CHALLENGES IN INTEGRATING HALON-ALTERNATE AGENTS INTO AUTOMATIC FIRE EXTINGUISHING SYSTEMS (AFES)

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ABSTRACT

The shift from established Halon-based Automatic Fire Extinguishing Systems (AFES) in military armored vehicles to ones that use more environmentally friendly suppression agents, while simultaneously meeting more stringent performance requirements, poses significant integration challenges. Integration issues that need to be addressed include selection of an appropriate agent, size and placement of extinguisher components, development of performance and operational safety qualification criteria, test methods, and third party approvals. This paper delves into the major steps required in modern AFES integration efforts.

INTRODUCTION

Military armored vehicles have incorporated Automatic Fire Extinguishing Systems (AFES) to protect the crew from combat fuel explosions caused by penetrating munitions for more than 20 years (ref. 1). Before the Montreal Protocol went into effect, Halon 1301 (bromotrifluoromethane) was the agent of choice in military vehicle crew-bay systems. Newer military vehicles have been protected using a Halon-alternate HFC agent (ref. 2). Unfortunately, HFC agents have significant Green-House Warming Potential (GWP). Therefore a third generation of agents with acceptable GWP may be applied in the future. Water with freeze-point depressant additives and Novec 1230 are promising third generation agents.

All Halon-alternate agents have significantly different physical properties than Halon. The result is that no replacement agents applied in a military crew-bay AFES have been a drop-in replacement for Halon. But Halon-alternate agents have been successfully integrated in military vehicle AFES. In all cases significant re-engineering has been required before acceptable fire suppression and operational safety was achieved. The major steps required in order to apply Halon-alternate agents are described in this paper.

Environmental legislation, principally the US DoD direction to phase out ozone-depleting materials such as Halon and other CFC's from military applications, led to a search for non-Halon, or "alternate" fire suppression agents. At about the same time, the US Army refined its safety requirements (ref. 3-4). TACOM conducted testing aimed at finding alternate agents that met the new medical and environmental requirements (ref. 5). Two agents were reported as acceptable: a blend of HFC-227ea (a type of heptafluoropropane) and 5% by weight dry chemical (based on sodium bicarbonate) and water with a freeze point depressant additive. The

HFC-227ea and dry chemical blend is now listed as HFC227-BC under the EPA's Significant New Alternatives Policy (SNAP) Program.

Alternate agents applied in crew-bay AFES were also studied in independent research done by Kidde (ref. 6). The first qualification of a crew-bay AFES using HFC227-BC was for the USMC Expeditionary Fighting Vehicle (EFV), formerly known as the AAAV (ref. 7).

REVIEW OF REQUIREMENTS FOR AFES CREW BAY PROTECTION SYSTEMS

The crew-bay AFES used in legacy vehicles to protect the crew use high-speed extinguishers charged with Halon 1301 (bromotrifluoromethane). The performance requirements for these systems were that they quickly extinguish a fuel explosion, typically in less than 250 ms. The first systems were designed to achieve 6 to 7% Halon 1301 concentration by volume in air and to meet NFPA 12A (1970) exposure limits. Much later, the EPA invented the No Observed Adverse Effects Limit (NOAEL) and the US Army Surgeon General specified a 6% maximum (ref. 3).

The results of medical research of combat related issues in armored vehicles were published in the late 1980's (ref. 3, 4). The Walter Reed Army Institute did extensive research into the health aspects of Halon systems and recommended limits on criteria other than fire out time (ref. 4). A result was the refinement of performance and safety requirements for crew-bay AFES.

During the 1990's the US Army developed a requirement for lighter armored vehicles than the M1 Abrams and Bradley Fighting Vehicle (BFV). The new vehicles had to be light enough to be transportable by a C-130 and to travel on paved roads without damaging them. The specification for the Brigade Combat Team (BCT) family of armored vehicles included that it be air transportable in a C-130 and incorporated the latest medical and environmental requirements. The Future Combat Vehicles that will be part of the Future Combat System are expected to impose similar requirements. Figure 1 illustrates the trends described here (ref. 2).

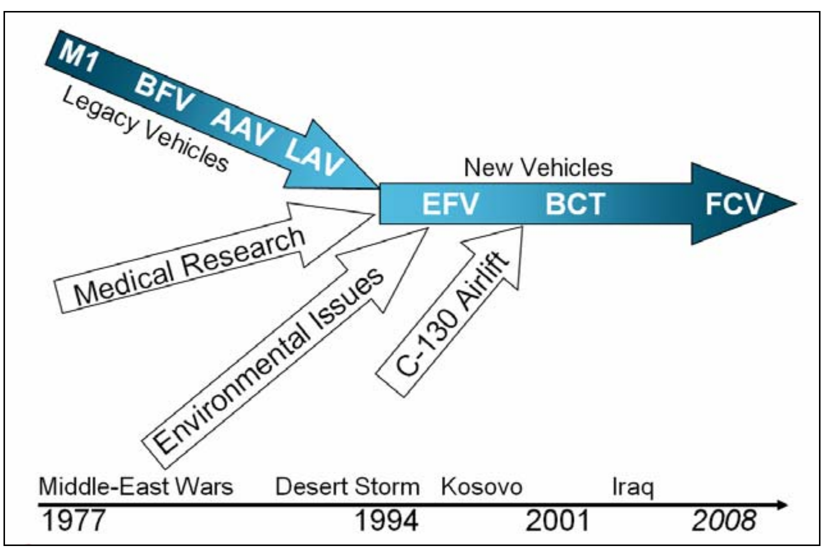

Figure 1. Evolution of US Armored Vehicles

Associated with the Army's push to develop a new crew-safe fire-suppression agent were new safety, test methodology, instrumentation, and approval issues. In addition to obtaining SNAP listing, the new agent needed to be approved by US Army Center for Health Promotion and Preventive Medicine (USACHPPM). Existing criteria for impulse force and discharge noise studies had to be revisited, and new areas of concern, such as soft tissue damage due to exposure to cryogenic fluid and dust bombardment had to be addressed. Medical criteria for the latter may need to be developed for military applications. Finally, high-speed concentration measurement instrumentation needed to be changed to accommodate agent property differences.

The new performance requirements were mainly based on reports to the US Army Surgeon General from the medical community (ref. 3, 4). Highlights are listed in Tables 1 and 2. Maximum HFC227-BC fire suppression agent exposure concentrations were based on NFPA-2001 (2000). The acceptable acid gas levels can be based on exposure times (ref. 4) or a peak recorded level (ref. 3). The application-specific Fire Suppression requirement is developed during the Performance Verification Tests by the US Army (see for example, ref. 8).

Parameter	Requirement
Fire Suppression	Extinguish all flames without re-flash*
Skin Burns	Less than second degree skin burns: <1316 °C-s over 10 s or heat flux < 160 kJ/m^2 (<2400 °F-s over 10 s or heat flux < 3.9 cal/cm^2)
Overpressure	Less than lung damage: 80 kPa (11.6 psi)
Agent Concentration	Not to exceed LOAEL**
Acid Gases (HF + CF_2O)	See Table 2
Oxygen Levels	Not below 16% for 5 s average
Discharge Noise	Not to exceed hearing protection level: With hearing protection ------- 162 dB Without hearing protection --- 140 dB
Discharge Forces	Not to exceed 78 m/s^2 (8 g) over 30 ms

* Usually demonstrated in Performance Verification Tests

** Lowest Observed Adverse Effects Level per NFPA-2001 (2000).
LOAEL for HFC-227ea is 10.5%.

Table 1. Derived Extinguisher System Performance Requirements for US Army Vehicles

Authority	Criteria
US Army Surgeon General (Feb 1987)	HF <1,000 ppm peak
Walter Reed (Sep 1989)	HF Delayed Incapacitation 746 – 2237 ppm-min over 5 min HF Immediate Incapacitation 1491- 4473 ppm-min over 5 min
USMC EFV/AAAV (1999)	HF <1,500 ppm, time-weighted average over 30 sec HF <150 ppm, time-weighted average over 5 min

Table 2. Acid Gas Exposure Requirements

CHALLENGES IN SWITCHING FROM HALON TO ALTERNATE AGENT

The higher boiling point of HFC-227ea results in a larger liquid fraction in the extinguisher discharge. This poses two challenges: the larger density of the liquid compared to the gaseous suppression agent makes it imperative that the nozzle be located so that the discharge is not directed at the crew, and the liquid agent is less likely to go around obstructions so, to prevent reflash fires, it is essential that the nozzles are located to direct agent toward areas where fuel might collect.

Solid models can be used to model the discharge of the liquid suppression agent. An image of the solid model for a front right extinguisher assembly is shown in Figure 2.

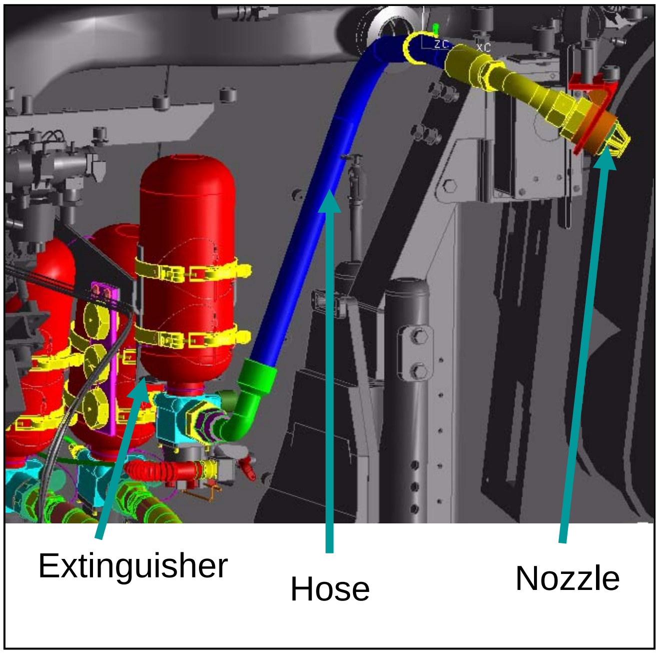

Figure 2. Extinguisher system with hose (projection of solid model generated by GDLS-Canada, ref. 2)

Another area of concern is the combustion byproducts of the agent created during a suppression event. Although this had been studied in general, it had not been addressed for a system using discharge hoses because systems using Halon 1301 did not require hoses. This concern is addressed during system validation using live-fire fuel-spray tests as described below.

SYSTEM VALIDATION

The validation of the crew-bay AFES is comprised of several key activities:

- Component Verification
- Solid modeling of the vehicle and AFES components

- Agent Concentration Tests
- Live Fire System Tests

System Validation – Component Verification

The major components of the crew-bay AFES are the fire sensors, controller, extinguisher and harness. The fire sensors, controller and harness are standard qualified products. The alternate-agent extinguisher system may not be standard – if not, testing is necessary to verify compliance with the requirements, some of which are listed above. For example, Kidde has performed tests to verify discharge force (ref. 9) and discharge noise (ref. 10) from Halon-alternate extinguishers.

System Validation – Solid Modeling

Solid models can be used to locate the AFES components as described above. The models are used to check the suppression agent distribution pattern, see Figure 3.

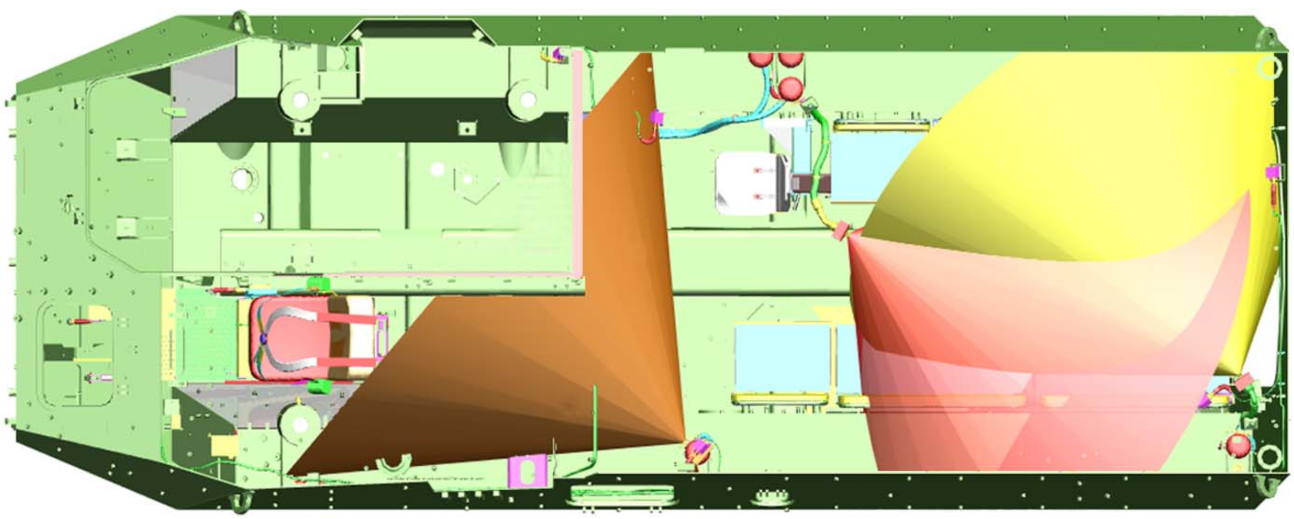

Figure 3. Extinguisher System Agent Distribution Pattern (top view). (Projection of solid model generated by GDLS-Canada, ref. 2)

System Validation – Agent Concentration Tests

The purpose of the agent concentration tests is to ensure that the:

- Suppression agent reaches minimal levels quickly enough for effective suppression of fuel explosions and that the
- Long-term agent exposure concentration at crewmember breathing locations did not exceed the maximum level.

Various methods of measuring agent concentration include Non-Dispersive Infrared (NDIR) and Fourier Transform Infrared (FTIR) Spectroscopy (ref. 4). Tests are run with hatches open and closed, with and without airflow.

System Validation – Fuel-Spray Fires

Once the crew AFES has been integrated onto the vehicle with distribution details such as hose lengths and nozzle locations defined, the next step is a series of live-fire fuel-spray tests. The minimum goal of these tests is to gain a sense of confidence in the system performance as compared to the requirements (ref. 11). Kidde tests of Halon-alternate suppression agents have been conducted on a Vickers FV432 armored personnel carrier obtained from the British Army. Instrumentation used in the tests measured compartment pressure, temperature, oxygen levels and total fluorine ion concentration.

Figure 4. Kidde Live-Fire Test on an Armored Vehicle a) Test vehicle side view and b) Test vehicle rear view showing vent panel

Previous experience has shown that welding of doors, hatches *etc*. was necessary to ensure adequate sealing of vehicles when carrying out crew bay suppression tests (ref. 12). This was not possible, as the vehicle was on loan. Therefore a different approach was tried. The large roof hatch was secured with universal beams positioned above and below the vehicle, as shown in Figure 4a. The bulkhead between the driver's compartment and the main crew compartment was sealed with thick plywood. The rear doors were propped open and another similarly thick plywood fixture was fabricated to fill the door frame. An industrial explosion venting program was used to design a suitable vent to keep the pressure rise to reasonable levels. This vent was provided by a hole cut in the rear plywood door, shown in Figure 4b. To generate an initial pressure rise, the vent was covered with a thin laminate layer. During unsuppressed tests this layer was verified to rupture at the required pressure.

The fuel-spray fire was produced using a spray bar and pyrotechnic igniters. The severity of the fire was adjusted by varying the fuel spray pressure, length of the spray bar, number of igniters and delay between commencing the spray and ignition. The unsuppressed fire used in the final validation tests by Kidde is shown in Figure 5.

Figure 5. Kidde Live-Fire Test – Unsuppressed Fire (side view)

System Validation – Independent Evaluator

The final steps in system validation often involve tests designed and conducted by the end user, for example, the US Army. The end user independent evaluator tests can include agent concentration measurements and live-fire tests. The AFES vendor may or may not be present during these tests.

CONVERSION FROM HALON TO ANOTHER AGENT

Converting an armored vehicle crew-bay automatic fire protection system from one suppression agent to another is not trivial. In addition to the steps described earlier, Integration issues that must be addressed or re-addressed include:

1. Selection of an appropriate agent

2. Review of performance qualification criteria (eg, fire suppression performance including toxic by-products)

3. Review of environmental qualification criteria (eg, operational and storage temperature limits)

4. Review of operational safety qualification criteria (eg, discharge acceleration forces)

5. Size and placement of extinguisher components (eg, a different quantity of agent and/or different nozzle design and/or placement may be required)

6. Material compatibility (eg, are the seals used in the Halon extinguishers compatible with the replacement agent for the life of the product?)

7. Qualification test methods and plan (to verify design based on above)

8. Third party approvals (if required)

9. Conversion Procedure. A conversion procedure must include a description of the necessary steps for safe and legal Halon disposal/recycling as well as compressed cylinder handling and technician training.

10. Post-deployment support issues to address:

    a) Is AFES warranty affected?

    b) Revised vehicle documentation including spares parts lists and operation and maintenance manuals and instructions will be required.

CONCLUSION

Medical and Environmental concerns necessitated changes in armored vehicles including changes to the crew-bay AFES. A major change in the AFES was the switch from Halon 1301 to a Halon-alternate suppression agent such as a blend of HFC-227ea and sodium-bicarbonate-based dry chemical.

The integration of the Halon-alternate suppression agents in crew-bay AFES presents unique challenges. The integration of new installations must include solid modeling, agent concentration tests and ultimately successful live-fire tests in several locations. Additional steps are required for a conversion from an existing Halon to a Halon-alternate agent.

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