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Halon 1301 Replacement Total Flooding Fire Testing, Intermediate Scale

Ronald S. Sheinson,[a] Harold G. Eaton,[b] Bruce H. Black,[c] Roger Brown, Howard Burchell, Alexander Maranghides,[c] Clark Mitchell,[c] Glen Salmon,[d] and Walter D. Smith.

NAVAL RESEARCH LABORATORY
Navy Technology Center for Safety and Survivability
Code 6180, Washington, DC 20375-5342 USA
(202) 404-8101, Fax (202) 767-1716

INTRODUCTION

Due to recent national and international legislation, the production of the brominated halocarbons that the U.S. Navy uses for fire fighting applications was halted in the developed countries on 1 January, 1994 [1]. The intermediate scale tests described below conducted for the Naval Sea Systems Command [2] are part of the Naval Research Laboratory's (NRL) Halon 1301 Total Flooding Extinguishment Replacement Program [3].

The purposes of these intermediate scale tests are to determine the effects of replacement agent design concentration and discharge time on fire out time and decomposition product formation. Test results will then provide the technology base for the design of the test matrix for NRL's full scale halon replacement tests. These full scale tests will be conducted aboard the Navy's full scale fire research ship, the Ex-USS SHADWELL.

The agents tested were CF_3H manufactured by E.I. DuPont de Nemours and Co. as FE-13, C_3F_7H manufactured by Great Lakes Chemical Corporation as FM-200, and C_4F_{10} manufactured by 3M as CEA-410.

TEST FACILITY

Tests were conducted at NRL's Chesapeake Bay Detachment (CBD) facility in a 56 m^3 (2000 ft^3), 4.0*3.4*4.3 m (13*11*14 ft) test compartment (Figure 1). The discharge system was made of 3.2 and 3.8 cm. (1.25 and 1.5 inches) internal diameter steel piping and had total internal volume of approximately 3250 cm^3 (200 in^3) from the bottle valve to the nozzle. The agent tank was a standard 125 lbs. bottle used in Navy halon systems. The tank was used in a partially inverted position with no dip tube. This tank configuration compared to the upright tank with dip tube yields more reproducible agent discharges due to the complete evacuation of liquid agent from the tank. The discharge nozzles used were the standard Navy 4 hole

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Supported by the U.S. Naval Sea Systems Command

[a] Author to whom correspondence should be addressed.

[b] Currently at Office of Naval Research.

[c] GEO-CENTERS, Inc. Fort Washington, MD.

[d] Hughes Associates, Inc. Columbia, MD.

(horizontal cross) currently employed in Halon 1301 shipboard discharge systems. Nozzle discharge orifice diameter was varied from 0.56 to 1.43 cm (7/32 to 9/16 in). The nozzle was located off-center 1 m (3.3 ft) from the nearest wall, 0.9 m (3 ft) below the ceiling. The baseline fire was a 0.23 m^2 (2.5 ft^2) heptane pool. A heptane spray was used for reignition attempts. Spray reignition is easier than pool reignition. The fire pan was located 50 cm (20 in) from the closest wall, and 20 cm (8 in) above the floor. The test compartment was equipped with overpressure relief vents on the roof, and a standard size door on the front wall. Opening both the vents and the door greatly enhanced air flow through the compartment.

INSTRUMENTATION AND DATA ANALYSIS

The compartment and discharge system instrumentation and the equipment used for data analysis are listed below:

- Gas temperatures were measured by thermocouples (TCs) at four heights.
- Ten kerosine lanterns were mounted in the compartment as agent concentration telltales.
- TCs were used to monitor the fire pan, the reignition spray, and each telltale.
- Compartment pressure was measured.
- Agent concentrations were measured both continuously and discreetly over time. Continuous measurements were performed by drawing gas samples from four different heights in the chamber to four IR analyzers. Grab samples were used for discrete concentration determinations at the top of the chamber and at fire level. They were remotely activated during and after discharge. Post test analysis of the agent grab samples by Gas Chromatography yielded agent concentrations.
- Continuous monitoring of CO, and CO_2 and O_2 was performed on the same sample lines as for the continuous agent sampling.
- Acid concentrations were determined by drawing a volume of gas through a sodium bicarbonate coated teflon tube, then rinsing the tube with distilled water, and analyzing the solution by Ion Chromatography [4].
- A Radiometer and Calorimeter, both water cooled, were used to monitor heat release rates.
- Four video cameras (3 visible and one IR) were used. One visible and the IR camera were focused on the fire, and another visible camera was focused on the discharge nozzle. Lights were used to illuminate the discharge nozzle. The fourth visible video camera was located external to the test compartment and aimed at the overpressure vents on the roof.
- Temperatures were measured in the piping and at the nozzle.
- Pressures were measured in the piping, at the nozzle, and for some tests, in the agent bottle.

DATA ACQUISITION AND STORAGE

Two computers were used, a MASSCOMP minicomputer and an IBM 286 PC with Lab Notebook software package. The MASSCOMP was used for the continuous sampling analyzers and the thermocouples data acquisition (at 1 Hz) and storage. The PC was used for faster (10 Hz) discharge system temperature and pressure data acquisition and storage. A CHRONTOL XT microprocessor based timing device was used for grab sample activation.

TEST PROCEDURE

The compartment instrumentation, the MASSCOMP, PC and CHRONTROL devices were prepared, the fuel loaded, and the compartment evacuated. The fire was remotely ignited; the compartment vents and door were open to provide ventilation. Forty-five seconds after ignition the vents and door were shut. The fire burned for another 15 seconds, and the agent was then discharged. End of liquid run off at the nozzle (when visible) and fire out where recorded. Reignition attempts where performed every minute for up to 10 minutes if spray ignition did not occur. The IR camera was used to monitor reignition events. The compartment was then ventilated for 30 minutes. The grab samples were retrieved and subsequently analyzed.

RESULTS AND DISCUSSION

N-heptane pool fires over a range of sizes have been previously employed in this facility. The selected size of 0.23 m^2 baseline pool fire proved more an extinction challenge than both smaller and larger fires. The spray fire fuel flowrate (pressurized with N_2 to yield a flow rate of 1 liter per minute) was comparable to the burning rate of the 0.23 m^2 pool. The spray fire is easier to extinguish than the pool fire, but also easier to reignite.

The NRL Cup Burner values for the replacement agents tested and Halon 1301 are found in Table 1.1.0 [5].

Table 1.1.0
NRL Cup Burner Values
n-Heptane

Agent	Concentration % vol.
Halon 1301	3.1
FE-13	12
FM-200	6.6
CEA-410	5.2

For all halon replacement agents tested, a higher design concentration for similar discharge times yielded shorter fire out (extinguishment) times (Tables 1.1.1 to 1.1.3). This behavior also holds for Halon 1301 (Table 1.1.4). Higher design concentrations also generated lower levels of hydrogen fluoride (HF) (Tables 1.2.1 to 1.2.3). For a 5 second FE-13 discharge time, an increase from 20 % to 52 % above Cup Burner results in a decrease in fire out from 13 to 6 seconds, and a reduction of the maximum HF value recorded from 8300 parts-per-million by volume (ppm) to 3400 ppm. Data for FE-13, FM-200, and CEA-410 can be seen in Tables 1.1.1 to 1.2.2. The shorter fire out is due to the agent reaching the extinguishing concentration sooner. The lower HF generation is due to the shorter exposure of agent below the extinguishing concentration to the fire.

Table 1.1.1
FE-13
Effect of Design Concentration on Fire Out Time

Design Concentration %	Discharge Time (sec)	Fire Out Time (sec)
11.5 (CB - 4%)(N2)	7.5	40
12.7 (CB + 6%)(O2)	8.7	30
14.4 (CB +20%)(L2)	5.0	13
15.3 (CB + 28%)(K2)	5.6	10
18.2 (CB + 52%)(D2)	5.0	6
20.9 (CB + 74%)(A2)	5.9	4

Table 1.1.2
FM-200
Effect of Design Concentration on Fire Out Time

Design Concentration %	Discharge Time (sec)	Fire Out Time (sec)
8 (CB + 21%)(S)	5.1	10
9.8 (CB + 48%)(W)	5.5	7
7 (CB + 6%)(H2)	10.7	26
7.4 (CB + 12%)(P)	12.3	17
10.8 (CB + 64%)(L2)	10.5	12

Table 1.1.3
CEA-410
Effect of Design Concentration on Fire Out Time

Design Concentration %	Discharge Time (sec)	Fire Out Time (sec)
5.7 (CB + %)(N)	3.5	24
6.4 (CB + %)(P)	5.2	14
6.8 (CB + %)(R)	5.0	13
7.3 (CB + %)(S)	5.3	7

Table 1.1.4
HALON 1301
Effect of Design Concentration on Fire Out Time

Design Concentration %	Discharge Time (sec) (High Ullage)	Fire Out Time (sec)
3.7 (CB + 19%)(T2)	2.3	10
4.4 (CB + 42%)(Y2)	3.3	10
4.7 (CB + 52%)(Z2)	3.1	8
4.8 (CB + 55%)(A3)	2.2	7

Table 1.2.1
FE-13
Effect of Design Concentration on HF Production
(for Fire Out > = Discharge Time)

Design Concentration %	Discharge Time (sec)	HF_{max} (ppmv)
11.5 (CB - 4%)(N2)	7.5	34000
14.4 (CB + 20 %)(L2)	5.0	8300
15.3 (CB + 28 %)(K2)	5.6	4700
18.2 (CB + 52%)(D2)	5.0	3400
20.9 (CB + 74%)(A2)	5.9 (Fire Out Time: 4 sec.)	3000
18.1 (CB + 51%)(I2)	17.3	9700
19.7 (CB + 64%)(B2)	19.1	7500

Table 1.2.2
FM-200
Effect of Design Concentration on HF Production
(Discharge Times: ~5 seconds)

Design Concentration %	Fire Out Time (sec)	HF_{max} (ppmv)
8 (CB + 21%)(S)	10	8000
8.2 (CB + 24%)(Z)	12	6300
8.3 (CB + 26%)(A2)	11	5100
9.8 (CB + 48%)(W)	7	2500

Acid formation was found to be very sensitive to lower agent design concentrations (Cup Burner to Cup Burner + 30%). Variation in high agent design concentrations produced relatively small changes in maximum HF observed values, while reaching a plateau at very high concentrations (Cup Burner + 75%).

Under similar fire and discharge conditions the replacement agents tested produced much higher acid concentrations than Halon 1301. Table 1.3 lists the fire out times and HF maximum values recorded for similar fire scenarios, concentrations and discharge times for Halon 1301, FE-13, FM-200, and CEA-410.

Table 1.3
Fire Out Time and Acid Generation Comparison between Halon 1301
and FE-13, FM-200, and CEA-410

Agent	Concentration %	Discharge Time (sec)	Fire Out (sec)	HFmax (ppmv)
CEA 410	7.6 (CB + 46%)	5.7	6	2900
FE-13	18.2 (CB + 52%)	5.0	6	3400
FM-200	9.8 (CB + 48%)	5.5	7	2500
Halon 1301	4.7 (CB + 52%)	3.1 (high ullage)	8	600

For similar design concentrations longer discharge times produced longer fire out times (Tables 2.1.1 and 2.1.2) and higher HF values (Tables 2.2.1 and 2.2.2). Longer fire out times are due to the longer time it took the agent to reach the extinguishing concentration. This longer exposure of agent to the fire at below extinguishing concentrations is responsible for the higher measured HF values.

Table 2.1.1
FE-13 Effect of Discharge Time on Fire Out Time
(for similar Design Concentrations)

Design Concentration %	Discharge Time (sec)	Fire Out Time (sec)
12.9 (CB + 8%)(M2)	4.4	16
12.7 (CB + 6%)(O2)	8.7	30
14.4 (CB + 20%)(L2)	5.0	13
14.5 (CB + 21%)(U)	5.7	16
16.7 (CB + 39%)(X)	3.9	8
16.7 (CB + 39%)(V)	5.2	18

Table 2.1.2
FM-200 Effect of Discharge Time on Fire Out Time

Discharge Time (sec)	Design Concentration %	Fire Out Time (sec)
5.1(A2)	8.3 (CB + 26%)	11
15.7(B2)	8.6 (CB + 30%)	19
5.7(U)	9.7 (CB + 47%)	6
17.5(V)	9.7 (CB + 47%)	17

Table 2.2.1
FE-13 Effect of Discharge Time on HF Production
(Design Concentration: 18.1-18.2 % (Cup Burner + 51-52%))

Discharge Time (sec)	Fire Out (sec)	HF_{max} (ppmv)
5.0(D2)	6	3400
17.3(I2)	19	9700
43.8(E2)	32	> =9400 (Missing Sample)

Table 2.2.2
FM-200 Effect of Discharge Time and Design Concentration on HF Production
(Fire Out > = Discharge Time)

Discharge Time (sec)	Design Concentration %	HF_{max} (ppmv)
10.5(L2)	10.8 (CB + 64%)	2800
5.5(W)	9.8 (CB + 48%)	2500
19.2(X)	9.7 (CB + 47%)	6000
5.1(A2)	8.3 (CB + 26%)	5100
15.7(B2)	8.6 (CB + 30%)	12000

Agent concentration-time profile variations in the compartment can result in significant variations in fire out time and HF produced for apparently similar test conditions. Figure 2 shows the effects of a slight variation in the concentration-time profile on fire out time for two FM-200 tests. Both tests were performed at a design concentration of 8.2 %, with discharge times of 5 seconds. The small measured concentration variations during and shortly after discharge (0.9 % difference at 4 seconds) resulted in fire out times of 6 and 12 seconds. Such variations in agent concentration can result from variations in factors such as wind loading or temperature differences between the compartment and outdoors.

For similar design concentrations and discharge times a larger fire (1.1 m^2 compared to 0.23 m^2) resulted in accelerated fire extinguishment. The higher compartment temperature from the larger fire resulted in lower air density in the compartment. This produced a higher effective agent concentration (constant agent weight). Oxygen depletion was also observed since the compartment was not vented and the fire was ventilation controlled, facilitating its suppression [6]. These two effects were responsible for the more rapid fire out times associated with the larger fires. Despite the faster fire out times, the larger fire produced 3 to 5 times more HF. These higher values are due to the increased flame surface area (and increased quantity of reactive combustion species) of the larger fire. The effects of oxygen concentration and compartment temperature on fire out and HF is shown in Tables 3.1 to 3.3.

Table 3.1
FE-13 Effect of Fire Size on Fire Out and HF Production
(Design Concentration: 18.2% (Cup Burner + 52%))

Fire Size (ft^2)	Discharge Time (sec)	$T_{enclosure}$ (C)	Agent Equil. Conc. (%)	Fire Out Time (sec)	HF_{max} (ppmv)
$2.5^{(D2)}$	5	30(bottom)- 50(top)	18.4	6	3400
$12^{(J2)}$	5	170(bottom)- 300(top)	23.7	3	11000

Table 3.2
FM-200 Effect of Fire Size on HF Production
(Design Concentration: 8.3% (Cup Burner + 26%))

Fire Size (ft^2)	Discharge Time (sec)	Fire Out Time (sec)	HF_{max} (ppmv)
$2.5^{(A2)}$	5.1	11	5100
$12^{(G2)}$	4.3	3	26000

Table 3.3
HALON 1301 Fire Size Effects
Design Concentration 4.7-4.8% (High Ullage)

Fire Size (ft^2)	Discharge Time (sec)	Agent Conc. (%)	O_2 Conc. (%)	Fire Out (sec)	HF (ppmv)
$2.5^{(Z2)}$	3.1	4.5	>18	8	600 @ 5 sec
$12^{(H3)}$	2.4	6.2	<15	3	1700 @ 5 sec 7200 @ 10 sec

CONCLUSIONS

Tests conducted on the three halon replacements (FE-13, FM-200, and CEA-410) revealed that although design concentrations 20 % above cup burner can suppress large turbulent pool fires. However such low design concentrations maybe undesirable because of the increased time required to effect extinguishment and the extensive generation of decomposition products. The data also show that longer agent discharge times yield higher decomposition products. Increasing fire size was found to reduce fire out times for a ventilation controlled, high temperature environment. The already high acids associated with large flame surface areas will increase if the compartment is well ventilated, has lower temperatures, and the fire is not oxygen limited.

For the design of an effective fire suppression system the fire threat and the environment the system will operate in should be clearly understood. System design concentration and agent discharge time with the desired safety margins should then be selected to ensure the desired fire out time, acceptable quantities of decomposition products, and adequate reignition protection.

REFERENCES

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FIRE TEST CHAMBER

TOP VIEW

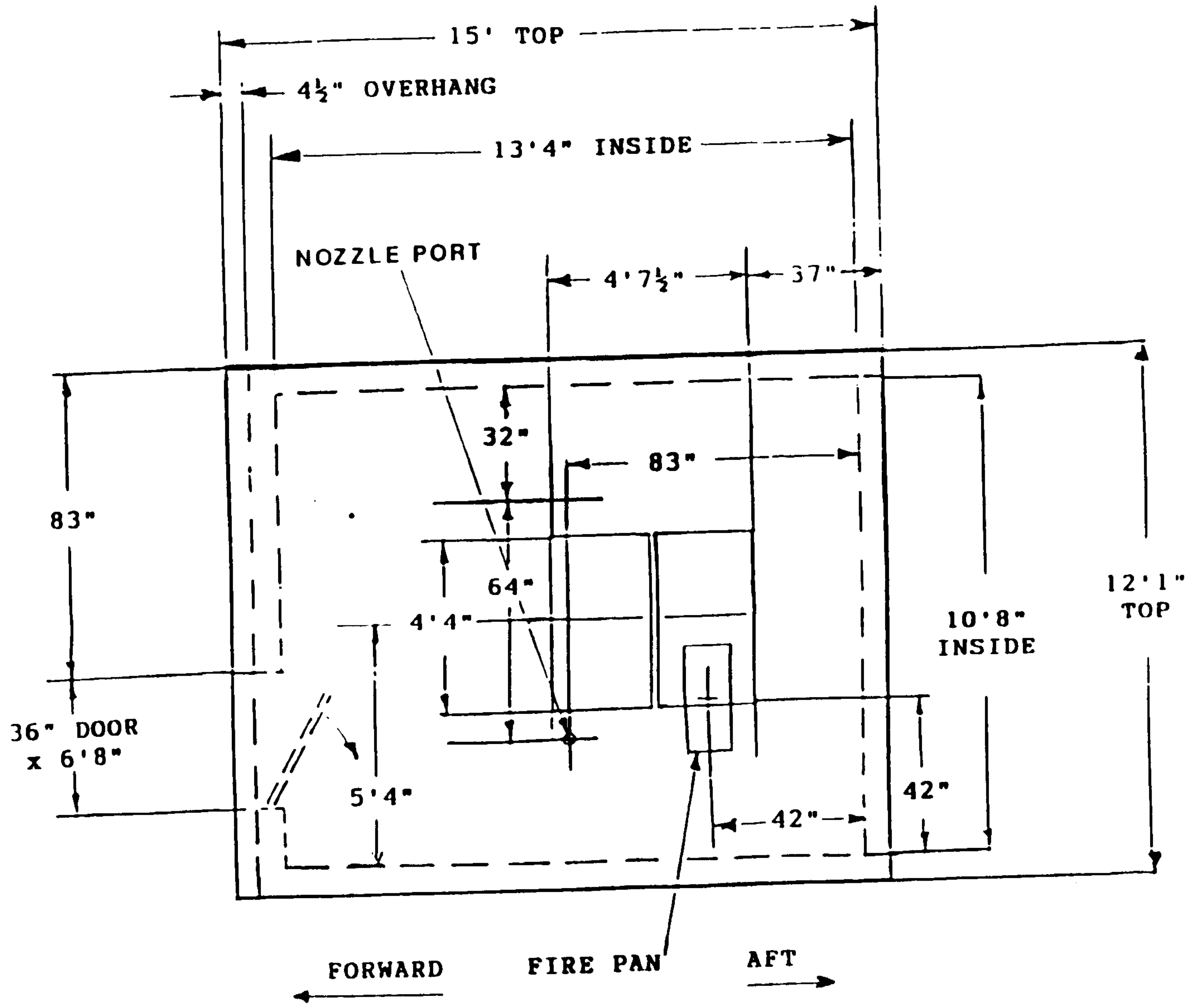
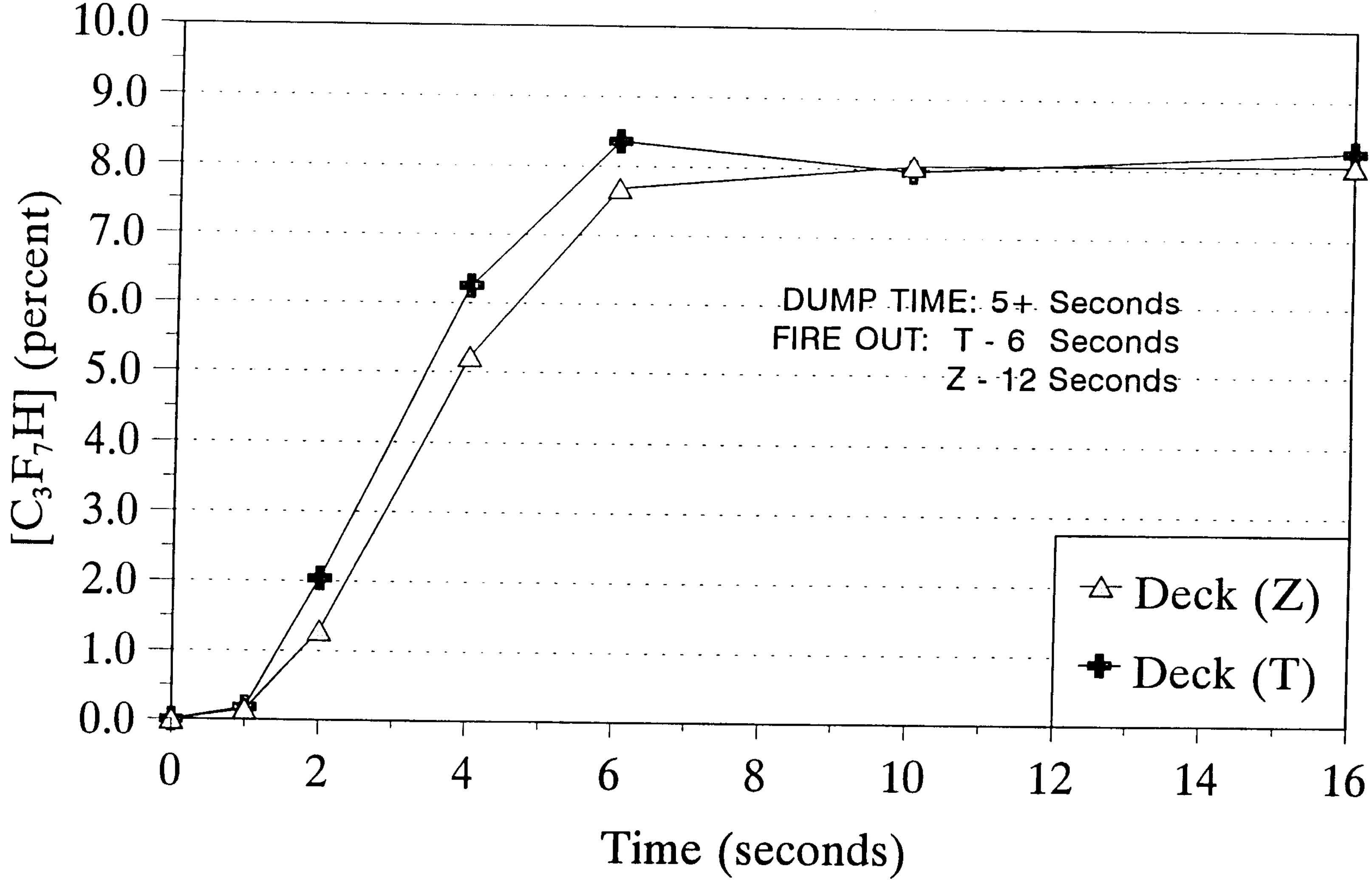


Figure 1

FM-200 (C_3F_7H) 8.2%

2.5 ft^2 n-Heptane Pan Fire

3/8" Navy Nozzle



Comparison: Tests T & Z

Figure 2