CURRENT STATUS of the HALON REPLACEMENT PROGRAM for ARMY GROUND COMBAT VEHICLES

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1. INTRODUCTION

The Army uses Halon 1301 in three ground combat vehicle fire fighting applications: on-board handheld extinguishers; fixed fire extinguishing systems (FFES) for engine compartments, and explosion suppression systems for crew compartments. Separate concurrent programs for replacing Halon 1301 in these applications are underway.

Although combat vehicles typically have a large volume, interior volume is very limited and virtually all of the space is claimed. Any significant growth in volume of the fixed fire extinguishing systems will be at the expense of other on-board systems such as fuel, ammunition, etc. Increased space claims may also require re-design, relocation, and retrofit of adjacent unrelated systems, significantly increasing the retrofit costs. Logistic impacts may exceed the retrofit costs: the fixed systems are recharged and repaired in the field, so changes in agent, hardware, repair parts, tools, and recharging equipment may be required. The incentive to maximize the use of existing hardware while considerable, is secondary to minimizing space claim growth.

2. HAND-HELD EXTINGUISHER PROGRAM

The Army has selected 2.5-lb C02 hand-held extinguishers as replacements for the 2.75-lb Halon 1301 extinguishers currently in use in ground combat vehicles. Fit tests have been conducted and C02 concentration mapping in **8** different combat vehicles has been completed to provide data for health hazard assessments. Evaluation by the Army Surgeon General has recently been provided.

3. ENGINE COMPARTMENT PROGRAM

The engine compartment Halon replacement program was structured to encourage evaluation of a broad spectrum of replacements, and is not limited to a search for a "drop-in" replacement agent. While the primary objective is to identify a cost-effective replacement system for retrofit, knowledge of vehicle fire conditions and performance of candidate systems gained during the program will be applied to improving the fire survivability of future vehicles.

The Army Tank-automotive and Armaments Command (TACOM) issued a request for proposals in March **1994,** and awarded contracts for evaluation of six proposals with testing commencing in August **1994.** Additionally, two Cooperative Research and Development Agreements (CRDAs) were established between TACOM and industry, and several other commercially available fire extinguishing agents which were not proposed by industry, were purchased for evaluation.

A three phase approach was selected to focus the program by identifying unsuitable designs early and concentrating on those with greater potential for success.

Phase 1 includes basic contract requirements with an option for additional testing, and consists of screening of the candidates in a generic test fixture. Designs which showed potential for this application were awarded options in February 1995 for further testing. This testing is currently underway.

Contract requirements:

Extinguish the fires without reflash
Agent volume must be less than 1000 in^3 (200 in^3 desired)
Operating range must be -25" to +140° F (-60 to +160 desired)
Ozone Depletion Potential (ODP) must be less than 0.2 (0 desired)
Agent must not contain Class I or II ODP substances
Agent must be safe to handle and use
Minimal cleanup (air or low pressure water)
Non-corrosive

Phase 2 includes a contract option which consist of testing the successful Phase 1 designs in a combat vehicle with an operating engine. Also included in Phase 2 are off-line evaluations of toxicity, compatability, and stability as required.

Phase 3 consists of testing the prototype design(s) down-selected by the program managers for each combat vehicle.

The Phase 1 test fixture was built from an M60A3 tank hull and non-operational powerpack. Systems to induce airflow, simulate a hot fuel load, and simulate a fuel line leak onto a hot surface such as a turbocharger or exhaust manifold, were installed. Additional systems have been included to recover fuel and washdown water for recycle. Thermocouples, pressure and strain gages, airflow sensors and ports for video cameras were installed to monitor fixture and fire extinguishing system performance. The fixture is intended to be "generic" and represents typical combat vehicle operating conditions, not specifically M60 operating conditions.

Airflow rates on the order of 1 to 2 air exchanges per second are necessary to cool combat vehicle engine compartments. Since fuel is commonly stored in or adjacent to the engine compartment and may be recirculated to cool fuel injectors, fuel temperatures exceeding the flash point may result. Leaks in pressurized fuel or hydraulic lines and hoses caused by heat, vibration, poor maintenance or battle damage can produce hot fuel sprays onto exhaust manifolds or turbochargers, resulting in intense fires. Once extinguished, these fires may reignite if the extinguishant is drawn from the compartment before the engine can be shutdown.

It is Army practice that engine shutdown be "a conscious act of the crew", precluding automatic systems that stop the engine prior to activation of the extinguishing system.

To cover the range of possible operating conditions, six different types of test fires, representing spray and pool fires with and without airflow were defined:

Type 1 - combination fire w/ airflow
Type 2 - combination fire w/o airflow
Type 3 - bilge only w/ airflow
Type 4 - bilge only w/o airflow
Type 5 - fuel spray w/ airflow
Type 6 - fuel spray w/o airflow

JP-8, the NATO "universal" fuel, is used for all fires. Bilge fires are conducted with 8 gallons of fuel at ambient temperature, resulting in a pool area of approximately 21 ft^2. Fuel spray fires are conducted with the fuel heated above the flash point (approx 60°C); flow rates are approximately 1.1 gpm at 40 psi through a 1/8-in. diameter orifice onto a surface hot enough to insure autoignition (approx 650°C). For fire Types 1 thru 4, the bilge fire is allowed to burn for 3 minutes prior to extinguishant release or fuel spray initiation. The fuel spray is started 15 seconds prior to extinguishant release and continued for 30 seconds after release.

Candidate fire extinguishing systems are evaluated primarily against Type 2 and 3 fires. Since the ignition source and fuel spray for Type 1 and 5 fires are continuously available, and the extinguishant is rapidly removed by the airflow, these fires are almost impossible to extinguish unless sufficient extinguishant concentration can be maintained until the airflow or fuel spray are shut off. Types 4 and 6 are less severe than Types 3 and 2, respectively.

The Phase 1 test fixture performance is repeatable and Type 2 and 3 fires provide credible challenges to the fire extinguishing system. A 7-lb Halon 1301 fire extinguisher will repeatably extinguish a Type 3 fire when used with the standard distribution system; the same system charged with 6-lbs of Halon will not.

Nine types of fire extinguishants and/or extinguishing systems have been tested to date.

Iodoheptafluoropropane (C_3F_7I)
Powsus Gelled Agent (PGA)
Inert Gas Generator System
Hybrid Inert Gas Generator System (GG + water)
SFE Pyrotechnically Generated Aerosol
FM-200 (HFC-227ea)
FE-36 (HFC-236fa)
Dessikarb (Sodium bicarbonate based dry powder)
Water mist with additives

Initial Test Results

Figures 1 and 2 show relative performance by fire type, with comparisons to Halon 1301 and CO_2.

Iodocarbons were effective, however, due to toxicity concerns, no further testing is planned.

Gelled agent indicated potential, but the distribution system needs improvement. The design requires some changes to existing hardware and post-discharge cleanup is required. Further testing is planned.

Gas generators were unsuccessful against Type 3 fires; no further testing is planned. The hot, high pressure gases produced added heat to the fire zone and disturbed the fuel pool, intensifying the fire.

Hybrid gas generators indicated potential. The addition of a liquid agent which is vaporized by the hot gas reduces the temperature and pressure of the discharge, reducing the disturbance to the fuel pool. New hardware will be required.

Aerosols were unsuccessful against Type 4 fires; no further testing is planned. Although the agent appeared to be well dispersed throughout the compartment, apparently it was unable to penetrate the fire plume.

HFCs such as 227ea and 236fa were effective with standard hardware. Increased performance may be possible with improved hardware. Low temperature performance has not been assessed. Further testing is planned.

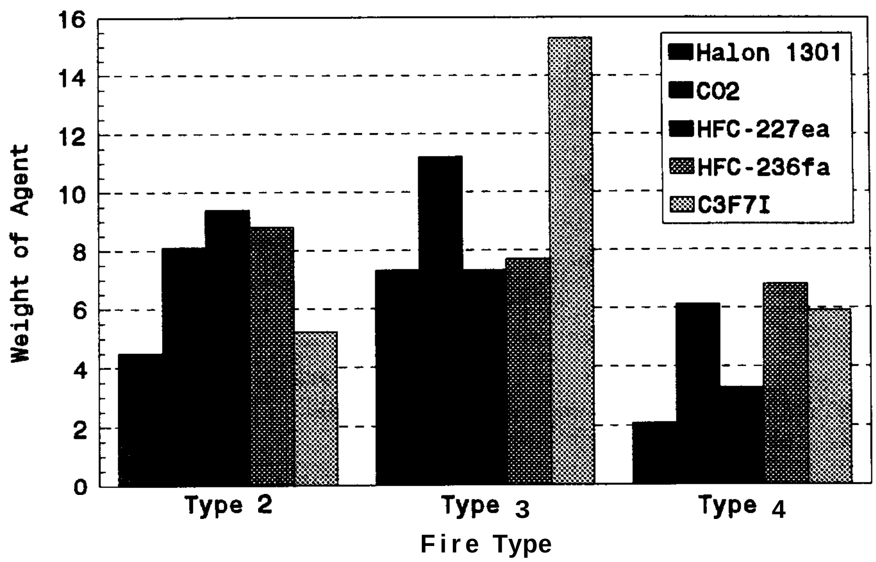
Dessikarb was effective, but the distribution system needs improvement. The design requires some changes to existing hardware and post-discharge cleanup is required. Additional testing is planned.

Water mist was effective. The long discharge time provides the best performance to date against Type 1 fires. New hardware will be required, and freezing and electrical conductivity are problems that must be addressed. Additives are being evaluated both for performance enhancement and freezing point suppression. Additional testing is planned.

The Phase 2 test fixture is currently under construction and is being built from a second M60A3 tank hull with an operating powerpack. Testing will be conducted under normal M60A3 operating conditions against Type 2 and 3 fires to assess candidate system performance in an actual combat vehicle. Modifications will include systems to simulate a hot fuel load (the engine fuel will be located off-board for safety reasons), and simulate a fuel

Engine Compartment Test Data

Weight of Agent Required for Extinguishment



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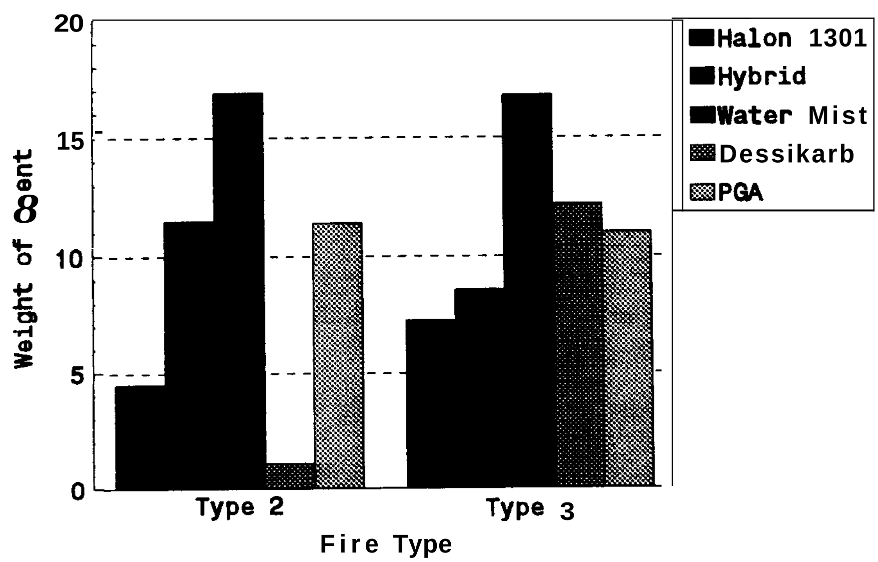

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line leak onto a hot surface. Protective measures will be taken to extend the life of vulnerable engine components; additional engines have been obtained from vehicles being demilitarized.

The Phase 3 testing of agents or systems which down-selected by the program managers based on Phase 2 results will be conducted in actual combat vehicles, with fire extinguishing systems specifically engineered for each vehicle. Modifications similar to the Phase 2 fixture will be made as required. Preliminary testing will be conducted to insure proper fit and agent distribution prior to efficacy tests.

Lessons Learned

The distribution system design is crucial to the performance of the fire extinguishing system:

a) Potential replacement fire extinguishing agents require more distribution system engineering than gaseous agents such as Halon or carbon dioxide, which readily fill the engine compartment.

b) Due to the complicated geometry of the engine compartment and the proximity of the nozzles to the fuel pool, the location and orientation of the discharge nozzles can greatly affect the amount of agent required to extinguish the fire. Improperly located nozzles can result in uneven coverage forcing the agent to "chase" the fire or disturb the fuel pool and intensify the fire. Achieving near simultaneous coverage of the entire compartment with minimal disturbance of the fuel pool is especially important when attempting to extinguish fires under high airflow conditions. With several systems tested, slight adjustments to the nozzles produced significantly improved performance.

c) Systems must be engineered for each application, and efficacy testing of the final design under different operating conditions is necessary to insure adequate performance. The test results show that agent performance is not constant across fire types (Fig 1 & 2). When used with the standard distribution rakes, higher boiling halocarbons such as FM-200 were approximately equivalent to Halon 1301 against Type 3 fires, but required more agent to extinguish Type 2 fires. Increasing the system pressure improved the vaporization, improving performance against Type 2 fires, but also increased the disturbance of the fuel pool, degrading performance against Type 3 and 4 fires.

d) Engine shutdown prior to agent release stops the airflow and fuel spray; all fires become type 4 fires. While attacking the fire as quickly as possible, automatic operation of engine compartment fire extinguishing systems places the greatest challenge on the agent.

e) Each service has significantly different operational conditions and performance requirements; aircraft, watercraft and armored vehicles pose unique extinguishment problems. Adequate performance of a fire extinguishing system in one application may or may not be adequate under other services conditions.

Conclusions

To date no agent has been identified as a suitable Halon 1301 replacement for ground combat vehicle engine compartments. All of the promising technologies have potential weaknesses that need to be assessed further, particularly performance at temperature extremes.

Distribution systems must be engineered for each vehicle and efficacy testing of the final design against different fire types is critical.

4. CREW COMPARTMENT PROGRAM

The performance requirements for fire protection systems for crew occupied areas are far more stringent than for engine compartments: the system must be capable of detecting and supressing the deflagration caused by ballistic penetration of a hydrocarbon fuel source before incapacitating injuries are produced. Crew casualty assessment criteria and test methodology for overpressure, toxic gases and thermal effects were developed by the Walter Reed Army Institute of Research (WRAIR) during congressionally mandated Live Fire testing of ground combat vehicles conducted during the 1980s (ref 1) and are currently being reviewed by the Army Medical Command for applicability to' this program. This methodology is designed to predict injury levels from test data. A satisfactory replacement system must be capable of preventing incapacitating injury to crew members from heat or toxic combustion products, including acidic decomposition products from halogenated fire extinguishants.

The crew compartment test fixture was built from a Bradley Fighting Vehicle hull. The interior volume is approximately 450 ft^3. Systems to induce airflow and simulate a hot fuel load were installed. Threat munitions are fired through a replaceable armor "window" in the hull into a 15-gallon fuel tank filled with 10-gallons of JP-8 fuel heated to approximately 65°C (150°F). A ''make" screen attached to the armor completes a circuit upon the penetration of the projectile or shaped charge jet, activating the extinguishers after a fixed time delay (approx 25-msec), to eliminate fire sensor performance as a variable. Pressurized hydraulic fluid reservoirs can be substituted for the fuel tanks. Pan fires simulating spilled fuel and three dimensional fires simulating leaking fuel fired heaters can also be conducted. The crew compartment includes ammunition containers and simulated missile launchers to provide representative stowage. A backup 1000-lb CO_2 system is installed to protect the test fixture.

Piezoresistive pressure gages are installed at several locations to measure peak and quasi-static overpressures. Fast response type K thermocouples to measure temperatures and heat flux gages to evaluate crew burn potential are installed in the compartment and at crewmember positions. Standard fire sensors and "referee" detectors are installed to assist in determining fire intensity and extinguishment times. Strain gages are mounted on the extinguishers to determine discharge rates. Interior and exterior standard and high speed (500 fps) video cameras record the test event and assist in determining fire intensity and extinguishment time. Sample collectors are included to determine the concentrations of combustion products.

The fixture is sealed and pressure tested before each trial and the leakage rate is adjusted to insure repeatable test conditions. The pressurizing blower can also be used to simulate a Nuclear, Biological and Chemical (NBC) overpressure system or ventilation blower.

Initially, the investigation will focus on currently available, total flooding fire extinguishants, such as HFC-227ea and HFC-23 in standard crew compartment extinguishers. Efforts will be concentrated on optimization of agent quantity and pressurization, extinguisher location and nozzle design. If necessary, additional testing with other agents such as PFC-410 and HFC-236fa will be conducted.

Several preliminary trials were conducted with limited instrumentation in late 1994 to assess the fixture integrity, shock levels on the instrumentation and the fuel tank design; extinguishers filled with HFC-227ea were included. With a programmed delay of 25 msec after penetration, extinguishment was achieved in approximately 250 msec. with **10** lbs **of** agent. In a second test, with a programmed delay of 500 msec., extinguishment was achieved within 800 msec. but a large fireball and copious quantities of thick black smoke were produced inside the vehicle. No combustion products were measured during these preliminary trials.

5. SUMMARY/STATUS

The handheld program is nearing completion: C02 extinguishers have been selected as Halon **1301** replacements for use in ground combat vehicles and contracts have been let for the initial quantities required; retrofits are scheduled to start this summer.

The engine compartment Phase II program is scheduled to commence in July 1995, with an agent down-select in 1996. Phase III will commence in 1996 leading to a final agent selection by the end of 1996.

The crew compartment fixture is complete and instrumentation checkout is underway. Agent distribution mapping and discharge time testing will commence shortly, followed by baseline testing with Halon 1301. The crew compartment program has agent decision points in 1996 for current generation extinguishants and in FY99 if additional extinguishants must be evaluated.

References:

1. Ripple, Gary R. and Mundie, Thomas G., Medical Evaluation of Nonfragment Injury Effects in Armored Vehicle Live Fire Tests. Instrumentation Requirements and Injury Criteria, Walter Reed Army Institute of Research, September 1989.