ENGINE COMPARTMENT HALON 1301 REPLACEMENT PROGRAM (ECHRP): STATUS AND SUCCESSES

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ABSTRACT

The research program to identify alternatives to HALON 1301 in fire extinguishing systems (FES) of Army ground based systems, tanks and trucks is complete. Three programs of record are in various stages of completeness, crew compartment, hand held and engine compartment. This paper focuses on the engine compartment halon replacement program (ECHRP) and its status.

Several different FES design solutions were identified that could satisfy the requirements of the ECHRP. None of the FES tested were a “drop-in” agent or distribution replacement system. Testing dramatically demonstrated that the ability of any FES to extinguish combustion is as dependant on the agent distribution system for optimum effectiveness as it is on the agent itself.

Based on the Army’s required logistic optimizations for individual materiel, the Army chose to use one or two concepts recommended for fire extinguishing within vehicles. These were a ‘heptafluorocarbon’ (FE-36, FM-200, isomers of, etc.) and a dry powder based extinguishant system. For engine compartments, the Bradley PM adopted an FM-200 solution and the Abrams PM is working on a dry powder solution.

The US Army’s replacement of halon extinguishing systems for engine compartments is in process for many Army vehicles.

INTRODUCTION

Halon 1301 has been used for decades as the primary fire and explosion extinguishing material for a multitude of industrial and military applications. However, halons have very high ozone depleting potentials and their production was stopped in 1994 in most of the world. The U.S. Army Tank-Automotive Research, Development and Engineering Center (TARDEC), the laboratory of the U.S. Army Tank-automotive and Armament Command (TACOM) that conducts research on issues affecting ground combat vehicles, initiated the Halon Replacement Program (HRP) to identify and develop replacement technologies to satisfy the performance and logistics requirements of fire protection for ground combat vehicles.

Early investigations indicated that a universal solution would not be available to the fire protection community for all the systems that used halon. Hence, multiple agents would probably be required to address the wide range of military applications currently satisfied by halon 1301.

This paper summarizes the results and findings of the HRP. It addresses the halon elimination efforts in three separate ground combat vehicle applications: engine compartment fire suppression, crew compartment explosion suppression, and hand-held fire extinguishers.

ENGINE COMPARTMENT PROJECT

TEST SET-UP

The engine compartment program halon replacement program was divided into three phases. Phase I testing was conducted in an M60 tank hull using a non-functional power pack with combustible materials not required for conduct of the test removed. Airflow was rerouted to draw air in through the exhaust grille, past the engine and out through the turret using an external exhaust blower. This phase of testing was originally structured with six fire scenarios:

Type I	Combined Bilge Fire and Fuel Spray with Airflow
Type II	Combined Bilge Fire and Fuel Spray w/o Airflow
Type III	Bilge Fire with Airflow
Type IV	Bilge Fire w/o Airflow
Type V	Fuel Spray with Airflow
Type VI	Fuel Spray w/o Airflow

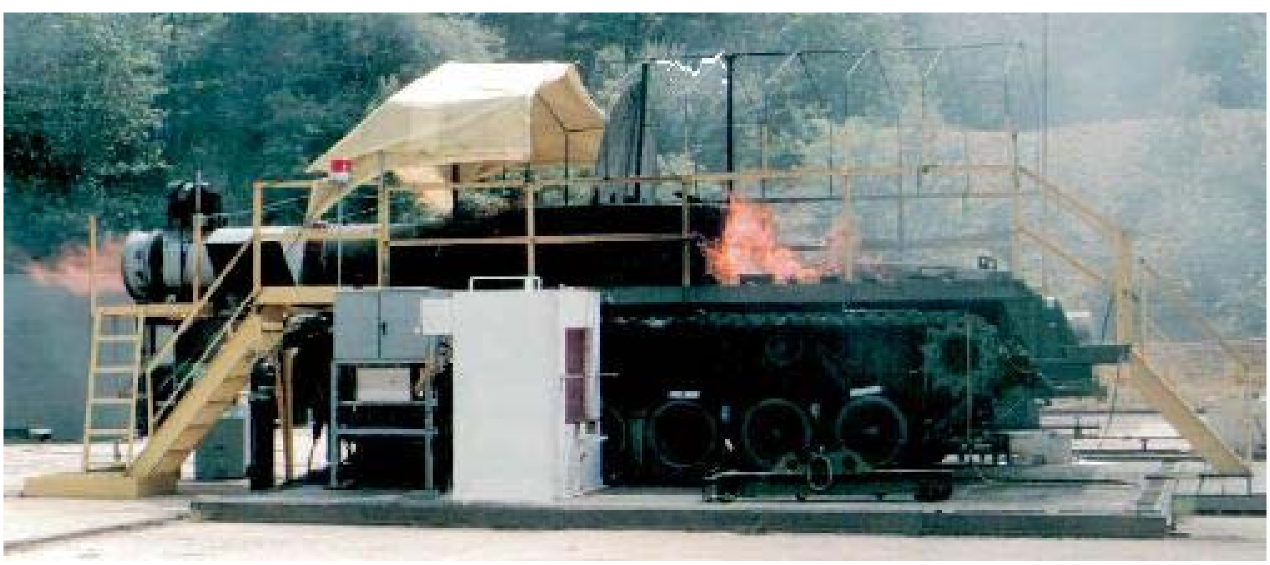

Figure 1. Phase I Test Setup

The Type I fire scenario (shown above) was conducted as follows: A combined Class A/B fire consisting of eight gallons of JP-8 fuel was ignited and allowed to burn for 1.5 minutes. The exhaust blower was then operated at 11,000 cfm (approximately two air exchanges per second) for another 1.5 minutes. A fuel spray consisting of heated JP-8 pressurized to 40 psig was then discharged through an 1/8" orifice onto a 1200^{o}F heated surface. The spray continued for 15 seconds before the agent was manually discharged. The fuel spray continued for 30 seconds after extinguisher activation. Fire severities were scaled so that seven pounds of halon would be required to reliably extinguish the fires. The test parameters of airflow, fuel spray, and/or bilge ignition were varied to create the other fire types.

Minimum agent weights required to extinguish the fire without reflash were determined. No fire-out time criterion was used. As testing progressed it was determined that the Type I fire was too severe - none of the agents, including Halon 1301, could extinguish it without reflash, and the Type IV scenario was too benign - almost all of the agents could extinguish it with minimal weight. With sufficient preburn times, Type V and VI fires became Type I and II fires, respectively. Therefore, testing focussed on the Type II and III fire scenarios. The Type III fire represents a typical fire that an automatic system (e.g., M1 Abrams first shot) would be expected to encounter, while the Type II fire represents a severe fire that a manual system (e.g., M1 Abrams second shot or M2/M3 Bradley) could encounter.

PHASE I RESULTS

The results of Phase I testing are summarized below:

Table I. Phase I Agent Weights and Volume

	Weight (lbs)		Volume (in^3)*
Agent	Type II	Type III	
Halon 1301	5.0	7.0	204
CO_2	8.0	12.0	576
FM-200	9.0	7.0	288
FE-36	9.0	9.0	288
FE-25	< 9.5	9.0	~387
PGA	8.5	Unknown	??
Dessikarb	2.0	6.6	204
HGG/FM-200	12.4	9.3	320
Water mist	17.0	8.7	610

*storage volume of agent with overpressure required to extinguish both Type II and III fires

CO_2: CO_2 was tested in the standard M60 delivery system. CO_2 was tested as a baseline for Phase I, but due to its large agent storage volume requirements, it was not pursued in Phase II.

FM-200: FM-200 (HFC-227ea) was tested with several different distribution systems, but the best performance was achieved with the standard M60 CO_2 distribution system. It performed better against Type III fires than it did against Type II fires due to its higher boiling point. The long preburn times and high surface temperatures may enhance its performance relative to Halon. FM-200 appears to extinguish fires much slower than Halon 1301 (4-12 seconds vs. 1 second) because of its slower vaporization. FM-200 was also successful at low temperatures (-25^{o}F and below). There is approximately a 40% volume penalty relative to Halon 1301. Fill density is a critical factor when considering bottle size for FM-200. A minimum of 30% ullage is required to ensure sufficient N_2 for complete agent discharge from the extinguisher. FM-200 was tested in Phase II.

FE-36: The performance characteristics of FE-36 (HFC-236fa) are very similar to FM-200. Given the advantages of having two agents that perform equivalently in common hardware, FE-36 was tested in Phase II.

FE-25: FE-25 (HFC-125) was tested with the standard M60 CO_2 distribution system. Due to its lower liquid density at high temperatures, FE-25 is approximately 25% less efficient by volume than FM-200 or FE-36. Therefore, FE-25 was not tested in Phase II.

PGA (Envirogel): Several formulations of Powsus Gelled Agent (PGA, a.k.a. Envirogel) were tested in Phase I. The formulation favored by the manufacturer was FE-25 mixed with finely ground ammonium polyphosphate (APP) and a gelling agent overpressurized with nitrogen. The agent was tested in standard halon extinguishers with modified distribution tubing. Single stage solenoid valves needed to be cleaned after each discharge and rebuilt after every two to three discharges and pilot valves after every discharge. Consistent results were not obtained with PGA against Type III fires, possibly due to insufficient gelling of the mixture. PGA was not tested in Phase II.

FluoroIodoCarbons: In earlier tests trifluoromethyliodide (CF_3I) had been shown to be at least as effective as Halon 1301 using existing distribution hardware. However, emerging toxicological findings eliminated CF_3I from consideration. Heptafluorobutyliodide (C_3F_7I) was substituted in Phase I with encouraging results, but it also had severe toxicological penalties and was not evaluated further. The fluoroiodocarbons were not tested in Phase II.

Dessikarb: Dessikarb (DXP) is a finely ground sodium bicarbonate based dry powder. It was tested with squib valves and distribution tubing with multiple nozzles. DXP is more effective against Type II fires than against Type III. After several distribution changes, the DXP proved to be as effective as Halon 1301 by volume. DXP was chosen in part because it is much less corrosive and cleanup is minimized. DXP and several other dry powders were tested in Phase II.

Gas Generators: Gas generators (GG) burn a solid propellant to rapidly produce large volumes of inert gases (N_2, CO_2, and water vapor). This technique is similar to that used in automotive airbags. New storage cylinders and distribution hardware are required. The GGs performed with mixed results against Type II and III fires. Additional development would be required to package this into a production configuration. The GGs were not tested in Phase II.

Hybrid Gas Generators: Hybrid gas generators (HGG) use the GG to pressurize and discharge a liquid agent, in this case water or FM-200. Both were more effective than the straight GG, but the water's freeze point problems were not overcome. The HGG with FM-200 extinguished fires much more rapidly than FM-200 overpressurized with nitrogen because the hot gases help vaporize the FM-200 and the extra pressure provided more consistent agent distribution. An HGG/FM-200 system was tested in Phase II. New storage cylinders and distribution hardware are required. Additional development of this technology is ongoing.

Water Mist: The water mist system uses relatively large volumes of water at high pressure (3000 psi). New storage cylinders and distribution system are required. While the system was quite effective against Phase I fire scenarios, freeze point and space claim issues were not adequately addressed. The water mist system was not tested in Phase II.

Water Spray w/Additives: Several additives have been found that lower the freeze point of water to -60°F or below and enhance fire extinguishment. The water spray was tested with the M60 CO_2 distribution system with mixed results. Research continues to identify additives that enhance performance as well as provide adequate freeze point suppression. Water sprays were not tested in Phase II because their performance was not equivalent to FM-200.

Spectronix Solid Propellant Generated Aerosol (SPGA): Solid propellant is burned generating inert gases and fine dry particle (~1 micron) aerosol. New storage containers and distribution system are required. Due to the buoyancy of the hot effluent, none of the test fires could be extinguished. The Spectronix SPGA was not tested in Phase II.

Dynamite Nobel SPGA: The Dynamite Nobel SPGA is similar to the Spectronix units except they are packaged so the effluent is cooler and the discharge can be more readily directed. New storage containers and distribution system are required. Type II fires could be extinguished with six canisters, but fires reflashed. Mixed results were obtained for Type III fire tests. Available space in the engine compartment limited the number of canisters and locations. The Dynamite Nobel SPGA was not tested in Phase II.

PHASE II RESULTS

The Phase II test fixture was based on an M60 tank with a functional power pack. Type II fires were conducted similarly to those in Phase I but without the three-minute preburn time. Type III fires consisted of a 15-second preburn, then the engine was brought up to approximately 1500 rpm and the agent was immediately discharged (25-30 seconds after fire ignition). These tests were conducted to validate that the minimum agent volumes identified in Phase I were adequate to extinguish realistic vehicle fires with an operating engine, not to further minimize the amount of agent required.

Based on these results, two agents were recommended to the vehicle program managers for Phase III testing: FM-200 and sodium bicarbonate based dry powder.

Table II. Agent Properties

Candidate Trade Name	Chemical Formula	Liquid Density @77 F (lb/ft^3)	Vapor Pressure @77 F (psi)	Boiling Point (F)	Ozone Depletion Potential (ODP)	Global Warming Potential [a,b] (GWP)	Atmospheric Lifetime [a] (yrs)
FM-200	C_3F_7H	86.7	66.5	2.5	0	2900	36.5
FE-36	$C_3F_6H_2$	85.5	39.9	33.2	0	6300	209
FE-13	CF_3H	41.8	665	-115.7	0	11700	264
FE-25	C_2F_5H	78.0	190	-55.3	0	2800	32.6
PFC 410	C_4F_{10}	94.0	42	28.4	0	7000	2600
PFC 614	C_6F_{14}	105.0	4.5	132.0	0	7400	3200
Carbon Dioxide	CO_2	49.2	929.5	-109.1	0	1	variable
Halon 1301	CF_3Br	96.0	234.8	-72.0	12 - 16	5600	65

a – from Intergovernmental Panel on Climate Change (IPCC) 1995 Assessment Report
b – based on 100-year time horizon calculated using CO_2 as reference

FM-200 is compatible with current extinguishers in the Army inventory. For distribution systems like the M1, minor modifications may be all that is needed but single nozzle distribution systems will probably need to be expanded to provide adequate agent dispersion. FM-200 has zero ozone-depletion potential. FM-200 also shows potential as a substitute for portable fire extinguishers and crew compartment fire extinguishing systems. However, an agent increase of approximately 40% by volume is required to achieve equivalent performance to Halon 1301. Agent recovery and recycling are recommended.

With proper distribution, sodium bicarbonate powder has been shown to be as effective as Halon 1301 in high airflow conditions, and even more effective than 1301 in low airflow tests. Its environmental impact is negligible. The cost of the powder is less than 50 cents per pound, and can be supplied by many sources. However, a more elaborate distribution system is required for the powder to work properly. Valves, tubing, nozzles, and check valves all will likely need to be replaced. Powder is not appropriate for fixed or portable extinguishers to be used in occupied compartments or near sensitive electronics.

PHASE III RESULTS

Phase III testing was conducted in actual ground vehicles with the two recommended agents. Fire scenarios were defined by the respective vehicle program managers based on specific system requirements and vehicle fire histories.

Following an exhaustive test program for the M1, M2/M3, M992, MLRS and M9 ACE, both agents were chosen for certain applications. In general, HFC-227ea is being installed in vehicles that shut the engine off prior to agent discharge (including the M2/M3 Bradley Fighting Vehicle Series) because of its ease of retrofit while sodium bicarbonate powder will be used in vehicles with an automatic extinguishing system (including the M1) because of its superior performance. This offers the lowest overall life-cycle-cost solution for the Army. Retrofit of the HFC-227ea has been completed for the M2/M3 and MLRS and the powder systems are being applied to the M1 family of vehicles.

SUMMARY

The US Army has aggressively pursued alternatives to halon 1301 in its ground combat vehicles. Alternatives for all three ground vehicle applications have been identified and fielded. As of now, only the crew compartment explosion suppression system of our legacy vehicles, Abrams, Bradley and FAASV, are still reliant on halon.

ACKNOWLEDGMENTS

The authors would like to acknowledge the following for their assistance in this work.

- **Jack Phillips**, Program Executive Office, Ground Combat Systems (Abrams), Warren, MI.
- **David A. Koehler**, Corrpro Companies Incorporated, Manager, Army ODC Elimination Program, US Army Acquisition Pollution Prevention Support Office.
- **William (Bill) Bolt,**
- **Craig Herud,**
- **Stan Polyanski,**
- **Terry Tranor,**
- **Derek Erdley** and
- **Hal Cross**, (Combat Systems Test Activity - CSTA) Defense Test Center (DTC), Aberdeen Proving Ground, Maryland.
- **(An)Tony Finnerty,**
- **Reed Skaggs** and
- **Kevin Boyd,** Army Research Laboratory (ARL), Aberdeen Proving Ground, Maryland.
- **Joseph Lifke**,
- Ted A. Moore (**Smokey**),
- **E.T. Moorhead**,
- **Stephanie Skaggs**,
- **Douglas Dierdorf**,
- **Robert Tapscott** (CGET) and

- J. **Douglas Mather**, the University of New Mexico Engineering Research Institute (NMERI)

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