordnance just prior to use. Understandably, there was reluctance on the part of the Navy to employ liquid propellants under these conditions aboard crowded naval vessels. With the advent of the prepackaged concept the use of liquid propellants became practical, since the need for bulk stowage and for transfer and topping operations no longer existed. Indeed, experience with the prepackaging concept has proven that the safety of liquid propellant ordnance compares favorably with solid propellant ordnance.

3. The hazard potentials of explosives and propellants, whether liquid or solid, justify the use of special areas, special equipment, and special procedures. The need for these in the past has been determined primarily by unfortunate experiences; however, more recently the need has been based upon investigative research. Significant progress has been made in perfecting safety and damage control equipment and systems, particularly for those below-deck areas where items containing explosives and propellants are stowed and checked out. More progress is indicated for on-deck areas used for handling, loading, launching and other operations.

Water Coolant Systems

4. For many years sprinkler systems have been installed in high explosive magazines. Because of the "violence" of high explosives, the systems were designed primarily to control fires of nonexplosives within these areas or to reduce the temperatures resulting from fires in adjacent areas in order to prevent cook-off of the explosives. Sprinkler systems are now installed also in areas where items containing liquid or solid propellants, which are considerably less violent than explosives, are stowed. In these areas it has been found that the sprinkler system may serve as a means of subduing a propellant fire or reducing the severity of the resultant environment to prevent chain ignitions of other units not involved initially. The environment produced by the burning of propellants may differ from that produced by a "normal" fire in a compartment in several respects: the average rate of rise of pressure and temperature may be significantly greater, there may be significant

temperature and pressure gradients in the compartment, and extremely high-temperature, high-velocity gas streams may exist. In addition, the products resulting from combustion of propellants are different from those of other fires. It has been possible to obtain extensive data on the value of the sprinkler system under this expanded concept since systems have been used in magazine hazard investigations conducted at the Naval Weapons Laboratory, Dahlgren, since 1956. These investigations have provided the most realistic evaluation of the sprinkler system to date. To be effective for burning propellants, the tests indicated that a shorter actuation time was necessary and that the system had to be made more reliable. Actuation time was reduced by prefilling all sprinkler lines from the main control valve to the sprinkler heads with water. Keeping the water in these lines under conditions of shock, roll, and vibration of the ship was a major problem and required the design of new sprinkler heads. By prefilling the lines and making changes to speed up the control valve, the actuation time was reduced from the previous interval of 10 to 20 seconds to 0.8 to 1.0 seconds (1). The liquid propellants currently in use are hypergolic and a fire will result if both spill simultaneously and mix. Sprinkler systems have proven to be very effective, however, in controlling these fires (2,3,4). Sprinkler systems have been used only in enclosed compartments.

5. Special sprinkler system arrangements have been developed and used to keep the warhead components of missiles cool in the event of a fire (5). Other systems have been tailored to give uniform distribution to all areas

of congested magazines. These systems overcome the "umbrella effect" presented by the upper units in a stowage arrangement. These systems have been used only in magazines.

6. Another safety system using water is the water-injection system. This system was designed to apply water directly to the burning surface of an accidentally-ignited, solid, propellant grain to quench or diminish the burning rate. Since the water must be injected through the nozzle of the unit containing the propellant, the water pressure must exceed that of the combustion gases flowing in the nozzle. It is therefore advantageous to commence water flow as soon after ignition as possible, while the chamber pressure is relatively low. In conjunction with the Applied Physics Laboratory of Johns Hopkins University, the Naval Weapons Laboratory has developed an effective water-injection system for use with the TARTAR and TERRIER missiles (5). Key components of the system are the detector-nozzle assembly, which permits water flow to commence within a few milliseconds of ignition, and the pressure accumulator which maintains a high flow rate during the normal recovery interval, characteristic of the system's water pump. Large quantities of water are needed to be effective because of the thermodynamic properties of the propellant and the difficulty in applying water to all surface areas of the propellant that may be burning. This system has been used only in magazines.

Coolants Other Than Water

7. To date water is the only coolant that has been used in sprinkler and water-injection systems. This coolant is, of course, readily

available to the naval ship. Since these systems are not manually directed (aimed) toward the area of greatest need, a large percentage of the water consumed may be wasted. It is doubted, therefore, that coolants more expensive than water should be used in these systems. In contrast, fire-fighting hoses and other systems are manually directed; therefore, coolants other than water may be more efficient. Since sprinkler and water injection systems are automatic, reliable and accurate, prompt and correct detection is a must. There have been reports from the service that the older automatic sprinkler systems have lacked sufficient reliability and have been secured because of false actuations.

Controlled or Special Forms of Venting

8. Secondary, or chain, ignitions of propellants or explosives may be prevented or delayed through controlled venting of storage and handling compartments, particularly in conjunction with other damage control systems. Controlled venting can reduce the heat and pressure environment within the compartment. Studies have been conducted at the Naval Weapons Laboratory of the need for venting systems for magazines in certain attack aircraft carriers, the feasibility of providing such systems, and the parameters governing system design. At least one study (6) indicated that it is feasible to provide such a system and that the expected cost is not unreasonable in comparison with the risk involved in not providing it, on the basis of tentative estimates of costs and probabilities of accidents. The study recommended that a tentative decision to provide venting be made and that this decision be reviewed and reconsidered after preliminary designs and other studies have produced a basis for more accurate estimates of the costs involved.

9. Exhaust ducts or plenum chambers have proven to be useful as special forms of venting (7,8). They have been designed so that the gases and flames from an accidentally ignited propellant of a missile motor will be ducted directly to the atmosphere, keeping the temperature of the compartment near normal and preventing impingement of gases and flames on other units. All motors in a compartment are connected to the same plenum chamber by using a pressure-actuated gate (blowout-non-blow-in plate) behind each motor. These systems have been used in missile magazines and check-out areas.

Other Safety Devices and Systems

10. For many missiles and rockets the containers serve as a safety system. For others, flame shields are provided in deep and ready service stowage. Most missile and rocket motors contain a flame-resistant nozzle closure or one is provided in stowage (9,10). Each of these concepts is intended to prevent the flames from an ignited unit from impinging on the propellant of another.

11. Many safety systems are effective only if the item containing the propellant is restrained during burning. This is accomplished by providing restraining structures or by diverting all or a portion of the exhaust gases so as to cancel effectively the item's thrust (11). Restraining structures include tie bars, clamps, abutment plates, and stanchions. Gas diversion techniques include providing a temporary exhaust opening in the case (opposite the nozzle) or by attaching thrust neutralizers or nonpropulsive attachments (NPA's) to the nozzle

to divert the exhaust gases radially and uniformly. The former procedure is known as nonpropulsive assembly. At some time prior to use the unit is made propulsive by blocking off the opening opposing the nozzle or by removing the NPA. These methods are not being used as extensively as in the past because of the trend toward all-up assembly of missiles and rockets during all logistic phases and because of several accidents where service personnel forgot to remove NPA's under the stress of combat.

Cook-off Time

12. A research effort was initiated at the Naval Weapons Laboratory as a result of the USS FORRESTAL (CVA-59) incident to determine the comparative cook-off time of various bombs under representative "fuel fire" conditions such as existed on the deck of the FORRESTAL. The effectiveness of insulative coatings, applied to either the inner or outer surfaces of the bomb case, is being evaluated. The results of this effort should be applicable to handling areas such as hangar and flight decks as well as to magazines. Limited results to date (12) have shown that there is a significant difference in the cook-off times and violence of reaction between bombs loaded with various explosive compositions.

Exclusion of Flammable Materials in Vicinity

13. Much has been done to prevent the ignition or cook-off of explosives and propellants by excluding flammable or reactive materials from their immediate vicinity. Research is being conducted by naval

activities to select favorable construction materials and protective finishes for ships. These efforts have been reported elsewhere in Naval Research Laboratory Memorandum Report 1816 (13). A few practices such as packaging the BULLPUP engine in fiberboard shipping containers are counter to the philosophy of excluding flammables. It would appear advantageous, even now, to correct these practices.

Toxicity Hazards of Liquid Propellants and Warning Devices

14. In addition to the potential fire hazard, the liquid propellants currently in use, as well as those proposed for use in the immediate future, also present a toxicity hazard. Protective clothing and breathing equipment have been developed and are available to permit personnel to remove liquid "leakers" and perform other tasks (14). When liquid propellant units were first placed aboard naval vessels, toxic vapor detector systems, such as the GE MAF-IRFNA system, were installed permanently; however, subsequently they were found to be too sensitive and could not discriminate accurately (15). They were actuated by insignificant concentrations of propellant vapors or by the vapors of other volatiles from materials such as paint. They were consequently removed. Portable detectors are available on ships carrying liquid propellants, but these are rather inaccurate and lack the convenience of the permanently installed systems.

Safety and Damage Control Systems for Ships

15. Safety and damage control systems have not been overlooked entirely for on-deck areas where explosives and propellants are moved,

loaded on, or in, employing systems, and/or launched or fired. Many systems for the hangar and flight decks of aircraft carriers, for example, have been discussed elsewhere in Naval Research Laboratory Report Number 1816 (13). Others have been developed and are serving well, or are being developed. Blast deflectors, for example, are provided on the MARK 102 and 105 Rocket Launchers to direct exhaust gases away from ship's structure, from personnel on deck and from adjacent rounds and launchers. Where blast deflectors cannot be used, deckhouses, launcher loading doors, and other vulnerable structures are coated with insulative materials to protect them from the effects of firings. Finding suitable materials is difficult since they must withstand ignition shock, pressure, heat, and gas and particle erosion. At the same time they must not add appreciably to the weight of the structure particularly when used topside. An extensive effort has been conducted, for example, by the Naval Weapons Laboratory, Dahlgren (16) to find materials to protect the deckhouse of a guided missile cruiser behind the TARTAR launcher. Numerous materials such as intumescent paints, RTV silicone rubber compounds, stainless steels, etc., were evaluated in this program.

16. During gun, missile, and rocket firings, significant quantities of gas are produced. Because of the usual motion of the ship relative to the gas cloud and because firings have normally been conducted under favorable atmospheric conditions, shipboard toxicity problems in the past have been minimal. Propellants are being developed now which will produce gases that are more toxic than present propellants. Also,

increased firing rates of new weapon systems will result in gases being produced at a greater rate, with more gas produced during a given operation. Whether or not potential toxic hazards can be discounted in the future is a matter that requires consideration. Will gas masks or OBA's be required by on-deck personnel in the future? To what extent will this equipment degrade their performance? How will personnel belowdecks be protected from combustion products that may be drawn into the ship's ventilating system? Answers are now being sought to these and other personnel safety questions. Answers are not easily found. In a recent study to determine whether a new rocket propellant could be used safely aboard ship, all available films of firings from the class of ship involved were reviewed to approximate the average time that the ship remained within its own gas cloud. It became apparent, however, that the answer would be biased, since films of firings were made only on days when atmospheric conditions and the wind direction were favorable. In addition to the "paper study" approach, the Naval Weapons Laboratory has a team of scientists that monitors the environments aboard each class of ship as each new system is installed and tested or as problems arise subsequently. Environments monitored include blast, temperature, and gas toxicity. One technique employed is to use Naval Material Laboratory skin simulants, an inert material with an embedded thermocouple, the output of which can be related to burn damage to human skin. Transducers are employed to measure radiant and total energies. A survey has been conducted recently, for example, aboard the Italian Navy Ship DUILIO (18).

17. Programs now in progress to prevent accidental ignition of explosives and propellants and to reduce adverse effects from ignitions should be continued. New programs should be initiated when considered necessary. Current and future efforts to make explosives and propellants safer should be given proper emphasis since both the USS ORISKANY (CVA-34) and the USS FORRESTAL (CVA-59) accidents were caused by accidental ignitions of these materials in one form or another.

18. Short-term recommendations:

a. The HERO (hazards of electromagnetic radiation to ordnance), electrostatic, vibration, drop, and other safety tests of all new weapons systems should be continued. A safety review of each new system should be made from concept through development and service employment.

b. A program should be formulated to determine the safety requirements for each new system. This program should specify the complete gamut of safety tests considered necessary.

c. The series of cook-off tests now in progress at the Naval Weapons Laboratory should be continued and should not only encompass bombs, but rockets, missiles, and other ordnance as well.

d. Training of operating personnel, placing increased emphasis on safety for explosives and propellants, should be continued.

e. The need for check-out of systems, particularly of firing circuits, should be reduced. Where check-out is necessary, circuit-testing equipment which cannot produce ignition should be provided.

f. Any modifications to firing systems should be carefully reviewed for possible hazards from induced radio frequency currents.

For example, a "safety" ground may complete a circuit for such induced currents. The multipronged dummy shorting-plug suggested in Section V, paragraph 6, of Naval Research Laboratory Memorandum Report 1816 (13) might create such a hazard unless suitable precautions are taken.

g. Stowage and handling areas aboard ship should be reviewed to determine if the safety systems provided, such as sprinkling, are adequate. Special systems may be necessary as in the case of the ORISKANY where a method of dumping ignited flares overboard (19) was found to be necessary. Other possibilities, such as spreading fire blankets over explosive or flammable items when they are stowed in areas where systems do not exist, should be investigated.

19. Intermediate-term recommendations:

a. A study of the feasibility of incorporating an out-of-line or comparable safety system in the igniter of each rocket or missile motor/engine should be made. This study should determine the minimum weapons caliber for which this approach is practical, considering the cost of providing the system versus the possible consequences of an accidental ignition, the mechanical problems involved, and other related factors. It is conceivable that an out-of-line ignition system would have prevented the FORRESTAL and ORISKANY accidents. An out-of-line system is one in which at least one of the explosive elements of the ignition train is displaced sufficiently so that ignition of "upstream" elements cannot propagate beyond this element. The element is moved to an in-line position at some time prior to the intended firing.

b. Fire-fighting equipment as effective as the sprinkling systems in stowage areas should be provided for above-deck operational areas.

It is preferable that this equipment be automatic, but if this cannot be done, then some protection from blast and small fragments should be afforded to fire-fighting personnel. A review of films of the FORRESTAL accident indicates that all effective on-deck fire-fighting efforts ceased (understandably with the equipment available) when the first bomb detonated. The use of pedestal-mounted, fireboat nozzles around the catwalk of a carrier deck, for example, should be considered. The operators for these nozzles would be below the flight deck level; however, additional shielding could be provided. Fireboat nozzles having a range of 250 feet are believed to be available. It is estimated that three nozzles positioned around the periphery of the deck of the FORRESTAL would provide complete single coverage of the deck. Six nozzles would provide double coverage. The nozzles would be rugged and dependable since they would not be affected by salt spray or foreign material. This system could be used to supplement the Twin-Ball Fire Fighting Unit system developed by NRL.

c. Fire-fighting systems and procedures should be thoroughly tested. Tests should be conducted to determine the effectiveness of systems and techniques; for example, the most effective means of approaching fires at various areas of flight and hangar decks with available equipment should be determined. In these tests instrumented explosive and propulsion unit simulations could be used to determine cook-off time and, consequently, the effectiveness of the technique.

20. Long-term recommendations:

a. Squib and fuze-safety systems for air-launched weapons are needed which are removed only at the time of catapult launch (by the acceleration force) or by the pilot during flight. As an alternative, nonpropulsive attachments (NPA's) that do not have the disadvantages of current NPA's need to be developed.

b. Research is needed on more reliable toxic-vapor detector systems, including permanent and portable active systems and passive systems to be worn by personnel (comparable to radiation exposure badges).

c. Research should be continued on the tolerance of humans to the heat and toxic fumes produced by explosives and propellants. In particular there is a need for data on short-interval exposures (from milliseconds to minutes in duration).

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Section III. A Flame-Arrestor Material for Use in Aircraft Fuel Tanks

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Introduction

1. A novel and promising flame-arresting material for prevention of fires and explosions in aircraft fuel tanks was not included in Naval Research Laboratory Memorandum Report 1816, Section II, (1) for security reasons. Initially classified as "Secret," the material has since been declassified and was announced publicly on 14 September 1967 (2,3). The technique involves the insertion of the flame-arresting material inside the fuel tanks so that the tanks are essentially filled with it.

Nature of Reticulated Foam

2. "Reticulated Foam," as the flame-arresting material is called, is an open-celled, orange-colored, polyurethane foam which somewhat resembles an artificial sponge in appearance except that it consists mostly of voids, being a three-dimensional network of interconnecting strands. The foam was developed by the Scott Paper Company at Chester, Pennsylvania and later adapted by the Firestone Tire and Rubber Company at Akron, Ohio to reduce fuel "slosh" or "surge" in racing car tanks (2). The possibilities of using the foam to prevent or retard fires interested the Air Force, and they sponsored the original research to investigate its potential.

3. The foam has about 8 to 15 pores per lineal inch, with an average of ten. This is equivalent to a pore size of 0.08 to 0.13 (average 0.1) inches per pore. It weighs about 2 lb/cu.ft. and consists of about 97% voids. Thus, in a tank, it would displace about 3% of the fuel volume. On drainage there is also a retention of from 1 to 2% of the total fuel due to wetting of the foam so that the total penalty in fuel volume loss is from 4 to 5%. It is apparently fuel-insoluble, and after a single washing by filling the tank with fuel, it does not appear to have any deleterious effects on later charges of fuel, nor vice versa. Above 200°F it becomes unstable. Because it is so porous, fuel can run through it very readily and, therefore, there are no problems of pumping or drainage.

Reticulated Foam as a Flame Quencher

4. The Reticulated Foam apparently functions as a flame arrestor so that even a source of ignition, e.g., static, incendiary bullets, etc., will not cause a fire or explosion inside the tank. Flame-arrestor devices (of which the miner's safety lamp is an example) are designed to contain a number of small apertures or passages which provide sufficient surface to cool and extinguish (quench) a propagating flame provided its velocity is below certain limits. Pore spaces of about 0.1 inch would be expected to quench the flames of typical hydrocarbon-air mixtures at atmospheric pressure under quiescent conditions. The Bureau of Mines (4) has tested Reticulated Foam extensively for flame-arrestor effectiveness in both small-scale and full-scale flame propagation experiments with flammable gas mixtures of representative

hydrocarbon fuels and air at ambient temperature and various pressures. They found the foam material to be very effective in preventing fires and explosions under all conditions of their tests. Tests by the Air Force (5) on actual tanks have shown that an unprotected tank containing JP-4 at normal temperatures explodes violently when an incendiary bullet is shot through the vapor space, whereas a similar tank is indeed protected by the Reticulated Foam even when the incendiary bullet is lodged inside the tank and continues to burn. They have also found that other fuel problems caused by water, dirt, and microorganisms are not accentuated by the presence of the foam in the tank.

5. It must be recognized that penetration or rupture of a tank below the liquid level of the fuel will still allow fuel to spill freely, posing a fire hazard outside the tank similar to that from an unprotected tank. In this regard, the foam offers little protection in the event of a crash or violent rupture. The Navy has also been experimenting with Reticulated Foam, including incorporating it in the fuel tanks of operational aircraft. In some of these tests, the presence of foam in a tank full of fuel did seem to impart a degree of shock attenuation so that the tendency of the tank walls to rupture (or tear) was lessened when the tank was hit by a projectile (6).

Potential Use in Jet Aircraft Fuel Tanks

6. The Navy uses primarily JP-5 (a high-flash-point kerosene) whereas the Air Force uses mainly JP-4 (a wide-cut gasoline) for jet fuel. Because of its high flash point and low vapor pressure, JP-5 vapors in the ullage of a tank are ordinarily below their lower flammable

concentration limit. However, as was shown in World War II by Sullivan, Wolfe, and Zisman (7) for petroleum hydraulic fluids, and by Hedrick (8) for kerosene, incendiary bullets can indeed cause fires and explosions in unprotected tanks due to shatter followed by liquid spraying and subsequent mist formation, even for low-volatile fluids. Thus, even though the low-volatile JP-5 should offer less hazard than JP-4, it still cannot be considered completely safe when a fuel tank is hit by incendiaries or other high-velocity fragments.

7. Most of the other proposed inside-the-tank quenching devices, such as inerting and flame-quenching chemicals, foams, etc., are one-shot affairs. Reticulated Foam, however, offers protection against repeated sources of ignition. The main disadvantages of the foam are its weight, fuel volume loss, inability to withstand temperatures in excess of 200°F, and the need for removal in order to clean the tanks. Also, there are some airplane tanks in which it would be difficult to install the foam because of structure. However, it is sufficiently promising as a protective measure so that the Air Force is now in the process of approving it for operational use (5). In addition, the Federal Aviation Agency is studying it for use in commercial aircraft (3).

8. Short-term recommendations:

a. It is recommended that the Navy pursue the use of Reticulated Foam for aircraft subject to enemy fire, especially incendiaries, weighing the gain in fire protection against the trade-off of the weight, maintenance problems, or other penalties imposed. This should be done on a basis of aircraft type and operational requirements.

9. <u>Intermediate-term recommendations</u>:

a. The virtues of Reticulated Foam could offer some advantage in retarding the spread of fires as a result of flying fragments between adjacent aircraft when they are assembled in close array, such as on an aircraft carrier, or even when land based. This concept should be tested experimentally, e.g., at the Naval Weapons Laboratory, Dahlgren using techniques comparable to those described in references (7) and (8).

b. Data should be obtained including field experience, on the effects of temperature, temperature cycling, vibration, moisture, and aging on the integrity and elasticity of Reticulated Foam to ensure that foam debris will not become a problem, that the foam will not lose its effectiveness for fire protection, and that other undesirable effects on jet fuel or fuel systems will not occur. The effect of Reticulated Foam on generation and discharge of static electricity in the fuel tank or lines should also be investigated, even though it would be expected that electrostatic spark ignited fires would be quenched before they could get out of hand.

c. Variations in foam structure should be studied, such as pore size, type of polymer, and geometric arrangements of "packing" the foam inside the tanks, to decrease the penalty imposed by the foam in weight and fuel volume loss and still retain protection.

d. The use of flame-arresting materials, such as Reticulated Foam, may also be advantageous in other than aircraft fuel tanks, for example, in storage tanks for jet fuels, gasoline and other flammables on ships and ashore (e.g., fuel dumps). These and similar potential uses should be investigated.

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Section IV. Shipboard Fire Protection

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Introduction

1. One is amazed, especially in these days of technological advances, how little is understood and how little can be done in the event of a major conflagration. In short, the "state of the art" has a long way to go, and although in the last twenty years the fire engineering field has probably progressed further than in any other corresponding period in history, it is also true that there is frequently excessive delay in implementing these developments into practical everyday use. Since 1957 the Naval Applied Science Laboratory (NASL) has been engaged in productive fire-fighting research and development which was pointed toward resolving specific fire-fighting problems of the Navy. In this connection we have cooperated with industry to further this end and fire-fighting technology in general.

High-Expansion Foam System

2. A liquid fuel fire in a shipboard engine, boiler or machinery compartment is one of the more serious types of fire that can occur on shipboard. Such fires can be very difficult to fight because of the obstructions presented by machinery and because the fire also occurs in sumps and other inaccessible places beneath machinery. The compartment fire may be made still more inaccessible by the intense heat and smoke that fills the compartment, necessitating the evacuation of personnel.

That this is an important and continuing problem is evident from the many reports within the past few years of serious liquid fuel fires in engine, boiler, and machinery spaces in naval and merchant marine vessels. Therefore, we have been investigating the effectiveness of extinguishing agents for fighting liquid fuel fires in shipboard compartments. The Laboratory's investigation showed that the extinguishing agents presently available on shipboard (waterfog, mechanical foam, dry chemical powder, and carbon dioxide) were all effective, but they were only adequate for combatting fires in accessible spaces. The most effective of these agents are protein-stabilized mechanical foams which in a six percent water solution produce a closely knit foam-bubble structure having an expansion ratio of eight volumes of foam per volume of foam solution (1). This provides a relatively rigid blanket which has high heat resistance and is very efficient when it can be applied directly on a fire (2).

3. Because of the effectiveness of foam, this Laboratory investigated the possibilities of a "high-expansion foam" which had originated in England (3,4). High-expansion foam was first introduced into this country by the Bureau of Mines as an effective extinguishant for coal mine fires (5,6). This agent is a lauryl-sulfonate-base surfactant liquid which in a two percent concentration in water, with a high-expansion foam generator, will provide foam at ratios of from 400 to 1000 volumes of foam per volume of foam solution or from 50 to 125 times the volume of foam produced with the presently used protein-

stabilized mechanical foam solution and foam-generating equipment. Although high-expansion foam does not provide as dense a blanket and is not as heat resistant as mechanical foam, it is generated in a much larger volume and is sufficiently fluid to flow over, around, and under obstructions and to enter otherwise inaccessible areas to extinguish fires anywhere in a compartment (7,8,9).

4. From a review of the work conducted in England and in this country, this Laboratory found that the commercially available foam-generating equipment was unsuitable for shipboard service primarily because of excessive size, weight, lack of sufficient ruggedness, lack of a suitable foam-discharge guide, and susceptibility to failure or malfunctioning by corrosion or clogging. The foaming agents available were likewise unsatisfactory for shipboard service because of their failure to foam with seawater. Consequently, this Laboratory developed a foam-generating system which eliminated the above deficiencies (10, 11,12). A suitable shipboard foam generator, designated as type FG-1, is covered under a Laboratory procurement specification (13). For the development of high-expansion foaming agents for use with seawater, the cooperation of several foam specialty companies were obtained; namely, Walter Kidde Co., Mine Safety Appliances, Inc., Chemical Concentrates Corp., Mearl Corp., and National Foam Systems, Inc. A suitable foaming agent, designated as FA-1, was developed and is also covered under a Laboratory procurement specification (14). The FG-1 generator is a simple device. Air is blown by an electrically powered fan onto a Dacron cloth screen cone while the screen is being thoroughly

wetted by a two percent water solution of foaming agent at a rate of 25 gpm. The agent is introduced into the generator intake by an eductor in the fire main hose line. The foam produced by this system is ejected from the generator (shown in Fig. 1) at the rate of 1500 cubic feet per minute from an extensible foam guide (15) attached to the generator. The foam guide permits discharge of foam either vertically or horizontally. Fire-fighting personnel need not remain in the vicinity of the foam generator during a fire since the eductor can be at any convenient location of up to 250 feet from the generator. The FG-1 unit weighs approximately 130 pounds and can be readily carried by two men. After the system is set up, only one man is required to manipulate the equipment during a fire-fighting operation.

5. At a demonstration of the FG-1 foam generator conducted for the training personnel of the Naval Damage Control Training Center, Philadelphia, diesel fuel fires in the 735-square foot bilge areas in simulated engine and boiler room compartments were controlled in 90 seconds and extinguished in 2 minutes. At a test conducted by the Fleet Training Center, Norfolk, for COMTRALANT, the FG-1 system extinguished a 560-square foot diesel fire in a simulated hangar bay in 75 seconds. This system is presently undergoing service evaluation by the following Navy shore activities and Fleet units:

Naval Damage Control Training Center, Philadelphia
Fleet Training Center, Norfolk
Fleet Training Center, Newport
Fleet Training Center, San Diego

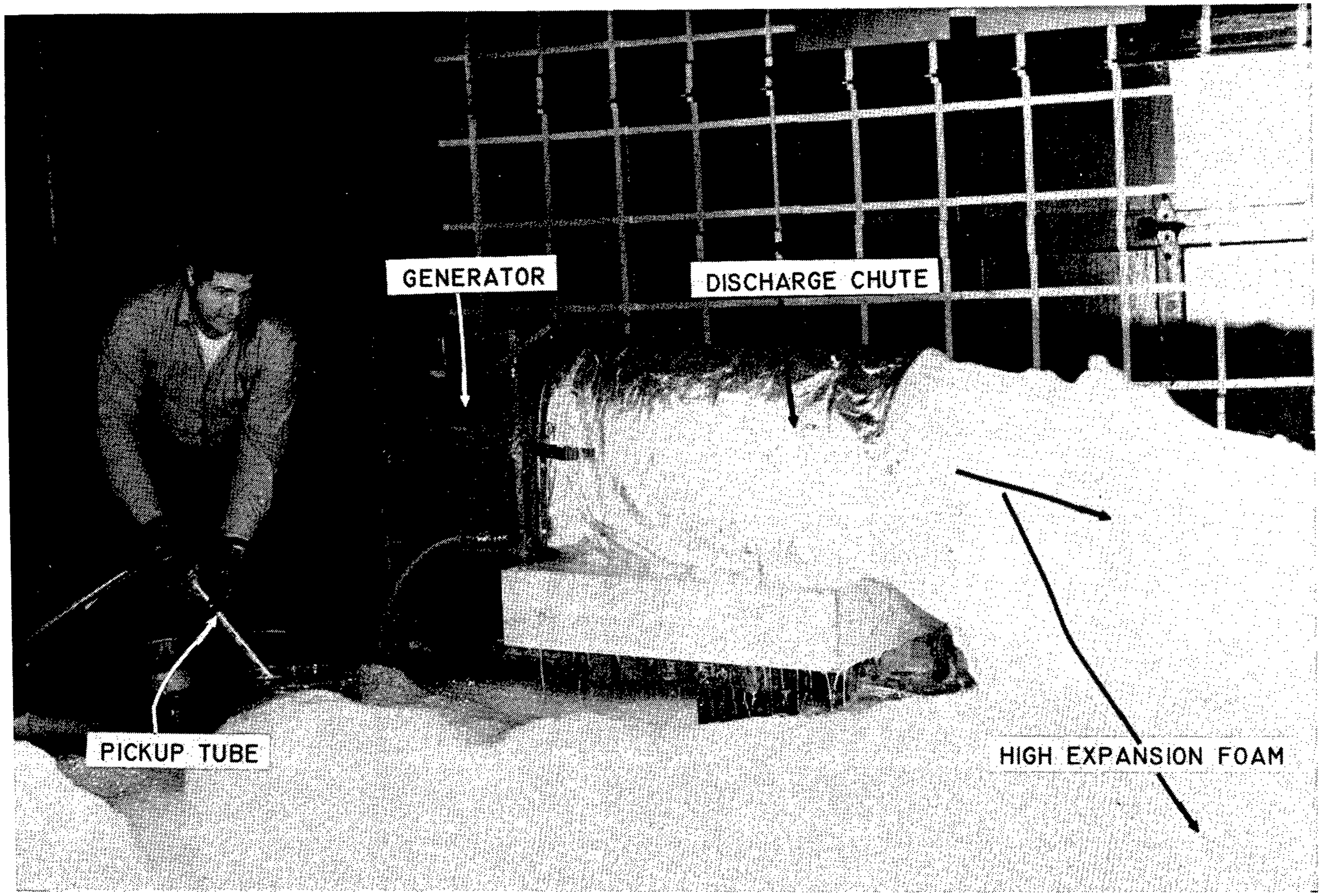

Fig. 1 - Portable high expansion foam system

Treasure Island Fire Fighting School, San Francisco
USS INDEPENDENCE (CVA-62)
USS HARLAN R. DICKSON (DD-708)
USS RIGEL (AF-58)
USS MAUNA KEA (AE-22)
USS BETELGEUSE (AK-260)

6. Current work at the Laboratory in the field of portable high-expansion foam units is aimed toward obtaining worthwhile improvements in the design of the FG-1 generator. These include the replacement of the electrical driven fan with one that is hydraulically powered and the replacement of the Dacron cloth screen with one of stainless steel construction. The utilization of portable, high-expansion, foam systems and low conductivity foaming agents for submarine fire protection are also being explored. Additional studies have indicated the feasibility of installed (fixed) high-expansion foam systems for fire protection of stowage spaces aboard cargo vessels (16), large shipboard machinery spaces and carrier hangar bays. Methodology has been devised and preliminary tests have been conducted to obtain design criteria for these installed systems (for Class A, B, and C fires). These criteria include the study of the optimum expansion ratio of foams with respect to fire performance and fluidity, minimum rate of foam rise, and the nature of the air supplied to the foam generators.

Protein-Stabilized Mechanical Foam Liquid

7. Since 1942 the protection against liquid fuel fires in the military service has depended primarily on the use of protein-stabilized, mechanical foam-liquid. Essentially, this liquid consists of a water

solution of hydrolyzed proteinaceous material which is stabilized and adjusted with bactericides, freezing-point depressants, chemical buffers, and inorganic salts. The mechanical agitation of foam-liquid, water, and air produces a mass of foam bubbles of lower specific gravity than all commonly used shipboard flammable liquids. This provides a relatively tough, stable, foam blanket which moves progressively across a burning surface to control and extinguish the fire by forming a seal between the volatile combustible vapors and the atmosphere. The foam maintains its stability because it is designed to resist attack by fuels commonly found in the Navy. Specification procedures and test criteria developed at this Laboratory for determining performance capabilities of this fire-extinguishing agent are used in the current fire-fighting, foam-liquid specification (1). NASL has had the responsibility for monitoring foam-liquid inspection and qualification testing for all the Armed Services and enforcing the related specifications and standards.

Deterioration of Foam-Liquids

8. Although a wealth of information and performance data are available on protein-stabilized mechanical foam-liquid, the storage life of such fire extinguishants remains an unknown factor. Some foam-liquids have deteriorated in less than a year, whereas others have been in storage in warehouses and on board ships for ten years or more and are still in good condition. Studies conducted at this Laboratory (17) have indicated that when a foam-liquid deteriorates in storage, the rate of deterioration is usually accelerated by any one or a combination of

the following conditions: exposure to the atmosphere, motion, accidental dilution, and temperature variation.

9. The deterioration of foam-liquid usually is accompanied by the formation of a visible, measurable, proteinaceous precipitate. Foam-liquids are two-phase colloidal solutions (or sols) consisting of solid protein particles dispersed in a liquid medium. It has been shown from zeta potential measurements that an electric charge surrounds each of these particles and keeps them from coagulating so that the dispersion is stable. It has been determined that the zeta potential can be lowered to a point of protein instability by the addition of hydrogen ions and salts of high valence. Accordingly, this Laboratory investigated (17,18) the use of the zeta potential of foam-liquid to derive a bench test for stability. This work was based on the theory that foam-liquids resisting precipitation by the addition of HCL (hydrogen chloride) or $LaCl_3$ (lanthanum chloride) would have zeta potentials of sufficient magnitude to prevent the protein from precipitating in storage. Foam-liquids conforming to the requirements of these tests, as received, were found to exhibit superior stability characteristics for as long as 18 months. After 18 months, however, the liquids no longer passed these tests and behaved similarly to those liquids which had not passed these tests when received. Therefore, original satisfactory performance in these tests did not insure good performance for more than 18 months. Attempts were therefore made to encourage and guide the foam-liquid industry in developing their formulations for conformity with these tests. Unfortunately, only one

manufacturer has demonstrated his ability to produce suitable material in accordance with the NASL test requirements. Rather than make the procurement of foam-liquid proprietary to that one manufacturer, it was decided to discontinue this particular Laboratory program in favor of the development of the Foam-Liquid Test Kit (described below).

10. It is well known that protein-containing foam-liquids have always been a difficult material to manufacture because of their unusually complex chemical constituents. These materials still have an unpredictable storage life. If properly formulated, they can be expected to remain serviceable from eight to ten years. However, even if properly formulated, environmental storage conditions may affect the period of their useful life.

Foam-Liquid Test Kit

11. In lieu of establishing the shelf life of foam-liquid, the initiation of an on-board inspection procedure was considered preferable. For this purpose, NASL developed a test kit for use by ship and shore personnel for periodic checks of the suitability of their foam-liquid stores. Basically, this testing kit (Fig. 2) provides a scaled-down version of some of the critical tests required by the foam-liquid specification. The kit weighs approximately 25 pounds and contains all the components necessary to perform three simple tests to establish the usability of foam-liquids; these are (a) a clogging test, (b) a sedimentation test, and (c) a drainage test. These tests are readily reproducible and pass-fail indications are explicit, and all can be conducted quickly by nonprofessional personnel. Essentially, the kit consists of an elec-

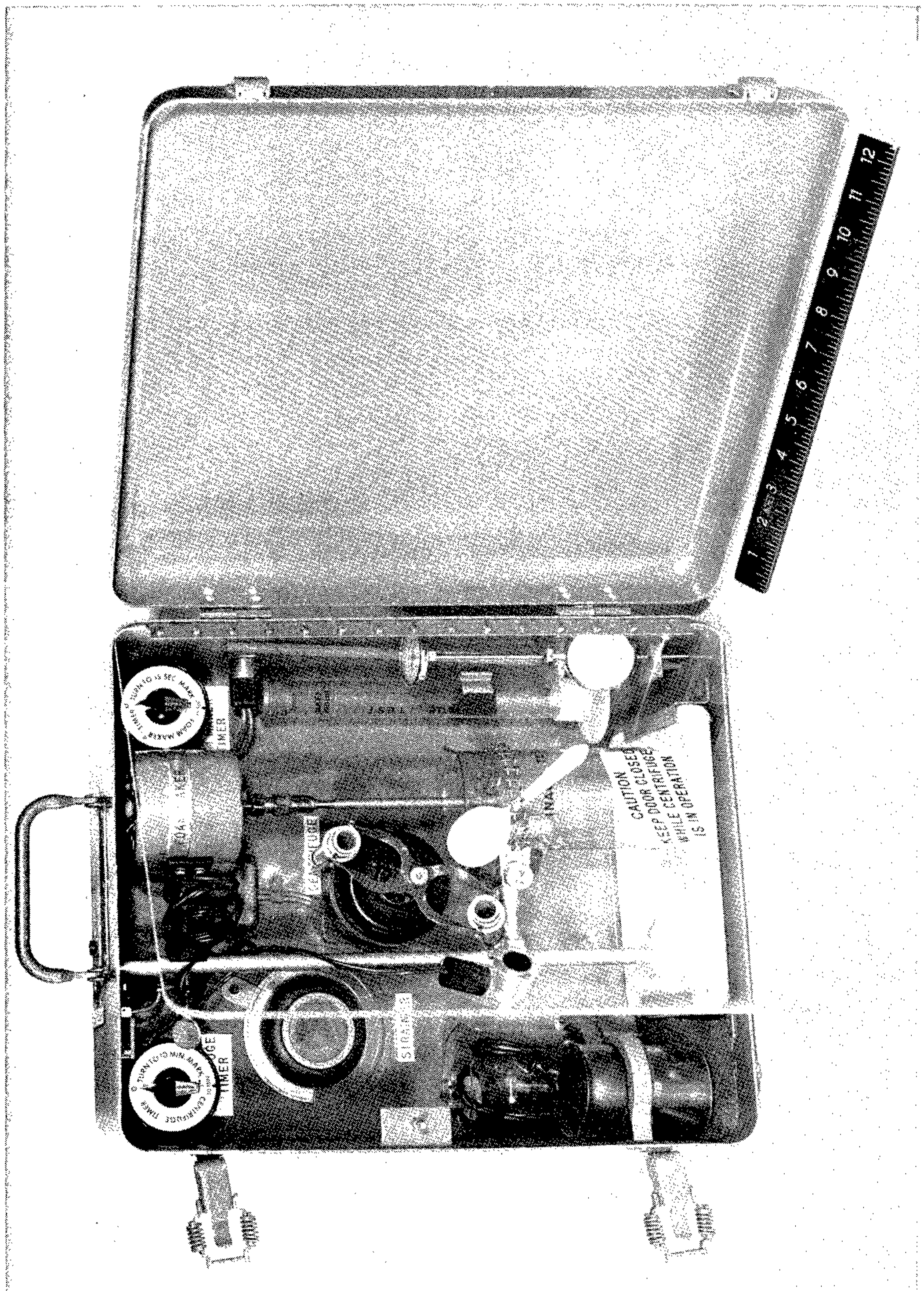

Fig. 2 - Fire fighting foam test kit

trically driven stirrer to generate foam from a solution of foam-liquid in water, an electrically driven centrifuge to precipitate minute suspended matter in the foam-liquids, an 80-mesh screen for filtering out larger particles, and various containers and measuring devices for carrying out simple laboratory procedures. The test kit is portable, easily maintained, safe to use, and can be set up for operation in a small space (see scale in Fig. 2).

12. The prototype test kit has been approved for naval use (19), and specification requirements for its procurement have been furnished (20). An initial procurement order of 100 kits is scheduled for Fleet distribution in June 1968. It is understood that subsequent purchase orders will be initiated by the Naval Ship Engineering Center (Code 6101C) in the near future.

Compatibility with Dry Chemicals

13. Although protein-stabilized mechanical foam is the Navy's principal agent for extinguishing hydrocarbon fires, it is limited in not having a fast knock-down time; i.e., such foams provide permanent extinguishment, but their fire-fighting action is relatively slow. An extremely rapid extinguishing agent evaluated by the Bureau of Standards (21) and introduced into the Navy by NRL (22), after having established the importance of using the finely ground material, is a dry powdered form of potassium bicarbonate now commercially designated as "Purple-K-Powder." This chemical also has a serious drawback; it does not protect an extinguished fuel surface against reignition. Combined agent attack using the powder to effect rapid extinguishment and foam to blanket the

fuel and prevent it from reflashing has offered attractive possibilities. However, until recently, attempts to combine the use of the commercially available protein-stabilized foams and dry powders have been unsuccessful because the foam blankets were rapidly destroyed in the presence of the powders (17,23,24). NASL has devised tests and criteria for determining the degree of compatibility between foams and powders (25). A compatible foam should be capable of withstanding substantial quantities of the dry chemical on top as well as beneath the foam blanket without the foam losing its vapor sealing ability. If there are any voids in the blanket, the presence of dry chemical in contact with the foam should not result in any significantly more rapid burn-back (flame spread) than would normally be expected with the foam alone (without powder present). In a cooperative effort between this Laboratory and National Foam Systems, Inc., a fluorinated, proteinaceous, fire-fighting, foaming agent was developed which was compatible with Purple-K-Powder. Specification requirements for this compatible protein foam have been prepared by NASL (26).

14. A synthetic fluorocarbon foaming agent called "Light Water," also compatible with Purple-K-Powder, was developed by NRL (27). A new experimental potassium chloride-based dry powder, also under investigation at NASL, has been found in preliminary laboratory work to be equivalent to potassium bicarbonate (Purple-K-Powder) dry chemical in fire-fighting capabilities, but superior to Purple-K-Powder in that it possesses a high degree of compatibility with conventional protein foams. Additional work on this dry chemical is in progress.

Foam-Powder System

15. To utilize a compatible combination of foam and dry powder, this Laboratory has also developed a dual-agent, fire-fighting system (28,29) intended for one-man application. The system (illustrated in Fig. 3) has a specially designed dual-agent gun (30) consisting of twin, side-by-side nozzles with machine-gun-type, fore-and-aft, pistol grip trigger valves for simultaneous or sequential application of the foam and powder. Associated devices for delivery of the powder to the gun include a chamber for the dry powder and a powder-pressurization cylinder. This system can utilize existing shipboard proportioners and fire-main seawater supply for its foam generation, and it could readily be used in existing shipboard fire-extinguishing installations.

Oscillating Nozzle for High-Capacity Foam System

16. Fighting large-scale fires on the flight decks of aircraft carriers has always been a problem of major and increasing concern to the Navy. Actuating the presently installed, manually-operated, fire-fighting foam system is time consuming, and the fire hoses are vulnerable to damage as they are dragged over obstacles on the deck. The fire-fighting crews are exposed to grave hazards when required to move among high explosives and hot fires, and the dense smoke increases the difficulty of locating the fire source and of accurately directing the hose streams. Equipment is needed which would blanket effectively the entire fire area in a minimum of time and with a minimum of personnel.

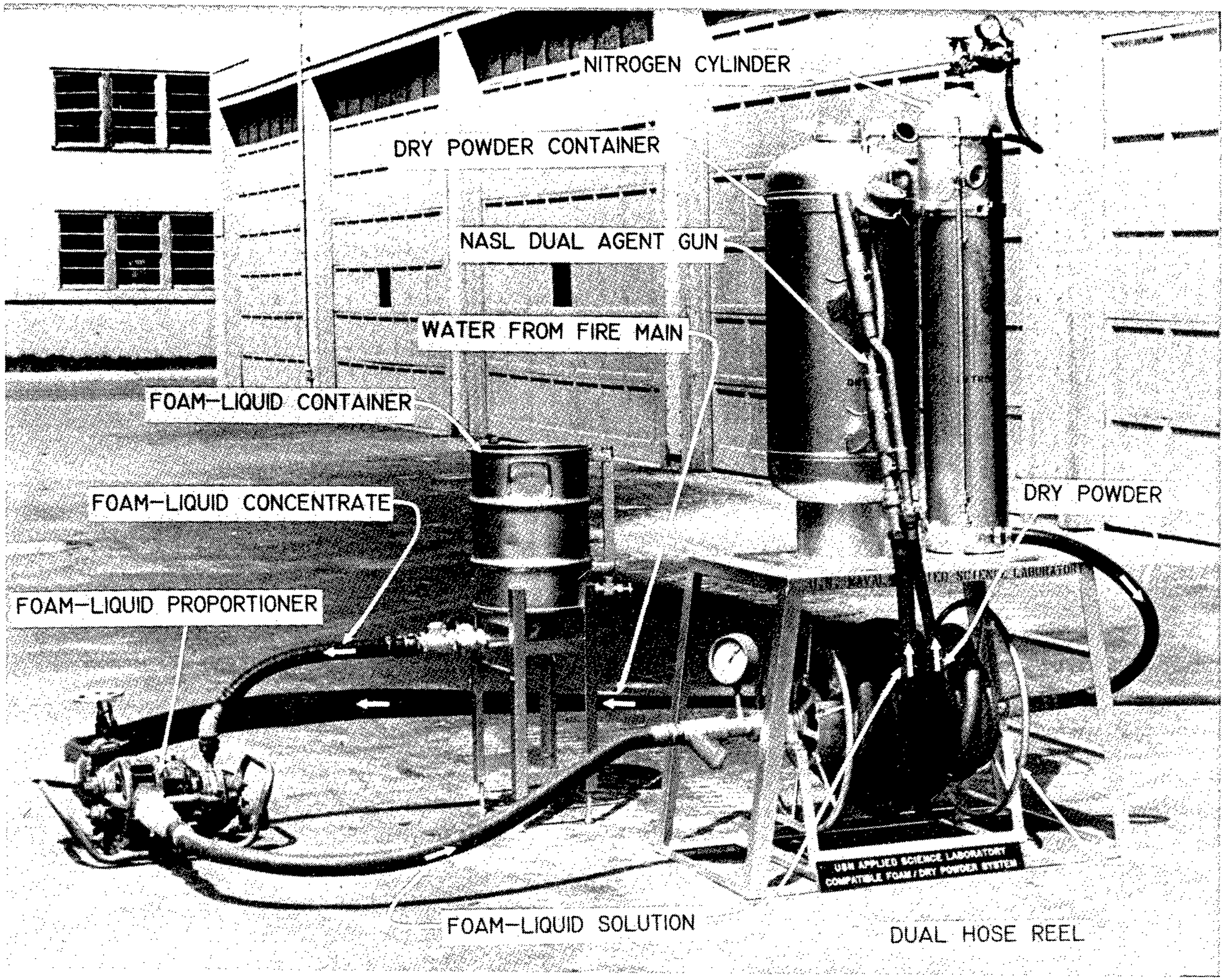

Fig. 3 - Dual agent fire extinguishing system

17. As a partial solution to this problem, this Laboratory has developed an automatic, oscillating, foam nozzle (31-35) to discharge alternating straight-stream foam (for approximately 100 feet) and dispersed foam (for approximately 30 feet) through an arc of 90° (as shown in Fig. 4). The nozzle is hydraulically operated by utilizing the system pressure of the foam-liquid solution. These oscillating nozzles were designed to be connected to the existing high-capacity, foam-fire stations and would rapidly provide a massive blanket of foam on the deck. The nozzle discharges approximately 4500 gallons of foam per minute at 100 psi line pressure.

Fire Protection of Nuclear Weapons

18. Studies by the Naval Weapons Evaluation Facility, Albuquerque, to determine the vulnerability of various naval nuclear weapons were initiated by the realization that the heat of a fire can activate the conventional explosives contained in the weapon. In the last fifteen years, numerous accidents have been reported in which a nuclear weapon was in the proximity of a fire. Of these incidents, several resulted in detonation and deflagration of the conventional explosive contained in the nuclear weapon. It was therefore considered essential that fire-fighting agents and techniques be evaluated for shielding and cooling a weapon engulfed in a fire in order to prevent the explosives from reaching their autoignition temperatures. This Laboratory was urged by the Naval Weapons Evaluation Facility to evaluate available materials and systems for such purposes.

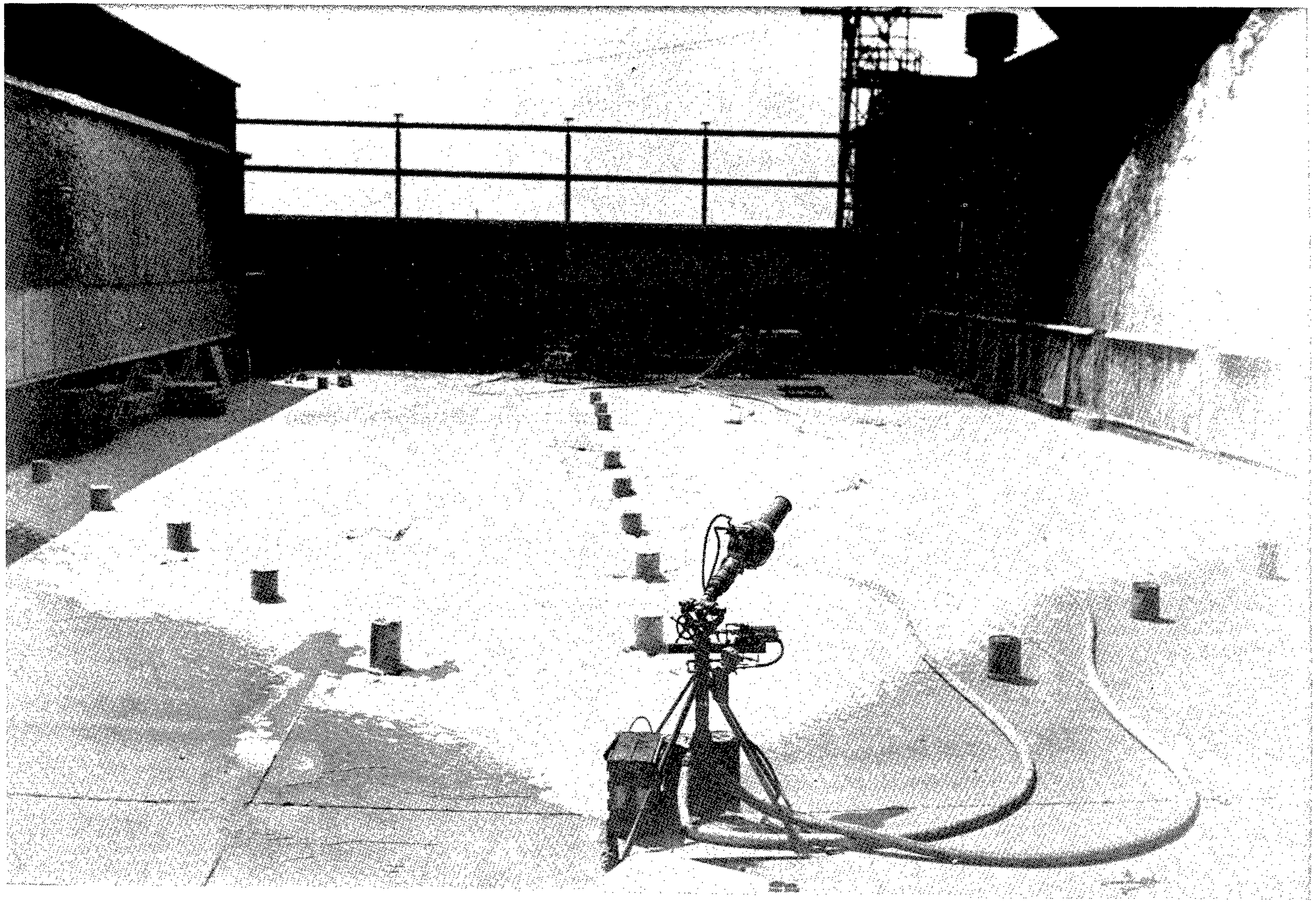

Fig. 4 - Oscillating nozzle for high capacity foam system

19. The object of the NASL evaluation was to determine the relative cooling effectiveness of two fire-fighting agents commonly available for use on naval vessels: seawater and protein-stabilized mechanical foam. A thermocouple instrumented, inert, depth-type, nuclear weapon was suspended over a 15-foot diameter tank which served as the fuel pan for a gasoline fire (36,37). Without any coolants being applied, the weapon was engulfed in a gasoline fire and data were collected to determine a time-temperature relationship to investigate the weapon's natural resistivity to intense flames and heat. When the internal temperature of the weapon had reached a predetermined critical value, one of the cooling agents was discharged directly onto the weapon. Again, data were collected to determine the time-temperature relationship to follow the cooling effectiveness of the agent. Water was applied to the weapon in the form of water fog or direct stream, and protein-stabilized foam was applied either in a dispersed pattern or as a direct stream.

20. The results of this work revealed:

a. The safe period for exposure of a nuclear weapon to a gasoline fire is approximately 10 minutes.

b. Of the agentsused, direct-stream water provided the most effective coolant for the weapon.

c. Protein-stabilized foam provided little or insignificant cooling of the weapon when exposed to a gasoline fire.

Rocket Propellant Fire Fighting

21. In a five-acre test site in a secluded area adjacent to Picatinny Arsenal, Dover, New Jersey, NASL has been conducting damage control studies, as needed by the Naval Ship Engineering Center, to determine the detonation hazard of advanced liquid and solid rocket propellants intended for shipboard use and also to develop means for fighting fires involving these propellants. This site is equipped with a concrete test pad, simulated missile magazine, propellant preparation and storage bunkers, and a control room which is shielded from the reactions at the test pad by a natural earth bank. The control room is fully equipped with recording and test control instrumentation; indirect viewing of all operations is provided by remote-control, closed-circuit television.

22. Studies conducted by this Laboratory in the 1950's on the JP-5/LOX (liquid oxygen) propellant combination (38), which had been proposed for the Jupiter Missile System, proved that this combination did in fact present a serious detonation hazard. The severity of explosions resulting from mixtures of JP-5 and LOX could be judged from the fact that a 1-ton steel explosion mat placed 3 feet from the test pad would be thrown about 10 feet when from 2 to 3 gallons of this propellant combination exploded. Such explosions would be sufficient to cause disabling damage to a ship. Consequently, JP-5/LOX was abandoned and the Jupiter Missile System was eventually redesigned to use solid instead of liquid propellants. NASL's findings of extreme detonations occurring in fires involving JP-5 and H_2O_2 (hydrogen peroxide) also led to abandoning these materials as shipboard propellants (39).

23. Work conducted on MAF (mixed amine fuel) and IRFNA (inhibited red fuming nitric acid) showed these propellants (40) to be relatively safe for shipboard use since they posed no detonation problems or difficulties with available fire-fighting agents. Solid rocket propellant fires (41) also did not present detonation hazards. Fires involving these propellants, however, were extremely difficult to extinguish. The only effective extinguishing means found to date involves complete water flooding of the propellant.

24. In more recent weapon systems the use of MHF (mixed hydrazine fuel) and CTF (chlorine trifluoride) has been contemplated. The MHF fuel was unique in that it was found to detonate upon burning by itself without the CTF oxidizer present (42). This Laboratory postulated that the hydrazine nitrate present in the fuel (the other components being hydrazine and monomethyl hydrazine) was responsible for this phenomenon. Subsequent MHF formulations without the hydrazine nitrate did not detonate when burning alone or in combination with the CTF oxidizer. Fires involving these propellants were readily extinguishable with conventional fire-fighting agents.

Summary

25. The foregoing discussions point up the research and development effort in fire engineering that have been emphasized at NASL.

a. In the field of high-expansion foam, portable high-expansion foam systems have been developed and units have been manufactured and sent to selected naval ships for front line evaluation (43,44). Investigations involving actual controlled fire tests in a simulated submarine environment are being planned at NASL to determine the feasibility of these foam systems for submarine fire protection. Methodology has been devised and preliminary tests have been conducted to obtain design criteria for installed (fixed) systems in large shipboard machinery spaces, cargo holds, and carrier hangar bays.

b. In the field of protein-stabilized foams, a test kit has been developed and is in the process of being manufactured by a contractor (45); it will soon be distributed to major ship and shore establishments. These test kits should serve as an important tool in assuring fire-fighting personnel that the foam-liquid being used possesses suitable fire-fighting capabilities. Until this type of foam-liquid is replaced by more sophisticated fire-fighting agents, these test kits should prove invaluable.

c. NASL has provided a double-barreled approach to fire fighting by the development of a compatible combination of a protein-stabilized foam with dry chemical; this causes a quick knock-down accompanied by immediate sealing of the fire area without fear of reignition.

d. An automatic, oscillating, foam nozzle has been developed which shows outstanding promise for a remote-controlled, rapid, massive, fire-fighting system for aircraft carrier flight deck protection.

e. In the field of weapon vulnerability, the way is now open for a possible approach to controlling open shipboard fires in which nuclear weapons are involved and in preventing such fires from becoming major conflagrations.

f. Relative to rocket-propellant fire fighting, the facilities and "know-how" are available for determining the potential hazards of new propellants proposed for shipboard use.

26. Short-term recommendations:

a. Incompatible fire-fighting agents exist on board ship today which should not be there. The availability of dry chemical extinguishers in close proximity to the high-capacity foam systems only tend to provide the fire fighters with a false sense of added protection. The presence of available discharged dry chemical powder in the vicinity of a fire will not only wreck an established foam blanket but may prevent its formation. Prompt steps should be taken to insure the compatibility of these fire-fighting agents by either substituting compatible protein foam (26) for the standard foams or by substituting compatible dry chemical powder (see paragraph 14) for the standard powders.

b. In order to provide capabilities for complete coverage, fire control, and extinguishment of aircraft carrier flight deck fires in the shortest possible period of time without requiring the fire fighters to man handlines, a program should be initiated to develop and install at the seventeen existing fire stations in the catwalk area a system of automatically-elevated, remote-controlled, oscillating foam nozzles (see paragraph 17). This system should provide wide, sweeping, overlapping foam patterns and should incorporate manual override facilities at each nozzle location.

c. The FG-1 high-expansion foam generators, referred to in paragraph 4, should be modified to include hydraulically powered fans and stainless steel screens and should be procured and distributed to all shipboard activities.

27. <u>Intermediate-term recommendations</u>:

a. Present day submarines do not have the capabilities for combatting and extinguishing major fires (46). The use of dry chemical powders and carbon dioxide extinguishers provides only marginal protection. A fire-fighting system currently available that offers high promise of eliminating submarine fire-fighting deficiencies is one involving the portable, high-expansion, foam generator. An accelerated effort should be made to develop this system for submarine application.

b. Need exists for improved fire protection of aircraft carrier hangar bays. The application of protein-stabilized mechanical foam from standard hangar monitors and foam sprinklers, which are often blocked from the fire by parked aircraft or other obstructions, provides only limited fire protection for specific areas in the hangars. Based on design criteria currently being developed by NASL, permanently-fixed, total-flooding, high-expansion foam systems, activated by fire detection devices, should be developed for potential installation in hangar bays to completely flood and fill the hangar in a matter of minutes, therein providing quicker control and extinguishment of spilled fuel and aircraft fires. Similar installed high-expansion foam systems should also be developed for fire protection of large shipboard machinery spaces and cargo holds.

c. The development of high-expansion foam liquid to optimize performance capabilities of both portable and installed high-expansion foam systems should be accelerated.

d. An extensive test program to establish the optimum method for fighting aircraft fuel fires involving nuclear weapons should be conducted. Once this information has been developed, it should be included in the Navy disaster control manuals.

e. Flame-sensing systems which will pinpoint the exact location of a fire and thus facilitate early extinguishment should be developed. Viewing devices using infrared or microwaves to permit "seeing" in spite of smoke need exploration--even if long-term effort is needed.

f. Means need to be developed for personnel escape from shipboard spaces. The use of illuminated exit signs, sound signals, touch techniques, or directional arrows pointing to the nearest access to the "outside" should be installed if available or should be investigated.

g. Lighter and longer-lasting breathing apparatus and lighter, waterproof, radiation-reflecting, protective clothing are needed for the fire fighters. Eventually such clothing should be air conditioned and should include radio communication equipment; however, a long-term effort may be required.

28. <u>Long-term recommendations</u>:

a. Electronic or chemical means for precipitating and removing smoke to promote visibility, safety, and fire fighting should be developed.

b. Greater fire-fighting capabilities of water through the addition of new chemical additives need more research.

c. The feasibility of developing sophisticated apparatus such as sound wave generators, ion generators, and pressure-wave generators for use as standard fire-fighting equipment should be investigated.

d. Unitized, sensitive, fire detection and automatic alarm devices are needed that will alert shipboard personnel of a fire at the earliest possible stage.

e. Further research is needed on fire and explosion suppression systems which are capable of extinguishment within milliseconds after their actuation.

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Section V. Recent Progress on Shipboard Fire-Fighting Methods, Equipment and Materials

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1. Since the publication of our contribution to NRL Memorandum Report 1816 (1), other fire-fighting R&D effort at NRL has been directed toward increasing the level of fire protection available to aircraft carriers. The two immediate goals have been: (a) the design and commercial procurement of the "second generation" shipboard "Twin Ball Fire Fighting Unit" similar to, but more effective than, the type originally furnished to the attack carriers (2), and (b) shipboard design and feasibility studies for utilizing the presently installed Nuclear-Biological-Chemical Washdown System of deck spray nozzles on aircraft carriers as an automated, segment-controlled, flight deck, fire-fighting system.

2. The operational success of the original "Twin Ball Fire Fighting Unit" on board the carriers on "Yankee Station" in the months following October 1967 was primarily due to two factors: first, all carrier fire-fighting personnel were required to attend a short training session at Cubi Point Naval Air Station, Philippine Islands, where an NRL specialist instructed them in the use of the new unit; and second, the utility of the dry chemical, "Purple-K-Powder," in combination with "Light Water" was tested on a portable platform as described earlier (1). There resulted a state of more complete emergency preparedness for deck accidents than ever before attained on board ship. In one fire incident

on the USS ORISKANY, the unit was reported to have quelled a serious fire in much less than a minute.

3. Following a series of conferences with carrier operating personnel and NAVAIRSYSCOM fire protection advisors, the decision was made that future units for carriers using the "twinned agent" system should be more compact in size so that they would fit on existing deck motive power devices. A period of redesign of the unit followed at NRL which resulted in the development of a package capable of being attached to the MD-3 aircraft towing tractor in the space provided for the rear-mounted, turbine-compressor, jet engine starter used on some of these vehicles. Because of the excessive mixing and dissipating effects of winds across deck areas, the ratio of dry chemical powder charge to that of the water solution of "Light Water" concentrate in the Twinned Unit was decreased to give longer total discharge time capability to the "Light Water" and a briefer total capability to the "Purple-K-Powder."

4. A commercial procurement contract for 120 of these packaged units was finalized in December 1967 (3). NRL personnel subsequently tested the performance of the first prototype model in preparation for their production (4). These devices will be furnished to all Fleet aircraft carriers for portable use on both flight and hangar decks.

5. The suggestion originally made by the Russell Committee for the employment of the NBC Washdown System of flush-mounted, flight deck, water spray nozzles for fire protection purposes is receiving vigorous action at NRL in support of NAVSHIPS' requests for information (5,6).

6. Preliminary fire extinguishment tests were carried out at the NRL fire test cell to determine the utility of existing shipboard fire-fighting materials for controlling large fires of JP-5 fuel on a deck area when very small quantities of agent are applied per square foot of fire. This is the approximate condition which would occur if the NBC Washdown System were employed. It was discovered that water spray is completely ineffective for "flat-spill-on deck," aircraft fuel fires of this type. Protein foam spray required inordinately long spray times (over two minutes) to accomplish fire extinguishment, but "Light Water" spray halted such fires in much less than a minute. Spray applications of 0.03 gal/min/sq ft of burning surface of JP-5 fuel were fully effective.

7. Since the detailed performance characteristics of existing shipboard installations of flush-mounted, deck spray-nozzle systems under carrier operating conditions was an unknown factor in considering the use of the NBC Washdown System, various tests were planned in conjunction with recommendations from the operating and command staff of the USS INDEPENDENCE (CVA-62). NRL fire research personnel performed these tests on board the INDEPENDENCE in December 1967 in the open sea with a fore-to-aft relative wind speed over the deck of 30 knots; the following results obtained on the flight deck have been reported recently (7):

a. Water spray patterns from the NBC Washdown System were very irregular but averaged 0.03 gal/min sq ft. This amount appears adequate from earlier NRL tests for fire extinguishment if "Light Water" is used in the system.

b. Deck-edge-positioned, fire-fighting nozzles produced very discontinuous spray patterns on the deck. With available water pressures and volumes, the center portion of the deck could not be reached. Nozzles in this area are believed to be highly vulnerable to interference by parked or "spotted" aircraft.

c. Air flow over the flight deck was usually found to be laminar in character up to a height of 6 feet. Marked diminishment in the air speed was found at 18 inches or less above the deck. Detrimental effects of wind on the discharge patterns of fire-extinguishing agents were not serious in the downwind direction, but the crosswind agent range or reach was severely limited.

d. "Mock-up" (or simulated) bombs and rockets, which had been mounted under the wings of aircraft on the flight deck during the NBC Washdown System spray tests, were impacted by water drops at rates of 0.015 gal/min/sq ft of exposed area. This rate of water delivery will remove about 150 BTU/min/sq ft when such munitions are so exposed to fire attack. Obviously, this result deserves the attention of ordnance experts.

8. The final "proof test" of a simulated portion of a carrier flight deck under actual fire conditions using identical water spray nozzles is nearing completion at NRL. This effort constitutes the only remaining phase of NRL testing planned before ship system design can proceed using "Light Water" in existing and new NBC Washdown Systems.

9. Perhaps the most glaring deficiency in the state of preparedness for fighting fires aboard aircraft carriers exists in the now archaic and poorly fitted High-Capacity, Fog-Foam Systems with which they are all equipped. This system has not been improved since its original design by NRL in 1946 (8). It is the first line of defense against all aircraft fuel fire hazards and is manned during all aircraft operations. Recent attention to this system by fire protection authorities of the Navy has given rise to the decision that a complete redesign of this equipment is to be started immediately with the objective of replacing protein foam materials with the more highly efficient "Light Water" concentrates. An entire prototype station will be designed and installed at the Combustion Suppression Research Center at NRL within this calendar year.

10. Short-term recommendations:

a. The second generation twinned-agent fire-fighting unit is now in commercial production (see paragraphs 3 and 4). The early installation of these units on board all aircraft carriers is urged on both flight and hangar decks.

b. The use of "Light Water" spray for extinguishing "flat-spill-on deck" aircraft fuel fires is recommended in preference to presently used protein-stabilized foam (see paragraph 6).

c. The use of deck-edge-positioned, fire-fighting nozzles are not recommended (see paragraph 7b).

d. The use of "Light Water" spray delivered to the flight deck by means of the existing NBC Washdown Spray System should be highly effective at rates of delivery of only 0.03 gal/min/sq ft of exposed area. Such a system of fire extinguishment appears very promising, and further tests are recommended.

e. Even bombs and rockets located on the flight deck under the shelter of aircraft wings will receive 0.015 gal/min/sq ft of "Light Water" from the NBC Washdown System. As this rate of water delivery corresponds to a removal of about 150 BTU/min/sq ft, the feasibility of protecting such ordnance during a flight deck fire deserves attention from ordnance experts.

11. Intermediate-term recommendations:

a. The presently used High-Capacity, Fog-Foam System on board aircraft carriers should be redesigned to use "Light Water" concentrates as the extinguishant.

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