



# Acquisition Directorate

---

## Research & Development Center

Report No. CG-D-02-09

# An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications

**Distribution Statement:**

This document is available to the U.S. public through the  
National Technical Information Service, Springfield, VA 22161

October 2008



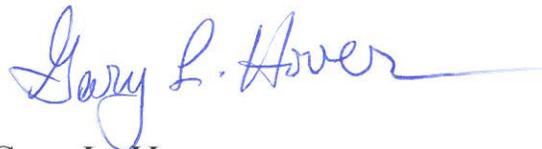
Homeland  
Security

# NOTICE

This document is disseminated under the sponsorship of the Department of Homeland Security in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

This report does not constitute a standard, specification, or regulation.



Gary L. Hover  
T&E Branch Chief  
United States Coast Guard  
Research & Development Center  
1082 Shennecossett Road  
Groton, CT 06340-6048



# An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications

## Technical Report Documentation Page

1. Report No. CG-D-02-09		2. Government Accession Number		3. Recipient's Catalog No.	
4. Title and Subtitle An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications				5. Report Date October 2008	
				6. Performing Organization Code Project No. 3386	
7. Author(s) E. Forssell, M. Boosinger, G. Back, E. Weaver, L. Nash, and D. Beene				8. Performing Report No. R&DC UDI # 863	
9. Performing Organization Name and Address Hughes Associates, Inc. 3610 Commerce Drive, Suite 817 Baltimore, MD 21227-1652  Science Applications International Corp. (SAIC) 23 Clara Drive, Suite 206 Mistic, CT 06355		U.S. Coast Guard Research and Development Center 1082 Shennecossett Road Groton, CT 06340-6048		10. Work Unit No. (TRAIS)	
				11. Contract or Grant No. Contract HSCG32-05-D-R00010/ Task Order HSCG32-07-J-100031	
12. Sponsoring Organization Name and Address U.S. Department of Homeland Security United States Coast Guard Office of Design and Engineering Standards Washington, DC 20593-0001				13. Type of Report & Period Covered Final Report	
				14. Sponsoring Agency Code Commandant (CG-5214) U.S. Coast Guard Headquarters Washington, DC 20593-0001	
15. Supplementary Notes The Hughes Associates, Inc. Technical Representative is Mr. Eric Forssell. The Coast Guard technical contact and COTR is Ms Elizabeth Weaver of the U.S. Coast Guard Research and Development Center, 860-441-2732. The Coast Guard Headquarters Sponsor is Mr. Louis Nash of the Lifesaving and Fire Safety Division (CG-5214).					
16. Abstract (MAXIMUM 200 WORDS) A full-scale fire performance evaluation was conducted to assist the USCG in developing a position on using pre-engineered fire extinguishing systems (PFESs) in larger compartments. Specifically the tests evaluated (1) the reliability of PFESs in irregular-shaped compartments with volumes up to 150 m <sup>3</sup> (5,297 ft <sup>3</sup> ); (2) the ability of the systems to distribute the agent in larger/irregular spaces; (3) the effects of ventilation on the extinguishing capability of the pre-engineered systems, and (4) the effect of the agents on diesel engine operations during the discharge of a fire extinguishing agent.  This test series was broken down into two parts. The initial set of tests assessed the capabilities of two "type approved" PFESs over a range of potential compartment configurations (a sensitivity analysis of application parameters). This assessment was performed in an enclosure(s) with a volume equivalent to the maximum allowed by the "type approval." The second set of tests assessed the ability to protect larger volumes/spaces with similar types of systems.  The results of these tests suggest that the approved systems have good actuation and fire extinguishing capabilities for their approved volumes; however, the results of these tests suggest that the current technology(s) need to be modified (e.g. increased agent design concentration) when applied to larger spaces in order to provide the same level of protection as that provided in the smaller volumes. Testing of the agents on an operating diesel engine showed the engine shut down immediately upon exposure to the agent without any sign of a run-away, and the diesel engine was successfully restarted after the test.					
17. Key Words fire, fire tests, gaseous agents, Halon 1301, Halon, total flooding, machinery space, pre-engineered, IMO, MSC/Circ. 848				18. Distribution Statement This document is available to the U.S. public through the National Technical Information Service, Springfield, VA 22161.	
19. Security Class (This Report) UNCLASSIFIED		20. Security Class (This Page) UNCLASSIFIED		21. No of Pages	22. Price



# An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications

---

(This page intentionally left blank.)



## EXECUTIVE SUMMARY

Pre-engineered Fire Extinguishing Systems (PFESs) are widely used in the U.S. domestic fleet from work-boats to small passenger vessels (up to 600 passengers). Due to concerns about achieving a proper distribution of fire extinguishing agent within a space using a single nozzle, current requirements limit the size for spaces protected with a PFES to 57 m<sup>3</sup> (2000 ft<sup>3</sup>). New vessel designs have produced a need for PFESs that can protect larger/irregular spaces and/or spaces that have forced ventilation.

The objective of this test program was to determine if PFESs can adequately and reliably protect shipboard machinery spaces with volumes up to 150 m<sup>3</sup> (5297 ft<sup>3</sup>). This included evaluating (1) the reliability of PFESs in irregular-shaped compartments with volumes up to 150 m<sup>3</sup> (5,297 ft<sup>3</sup>); (2) the ability of the systems to distribute the agent around obstructions in larger/irregular spaces; (3) the effects of ventilation on the extinguishing capability of the pre-engineered systems, and (4) the effect of the agents on diesel engine operations during the discharge of a fire extinguishing agent. The initial set of tests assessed the capabilities of two “type approved” PFESs over the range of potential compartment configurations (a sensitivity analysis of application parameters). The approved systems were selected as a representative of the PFESs approved by the Coast Guard. These systems and all configurations tested used the agent HFC-227ea which is a gaseous agent. This assessment was performed in an enclosure(s) with a volume equivalent to the maximum allowed by the “type approval.” The second set of tests assessed the ability to protect larger volumes/spaces with similar types of systems. Since there are currently no PFESs approved for these larger volumes, a surrogate single nozzle system was developed and tested during this evaluation. Again the gaseous agent HFC-227ea was used during testing for consistency.

A total of 49 tests were conducted during this investigation. Thirty six tests were conducted to evaluate the capabilities of two currently approved PFESs over a range of conditions. Of these 36 tests, 18 tests were conducted to assess the actuation characteristics of the system(s) and 18 tests were conducted to assess the fire extinguishing capabilities of the system(s). Twelve tests were conducted to determine the suitability of using PFESs to protect larger machinery spaces and one test was conducted to determine the outcome if the fire extinguishing agent was ingested in a running diesel engine. The results of these tests are summarized in the following paragraphs.

The actuation of a PFES was shown to be a function of fire size, fire location, enclosure aspect ratio, elevation of the PFES within the protected space, and the ventilation configuration. The results of these tests suggest that the PFES needs to be installed high in the compartment in order to increase the likelihood for a timely actuation (and to minimize the damage caused by the fire). The data also indicates that the vent configuration, PFES location and the fire location all combined to have a major effect on the actuation times of the system. The longest actuation times (most challenging configuration to detect) were observed when the PFES was located below the supply air ducts and the fire was located diagonally opposite the PFES in the corner under the exhaust. This suggests that the PFES should be installed away from the ducts supplying air to the space. The aspect ratio also had a major effect on the actuation times of the PFES and increased for compartments with higher aspect ratios. This suggests that the aspect ratio should be addressed as a constraint of the PFES.



## An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications

---

The approved PFESs were capable of extinguishing all the test fires conducted during this sensitivity analysis (with the exception of the telltale cup located directly above the cylinder in the first test). In contrast to the actuation analysis, the test configuration had little effect on the extinguishment capabilities of the system (the results were the same independent of the PFES location, compartment configuration (vent locations with respect to the PFES) and the compartment aspect ratio). The results of these tests suggest that the approved systems have good fire extinguishing capabilities for their approved volumes. However, it is still recommended that a 20 percent factor of safety be added to the test concentration (the concentration used to successfully complete the approval tests) to account for clutter/obstructions characteristic of an actual installation.

Tests were conducted in larger compartments to determine if the volume constraints placed on the current “type approvals” can be increased. The results of these tests identified two primary issues that need to be considered prior to approving these systems for larger volumes: actuation response times and agent design concentrations.

For a single-point heat detection/actuation system, the critical fire size (the size of the fire required to actuate the system) will scale proportionally with compartment volume. More specifically, increasing the volume of the space from 50 m<sup>3</sup> to 150 m<sup>3</sup> corresponds to an increase in the critical fire size from 750 kW to 2,250 kW. These larger fires could cause significant damage to the equipment in the space. The thermal decomposition product formation (i.e. hydrogen fluoride (HF)) may also be an issue for these larger fires (based on past International Maritime Organization (IMO) gaseous agent tests).

These tests also suggest that higher agent design concentrations are required to provide adequate fire extinguishing capabilities for larger compartments. To maintain consistent fire extinguishing capabilities between the various size spaces, the design concentration was increased by approximately 10 percent for 50 m<sup>3</sup> (1766 ft<sup>3</sup>) to 100 m<sup>3</sup> (3532 ft<sup>3</sup>) enclosures and over 30 percent for 100 m<sup>3</sup> (3532 ft<sup>3</sup>) to 150 m<sup>3</sup> (5297 ft<sup>3</sup>) enclosures. This may imply that while enclosure volumes of 100 m<sup>3</sup> (3532 ft<sup>3</sup>) are within reach of the PFES technology in terms of fire extinguishing capabilities (and system practicality), the higher concentrations required for the 150 m<sup>3</sup> (5297 ft<sup>3</sup>) enclosure may make these systems impractical for these spaces.

With respect to the concern associated with the fire extinguishing agent being ingested into the main engine(s), the exposed diesel generator shut down upon exposure to the agent with no indications of a run-away event and exhibited no acute adverse effects.

This test program was performed under a United States Coast Guard Research & Development Center project (USCG R&DC) for the Lifesaving and Fire Safety Division (CG-5214) of Coast Guard Headquarters. Commandant (CG-5214) will use this information to make policy decisions regarding approval of PFESs for installation within large or irregular spaces on maritime vessels.



**TABLE OF CONTENTS**

**1 INTRODUCTION.....1**

**2 OBJECTIVES.....1**

**3 APPROACH/TECHNICAL DISCUSSION.....1**

**4 FIRE SCENARIO DEVELOPMENT .....2**

    4.1 USCG “Type Approval” Requirements ..... 2

        4.1.1 Current Fire Test Requirements .....2

        4.1.2 Limitations of the Current Test Requirements .....3

    4.2 International Maritime Organization (IMO) Test Protocols ..... 3

    4.3 Protocol Selection/Development..... 4

**5 SYSTEM SELECTION/DEVELOPMENT .....5**

**6 TEST DESCRIPTION .....6**

    6.1 Test Compartment ..... 6

    6.2 Fire Scenarios ..... 11

    6.3 Diesel Engine Analysis ..... 17

    6.4 Extinguishing Systems ..... 18

    6.5 Instrumentation..... 19

        6.5.1 Test Enclosure and Fire Monitoring Instrumentation .....20

        6.5.2 PFES Instrumentation.....22

        6.5.3 Video Equipment.....22

**7 PROCEDURES.....22**

**8 RESULTS AND DISCUSSION.....22**

    8.1 Approved System Sensitivity Analysis ..... 23

        8.1.1 Actuation Time Evaluation .....23

        8.1.2 Fire Extinguishing Sensitivity Analysis .....27

        8.1.3 Approved System Sensitivity Analysis Summary.....32

    8.2 PFES Extinguishing Capabilities in Larger Enclosure Volumes..... 33

        8.2.1 Surrogate PFES Baseline Tests .....33

        8.2.2 Tests Conducted in Larger Enclosures .....35

    8.3 Effects of Agent on an Operating Diesel Engine ..... 37

**9 INTERPRETATION OF TEST RESULTS.....38**

    9.1 General ..... 38

    9.2 Implications for Currently Approved PFES..... 39

    9.3 Implications for Use of PFES in Larger Volumes ..... 39

**10 SUMMARY AND CONCLUSIONS.....40**

# An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications

---

10.1	Approved PFES Capabilities.....	40
10.2	PFES Protection of Larger Compartments.....	41
10.3	Agent Effects.....	41
<b>11</b>	<b>REFERENCES .....</b>	<b>42</b>
<b>APPENDIX A.</b>	<b>USCG REQUIREMENTS FOR “FIXED FIRE EXTINGUISHING SYSTEMS” (PRE-ENGINEERED).....</b>	<b>A-1</b>
<b>APPENDIX B.</b>	<b>U.S. COAST GUARD PRE-ENGINEERED SYSTEM APPROVALS.....</b>	<b>B-1</b>
<b>APPENDIX C.</b>	<b>BLACKSTONE OIL REPORT .....</b>	<b>C-1</b>



## LIST OF FIGURES

Figure 1. Generalized compartment geometry.....	7
Figure 2. Approved PFES sensitivity analysis compartment geometries.....	8
Figure 3. Increased compartment volume enclosure dimensions.....	9
Figure 4. Diesel engine mock-up.....	10
Figure 5. Sand burner and PFES locations.....	12
Figure 6. Test fire locations.....	13
Figure 7. Photograph of sand burner.....	14
Figure 8. Photograph of pan underneath the engine mock-up.....	15
Figure 9. Photographs of spray fire set-up.....	16
Figure 10. Photograph of wood crib set-up.....	17
Figure 11. BSCO PFES cylinder and actuator.....	18
Figure 12. Sea-Fire FD series cylinder and actuators.....	19
Figure 13. Instrumentation schematic.....	21
Figure 14. Results of the actuation evaluation.....	24
Figure 15. Enclosure temperature during actuation test with Sea-Fire PFES in corner location, 500 kW propane burner, in 2:1 aspect ratio enclosure (Test 14).....	25
Figure 16. Temperature at PFES cylinder near actuator during actuation test with Sea-Fire PFES in corner location, 500 kW propane burner, in 2:1 aspect ratio enclosure (Test 14).....	25
Figure 17. System actuation times for the various test configurations.....	26
Figure 18. Actuation time as a function of separation distance between the PFES and the propane sand burner.....	27
Figure 19. BSCO PFES agent concentration comparison.....	29
Figure 20. Cylinder pressure from BSCO PFES test with heptane spray fire and diesel pan fire scenario (Test 29).....	30
Figure 21. Fire temperatures from BSCO PFES test with heptane spray fire and diesel pan fire scenario (Test 29).....	31
Figure 22. Fire temperatures from BSCO PFES test with diesel spray fire and heptane pan fire scenario (Test 30).....	31
Figure 23. Fire temperatures from BSCO PFES test with wood crib fire scenario (Test 28).....	32
Figure 24. Comparison of achieved agent concentrations with surrogate and BSCO PFES in 3:1 aspect ratio enclosure (7.7% design for BSCO (Test 26), 8.8% design for surrogate (Test 37)).....	35
Figure 25. Diesel generator drive shaft rotations during exposure to 7.7 percent HFC-227ea (Test 35).....	37
Figure 26. Agent concentration during diesel generator exposure (Test 35).....	38



## LIST OF TABLES

Table 1. Approved PFESs.....	6
Table 2. Test compartment dimensions and ventilation configuration.....	9
Table 3. Fire test parameters.....	11
Table 4. Propane sand burner parameters.....	14
Table 5. Spray fire parameters.....	16
Table 6. HFC-227ea properties.....	19
Table 7. Agent and decomposition product wave numbers.....	21
Table 8. Actuation test results.....	23
Table 9. Telltale scenario performance of the previously approved PFESs.....	28
Table 10. Approved PFES performance with larger fire scenarios in 3:1 aspect ratio enclosure.....	30
Table 11. Telltale scenario performance of surrogate PFES tests in 50 m <sup>3</sup> (1,766 ft <sup>3</sup> ) test enclosures.....	34
Table 12. Surrogate PFES and BSCO PFES performance with increasing enclosure volume.....	36



## LIST OF ACRONYMS, ABBREVIATIONS, AND SYMBOLS

ACH	Air Changes per Hour
ACM	Air Changes per Minute
C	Wood Crib Fire
Corner1	PFES Near Ventilation Exhaust and Fire Near Ventilation Supply
Corner2	PFES Near Ventilation Supply and Fire Near Ventilation Exhaust
CYL	Agent Cylinder or Cylinder Location
FTIR	Fourier Transform Infrared Spectrometer
G	Gas Sampling
H	Enclosure Height
HF	Hydrogen Fluoride
HRR	Heat Release Rate
IMO	International Maritime Organization
L	Enclosure Length
Lf	Distance Between Vent and Front Wall
LOAEL	Lowest Observable Adverse Effect Level - Concentration
Lr	Distance Between Vent and Rear Wall
Ls	Lengthwise Separation Distance Between Vents
Lv	Vent Length
Max	Maximum
MSC	Marine Safety Committee
N/A	Did Not Actuate
N/D	No Data
N/E	Not Extinguished
NOAEL	No Observable Adverse Effect Level - Concentration
P	Pan Fire
PFES	Pre-Engineered Fire Extinguishing System
R&DC	Research and Development Center
RTI	Response Time Index
S	Spray Fire
T	Thermocouple
TT	Telltale Fire
UL	Underwriters Laboratories, Inc
USCG	United States Coast Guard
W	Enclosure Width
Ws	Widthwise Separation Distance Between Vents
Ws1	Distance Between Vent and Side Walls
Wv	Vent Width



# An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications

---

This page intentionally left blank.



# An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications

---

## 1 INTRODUCTION

Pre-engineered Fire Extinguishing Systems (PFESs) are widely used in the U.S. domestic fleet from workboats to small passenger vessels (up to 600 passengers). Due to concerns about achieving a proper distribution of fire extinguishing agent within a cluttered space using a single nozzle, current requirements limit the size for spaces protected with a pre-engineered system to 57 m<sup>3</sup> (2,000 ft<sup>3</sup>). New vessel designs have produced a need for PFES that can protect larger/irregular spaces and/or spaces that have forced ventilation.

Currently, PFESs can only be arranged to stop the ventilation system after the system discharges. As a result, forced ventilation could reduce the fire extinguishing capabilities of the system by diluting and exhausting the agent. This could be problematic for the larger irregular-shaped spaces where the fire is located away from the agent discharge nozzle and near the supply air duct.

This test program was performed under a United States Coast Guard Research & Development Center (USCG R&DC) project for the Lifesaving and Fire Safety Division (CG-5214) of Coast Guard Headquarters. Commandant (CG-5214) will use this information to make policy decisions regarding approval of PFESs for installation within large or irregular spaces on maritime vessels.

## 2 OBJECTIVES

The objective of this test program was to determine if PFESs can adequately and reliably protect shipboard machinery spaces with volumes up to 150 m<sup>3</sup> (5,297 ft<sup>3</sup>). This included evaluating (1) the reliability of PFESs in irregular-shaped compartments with volumes up to 150 m<sup>3</sup> (5,297 ft<sup>3</sup>); (2) the ability of the systems to distribute the agent around obstructions in larger/irregular spaces; (3) the effects of ventilation on the extinguishing capability of the pre-engineered systems, and (4) the effect of the agents on diesel engine operations during the discharge of a fire extinguishing agent.

To achieve this objective, the program was broken down into three phases. The initial phase was to define the conditions and potential fire scenarios associated with this application and develop a set of tests for assessing the capabilities and limitations of PFESs in this application. These developed tests served as the basis for this evaluation. The second phase assessed the capabilities of two “type approved” PFESs over the range of potential compartment configurations (a sensitivity analysis of application parameters). This assessment was performed in enclosures with volumes equivalent to the maximum allowed by the “type approval.” The third phase assessed the ability to protect larger volumes/spaces with similar types of systems. Since there are currently no PFESs approved for these larger volumes, a surrogate single nozzle system was developed and tested during this evaluation.

## 3 APPROACH/TECHNICAL DISCUSSION

The program was broken down into three phases with separate objectives/goals. The initial phase defined the conditions and hazards associated with this application and developed a set of tests for assessing the capabilities and limitations of PFESs in this application. This phase consisted of comparing and contrasting

# An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications

---

the current test requirements, the requirements established for similar applications, and the actual spaces to which these systems apply.

The second and third phases of this program consisted of performance testing. The second phase evaluated the capabilities of approved PFESs at the design limits of the system for a range of compartment aspect ratios (fixed maximum approved volume) and ventilation configurations. This phase functioned as a failure modes analysis for a range of compartment and ventilation configurations. The results of the second phase provided data that could be used to refine the performance requirements established in the initial phase of this program. The final phase of this program assessed the ability to expand the current “type approvals” to greater volumes.

## 4 FIRE SCENARIO DEVELOPMENT

### 4.1 USCG “Type Approval” Requirements

The USCG approval requirements for “Fixed Fire Extinguishing Systems (Pre-Engineered)” are provided in Appendix A. These criteria determine the equivalency of new clean agent systems to the carbon dioxide systems currently specified in the various vessel regulations, and to the halon systems previously approved as equivalent to carbon dioxide systems. The requirements are based on Underwriters Laboratories, Inc. (UL) test standard UL 2166 “UL Standard for Safety for Halocarbon Clean Agent Extinguishing System Units.” This approval standard/listing includes the spectrum of component tests and a range of fire tests specific to the approval/application.

#### 4.1.1 Current Fire Test Requirements

The majority of the systems with USCG “type approvals” consist of a single, individually thermally activated nozzle either installed directly on the agent cylinder or connected to the cylinder through a simple pipe run (limited length and number of fittings). This type of system is defined by UL as an “automatic extinguisher unit” and must pass the fire tests specified in Section 36 of the approval standard (UL 2166).

The tests are conducted in two different enclosures with the same volume (the maximum volume for which the listing is requested). The first enclosure has the maximum coverage area and the minimum height requirement. The second enclosure is designed based on the maximum height requirement.

The fire tests consist of a nozzle distribution test conducted using “telltale” (small heptane pan fires) located in each corner of the space and an automatic operation test with a larger pan fire (a 2.5 ft<sup>2</sup> heptane pan fire) conducted at two locations (the center of the space and in a corner of the space). The tests are conducted without forced ventilation at the minimum extinguishing concentration of agent and with 60 air changes per hour (ACH) of forced ventilation at the design concentration of the system (typically 1.3 times the minimum concentration). Only the un-ventilated tests are required to meet UL 2166. The tests conducted with ventilation are additional tests required by the USCG. The telltale fire test(s) are conducted with a manually activated system and a 30-second preburn. The larger pan fire test is conducted with an automatically activated system.

# An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications

---

To successfully complete the tests, all fires must be extinguished within 30 seconds after the end of system discharge. During the automatic operation tests, the system must also activate within 60 seconds of ignition of the fire to successfully complete the test(s).

## 4.1.2 Limitations of the Current Test Requirements

The current fire tests (test configuration and fire scenarios) are not representative of typical machinery space conditions (environment and fire hazards). The space is uncluttered allowing the agent to easily flow throughout the enclosure. The fire scenarios are also limited, addressing only Class B pan/pool fires and not including an assessment of either spray fires and/or Class A fires (wood or plastic).

These limitations were addressed when developing the fire scenarios used during this evaluation.

## 4.2 International Maritime Organization (IMO) Test Protocols

Since there are currently no international test protocols for approving PFESs, the first step was to review the protocols for engineered systems to determine their applicability to this investigation. There are currently three International Maritime Organization (IMO) test protocols that may be applicable. These include: the water mist test protocol (Marine Safety Committee (MSC) Circular 668/728 (International Maritime Organization, 1994)); the gaseous agent test protocol (MSC Circular 848 (International Maritime Organization, 1998)); and the aerosol test protocol (MSC Circular 1007 (International Maritime Organization, 2001)). The three test protocols are all conducted in a 500 m<sup>3</sup> test enclosure with a diesel engine mockup located in the center.

The water mist test protocol has been modified numerous times and now consists of six fire extinguishing tests. The tests are conducted in a compartment with a large 2 m by 2 m vent opening located in the center of one of the walls/bulkheads. The fires are relatively large with respect to the volume of the compartment and must be extinguished in less than 15 minutes from system activation. The 15-minute extinguishment time is considered acceptable due to the thermal management capabilities of water mist (i.e., the temperatures in the space are significantly reduced and the likelihood for fire spread is minimized).

The gaseous agent and aerosol test protocols are each conducted in a closed compartment and consist of four similar fire tests (one agent distribution test and three larger fire tests). The first test (an agent distribution test) consists of small heptane pan fires referred to as telltales located in each of the eight corners of the test enclosure. The telltale fire tests are conducted at the minimum extinguishing concentration of the system/agent. Two of the larger fire tests consist of multiple fires (cribs, pans, and sprays) positioned around the diesel engine mockup. The remaining larger fire test consists of a large diesel bilge fire. The larger fire tests are conducted at the system manufacturer's design concentration. To successfully complete the tests, the test fires must be extinguished within 30 seconds of the end of agent discharge. The halocarbon gaseous agents are allowed a 10-second discharge time (maximum) while the inert gases and aerosol systems are allowed up to a 2-minute discharge time.

# An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications

---

## 4.3 Protocol Selection/Development

Due to the limitations of the UL 2166 fire scenarios and test configuration (see Section 4.1.2), a more representative set of tests was developed for this assessment. These tests were based on the IMO test protocols for approving engineered systems for larger machinery spaces. Some requirements/test procedures from UL 2166 were also incorporated in the approval tests.

Since the PFESs currently approved for this application by the USCG consist almost exclusively of gaseous agent systems (with a limited number of exceptions), the gaseous agent test protocol (MSC Circular 848) was selected to be the basis of this investigation.

The approach selected for this program was to scale down the test enclosure and fire scenarios required by MSC Circular 848 to simulate the characteristics of this application. The test enclosure volume was reduced by a factor of three to produce the 150 m<sup>3</sup> (5,297 ft<sup>3</sup>) target volume defined by the USCG. The ceiling height was reduced from 5 m to a standard deck height of 3 m. The width of the compartment was reduced from 10 m to 5 m which is more representative of the beams of the ships for which these systems will be approved. The 10 m length of the compartment remained the same. This length provides a somewhat challenging distance for a single nozzle to protect. Smaller compartments were built within the larger enclosure to evaluate the effects that compartment volume and aspect ratio have on the capabilities of these systems.

A metal structure with a bilge area and similar fire obstructions as the diesel engine mockup in MSC Circular 848 was located in the center of the space.

A forced ventilation system designed to provide 1 air change per minute (ACM) was installed in the test enclosure. The supply entered through the overhead of the space near the back of the compartment. The exhaust exited the space through openings in the overhead near the front of the compartment. All of the tests conducted during this test series were conducted with the ventilation system operating at 1 ACM. Additional details on the test enclosure and ventilation system are provided in Section 6. Discussions of scaling the test enclosure and ventilation system are also provided in Section 6.

It was originally intended to scale down the large fire tests/scenarios of MSC Circular 848 (Tests 2 through 4) for this evaluation (not the telltale fires in the agent distribution test (Test 1)). However, this approach became problematic for the smaller volumes in the target range. As a recap, these systems are being considered for spaces with volumes between 57 m<sup>3</sup> (2,000 ft<sup>3</sup>) to 150 m<sup>3</sup> (5,297 ft<sup>3</sup>). Two of the fire scenarios in MSC Circular 848 (Tests 2 and 3) consist of three individual fires run simultaneously. Scaling the heat release rates of the individual fires to the smallest volumes in the range makes these fires extremely small (e.g., some of the pan fires will be reduced to the size of a cup).

As a result, the approach selected for this evaluation (and proposed test protocol) consists of assessing the capabilities of these systems against all of the fire “types” conducted in MSC Circular 848 but re-organizing the fires that are conducted simultaneously. More specifically, the three large fire tests consisted of two pan/spray fire combinations and one test against a wood crib fire.

The total heat release rate (HRR) of the two Class B fire scenarios (i.e., pan fires and spray fires) were scaled to produce a heat release rate per unit volume of 14 kW/m<sup>3</sup> in the 57 m<sup>3</sup> (2,000 ft<sup>3</sup>) enclosure. This value is the average of the three large fires conducted in MSC Circular 848. Since it is difficult to scale

# An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications

---

down wood crib burning characteristics, the wood crib fuel package was the same as that used in MSC Circular 848. These three scenarios were used to assess the extinguishing capabilities of the system(s) independent of the size of the test compartment. This allowed for consistency between test programs and made these fires slightly more difficult to extinguish in the larger volumes due to an increase in the amount of oxygen available for combustion.

As with MSC Circular 848, the agent distribution tests (telltale fire tests) served as the starting point of the assessment. The telltale fire tests are intended to define the minimum agent concentration needed to extinguish the fires in a well ventilated machinery space. If all of the telltales were not extinguished, then the agent concentration was increased until extinguishment was achieved. These tests were conducted with the system activated manually 120 seconds after ignition of the last fire.

All the larger fire tests were conducted at the concentration used to successfully pass the telltale fire test. During these larger fire tests, the PFESs were manually activated to achieve the following preburn times: pan fires, 120 seconds; spray fires, 90 seconds; and wood crib fires, 360 seconds.

To successfully complete the fire extinguishing tests (including the telltale tests), all fires must be extinguished within 1 minute of system activation.

A propane burner adjusted to produce a heat release rate per unit volume of  $10 \text{ kW/m}^3$  was used to evaluate the actuation component of the PFES during this test program. The burner was located either in the center of the space on the bilge plate or on the floor in a corner of the enclosure. If the thermal actuator did not respond within 2 minutes of ignition during the test with the smaller fire, the heat release rate per unit volume of the burner was increased to  $15 \text{ kW/m}^3$  in subsequent tests.

## 5 SYSTEM SELECTION/DEVELOPMENT

The systems currently approved for this application by the USCG consist almost entirely of gaseous agent systems (with a limited number of exceptions). It was originally intended to expand the scope of these approvals to other technologies such as condensed aerosols and water mist in addition to the legacy gaseous agent systems during this investigation. However, after a review of the capabilities and limitations of these other technologies in this application, it was decided to focus on the systems/technologies that currently have “type approvals”. This approach allows for the use of the current approval to serve as a design basis for the larger volumes and allowed a comparison between a system approved using UL 2166 to one that meets the proposed test protocol.

A list of the approved PFESs is provided in Table 1. This table includes the name of the manufacturer, model/series number, the maximum protected volume, agent name, and agent type.

# An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications

Table 1. Approved PFESs.

Manufacturer	Model/Series	Maximum Volume		Agent Name	Agent Type
		(m <sup>3</sup> )	(ft <sup>3</sup> )		
Metalcraft/Sea-Fire, Inc.	FF	0.4–3.7	15–130	Envirogel	Dispersed Aerosol
Powsus, Inc.	FF	0.4-3.7	15–130	Envirogel	Dispersed Aerosol
BSCO, Inc.	Model 540	1.4–35.5	50–1250	FE 25	Gas
BSCO, Inc.	Model 560	Up to 85.1	Up to 3000	FE 25	Gas
Fireboy-Xintex, Inc.	CG2	0.7–28.4	25–1000	FE241	Gas
Fireboy-Xintex, Inc.	MA2	0.7–42.6	25–1500	FE241	Gas
Metalcraft/Sea-Fire, Inc.	FE	0.7–42.6	25–1500	FE241	Gas
BSCO, Inc.	Model 740	1.4–42.6	50–1500	HFC-227ea	Gas
Fireboy-Xintex, Inc.	CG2	0.7–28.4	25–1000	HFC-227ea	Gas
Fireboy-Xintex, Inc.	MA2	0.7–42.6	25–1500	HFC-227ea	Gas
Fireboy-Xintex, Inc.	GA	45.4–85.1	1600–3000	HFC-227ea	Gas
Metalcraft/Sea-Fire, Inc.	FG	0.7–6.8	25–240	HFC-227ea	Gas
Metalcraft/Sea-Fire, Inc.	FD	4.3–42.6	150–1500	HFC-227ea	Gas
Metalcraft/Sea-Fire, Inc.	FT	Not listed	Not listed	HFC-227ea	Gas
Pem All Fire Extinguisher Corp.	--	56.7	2000	HFC-227ea	Gas

Systems tested

## 6 TEST DESCRIPTION

### 6.1 Test Compartment

The tests were conducted in a simulated machinery space located at Intertek’s facility in Elmendorf, Texas. A generalized drawing of the large test compartment is shown in Figure 1. The test compartment was approximately 150 m<sup>3</sup> (5,297 ft<sup>3</sup>) with nominal dimensions of 5 m wide by 10 m long by 3 m high. Two sets of smaller compartments were constructed within the large one by installing interior partitions.

During the sensitivity analysis of the approved PFESs, three smaller compartments were constructed inside the large compartment (one at a time) as illustrated in Figure 2. These compartments each had nominal volumes of 50 m<sup>3</sup> (1,766 ft<sup>3</sup>) but different aspect ratios (1:1 to 3:1).

During the increased compartment volume tests, the compartment volume was increased but the aspect ratio was maintained at 2:1 as illustrated in Figure 3. The resulting compartment volumes that were tested include: 50 (1,766 ft<sup>3</sup>); 100 (3,531 ft<sup>3</sup>); and 150 m<sup>3</sup> (5,297 ft<sup>3</sup>). The dimensions for both sets of test compartments are given in Table 2.



# An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications

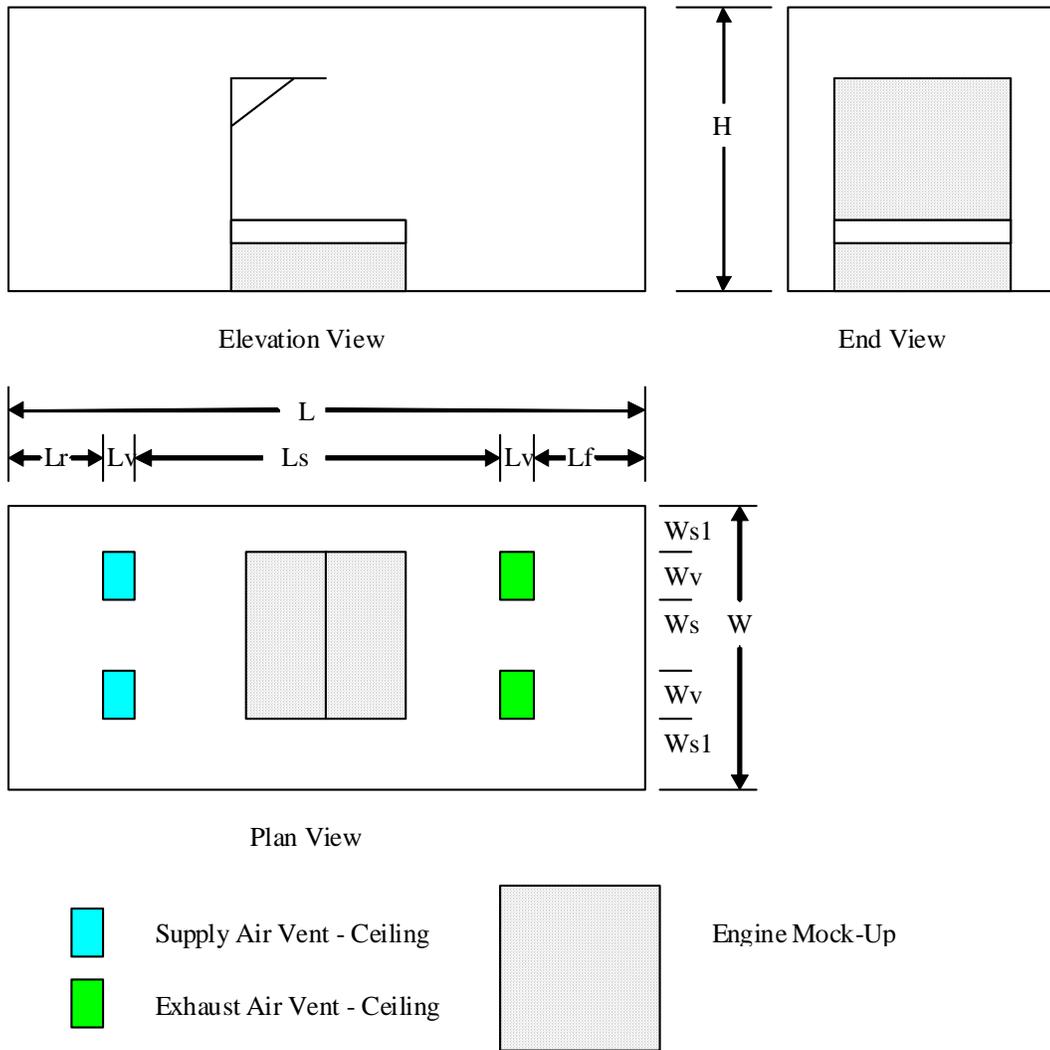


Figure 1. Generalized compartment geometry.



# An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications

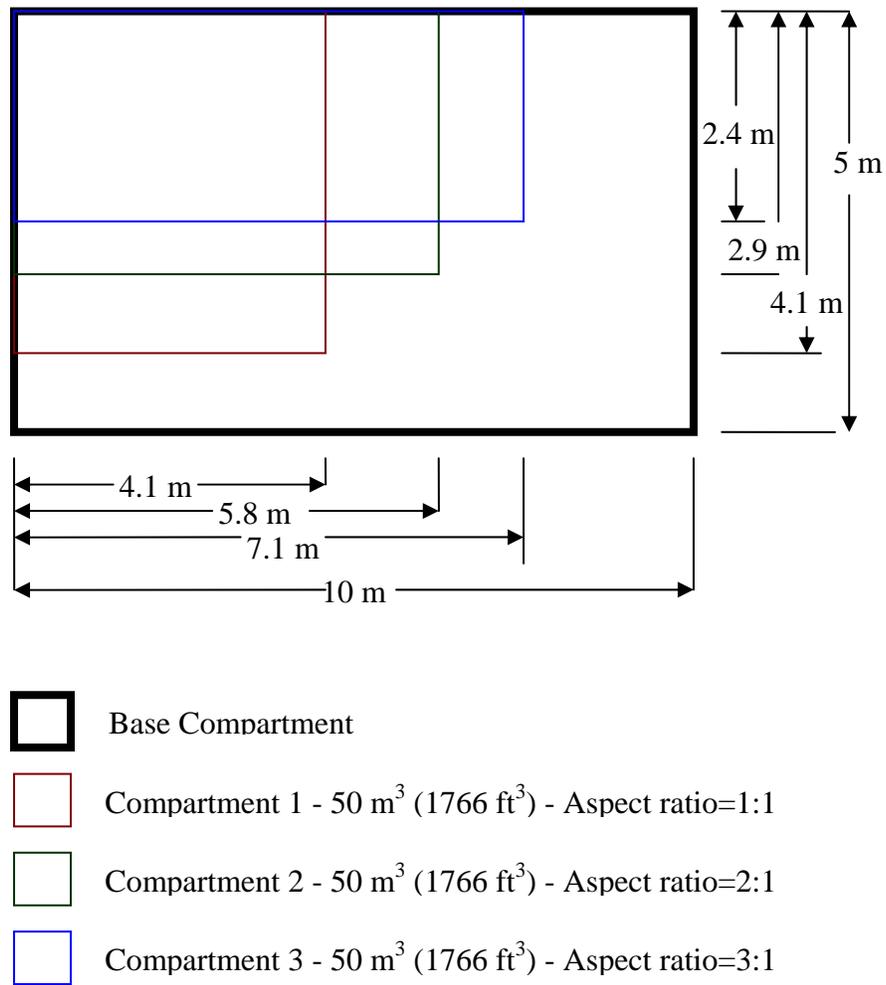
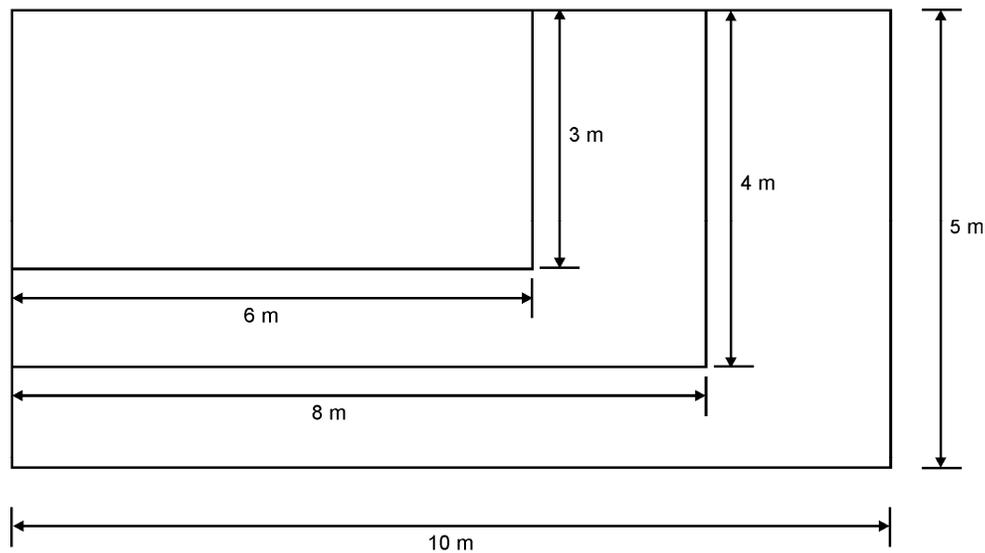


Figure 2. Approved PFES sensitivity analysis compartment geometries.



# An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications



Small Compartment Dimensions are Approximate

Figure 3. Increased compartment volume enclosure dimensions.

Table 2. Test compartment dimensions and ventilation configuration.

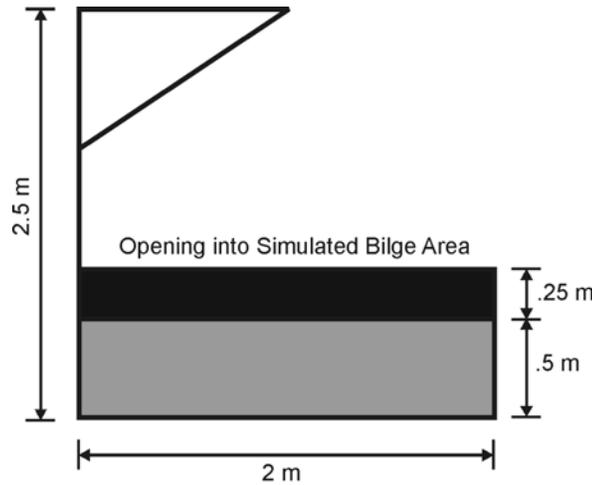
Enclosure Dimensions									Vent Dimensions							
Length, L		Width, W		Height, H		Volume		Aspect Ratio	Number of Vents		Length, Lv		Width, Wv		Area (Each)	
(ft)	(m)	(ft)	(m)	(ft)	(m)	(ft <sup>3</sup> )	(m <sup>3</sup> )		Supply	Exhaust	(ft)	(m)	(ft)	(m)	(ft <sup>2</sup> )	(m <sup>2</sup> )
13.4	4.1	13.4	4.1	9.9	3.0	1785	50.5	1.0	2	2	1.8	0.6	1.8	0.5	3.21	0.30
18.9	5.8	9.5	2.9	9.9	3.0	1778	50.4	2.0	2	2	1.8	0.6	1.8	0.5	3.21	0.30
22.9	7.0	7.6	2.3	9.9	3.0	1725	48.8	3.0	1	1	1.8	0.6	3.5	1.1	6.42	0.60
26.9	8.2	13.4	4.1	9.9	3.0	3573	101.2	2.0	1	1	1.8	0.6	7.2	2.2	13.14	1.22
31.7	9.7	16.0	4.9	9.9	3.0	5024	142.3	2.0	1	1	1.9	0.6	10.7	3.3	20.00	1.86

A metal structure designed to simulate the obstructions of the diesel engine mockup in MCS Circular 848 was located in the center of each compartment as shown in Figure 4.

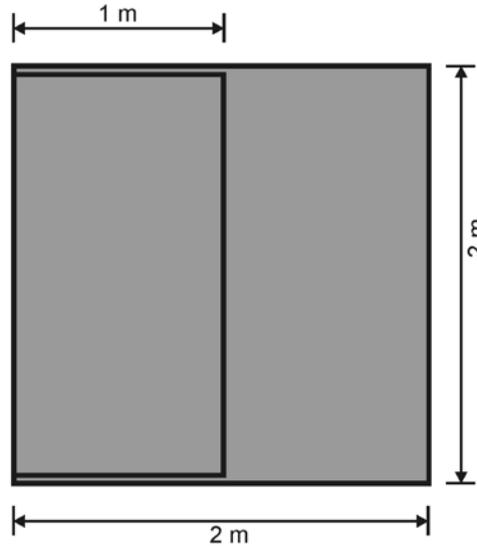
The test compartments were equipped with a forced ventilation system designed to provide 1 ACM. The supply air entered the compartment through two ducts located in the overhead of the back two ceiling quadrants as shown in Figure 1. The supply air vents were fed by a diesel-driven air blower via two 45 cm (18 in) diameter ducts. The products of combustion exited the compartment through two vent openings in the overhead of the front two ceiling quadrants. The exhaust vents were simple openings in the roof of the test compartment, without any ducting.

# An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications

The supply air was ducted into the compartment through the cavity created by two ceiling joist. As a result, the vent openings were cut in the ceiling between the two joists. This only allowed for expansion of the vent openings in one direction (parallel to the joists). In some scenarios, the two supply vents combined into a single vent. These vent opening dimensions are also given in Table 2.



Elevation View



Plan View

Figure 4. Diesel engine mock-up.



# An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications

## 6.2 Fire Scenarios

Five fire scenarios were developed and used as the basis of this evaluation. These fire scenarios are summarized in Table 3 and consisted of a sand burner to evaluate the thermal actuator response, telltale fires to evaluate the distribution of the agent throughout the enclosure, and three larger fire scenarios to validate system performance against representative fire scenarios. The sand burner tests (Fire Scenario 1) were conducted over a range of compartment configurations (i.e., the center of the space and in two diagonally opposite corners of the space) to assess the effects that these configurations have on the actuation characteristics of the approved PFESs. The location of the sand burner and the PFES during these tests are shown in Figure 5. The agent distribution tests, telltale fire tests (Fire Scenario 2), were conducted upon successful completion of the actuation tests in each of the compartment geometries.

The PFESs were evaluated against the three large fires scenarios (Fire Scenarios 3 through 5) to validate the extinguishing capabilities of the previously approved systems after completion of the telltale and actuation tests. These tests were conducted in the compartment with the highest aspect ratio in which the system had successfully completed the activation (if applicable) and agent distribution tests. The increased compartment volume tests were focused on assessing the fire extinguishment capabilities of the PFES using only Fire Scenarios 2 through 5. The locations of these fires within the test enclosure are shown in Figure 6.

Table 3. Fire test parameters.

Fire Scenario	Nominal Total Heat Release Rate	Components	Nominal Heat Release Rates	Location (Figures 5 and 6)
1	500 kW or 750 kW	Propane sand burner	500 kW or 750 kW	Center, Corner 1, or Corner 2
2	~24 kW	82 cm <sup>2</sup> heptane pan fires (telltale)	~3 kW/ea	Corners (TT)
3	780 kW	Low pressure heptane spray fire 0.25 m <sup>2</sup> diesel pan fire	470 kW 310 kW	Side of mockup (S) Under mockup (P)
4	970 kW	Low pressure diesel spray fire 0.25 m <sup>2</sup> heptane pan fire	500 kW 470 kW	Side of mockup (S) Under mockup (P)
5	300 kW	Wood crib	300 kW	Deck level (C)



# An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications

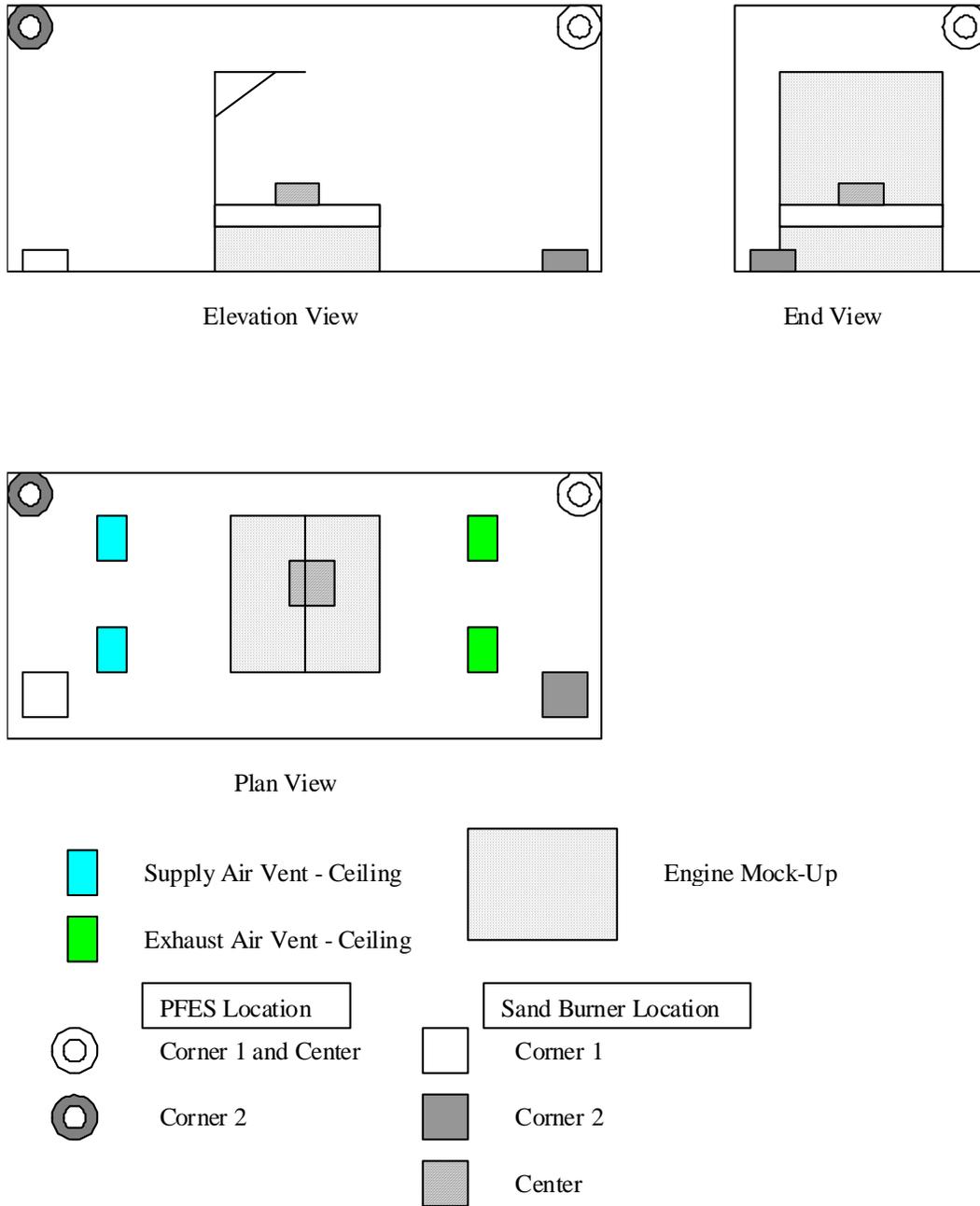


Figure 5. Sand burner and PFES locations.

# An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications

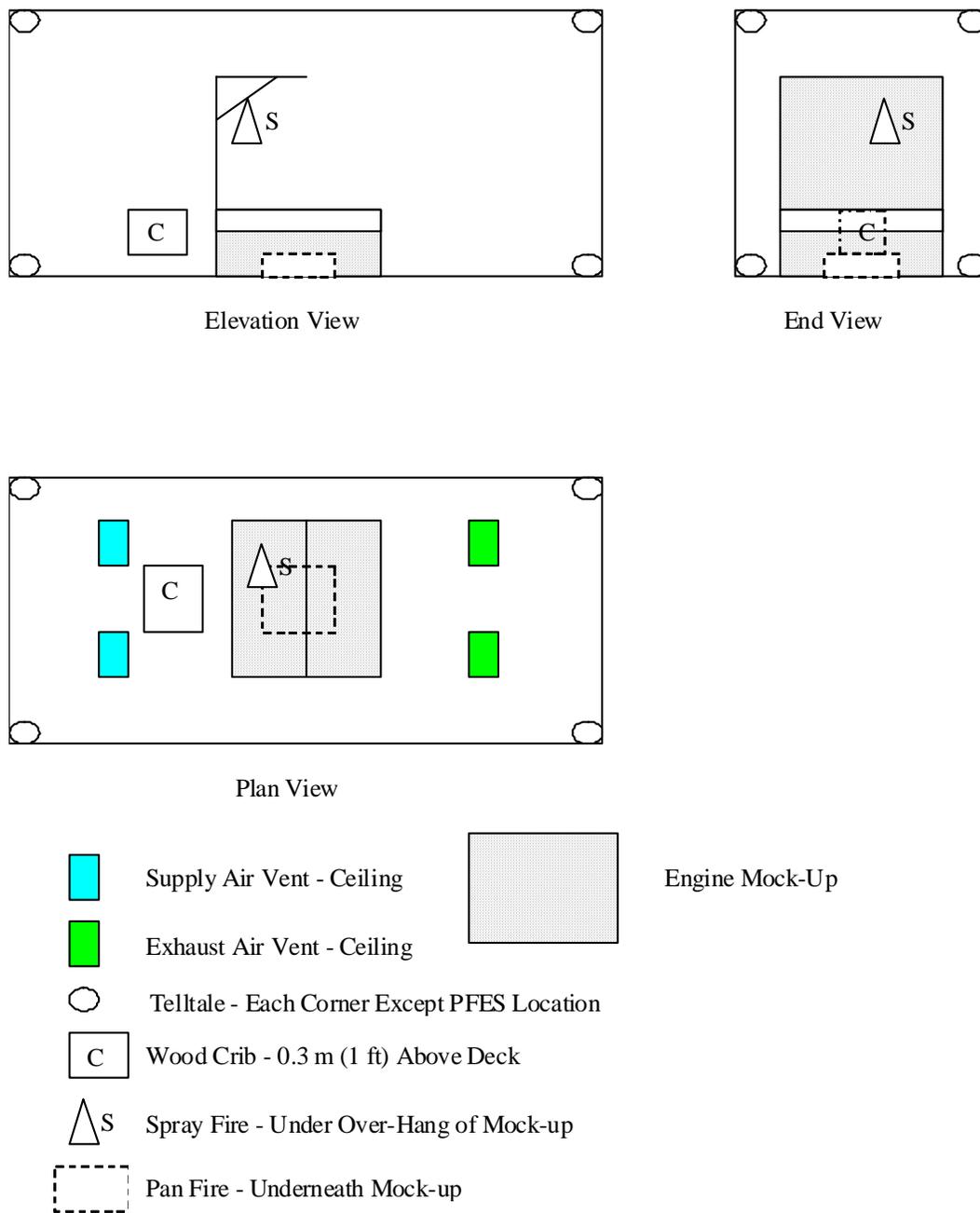


Figure 6. Test fire locations.

The actuation assessment was initially conducted with a 500 kW propane-fueled sand burner which corresponds to a HRR per unit volume of  $10 \text{ kW/m}^3$ . This fire has the same HRR as the heptane pan fire in the current fire test protocol. The fire was initially located in the center of the enclosure, on top of the deck plate of the diesel engine mock-up. For subsequent tests, it was relocated to the corner of the enclosure diagonally opposite the PFES location. The initial corner configuration had the PFES cylinder located in the front-right corner, near the ventilation exhaust (corner 1 configuration). The actuation test was also performed with the PFES cylinder and the propane burner relocated to opposite ends of the test compartment.

## An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications

This configuration had the PFES cylinder in the rear-right corner, near the ventilation supply while the burner was moved to the front-left corner, near the ventilation exhaust (corner 2 configuration). If the PFES did not activate within the 2-minute time limit, the HRR of the burner was increased to 750 kW. Parameters of the burner are given in Table 4, and a photograph of the burner is given in Figure 7.

Table 4. Propane sand burner parameters.

Fire Size (kW)	Propane Flow Rate		Burner Size				Propane Velocity	
	(lpm)	(CFM)	(m <sup>2</sup> )	(ft <sup>2</sup> )	(m)	(ft)	(cm/s)	(ft/min)
500	354	12.5	0.37	4.0	0.61	2.0	1.59	3.13
750	531	18.8	0.37	4.0	0.61	2.0	2.38	4.69



Figure 7. Photograph of sand burner.

The agent distribution test fire scenario (Fire Scenario 2) consisted of small heptane telltale fires located in the corners of the enclosure. These telltale fires consist of a 10 cm (4 in) diameter steel cup, 15 cm (6 in) in depth fueled with a 5 cm (2 in) layer of heptane floating on a water substrate and a 5 cm (2 in) freeboard. These are the same telltales as those used in MSC Circular 848. The telltale was not installed at the PFES cylinder location during these tests.



## An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications

---

The pan used in Fire Scenarios 3 and 4 was square in shape, had an area of 0.25 m<sup>2</sup> (2.7 ft<sup>2</sup>), and was constructed of 3.2 mm steel plate with welded joints. The pan was 15 cm (6 in) in depth with a side dimension of 50 cm (20 in). The pan was filled with a 2.5 cm deep layer of water and a 5 cm deep layer of either heptane or diesel fuel (12.5 L) depending on the test. During Fire Scenario 3, 0.2 L of heptane was added to the diesel pan fire to aid in ignition. A photograph of the pan positioned underneath the engine mock-up is provided in Figure 8.



Figure 8. Photograph of pan underneath the engine mock-up.

The spray fire parameters are given in Table 5. The low-pressure diesel and heptane spray fires were produced using a pressurized fuel tank and a pipe network constructed of 0.6 cm (0.25 in) stainless steel tubing. A manual quarter turn ball valve was used to control the fuel flow during the test. The fuel tank was pressurized with nitrogen from a regulated cylinder. The spray fire was ignited using a telltale cup placed just underneath the fuel spray downstream of the nozzle. Photographs of the spray fire setup are given in Figure 9.

The fires were ignited to produce the following preburn times prior to PFES actuation: wood crib fires, 360 seconds; pan fires, 120 seconds; and spray fires, 90 seconds.



# An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications

Table 5. Spray fire parameters.

Fire Type	Description
Spray nozzle	Wide spray angle (120–125) full cone type
Nozzle make	Bete Fog Nozzle
Nozzle model	P28
Pressure	7 bar, gauge (100 psig)
Fuel flow	0.011 kg/s: Heptane 0.012 kg/s: Diesel
Fuel temperature	20 ± 5 °C
Nominal heat release rate	475 kW: Heptane 500 kW: Diesel



Figure 9. Photographs of spray fire set-up.



## An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications

---

The wood crib consisted of four layers of six members each. Each member was trade size 5 x 5 x 45 cm (actual 3.8 x 3.8 x 45 cm) fir lumber and had a moisture content between 9 percent and 13 percent. The wood crib was placed on an angle iron frame 0.3 m above the deck. The crib was ignited using the 0.25 m<sup>2</sup> pan fueled with 0.75 L of heptane. This amount is less than that specified in MSC Circular 848 to ensure that the heptane had burned out prior to activation of the PFES and to avoid the heptane pan from activating the PFES prior to completion of the preburn of the wood crib. The wood crib was weighed both before and after each test to determine the mass loss that occurred during the test. A photograph of the wood crib set-up is provided in Figure 10.



Figure 10. Photograph of wood crib set-up.

In order to successfully pass these tests, all fires must be extinguished within 60 seconds of the system activation. This is slightly longer than the 40 seconds allowed in MSC Circular 848 (10 seconds for discharge and 30 seconds for extinguishment). In addition to the extinguishment time requirement, the mass loss of the wood crib in Fire Scenario 4 cannot exceed 60 percent of its original weight.

### 6.3 Diesel Engine Analysis

A small diesel-engine-driven generator was used to assess the potential for a runaway condition to occur during system discharge. There was a concern that this runaway condition could potentially result from the ingestion of the agent into the engine during/after system activation. A Duro Power 7500 Diesel generator rated for 6,000 W of electricity incorporating a 9 HP diesel motor was utilized for this evaluation. This test was conducted with an approved PFES system in the 50 m<sup>3</sup> test compartment with a 3:1 aspect ratio.



# An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications

## 6.4 Extinguishing Systems

Two PFES manufacturers were included in this evaluation: BSCO, Inc. and Metalcraft/Sea-Fire, Inc. These two manufacturers were selected since they both have type approvals for volumes up to 42.5 m<sup>3</sup> (1,500 ft<sup>3</sup>). The datasheets for the two systems (from the U.S. Coast Guard list of Approved Equipment) are provided in Appendix B.

The BSCO 740 series PFES can be actuated either automatically by a thermal actuator or manually. The thermal actuator consists of a glass bulb which is knocked out by a lever arm during manual activation. The agent, itself, discharges through the openings surrounding the glass bulb. Photographs of the agent storage cylinder and the thermal actuator are shown in Figure 11.



Figure 11. BSCO PFES cylinder and actuator.

The Sea-Fire FD1500M PFES has a similar actuation system and can be actuated either automatically or manually. Photographs of the cylinder and actuator are provided in Figure 12.

Since there are no PFESs designed for the larger volumes to be tested (the hardware does not exist), a surrogate system was developed for testing purposes. This surrogate system consisted of a single 180° pendant nozzle that was supplied with agent by a cylinder located just outside the space. The nozzle was installed at the PFES location assessed in the previous sensitivity analysis. The system was constructed with components that have been tested and approved using MSC Circular 848. The nozzle was installed within its approved coverage area, but it was not approved for the corner location (it was only tested and approved for an installation that was high in the center of the bulkhead aiming outward). The surrogate system was manually actuated during this evaluation.

All of the PFESs included in this assessment discharged HFC-227ea (FM-200, FE-227) as the extinguishing agent. Some selected properties of HFC-227ea are given in Table 6. This agent has been successfully tested against MSC Circular 848 with fire protection hardware from a variety of manufacturers: Metalcraft/Sea-Fire, Kidde-Fenwal, Fike, and Chemetron. The majority of these tests were conducted with a concentration of 6.7 percent (7.2 percent by some manufacturers) as the minimum extinguishing concentration (telltale fire scenarios) and at 8.6 percent as the minimum design concentration (larger fire scenarios). During these tests, the systems were initially designed with a concentration of 7.4 percent.



Figure 12. Sea-Fire FD series cylinder and actuators.

Table 6. HFC-227ea properties.

Name	HFC-227ea (FM-200, FE-227)
Chemical Formula	CF <sub>3</sub> CHFCF <sub>3</sub>
Molecular Weight	170.03
Normal Boiling Point, °C	-16.4
Vapor Pressure, MPa at 21 °C	0.41
Agent Vapor Density, kg/m <sup>3</sup> at 21 °C and 101.325 kPa	7.264
n-heptane Cup Burner, % Volume	6.7
Minimum Design Concentration – IMO MSC Circular 848, % Volume	8.6
NOAEL Concentration, % Volume	9
LOAEL Concentration, % Volume	10.5

NOAEL: No observable adverse effect level

LOAEL: Lowest observable adverse effect level

## 6.5 Instrumentation

The instrumentation scheme used during these tests is similar to that required by MSC Circulars 668, 848, and 1007. Instruments were installed in the test compartment to monitor the thermal conditions in the space, the status of each fire, ventilation conditions, and the agent concentration history during each test. Instruments were installed on the fire extinguishing system to monitor the discharge characteristics of the system (e.g., the pressure and discharge time of the system).



# An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications

---

## 6.5.1 Test Enclosure and Fire Monitoring Instrumentation

The test enclosures were instrumented to measure air temperatures, fire/flame temperature (to note extinguishment time), fuel system pressure (for the spray fires), agent concentration, and carbon monoxide, carbon dioxide, and oxygen gas concentrations. A schematic layout of the instrumentation is given in Figure 13.

### 6.5.1.1 Air/Gas Temperature Measurements

A thermocouple tree was installed near the back right corner of the test compartment. The tree consisted of five thermocouples positioned at the following heights above the deck: 0.6, 1.2, 1.8, 2.4, and 2.9 m. Inconel-sheathed Type K thermocouples (0.16 cm diameter Omega Model KMQIN-062U-600) were used for this application.

### 6.5.1.2 Fire Temperature Measurements

Each fire was instrumented for temperature to aid in the determination of extinguishment time. One thermocouple was placed inside the wood crib, in the flame region 20 cm above the pan and telltale cup fires and 45 cm downstream of the spray fire nozzles. Inconel-sheathed, Type K thermocouples (0.16 cm diameter Omega Model KMQIN-062E-6 and KMQIN-062U-600) were used for this application.

### 6.5.1.3 Gas Concentration Measurements

Carbon monoxide, carbon dioxide, and oxygen concentrations were measured from 1.5 m above the deck as shown in Figure 13. The gas samples were pulled through 0.6 cm stainless steel tubing and a Drierite-packed filter using a vacuum sampling pump at a flow rate of 1 Lpm, resulting in a transport delay of approximately 30 seconds. Siemens Oxymat 6 and Ultramat 23 Analyzers were utilized for this application.

### 6.5.1.4 Fuel System Pressure Measurements

The spray fire fuel pressure was measured in the pipe network using a Setra Model 205-2 pressure transducer with a full-scale range of 1.7 MPa (250 psig).

### 6.5.1.5 Agent and Hydrogen Fluoride (HF) Concentration

The agent and hydrogen fluoride (HF) concentrations were measured using a KVB/Analect Diamond 20 Fourier Transform Infrared Spectrometer (FTIR) configured with an open path for in situ measurements inside the space. This configuration employed two flat 90° mirrors (Analect Model OBE-100), two light pipes, and two 3.8 cm diameter calcium fluoride (CaF<sub>2</sub>) windows. A 56 cm (22 in) active path length was used during these tests. The active path was located 1.3 m above the deck, 25 cm (10 in) from the right wall, and started (5.7 ft) from the rear wall as shown in Figure 13. Spectra were obtained every 6 seconds with each spectra being the average of four scans. Agent and HF concentrations were determined by comparison with spectra obtained using known concentrations using the absorbencies at wave numbers shown in Table 7. The HF concentrations implied by the absorbencies at wave numbers 4,003, 4,041, and 4,077 cm<sup>-1</sup> were averaged together.



# An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications

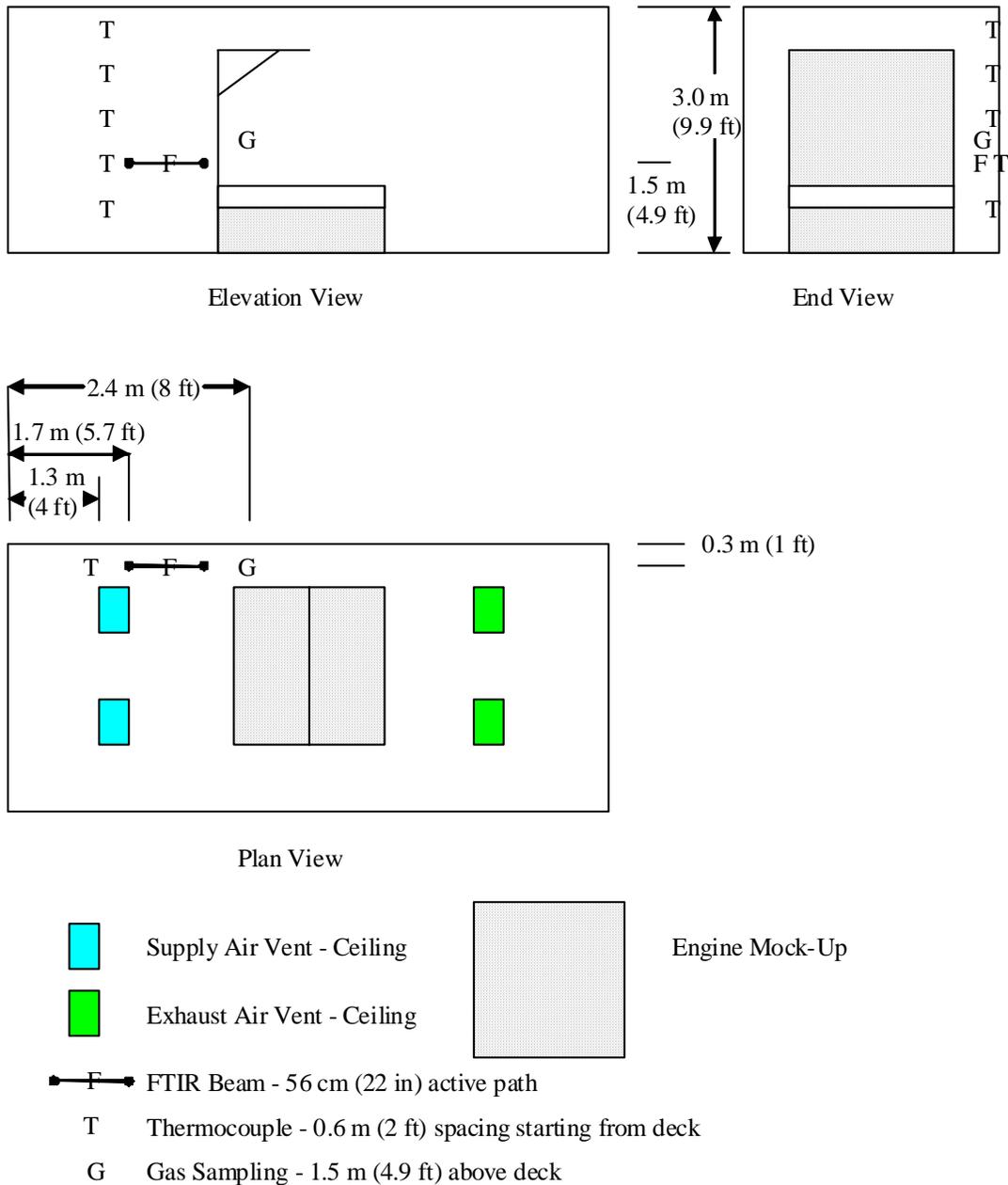


Figure 13. Instrumentation schematic.

Table 7. Agent and decomposition product wave numbers.

Agent/Compound	Wave Number (cm <sup>-1</sup> )
FM-200	2034
HF	4003, 4041, and 4077

# An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications

---

## 6.5.2 PFES Instrumentation

The PFES cylinder pressure was measured by removing the pressure switch at the cylinder and replacing it with a pressure transducer. Omega Engineering Model PX603-1KG-05V pressure transducers with a range of 0-6.9 MPa, gauge (0-1,000 psig) were utilized for this measurement.

## 6.5.3 Video Equipment

A video camera was used to visually document the events of the test. The camera was located either inside the compartment or outside of the compartment along the front wall to obtain a view of a test fire and system discharge.

## 7 PROCEDURES

Prior to the start of the test, the ventilation system was started and adjusted to deliver 1 ACM throughout the compartment, the fire scenarios were set, and the test fuel was staged just outside of the compartment. The ventilation system remained active throughout the test. The video and data acquisition systems were activated, marking the beginning of the test. After the start of the data acquisition system, the test fires or ignition cups were fueled and ignited, and the compartment was cleared of test personnel. Manual activation timing was driven by the fires specific to the test scenario: the wood crib fires were allowed to burn 360 seconds (6 minutes) prior to activation; the pan fires were allowed to burn 120 seconds (2 minutes) prior to activation; and the spray fires were allowed to burn 90 seconds (1.5 minutes) prior to activation. The fuel for the spray fire was secured after the fire was confirmed to be extinguished (indicated by the drop in temperature measured by the fire thermocouples). The test compartment remained secured for 10 minutes after activation. On completion of the test, the door was opened and the compartment was prepared for the next test.

For the actuation evaluation, the propane burner was secured after the PFES activated or 2 minutes had elapsed from ignition of the burner. In some cases, the test was allowed to extend beyond 2 minutes to determine the actuation time for the scenario.

## 8 RESULTS AND DISCUSSION

A total of 49 tests was conducted during this investigation. Thirty-six tests were conducted to evaluate the capabilities of two currently approved PFESs over a range of conditions. Of these 36 tests, 18 were conducted to assess the actuation characteristics of the system(s) and 18 were conducted to assess the fire extinguishing capabilities of the system(s). Twelve tests were conducted to determine the suitability of using PFESs to protect larger machinery spaces and one test was conducted to determine the outcome if the agent was ingested in a running diesel engine.

The results of these tests are broken into two assessments: an evaluation of the capabilities of previously approved PFESs and an evaluation of PFESs in larger spaces. A secondary evaluation was also performed on the effects of the extinguishing agent on an operating diesel engine that draws its combustion air from the space in which it is installed.

# An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications

## 8.1 Approved System Sensitivity Analysis

The 50 m<sup>3</sup> (1,766 ft<sup>3</sup>) test enclosures in which this assessment was performed were 18 percent larger than the 42.5 m<sup>3</sup> (1,500 ft<sup>3</sup>) enclosure for which the PFESs were previously approved. As a result, the agent concentration was less than previously tested during the “type approval” (7.4 percent versus 8.7 percent). This reduced agent concentration makes the results of the fire extinguishing tests conservative when compared to the expected capabilities of an actual installation.

The performance of these systems can be divided into two functions: detection of the fire by the thermal actuator and the suppression of the fire once actuated. These functional capabilities were evaluated separately.

### 8.1.1 Actuation Time Evaluation

The results of the detection/actuation performance evaluation are summarized in Table 8 and are shown graphically in Figure 14.

Table 8. Actuation test results.

Test	Enclosure			PFES		Propane Burner		Planar Distance Between Burner and Cylinder		Actuation Time (sec)
	Volume		Aspect Ratio	Manufacturer	Location	Location	Heat Output (kW)	(ft)	(m)	
	(ft <sup>3</sup> )	(m <sup>3</sup> )								
Test 3	1785.1	50.5	1.0	BSCO	1-Low	Center	500	9.5	2.9	N/A
Test 4	1785.1	50.5	1.0	BSCO	1-High	Center	500	9.5	2.9	34.8
Test 8	1785.1	50.5	1.0	BSCO	1-High	Corner	500	19.0	5.8	49.3
Test 15	1778.2	50.4	2.0	BSCO	1-High	Corner	500	21.1	6.4	41.4
Test 33	1725.0	48.8	3.0	BSCO	1-High	Corner	500	24.1	7.3	98.5
Test 9	1785.1	50.5	1.0	BSCO	2-High	Corner 2	500	19.0	5.8	90.6
Test 12	1785.1	50.5	1.0	BSCO	2-High	Corner 2	750	19.0	5.8	84.7
Test 17	1778.2	50.4	2.0	BSCO	2-High	Corner 2	750	21.1	6.4	90.1
Test 31	1725.0	48.8	3.0	BSCO	2-High	Corner 2	750	24.1	7.3	173.4
Test 5	1785.1	50.5	1.0	Sea-Fire	1-Low	Center	500	9.5	2.9	N/A
Test 6	1785.1	50.5	1.0	Sea-Fire	1-High	Center	500	9.5	2.9	30.6
Test 7	1785.1	50.5	1.0	Sea-Fire	1-High	Corner	500	19.0	5.8	40.5
Test 14	1778.2	50.4	2.0	Sea-Fire	1-High	Corner	500	21.1	6.4	37.7
Test 34	1725.0	48.8	3.0	Sea-Fire	1-High	Corner	500	24.1	7.3	58.4
Test 10	1785.1	50.5	1.0	Sea-Fire	2-High	Corner 2	500	19.0	5.8	N/A
Test 11	1785.1	50.5	1.0	Sea-Fire	2-High	Corner 2	750	19.0	5.8	63.0
Test 16	1778.2	50.4	2.0	Sea-Fire	2-High	Corner 2	750	21.1	6.4	107.9
Test 32	1725.0	48.8	3.0	Sea-Fire	2-High	Corner 2	750	24.1	7.3	114.3

N/A: PFES did not actuate during the 2-minute time limit



# An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications

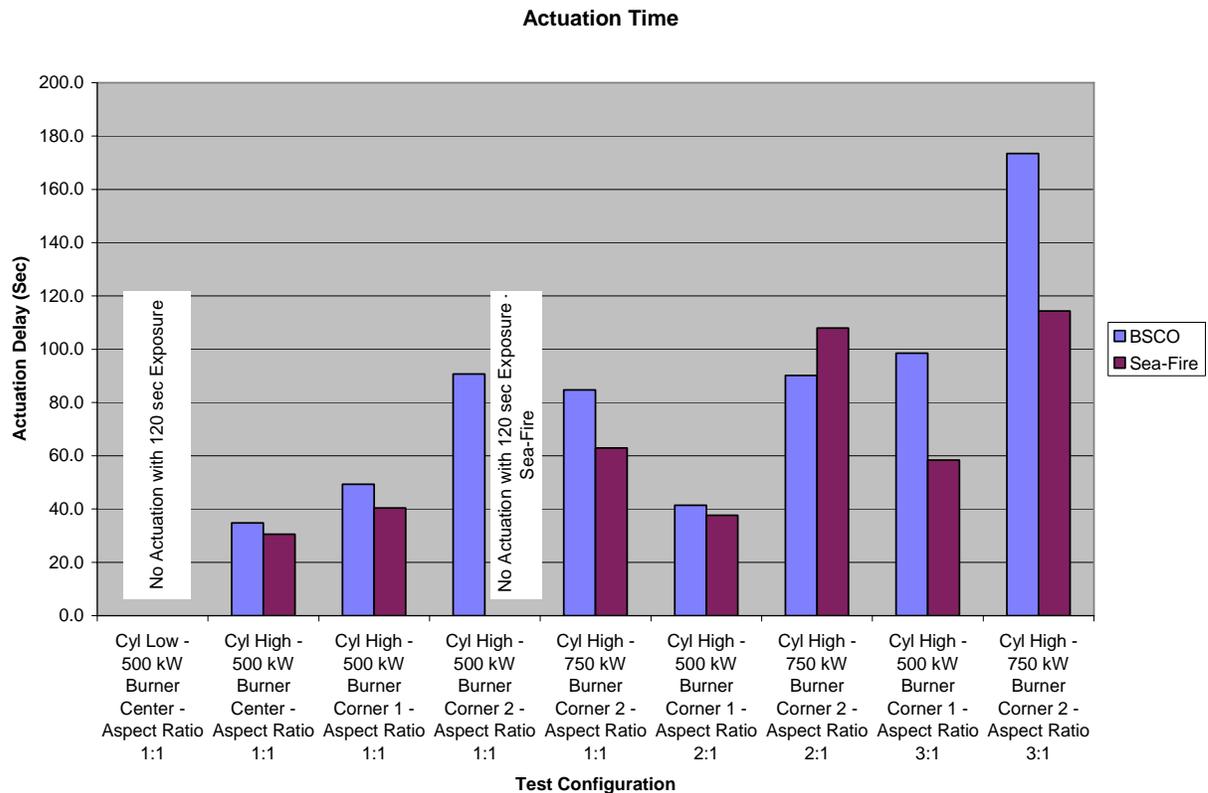


Figure 14. Results of the actuation evaluation.

Figure 15 shows the enclosure temperatures measured by the thermocouple tree in the center of the compartment for Test 14. Figure 16 shows the temperature measured at the PFES location also for Test 14. As can be seen from these figures, the temperature at the PFES had exceeded the bulb rating temperature of 79.4 °C (175 °F) for nearly 23 seconds prior to PFES activation. This is due to the thermal lag of the bulb (referred to as the Response Time Index (RTI)) and is similar to that encountered with automatic sprinkler systems.

### 8.1.1.1 PFES Elevation

During the first actuation test conducted with each system (Test 3 with BSCO and Test 5 with Sea-Fire; 500 kW fire in the center of the space and the PFES installed low in the corner), the PFES failed to actuate within the 2-minute exposure time. This suggests that the PFES needs to be installed high in the compartment in order to increase the likelihood for a timely actuation (and to minimize the damage caused by the fire). When the PFES was raised, both systems actuated in less than 35 seconds from ignition of the burner.



# An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications

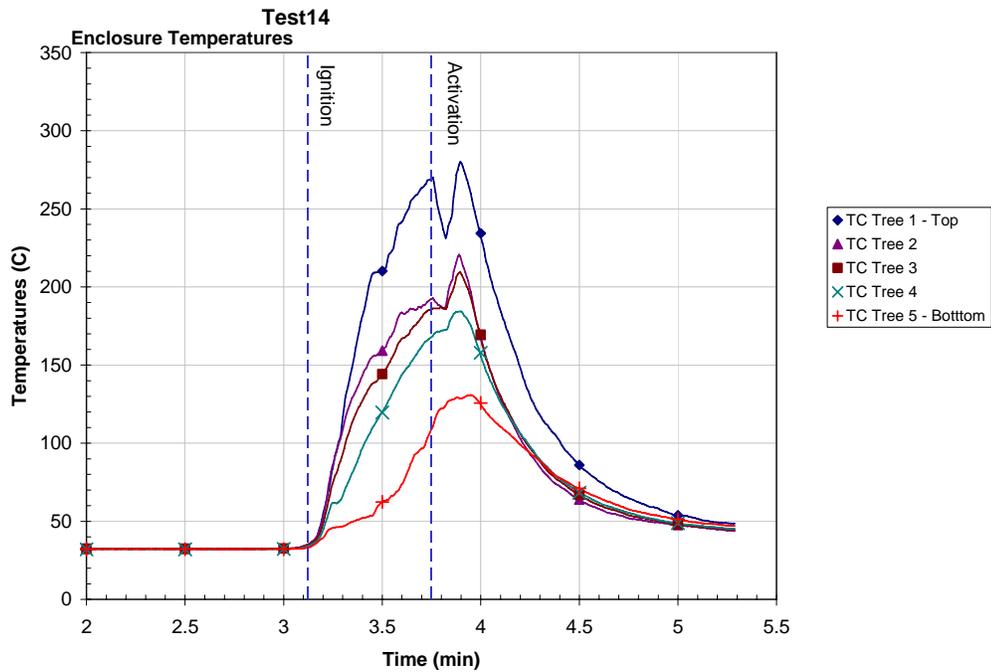


Figure 15. Enclosure temperature during actuation test with Sea-Fire PFES in corner location, 500 kW propane burner, in 2:1 aspect ratio enclosure (Test 14).

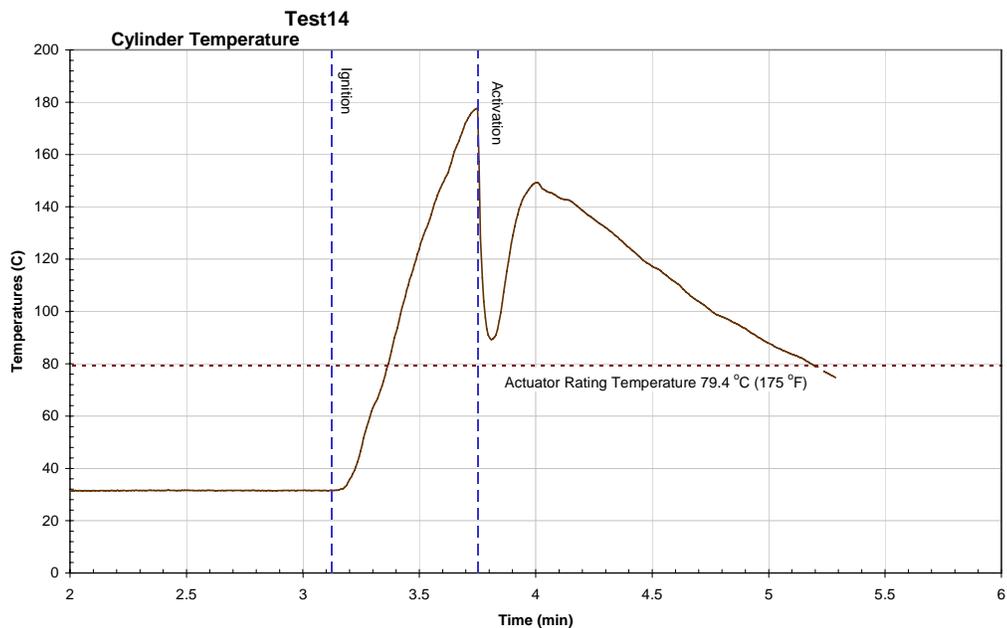


Figure 16. Temperature at PFES cylinder near actuator during actuation test with Sea-Fire PFES in corner location, 500 kW propane burner, in 2:1 aspect ratio enclosure (Test 14).

# An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications

## 8.1.1.2 Compartment Configuration

Figure 17 shows the actuation times for the range of compartment configurations assessed during this investigation. The data indicates that the vent configuration, PFES location, and the fire location all combined to have a major effect on the actuation times of the system. The fastest actuations times were recorded when the fire was located in the center of the space and the PFES was located near the exhaust. The actuation times became longer when the fire was moved from the center of the space to the corner diagonally opposite the PFES (fire near the supply air ducts (Corner 1) and the PFES located near the exhaust). The longest actuation times (most challenging configuration to detect) were observed when the PFES was located below the supply air ducts and the fire was located diagonally opposite the PFES in the corner under the exhaust (Corner 2).

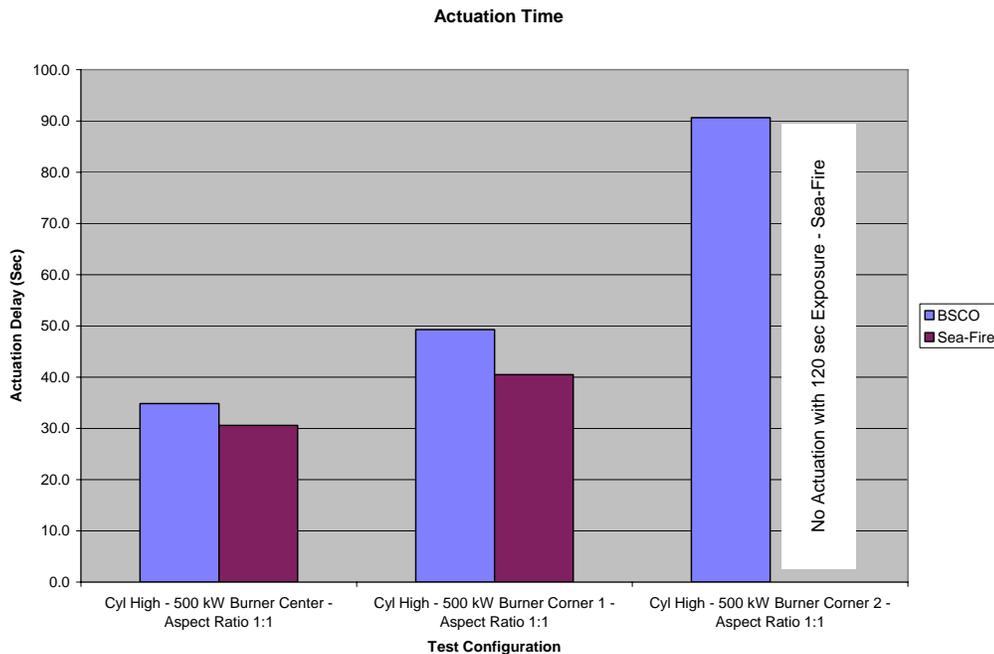


Figure 17. System actuation times for the various test configurations.

## 8.1.1.3 Aspect Ratio

The aspect ratio also had a major effect on the actuation times of the PFES and increased for compartments with higher aspect ratios. The actuation times typically doubled as the aspect ratio increased from 1:1 to 3:1. With the fire located in the corner near the supply air ducts and PFES located near the exhaust (Corner 1), the actuation time increased from 50 to 100 seconds as the aspect ratio increased from 1:1 to 3:1. With the fire located near the exhaust and the PFES located near the supply air duct (Corner 2), the activation times increased from 85 to 175 seconds.

These results are also presented in the context of an increase in separation distance between the PFES and the propane burner as illustrated in Figure 18. Independent of how these results are presented, the increase in activation time is associated with a decrease in the thermal exposure to the cylinder/PFES. The gas temperatures in the upper layer and the radiation both decrease as the distance between the fire and the PFES is increased. In addition, the engine mock-up becomes more of an obstruction to air flow and radiation from the fire as the width of the enclosure is reduced.



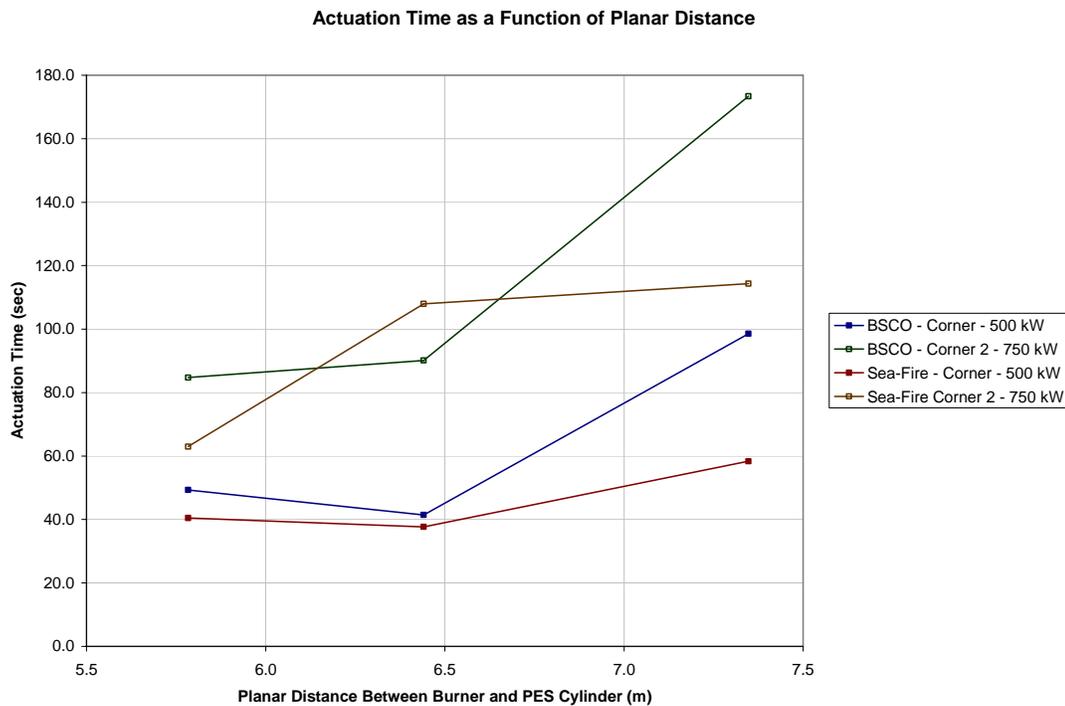


Figure 18. Actuation time as a function of separation distance between the PFES and the propane sand burner.

## 8.1.2 Fire Extinguishing Sensitivity Analysis

### 8.1.2.1 Telltale Fire Test Results

The extinguishing capabilities of the approved PFESs were first evaluated using the telltale fires located in all eight corners of the test compartment (except for the location where the PFES was installed). The results of this assessment are summarized in Table 9.

When the PFES was located low in the compartment (Test 1), the telltale directly above the cylinder was not extinguished. The remaining tests were all conducted with the cylinder installed high in the space.

The BSCO PFES had some difficulty extinguishing the telltales in the 1:1 aspect ratio enclosure with the last telltale extinguished 31.9 seconds after actuation. This delayed extinguishment is believed to be an anomaly. The remaining six telltales were all extinguished during agent discharge (in less than 7 seconds from system actuation). The BSCO PFES also extinguished all of the telltales in the other two compartments (2:1 and 3:1 aspect ratios) in less than 8 seconds.

The agent concentrations measured in the three enclosures are compared in Figure 19. In contrast to the actuation tests, the test/compartment configuration had little effect on the extinguishment capabilities of the system (results were the same independent of the fire and PFES proximity to the supply and exhaust air ducts).

## An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications

Table 9. Telltale scenario performance of the previously approved PFESs.

Test	Enclosure			Pre-Engineered System				Extinguishment Time (from PFES activation)							
	Volume		Aspect Ratio	Manufacturer	Location	Conc. (%)	Dis. Time (sec)	Lower				Upper			
								Left		Right		Left		Right	
	(ft <sup>3</sup> )	(m <sup>3</sup> )	Rear (sec)	Front (sec)	Rear (sec)	Front (sec)	Rear (sec)	Front (sec)	Front (sec)	Rear (sec)					
Test 13	1785.1	50.5	1.0	BSCO	1-High	7.4	7.0	6.4	1.6	1.9	31.9	6.4	0.4	CYL	0.7
Test 18	1778.2	50.4	2.0	BSCO	1-High	7.5	7.9	5.9	3.5	5.9	1.1	6.1	0.5	CYL	1.1
Test 21	1778.2	50.4	2.0	BSCO	2-High	7.5	7.4	7.4	6.1	3.0	1.2	0.6	3.9	1.2	CYL
Test 26	1725.0	48.8	3.0	BSCO	1-High	7.7	6.7	4.5	3.1	4.3	0.8	5.9	0.8	CYL	3.5
Test 25	1725.0	48.8	3.0	BSCO	2-High	7.7	7.6	6.6	7.1	4.8	4.8	0.6	4.8	3.0	CYL
Test 1	1785.1	50.5	1.0	Sea-Fire	1-Low	7.4	N/D	N/D	N/D	N/D	CYL	N/D	N/D	N/E	N/D
Test 2	1785.1	50.5	1.0	Sea-Fire	1-High	7.4	N/D	3.5	1.4	4.4	0.2	3.2	0.2	CYL	0.2
Test 19	1778.2	50.4	2.0	Sea-Fire	1-High	7.5	6.8	N/E	0.7	15.6	0.7	N/E	0.6	CYL	1.2
Test 20	1778.2	50.4	2.0	Sea-Fire	1-High	7.5	6.6	N/E	1.0	N/E	0.0	N/E	0.7	CYL	1.5

CYL: Agent cylinder location

N/D: No data recorded during the test

N/E: Fire not extinguished



# An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications

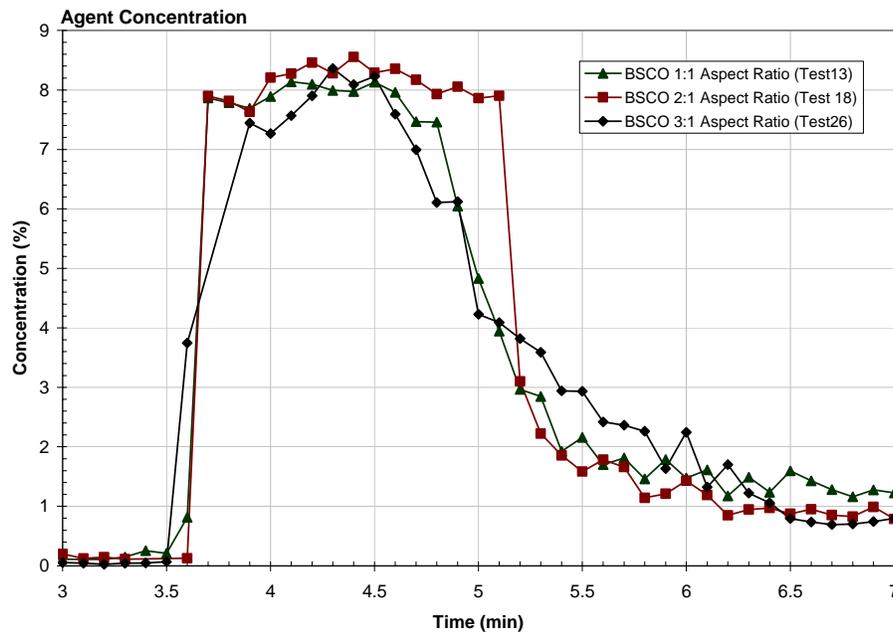


Figure 19. BSCO PFES agent concentration comparison.

The first two tests with the Sea-Fire PFES were performed with cylinders that were filled at Sea-Fire’s facility. During these two tests, the data acquisition system malfunctioned and failed to record the cylinder pressure during system discharge. The remaining tests were performed with the system/agent cylinder reconditioned and recharged at the test site.

The Sea-Fire PFES extinguished all the telltales in the compartment with the 1:1 aspect ratio but was unable to extinguish all of the telltales in a compartment with a 2:1 aspect ratio. The later tests (the ones that failed) were conducted with a system/cylinder that was recharged at the test site. There appears to be a problem with the discharge characteristics of the cylinders that were recharged at the test site. During removal of the cylinder after test, additional agent was discharged from the system. A second agent cylinder (different from the first) was then recharged and the same phenomenon occurred. Due to this change in the discharge characteristics of the system, the results of the suppression tests conducted with the recharged Sea-Fire PFES are not believed to be representative and will not be included in this investigation/assessment.

### 8.1.2.2 Larger Fire Scenario Performance with Approved PFESs

The fire extinguishing capabilities of the BSCO PFES were verified in the compartment with the 3:1 aspect ratio using the larger fire scenarios in the proposed protocol and are summarized in Table 10. As can be seen from this table, the large fires were typically extinguished during system discharge with the exception of the wood crib. The deep-seated nature of the wood crib fire requires additional soak time to completely extinguish the fire. The system pressure and the fire temperatures from these tests are shown in Figures 20 through 23. Note that these tests were conducted in an enclosure that was 18 percent larger than the rated volume of the PFES, adding a level of conservatism to these results.



# An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications

Table 10. Approved PFES performance with larger fire scenarios in 3:1 aspect ratio enclosure.

Test	Enclosure		Aspect Ratio	PFES			Fire Scenario	Extinguishment Time (from PFES activation)			
	Volume			Mfgr.	Conc. (%)	Discharge Time (sec)		Spray Fire (sec)	Pan Fire (sec)	Wood Crib (sec)	Last Fire (sec)
	(ft <sup>3</sup> )	(m <sup>3</sup> )									
Test 26	1725	48.8	3.0	BSCO	7.7	6.7	Telltals	--	--	--	5.9
Test 29	1725	48.8	3.0	BSCO	7.7	6.7	Heptane Spray and Diesel Pan	2.2	6.6	--	6.6
Test 30	1725	48.8	3.0	BSCO	7.7	6.7	Diesel Spray and Heptane Pan	3.2	9.8	--	9.8
Test 28	1725	48.8	3.0	BSCO	7.7	6.7	Wood Crib	--	--	21.1	21.1

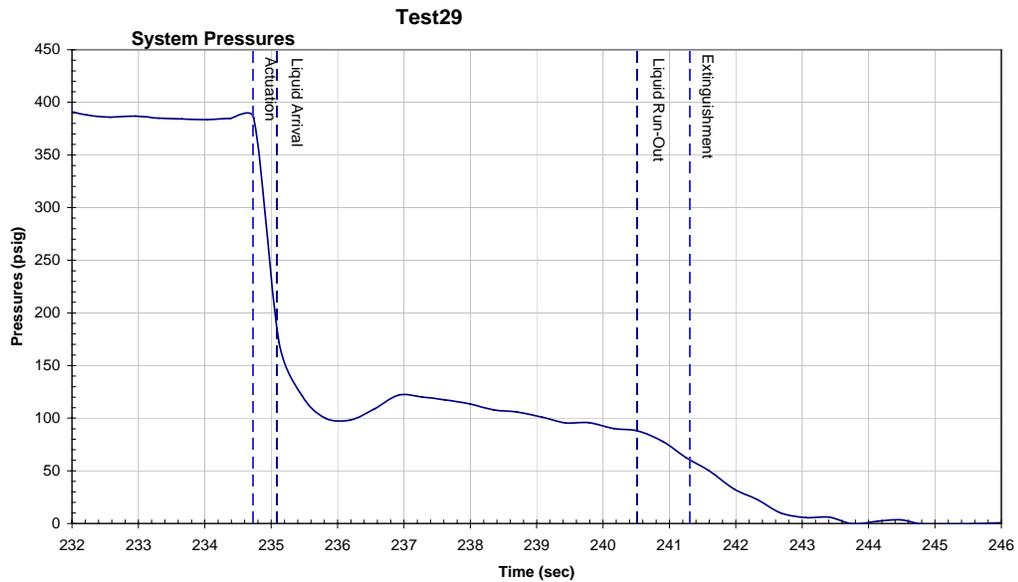


Figure 20. Cylinder pressure from BSCO PFES test with heptane spray fire and diesel pan fire scenario (Test 29).



# An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications

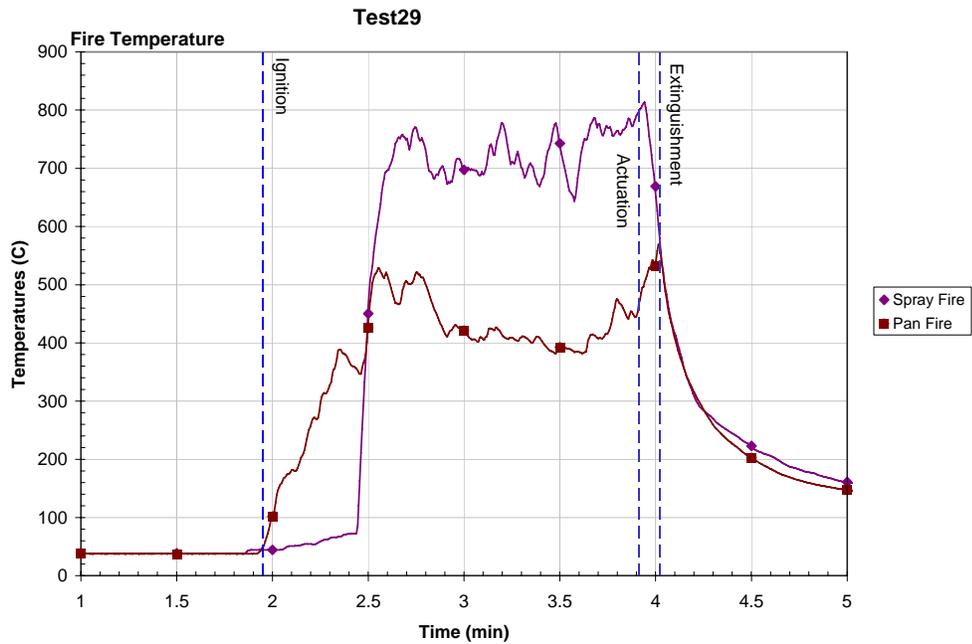


Figure 21. Fire temperatures from BSCO PFES test with heptane spray fire and diesel pan fire scenario (Test 29).

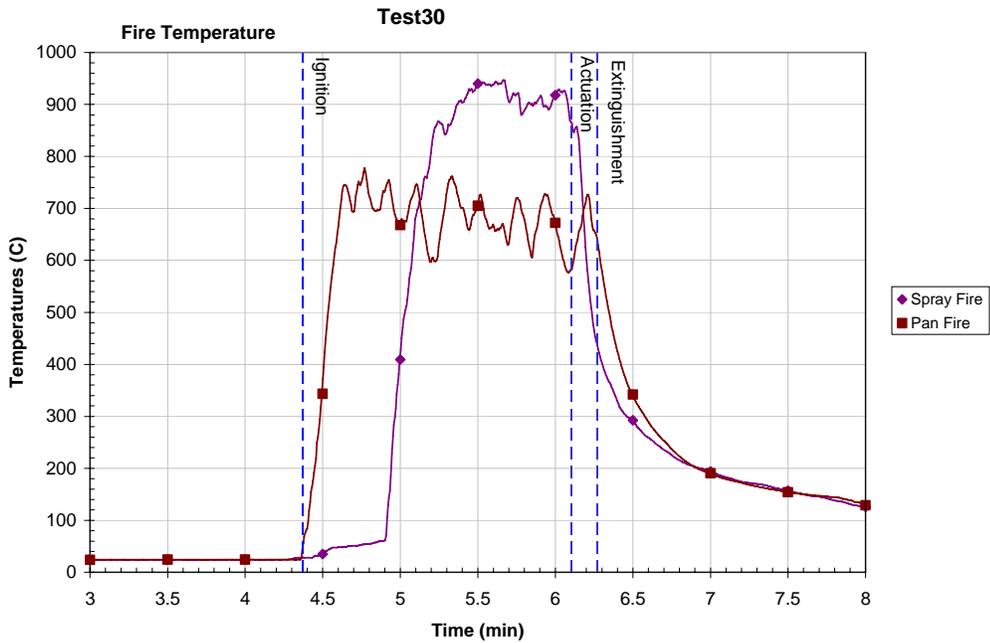


Figure 22. Fire temperatures from BSCO PFES test with diesel spray fire and heptane pan fire scenario (Test 30).



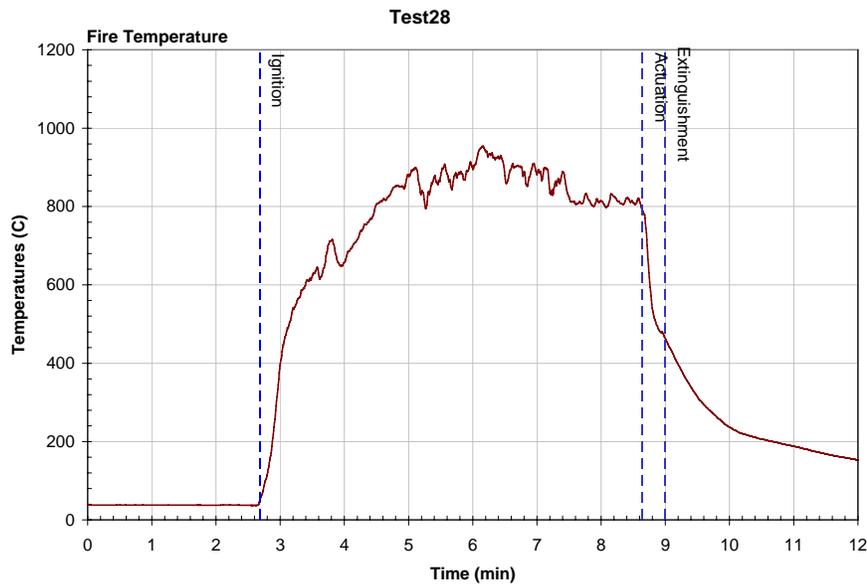


Figure 23. Fire temperatures from BSCO PFES test with wood crib fire scenario (Test 28).

### 8.1.3 Approved System Sensitivity Analysis Summary

#### 8.1.3.1 Actuation Sensitivity Analysis Summary

The results of these tests suggest that the PFES needs to be installed high in the compartment in order to increase the likelihood for a timely actuation (and to minimize the damage caused by the fire). The data also indicates that the vent configuration, PFES location, and the fire location all combined to have a major effect on the actuation times of the system. The longest actuation times (most challenging configuration to detect) were observed when the PFES was located below the supply air ducts and the fire was located diagonally opposite the PFES in the corner under the exhaust. This suggests that the PFES should be installed away from the ducts supplying air to the space. The aspect ratio also had a major effect on the actuation times of the PFES and increased for compartments with higher aspect ratios. This suggests that the maximum possible distance of the PFES to the fire should be limited. This can be achieved either by controlling the location of the installation or by limiting the volume and aspect ratio of the compartment.

#### 8.1.3.2 Fire Extinguishment Sensitivity Analysis Summary

The PFESs were capable of extinguishing all the test fires conducted during this sensitivity analysis (with the exception of the telltale cup located directly above the cylinder in the first test). In contrast to the actuation analysis, the test/compartment configuration had little effect on the extinguishment capabilities of the system (results were the same independent of the fire and PFES proximity to the supply and exhaust air ducts). The results of these tests suggest that the approved systems have good capabilities for this application. However, it is still recommended that a factor of safety should be added to the test concentration to account for clutter/obstructions characteristic of an actual installation.



## 8.2 PFES Extinguishing Capabilities in Larger Enclosure Volumes

Tests were conducted in larger compartments to determine if the volume constraints placed on the current “type approvals” can be increased to allow these systems to be used in larger spaces. Since there are no PFESs designed for these larger volumes (the hardware does not exist), a surrogate system was developed for testing purposes. This surrogate system consisted of a single nozzle that was supplied with agent by a cylinder located just outside the space. The nozzle was installed at the PFES location assessed in the previous sensitivity analysis (Section 8.1).

The tests focused strictly on evaluating the fire extinguishing capabilities of these systems. As a result, the actuation capabilities of the system were not evaluated in the larger test enclosures.

### 8.2.1 Surrogate PFES Baseline Tests

The first set of tests was conducted to define the baseline extinguishing capabilities of the surrogate system in the 50 m<sup>3</sup> (1,766 ft<sup>3</sup>) enclosure (and to adjust/optimize the system to match the capabilities of an approved PFES) and are shown in Table 11. However, the surrogate system was unable to match the capabilities of the approved system (BSCO) in the 50 m<sup>3</sup> (1,766 ft<sup>3</sup>) enclosure. This was attributed to the cylinder used for the surrogate system during the initial tests. More specifically, the dip tube did not extend all the way to the bottom of the cylinder. This causes more of the agent to be delivered as a vapor (primarily at the end of discharge) and extends the discharge time. As a result, the agent design concentration was never fully achieved and decayed faster for the surrogate than for the approved system as shown in Figure 24.



## An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications

Table 11. Telltale scenario performance of surrogate PFES tests in 50 m<sup>3</sup> (1,766 ft<sup>3</sup>) test enclosures.

Test	Enclosure		Aspect Ratio	Surrogate PFES			Extinguishment Time (from PFES activation)								
	Volume (ft <sup>3</sup> ) (m <sup>3</sup> )			Conc. (%)	Nozzle Orifice Area (in <sup>2</sup> ) (mm <sup>2</sup> )		Discharge Time (sec)	Lower				Upper			
								Left		Right		Left		Right	
	Rear (sec)	Front (sec)		Rear (sec)	Front (sec)	Rear (sec)	Front (sec)	Front (sec)	Rear (sec)						
Test 22	1778	50.4	2.0	7.5	0.230	149	7.8	N/E	N/E	9.6	24.0	N/E	3.6	CYL	1.2
Test 23	1778	50.4	2.0	7.5	0.328	211	6.3	8.3	21.5	5.9	N/E	7.1	1.1	CYL	1.1
Test 24	1778	50.4	2.0	7.5	0.660	426	4.2	4.2	5.4	1.8	N/E	3.0	0.6	CYL	1.2
Test 27	1725	48.8	3.0	7.7	0.660	426	4.3	N/E	N/E	5.6	N/E	4.4	0.3	CYL	0.9
Test 36	1725	48.8	3.0	8.8	0.660	426	6.0	58.2	4.6	36.0	6.3	N/E	0.7	CYL	5.1
Test 37	1725	48.8	3.0	8.8	2.071	1336	5.8	2.3	3.1	13.1	0.8	N/E	0.4	CYL	N/E

CYL: Agent cylinder location

N/D: No data recorded during the test

N/E: Fire not extinguished



# An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications

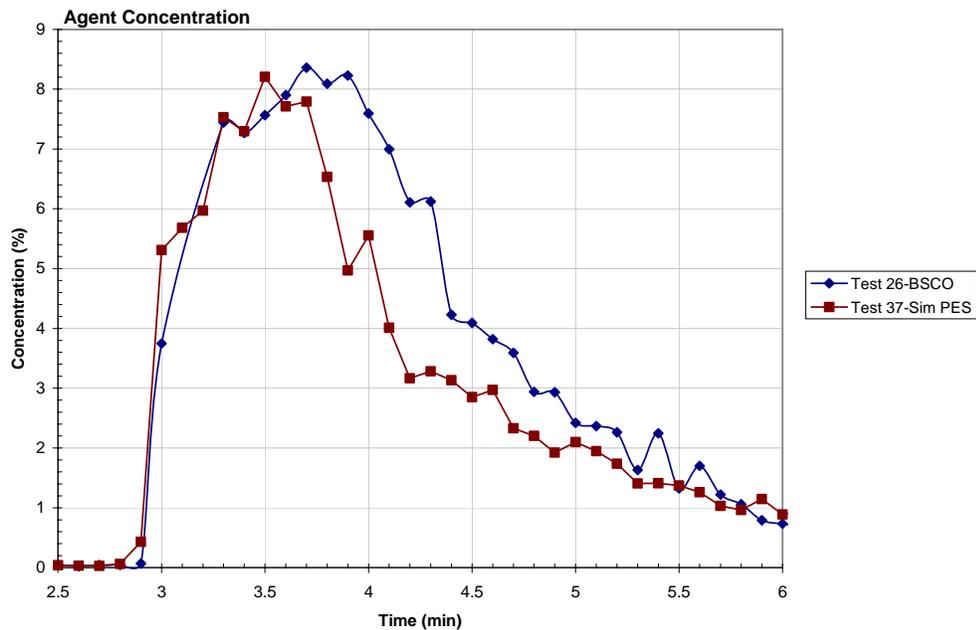


Figure 24. Comparison of achieved agent concentrations with surrogate and BSCO PFES in 3:1 aspect ratio enclosure (7.7% design for BSCO (Test 26), 8.8% design for surrogate (Test 37)).

## 8.2.2 Tests Conducted in Larger Enclosures

The cylinders used for the surrogate system in the larger enclosures had more efficient dip-tubes that extended almost to the bottom of the cylinder and, therefore, avoided some of the problems experienced during the baseline tests (tests conducted in the 50 m<sup>3</sup> (1,766 ft<sup>3</sup>) enclosure). However, the surrogate PFES did require higher design concentrations in the larger enclosures to achieve the required extinguishment capabilities (extinguishment times). These results are shown in Table 12.

Assuming that the baseline concentration of the surrogate system would be similar to that of the approved PFES (if there were no problems with the agent cylinders), the increase in design concentration is on the order of 10 percent for 50 m<sup>3</sup> (1,766 ft<sup>3</sup>) to 100 m<sup>3</sup> (3,532 ft<sup>3</sup>) enclosure and over 30 percent for 100 m<sup>3</sup> (3,532 ft<sup>3</sup>) to 150 m<sup>3</sup> (5,297 ft<sup>3</sup>) enclosures. It needs to be noted that the relatively large increases in design concentrations used during these tests (test conditions) may have caused the determined increase to be larger than actually required. A lower percent may have been identified if additional tests were conducted to better refine these values.

The ventilation configuration used during these tests may have also contributed to the increase in required agent concentration. Although the vent openings into the space were increased in an attempt to maintain a constant inlet air velocity for the larger enclosures, this was never verified. Based on the agent concentration measurements taken in the space during the tests conducted in the larger enclosures, there appears to be localized areas of lower agent concentrations in the region(s) below the supply air inlets. The higher agent concentrations may have been required to negate these localized effects.



## An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications

Table 12. Surrogate PFES and BSCO PFES performance with increasing enclosure volume.

Test	Enclosure			PFES			Fire Scenario	Extinguishment Time (from PFES activation)			
	Volume		Aspect Ratio	Manufacturer	Conc. (%)	Discharge Time (sec)		Spray Fire (sec)	Pan Fire (sec)	Wood Crib (sec)	Last Fire (sec)
	(ft <sup>3</sup> )	(m <sup>3</sup> )									
Test 26	1725.0	48.8	3.0	BSCO	7.7	6.7	Telltals	--	--	--	5.9
Test 29	1725.0	48.8	3.0	BSCO	7.7	5.4	Heptane Spray and Diesel Pan	2.2	6.6	--	6.6
Test 30	1725.0	48.8	3.0	BSCO	7.7	6.8	Diesel Spray and Heptane Pan	3.2	9.8	--	9.8
Test 28	1725.0	48.8	3.0	BSCO	7.7	5.2	Wood Crib	--	--	21.1	21.1
Test 38	3572.9	101.2	2.0	Surrogate	7.4	3.9	Telltals	--	--	--	N/E
Test 39	3572.9	101.2	2.0	Surrogate	7.4	4.0	Telltals	--	--	--	N/E
Test 40	3572.9	101.2	2.0	Surrogate	8.5	5.1	Telltals	--	--	--	6.2
Test 42	3572.9	101.2	2.0	Surrogate	8.5	4.6	Heptane Spray and Diesel Pan	11.4	10.4	--	11.4
Test 41	3572.9	101.2	2.0	Surrogate	8.5	5.5	Diesel Spray and Heptane Pan	1.2	5.1	--	5.1
Test 43	3572.9	101.2	2.0	Surrogate	8.5	4.8	Wood Crib	--	--	21.6	21.6
Test 44	5024.4	142.3	2.0	Surrogate	9.0	8.8	Telltals	--	--	--	N/E
Test 45	5024.4	142.3	2.0	Surrogate	9.0	6.3	Telltals	--	--	--	42.5
Test 46	5024.4	142.3	2.0	Surrogate	9.0	5.9	Heptane Spray and Diesel Pan	N/E	12.4	--	N/E
Test 47	5024.4	142.3	2.0	Surrogate	9.0	5.1	Heptane Spray and Diesel Pan	N/E	N/E	--	N/E
Test 48	5024.4	142.3	2.0	Surrogate	10.5	6.1	Heptane Spray and Diesel Pan	1.6	5.8	--	5.8
Test 49	5024.4	142.3	2.0	Surrogate	10.5	6.6	Diesel Spray and Heptane Pan	1.5	6.4	--	6.4



## 8.3 Effects of Agent on an Operating Diesel Engine

A test was conducted to determine the effect that the extinguishing agent would have on an operating combustion (diesel) engine (if ingested into the engine). During Test 35, a diesel generator, Duro Power 7500, was placed in the 50 m<sup>3</sup> (1,766 ft<sup>3</sup>) enclosure. The diesel generator draws its air for combustion from the surrounding atmosphere which in this case is the protected enclosure. Upon discharge, the diesel engine would ingest the agent:air mixture within the test compartment. Instruments were installed to measure the diesel engine speed during the test. The engine was started and was allowed to operate normally for 1 minute prior to discharge of the BSCO PFES.

The diesel engine speed measured during this test is shown in Figure 25. The compartment agent concentration (ingested into the engine) is shown in Figure 26. As shown by these figures, the engine shut down immediately upon exposure to the agent without any sign of a run-away event. At the conclusion of the test (after the space was ventilated and returned to ambient conditions), the diesel generator was successfully restarted. After testing, oil samples from the diesel generator were sent for analysis. Results which are reported in Appendix C, show the TAN was 3.3 which is fairly acidic.

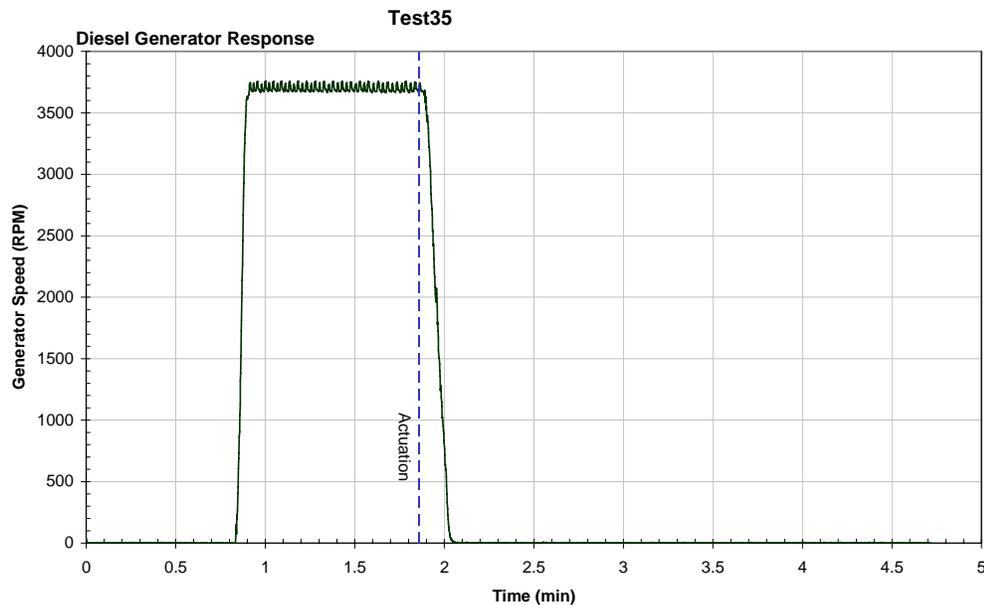


Figure 25. Diesel generator drive shaft rotations during exposure to 7.7 percent HFC-227ea (Test 35).



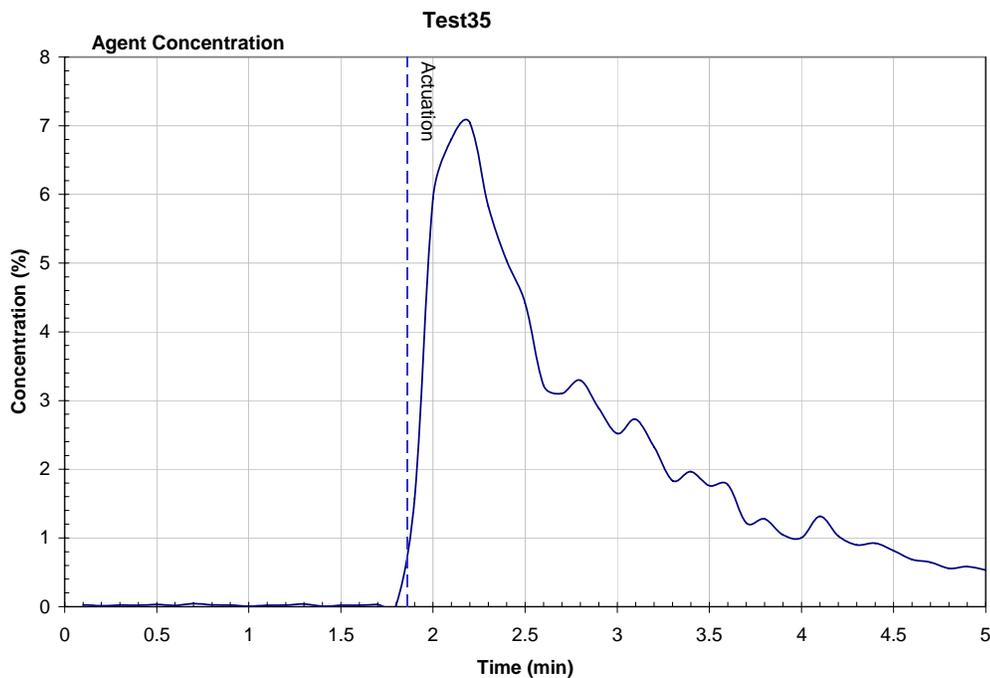


Figure 26. Agent concentration during diesel generator exposure (Test 35).

## 9 INTERPRETATION OF TEST RESULTS

### 9.1 General

The ventilation rate and configuration can significantly affect the PFES performance. During these tests, the fires were located away from the supply ducts, allowing for a well mixed environment at the fire location (limited localized affects). It will always be difficult to extinguish fires in the area(s) directly in front of the supply ducts.

The ventilation rate will also have a dramatic impact on the maximum agent concentration and the hold-time of the agent in the protected space; the higher the ventilation rate, the lower the peak agent concentration and the shorter the agent hold-time. The shorter agent hold-times increase the likelihood of re-flash, making it highly desirable for the PFES to automatically shut down the electrical and fuel sources. This is not addressed in the fire scenarios proposed for this assessment nor was it ever addressed in the previously awarded “type approvals.”

It is recommended that a factor of safety be added to the test concentration to account for the clutter which is characteristic of an actual installation and is not simulated in typical approval tests. IMO requires that the telltale fire tests in MSC Circular 848 be conducted at 83 percent of the design concentration, resulting in a 20 percent factor of safety between the approval test(s) and an actual installation. As a result, it is recommended that the design concentration be defined as 120 percent of the concentration required to pass these tests. This recommendation for a factor of safety applies regardless of the enclosure volume. Another ap-



# An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications

---

proach for achieving this factor of safety would be to define the maximum volume of the system as 83 percent of that tested.

## 9.2 Implications for Currently Approved PFES

The results of these tests suggest that the approved systems have good capabilities for this application and as a result, the current test protocol also appears to be adequate. However, additional design constraints should be added to the actual installations of the PFES and are listed as follows:

- The PFES should be installed high in the space while avoiding the 4-in dead zone at the intersection of bulkhead and overhead,
- The PFES should not be installed near supply ducts where the air can impinge on the actuator and delay or prevent the system from responding, and
- The PFES should be installed so the maximum possible distance of the system from the fire is minimized, either through installed location or through limits on maximum volume and aspect ratio.

The performance requirements for actuation of the PFES also need to be discussed further. The actuation capabilities observed during these tests should be representative of the technology as a whole and may define a potential short-coming of the system(s).

Under worst case conditions, the size of the fire required to cause system actuation can be fairly large and produce significant damage to the engine compartment/machinery space prior to actuation. In addition, the time required for the system to actuate may be longer than expected. Although the systems must actuate and extinguish the fire in less than 60 seconds during the approval test (as per the current requirements), in an actual installation, it may take on the order of 3 minutes for the system to respond as observed during these tests. As a reference point, the survivability requirements for fuel hoses on recreational boats are based on a 150-second (2.5 minutes) fire exposure (46 CFR 183.590).

If the objective of the system is to save the ship and reduce the likelihood for fire spread outside of the engine compartment, then the approval test and currently approved systems are probably acceptable. On the other hand, if the objective of the system is to minimize the damage to the engine compartment and contain the fire to the location/equipment of origin, a more sensitive actuation system would be required. Note that for enclosures greater than 28.3 m<sup>3</sup> (1,000 ft<sup>3</sup>), a back-up manual activation device is required for these systems providing an additional level of safety.

## 9.3 Implications for Use of PFES in Larger Volumes

There are two primary implications that can be drawn from this investigation regarding the use of PFESs in larger spaces. The first implication is associated with the activation of these systems in these larger spaces. For a single-point heat detection/actuation system, the critical fire size (the size of the fire required to actuate the system) will scale proportionally with compartment volume. As a result, increasing the volume of the space from 50 m<sup>3</sup> (1,766 ft<sup>3</sup>) to 150 m<sup>3</sup> (5,297 ft<sup>3</sup>) corresponds to fire sizes increasing from 750 kW to 2,250 kW. Although the system would likely prevent the spread of the fire to other spaces, the fire would



# An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications

---

cause significant damage to the affected space. The thermal decomposition product formation (i.e., HF) due to the quantity of agent reacting with the flames would also be significant based on past IMO gaseous agent tests.

The second implication is associated with the need to use a higher agent design concentration for the larger compartment volumes. These test results demonstrated the ability for the PFES to extinguish fires in enclosures as large as 100 m<sup>3</sup> (3,531 ft<sup>3</sup>) with only a modest 10 percent increase in concentration. However, a larger increase (over 30 percent) was required to extinguish the test fires in the 150 m<sup>3</sup> (5,297 ft<sup>3</sup>) enclosure. The implication being that, while enclosure volumes of 100 m<sup>3</sup> (3,531 ft<sup>3</sup>) may be within reach of the PFES technology in terms of fire extinguishing capabilities, the higher concentrations required in the 150 m<sup>3</sup> (5,297 ft<sup>3</sup>) enclosure may make these systems impractical for these spaces.

## 10 SUMMARY AND CONCLUSIONS

A total of 49 tests were conducted during this investigation. Thirty-six tests were conducted to evaluate the capabilities of two currently approved PFESs over a range of conditions. Of these 36 tests, 18 tests were conducted to assess the actuation characteristics of the system(s) and 18 tests were conducted to assess the fire extinguishing capabilities of the system(s). Twelve tests were conducted to determine the suitability of using PFESs to protect larger machinery spaces and one test was conducted to determine the outcome if the fire extinguishing agent was ingested in a running diesel engine.

### 10.1 Approved PFES Capabilities

The actuation of a PFES was shown to be a function of fire size, fire location, enclosure aspect ratio, elevation of the PFES within the protected space, and the ventilation configuration. The results of these tests suggest that the PFES needs to be installed high in the compartment in order to increase the likelihood for a timely actuation (and to minimize the damage caused by the fire). The data also indicates that the vent configuration, PFES location, and fire location all combined to have a major effect on the actuation times of the system. The longest actuation times (most challenging configuration to detect) were observed when the PFES was located below the supply air ducts and the fire was located diagonally opposite the PFES in the corner under the exhaust. This suggests that PFESs should be installed away from the ducts supplying air to the space. The aspect ratio also had a major effect on the actuation times of the PFES and increased for compartments with higher aspect ratios. This suggests that the PFES should be installed so the maximum possible distance of the system from the fire is minimized, either through installed location or through limits on maximum volume and aspect ratio.

The approved PFESs were capable of extinguishing all the test fires conducted during this sensitivity analysis (with the exception of the telltale cup located directly above the cylinder in the first test). In contrast to the actuation analysis, the test/compartment configuration had little effect on the extinguishment capabilities of the system (results were the same independent of the fire and PFES proximity to the supply and exhaust air ducts). The results of these tests suggest that the approved systems have good fire extinguishing capabilities for this application. However, it is still recommended that a 20 percent factor of safety be added to the test concentration to account for the clutter in an actual installation. This recommendation applies re-



# An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications

---

ardless of the enclosure volume and could take the form of a 20 percent increase in the agent quantity in the unit/cylinder over what was tested or by limiting the approval to 83 percent of the test compartment.

## 10.2 PFES Protection of Larger Compartments

Tests were conducted in larger compartments to determine if the volume constraints placed on the current “type approvals” can be increased to allow these systems to be used in larger spaces. The results of these tests identified two primary issues that need to be discussed before such an allowance should be considered: actuation response times and agent design concentrations.

For a single-point heat detection/actuation system, the critical fire size (the size of the fire required to actuate the system) will scale proportionally with compartment volume. As a result, increasing the volume of the space from 50 m<sup>3</sup> (1,766 ft<sup>3</sup>) to 150 m<sup>3</sup> (5,297 ft<sup>3</sup>) corresponds to the critical fire size increasing from 750 kW to 2,250 kW. Although the system would likely prevent the spread of the fire to other spaces, the fire would cause significant damage to the affected space. The thermal decomposition product formation (i.e., HF) may also be an issue for these larger fires (based on past IMO gaseous agent tests).

These tests showed that higher agent design concentrations are required to provide adequate fire extinguishing capabilities for larger compartments. To maintain capabilities, the design concentration was increased by approximately 10 percent for 50 m<sup>3</sup> (1,766 ft<sup>3</sup>) to 100 m<sup>3</sup> (3,532 ft<sup>3</sup>) enclosures and over 30 percent for 100 m<sup>3</sup> (3,532 ft<sup>3</sup>) to 150 m<sup>3</sup> (5,297 ft<sup>3</sup>) enclosures. This may imply that, while enclosure volumes of 100 m<sup>3</sup> (3,532 ft<sup>3</sup>) are within reach of the PFES technology in terms of fire extinguishing capabilities (and system practicality), the higher concentrations required for the 150 m<sup>3</sup> (5,297 ft<sup>3</sup>) enclosure may make PFESs impractical for these spaces.

## 10.3 Agent Effects

With respect to the concern associated with the fire extinguishing agent being ingested into the main engine(s), the exposed diesel generator shut down upon exposure to the agent with no indications of a run-away event and exhibited no acute adverse effects.



# An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications

---

## 11 REFERENCES

46 CFR 162.029 (2007), Code of Federal Regulations.

BSCO Fire Systems, March 2008, [On-line] Available: [www.bscofiresystems.com/products.html](http://www.bscofiresystems.com/products.html).

Forssell, E.W., Back, G.G., Beyler, C.L., DiNenno, P.J., Hansen, R., and Beene, D., “An Evaluation of the International Maritime Organization’s Gaseous Agents Test Protocol,” *Fire Technology*, **37** (1), January 2001, pp. 37–67.

International Maritime Organization (1994), Alternative Arrangements for Halon Fire-Extinguishing Systems in Machinery Spaces and Pump-Rooms (IMO FP39 MSC Circular 668), London, England.

International Maritime Organization (1996), International Convention for The Safety of Life At Sea (SOLAS 74), London, England.

International Maritime Organization (1998), Revised Guidelines for Approval of Equivalent Fixed Gas Fire Extinguishing Systems, As Referred to in SOLAS 74, for Machinery Spaces and Cargo Pump Rooms (IMO FP42 MSC Circular 848). London, England.

International Maritime Organization (2001), Guidelines for the Approval of Fixed Aerosol Fire Extinguishing Systems as Referred to in SOLAS 74, for Machinery Spaces (IMO FP44 MSC Circular 1007). London, England.

Metalcraft/Sea-Fire, March 2008. [On-line] Available: [www.sea-fire.com/SF/ProductsSeaFire/PreEngineered/FD\\_FM200/FD.html](http://www.sea-fire.com/SF/ProductsSeaFire/PreEngineered/FD_FM200/FD.html).

Underwriters Laboratory UL 2166 (2001), UL Standard for Halocarbon Clean Agent Extinguishing System Units, Northbrook, Illinois.



**APPENDIX A. USCG REQUIREMENTS FOR “FIXED FIRE EXTINGUISHING SYSTEMS” (PRE-ENGINEERED)**

**A.1 APPROVAL CATEGORY: 162.029**

**A.1.1 APPROVAL GUIDANCE & INFORMATION:**

U.S. Coast Guard regulations require the installation of U.S. Coast Guard approved fixed gaseous extinguishing systems on certain U.S. registered inspected vessels, and permit the substitution of an approved system for one of the required approved portable fire extinguisher on pleasure craft.

In order to obtain a certificate of approval (i.e., “type approval”), compliance with the following criteria is required. These criteria determine the equivalency of new clean agent systems to the carbon dioxide systems currently specified in the various vessel regulations, and to the halon systems previously approved as equivalent to carbon dioxide systems. This updates and supplements the test program outlined in our Notice of Proposed Rulemaking published in the Federal Register on Wednesday, January 9, 1991, pages 829 through 836, to enable inclusion of clean agent replacements for halons.

Approvals are issued only for complete systems made up of specific components and utilizing specific extinguishing agents. Approval is not issued for individual system components, such as individual hardware or extinguishing agents.

The extinguishing agent must be acceptable to the U.S. Environmental Protection Agency (EPA) under the Significant New Alternatives Policy (SNAP list) without restrictions that limit its use in marine applications.

The agent must be recognized as a fire extinguishing medium by NFPA Standard #2001 on Clean Agent Fire Extinguishing Systems.

Systems must be listed and labeled for marine use by an Accepted Independent Testing Laboratory accepted by the Coast Guard under 46 CFR 159.010. Laboratories currently so accepted are FM and UL. All tests must be conducted under the control of the laboratory. To be acceptable, the laboratory, must apply, and be accepted, in accordance with 46CFR 159.010 prior to conducting any tests. A laboratory must demonstrate independence and technical expertise in the evaluation of the fire suppression systems in accordance with the latter regulation.

Systems must be intended for installation in spaces that are normally unoccupied, and that personnel can leave within 10 seconds after the system is actuated.

Systems are approved based on fire tests in simulated compartments of pre-determined size, and are not designed individually for each engine compartment.

The primary system actuator must be automatic if the agent cylinder is installed in the protected space.

Systems must have discharge indicators for installation at each helmsman’s position.



## An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications

---

System components must meet UL 2166 “Standard for Halocarbon clean agent Extinguishing System Units.”

System must be intended for the protection against Class B hazards (flammable liquids) in machinery and bilge spaces, and Class C hazards (non-shock hazard when discharged into energized electrical equipment).

Systems intended for installation in small passenger vessel (46 CFR Subchapters T and K) must have manual (mechanical) back-up actuators, audible alarms, and automatic engine and ventilation shutdown upon system discharge. The engine shutdown feature must have a mechanism to quickly restart the engine(s).

Systems using fusible elements for actuation are limited to installation in spaces not exceeding 2000 cubic feet. Systems for larger unoccupied spaces or any spaces intended for human occupancy must be specifically designed for each space protected, i.e., engineered, and must provide personnel safeguards such as limits on the agent concentration, discharge delays, and pre-discharge alarms.

Systems for fishing industry vessels are limited to spaces not exceeding a volume of 1200 cubic feet.

The volume of the compartment protected must be the gross volume: the length times the width times the depth of the compartment. The volume of installed equipment such as engine blocks and fuel tanks may not be deducted, unless the boat manufacture attaches a placard that states the volume of the installed tanks and engine blocks.

Systems must be self-contained, i.e., not require an external source of power such as the boat’s electrical system for activation.

Systems must be intended for installation in engine compartments where natural ventilation does not exceed one air change per minute. If the natural ventilation is expected to be greater, a system tested under the higher air flow conditions must be installed.

Systems containing a charge of nitrogen in addition to the extinguishing agent must have a listed pressure gage. This gage is not a substitute for the required discharge indicator.

Systems intended for installation in volumes of 1000 cubic feet and larger must have a manual back-up actuator.

The system must be tested by the independent lab as follows:

1. Discharge tests per section 23 of UL2166.
2. Valve leakage tests per section 24 of UL2166.
3. Hydrostatic tests per section 25 of UL2166.
4. 30-day elevated temperature test per section 26 of UL2166.
5. Temperature cycling test per section 27 of UL2166.
6. Salt-spray corrosion tests per section 28 of UL2166.



## An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications

---

7. 500 cycle operation tests per section 29 of UL2166.
8. One-Year leakage test per section 32 of UL 2166.
9. Mounting device test per section 33 of UL2166.
10. Manual actuator test per section 41 of UL 2166.
11. Tests of pressure gages and indicators per sections 44 through 49 UL2166.
12. Tests of elastomeric parts per section 51 of UL 2166.
13. Pressure relief test per section 53 of UL2166.
14. Nameplate exposure, adhesion and abrasion tests per sections 54 through 56 of UL2199.
15. Marine tests per Supplement SA of UL 2166, including salt-spray corrosion, vibration resistance, and shock resistance tests.

The system must meet a 7-day high temperature exposure test. Each fully charged system must be conditioned for 7 days at 175 °F. It may not rupture during or after the test. It need not be capable of operation after the test. No system having a cylinder valve with a fusible plug that melts below 175 °F, or contains a rupture disc or other relief device, need be subjected to this test.

Fire tests must be conducted in accordance with UL2166. For systems without piping the fire tests of section 36 of UL 2166 must be conducted. The test must be repeated at the system manufacturer's design concentration and under conditions of one air change per minute for the test enclosure.

The fire tests must include tests at cup burner concentrations, and at the manufacturer's recommended design concentration. For the latter the test compartment must be ventilated at one air change per minute.

System not incorporating an automatic engine shutdown feature must have placards for attaching to each helmsman's position stating that the engine(s), generator, and any powered ventilation must be shutdown upon system activation.

Each system must have an owner's instruction manual containing installation and maintenance instructions. Systems for pleasure craft are generally intended to be installed by the boat owner. Systems for inspected vessels are more complex since they require engine shutdowns, and are to be installed by system distributors or marine electricians. The owner's manual must be specific to marine applications and must include the following:

1. Maximum gross volume limitations and maximum engine room/bilge dimensions.
2. Storage temperature range.
3. Coast Guard approval number.
4. Rated temperature of fusible link actuator.
5. Whether cylinders are refillable or nonrefillable.



# An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications

---

6. Instructions on the safe disposal of the extinguishing agent.
7. Instructions on the periodic hydrostatic testing requirements for the agent cylinder if refillable.
8. A statement that only one system may be installed in each protected volume, unless each system is individually rated to protect the space.
9. General maintenance instructions.

The Coast Guard does not test materials or systems for approval but rather specifies the required test methods and minimum performance criteria for approval. The testing must be performed on the product by a Coast Guard Accepted Independent Laboratory.

## A.1.2 SUBMITTAL PACKAGE

(Please submit the follow information in the Submittal Package)

A cover letter requesting Coast Guard Type Approval of the equipment.

A test report from the independent laboratory showing compliance of the product or equipment with UL2166.

Evidence that an acceptable follow-up factory inspection program is in place in each factory location. This could be demonstrated by providing an original copy of the contract for a follow-up program between the manufacturer and the Accepted Independent Laboratory. The follow-up program must show that no unauthorized changes can be made to the equipment without proper review and approval by the Accepted Independent Laboratory.

An installation and maintenance manual as per paragraph number 23 of this section.

Please send the Submittal Package and other related information to the following address:

Commandant (G-MSE-4)  
2100 Second Street, S.W.  
Washington, DC 20593-0001

Once the equipment has been approved by this office it will receive Coast Guard Type Approval and a Certificate of Approval (COA). The COA will be issued for 5 years and will remain valid during that time period if the product meets the testing of the Quality Control Program.



**APPENDIX B. U.S. COAST GUARD PRE-ENGINEERED SYSTEM APPROVALS**

Coast Guard Approval Number: 162.029/0000245/0  
Issued: 9/8/2005 9:32:33 AM  
Expires: 9/8/2010  
Approval Status: APPROVED

**FIXED FIRE EXTINGUISHING SYSTEM**

BSCO, INC  
343-B Granary Road  
Forest Hill, MD 21050  
UNITED STATES

---

Model 740, automatic pre-engineered FE 227 units with cylinder mounted discharge nozzle.

Approved for the protection of unoccupied engine compartments against flammable liquid (Class-b) fire hazards on recreational boats and certain other uninspected vessels. Approval covers 25 cylinder sizes with a range of fill capacities, Part Nos. 740002 (fill range 1 - 2.2 lb.) through 740065 (fill range 60.5 - 65 lb.) for installation in protected volumes of 50 cubic feet through 1500 cubic feet, respectively. Units installed in volumes of 1000 cubic feet and larger, Part Nos. 740043 - 740065, must include a manual release. Subject to OCMI review, may also be installed in spaces up to 1,500 cubic feet on inspected vessels if equipped with additional system manufacturer supplied accessories and alarms for engine and fan shutdown and engine restart as required by the applicable subchapter. Electrical installation to be in accordance with the applicable section of 46 CFR, Subchapter T or K.

Identifying data: FM Report No. 3021620, class 5612 and FM letter dated August 16, 2005, USCG letter dated 8 September 2005, and manufacturer's instruction manual PN49015 and owner's manual PN 490016 dated June 2005.

Follow-up Program: FM

Approval valid for products manufactured at the above location and: Catef srl Via dei Lecci 55049 Viareggio (lu) Italy

---

EC/US MRA Approved: False

\*\*\* END \*\*\*

**NOTICE: This is NOT an official certificate**



# An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications

---

USCG CGMIX Approved Equipment

## Equipment Details:

Coast Guard Approval Number: 162.029/0000237/0  
Issued: 7/1/2005  
Expires: 9/14/2010  
Approval Status: APPROVED

## FIXED FIRE EXTINGUISHING SYSTEM

METALCRAFT, INC

---

"Sea-fire" FM200 pre-engineered fire extinguishing systems  
Models FG25A/FG25M - FG240A/FG240M, FD150A/FD150M -  
FD1500A/FD1500M inclusive.

Maximum protected volume is 25 through 240 cu. ft. for FG series (0.7 through 6.8 cu. m), and 150 through 1500 cu. ft. for FD series (4.2 through 42.5 cu. m). Systems with automatic or automatic/manual actuation approved for installation in unmanned engine compartments on recreational boats and certain other uninspected vessels. Subject to OCMI review, series with manual back-up actuator may be installed on inspected vessels if equipped with the additional system manufacturer supplied accessories as required by applicable subchapter.

Identifying Data: FM Approved Agreement dated March 23, 2000, Report Job Identification 3007407, dated March 18, 2000, FM Approval Report 3021164 dated July 12, 2004 and Metalcraft Instruction Manual Part No. 123-194 Rev A.

Follow-up program: FM

Electrical installation to be accordance with the applicable sections of 46 CFR, Subchapter T or K.

This certificate amends approval no. 162.029/237/0 to recognize the acceptance of DOT 3AL aluminum cylinders.

---

EC/US MRA Approved: False

\*\*\* END \*\*\*

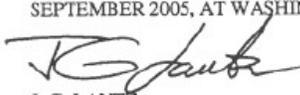
**NOTICE: This is NOT an official certificate**

<http://psix.uscg.mil/Equipment/EquipmentDetails.aspx?EQID=11602>

3/28/2008



# An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications

	<b>U. S. Department of Homeland Security</b>
	<b>United States Coast Guard</b>
<b>Certificate of Approval</b>	
Coast Guard Approval Number: 162.029/237/0	Expires: 14 September 2010
FIXED FIRE EXTINGUISHING SYSTEM	
METALCRAFT, INC	
"Sea-fire" FM200 pre-engineered fire extinguishing systems Models FG25A/FG25M - FG240A/FG240M, FD150A/FD150M - FD1500A/FD1500M inclusive.	
Maximum protected volume is 25 through 240 cu. ft. for FG series(0.7 through 6.8 cu. m), and 150 through 1500 cu. ft. for FD series (4.2 through 42.5 cu. m). Systems with automatic or automatic/manual actuation approved for installation in unmanned engine compartments on recreational boats and certain other uninspected vessels. Subject to OCMI review, series with manual back-up actuator may be installed on inspected vessels if equipped with the additional system manufacturer supplied accessories as required by applicable subchapter.	
Identifying Data: FM Approved Agreement dated March 23, 2000, Report Job Identification 3007407, dated March 18, 2000, and Metalcraft Instruction Manual Part No. 123-048, Issue 3/00.	
Follow-up program: FM	
Electrical installation to be accordance with the applicable sections of 46 CFR, Subchapter T or K.	
This certificate extends and renews approval no. 162.029/237/0 dated 14 September 2001.	
*** END ***	
THIS IS TO CERTIFY THAT the above named manufacturer has submitted to the undersigned satisfactory evidence that the item specified herein complies with the applicable laws and regulations as outlined on the reverse side of this Certificate, and approval is hereby given. This approval shall be in effect until the expiration date hereon unless sooner canceled or suspended by proper authority.	
	GIVEN UNDER MY HAND THIS 14 <sup>th</sup> DAY OF SEPTEMBER 2005, AT WASHINGTON D.C.  J. G. LANTZ Chief, Lifesaving and Fire Safety Standards Division BY DIRECTION OF THE COMMANDANT

DEPT. OF HOMELAND SECURITY, USCG, CGHQ-10030  
(REV. 3-03)



# An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications

---

This page intentionally left blank.



# An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications

## APPENDIX C. BLACKSTONE OIL REPORT



### OIL REPORT

LAB NUMBER: D52345      UNIT ID: 1  
 REPORT DATE: 9/17/2008      CLIENT ID: 32632  
 CODE: 1/392      PAYMENT: CC: MC

<b>UNIT</b>	MAKE/MODEL: Duro Power 7500, 9 HP	OIL TYPE & GRADE: 15W/40
	FUEL TYPE: Diesel	OIL USE INTERVAL: Hours
	ADDITIONAL INFO:	

<b>CLIENT</b>	ERIC FORSELL	PHONE: (410) 737-8677 Ext: 218
	HUGHES ASSOCIATES	FAX:
	3610 COMMERCE DR SUITE 817	ALT PHONE:
	BALTIMORE, MA 21227	EMAIL: erikf@haifire.com

**COMMENTS** ERIC: Nothing unusual showed up in this sample. Universal averages show typical wear levels from this type of generator after about 150 hours use on the oil. We don't know how long this oil was run, but if it was longer, that could account for the higher iron that we found. All other wear read well within the normal range, so we doubt iron is a problem and we think the engine is doing well mechanically. The TAN was 3.3, which is fairly acidic, but may be normal depending on what this oil started out as. The TOX was less then 200 PPM. No fuel dilution or water found.

<b>ELEMENTS IN PARTS PER MILLION</b>	MI/HR on Oil		<b>UNIT / LOCATION AVERAGES</b>					<b>UNIVERSAL AVERAGES</b>
	MI/HR on Unit							
	Sample Date	09/10/08						
	Make Up Oil Added							
ALUMINUM	3	3						3
CHROMIUM	1	1						1
IRON	23	23						19
COPPER	2	2						5
LEAD	2	2						4
TIN	1	1						1
MOLYBDENUM	2	2						2
NICKEL	0	0						0
MANGANESE	0	0						1
SILVER	0	0						1
TITANIUM	0	0						0
POTASSIUM	1	1						2
BORON	2	2						62
SILICON	10	10						7
SODIUM	6	6						7
CALCIUM	1817	1817						2225
MAGNESIUM	631	631						546
PHOSPHORUS	934	934						917
ZINC	1252	1252						1236
BARIUM	1	1						1

<b>PROPERTIES</b>	Values Should Be*					
SUS Viscosity @ 210°F	71.7	69-82				
cSt Viscosity @ 100°C	13.40	12.7-16.3				
Flashpoint in °F	415	>405				
Fuel %	<0.5	<2.0				
Antifreeze %	-	0				
Water %	0.0	0.0				
Insolubles %	0.3	<0.7				
TBN						
TAN	3.3					
ISO Code						

\* THIS COLUMN APPLIES ONLY TO THE CURRENT SAMPLE

416 E. PETTIT AVE. FORT WAYNE, IN 46806 (260) 744-2380 www.blackstone-labs.com  
 ©COPYRIGHT BLACKSTONE LABORATORIES 2007 LIABILITY LIMITED TO COST OF ANALYSIS



# An Evaluation of Pre-Engineered Fire Extinguishing Systems for Machinery Space Applications

---

This page intentionally left blank.

