US ARMY GROUND VEHICLE HALON REPLACEMENT PROGRAMS

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ABSTRACT

The reduction of tlie ozone concentration is a concern. Hal1111 1301 has been identified as having a very high ozone depleting potential. 1301 is used as the main lire and explosion extinguishing agent for many military applications, particularity in the protection of ground combat vehicles and their crews. The Italon Replacement Program seeks to identify. develop. integrate and apply a replacement technology that will function as well as halon lor ground combat vehicles. Early investigations proved that the fire protection community could not find a single solution for all the systems that used halon. Each application or fire scenario would require a different solution. This paper delineates the tests used to provide scientific repeatability and tlie solutions resulting from those test sequences that arc complete. Future work includes the proving and optimization of individual solutions for each vehicle.

INTRODUCTION

Halon-based fire-extinguishing systems are widely used throughout the world to protect military ground combat vehicles. The US Army has aggressively pursued environmentally and toxicologically acceptable alternatives to Halon 1301 for its three ground vehicle applications: crew compartment automatic ‘explosion’ suppression systems, engine compartment fire-extinguishing systems. and portable extinguishers. To date, the 2.75 lb 1301 portable extinguishers have been replaced with 2.5 lb CO_2 units in most vehicles. The MI Abrams tank. due to health concerns, still retains the Halon 1301 handheld extinguisher. Replacements have also been selected for vehicle engine compartments. Sodium bicarbonate-based dry powder will be used in vehicles with an automatic extinguishing system (including the MI) because of its superior performance. HFC-227ea will he used in vehicles that shut the engine off prior to agent discharge (including the M2/M3 Bradley Fighting Vehicle) because of its ease of retrofit. The remaining research challenge is to perfect the application of a fire extinguishing agent and its distribution system for crew compartments, that can be retrofit into current vehicles as well as address the needs of future vehicles.

CREW COMPARTMENT PROGRAM

With the exception of the fonner Soviet Bloc countries, Halon 1301 has been the agent of choice to protect vehicle crewmen against burns from ballistically initiated fuel or hydraulic tluid fires. The US Army will need to support future ground combat vehicles with crew protection, including the Crusader. Future Scout and Cavalry System, and Advanced Amphibious Assault Vehicle (AAAV). Our biggest challenge will he integrating the identified technologies into vehicle systems that are in or just beyond the prototype design phase. Space constraints and toxicology concerns become over-riding considerations. Ballistic testing of explosion extinguishing systems on any prototype is too expensive to undertake. Fire-extinguishing technologies will also need to be tested and demonstrated on the current fielded systems to provide an affordable means of retrofit. The lessons learned during current vehicle tests are the stepping stones for the success of future vehicle integration of fire survivability technologies.

The Army currently has three fielded ground vehicles using Halon 1301 to protect their crew compartments: the MI Abrams main battle tank. the M2/M3 Bradley Fighting Vehicle, and the M992 Field Artillery Ammunition Support Vehicle. The crew compartments of these vehicles range in volume from 250 to 700 ft^3 and employ from seven pounds of agent in a single shot to 21 lbs in each of two shots. The fire extinguishing system agent volumes range from 204 in' to 1224 in^3, respectively.

The Army Surgeon General has established the guidelines shown in Table 1 as the minimum acceptable requirements of automatic fire extinguishing systems for crew compartments. These parameters have been established at levels that would not result in incapacitation of the crewmen from the fire and its extinguishment and would allow them to take corrective action.

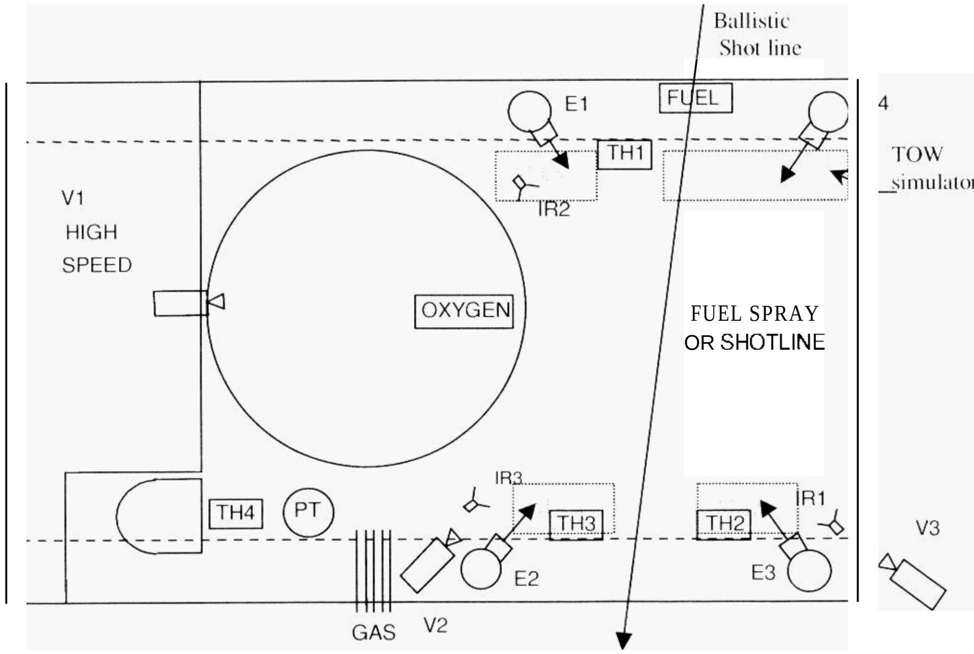
TABLE 1. CREW SURVIVABILITY CRITERIA.

Parameter	Reauirement
Fire Suppression	Extinguish all flames without re-flash
Skin Bums	Less than second degree (<2400 "F-sec over 10 sec or heat flux < 3.9 cal/cm^2)
Overpressure	Less than 11.6 psi
Agent concentration	Not to exceed NOAEL (No Observed Adverse Effects Level)
Acid gasses	Less than 1000 ppm peak
Oxygen levels	Not below 16%

The Army's crew compartment test program is divided into three phases. Phase I was a proof-of-concept and screening phase of multiple agents and technologies. Phase II consists of further development testing of several of the most promising concepts from Phase I. Testing is being conducted at the Army's Aberdeen Test Center in Aberdeen, Maryland. If performance and system integration issues can be successfully addressed, a single concept will be recommended for Phase III testing, which will test the prototype fire extinguishing system in the affected ground vehicles, starting in 2000.

TEST SETUP

The crew test fixture has been constructed from a derelict ground vehicle hull and turret. A top down layout of the fixture is shown in Figure 1. The fixture has an interior volume of approximately 450 ft^3 when empty (Phase I testing). For Phase II testing, three "tin" mannequins and a four-unit TOW missile rack (dashed boxes) were added to simulate a partial loading (worst case shadow effect). The cargo and turret hatches and ramp door were secured during each test while the driver's hatch was allowed to pop open and shut to relieve internal overpressures while minimizing airflow.



PT--TOTAL PRESSURE
GAS--HF, HBR, FT-IR PICKUPS
TH--SKIN TEMPERATURE, HEAT FLUX

V--VIDEO CAMERA
IR--INFRARED DETECTOR
E--EXTINGUISHER POSITION

Figure 1. Crew compartment test setup.

Instrumentation includes high-speed and standard video, 1 micron infrared detectors. heat flux gages, thermocouples, and pressure gages. Four types of instrumentation measure acid gas exposure levels: ion selective electrodes (grab hag sampling), sorbent tubes (NIOSH procedure 7903). midget impingers. and FT-IR analyzers. The FT-IR is the only one of these methods that reports levels of the gases themselves, as opposed to fluorine or bromine ions. Gas species tested for include oxygen (O_2), hydrogen fluoride (HF), hydrogen bromide (HBr), and carbonyl fluoride (COF_2). Nitrogen oxide (NO), nitrogen dioxide (NO?). ammonia (NH_4^+), carbon monoxide (CO), end carbon dioxide (CO_2) levels are also monitored during certain gas generator tests.

Two test scenarios were conducted in Phase I: fuel spray fires and ballistic penetrations. The spray fire is generated using a specially designed nozzle that is fed by approximately 0.3 gallons of JP-8 heated to ~ 185 °F and pressurized to 1200 psi. Fuel flow continues for approximately 1.2 sec with the igniter energized for the duration of the spray to simulate the reignition sources present during a typical ballistic event. The spray fires are monitored with three one-micron infrared detectors. The extinguishing system is activated automatically after an 11 msec delay from the time the fire energy exceeds **a** predetermined threshold. Ballistic fires are generated by firing a 2.7 in shaped charge through an 18.7 gallon (2.25 ft') capacity aluminum fuel cell filled with 11 gallons of JP-8 heated to 165 °F. The fire extinguishing system is activated 25 msec after warhead initiation to eliminate the variability of the detection system.

OBSERVATIONS

Baseline tests have been conducted with Halon 1301 and HFC-227ea using standard Army extinguishers and nozzles. These tests indicate that a total agent weight of 10 Ibs of 1301 delivered by three extinguishers is required to successfully extinguish both the fuel spray and ballistic fires. Lower agent weights lead to longer fire-out times and the byproduct levels rise significantly. Fifteen (15) lbs of HFC-227ea provided approximately equivalent fire-out times to 10 lbs of 1301, except the HF levels for HFC-227ea (when used alone) were unacceptable. However, HFC-227ea with bicarbonate of soda (BS or sodium bicarbonate) "suspended" (mixed) within the HFC required only 12 lbs of material (in four standard 144 in^3 extinguishers) for equivalent performance and reduced the HF to below detectable levels (BDL, < 35 ppm) in both the spray and ballistic tests. Engineering of the HFC-227ea/dry powder fire extinguishing system design must account for the safe operation over the required operating temperature range (-25 "F through 140°F) and the storage temperature range (-65°F through 160 "F). The temperature and heat flux data indicate that burn thresholds are not being exceeded under these scenarios for either the ballistic or the spray fire for those HFC-227ea/dry powder systems tested.

The results of a sample of six baseline tests are found in Table 2. Note that the data are consistent with what we expected to find in our environment: (I) The delivery of the agent is as or more important than the agent itself, and (2) the faster the fire is extinguished, the lower the byproduct levels (acid gases) are.

TABLE 2. PHASE I (W/O CLUTTER) BASELINE BALLISTIC TEST DATA.

Agent ‡	Total Weight (lbs.)	Bottle Config # x in'	IR fire-out (msec)	Video fire-out (msec)	2-Min Ave HF (ppm)	Peak HF (ppm)
Halon 1301	8.I	2 x 144	241 – 555	~ 202	1473 – 2205	unavailable
Halon 1301	10	3 x 144	161 – 384	120 – 368	316 – 995	1310
Halon 1301 + BS	10 + 0.3	3 x 144	440 – 3000	120 – 142	274 – 498	320
FM-200	11.9	2x144	reflash	220 – unk	19500 - 20.56 I	unavailable
FM-200	12.1	3x144	- 2200	250 – 980	1741 – 4473	unavailable
FM-200	14.7	3 x 144	2000 – 4000+	reflash	2x01 – 2933	12700
FM-200	15	4 x 144	211 – 234	200 – 320	947 – 1176	1360
FM-200 + BS	12.2 + 0.3	3 x 144	189–3.58	100 – 170	BDL	BDL

‡ – All agents used the "standard" Army equipment bottles, valves, and nozzles.
BDL – below detection limits, less than 35 ppm.

Several alternative concepts were evaluated under Phase I. They can be divided into five categories: fluorocarbons (i.e., HFCs and PFCs) with nitrogen overpressure, water spray with nitrogen overpressure, hybrid gas generators with HFCs, hybrid gas generators with water and novel distribution systems, e.g., wet main systems. Representative data are displayed in Table **3.** Various additives to inhibit freezing and enhance effectiveness of the water and to neutralize acid byproducts generated from the HFCs were also investigated.

TABLE 3. PHASE I (W/O CLUTTER) BALLISTIC TEST DATA.'

Agent – distribution system	Total Weight (lbs)	Bottle Config # x in³	IR fire-out (msec)	Video fire-out (msec)	I-Min Ave HF (ppm)
CEA-30X – ss	19.1	4 x 144	120–123	100 - 110	4600 – 4794
CEA-30X + BS –ss	19.4 + 0.5	4 x 144	157–181	120 – 150	1150 – 1784
FM-200 – ss	18.0	3 x 204	213 – 302	I06 – 200	2600 – 2900 ¥
FM-200 – gg	15.9	3 x 126	186 – 239	106–150	1410 – 6798 ¥
FM-200 + BS –ss	16.4 + 1.5	3 x 204	1X0 – 227	162 – 170	125 – 573
FM-200 + BS – gg	10 + 1.25	3 x x4	134–149	104–150	85 – 440
H_2O/KAce – gg	**33.6**	2 x 244	184 – 253	118 – 250	n/a
H_2O/KAce – gg	21	3 x 147.4	160 – 383	92 – 168	n/a
H_2O/KAce – wm	10.5	3 x 204	124 – 215	90 – 300	n/a

† – **Peak** HF values are **not** yet available for these tests.
¥ – 2 min average
ss – **standard** Army type system with nitrogen overpressure
gg – gas generator for agent expulsion
wm – wet main distribution system

Under Phase II, the following three primary trade-off concepts are being evaluated and testing should he completed by September 1999:

1. Wet-mains versus stand-alone extinguishers
2. Hybrid gas generators versus confined nitrogen expulsion
3. HFC-227ea/dry powder versus water/ potassium acetate

The Baseline data for Phase II are slightly different from those of Phase I (Table 4). The data demonstrate the increased difficulty of extinguishing deflagrations while moving the agent around clutter. They also point out that the distribution system is critical in the overall optimization process for a particular fire/explosion scenario.

TABLE 4. PHASE II (W/ CLUTTER) BASELINE TEST DATA.

Agent ‡	Total Weight (lbs)	Bottle Config # x in'	IR fire-out (msec)	Video fire-out (msec)	2-Min Ave HF (ppm)	Peak HF (ppm)
I30I	9.Y	3x144	777-1023	750-1000	2063	10348
130I	16	4x144	159-167	150-1X0	1789	3483
I30I	12	4x144	179-193	180-220	1472	2031
1301	10	4x144	189-268	220-250	1086	1302
FM-200	16	4x144 §	172-216	1XO-240	x44	1051
FM-200	12	4x144	185-220	190-260	I344	1636
FM-200 + BCS ✞	12+1	4x144	173-214	1xo-220	70	134

‡ – All agents used the "standard" Army equipment bottles, valves. and nozzles.
§ – bottles reoricntcd for **this** and subsequent tests
✞ – 0.25 lbs **of** sodiuni bicarbonate was added to each of the extinguishers.

Anomalies arise in the data for the Phase II baseline tests using Halon 1301 in the cluttered crew compartment. The HF data for halon appear suspect. However, the data can be explained by the increased ullage of nitrogen over the 1301 providing a mixing effect assisting the agent distribution around the manikins. This ability continues until the lack of agent forms a sharp reverse in the extinguishment trend. The data emphasize the "forgiveness" Halon I301 has as a fire extinguishing agent. No optimization of the standard system was done for the halon system with clutter. Therefore, 1believe we are seeing the optimization process of the 1301 system tested occurring within our data.

Please note also that the first line is a poorly distributed system (Table 4). There were only three 144 in^3 bottles versus the better distribution of a four-bottle system (see the fourth line). The effect is dramatically demonstrated by the peak HF concentration value being reduced by an order of magnitude and the halving of the 2 min average HF concentration.

Based on a statistically small number of trials of each system configuration and agent quantity, especially for the ballistic tests, the following trends are noted. Further testing is ongoing to develop sufficient sample sizes to define completely the system parameters for the most promising approaches.

- The spray fire scenario is a reproducible event and changes in configuration are relatively easy to assess. The fuel spray simulator is an inexpensive method for optimizing system performance prior to ballistic testing.
- Ballistic tests are much more variable than the spray tests. Multiple ballistic test firings are required per system configuration to get an accurate. overall assessment of system performance.
- After achieving a successful fire extinguishment concentration, adding additional HFC does not necessarily further reduce the fire-out time. but can lead to significant reductions in observed byproduct levels. This is shown best by the spray test fires.
- Discharging an acid scavenger along with the HFC can significantly reduce the HF levels, sometimes to BDL. As little as 5 wt.% by weight of acid scavenger added to the HFC or stored in the nozzle has shown dramatic reductions in overall F-ion (free available fluorine) production.
- Plain water sprays delivered using simple nitrogen overpressure (750 – 1000 psi) can suppress the initial fire event very quickly, but the fire typically reflashes within 1 sec.
- Select freeze point suppressants, such as 40 wt.% potassium acetate (KAce), can be added to the water sprays to improve efficacy, as well as permit low temperature storage and operation. Water/KAce solutions successfully inhibit reflash of the fire and retain the reduced fire-out times when a gas generator is used for agent expulsion. However, the electrical conductivity of these mixtures might preclude their use. Water/KAce solutions are highly conductive in the liquid form (up to seven times that of water). However, the solutions are used in the mist form for firefighting. As a mist, the solutions may not be a significant conductivity problem. Then again, the mist could condense on exposed electrical equipment and shorting might occur.
- Water/KAce solutions delivered via gas generator hybrids successfully inhibit reflash and operate faster than Halon 1301 systems using standard bottles with nitrogen overpressure. The cooling provided will function against a larger range of fire types and scenarios than 1301. Underwriters Laboratories has listed handheld water/KAce fire extinguishers for Class A, B and C fires. However, visibility reduction due to water/KAce fog production

needs to be addressed. Cleanup from the water/KAce type tests indicates that **a** method of cleanup different from that presently used in the MI Abrams will be needed.

- The delivery system, specifically, the number, location, and direction of distribution points (nozzles or orifices), their mass flow rate, and the agent travel length (time to individual flame fronts) are keys to evaluating the wet main concepts versus the stand alone extinguishers. Wet main systems might utilize the space between crewmen and the roof, making the old bottle space available for other uses. In turn, wet mains can become additional bump hazards. Each systcrn type should be evaluated for optimization within individual vehicle applications due to concerns outside of this research program.

FUTURE ACTIVITIES

A recommendation is required by September 1999 as to which replacement solution should be introduced into individual system testing in the affected vehiclcs or whether the Army must continue to rely on its halon reserve until additional agents become available for evaluation. Critical activities necessary to meet that objective include the following:

- Down-selected approaches are being tested in the crew fixture in Phase II with realistic vehicle clutter and space claim using Phase I ballistic threat and shot line. Additionally. temperature conditioning of agent containers is done to ensure performance at cold cxtremes. Design guidelines will be developcd to assist system integration efforts rcquired for Phase III.
- Freeze point suppressants, performance enhancement additives. acid byproduct scavengers, and agent misting techniques will be furthcr evaluated to minimize the space claim and retrofit impact of the candidate systems.
- Toxicology studies to bc completed by the Walter Reed Army Institute of Research will further refine the criteria for HF exposures. It is necessary to know the maximum exposures and duration that crewmen can tolerate without significantly degrading their performance or forcing them to abandon the vehicle.
- A fire model is under development for the crcw spray fire scenario. This is a joint effort between DoD, DOE. and Sandia National Labs to produce a verified design tool to predict the most probable outcome of a fire threat for any platform. An intermediate step should produce a model that includes crew compartment clutter. which will bc useful in the Phase III analyses.

SUMMARY

The Army is aggressively pursuing alternatives to halon in its last ground vehicle application — crew compartments of combat vehicles. By far, this application poses the greatest technical challenges because of the stringent performance, toxicological. and retrofit requirements involved. The research part of this program is in its last stages. A significant amount of work remains to be completed in the short time left beforc a decision will be made whether or not any of the current commercially available agents and technologies (with optimizations) is suitable for this application. Test results to date have been extremely encouraging. However. the most difficult testing with clutter still remains to be complctcd. After the clutter testing is complcte, optimization work is planned for the individual vehicle fleets (M1, M2/M3, FAASV, etc.) with their maximum credible threat scenarios.