

## **FIRE SUPPRESSION SCALING ISSUES IN DIFFERENT COMPARTMENT SIZES**

Scott Ayers<sup>a</sup>, Ronald S. Sheinson, Alexander Maranghides<sup>a</sup>, Derrick Morse and Dariusz Szwarc  
Navy Technology Center for Safety and Survivability  
Combustion Dynamics Section, Code 6185  
Naval Research Laboratory  
Washington, DC 20375-5342 USA  
Tel: (1-202) 404-8101; Fax: (1-202) 767-1716  
Email: [sheinson@code6185.nrl.navy.mil](mailto:sheinson@code6185.nrl.navy.mil)

### **INTRODUCTION**

Fire suppression is a most unique field of study, employing the disciplines of chemistry, reaction kinetics, physics, fluid mechanics, heat transfer, and thermodynamics among others. In the case of compartment fire suppression with a gaseous halon replacement, the task of understanding suppression is particularly challenging yet extremely important. Improper suppression can lead to extensive structural and content damage, longer burning, and possible deflagrations. The Navy Technology Center for Safety and Survivability (NTCSS) at the Naval Research Laboratory (NRL) is studying total flooding compartment fire suppression. The technical goal is to gain a better understanding of fire suppression. The programmatic goal is to develop design guidance for optimum total flooding clean agent suppression systems. A number of agents have been evaluated in several compartment sizes ranging from 28 m<sup>3</sup> to 840 m<sup>3</sup>. The Navy's concerns in compartment fire suppressions are limiting the damage and recovering the space. Metrics include the time the fire burns and the dangers of the compartment atmosphere post-fire, including the hydrogen fluoride acid gas (HF) levels. Based on NRL's evaluations and guidance, the Navy has chosen HFC-227ea (1,1,1,2,3,3,3-heptafluoropropane) for future ship usage; these systems will be used in new ship classes for clean agent replacement of halon systems as currently used by the US Navy.

Quick fire extinguishment and reduced HF production are the keys to fire suppression system success. Delivering the agent in sufficient quantities to all areas of the compartment is a must. The fire extinguishment time, HF production, and minimization of obstruction-induced suppressant inhomogeneities are critical in the adequacy of the suppression. Careful experimentation has led to agent design concentrations that keep these critical quantities low in specific sized compartments. However as the compartment size increases, the agent design concentrations found to be adequate in smaller compartments may no longer suffice.

Early experiments in a 56 m<sup>3</sup> compartment led to down-selecting several candidate gaseous clean agent halon replacements, among them HFC-227ea and HFC-23 [1]. Further testing led to recommendations on design concentrations and discharge times. These tests documented the increase in extinguishment time (Figure 1) and HF production (Figure 2), with decreased agent design concentration. A more relevant metric is the actual agent concentration measured near the fire. Lower concentrations near the fire produced longer burning fires and more HF production. The 56 m<sup>3</sup> compartment experiments quantified the effects of agent concentration

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<sup>a</sup> GEO-CENTERS, Inc., Lanham, MD, USA

on suppression results. Decreasing the agent concentrations toward but still higher than the cup burner extinction value led to significantly increased extinguishment times and HF productions.

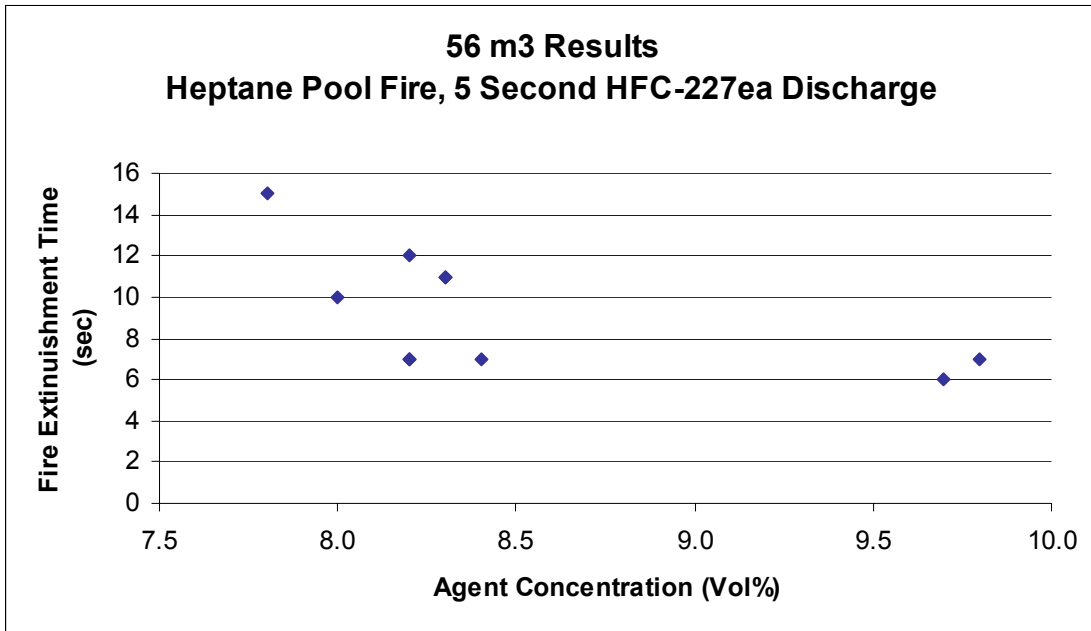


Figure 1. 56 m<sup>3</sup> time to extinguishment results

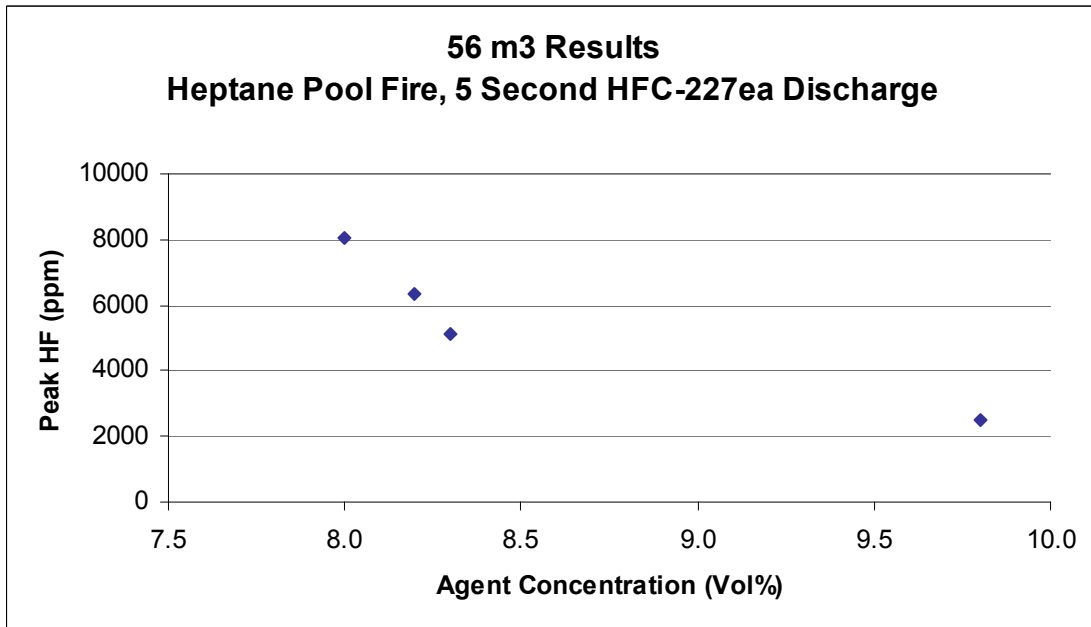


Figure 2. 56 m<sup>3</sup> HF production results

The 56 m<sup>3</sup> compartment was very open with very little obstruction. The gas phase concentration inhomogeneities produced by obstacles were not studied. Based on results from these experiments, a real-scale test series aboard the *Ex-USS SHADWELL* was conducted [2].

This test series objective was to select the replacement agent, quantify the agent actions under real-world Navy ship conditions, and validate system design guidance. The compartment size tested was significantly larger at 840 m<sup>3</sup>. Based on this test series and the previous experiments, HFC-227ea was chosen as the Navy's clean agent Halon replacement. While this compartment contained obstacles, the nature of these obstacles simulated large engine components, allowing for large open spaces. Therefore the results could not be extrapolated to more cluttered compartments such as a flammable liquid storage room (FLSR).

### **EVALUATING FIRE EXTINCTION FOR FLSR CONFIGURATIONS**

Following the work on the *Ex-USS SHADWELL*, a multi-phase test series was established to provide design guidance for HFC-227ea fire suppression systems in FLSRs. The test series evaluated varying the compartment size from 28 m<sup>3</sup> [3] to 126 m<sup>3</sup> [4]. Initial results for a 297 m<sup>3</sup> are reported here. See Table 1 for each compartment's dimensions. Unlike in the open 56 m<sup>3</sup> compartment or the 840 m<sup>3</sup> compartment with open spaces, FLSRs are cluttered with containers, drums, and other obstructions that greatly hinder agent spread the compartment (Figure 3). The fire threat includes volatile, difficult to extinguish flammable liquids including methanol. These tests challenge the agent to suppress highly obstructed fires in cluttered spaces.



**Figure 3. Example of the clutter in a FLSR test compartment**

**Table 1**

**Compartment Dimensions**

Volume (m <sup>3</sup> )	Length [Forward-Aft] (m)	Width [Port-Starboard] (m)	Height (m)
28.0	3.05	3.05	3.05
126	10.7	3.86	3.05
297	10.7	6.10	4.57

As seen in Table 2, for similar design concentrations, an increase in fire extinguishment time and HF production is observed in going from the 28 m<sup>3</sup> compartment to the 126 m<sup>3</sup> compartment, even with a modest increase in design concentration.

**Table 2**

**Suppression Test Results**

	28 m <sup>3</sup>	126 m <sup>3</sup>
Design Concentration (Vol %)	11.1	11.6
Cascading Fire Extinguishment (sec)	8	13
Pan Fire Extinguishment (sec)*	10	8
Peak HF (ppm)	2500	4000
Average HF after 15 minutes (ppm)	40	300

\*The slight decrease in pan extinguishment can be attributed to the increased design concentration

The data in Table 2 leads one to believe that with the same design concentration in the 297 m<sup>3</sup> compartment, longer fire extinguishment times and greater HF levels would occur. In reality, the first test conducted in the 297 m<sup>3</sup> compartment had a short fire extinguishment time (cascading: 4 seconds, pan: 9 seconds) and lower HF production (1400 ppm peak) [5]. These findings are attributed to the main fire being in a region of very high agent concentration. Preliminary results from a subsequent fire extinguishment test (design concentration 11.4%) with the fire location changed to a location of relatively lower agent concentration, did show an expected longer fire extinguishment time of 17 seconds for the cascading fire and 10 seconds for the pan fire, with continued flashing at the ignition source and HF levels up to 14,000 ppm. The inability to predict fire extinguishment times, HF production, and large temporal-spatial agent inhomogeneities demonstrates the need to test design concentrations in varying sized and configured compartments.

**INHOMOGENEITIES**

Comparison of the agent inhomogeneity in the compartment is needed to better understand the effect of the suppression. As the compartment becomes larger, the agent inhomogeneity becomes more significant, as shown by test results in Figure 4. The agent concentration inhomogeneity is a factor in the evaluation of suppression test results. Shipboard halon system discharges aboard the USS CHANCELLORSVILLE produced tremendous agent variation, a concentration range of a factor of almost five, in the high ceiling engine room compartment [6].

Suppression tests with a very carefully designed discharge system aboard the *ex-USS SHADWELL* 840 m<sup>3</sup> compartment still showed inhomogeneities of +/- 20 %.

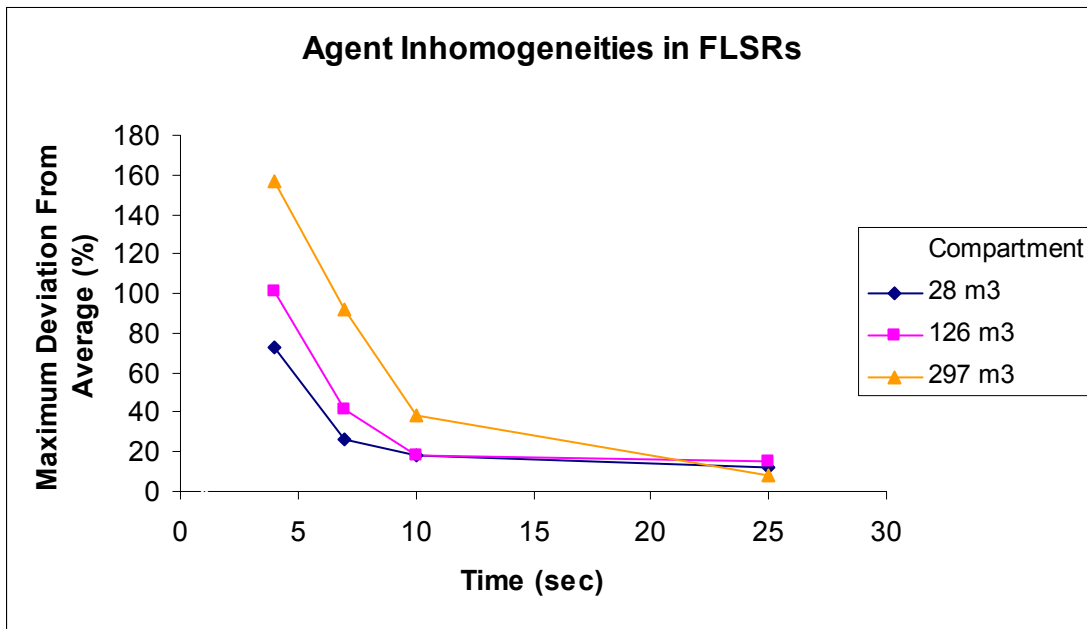


Figure 4. Agent inhomogeneities in the three FLSRs (Discharge initiation at t=0)

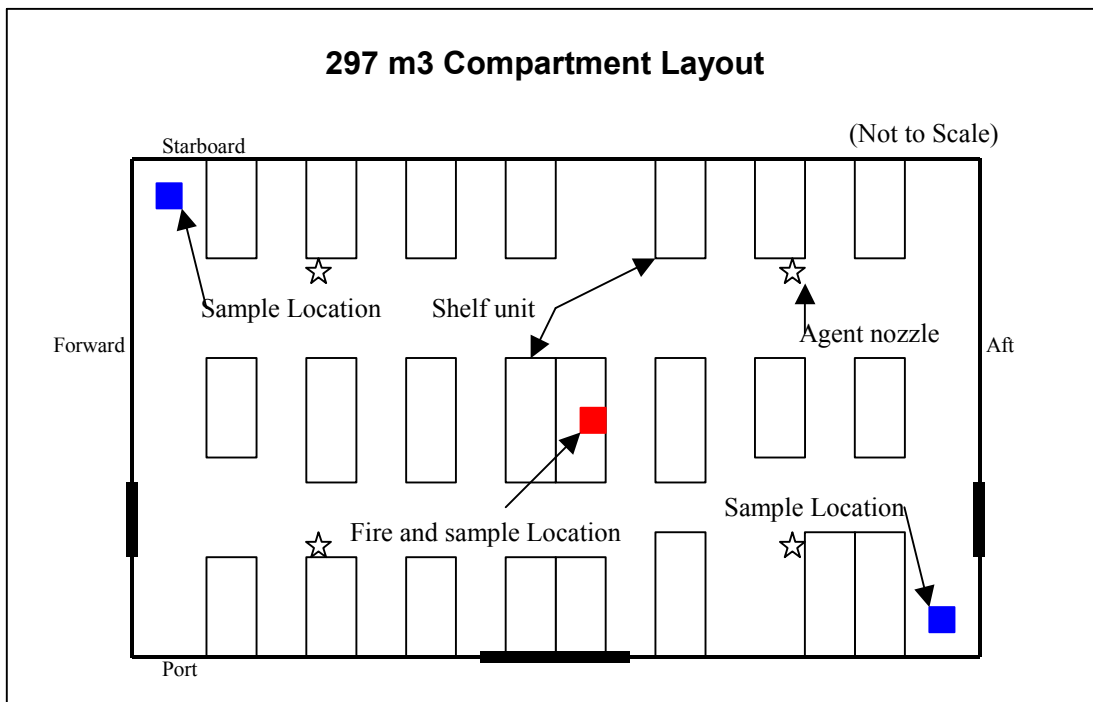


Figure 5. 297 m<sup>3</sup> FLSR Compartment Layout

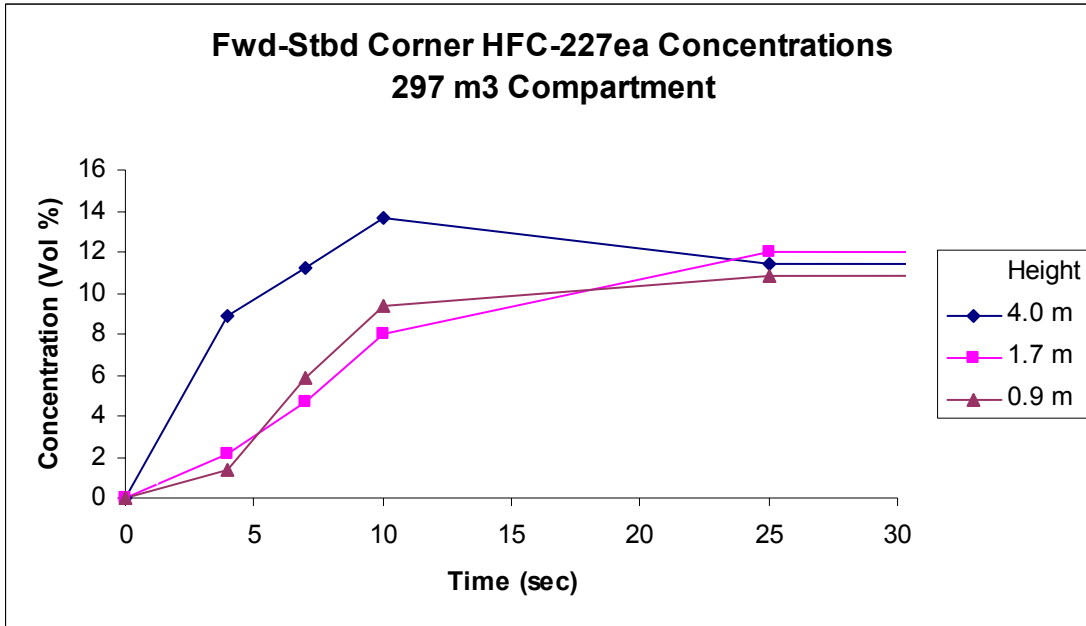


Figure 6. HFC-227ea concentrations at three heights in the forward-starboard corner

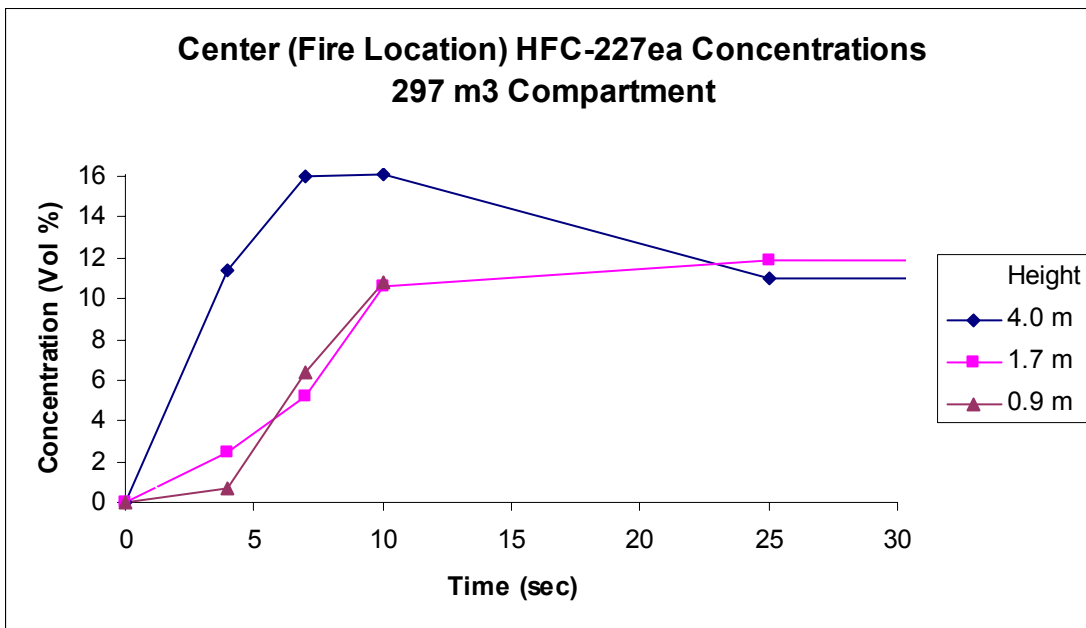


Figure 7. HFC-227ea concentrations at three heights in the center (fire location)

The layout for fire suppression testing in the 297 m<sup>3</sup> compartment is shown in Figure 5. As seen in Figure 6 – Figure 8, the agent concentration in this compartment varies significantly with location, height and time. In two of the three sampling locations, the 4.0 m height concentrations are much higher than the 1.7 m or 0.9 m concentrations. The third location shows an agent concentration at 4.0 m that is similar to the lower two concentrations due to the obstructions high at nozzle level created by obstacles at that site.

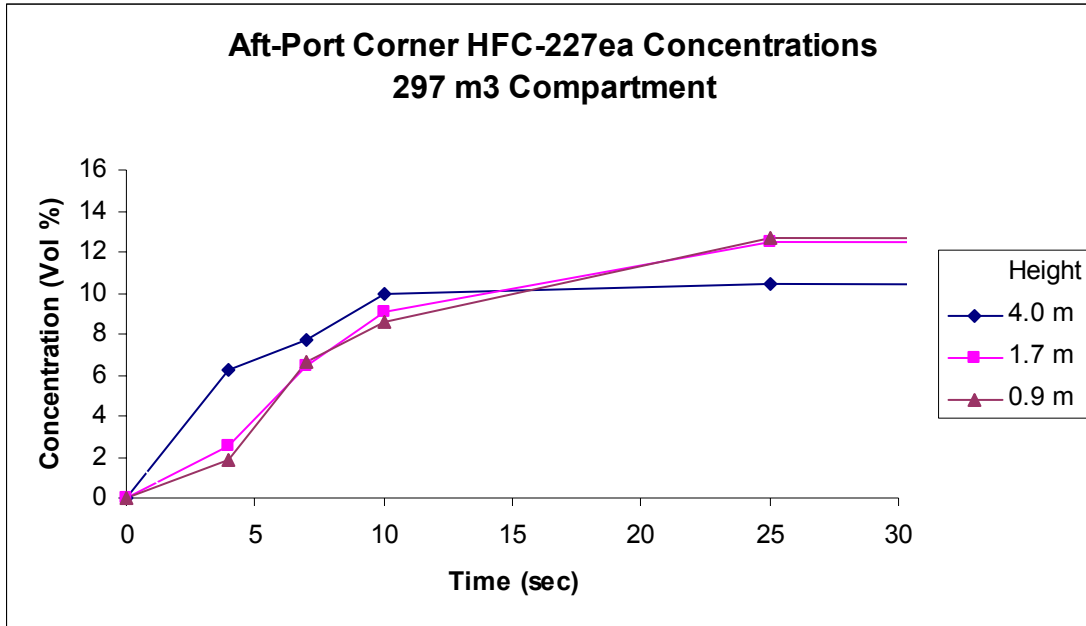


Figure 8. HFC-227ea concentrations at three heights in the aft-port corner

## DISCUSSION

Figure 4 shows a tremendous increase in the inhomogeneities from 126 m<sup>3</sup> to 297 m<sup>3</sup>. Figure 6 and Figure 7 show significant differences in concentration with height. Since the agent is introduced high and horizontally, the inhomogeneities are exaggerated with increased height as the agent mixes. The lower regions and those that are highly obstructed require more time to reach a steady level and therefore experience more time in low levels of concentration. An increase in height leads to larger inhomogeneities in the vertical direction. Figure 8 shows lower agent concentrations relative to those shown in Figure 6 and Figure 7; the fire was moved to this location for the second suppression in the 297 m<sup>3</sup> compartment as a more challenging agent performance test.

If a fire exists in a region of lower agent concentration, it will take longer to extinguish it and it will produce more HF. Results in the 56 m<sup>3</sup> compartment quantified this. There exist several possible solutions of increasing the agent concentration of the relatively low regions in larger compartments. First the agent could be delivered to the compartment faster, thereby increasing the convective mixing. This solution would require larger piping networks. However, past some point larger pipe volume will actually slow down the flow and higher pressures would be needed. Since the US Navy uses 4.1 MPa (600 psig) nitrogen pressurant gas, higher pressures would be non-standard and difficult to implement.

A second potential solution is increasing the number of agent discharge nozzles to discharge the agent into more areas of the compartment. The increase in nozzles would however, reduce the discharge momentum at each nozzle. With less momentum, the agent would not mix as well and would have reduced ability to penetrate obstructions. In the 840 m<sup>3</sup> testing, a two-tiered, nine nozzle system was evaluated. This system, with nozzles located around the large

obstructions and reduced vertical distance required to be covered by each nozzle, still had prolonged inhomogeneities of +/- 20% for long periods of time. Another approach would be to utilize nozzles with more than just horizontal discharge direction. This is a difficulty in Navy ships with occupied compartments, as downward momentum during inadvertent discharge could expose personnel to injury from the direct agent discharge stream. Limited additional nozzles below the ceiling, but well above head height, may be possible for some compartment configurations.

An approach to the inhomogeneity concern would be to increase the agent concentration; the absolute concentration of the relatively low regions would be increased to acceptable levels. This solution would require more agent, but may be more feasible than other potential solutions.

With a completion of the 297 m<sup>3</sup> HFC-227ea testing expected by the end of summer 2002, it is expected that general design guidance for HFC-227ea in compartments of volumes up to 297 m<sup>3</sup> will be established. An additional test series will be initiated next year to determine the parameters of using the patented NRL Water Spray Cooling System (WSCS) [7] in conjunction with HFC-227ea for large obstructed FLSRs. Earlier work has demonstrated that WSCS will be required in such spaces to achieve acceptable cooling, HF mitigation and enhanced safe re-entry for these volatile, difficult to extinguish, flammable liquid fire threat scenarios. The NRL WSCS with HFC-227ea approach has already been implemented by the US Army to replace over 60 halon 1301 systems in their less obstructed, less volatile fuel watercraft engine rooms.

## **CONCLUSION**

Based on testing several sized compartments by NRL, it has been shown that compartment size and especially height variations plays an important role in selecting a design concentration. A design concentration that is suitable in a smaller FLSR compartment will result in greater inhomogeneities in a larger compartment. Reduced agent concentration result in longer fire extinguishment times and more HF production, potentially making the design concentration inadequate. A solution to overcome scaling effects due to increases in compartment volume, in addition to careful system design, is to increase the design concentration thereby assuring the minimum agent concentration in all areas. Space, weight and cost considerations will also be factors in determining fire suppression system characteristics.

## **ACKNOWLEDGEMENTS**

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