EXPLOSION SUPPRESSION IN OCCUPIED SPACES

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1. Introduction

The impending unavailability of Halon has particularly serious implications for protection against fast fires or explosions in occupied spaces such as aerosol can filling rooms and the crew bays of armored fighting vehicles. In such applications, the seventy and rapid development of the hazard require extinguishant concentrations and rates of delivery which are much higher than those used in conventional systems. At the same time, there must be no threat to personnel either from the agent or from its discharge.

Studies are in progress into potential replacements for Halon in the high rate discharge (HRD) suppression systems used to protect against each of these threats. The experimental simulations used are described. The importance of assessing the suppressed events on the basis of the physiological hazard actually presented, rather than seeking simply to reproduce the Halon benchmark, is discussed. The results show that some of the new halocarbon agents exhibit performance comparable to Halon, and that aqueous solutions of certain inorganic salts perform similarly on an agent mass basis. Considerations of toxicity and other aspects of use in occupied spaces lead to a very short list of viable candidate alternatives.

2. AFV Crew Compartments

2.1 Hazard and Simulation

The most severe challenge in this application is the fast fire or explosion which may **ensue** following penetration of the crew compartment and a fuel reservoir by an incoming projectile. A highly inhomogeneous, turbulent cloud of fuel droplets and vapor is sprayed into the crew bay, and the passage of the round provides multiple, high energy, simultaneous ignition points. Extensive live firing trials on this type of event have been conducted in the past. The results of these trials were assessed according to standard explosion theory by measuring the peak rate of pressure rise which **is** then normalized to a 1 m^3 volume to give a standard figure of severity known as the K value.

In simulating this event, hot diesel oil was sprayed under pressure into a fully sealed **6.2** m^3 cylindrical test vessel and ignited centrally using a 5 kJ pyrotechnic device after a fixed delay period. Control of the dispersion pressure, fuel temperature and ignition delay allowed a K value equivalent to the

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worst case measured in live trials to be reliably reproduced, although the inhomogeneity of the fuel cloud, the multiplicity of ignition sources, and the clutter typical of a vehicle - which will exacerbate the explosion - clearly are not present.

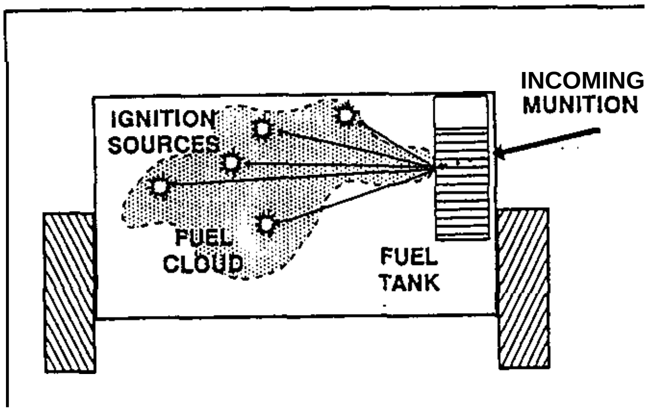

Fig. 1 Combat projectile explosion.

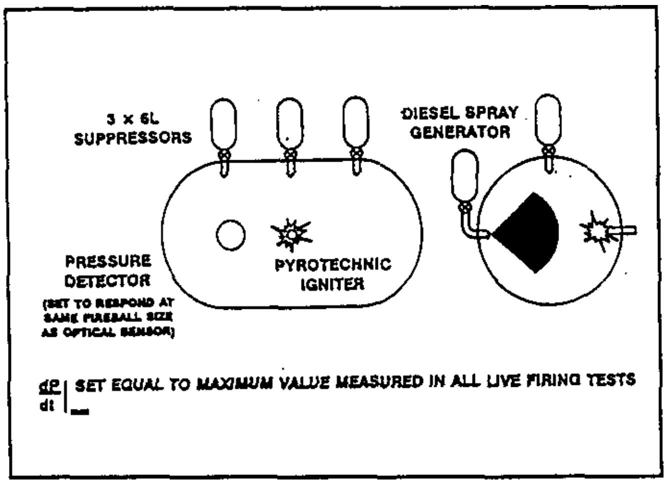

Fig. 2 6.2 m^3 test vessel.

2.2 Suppression Tests

In suppression tests, a pressure sensor was used to activate up to three 6 L suppressors fitted with the standard fast-acting valves currently used in the Halon 1301 system. The pressure sensor had previously been calibrated to respond at the same fireball size as the optical detectors normally used in this application.

Suppression tests were undertaken with Halon 1301 as a baseline. Evaluations were also made using water, with and without additives (various additives have been investigated, but the results reported here relate only to non-toxic and minimally- or non-corrosive solutions), and with the new halocarbons, FE-13, FM-200, PFC-410 and PFC-614. The halocarbons were also tested in mixtures, but no substantial performance benefit was obtained, and the results are not reported here. Achievement of the best performance with the aqueous agents and most of the halocarbons required the nozzle design to be modified compared to the Halon standard.

2.3 Results

In the absence of suppression or at low agent concentrations, the ultimate pressure generated is typically 5 to 8 bar. When the concentration of suppressant is sufficiently increased, suppression is successful and the resultant pressure drops abruptly to around 1 bar. This pressure is higher than would be acceptable in an occupied space, but armored fighting vehicles are a great deal less well sealed than the test vessel. The worst case event experienced in live trials gave a maximum pressure

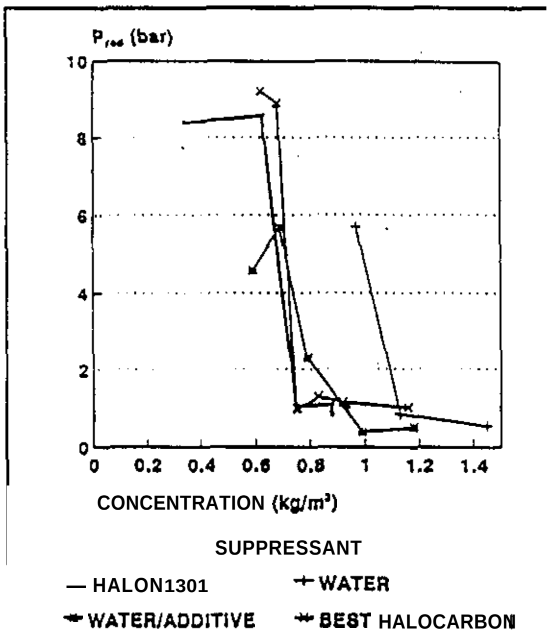

Fig. 3 Crew bay results.

of 3 bar, compared with 5 bar or more measured here. The **same** concentration of Halon required to achieve a successful suppression in these tests was employed in live fire trials and resulted in a peak pressure of around 0.3 bar and a fire extinction time of some 100 ms. This is a survivable result. It is thus considered that the successll suppressions reported here are indicative of a survivable outcome in the combat event in a vehicle.

Water alone was effective only at rather high concentrations. FE-13 was not effective at the maximum concentration realistically achievable with the hardware used. Given the good results obtained with other agents and the importance of minimizing stored volume, FE-13 was not pursued further. Water with additives and the other halocarbons were successful in suppressing the event in mass concentrations similar to that required using Halon 1301, and these results are shown in Table 1.

Table 1

Agent	Mass Conc kg/m^3	Liquid Vol. L/m^3	Vapor Conc Vol%
Halon 1301	0.8	0.5	12
FM-200	0.8	0.5	11
PFC-410	0.8	0.5	8
PFC-614	0.9	0.5	7
Water + Additives	0.7	0.7	n/a

2.4 Selection of Agents

The Halon 1301 concentration required is equivalent to the agent concentration which was found to **be** necessary to successfully suppress the worst case events simulated here. The severity of these events necessitates such concentrations, which are much higher than those normally used in total flooding systems. **By** the same token, the concentrations of the new halocarbons required are also increased over their total flood levels, In the case of FM-200, with a LOAEL (Lowest Observable Adverse Effects Level) of **10.5%,** these exceed the concentrations acceptable for use in manned areas. PFC-614 is less effective by mass than PFC-410, and though this is normally a secondary consideration in these applications, it renders it the less attractive of the two.

Thus, the perfluorocarbon PFC-410 is effective in crew bay explosion protection. Water with additives is also effective, but the problem of protecting the installation against freezing needs to be resolved. It is recognized that factors such as environmental parameters must also be taken into account when specifying agent options. Clearly the decision tree is complex involving multiple, sometimes competing, considerations.

Finally, it is important to note that although the trials described represent good simulations of the worst case combat events in crew bays, important features of this event (inhomogeneity, multiple ignition points and clutter) are not reproduced. No alternative can be fielded until live firing trials have been completed.

3. Aerosol Can Filling Rooms

3.1 Hazard and Simulation

Aerosol products are those which dispense atomized liquids or powders from pressurized nozzles. Some aerosol products use pumps to develop the pressure necessary to achieve product atomization. The focus here is the hazard associated with the manufacture of prepressurized products. These products are usually packaged in steel cans and are pressurized with a volatile single or multicomponent propellant which provides an initial product pressure of the order of 50 to 100 psig depending on specific requirements. Prior to the mid 1970s the propellant formulations consisted of CFCs. The aerosol products industry responded quickly to the announcement by Rowland and Molina in 1974 that CFCs were detrimental to stratospheric ozone. As early as December of 1974 some aerosol businesses were evaluating alternatives to CFCs for use as propellants in aerosol cans (Roan, p. 60). Today the majority of prepressurized aerosol products employ propellant mixtures the components of which are flammable in air. Included among propellant components in common use today are propane, isobutane, dimethyl ether, and HFC-152a. All of these are flammable gases at ambient conditions.

The use of flammable propellants in manufacturing necessitated redesign of the operating spaces. Safety systems were introductd to both reduce the likelihood of an occurance of propellant leaks and also to remediate the situation should a gas leak occur (gas detection and ventillation enhancement). Explosion protection systems are now required in aerosol can filling rooms as a safety measure of last resort in the event that gas should leak at a high rate and become ignited prior to detection by gas sensors (NFPA 30B, Sec. 3-12). While aerosol product manufacturing rooms are not normally occupied it is common practice to have personnel enter these spaces when the potential for propellant leaks and explosions is present. Consequently, explosion suppression systems used Halon 1301 as the suppressing agent as it was found to be effective in suppressing localized deflagrations at agent vapor concentrations for which brief personnel exposure was permitted under **OSHA** regulations (OSHA). **The** goal of the present work is to identify a satisfactory alternative to Halon 1301 in these applications.

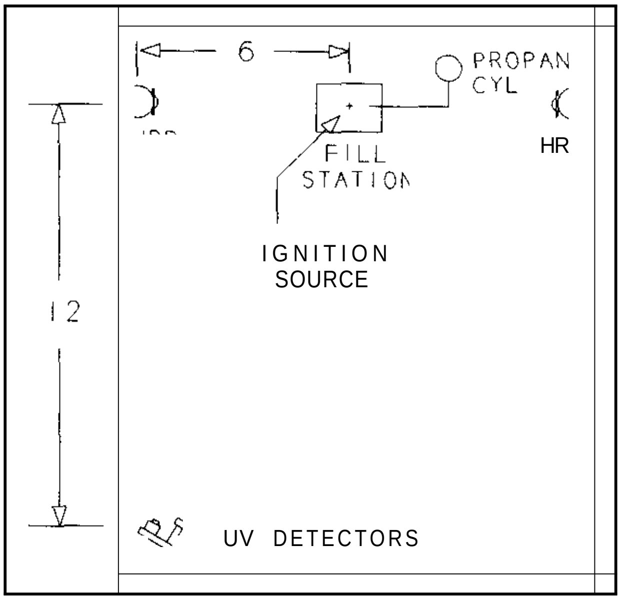

Fig. 4 Simulated aerosol filling room.

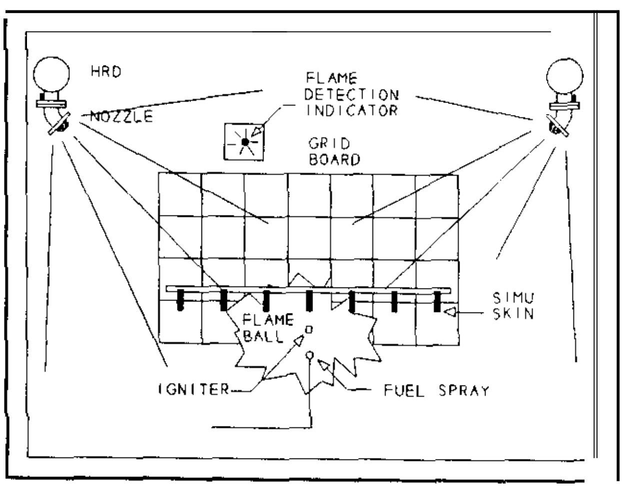

Fig. *5* Suppression test configuration.

The aerosol filling room hazard was simulated in a test room measuring 18.2 x **14.5** x 10.7 ft **high.** Pressurized propane was released through a dispersing nozzle located 1 ft below a weak spark ignition source. The ensuing ignition of the turbulent propane-air mixture developed a fast combustion event. The event was in part a deflagration, i.e., flame propagation through a fuel-air mixture with a composition within the flammable limits, and in part a flash **fire.** The dimensions of the unsuppressed flame ball were controlled by the quantity of the fuel and the dispersion pattern of the nozzle. Initial tests used 90 g of propane and resulted in unsuppressed flames measuring approximately **7** ft wide by 5 ft high by 4 ft deep. Such an event poses a severe threat to operating personnel who may be present. Further, such events ***are*** not merely hypothetical in nature. **A** number of such events have occurred. In at least one case an operator was confronted with a developing flame ball which was ignited right in front of him. The flame progressed only far enough to burn the hair on his extended forearms before the Halon 1301 suppression system extinghushed the event.

3.2 Suppression Tests

The objective of the suppression trials in progress is to assess the suitability of the substitutes in protecting the hazard described. Tests have been conducted using the agents listed in Table 2.

Table 2

Summary of Key Agent Properties

Agent	Trade Name	B.P. °C	P_{vap} kPa	Exting. Conc. vol %	LOAEL vol%	ΔH^*_{vap} kJ/kg	Flash Fract'n
Halon 1301	---	-57.7	1619	2.9	10.0	119	0.50
HFC-227ea	FM-200	-16.4	455	5.8	10.5	132	0.28
PFC-410	CEA-410	-2	268	5.5	>40	97	0.12
HFC-236fa	FE-36	-1.5	275	5.1	15	161	0.17
Water	---	100	3.1	n/a	n/a	2568	nil

Note: As used here AH*, is defined as the enthalpy required to convert liquid from the liquid state at its normal boiling point to vapor. In the case of water ΔH^*_{vap} includes the sensible heat required to heat the liquid from 25 to 100°C. This definition was chosen as being representative of the heat abstraction capability of agent mist which enters the flame ball.

The simulated fill room layout and suppression system arrangement is shown schematically in the figures below. The test suppression system used two Fenwal 5L spherical high rate discharge (HRD) extinguishers, each having a volume of 11 liters, mounted 8 ft above floor level and 6 ft to either side of the "fill station". Agent hemispherical distribution nozzles were mounted on the ends of 45" elbows. An ultraviolet flame detector was located 12 ft from the ignition point. The ignition spark was very weak and did not emit sufficient W to cause the detectors to go into alarm. The spark power was shut off at the time of actuation of the suppression system. The flame detector signal was passed to an explosion suppression control panel which in turn discharged the explosive actuators in the HRDs.

In order to measure the extent of protection provided in suppression mals a linear array of thin polyethylene strips was suspended 1 ft above the ignition point. The strips were spaced at 12 inch intervals. The polyethylene strips measured 0.5 x 6 inches and were 0.0010 inches thick. The strips were hung from a horizontal rod and weighted on the end to prevent movement away from the rapidly advancing flame front. Since the strips were intended to simluate skin they are referred to henceforth as SimuSkin strips. Flame effects on the SimuSkin strips were characterized as: 0 = No damage; 1 = Slightest singeing; 2 = Significant deformation; 3 = Completely destroyed.

Each event was recorded on VHS video tape and on 16 mm color film at 200 frames per second. Cameras were located outside the test room and viewed the event through a window opening. An optical indicator was used to show when the explosion suppression system had been discharged. A flash bulb was discharged by the panel at the same time as the HRDs. The flash bulb, partly screened so as not to blind the camera image, was visible in the field of view of the video equipment. Thus, it was possible to determine the size of the flame ball at the time of actuation and the precise time required to achieve extinguishment from the times of ignition and detection.

The extent of HF formation was judged only in a relative sense by smell in the immediate vicinity to the test room after each test. Quantitative methods were not used.

It is typical in fill room protection designs to employ 0.90 kg of Halon **1301** per cubic meter of protected space. **A** design for the 80 m^3 test room would call for **72.8 kg** Halon. Tests of replacement agents were conducted using 10 kg of replacement halocarbon or **5** kg water in each HRD.

3.3 Results

The main results of the trials were as follows:

1. Video and film analysis showed that flame detection occurred at a visible flame ball diameter of about **8** to **12** inches.

2. Complete extinguishment of the deflagration propane-air cloud was achieved in approximately **150** ms after detection in all cases.

3. Propane continued to issue from the nozzle during and after suppression and was not reignited.

4. SimuSkin sample damage was equivalent for each of the halocarbons tested but was only 1/3 as severe in water tests.

5. In the halocarbon tests HF level was greatest for **FM-200,** less for **CEA-410,** and least for **FE-36.** It was not necessary to vacate the vicinity of the test room after the **FE-36** test whereas thiss was deemed necessary after tests with the other two halocarbons.

6. Maximum flame ball extension was about 4ft in suppression tests. The absence of burned SimuSkin samples in this range is attributed to the brevity of flame exposure of samples to high temperature. Recall the "hand over the candle flame" trick.

3.4 Discussion

The effectiveness of agents in these applications will depend on the various physical properties of the liquid and gas phases. Water appears to offer good basic protection against personal injury at the scale of hazard evaluated. However, water lacks continuing inerting ability

The apparent efficiency of water in these tests suggests that droplet effects are more important than vapor effects. The relatively lower HF levels, as sensed by smell, for the higher boiling point **halocarbons** also suggests that heat extraction and dilution by vaporization of droplets at the reaction zone is significant.

The number of trials to date has been limited. Additional work is required to examine suppression effectiveness **against** larger fuel-air cloud masses and to assess effects of a persistent ignition source.

Table 3

Aerosol Fill Simulation Suppression Test Results

Agent	SimuSkin Burn Level	HF "Nose" Test
Halon 1301	not tested	not tested
HFC-227ea	0-0-3-3-0	Most
PFC-410	0-3-3-0-0	Less
HFC-236fa	0-0-3-3-0	Least
Water	0-0-2-0-0	n/a

4. References

OSHA Sec. 1910.162(b)(6)(i) - (b)(6)(iii)

NFPA 30B, Manufacture and ***Storage of*** Aerosol *Products*, National Fire Protection Association, Quincy, MA, 1990.

Roan, Sharon L., Ozone Crisis, John Wiley & Sons, Inc., New York, 1990.