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COAST GUARD RESEARCH AND DEVELOPMENT CENTER GROTON CONN F/6 13/12  
PORTABLE EXTINGUISHER EVALUATION FOR COAST GUARD CUTTERS.(U)  
JUL 78 D E BEENE, R C RICHARDS

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16. Abstract This test series evaluated existing extinguishers for use against incipient Class B fires occurring in machinery spaces aboard Coast Guard cutters. The tests were conducted on a full-scale machinery space mockup constructed inside a cargo hold on the SS MAYO LYKES at the U.S. Coast Guard Fire and Safety Test Detachment in Mobile, Alabama. The testing compared three dry chemical and two gaseous extinguishing agents on bilge fires, running fuel fires, and spray fires.  Test results showed: (1) dry chemical portable extinguishers have a greater extinguishing capacity than gaseous agents on machinery space fires, (2) application technique is more important than dry chemical agent selection when considering fire-fighting effectiveness, (3) Halon 1211 will effectively extinguish machinery space fires but does not have the extinguishing capacity of the dry chemicals, and (4) carbon dioxide portable extinguishers are ineffective against machinery space fires of the size tested.			
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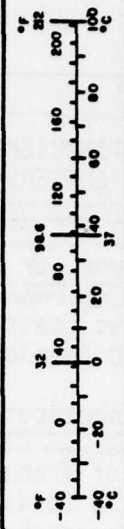
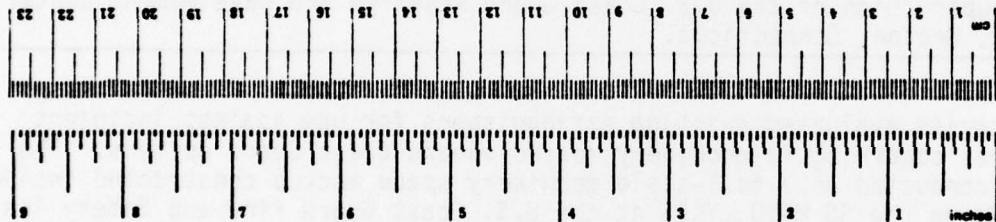
# METRIC CONVERSION FACTORS

## Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
<b>LENGTH</b>				
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
<b>AREA</b>				
in <sup>2</sup>	square inches	6.5	square centimeters	cm <sup>2</sup>
ft <sup>2</sup>	square feet	0.09	square meters	m <sup>2</sup>
yd <sup>2</sup>	square yards	0.8	square meters	m <sup>2</sup>
mi <sup>2</sup>	square miles	2.6	square kilometers	km <sup>2</sup>
ac	acres	0.4	hectares	ha
<b>MASS (weight)</b>				
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
<b>VOLUME</b>				
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.96	liters	l
gal	gallons	3.8	liters	l
ft <sup>3</sup>	cubic feet	0.03	cubic meters	m <sup>3</sup>
yd <sup>3</sup>	cubic yards	0.76	cubic meters	m <sup>3</sup>
<b>TEMPERATURE (exact)</b>				
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

## Approximate Conversions from Metric Measures

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



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

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The United States Coast Guard appreciates the assistance of Amerex Corporation, Graviner Incorporated, and Imperial Chemical Industries in providing materials, test equipment, and expertise which led to the successful accomplishment of this test program. The tests described in this report are part of a continuing fire research program planned and conducted by the United States Coast Guard with the participation and willing cooperation of private industry.

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## 1.0 INTRODUCTION

The first line of defense against a fire on a Coast Guard cutter is the use of a portable extinguisher by on-scene personnel. In the past the portable extinguisher has proven itself to be an important tool for controlling incipient fires. The development of improved extinguishing agents has prompted a reevaluation of the portable extinguishers used for the protection of Coast Guard cutters and their crews.

### 1.1 Problem Statement

The Class B fire constitutes the most serious fire threat aboard Coast Guard cutters. In the fiscal years 1972 through 1976, Coast Guard casualty reports indicate that Class B fires accounted for 68 percent of all fire losses aboard its cutters. The estimated monetary loss for these fires, which occurred most often in machinery spaces, was over a million dollars. Immediate extinguishment of incipient Class B fires could reduce these losses significantly. New portable extinguishers must be evaluated for this task.

### 1.2 Test Objectives

This test series evaluated existing portable extinguishers for use against incipient Class B fires aboard Coast Guard cutters. Extinguishers were limited to those currently available commercially. The total weight of each extinguisher including agent did not exceed 55 pounds. The primary objectives were to determine which portable extinguisher: (1) was most effective in extinguishing a bilge fire, a running fuel fire, and a fuel spray fire; (2) rated highest when considering availability, serviceability, reliability, toxicity, cleanup, and cost; and (3) best fulfilled Coast Guard needs if (1) and (2) did not coincide.

A secondary objective was to determine the extinguishing effectiveness of portable extinguishers when applied on bilge fires through openings in the deck plating.<sup>1</sup> A tertiary objective was to evaluate the endurance of aluminum deck plating when subjected to the weight of a fire fighter during a bilge fire.

## 2.0 BACKGROUND

### 2.1 General

A portable extinguisher is a first aid device for extinguishing small or incipient fires. It is a non-automatic device designed to permit discharge of an extinguishing agent at the control and direction of an operator. It can be carried (portable) or wheeled (semi-portable) to the fire scene.

Presently, portable fire extinguishers used on Coast Guard cutters must comply with Military Specification MIL-E-24091B (Ships),<sup>2</sup> Military Specification MIL-E-24269A (Ships),<sup>3</sup> and Federal Specification O-E-915C.<sup>4</sup> Federal Specification O-E-915C further requires that all approved Class B extinguishers must first be tested, rated, and classified by Underwriters Laboratory, Incorporated (UL). UL rating (e.g., the 10 in 10 B:C) gives the extinguisher's relative fire area extinguishing capabilities in the hands of a novice fire fighter. The UL classification (e.g., the B:C in 10 B:C) tells what type fire the extinguisher will effectively extinguish. Each of the four classifications (A, B, C, and D) has a different performance approval test. Class A, B, and D ratings are based on extinguishing fires of determined size and description, while Class C rating is determined by the conductivity of the agent.

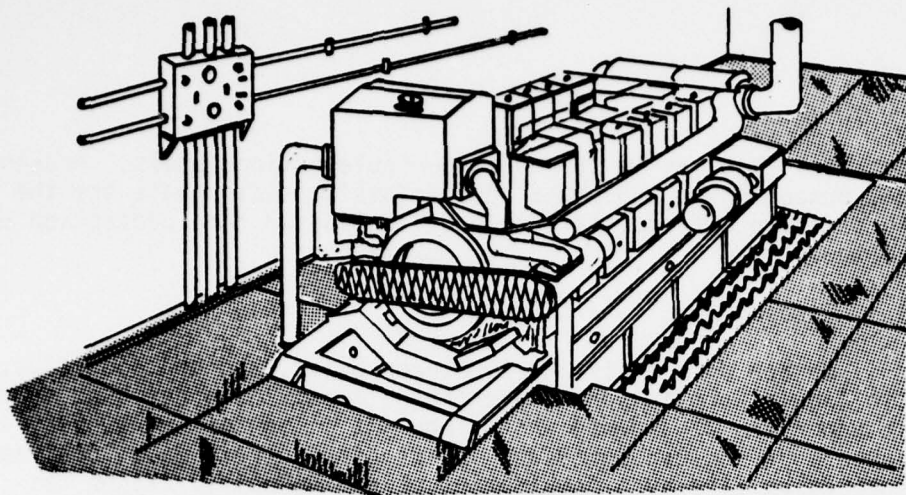
Human performance plays a critical role in extinguishing a fire.<sup>6</sup> To standardize the human performance factor in the test, the fire fighter had been well trained in fighting Class B fires and had reached the plateau of his learning curve. Standardizing the human performance in this way and statistically designing the testing sequence permitted an evaluation of each extinguisher based on its extinguishing capabilities.

### 2.2 Class B Fires

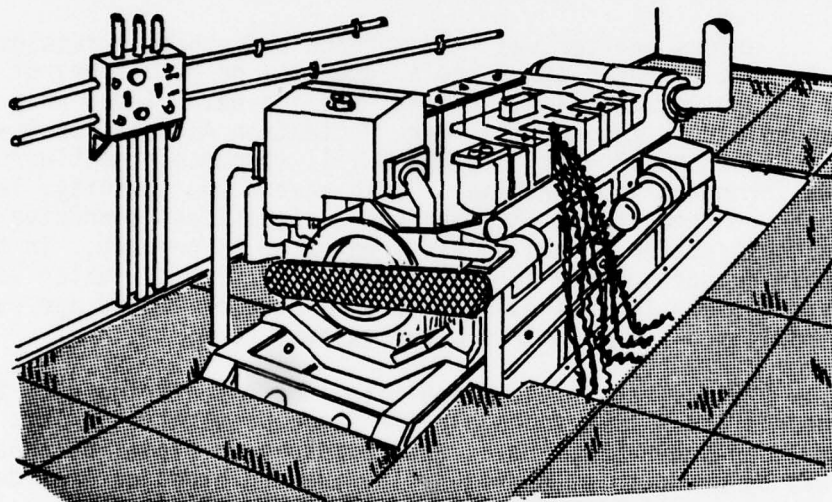
Typically, Class B fires occur in engine/machinery spaces. An examination of these spaces reveals three types of Class B fires to consider (Figure 1). Type 1 is a two-dimensional bilge fire with obstructions. An example is oil burning beneath solid deck plating and an engine or boiler with obstructions from piping, foundations, and structural members. Type 2 is a three-dimensional running fuel fire with obstructions. An example is diesel oil igniting and flowing down the side of an engine into the bilges and initiating a bilge fire. Type 3 is a three-dimensional oil spray fire with obstructions. An example is pressurized oil sprayed from a ruptured oil or fuel line which ignites on a hot surface and causes a bilge fire.

### 2.3 Extinguishing Agents

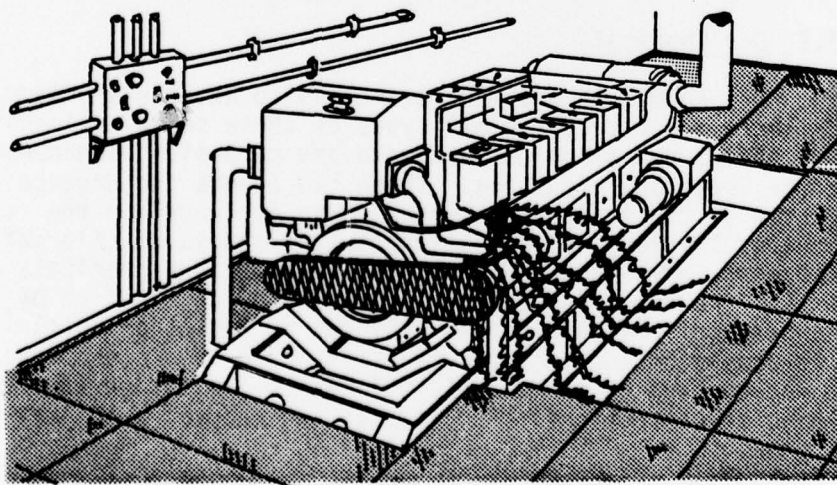
In recent years new extinguishing agents have been developed and made available in portable extinguishers. Of the new gaseous agents, Halon 1301 and 1211 are considered the most promising. Presently, Halon 1301 is available only in 2.75-pound portable extinguishers. New dry chemicals such as "Monnex" and "Super K" (both trade names) are also being utilized. Other fire-fighting agents such as foams and aqueous film-forming solutions are available but the effectiveness of these agents is severely limited because of



**BILGE FIRE**



**RUNNING FUEL FIRE**



**SPRAY FIRE**

**FIGURE 1**

**MACHINERY SPACE FIRES**

the small quantities that can be stored in portable extinguishers. Presently, carbon dioxide, monoammonium phosphate, and potassium bicarbonate are the agents used in portable extinguishers to provide Class B fire protection on Coast Guard cutters.

### 2.3.1 Gases

Carbon dioxide is inert, noncorrosive, and nonconductive. It is stored in liquid form in portable extinguishers. When released to the atmosphere, it vaporizes as a dense white fog. It is nontoxic; however, it is dangerous because a person can suffocate in its atmosphere. In a local application, CO<sub>2</sub> suppresses fire by a combination of gas velocity, oxygen displacement, cooling, and a displacement of the flammable vapors necessary for combustion. The biggest concern with CO<sub>2</sub> is a reignition of flammable vapors by a hot metal surface after the CO<sub>2</sub> is diluted with air.

Halons are derived from methane and ethane molecules which have had one or more hydrogen atoms replaced by one or more atoms of the halogen elements: fluorine, chlorine, bromine, and iodine.<sup>7</sup> Today only two Halons are recognized in the National Fire Protection Association Standards as safe extinguishing agents.<sup>8</sup> They are Halon 1211 (bromochlorodifluoromethane) and Halon 1301 (bromotrifluoromethane). Both have a low toxicity, leave no residue, and are nonconductive. Neither has a significant corrosive action on commonly used construction metals unless free water is present. In that case, acidic breakdown products react to form a corrosive liquid. Halon 1211 is discharged from a portable extinguisher as a mixture of liquid and vapor droplets. Halon 1301 is discharged in a clear gaseous form.

Halons act as flame inhibitors by interfering with the combustion process which is responsible for flame propagation. This interference is known as chain-breaking.<sup>9</sup> Upon exposure to flame, both Halons break down into by-products of hydrogen fluoride and hydrogen bromide. These products have a distinctive sharp odor and are irritants to the respiratory system and the eyes.

### 2.3.2 Dry Chemicals

Dry chemicals are used primarily to extinguish flammable liquid fires. There are five principal types of these solid extinguishing agents. Two of these, monoammonium phosphate and potassium bicarbonate, are currently used on Coast Guard cutters. These two agents and urea-potassium bicarbonate, known by the trade name Monnex, were evaluated in the tests. Sodium bicarbonate, the least effective agent, and potassium chloride, the most corrosive agent, were excluded from the testing. Dry chemicals are introduced to the fire as fine powders. They extinguish the fire by a chain-breaking mechanism similar to Halons.<sup>9</sup> A degree of radiation shielding of the operator is provided since the agent is dispersed in a cloud form. Dry chemicals are not considered to be toxic but can be irritating if breathed in sufficiently high concentrations. Application can reduce visibility of the fire in small areas.

### 3.0 APPROACH/PROCEDURES

The portable extinguisher testing took place at the U.S. Coast Guard Fire and Safety Test Detachment (F&STD) in Mobile, Alabama. It was conducted in the upper level of Cargo Hold No. 5 on board the SS MAYO LYKES (Figure 2). The extinguishers were tested on Class B fires which simulated those occurring inside machinery spaces aboard Coast Guard cutters. The observed extinguishment capabilities as well as agent characteristics were considered in evaluating the extinguishers.

The three primary independent variables for this test series were the fire types, extinguishers, and operators (Figure 3). Other test parameters maintained constant were: engine mockup geometry, deck plate configuration, preburn time, ignition source, fuel type, fire-fighting technique, and ventilation. The primary dependent variable measured was extinguishment time.

#### 3.1 Machinery Space Mockup

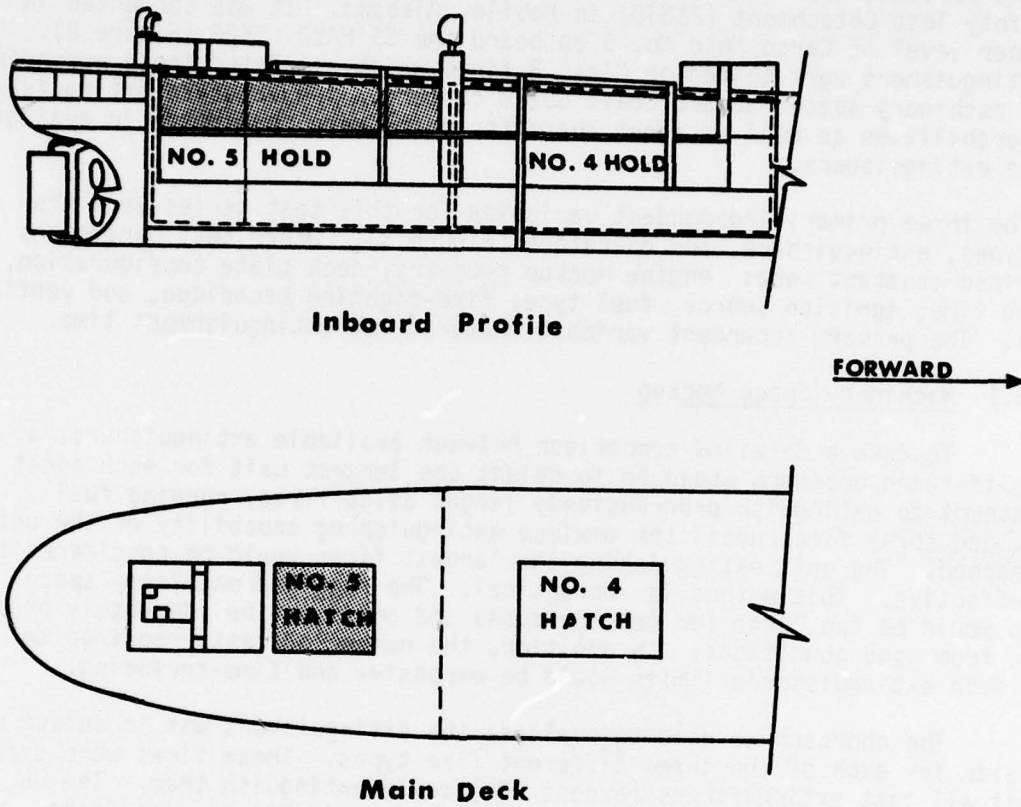
To make a detailed comparison between available extinguishers, a straightforward approach would be to select the largest unit for each agent and attempt to extinguish progressively larger bilge fires, running fuel fires, and spray fires until the maximum extinguishing capability of the unit was reached. The unit extinguishing the largest fires would be considered the most effective. This method is impractical. The required machinery space mockup would be too large for test purposes and could not be adequately protected from wind conditions. In addition, the number of tests required to reach each extinguisher's limits would be expensive and time-consuming.

The approach we used to evaluate the extinguishers was to select one fire size for each of the three different fire types. These fires were sized so that all test extinguishers (except CO<sub>2</sub>) could extinguish them. The UL rating for CO<sub>2</sub> is so low that it was expected to be ineffective on fires sized for the other agents.

To this end, a machinery space mockup was constructed (Figure 4) to simulate an engine room found on board a Coast Guard cutter. It consisted of a simulated bilge area and diesel engine casing (Figure 5). The bilge area had a steel framework covered by steel deck plates. The frame spacing, bilge piping, and engine arrangement were comparable to that found on board a 210-foot cutter (Figure 6). Two deck plates made of aluminum diamond plate were constructed to fit the 4.5-foot by 6-foot bilge area.

#### 3.2 Machinery Space Fires

Three types of Class B fires were created in the machinery space mockup: a bilge fire, a running fuel fire, and a fuel spray fire. Each fire was started by an instantaneous ignition source. No. 2 marine diesel was the test fuel. Fire area for the bilge fire, fuel flow rate for the running fire, and fuel pressure for the spray fire were the parameters controlled to vary the fire sizes. These parameters were within the range of existing conditions aboard Coast Guard cutters. The values used for these parameters were recommended and verified by Commandant (G-ENE) staff.



**SS Mayo Lykes (Stern Section)**

 = TEST AREA

Total Volume of upper level, No. 5 Hold is 55,000 ft<sup>3</sup>.

FIGURE 2  
 LOCATION OF TEST AREA ON SS MAYO LYKES

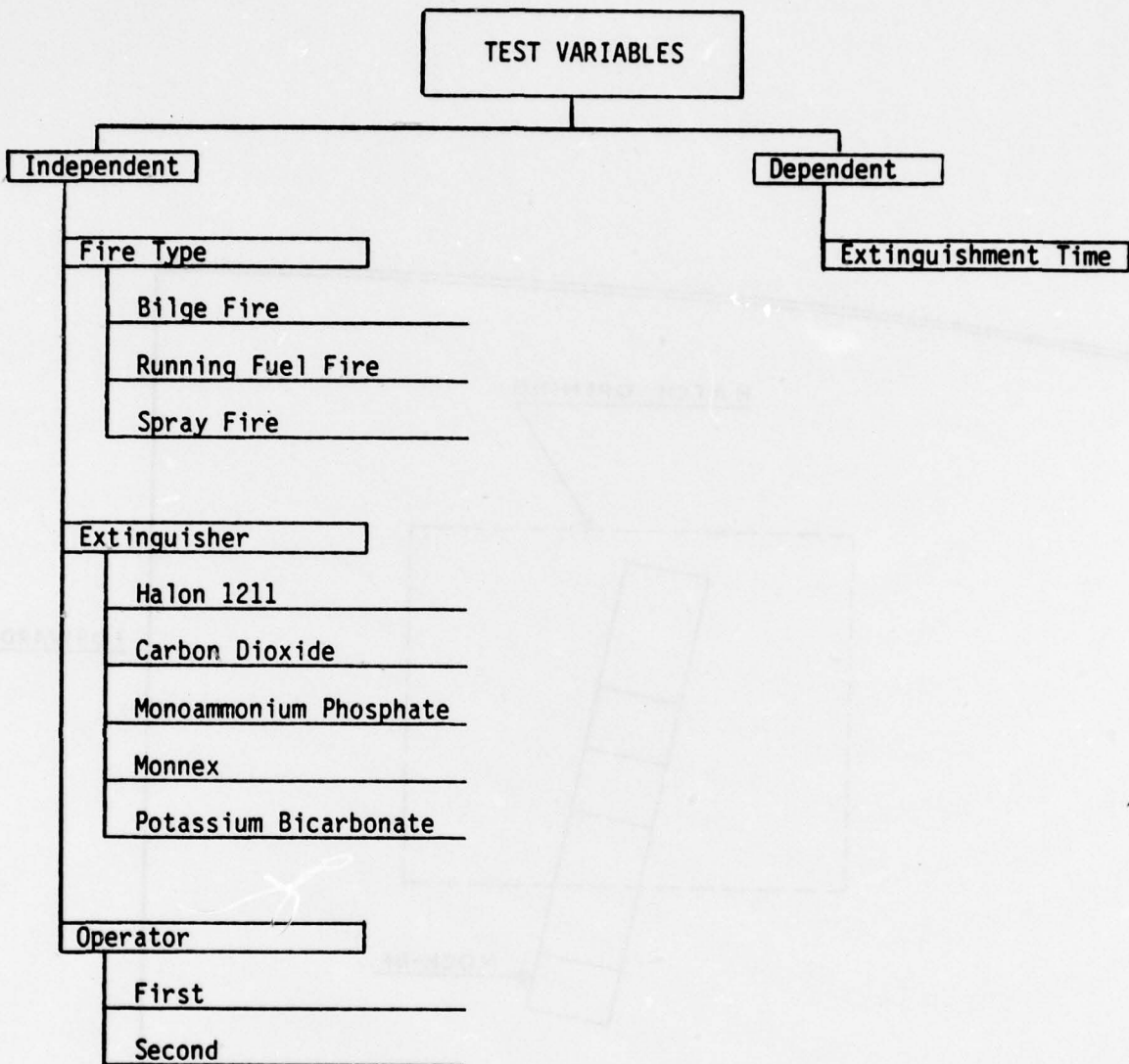


FIGURE 3  
SCHEMATIC DIAGRAM OF TEST VARIABLES

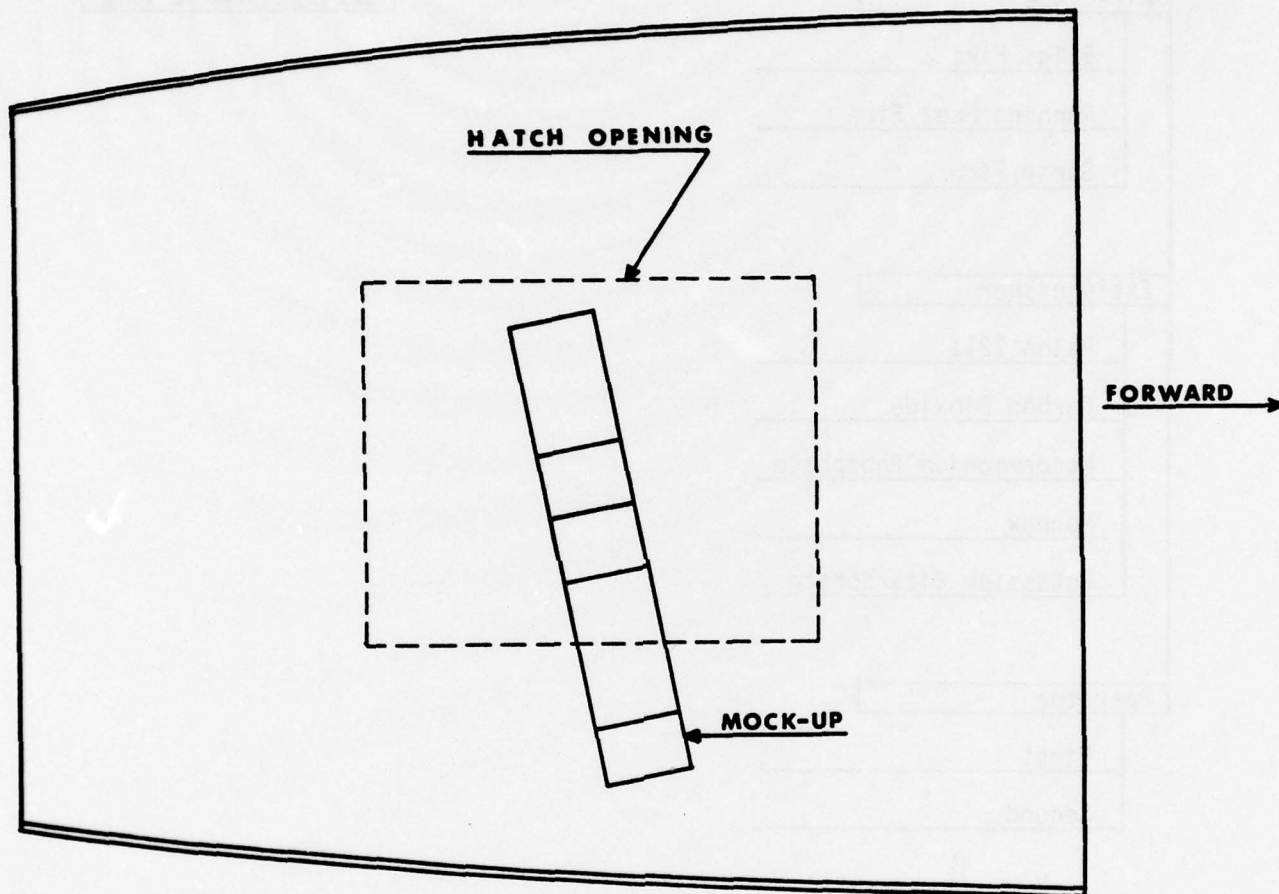


FIGURE 4  
PLAN VIEW OF UPPER LEVEL OF NO. 5 HOLD

**LEGEND**

⊕ = THERMOCOUPLES 1 Thru 5

• = RUNNING FUEL and SPRAY FUEL SOURCE

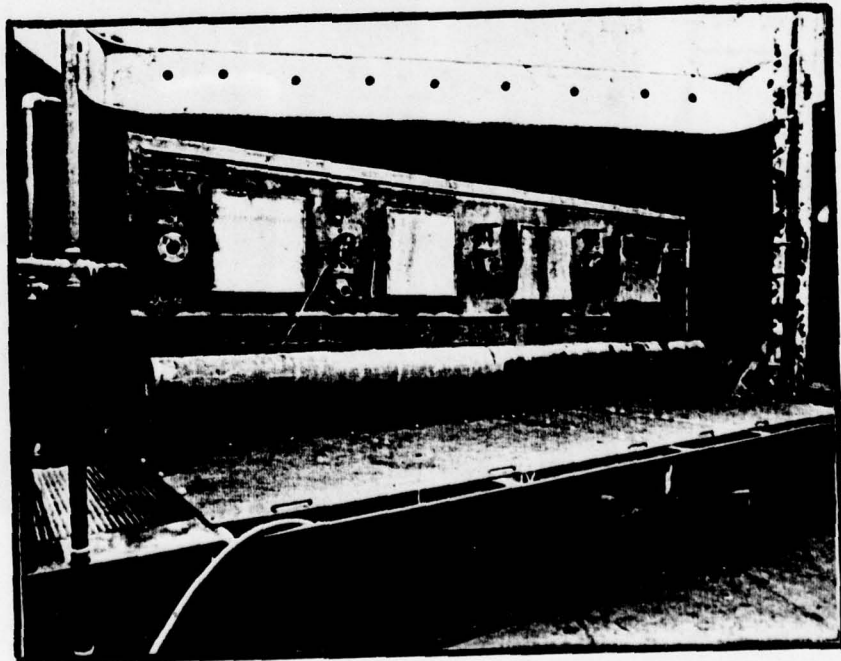
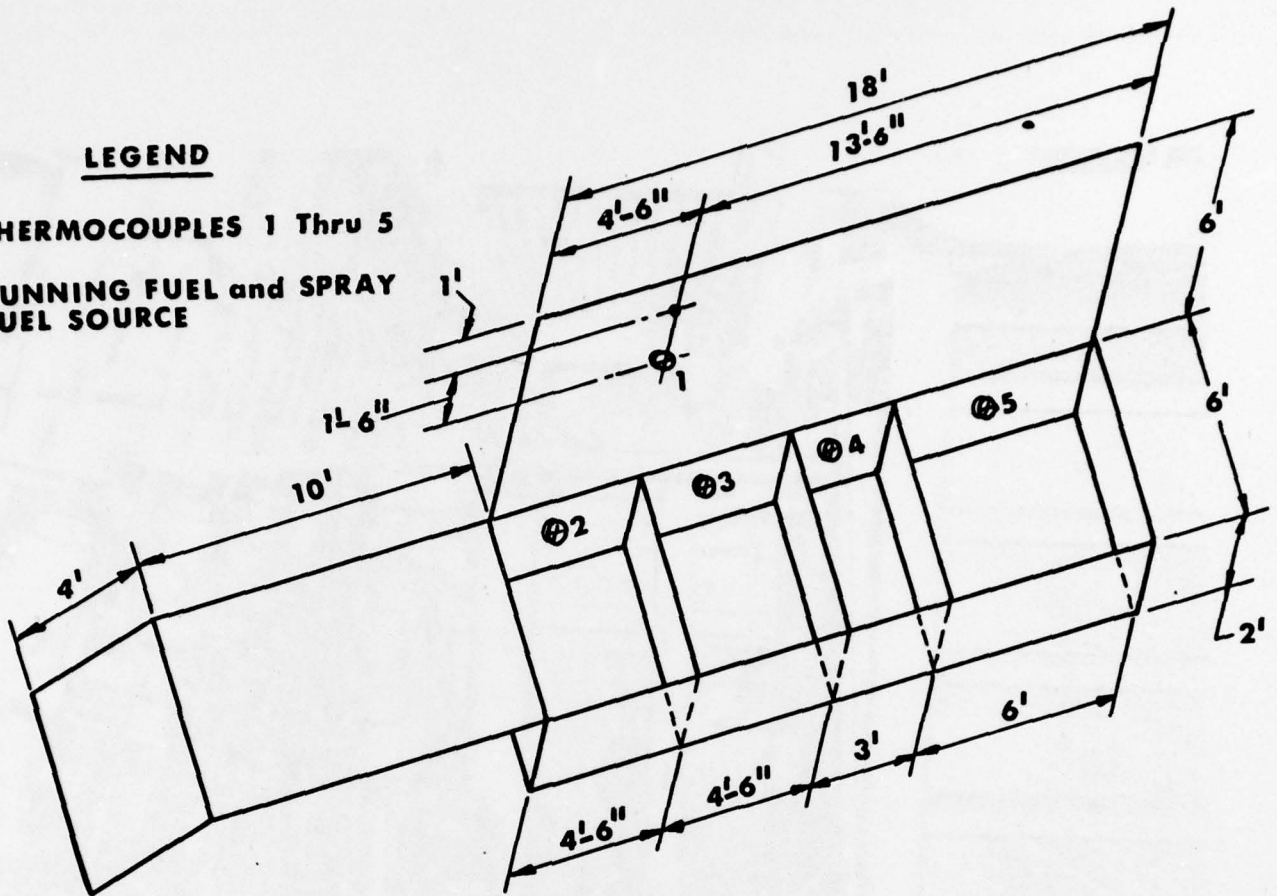


FIGURE 5  
ENGINE ROOM MOCK-UP

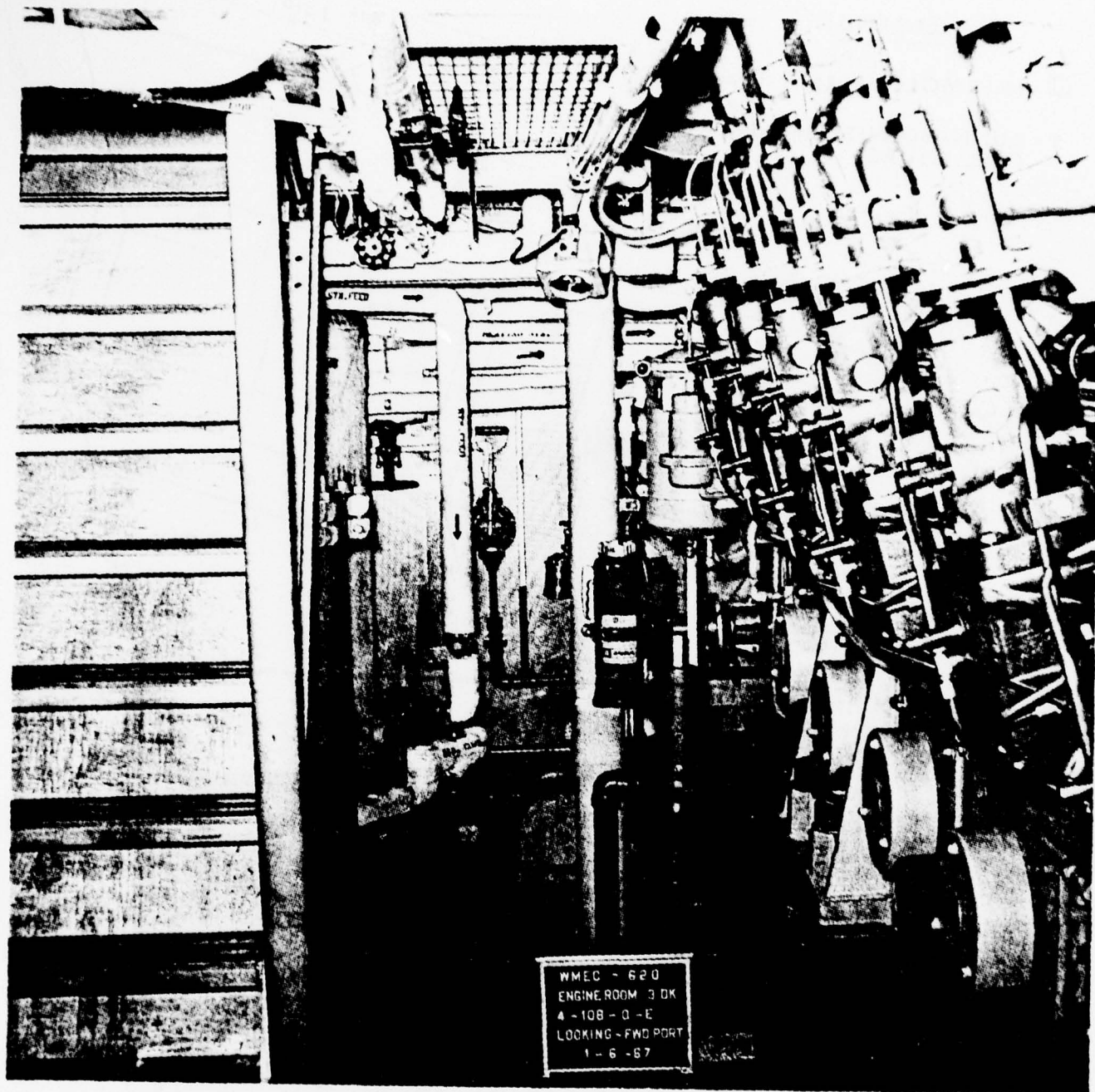


FIGURE 6  
ENGINE ROOM OF 210-FOOT CUTTER

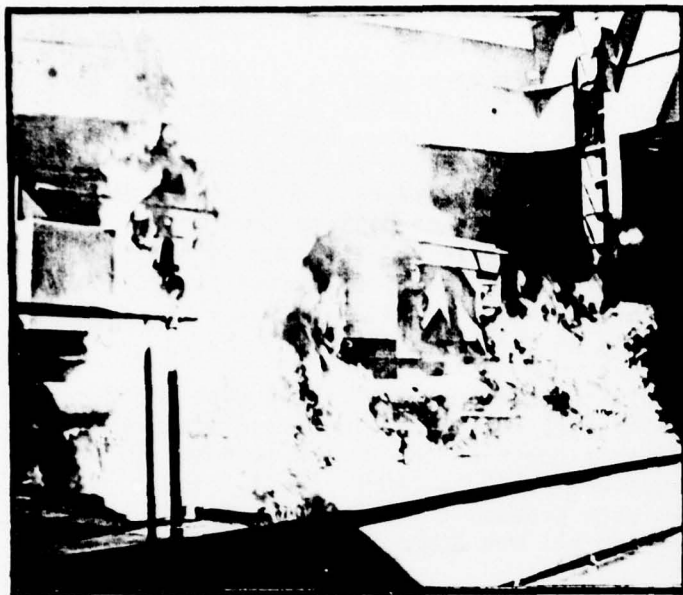
To size these fires, four extinguishers were used in a series of preliminary tests (Appendix A). Each of these extinguishers was chosen because it had the smallest quantity of agent of its type. Each extinguisher was discharged on a spray fire. A fire area of 80 square feet was used to start. The fire area was decreased in subsequent tests until only one of the extinguishers (other than the CO<sub>2</sub> units) was capable of putting the fire out. This fire size was taken as the final test size for the running fuel fires and spray fires. The bilge fire was found to be almost twice as easy to extinguish as a spray fire so 108 square feet was used as its final test size. The final test fires had the following characteristics:

Bilge Fire: A bilge area of 108 square feet was filled with water to a depth of five inches. The test fuel (No. 2 marine diesel) was floated on top of the center to a depth of one to two inches. This fuel pumped onto the water was preheated to 140°F (62°C). These fires were permitted a one-minute preburn after they had become fully involved before extinguishment was attempted.

Running Fuel Fire: The running fuel fire had preheated fuel flowing down the engine casing and into the bilge area. The flow rate was three gallons per minute. Fuel coverage of the bilge area and the engine was regulated to control the fire severity. The bilge area permitted to burn was 60 square feet. Enough fuel was initially allowed to flow down the casing and onto the water in the bilge to permit a one-minute preburn after full involvement and still provide the extinguisher operator time for extinguishment without the fire being extinguished due to lack of fuel. The fuel flow was continued throughout the entire extinguishment phase.

Fuel Spray Fire: This fire involved the preheated marine diesel fuel being forced through a nozzle to produce a spray. The spray was directed against the engine casing where it drained down onto the water in the bilge. Fire severity was controlled by regulating the fuel coverage on the engine and in the bilge as well as the spray characteristics. The pressure at the nozzle was approximately forty pounds per square inch, the flow rate was three gallons per minute, and the bilge area was sixty square feet. Again, enough fuel was initially allowed to flow down the casing and into the bilge to permit a one-minute preburn after full involvement and still provide the extinguisher operator time for extinguishment without the fire being extinguished due to lack of fuel. The fuel spray was continued throughout the entire extinguishment phase.

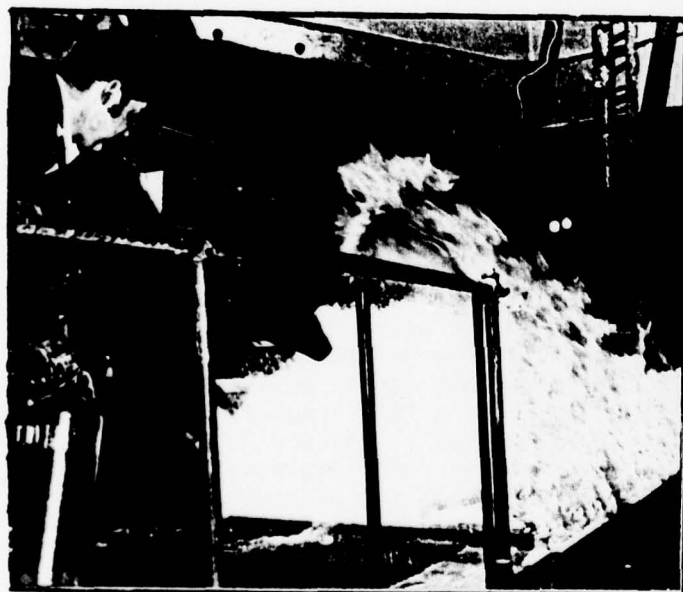
Establishing the fire size (Figure 7) was difficult because an extinguisher's UL rating does not necessarily indicate its relative capability when used on obstructed fires. This was further complicated because each time the fire situation changed, it required a number of extinguishment attempts by the operator to gain a reasonable degree of knowledge, control, or confidence for the new situation. Once this occurred, the fires were extinguished regardless of which extinguisher (except the carbon dioxide unit) was used. This learning adjustment was necessary for each operator even though they had previous fire-fighting experience, had studied slides and films on using portable extinguishers, and had practiced using the different extinguishers two months earlier on fire situations similar to those in the testing. It appeared that whenever the fire type changed, the operator's performance for that new situation progressed along a learning curve.



TEST FIRE



DRY CHEMICAL EXTINGUISHMENT



NO EXTINGUISHMENT WITH CARBON DIOXIDE



HALON 1211 EXTINGUISHMENT

FIGURE 7

ESTABLISHING TEST FIRE SIZES

Two additional bilge fires (4.5 feet by 6 feet) were conducted in which aluminum deck plating replaced the steel plating. Before the test, a 200-pound weight was placed on the aluminum plating to subject it to the loading which would be produced by a fire fighter with an extinguisher during a fire.

### 3.3 Extinguishers and Extinguishment

The seven extinguishers evaluated are listed in Table 1 along with their principle characteristics. Halon 1211 and Monnex were each used in two different models of extinguishers. The models differed in agent content by approximately 25 percent. This was done to show whether the quantity of agent used is an essential factor in the extinguishment of obstructed machinery space fires even though the extinguishers' UL ratings on Class B fires are identical.

The extinguishers tested were either stored-pressure or gas cartridge-operated types. One possible problem area with the stored pressure type is the seated O-ring in the extinguisher's refill cap. With constant recharging and exposure to a marine environment, the O-ring seat could become pitted and incapable of holding a pressurized charge. The cartridge-operated type does not have this problem.

The standard discharge nozzle supplied with each extinguisher was used during the test series. This nozzle gave the minimum effective discharge on Class B fires as specified by UL Standard 711. Dry chemical extinguishers used aboard Coast Guard cutters must conform to MIL-E-24091B (Ships)<sup>2</sup> which requires a higher discharge rate than does UL Standard 711. This is accomplished by the use of a high flow rate nozzle. Theoretically, this nozzle will provide quicker control of a fire because of the increased discharge rate. However, as the discharge rate increases, the time that an operator has to extinguish a fire decreases. Thus, the high-rate discharge provides for either quicker extinguishment or results in no extinguishment. UL standards permit a lower discharge rate, thus an extinguisher will discharge for a longer time. This provides the operator with more of a chance to recover from slight deficiencies in his technique.

Extinguishment was attempted through openings normally found at the junction of the engine and deck plating. If extinguishment was found to be impossible due to inability to direct the agent onto the fire, then a systematic pattern of openings was to be made in the deck plating and extinguishment would be attempted through these openings. The first method permitted a realistic comparison of the extinguishing capabilities of the different agents on obstructed bilge fires since aboard ship all deck plating is required to be bolted down and cannot be readily removed during fire-fighting operations. This plating has some small openings to accommodate piping and structural members but the addition of a systematic pattern of openings might permit more effective agent placement.

Each operator attempted extinguishment using the same approach lane. The operators were instructed to use specific extinguishment techniques and to discharge the extinguisher's contents completely. Their extinguishment

TABLE 1  
EXTINGUISHERS EVALUATED

EXTINGUISHER DESIGNATION MANUFACTURER (AGENT)	MANUFACTURER'S MODEL NUMBER	AGENT WEIGHT (LBS)	UL RATING	TOTAL WEIGHT FULLY CHARGED (LBS)	TEST RUNS				
					BTLGE	RUNNING	SPRAY	DISCHARGE TOTAL	
General (Carbon Dioxide)	15 RM	15	10 BC	46	4			1	5
Graviner (Halon 1211)	22-18	22	2A-60 BC	40	4	4	4	1	13
Amerex (Halon 1211)	361	17	2A-60 BC	36	4	4	4	1	13
Chemtron (Monnex)	20 SF-MX	19	120 BC	46	4	4	4	1	13
Amerex (Monnex)	438	17	120 BC	36	4	4	4	1	13
Ansu 1 (Monoammonium Phosphate)	14354	25	20A-80 BC	49	4	4	4	1	13
Ansu 1 (Potassium Bicarbonate)	14356	27	120 BC	51	4	4	4	1	13
TOTAL					28	24	24	7	83

attempts during the preliminary fire-sizing tests permitted them to be on the upper plateau of their learning curve. Thus operator experience was removed as a variable.

The large number of test fires required a quick effective method of extinguishment in case the portable extinguishers failed to extinguish the fires. Three percent protein foam was tried but rejected because its removal for each successive test created too many problems. For example, burning the foam off took too long and resulted in unrealistic preburn times and temperatures.

The solution was an installed sprinkler system in the bilge area. A sprinkler head in each bilge compartment required only a ten-second water discharge to extinguish the bilge fires. The water spray struck the hot bilge coamings and deck plates, creating enough steam to immediately extinguish the bilge fires. It also provided a cooling effect which helped prevent any flashbacks. This cooling effect dropped the bilge temperatures by 932°F (500°C) in less than three minutes (Figure 8).

#### 3.4 Observations and Measurements

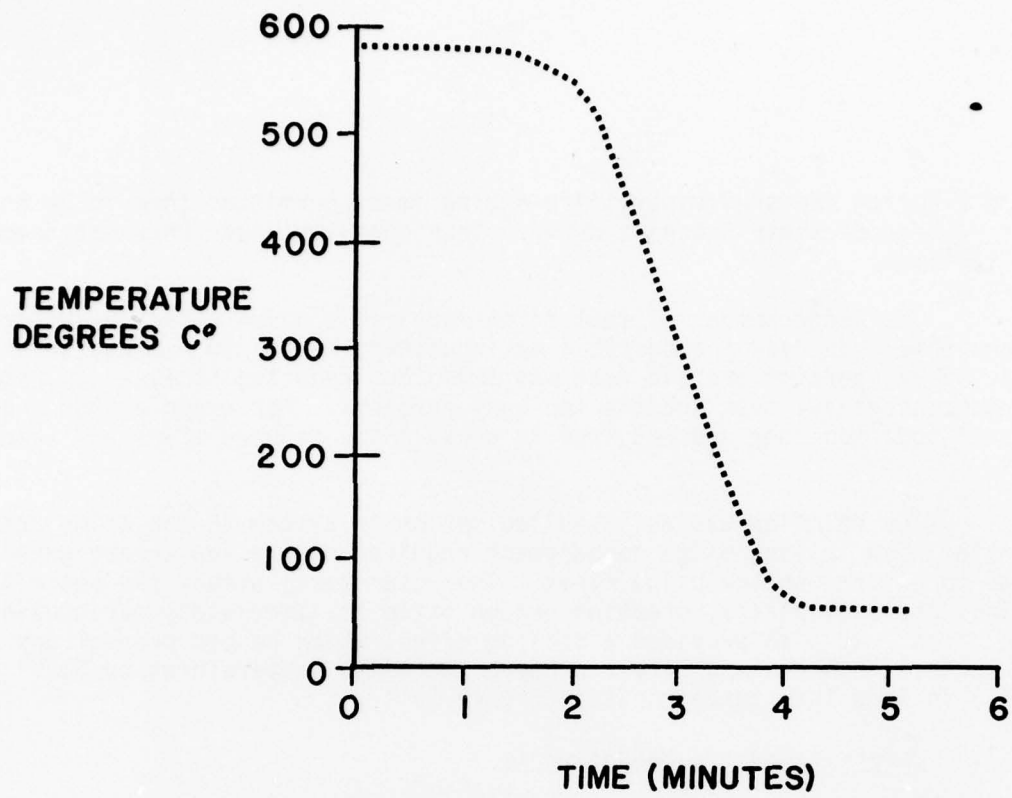
Visual observations and color videotape recordings were made for each test from the main deck looking down into Cargo Hold No. 5 along the length of the simulated bilge and engine casing (Figure 9). This position provided the best view for observing the fire activity inside the bilge coamings. Video recordings taken from this position also presented a clear documentation of each extinguisher's pattern and range in the different fire situations.

Wind speed and direction was measured on the main deck. It varied from two to ten miles per hour during the tests but did not have a noticeable effect on the tests being conducted inside the cargo hold. Ambient temperature ranged from 60°F (16°C) to 88°F (31°C). Relative humidity varied between 45 and 82 percent. Neither ambient temperatures nor humidity had a noticeable effect on the degree of difficulty in extinguishment or in the intensity of the fire.

Two strip chart recorders were used to record thermocouple readings on the engine casing and in the bilge area. Five Type K Inconel-sheathed thermocouples were installed on the machinery space mockup (Figure 6). The thermocouples designated for the bilge area were 6 inches (15.2 cm) away from the engine casing and 6 inches (15.2 cm) above the fuel level. During all of the extinguisher test fires, the maximum temperature reached inside the bilge area and on the engine casing was 527°F (275°C) (Figure 10).

Static extinguisher weights were recorded before and after agent discharge. Discharge curves were determined for each extinguisher prior to testing by dynamically measuring the weight loss as a function of time during a total discharge of the extinguisher.

Extinguishment time was considered as the time from the start of agent application until all fire in the bilge area was visibly out. Agent discharge was continued until the extinguisher was empty in order to prevent



**SPRINKLER EFFECT ON BILGE TEMPERATURES**

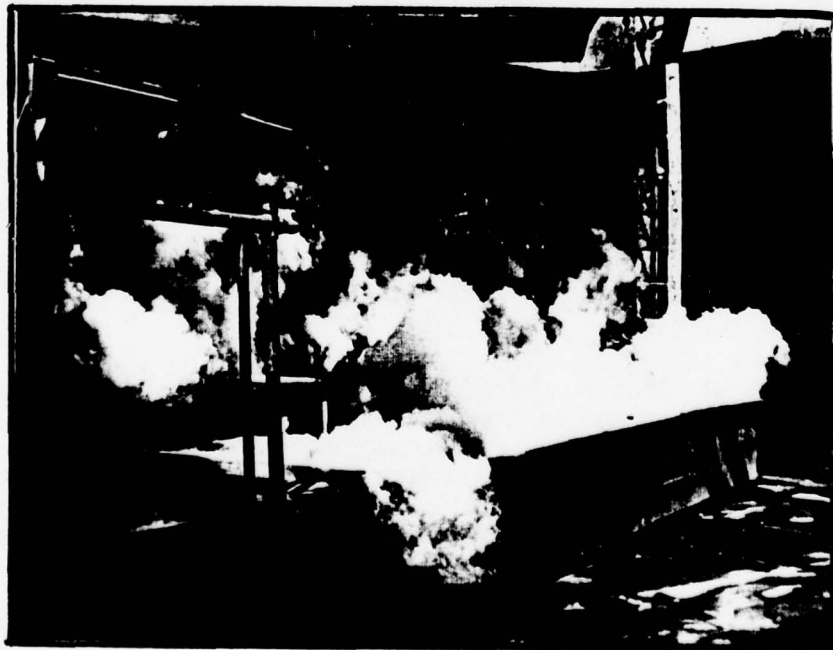


FIGURE 8

BILGE SPRINKLER EXTINGUISHMENT SYSTEM



VIDEO RECORDING ANGLE



VIDEO RECORDING

FIGURE 9

VISUAL DOCUMENTATION WITH VIDEO TAPE RECORDINGS

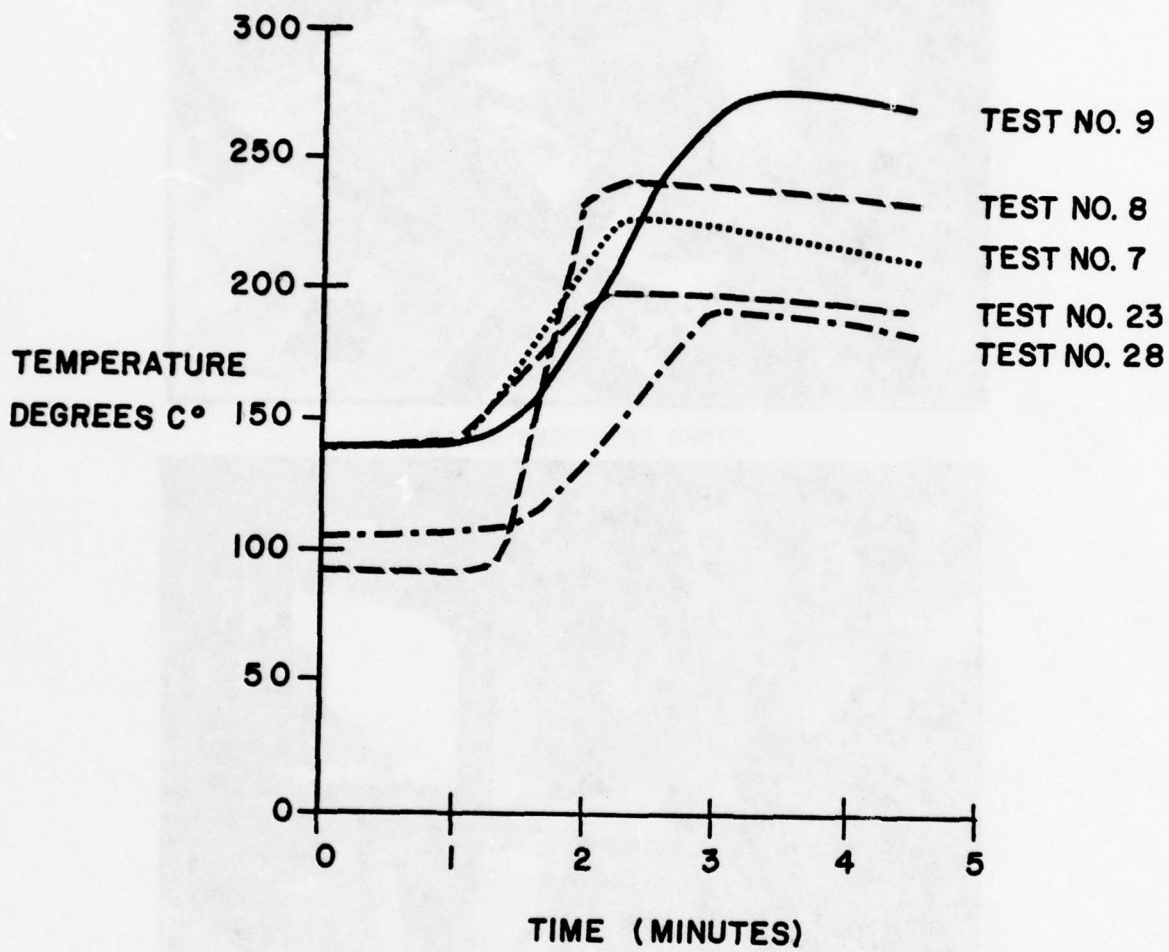


FIGURE 10  
TEMPERATURE HISTORIES DURING BILGE FIRES

the possibility of flashback. Extinguishment times were determined by stopwatch during the tests and rechecked by reviewing the videotape recordings which have the time displayed after the tests.

### 3.5 Experimental Error

The program strategy was designed to provide reliable results in the presence of experimental errors. These errors could be classified as either bias or random errors. Randomization and blocking were utilized to eliminate or identify bias errors attributed to different fire types, extinguishing agents, extinguishers, operators, and environmental factors.<sup>10,11</sup> The test schedule in Table 2 randomized the testing sequence of the extinguishers. This schedule was identical for the three fire types. Each schedule had twenty-four test runs and used each extinguisher model four times. The alternating use of different fire fighters also reduced the bias error associated with fire extinguishment technique. The combination of randomization and alternating operators reduced any additive learning effects by not allowing one operator to use the same equipment consecutively.

The primary tool for handling random error was replication because the average of a number of experimental observations provides more reliable data than a single observation. A small number of replications is helpful and essential in lowering random errors. Each type of extinguisher was tested four times on each fire type. This number of replications was high enough to assure test validity but was not excessive.

### 3.6 Selection Criteria

The criteria for selecting a portable extinguisher include the extinguisher's effectiveness, cost, availability, reliability, serviceability, agent toxicity, cleanup, and corrosion (Figure 11). Measures of effectiveness will be discussed below. Costs were determined by a market survey of different manufacturers as presented in Table 3. It is noteworthy that the cost of Monnex has decreased by 22 percent over the past five years while the cost of the other agents has increased with inflation. Availability does not appear to be a critical factor. All of the test extinguishers were supplied by local distributors within a two-week delivery time. Large quantities of agent were found to be limited in specific metropolitan areas but could be delivered by the manufacturers within a few weeks. Requirements for serviceability and reliability of portable extinguishers used on Coast Guard cutters are given in military and federal specifications.<sup>2,3,4</sup> Toxicity, cleanup, and corrosion will be discussed in Section 4.0.

The most direct approach for determining an extinguisher's effectiveness is to measure extinguishment times on a series of fires. Any agent remaining in an extinguisher after total extinguishment of the fire would naturally provide a "reserve" capacity that could be used to extinguish additional fire area. To determine this discharge, curves were determined and plotted as the weight of agent discharged versus the discharge time. The reserve capacity can then be simply determined by taking the ratio of the weight of agent remaining after a test fire extinguishment divided by the weight of the original agent charge. Actual discharge curves, such as shown in Figure 12, generally are nonlinear. At some point, when a discharge curve

TABLE 2  
TEST SCHEDULE

<u>TEST</u>	<u>OPERATOR NUMBER</u>	<u>EXTINGUISHER MODEL</u>
1	one	Graviner (Halon 1211)
2	two	Amerex (Monnex)
3	one	General (Carbon Dioxide)
4	two	Graviner (Halon 1211)
5	one	Chemetron (Monnex)
6	two	General (Carbon Dioxide)
7	one	Ansul (Potassium Bicarbonate)
8	two	Chemetron (Monnex)
9	one	Amerex (Halon 1211)
10	two	Ansul (Potassium Bicarbonate)
11	one	Ansul (Monoammonium Phosphate)
12	two	Amerex (Halon 1211)
13	one	Amerex (Monnex)
14	two	Ansul (Monoammonium Phosphate)
15	one	Graviner (Halon 1211)
16	two	Amerex (Monnex)
17	one	General (Carbon Dioxide)
18	two	Graviner (Halon 1211)
19	one	Chemetron (Monnex)
20	two	General (Carbon Dioxide)
21	one	Ansul (Potassium Bicarbonate)
22	two	Chemetron (Monnex)
23	one	Amerex (Halon 1211)
24	two	Ansul (Potassium Bicarbonate)
25	one	Ansul (Monoammonium Phosphate)
26	two	Amerex (Halon 1211)
27	one	Amerex (Monnex)
28	two	Ansul (Monoammonium Phosphate)

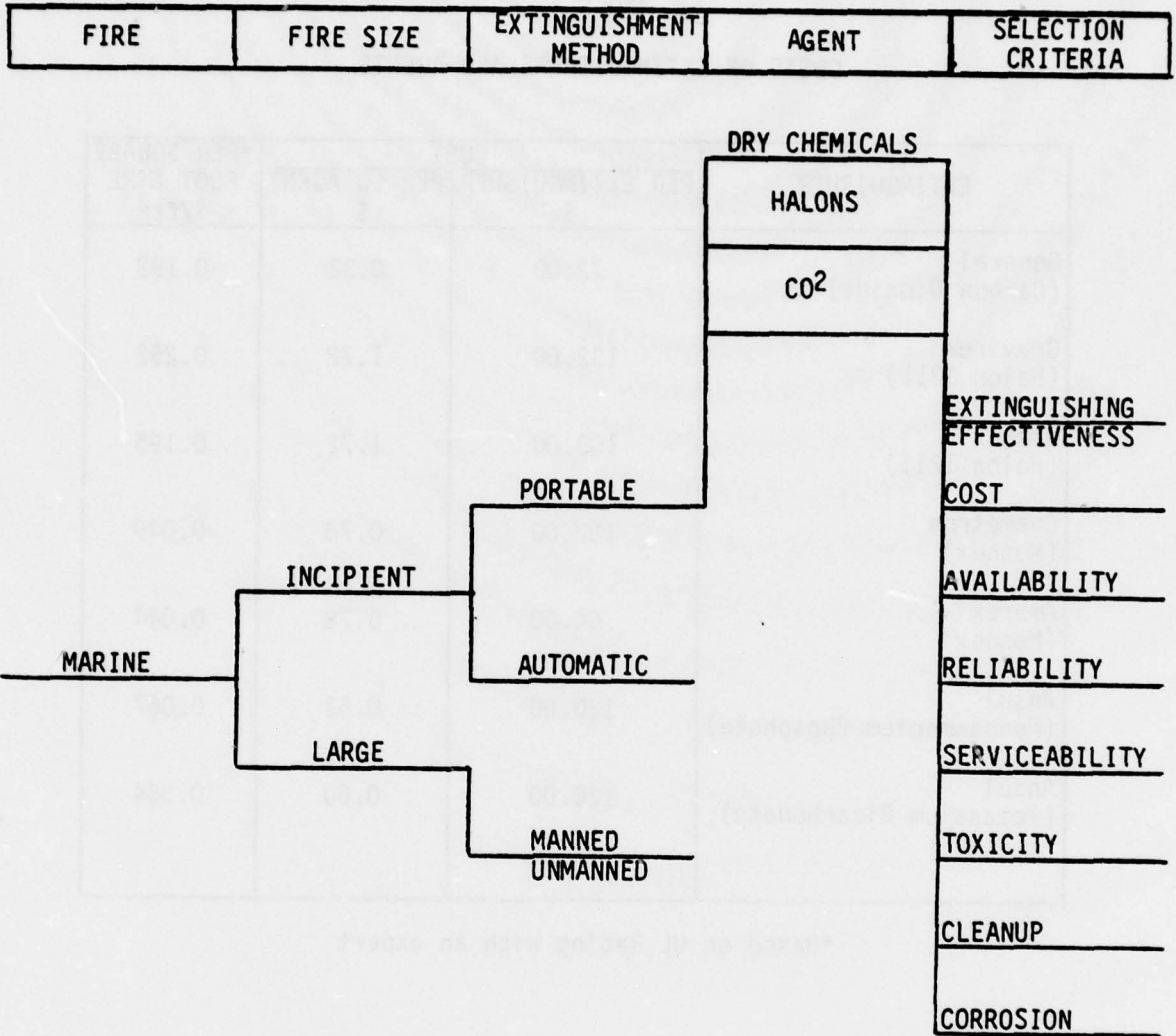


FIGURE 11

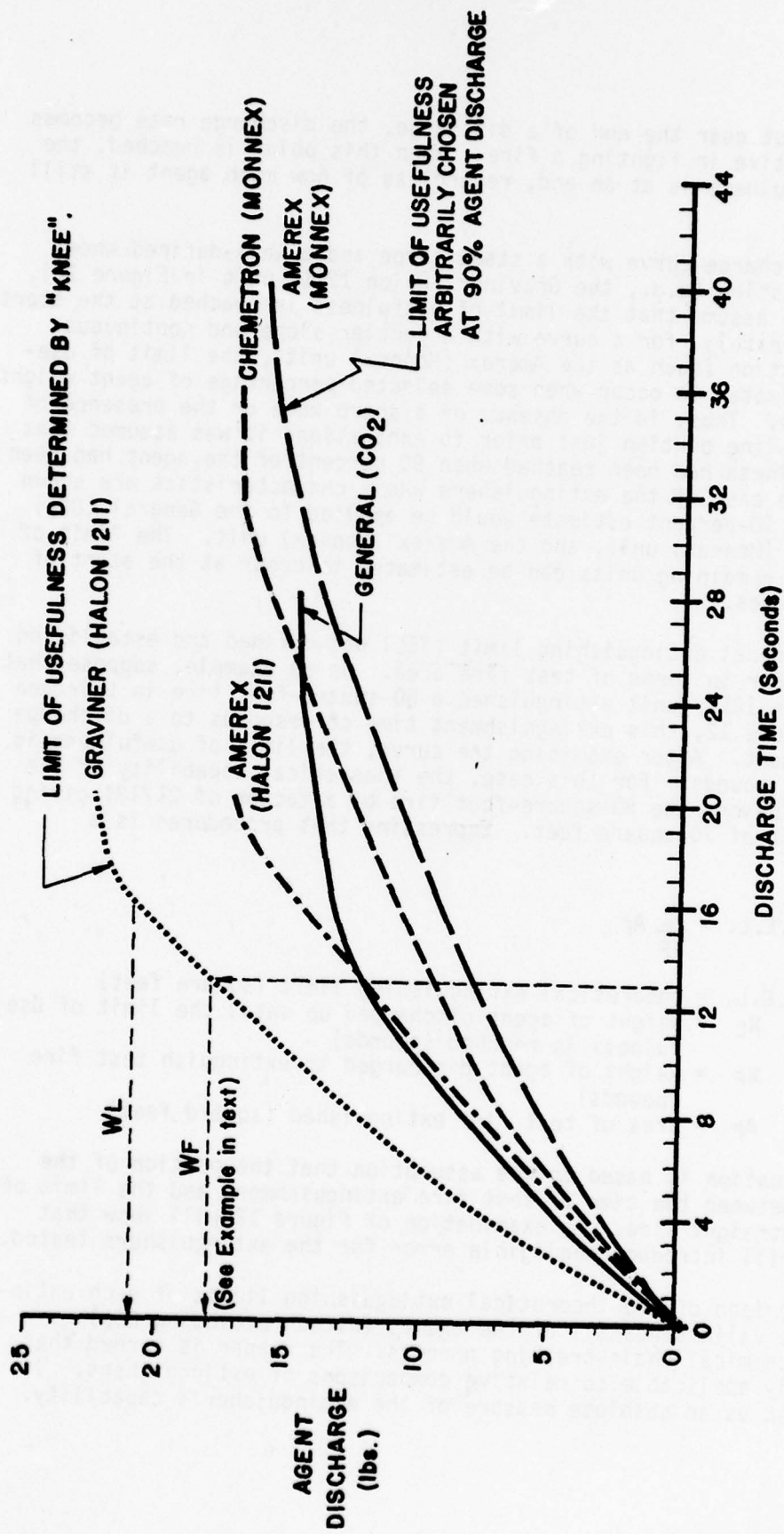
PORTABLE EXTINGUISHERS PLACEMENT ON THE HIERARCHY OF MARINE FIRE FIGHTING

TABLE 3

## COSTS OF EXTINGUISHERS AND AGENTS

EXTINGUISHER	COST		*PER SQUARE FOOT FIRE \$/ft <sup>2</sup>
	PER EXTINGUISHER \$	PER LB AGENT \$	
General (Carbon Dioxide)	72.00	0.32	0.192
Graviner (Halon 1211)	132.00	1.72	0.252
Amerex (Halon 1211)	100.00	1.72	0.195
Chemetron (Monnex)	182.00	0.78	0.049
Amerex (Monnex)	64.00	0.78	0.044
Ansul (Monoammonium Phosphate)	120.00	0.53	0.067
Ansul (Potassium Bicarbonate)	120.00	0.60	0.054

\*Based on UL Rating with an expert



PORTABLE EXTINGUISHER DISCHARGE CHARACTERISTICS  
(Based on Preliminary Test Data)

FIGURE 12

starts to flatten out near the end of a discharge, the discharge rate becomes too low to be effective in fighting a fire. When this point is reached, the extinguisher's usefulness is at an end, regardless of how much agent it still contains.

For a discharge curve with a steep slope and a well-defined knee just prior to exhaustion (e.g., the Graviner (Halon 1211) unit in Figure 12), it is reasonable to assume that the limit of usefulness is reached at the start of the knee. Alternately, for a curve with a gentler slope and continuous curvature to exhaustion (such as the Amerex (Monnex) unit), the limit of usefulness can be estimated to occur when some selected percentage of agent weight has been discharged. Thus, in the absence of a sharp knee or the presence of a lengthy straight-line portion just prior to exhaustion, it was assumed that the limit of usefulness had been reached when 90 percent of the agent had been discharged. In the case of the extinguishers whose characteristics are shown in Figure 12, this 90-percent estimate would be applied to the General (CO<sub>2</sub>) unit, the Chemtron (Monnex) unit, and the Amerex (Monnex) unit. The limit of usefulness for the remaining units can be estimated to occur at the start of the knee on the curves.

A theoretical extinguishing limit (TEL) was defined and established for each extinguisher in terms of test fire area. As an example, suppose that the Graviner (Halon 1211) unit extinguished a 60-square-foot fire in thirteen seconds. From Figure 12, this extinguishment time corresponds to a discharge of 18 pounds of agent. After examining the curve, the limit of usefulness is estimated to be 21 pounds. For this case, the theoretical capability of the unit would extend beyond the 60-square-foot fire by a factor of 21/18, giving a theoretical limit of 70 square feet. Expressing this procedure is a formula:

$$T.E.L. = \frac{W_L}{W_F} A_F$$

where T.E.L. = theoretical extinguishing limit (square feet)  
W<sub>L</sub> = weight of agent discharged up until the limit of usefulness is reached (pounds)  
W<sub>F</sub> = weight of agent discharged to extinguish test fire (pounds)  
A<sub>F</sub> = area of test fire extinguished (square feet)

This equation is based on the assumption that the portion of the discharge curve between the time of test fire extinguishment and the limit of usefulness is a straight line. An examination of Figure 12 will show that this assumption will introduce negligible error for the extinguishers tested.

A comparison of the theoretical extinguishing limits of each extinguisher should be valid since all of the agents tested (excluding CO<sub>2</sub>) extinguish by a chemical chain-breaking process. The reader is warned that the T.E.L. is only applicable to relative comparisons of extinguishers. It should not be used as an absolute measure of the extinguisher's capability.

## 4.0 RESULTS AND DISCUSSION

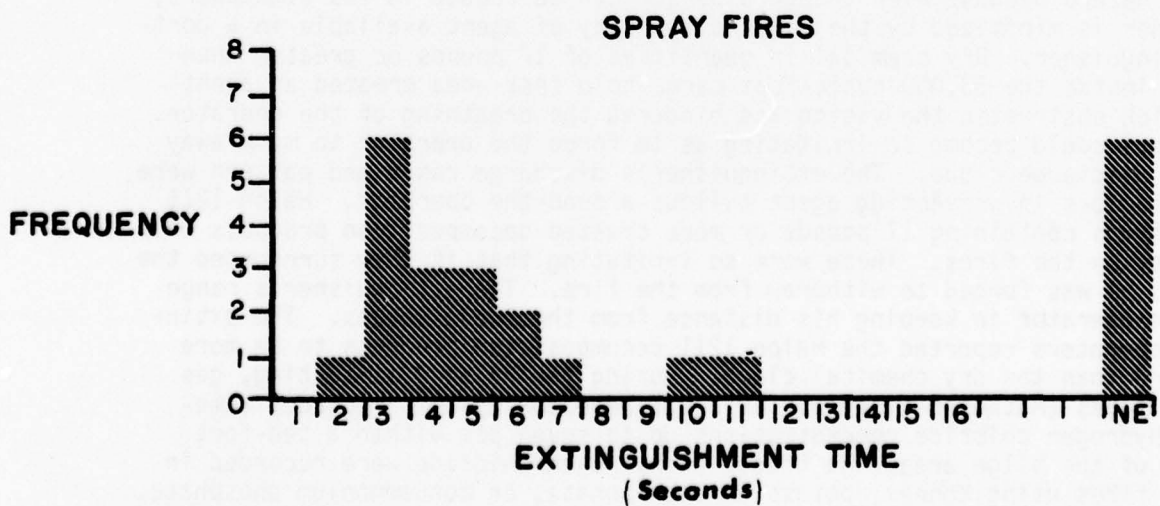
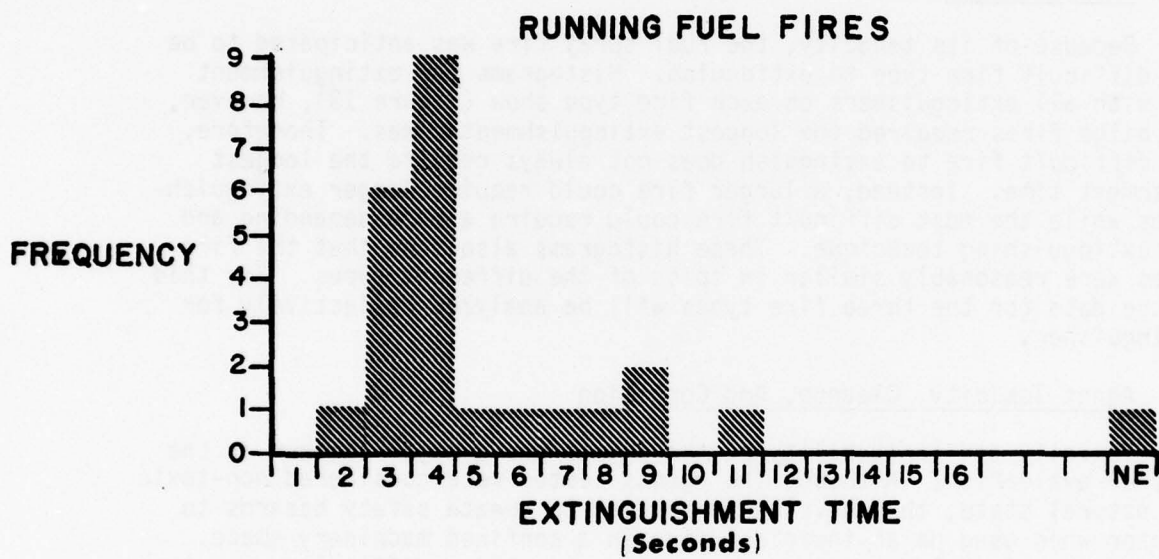
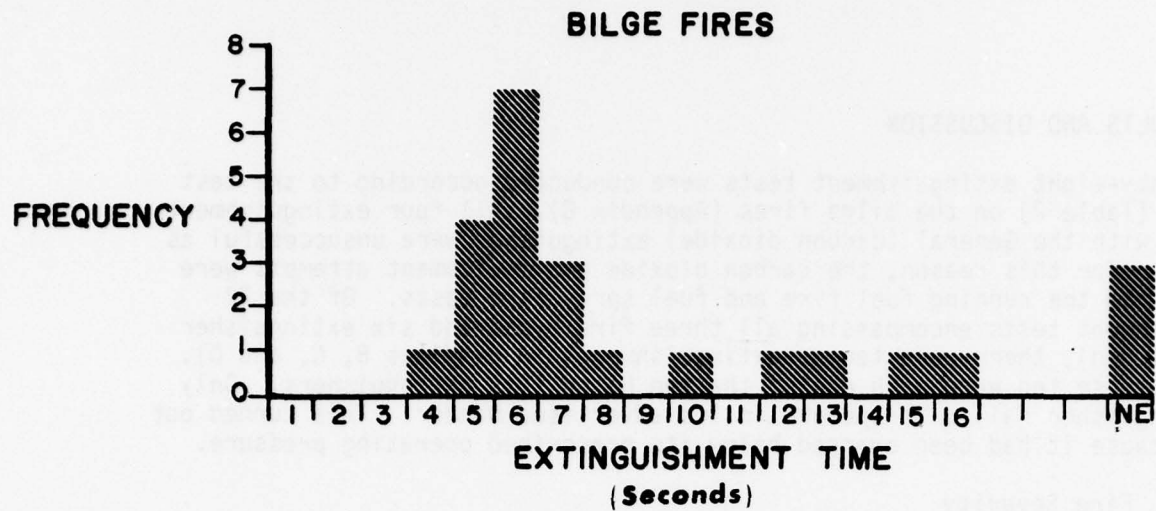
Twenty-eight extinguishment tests were conducted according to the test schedule (Table 2) on the bilge fires (Appendix B). All four extinguishment attempts with the General (carbon dioxide) extinguisher were unsuccessful as expected. For this reason, the carbon dioxide extinguishment attempts were dropped from the running fuel fire and fuel spray fire tests. Of the 72 extinguishment tests encompassing all three fire types and six extinguisher (CO<sub>2</sub> excluded), there were ten no-extinguishments (Appendices B, C, and D). Eight of these ten were with one of the two Halon 1211 extinguishers. Only one extinguisher failed to operate in its advertised manner. This turned out to be because it had been charged below its prescribed operating pressure.

### 4.1 Fire Severity

Because of its tenacity, the fuel spray fire was anticipated to be the most difficult fire type to extinguish. Histograms for extinguishment attempts with all extinguishers on each fire type show (Figure 13), however, that the bilge fires required the longest extinguishment times. Therefore, the most difficult fire to extinguish does not always require the longest extinguishment time. Instead, a larger fire could require longer extinguishment times while the most difficult fire could require a more demanding and critical extinguishing technique. These histograms also show that the fire severities were reasonably similar in spite of the different types. For this reason, the data for the three fire types will be analyzed collectively for each extinguisher.

### 4.2 Agent Toxicity, Cleanup, And Corrosion

Toxicity and irritability of the agents was a major concern in the extinguisher evaluation. Although the agents tested were considered non-toxic in their natural state, they have the potential to create safety hazards to the operator when used on an incipient fire in a confined machinery space. These hazards would include vision obstruction, breathing difficulty, and the irritating products of agent breakdown. Carbon dioxide presented the least possible hazard because even though a person can suffocate in its atmosphere, this danger is minimized by the limited quantity of agent available in a portable extinguisher. Dry chemical in quantities of 17 pounds or greater when released inside the 33,000-cubic-foot cargo hold test area created an agent cloud which obstructed the vision and hindered the breathing of the operator. This effect could become so irritating as to force the operator to move away from the discharge cloud. The extinguisher's discharge range and pattern were the key factors in preventing agent buildup around the operator. Halon 1211 extinguishers containing 17 pounds or more created decomposition products when discharged on the fires. These were so irritating that if they surrounded the operator, he was forced to withdraw from the fire. The extinguisher's range aided the operator in keeping his distance from the these gasses. The extinguisher operators reported the Halon 1211 decomposition products to be more irritating than the dry chemical cloud. During the Halon 1211 testing, gas detector tubes (Matheson-Kitagawa Toxic Gas Detector System) recorded atmospheric hydrogen chloride concentrations up to seven ppm within a ten-foot diameter of the bilge area. No traces of hydrogen chloride were recorded in the test fires using Monnex, potassium bicarbonate, or monoammonium phosphate.



HISTOGRAMS FOR 24 EXTINGUISHMENT ATTEMPTS ON 3 DIFFERENT FIRE TYPES.

FIGURE 13

The difficulty of agent cleanup was recorded for each extinguisher model. Halon 1211 and carbon dioxide become gasses upon exposure to the atmosphere and, therefore, leave no residue for cleanup. The Monnex, potassium bicarbonate, and monoammonium phosphate left dry chemical up to 1/8-inch (0.32 cm) deep on the horizontal surfaces and crevices reached by the agent discharge. Whenever the agent discharged passed directly through the pressurized fuel spray, the powder became saturated with fuel oil and formed a paste which adhered to the engine casing and deck surfaces. This paste was removed with a water spray after each test. Any powder which fell into the marine diesel fuel settled to the bottom and did not affect successive tests.

This test program was not designed to quantitatively determine the corrosive effects of the different agents. Previous extensive laboratory testing done by private research<sup>12,13</sup> reveals the corrosive effects of the test agents to have little or no effect on aluminum, brass, steel, or metals normally found in machinery spaces.

#### 4.3 Extinguisher Characteristics

Data for agent discharge curves was taken for each type of extinguisher. A fourth-order polynomial equation was fit to this data and is shown plotted in Figure 14. The limit of usefulness for each extinguisher is marked on each curve. Table 4 shows the average discharge rate, the time to the limit of usefulness, and the useful weight of agent in the extinguisher.

Two types of discharge patterns were produced by the different dry chemical extinguishers. One pattern held together tightly for a longer range than the other pattern which produced a wider spray. The tight pattern resulted in greater range but required more operator skill to engulf spray or running fuel fires. The short wide pattern quickly engulfed the spray or running fuel fires but required more operator skill to attack a large bilge fire. The unit with the shorter range was charged to 195 psig. The unit with longer range was charged to 350 psig. This additional pressure required the extinguisher cylinder to be of heavy-duty construction and added eight pounds to the cylinder weight. The lighter unit provided ample extinguishing range for machinery space fires.

#### 4.4 Extinguishment Times

Extinguishment time was the primary factor used to determine the most effective extinguisher. This would be a unit which repeatedly had short extinguishment times. The histograms shown in Figure 15 are for twelve extinguishment attempts for each extinguisher, four attempts on each of the three fire types. On these diagrams, the more efficient unit would show up as heavily weighted at the left. The no-extinguishment points and the skewed distribution apparent in these histograms makes it inappropriate to use descriptive statistics which are based on a normal distribution.

The frequency of extinguishment times which is weighted towards short times and then asymptotically decreases towards long times is properly described by a Weibull distribution.<sup>14</sup> This distribution also accounts for the no-extinguishments by including them in the distribution without exaggerating the already skewed curve. It is mathematically described by the function:

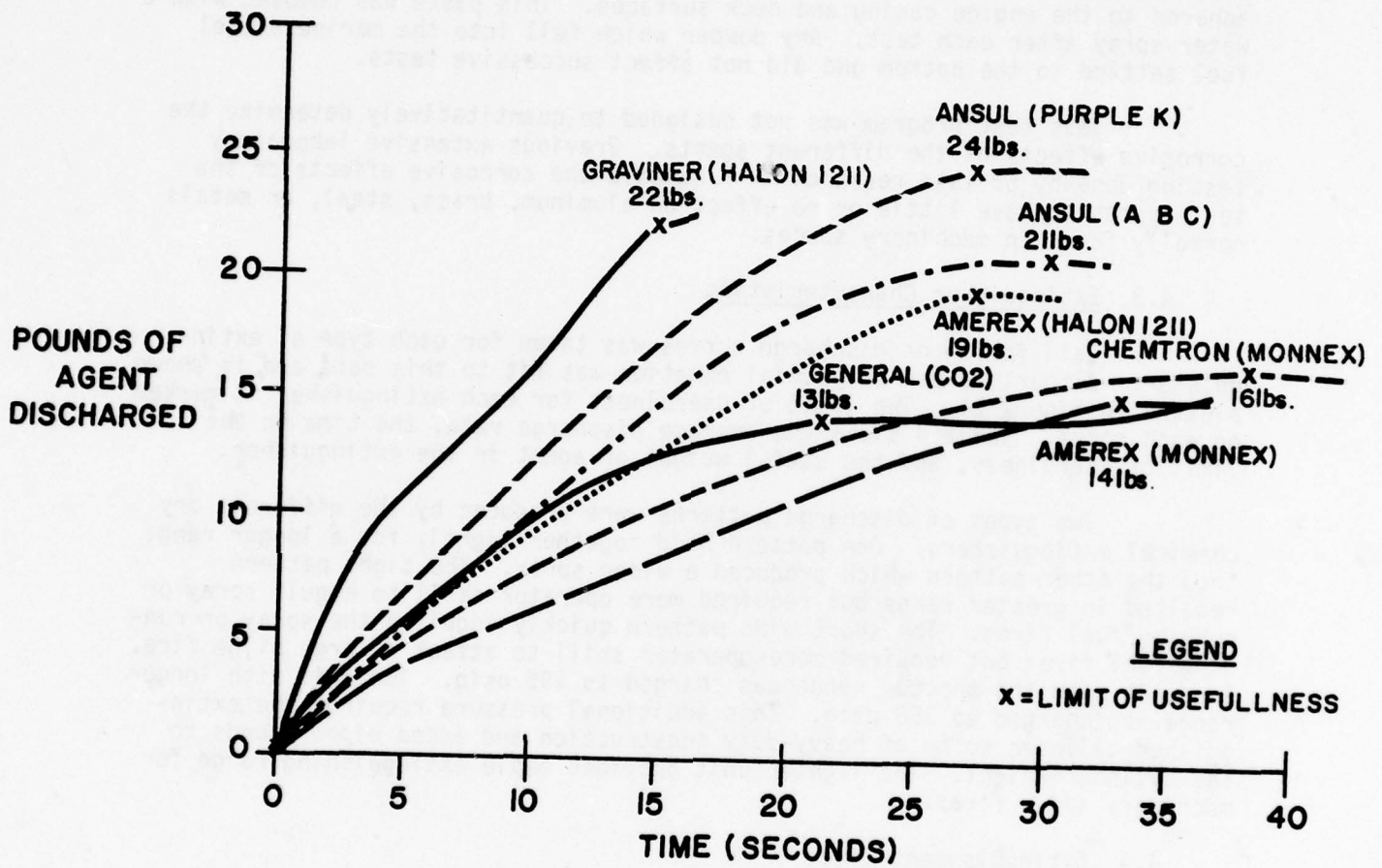
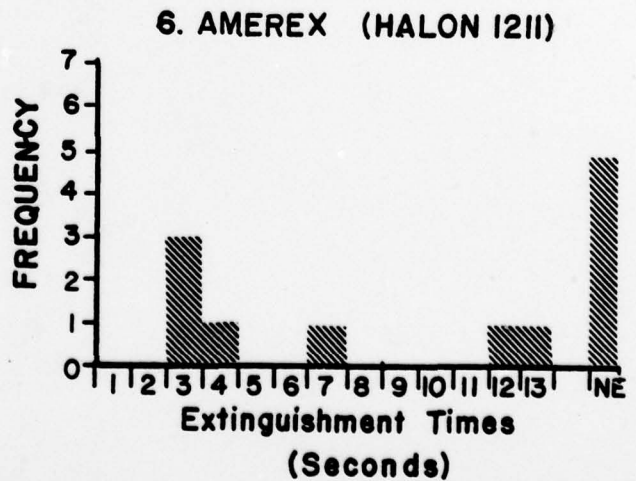
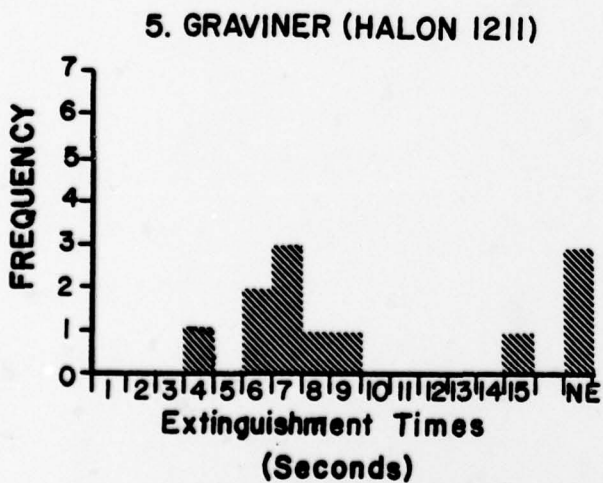
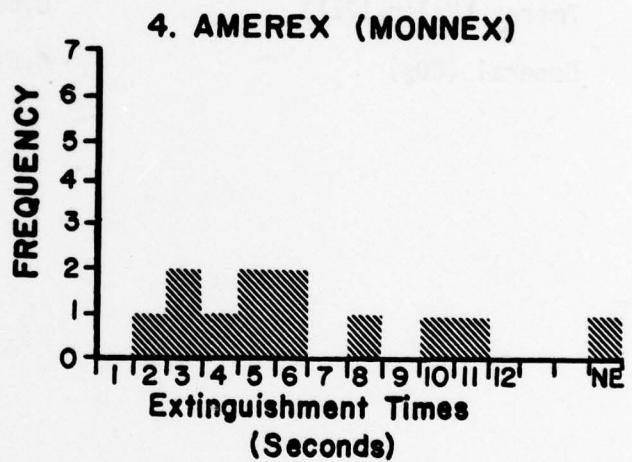
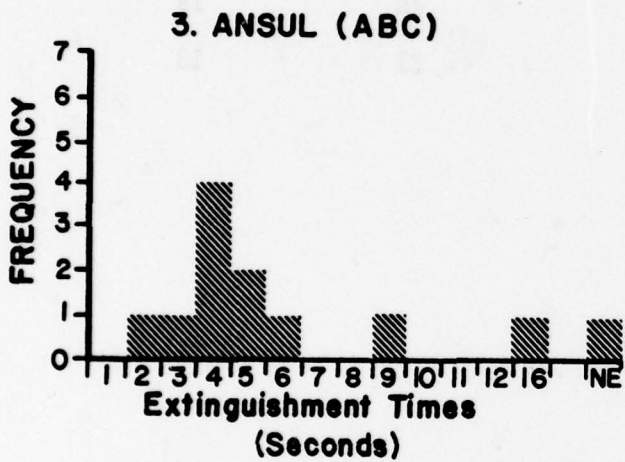
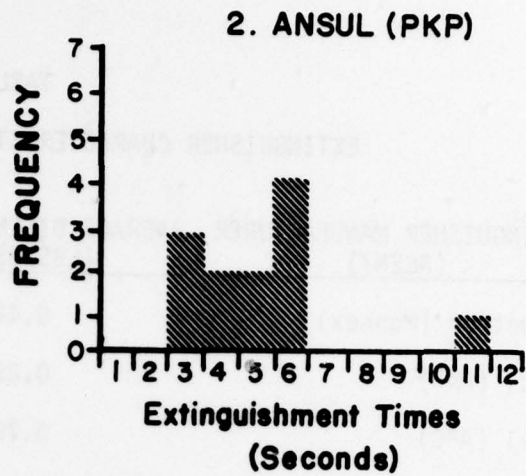
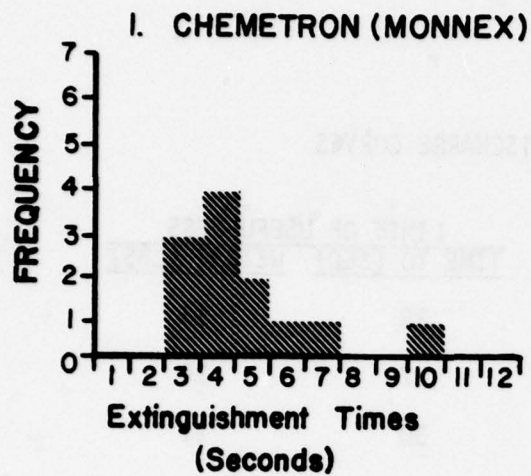


FIGURE 14  
EXTINGUISHER DISCHARGE CURVES

TABLE 4  
EXTINGUISHER CHARACTERISTICS FROM DISCHARGE CURVES

EXTINGUISHER MANUFACTURER (AGENT)	AVERAGE DISCHARGE RATE (LBS/SEC)	LIMIT OF USEFULNESS	
		TIME TO (SEC)	WEIGHT (LBS)
Chemetron (Monnex)	0.42	38	16
Ansu1 (PKP)	0.89	27	24
Ansu1 (ABC)	0.70	30	21
Amerex (Monnex)	0.41	34	14
Graviner (Halon 1211)	1.47	15	22
Amerex (Halon 1211)	0.68	28	19
General (CO <sub>2</sub> )	0.62	21	13



**HISTOGRAMS FOR EXTINGUISHMENT TIMES**

FIGURE 15

$$f(t) = \alpha \beta t^{\beta-1} e^{-\alpha t^\beta}$$

where  $t$  = extinguishment time

Estimates of  $\alpha$  and  $\beta$  are obtained from a graphical technique and then the mean extinguishment time and standard deviation may be calculated for the distributions. Plots of this distribution are presented in Figure 16 for the data displayed in Figure 15. The mean extinguishment time and the standard deviation for that time is listed on each plot.

These distributions are only slightly skewed as seen in Figure 16, thus confidence levels derived from the standard deviation and mean of the Weibull function can be interpreted as for a normal distribution.

Figure 17 graphically represents the confidence that should be placed on the data for extinguishment during a specific time frame. The first confidence level 68 percent is determined by taking the interval between the mean minus one standard deviation and the mean plus one standard deviation. Similarly, the second and third confidence levels 95 percent and 99 percent are determined by the mean +two standard deviations and the mean +three standard deviations respectively. As an example, consider the Ansul (PKP) extinguisher. At the 68 percent confidence level, we can say that this extinguisher will extinguish any one of the three test fires within three to seven seconds 68 percent of the time. That is probably not reliable enough for protecting the lives and property of the Coast Guard. So, let us look at the 99 percent confidence level. At this level the extinguisher will extinguish the fire within zero to eleven seconds 99 percent of the time. Note that, mathematically, this range would be minus one to eleven seconds but anything less than about one second is physically impossible. The other information displayed in Figure 16 is the time at which the extinguisher has reached its limit of usefulness.

A good relative ranking can be made using the information in Figure 16. First, it is clear that the Chemetron (Monnex) extinguisher is the best. While the extinguishment time interval at any confidence level is similar to that of the Ansul (PKP) unit, the extra discharge time up to the limit of usefulness is eleven seconds longer and would thus provide a greater capacity for the extinguisher. Second, both Halon 1211 units are clearly inferior. In fact, the extinguishment time interval at the 95 percent confidence level overlaps the limit of usefulness; thus, we could only be 68 percent certain of extinguishing one of the fires with either of these units. The other three extinguishers are fairly similar in their capabilities. One can trade a decreased extinguishment time interval for an increased limit of usefulness time. They are shown in Figure 17 in the order the authors consider appropriate.

It is interesting to examine the results of the two pairs of extinguishers which contained the same agents. The Chemetron (Monnex) extinguisher came out clearly superior to the Amerex (Monnex). This difference cannot be explained by their discharge rates as they were very similar: 0.42 and 0.41 pounds per second respectively. It cannot be explained by the total weight in each extinguisher (16 and 14 pounds respectively) because extinguishment was accomplished prior to either extinguisher being even 50 percent discharged. It is explained by the difference in the discharge patterns from the two

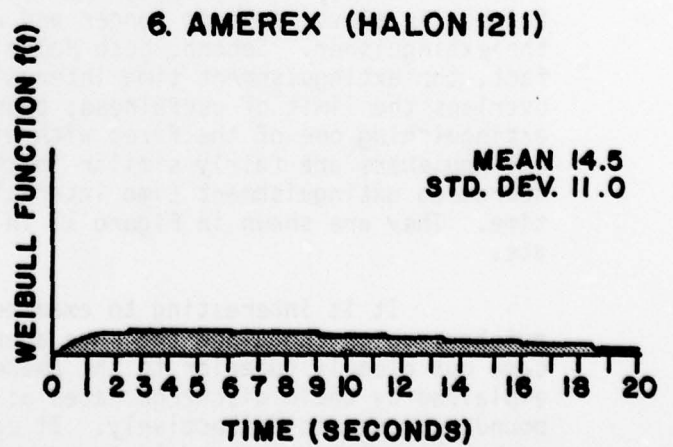
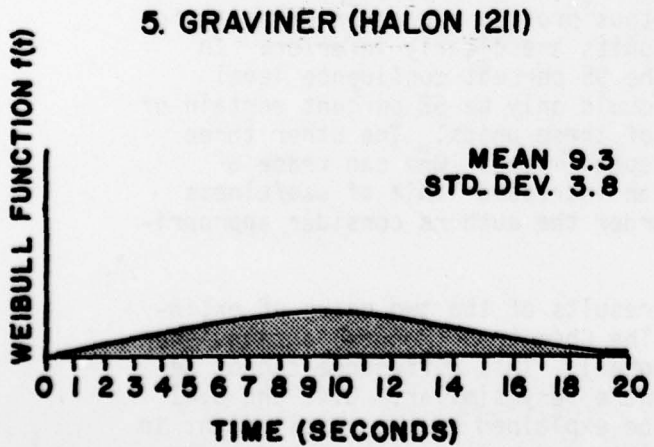
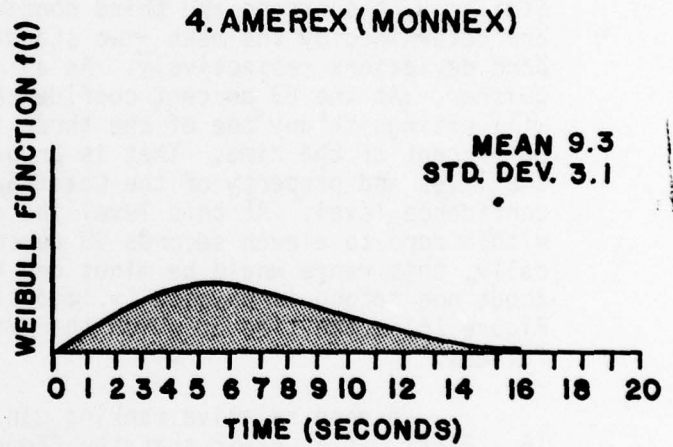
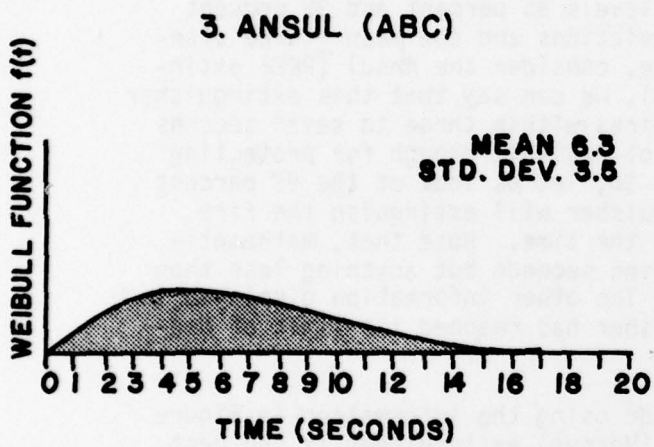
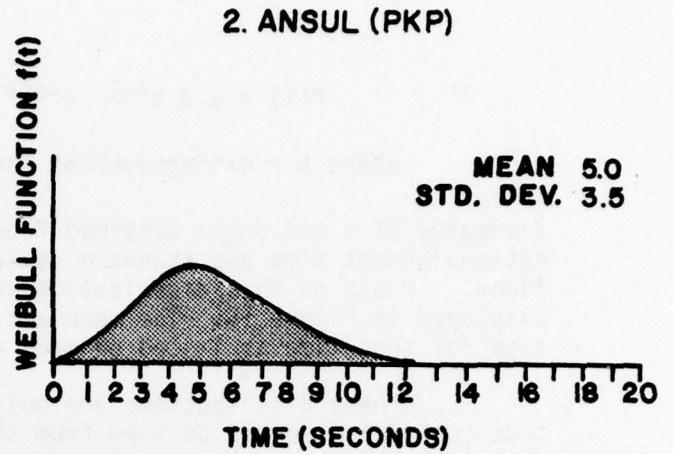
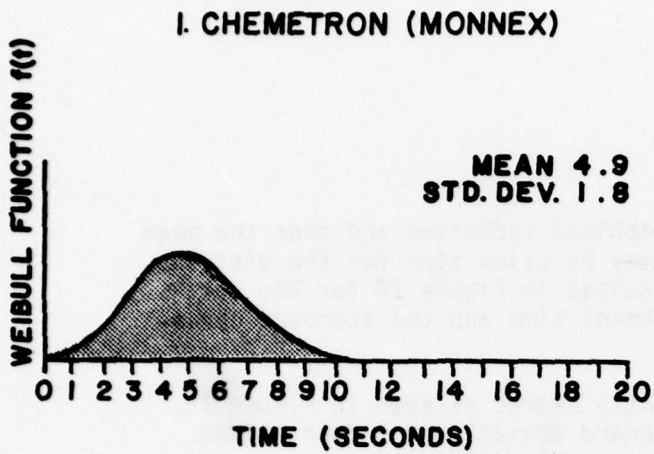
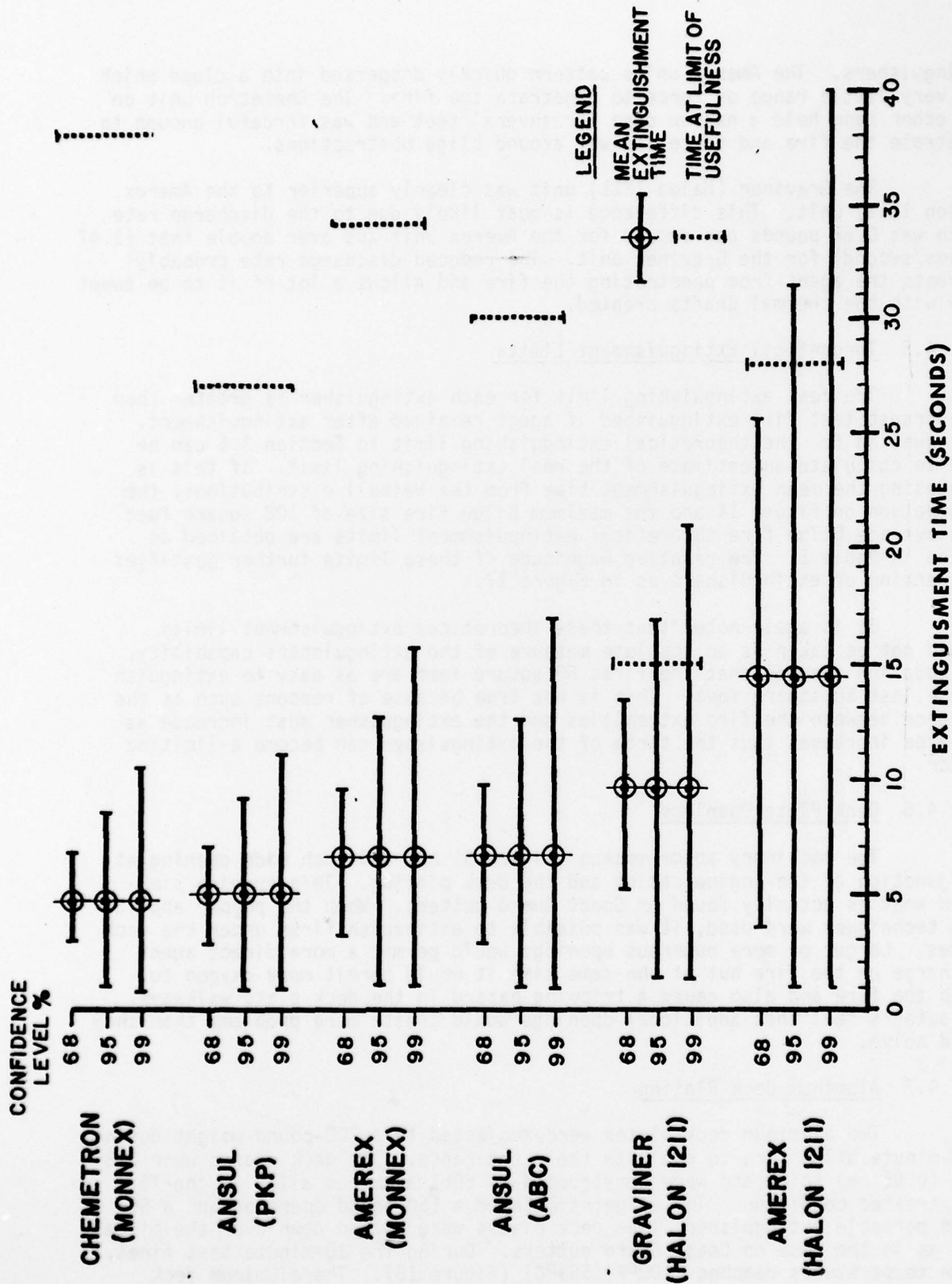


FIGURE 16  
WEIBULL DISTRIBUTIONS FOR EXTINGUISHMENT TIMES



CONFIDENCE LEVELS FOR EXTINGUISHMENT BASED ON WEIBULL DISTRIBUTION STANDARD DEVIATIONS

FIGURE 17

extinguishers. The Amerex units pattern quickly dispersed into a cloud which had very little range or force to penetrate the fire. The Chemetron unit on the other hand held a narrow cone for several feet and was forceful enough to penetrate the fire and force its way around bilge obstructions.

The Graviner (Halon 1211) unit was clearly superior to the Amerex (Halon 1211) unit. This difference is most likely due to the discharge rate which was 0.68 pounds per second for the Amerex unit and over double that (1.47 pounds/second) for the Graviner unit. The reduced discharge rate probably prevents the agent from penetrating the fire and allows a lot of it to be swept away with the thermal drafts created.

#### 4.5 Theoretical Extinguishment Limits

The real extinguishing limit for each extinguisher is greater than the largest test fire extinguished if agent remained after extinguishment. The equation for the theoretical extinguishing limit in Section 3.6 can be used to calculate an estimate of the real extinguishing limit. If this is done using the mean extinguishment time from the Weibull distributions, the information on Figure 14 and the maximum bilge fire size of 108 square feet then average bilge fire theoretical extinguishment limits are obtained as listed in Table 5. The relative magnitude of these limits further justifies the ranking of extinguishers as in Figure 17.

It is again noted that these theoretical extinguishment limits should not be taken as an absolute measure of the extinguishers capability. The equation assumes that the first 50 square feet are as easy to extinguish as the last 50 square feet. This is not true because of reasons such as the distance between the fire extremities and the extinguisher must increase as the area increases thus the throw of the extinguisher can become a limiting factor.

#### 4.6 Deck Plate Openings

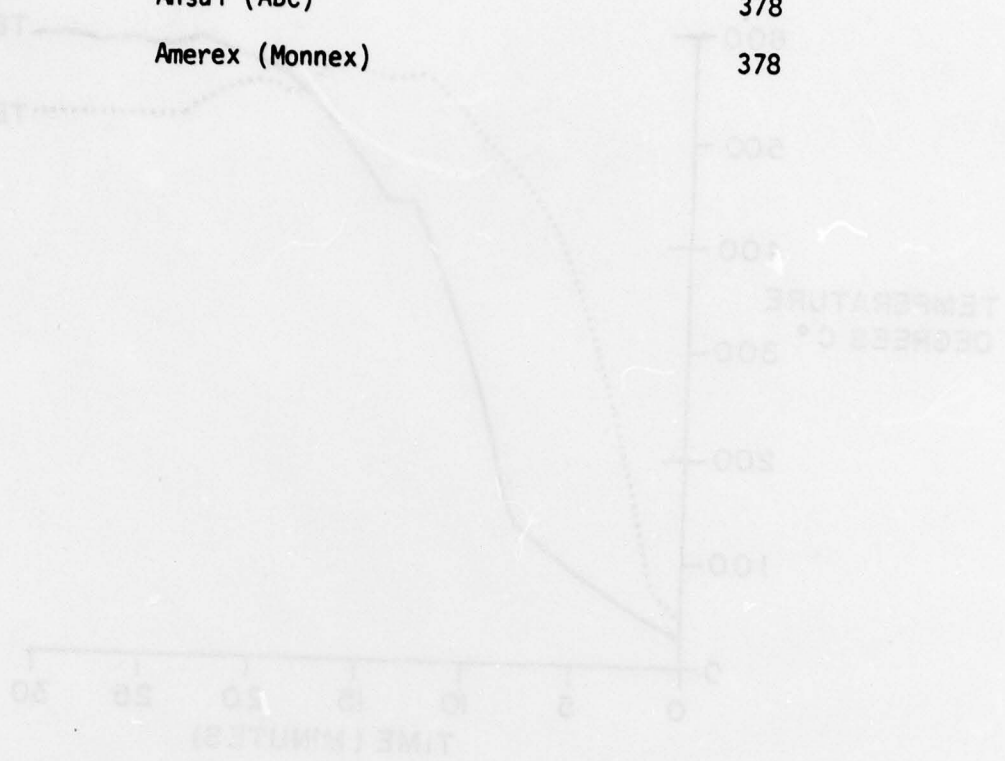
The machinery space mockup (Figure 5) had a 6-inch wide opening at the junction of the engine casing and the deck plating. This opening simulated what is actually found on Coast Guard cutters. When the proper application techniques were used, it was possible to extinguish fires under the deck plates. Larger or more numerous openings would permit a more direct agent discharge on the fire but at the same time it would permit more oxygen to reach the fire and also cause a tripping hazard in the deck plate walkways. The authors feel that additional openings would create more problems than they would solve.

#### 4.7 Aluminum Deck Plating

Two aluminum deck plates were subjected to a 200-pound weight during a 30-minute bilge fire to evaluate their endurance. The deck plates were 3/8-inch (0.95 cm) thick and were constructed of 6061 aluminum alloy in the T6 heat-treated condition. The weight simulated a 150-pound operator and a 50-pound portable extinguisher. The deck plates were bolted down over the bilge area as is the case on Coast Guard cutters. During the 30-minute test fires, bilge temperatures reached 1100°F (593°C) (Figure 18). The aluminum deck plates deflected downward three inches (0.95 cm) but did not melt, collapse, or fail to support the weight.

TABLE 5  
 THEORETICAL EXTINGUISHMENT LIMITS FOR DRY CHEMICAL EXTINGUISHERS

	Average TEL (ft <sup>2</sup> )
Chemetron (Monnex)	432
Ansul (PKP)	399
Ansul (ABC)	378
Amerex (Monnex)	378



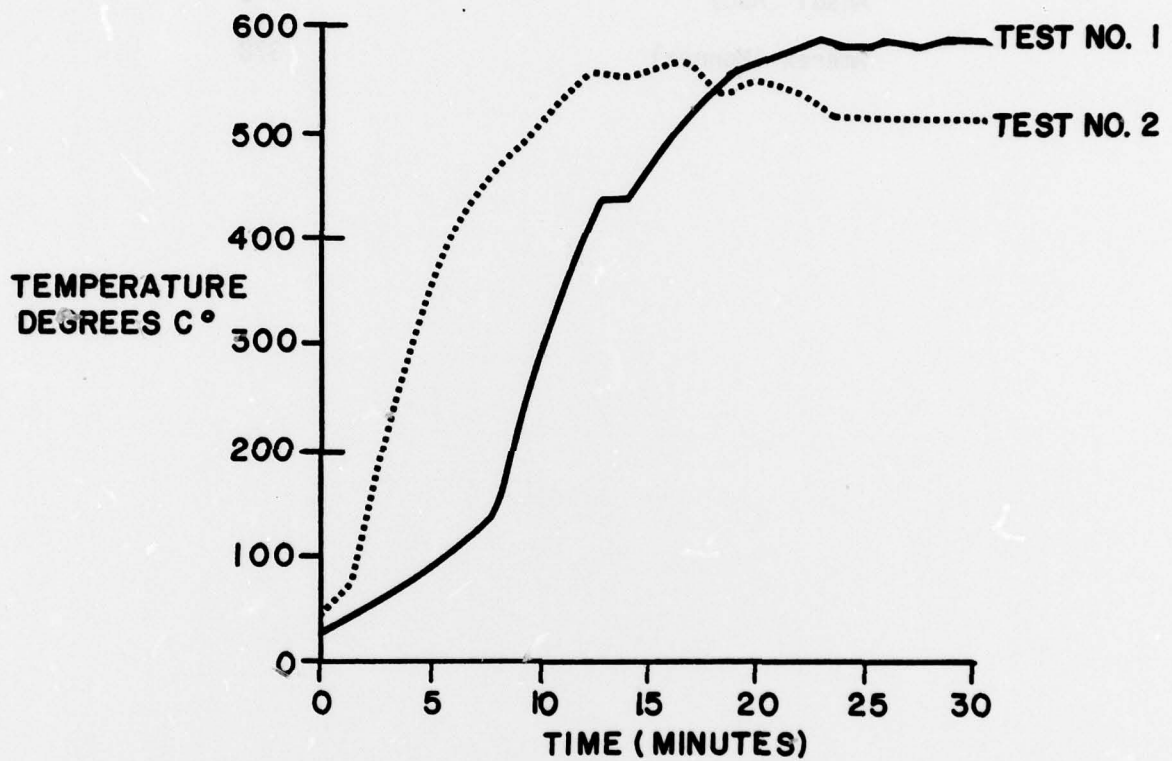


FIGURE 18  
 30-MINUTE BILGE TEMPERATURES DURING ALUMINUM DECK PLATE TESTS

## 5.0 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions were reached after an evaluation of all test results:

1. Carbon dioxide portable extinguishers are ineffective against machinery space fires.
2. Halon 1211, Monnex, potassium bicarbonate, and monoammonium phosphate portable extinguishers are effective against machinery space fires.
3. Dry chemical extinguishers have a greater extinguishing capacity than Halon 1211 extinguishers on machinery space fires.
4. The Chemetron (Monnex) extinguisher was somewhat superior to the other dry chemical extinguishers tested.
5. Operator application technique is more critical than the type of dry chemical extinguisher used on incipient machinery space fires.
6. Deck plate openings large enough to pass an extinguisher's discharge to a bilge fire would create more problems than they would solve.

Existing openings are large enough to pass sufficient agent to the bilge area to extinguish a fire. Larger deck openings would permit more agent to reach the fire but would not affect the primary problem for extinguishment which is the technique used in applying the agent. Larger openings would also permit more air to reach the fire thus making it more difficult to extinguish, and they would create an additional tripping hazard to the cutter's crew.

7. Aluminum deck plates do not melt or collapse when subjected to a 200-pound weight and a 30-minute bilge fire.

Based on the above conclusions, the following recommendations are made:

1. Do not replace the dry chemical extinguishers currently being used on Coast Guard cutters with Monnex extinguishers. While the Chemetron (Monnex) extinguisher was clearly the best, the rest of the dry chemical extinguishers were also very effective so that the cost of a special procurement to retrofit all cutters does not appear worthwhile.
2. Increase the effectiveness and, if necessary, the extent of training and hands-on experience with dry chemical portable extinguishers. Specialized instruction and training films could be used to increase a crew's awareness of the capabilities and limitations of these extinguishers. Personnel frequently manning the engine room (a fire hazard area) could discharge extinguishers on simulated bilge fires prior to their annual test and recharge.
3. Carbon dioxide extinguishers should be replaced in any location where they might be used for Class B fires as well as the Class C fires they were intended for. They should be replaced with dry

chemical extinguishers unless a "clean" agent is required in which case they should be replaced with Halon 1211. This recommendation would assure that the first person on-scene would not attack a fire with an ineffective extinguisher.

4. An additional investigation is recommended to check the feasibility of exchanging Monnex for potassium bicarbonate in the dry chemical extinguishers presently used on Coast Guard cutters. The advantage of this exchange is that larger quantities of the slightly more effective agent would be available. The largest portable extinguisher with potassium bicarbonate contains six more pounds of agent than the largest Monnex portable extinguisher. In addition, the changeover would only involve the cost of changing agents and not extinguishers. Limited fire testing in this program showed the extinguishing effectiveness of Monnex was not adversely affected when used in potassium bicarbonate extinguishers. Additional work is needed to investigate the feasibility and effectiveness of a dry chemical exchange.

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APPENDIX A  
PRELIMINARY TESTS

TEST #	EXTINGUISHER/AGENT	UL RATING	FIRE SITUATION			EXTINGUISHMENT TIME (SECONDS)
			FIRE SIZE (SQ FT)	FUEL PRESSURE (PSIG)	FUEL FLOW (GPM)	
91	Ansul (Potassium Bicarbonate)	120 BC	80	40	3	NE
92	Amerex (Halon 1211)	2A-60 BC	80	40	3	NE
93	Amerex (Monnex)	120 BC	80	40	3	NE
94	Ansul (Monoammonium Phosphate)	20A-80 BC	80	40	3	NE
95	Ansul (Potassium Bicarbonate)	120 BC	60	40	3	NE
96	Ansul (Monoammonium Phosphate)	20A-80 BC	60	40	3	NE
97	Amerex (Monnex)	120 BC	60	40	3	15
98	Graviner (Halon 1211)	2A-60 BC	60	40	3	NE
81	Ansul (Potassium Bicarbonate)	120 BC	60	*2	3	NE
82	Graviner (Halon 1211)	2A-60 BC	60	*2	3	NE
83	Amerex (Monnex)	120 BC	60	*2	3	13
84	Ansul (Monoammonium Phosphate)	20A-80 BC	60	*2	3	NE
91A	Ansul (Potassium Bicarbonate)	120 BC	30	40	3	11
92A	Amerex (Halon 1211)	2A-60 BC	30	40	3	19
93A	Amerex (Monnex)	120 BC	30	40	3	5
94A	Ansul (Monoammonium Phosphate)	20A-80 BC	30	40	3	5
95A	Graviner (Halon 1211)	2A-60 BC	30	40	3	5.5
96A	Amerex (Halon 1211)	2A-60 BC	30	40	3	6.1
At this point, the fuel spray on the engine casing was positioned 6 inches (15.2 cm) closer to the operator						
81A	Ansul (Potassium Bicarbonate)	120 BC	60	40	3	NE
82A	Amerex (Halon 1211)	2A-60 BC	60	40	3	7
83A	Amerex (Monnex)	120 BC	60	40	3	7
84A	Ansul (Monoammonium Phosphate)	20A-80 BC	60	40	3	NE
85A	Ansul (Potassium Bicarbonate)	120 BC	60	40	3	NE
86A	Amerex (Monnex)	120 BC	80	0	0	4
87A	Ansul (Monoammonium Phosphate)	20A-80 BC	80	0	0	2.2
88A	General (Carbon Dioxide)	10 BC	80	0	0	NE

\* = approximately

APPENDIX B

BILGE FIRE TESTS

TEST #	EXTINGUISHER/AGENT	UL RATING	FIRE SITUATION			EXTINGUISHMENT TIME (SECONDS)
			FIRE SIZE (SQ FT)	FUEL PRESSURE (PSIG)	FUEL FLOW (GPM)	
1	Graviner (Halon 1211)	2A-60 BC	108	0	0	7
4	Graviner (Halon 1211)	2A-60 BC	108	0	0	NE
15	Graviner (Halon 1211)	2A-60 BC	108	0	0	7
18	Graviner (Halon 1211)	2A-60 BC	108	0	0	15
2	Amerex (Monnex)	120 BC	108	0	0	6
13	Amerex (Monnex)	120 BC	108	0	0	8
16	Amerex (Monnex)	120 BC	108	0	0	6
27	Amerex (Monnex)	120 BC	108	0	0	5
3	General (Carbon Dioxide)	10 BC	108	0	0	NE
6	General (Carbon Dioxide)	10 BC	108	0	0	NE
17	General (Carbon Dioxide)	10 BC	108	0	0	NE
20	General (Carbon Dioxide)	10 BC	108	0	0	NE
5	Chemetron (Monnex)	120 BC	108	0	0	5
8	Chemetron (Monnex)	120 BC	108	0	0	6
19	Chemetron (Monnex)	120 BC	108	0	0	7
22	Chemetron (Monnex)	120 BC	108	0	0	10
7	Ansul (Potassium Bicarbonate)	120 BC	108	0	0	6
10	Ansul (Potassium Bicarbonate)	120 BC	108	0	0	6
21	Ansul (Potassium Bicarbonate)	120 BC	108	0	0	6
24	Ansul (Potassium Bicarbonate)	120 BC	108	0	0	5
9	Amerex (Halon 1211)	2A-60 BC	108	0	0	NE
12	Amerex (Halon 1211)	2A-60 BC	108	0	0	NE
23	Amerex (Halon 1211)	2A-60 BC	108	0	0	13
26	Amerex (Halon 1211)	2A-60 BC	108	0	0	12
11	Ansul (Monoammonium Phosphate)	20A-80 BC	108	0	0	6
14	Ansul (Monoammonium Phosphate)	20A-80 BC	108	0	0	5
25	Ansul (Monoammonium Phosphate)	20A-80 BC	108	0	0	4
28	Ansul (Monoammonium Phosphate)	20A-80 BC	108	0	0	16

APPENDIX C  
SPRAY FIRE TESTS

TEST #	EXTINGUISHER/AGENT	UL RATING	FIRE SITUATION			EXTINGUISHMENT TIME (SECONDS)
			FIRE SIZE (SQ FT)	FUEL PRESSURE (PSIG)	FUEL FLOW (GPM)	
1	Graviner (Halon 1211)	2A-60 BC	60	40	3	NE
4	Graviner (Halon 1211)	2A-60 BC	60	40	3	NE
15	Graviner (Halon 1211)	2A-60 BC	60	40	3	6
18	Graviner (Halon 1211)	2A-60 BC	60	40	3	7
2	Amerex (Monnex)	120 BC	60	40	3	5
13	Amerex (Monnex)	120 BC	60	40	3	10
16	Amerex (Monnex)	120 BC	60	40	3	NE
27	Amerex (Monnex)	120 BC	60	40	3	3
5	Chemetron (Monnex)	120 BC	60	40	3	5
8	Chemetron (Monnex)	120 BC	60	40	3	4
19	Chemetron (Monnex)	120 BC	60	40	3	3
22	Chemetron (Monnex)	120 BC	60	40	3	3
7	Ansu1 (Potassium Bicarbonate)	120 BC	60	40	3	11
10	Ansu1 (Potassium Bicarbonate)	120 BC	60	40	3	6
21	Ansu1 (Potassium Bicarbonate)	120 BC	60	40	3	5
24	Ansu1 (Potassium Bicarbonate)	120 BC	60	40	3	4
9	Amerex (Halon 1211)	2A-60 BC	60	40	3	NE
12	Amerex (Halon 1211)	2A-60 BC	60	40	3	NE
23	Amerex (Halon 1211)	2A-60 BC	60	40	3	3
26	Amerex (Halon 1211)	2A-60 BC	60	40	3	3
11	Ansu1 (Monoammonium Phosphate)	20A-80 BC	60	40	3	NE
14	Ansu1 (Monoammonium Phosphate)	20A-80 BC	60	40	3	4
25	Ansu1 (Monoammonium Phosphate)	20A-80 BC	60	40	3	3
28	Ansu1 (Monoammonium Phosphate)	20A-80 BC	60	40	3	2

## APPENDIX D

## RUNNING FUEL FIRE TESTS

TEST #	EXTINGUISHER/AGENT	UL RATING	FIRE SITUATION			EXTINGUISHMENT TIME (SECONDS)
			FIRE SIZE (SQ FT)	FUEL PRESSURE (PSIG)	FUEL FLOW (GPM)	
1	Graviner (Halon 1211)	2A-60 BC	60	*2	3	8
4	Graviner (Halon 1211)	2A-60 BC	60	*2	3	6
15	Graviner (Halon 1211)	2A-60 BC	60	*2	3	4
18	Graviner (Halon 1211)	2A-60 BC	60	*2	3	9
2	Amerex (Monnex)	120 BC	60	*2	3	4
13	Amerex (Monnex)	120 BC	60	*2	3	11
16	Amerex (Monnex)	120 BC	60	*2	3	3
27	Amerex (Monnex)	120 BC	60	*2	3	2
5	Chemetron (Monnex)	120 BC	60	*2	3	4
8	Chemetron (Monnex)	120 BC	60	*2	3	4
19	Chemetron (Monnex)	120 BC	60	*2	3	4
22	Chemetron (Monnex)	120 BC	60	*2	3	3
7	Ansul (Potassium Bicarbonate)	120 BC	60	*2	3	3
10	Ansul (Potassium Bicarbonate)	120 BC	60	*2	3	4
21	Ansul (Potassium Bicarbonate)	120 BC	60	*2	3	3
24	Ansul (Potassium Bicarbonate)	120 BC	60	*2	3	3
9	Amerex (Halon 1211)	2A-60 BC	60	*2	3	7
12	Amerex (Halon 1211)	2A-60 BC	60	*2	3	4
23	Amerex (Halon 1211)	2A-60 BC	60	*2	3	3
26	Amerex (Halon 1211)	2A-60 BC	60	*2	3	NE
11	Ansul (Monoammonium Phosphate)	20A-80 BC	60	*2	3	4
14	Ansul (Monoammonium Phosphate)	20A-80 BC	60	*2	3	4
25	Ansul (Monoammonium Phosphate)	20A-80 BC	60	*2	3	5
28	Ansul (Monoammonium Phosphate)	20A-80 BC	60	*2	3	9

\* = approximately