CREW COMPARTMENT HALON REPLACEMENT PROGRAM FOR AUTOMATIC FIRE EXTINGUISHING SYSTEMS (AFES): STATUS AND SUCCESSES

Steve McCormick
Damage Reduction Team Leader
U.S. Army Tank-Automotive Research, Development & Engineering Center
Warren, MI 48397-5000
mccormis@tacom.army.mil
586-753-2610
and
Mike Clauson
Damage Reduction, Engineer
U.S. Army Tank-Automotive
Research, Development & Engineering Center
Warren, MI 48397-5000
michael.john.clauson@us.army.mil
586-574-7654

ABSTRACT

The research program to identify alternatives to HALON 1301 in automatic fire extinguishing systems (AFES) of Army ground vehicles is complete. Three programs of record for halon replacements are in various stages of completeness, crew compartment, handheld and engine compartment. This paper focuses on the crew compartment replacement program for AFES and its status.

Different AFES design solutions were found that could satisfy the requirements of the crew replacement program. None of the agents tested are considered a "drop-in" for the agent into existing vehicle distribution systems. Testing dramatically demonstrated that the ability of any AFES to extinguish combustion is dependant on the agent properties and the distribution system.

The test results, based on the optimizations of individual materiel, gives the Project Executive Office or Project Manager (buyer) a choice for fire extinguishing within vehicle crew compartments. The two most efficacious concepts were an HFC (FM-200, equivalent) with 5% dry powder and a water based extinguishing system to replace the crew halon AFES.

The crew compartment halon AFES replacement program is in process for 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.

CREW COMPARTMENT PROGRAM

With the exception of the former Soviet Bloc countries, Halon 1301 has been the agent of choice to protect vehicle crewmen against burns from ballistically-initiated fuel or hydraulic fluid fires. The US Army currently has three fielded ground vehicles using Halon 1301 to protect their crew compartments: the M1 Abrams main battle tank, the M2/M3 Bradley Fighting Vehicle, and the M992 Field Artillery Ammunition Support Vehicle (FAASV). The crew compartments of these vehicles range in volume from 250 to 700 ft^3 and employ from seven pounds of halon 1301 in a single shot to 21 pounds in each of two shots. We also must consider future ground combat vehicles with crew protection, including the Crusader, the Interim Armored Vehicle (IAV), the Future Combat System, and the US Marine Corps Advanced Amphibious Assault Vehicle (AAAV).

The Army Surgeon General has established the guidelines shown in Table I as the minimum acceptable requirements of automatic fire extinguishing systems for occupied vehicle compartments. These parameters have been established at levels that would not result in incapacitation of the crewmen from the fire and its extinguishment, allowing them to take corrective action and potentially to continue their mission.

Table I. Crew Survivability Criteria

PARAMETER	REQUIREMENT
Fire Suppression	Extinguish all flames without re-flash
Skin Burns	Less than second degree burns (<2400°F-sec over 10 seconds or heat flux < 3.9 cal/cm^2)
Overpressure	Less than 11.6 psi
Agent concentration	Not to exceed LOAEL*
Acid gasses	Less than 1,000 ppm peak
Oxygen levels	Not below 16 %

* LOAEL – Lowest Observed Adverse Effects Level

The Army's crew compartment test program was divided into three phases. Phase I was a proof of concept and a screening phase of multiple agents and technologies. Phase II consisted of further developmental testing of several of the most promising concepts from Phase I. Testing was conducted at the Army's Aberdeen Test Center in Aberdeen, Maryland.

Based on performance and system integration issues, two agents were recommended to the vehicle program managers for Phase III testing, where prototype fire extinguishing systems re to be evaluated in the affected ground vehicles.

TEST SETUP

The crew test fixture was constructed from an excess ground vehicle hull and turret. A top down layout of the fixture is shown in Figure 2, below. The fixture had an interior volume of approximately 450 ft^3 empty as used in Phase I testing. For Phase II, three "tin" mannequins and a four-unit TOW missile rack (added in dashed lines) were added to simulate partial vehicle stowage. The cargo and turret hatches and ramp door were secured during each test while the driver's hatch was allowed to pop open to relieve internal overpressures while minimizing airflow.

Instrumentation included high-speed and standard video, 1-micron infrared detectors, heat flux gages, thermocouples, and pressure gages. Four types of instrumentation measured acid gas exposure levels: ion selective electrodes (grab bag sampling), sorbent tubes (NIOSH procedure 7903), midget impingers, and FT-IR analyzers. The FT-IR was the only one of these methods that reported levels of the gases themselves, as opposed to fluorine or bromine ions. Gas species tested for included oxygen (as O_2), hydrogen fluoride (HF), hydrogen bromide (HBr), and carbonyl fluoride (COF_2). Nitrogen oxide (NO), nitrogen dioxide (NO_2), carbon oxide (CO), and carbon dioxide (CO_2) levels were also monitored during certain gas generator tests.

Two test scenarios were conducted in Phases I and II: fuel spray fires and ballistic penetrations. The spray fire was generated with approximately 0.3 gallons of JP-8 heated to 180-190°F and pressurized to 1200 psi using a specially designed nozzle. Fuel flow continued for approximately 1.2 seconds with the igniter energized for the duration of the spray to simulate the re-ignition sources present during a typical ballistic event. The spray fires were monitored with three one-micron infrared detectors. The extinguishing system was activated automatically after an 11-millisecond delay from the time the fire energy reached a predetermined threshold. Ballistic fires were generated by firing a 2.7 inch shaped charge through an 18.7 gallon (2.25 ft^3) capacity aluminum fuel cell filled with 11 gallons of JP-8 heated to 165°F. The fire extinguishing system was activated 25 milliseconds after warhead initiation to eliminate the variability of the detection system.

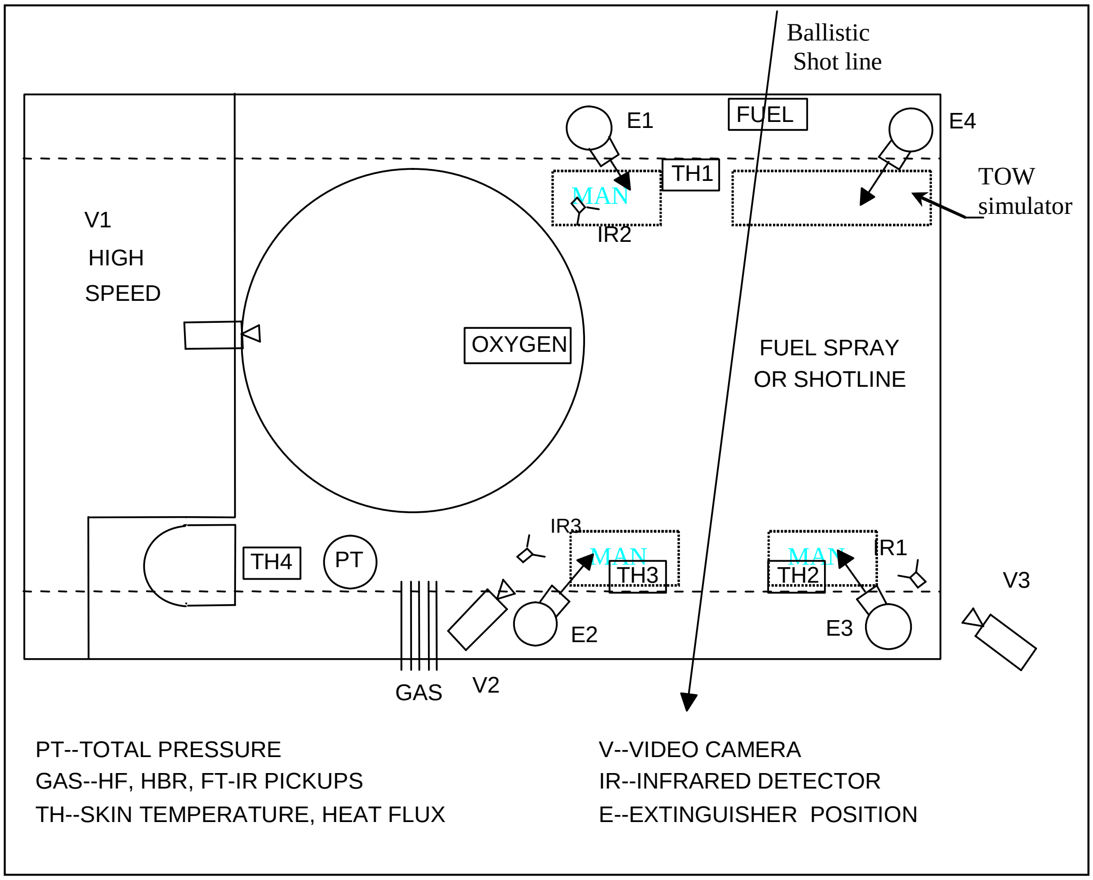


Figure 2. Crew Compartment Test Fixture.

PHASE I RESULTS

A sample of baseline test results is found in Table II. The data are consistent with two trends that we expect to find in this environment:

1) Delivery of the agent is as important, or more so, than the agent itself, and
2) The faster the fire is extinguished, the lower the by-product levels (acid gases) are.

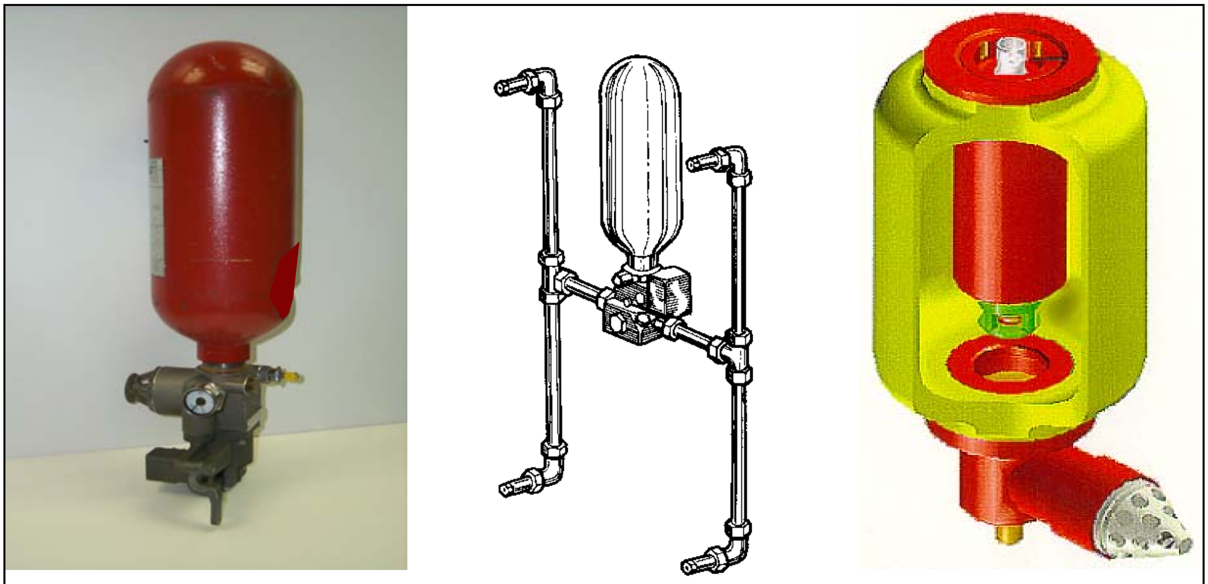
Several alternative concepts were also evaluated under Phase I. They can be divided into five categories: fluorocarbons (i.e., HFCs and PFCs) with nitrogen overpressure, water spray with nitrogen overpressure, hybrid gas generators with HFCs, hybrid gas generators with water, and novel distribution systems (e.g. wet main systems). Typical distribution systems are illustrated in Figure 2.

Various additives to inhibit freezing and enhance effectiveness of the water and to neutralize acid byproducts generated from the HFCs were also investigated. Representative data are displayed in Table V for several of the configurations tested. Thermocouple and heat flux data indicate that burn thresholds are not being exceeded under these scenarios for either the ballistic or the spray fire for the HFC-227ea/dry powder systems.

Table II. Phase I (w/o clutter) Baseline Ballistic Test Data

Agent ‡	Total Weight (lbs.)	Bottle Config # x in^3	IR fire-outs (msec)	Video fire-outs (msec)	2-Min Avg. HF (ppm)	Peak HF (ppm)
Halon 1301	8.1	2 x 144	241 – 555	~ 202	1500 – 2200	Unavailable
Halon 1301	10.0	3 x 144	161 – 384	120 – 368	300 – 1000	1300
Halon 1301 + BCS	10.0 + 0.3	3 x 144	440 – 3000	120 – 142	300 – 500	600
FM-200	11.9	2 x 144	Reflash	220 – unk	19500 –20600	Unavailable
FM-200	12.1	3 x 144	~ 2200	250 – 980	1700 – 4500	Unavailable
FM-200	14.7	3 x 144	2000 – 4000+	reflash	2800 – 3000	12700
FM-200	15.0	4 x 144	211 – 234	200 – 320	900 – 1200	1400
FM-200 + BCS	12.2 + 0.3	3 x 144	189 – 358	100 – 170	BDL	BDL

‡ - All tests used the ‘standard’ Army extinguishers and nozzles with N_2 overpressure.
BCS - bicarbonate of soda powder added to liquid agent
BDL - below detection limits (less than 35 ppm)



Nitrogen **Wet Main** **Hybrid**

Figure 3. Candidate Agent Delivery Methods

Table III. Phase I (w/o clutter) Ballistic Test Data

Agent / Distribution system	Total Weight (lbs.)	Bottle Config. # x in^3	IR Fire-out (msec)	Video Fire-out (msec)	1-Min Avg. HF (ppm)
CEA-308 – ss	19.1	4 x 144	120 – 123	100 - 110	4600 – 4800
CEA-308 + BCS – ss	19.4 + 0.5	4 x 144	157 – 181	120 – 150	1150 – 1800
FM-200 – ss	18.0	3 x 204	213 – 302	106 – 200	2600 – 2900 ¥
FM-200 – gg	15.9	3 x 126	186 – 239	106 – 150	1400 – 6800 ¥
FM-200 + BCS –ss	16.4 + 1.5	3 x 204	180 – 227	162 – 170	100 – 600
FM-200 + BCS – gg	10.0 + 1.25	3 x 84	134 – 149	104 – 150	100 – 400
H2O/Kace – gg	33.6	2 x 244	184 – 253	118 – 250	n/a
H2O/Kace – gg	21.0	3 x 147	160 – 383	92 – 168	n/a
H2O/KAce – wm	10.5	3 x 204	124 – 215	90 – 300	n/a

¥ - two minute average
ss – standard Army system with nitrogen overpressure
gg – gas generator for agent expulsion
wm – wet main distribution system

PHASE II RESULTS

The baseline tests of Phase I using standard Army extinguishers were repeated with clutter and the results are shown in Table IV. As can be seen by comparing tables II and III, the clutter increased the fire suppression challenge. Based on the results of Phase I and guidance from the EPA Significant New Alternatives Policy (SNAP) program, wet mains and hybrid gas generators, and combinations thereof, and HFC-227ea/dry powder and water/potassium acetate agents were selected for further evaluation in Phase II.

Table IV. Phase II (w/clutter) Baseline Test Data

Agent ‡	Total Wt (lbs)	Bottle # x in^3	IR Fire- (msec)	Video Fire-Out (msec)	2-Min Avg. HF (ppm)	Peak HF (ppm)
1301	9.9	3x144	777-1023	750-1000	2100	10300
1301	16	4x144	159-167	150-180	1800	3500
1301	12	4x144	179-193	180-220	1500	2000
1301	10	4x144	189-268	220-250	1100	1300
FM-200	16	4x144 §	172-216	180-240	800	1100
FM-200	12	4x144	185-220	190-260	1300	1600
FM-200+BCS ✞	12+1	4x144	173-214	180-220	70	150

‡ - All tests used the ‘standard’ Army equipment bottles, valves and nozzles.
§ - bottles reoriented for this and subsequent tests
✞ - 0.25 pound of sodium bicarbonate was added to each extinguisher.

Representative results of the Phase II ballistic tests with clutter are shown in Table V. Note that the improved distribution systems accounted for reduced extinguishing times and lower HF levels even while using less agent and/or fewer extinguishers. Even for those tests with extended extinguishing times the byproduct levels were significantly lower than for equivalent tests in Phase I or baseline tests of Phase II.

Table V. Phase II (w/clutter) Ballistic Test Data

Agent /Delivery System	Total Wt (lbs)	Bottle # x in^3	IR Fire- (msec)	Video Fire-Out (msec)	2-Min Avg. HF (ppm)	Peak HF (ppm)
FM-200 - gg	18.0	3x195	93-96	92-140	320	330
FM-200 - gg	18.0	3x195	106-135	86-210	230	950
FM-200 + BCS - gg	18.0+0.6	2x192	159-188	152-180	50	70
FM-200 + BCS - gg	15.0+0.6	2x195	34-385	450	330	380
FM-200 + BCS - gg	12.0+0.6	2x142	277-431	400-730	560	790
FM-200 - wm	16.2	Wet main	407-937	784-1000	1500	2100
FM-200+BCS - wm	11.2+0.8	Wet main	1272-1656	810-1290	700	1300
H_2O/Kace - gg	10.2	3x142	136-156	124-200	n/a	n/a
H_2O/Kace - gg	10.2	3x142	180-245	102-350	n/a	n/a
H_2O/Kace – wm	24.0 *	Wet main	221-317	260-650	n/a	n/a

gg – gas generator for agent expulsion
wm – wet main distribution system
* - discharge extended well beyond extinguishing time

PHASE II OBSERVATIONS

Baseline tests with Halon 1301 and HFC-227ea using standard Army extinguishers and nozzles indicate that a total agent weight of ten pounds 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 pounds of HFC-227ea provided approximately equivalent performance except the HF levels were elevated. However, HFC-227ea with a small amount of sodium bicarbonate imbedded or ‘suspended’ within the HFC required only 12 pounds of material (divided between four standard 144 in^3 extinguishers) and dramatically reduced the HF in both the spray and ballistic tests. Temperature and heat flux data indicate that burn thresholds were not exceeded for either the ballistic or the spray fires for the HFC-227ea/dry powder systems tested.

The baseline data for Phase II is slightly different than that of Phase I (see Table IV). The data demonstrate the increased difficulty of extinguishing deflagrations while distributing the agent around clutter. It also points out the agent delivery system is critical in the overall optimization process for a particular fire/explosion scenario. Please note that the first line of data represents a poorly distributed system. There were only three 144 in^3 bottles versus the better distribution of a four bottle system (see the 4th 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-minute average HF concentration.

The following trends were observed:

- 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.

- Discharging an acid scavenger along with the HFC can significantly reduce the HF levels, sometimes to below detectable levels. As little as 5 % by weight added to the HFC or stored in the nozzle has shown dramatic reductions in overall HF production. Overall, the BCS reduced the byproducts by an average of 50% independent of the delivery system used.

- The hybrid gas generators provide faster and more consistent discharges than the nitrogen overpressure system. This can result in faster fire-out times and significantly lower byproduct levels.

- Plain water sprays can suppress the initial fire event, but the fire typically reflashes within one second using simple nitrogen overpressure for agent expulsion. Freeze point suppressants (such as potassium acetate) can be added to the water sprays.

- Water/salt solutions successfully inhibit reflash of the fire and substantially reduce fire out times. These solutions can be highly conductive in the liquid form (up to seven times that of water), but they may not be a significant conductivity problem when misted.

- Water/anti-freeze solutions delivered using gas generator hybrids successfully inhibit reflash and operate faster than Halon 1301 systems, providing cooling and operation against class A and B fires. Visibility reduction due to water/anti-freeze fog production and clean-up issues need to be further addressed.

Performance equivalent to halon 1301 can be achieved with available agents and delivery system technologies. Crew survivability criteria have been satisfied against ballistic fires with HFC-227ea concentrations well below accepted exposure limits. Adding small amounts of sodium bicarbonate powder to the HFC reduces acid gas formation by half. Water mist with potassium acetate salt also proved to be very effective with no concern of hazardous byproducts and simple cleanup. Hybrid gas generators offer a smaller overall envelope for the same agent weight, pressure on demand, and a more consistent agent discharge. Wet mains allow the agent to be prepositioned for very rapid agent dispersion and offer the flexibility of nozzle locations.

Therefore, the following two agents were recommended to the ground vehicle program managers for crew compartment explosion suppression in December 1999:

1) HFC-227ea with 5% sodium bicarbonate powder by weight added to minimize HF

2) A 50/50 blend of water and potassium acetate by weight to suppress the freeze point to below -60°F and to enhance suppression capability.

Because these agents don't vaporize as readily as 1301, more sophisticated delivery systems than the standard extinguisher with nitrogen overpressure may be required in certain vehicle applications. Other trade-offs must also be considered before final agent and distribution hardware decisions can be made. These include system integration and retrofit impacts, initial purchase and sustainment costs, maintenance burden, long-term environmental impacts and policies, and the viability of the Army's halon reserve.

PHASE III

Priority and focus of the crew halon replacement program have been on vehicles under development. The Stryker vehicle is the first combat vehicle newly developed for the Army since the phase-out of halon production. Based on the results of phase II, FM-200/powder agent was chosen for use in the Stryker crew compartment. This system and agent have successfully completed live-fire testing and now set the standard for future vehicles such as the Future Combat System (FCS) and defines the retrofit impact for current legacy vehicles including M1 Abrams, M2/M3 Bradley and M992 FAASV. The cost of retrofit versus current logistics costs is driving the decision to have the legacy systems rely on the Halon reserve stockpiles. While commonality is a goal, along with environmental stewardship, it is more cost-effective to consume the existing Halon reserve (a sunk cost) and then retrofit the legacy systems if/when Halon 1301 is no longer available or approved for use.

APPLICATIONS

The following table gives examples of alternatives to halon 1301 that have been applied to Army ground vehicles:

Application	Extinguisher type	Use example
Hand Held Extinguishers	CO_2 H_2O + acetate	Bradley Abrams
Engine Compartment	FM-200 FE-25 Dry Powder	Bradley FV Stryker Abrams
Crew Compartment	FM-200 + powder Hybrid dist. H_2O	Stryker

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.
- **Anthony (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)
- **Ronald Sheinson**, and
- **Alexander Maranghides,** Navy Research Laboratory, Navy Technology Center for Safety and Survivability Combustion Dynamics Section, Code 6185, Naval Research Laboratory Washington, DC

REFERENCE CITATIONS

- National Fire Protection Association handbook, 14th ed. . Gordon P. McKinnon Boston, MA ; 1976
- Evaluation of Halon Alternatives. . Robin, M. L. ; 1991
- Fine Water Sprays for Fire Protection: A Halon Replacement Option. . Papavergos, P. G. ; 1991
- Advanced Streaming Agent Program. . Skaggs, S. R. ; Dierdorf, D. S. ; Moore, T. A. ; 1994
- Scientific Assessment of Ozone Depletion. .National Oceanic and Atmospheric Admininstration, et al ; 1994
- Comparison of Methods for Measuring Hydrogen Fluoride Gas as a Fire Suppression By-Product. . Hoke, S. H. ; Clay, M. L. ; McNesby, K. L. ; Miser, C. S. ; Leonnig, M. K. ; Polyanski, S. ; Herud, C. ; Bolt, W. ; 1997

- Crew Compartment Alternate Agent Test Program. . Polyanski, S. ; Bolt, W. ; Herud, C. ; 1997
- Current Status of the Halon Replacement Program for Army Ground Combat Vehicles. . Bolt, W. ; Erdley, D. ; Herud, C. ; McCormick, S. ; 1995
- Decomposition Product Analysis of Halon Replacements: An Interlaboratory Comparison. . Moore, T. A. ; Dierdorf, D. ; Hanauska, C. ; 1994
- Development of Fire and Suppression Models for DOD Vehicle Compartments: Background, Objectives, and Methodology. . Gritzo, L. A. ; Tucker, J. R. ; Ash, L. ; 1999
- Diodie Laser-Based Sensor for Fast Measurement of Binary Gas Mixtures. . McNesby, K. L. ; Skaggs, R. R. ; Morris, J. B. ; Kennedy, B. ; Miziolek, A. W. ; Jackson, W. M. ; McLaren, I. A. ; 1999
- Effects of Obstruction on Flame Suppression Efficiency. . Takahashi, F. ; Schmoll, W. J. ; Strader, E. A. ; Belovich, V. M. ; 1999
- Evaluation and Testing of Clean Agents for U.S. Army Combat Vehicle Portable Fire Extinguishers. . Moore, T. A. ; Lifke, J. L. ; 1997
- Evaluation of Alternative Agents for Suppression of Fuel Spray Explosions in Military Vehicle Crew Compartments. . Chattaway, A. ; Dunster, R. G. ; Spring, D. J. ; 1999
- Evaluation of Non-Pyrotechnically Generated Aerosols as Fire Suppressants. . Chattaway, A. ; Dunster, R. G. ; Gall, R. ; Spring, D. J. ; 1995
- Fire Suppression Testing of HFC-125, CF3I, and IG-541 for Fire Protection in Engine Compartments of Armoured Vehicles. . Su, J. Z. ; Kim, A. K. ; Liu, Z. G. ; Crampton, G. P. ; Kanabus-Kaminska, M. ; 1998
- Fire-Extinguishing Powders. . Finnerty, A. E. ; VandeKieft, L. J. ; 1997
- Further Advances in the Development of Hybrid Fire Extinguisher Technology. . Lu, Y. C. ; Wierenga, P. ; 2000
- Halon Replacement Program for Combat Vehicles: A Status Report. . Bolt, W. ; Herud, C. ; Treanor, T. ; McCormick, S. ; 1996
- Halon Replacement Program for Combat Vehicles: A Status Report. . Bolt, W. ; Herud, C. ; Treanor, T. ; McCormick, S. ; 1997
- Investigation of Extinguishment by Thermal Agents Using Detailed Chemical Modeling of Opposed-Flow Diffusion Flames. . Pitts, W. M. ; Blevins, L. G. ; 1999
- Issues in Numerical Simulation of Fire Suppression. . Tieszen, S. R. ; Lopez, A. R. ; 1999
- Laboratory Optimization and Medium-Scale Screening of Iodide Salts and Water Mixtures. . Moore, T. A. ; Weitz, C. A. ; McCormick, S. ; Caluson (Clauson), M. S. ; 1996
- Nitrogen Gas as a Halon Replacement. . Moore, T. A. ; Yamada, N. A. ; 1998
- Novel Device for Disseminating Fire Extinguishing Agents. . Peregino, P. J., II ; Finnerty, A. E. ; Hillstrom, W. ; vandeKieft, L. J. ; 1997
- Novel Device for Disseminating Fire Extinguishing Agents. Part 2. . Peregino, P. J., II ; Finnerty, A. E. ; VandeKieft, L. J. ; 1998

- n-Propyl Bromide and Bromoalkane Testing. . Moore, T. A. ; Lifke, J. L. ; 1998
- Perfluorohexane Clean Extinguishing Agent for Streaming and Local Application systems. . Pignato, J. A., Jr. ; Ruffing, J. F. ; 1994
- Reduced HF Production With the Use of Additives. . MacElwee, D. B. ; Skaggs, R. R. ; Horton, D. ; Moore, T. A. ; 1999
- Spectroscopic Studies of Inhibited Opposed-Flow Propane/Air Flames. . Skaggs, R. R. ; Daniel, R. G. ; Miziolek, A. W. ; McNesby, K. L. ; Babushok, V. I. ; Tsang, W. ; Smooke, M. D. ; 1999
- Suppressant Performance Evaluation in a Baffle-Stabilized Pool Fire. . Grosshandler, W. L. ; Donnelly, M. K. ; Charagundla, S. R. ; Presser, C. ; 1999
- Suppression Effectiveness Screening for Impulsively Discharged Agents. . Grosshandler, W. L. ; Hamins, A. ; Charagundla, S. R. ; 2000
- Suppression Mechanisms of Alkali Metal Compounds. . Williams, B. A. ; Fleming, J. W. ; 1999
- Tropodegradable Halocarbons and Main Group Element Compounds. . Mather, J. D. ; Tapscott, R. E. ; 1999
- U.S. Army Ground Vehicle Crew Compartment Halon Replacement Program. . Polyanski, S. ; McCormick, S. ; Clauson, M. S. ; 1998
- U.S. Army Ground Vehicle Crew Compartment Halon Replacement Program. . McCormick, S. ; Clauson, M. S. ; Cross, H. M. S. ; 2000
- U.S. Army Ground Vehicle Halon Replacement Programs. . McCormick, S. ; Clauson, M. S. ; Cross, H. M. S. ; 1999
- U.S. Army Ground Vehicle Halon Replacement Programs. . McCormick, S. ; Clauson, M. S. ; Cross, H. M. S. ; 1999
- Update on Water as a Three-Dimensional Fire-Extinguishing Agent. . Peregino, P. J., II ; Finnerty, A. E. ; VandeKieft, L. J. ; 1999
- Update on Water as a Three-Dimensional Fire-Extinguishing Agent. . Peregino, P. J., II ; Finnerty, A. E. ; VandeKieft, L. J. ; 1999
- Metabolism and Pharmacokinetics of Halon 1211 and Its Potential Replacements HCFC-123 and Perfluorohexane. . Brashear, W. T. ; Vinegar, A. ; 1992
- Inerting of Methane-Air Mixutres by Halon 1301 (CF3Br) and Halon Substitutes. . Zlochower, I. A. ; Hertzberg, M. A. ; 1991
- Control of Aircraft Post-Crash Spilled Fuel Burning Through Vapor-Phase Inerting. . Wright, B. R. ; Zallen, D. M. ; 1992
- Fire Suppression and Inertion Testing of Halon 1301 Replacement Agents. . Heinonen, E. W. ; Skaggs, S. R. ; 1992
- Technical Assessment for the SNAP Program. . Skaggs, S. R. ; Tapscott, R. E. ; Moore, T. A. ; 1992

- Alternative Agent Combustion Product Formation, flame Suppression and Flammability Characteristics. . Holmstedt, G. ; Andersson, J. ; 1993
- Propane Inerting Concertrations of Two Halon Replacement Gases Blended With Nitrogen. . Zalosh, R. ; Edwards, R. J. ; 1994
- Simulation Studies of the Influence of Fluorine and Bromine Containing Fire Suppressants on Ignition Behavior. . Babushok, V. I. ; Burgess, D. R. F., Jr. ; Tsang, W. ; Miziolek, A. W. ; 1994
- Investigation of the Energy Content of High Voltage Ignition Sources. . Heinonen, E. W. ; Crawford, J. F. ; 1995
- Methods Development for Measuring and Classifying Flammability/Combustibility. . Heinonen, E. W. ; Tapscott, R. E. ; 1995
- Phosphorus Nitrides as Fire Extinguishing Agents. . Skaggs, S. R. ; Kaizerman, J. ; Tapscott, R. E. ; 1995
- Water Vapor as an Inerting Agent. . Dlugogorski, B. Z. ; Hichens, R. K. ; Kennedy, E. M. ; Bozzelli, J. W. ; 1997
- Fuel Inertion Live Munitions Testing Using CF3I. . VanHorn, S. R. ; Vitali, J. A. ; 1999
- Gas Phase Combustion Suppression of Various Fuels By CF3I. . Glass, S. ; Dhooge, P. ; Nimitz, J. S. ; 1999
- Evaluation of Advanced Agent Working Group Agents by Kidde. . Grigg, J. ; Chattaway, A. ; 2001
- Determination of CF3J Inerting Concentration Methane-Air and Heptane-Air Mixtures. . Lisochkin, Y. A. ; Poznyak, V. I. ; Belevtcev, E. ; 2002
- FIREPASS: New Technology for Total Flood Applications. . Kotliar, G. K. ; Currin, J. D. ; 2003
- Influence of the Ignition Source Energy on the Experimental Values of Some Halons Inerting Concentrations. . Lisochkin, Y. A. ; Poznyak, V. I. ; Belevtcev, E. ; Kunina, L. N. ; 2003
- Halon Replacement Agent Testing: Procedures, Pitfalls and Interpretation. . Baldwin, S. P. ; Brown, R. ; Burchell, H. A. ; Driscoll, D. C. ; Eaton, H. C. ; Salmon, G. ; St. Aubin, J. ; Sheinson, R. S. ; Smith, W. D. ; 1992
- Modes of Chemical Suppression Action: Guidance for Agent Evaluation. . Sheinson, R. S. ; Baldwin, S. P. ; 1993
- Total Flooding Fire Suppressant Testing in a 56 m3 (200 ft3) Compartment. . Sheinson, R. S. ; Eaton, H. G. ; Black, B. H. ; Brown, R. ; Burchell, H. A. ; Salmon, G. ; St. Aubin, J. ; Smith, W. D. ; 1993
- Development of a Computer Model to Predict the Transient Discharge Characteristics of Halon Alternatives. . Bird, E. B. ; Giesecke, H. D. ; Hillaert, J. A. ; Friderichs, T. J. ; Sheinson, R. S. ; 1994
- Development of Computer Models for the Discharge of Halon Alternatives. . Kim, S. K. ; Lestina, T. J. ; Giesecke, H. D. ; Sheinson, R. S. ; 1994

- Halon 1301 Replacement Total Flooding Fire Testing, Intermediate Scale. . Sheinson, R. S. ; Eaton, H. G. ; Black, B. H. ; Brown, R. ; Burchell, H. A. ; Maranghides, A. ; Mitchell, C. ; Salmon, G. ; Smith, W. D. ; 1994
- Intermediate Scale Fire Extinguishment by Pyrogenic Solid Aerosol. . Sheinson, R. S. ; Eaton, H. G. ; Zalosh, R. ; Black, B. H. ; Brown, R. ; Burchell, H. A. ; Salmon, G. ; Smith, W. D. ; 1994
- Fire Extinction System Selection Criteria. . Sheinson, R. S. ; Maranghides, A. ; 1995
- Halon Replacement Research at the Naval Research Laboratory. . Fleming, J. W. ; Papas, P. ; Sheinson, R. S. ; 1995
- Large Scale (840 m3) HFC Total Flooding Fire Extinguishment Results. . Sheinson, R. S. ; Maranghides, A. ; Eaton, H. G. ; Barylski, D. ; Black, B. H. ; Brown, R. ; Burchell, H. A. ; Byrne, P. ; Friderichs, T. J. ; Mitchell, C. ; Peatross, M. J. ; Salmon, G. ; Smith, W. D. ; Williams, F. W. ; 1995
- Physical and Chemical Characteristics of SFE Fire Suppressant Atmospheres: Comparison of Small With Large Scale Laboratory Atmospheres. . Kimmel, E. C. ; Smith, E. A. ; Reboulet, J. E. ; Black, B. H. ; Sheinson, R. S. ; Carpenter, R. L. ; 1995
- Results of Benchmark Comparisons of Calculated and Measured Flow Parameters for Discharges of Halon Replacement Chemicals. . Bird, E. B. ; Giesecke, H. D. ; Friderichs, T. J. ; Maranghides, A. ; Sheinson, R. S. ; 1995
- Total Flooding Agent Distrubiton Considerations. . Maranghides, A. ; Sheinson, R. S. ; Barylski, D. ; Black, B. H. ; Friderichs, T. J. ; Peatross, M. J. ; Smith, W. D. ; 1995
- Conducting Real Scale Halon Replacement Tests Aboard the ex-USS SHADWELL: Overall Test Design. . Peatross, M. J. ; Maranghides, A. ; Sheinson, R. S. ; Black, B. H. ; Smith, W. D. ; 1996
- Discharge System Modifications: Real Scale Halon 1301 Replacement Testing. . Maranghides, A. ; Black, B. H. ; Sheinson, R. S. ; Friderichs, T. J. ; Peatross, M. J. ; 1996
- Effects of a Water Spray Cooling System During Real Scale Halon 1301 Replacement Testing on Post Fire Suppression Compartment Reclamation. . Maranghides, A. ; Sheinson, R. S. ; Black, B. H. ; Peatross, M. J. ; Smith, W. D. ; 1996
- Real Scale Halon Replacement Testing Aboard the ex-USS SHADWELL: Phase 2. Post Fire Suppression Compartment Characterization. . Black, B. H. ; Maranghides, A. ; Sheinson, R. S. ; Peatross, M. J. ; Smith, W. D. ; 1996
- Cup Burner as a Suppression Mechanism Research Tool: Results, Interpretations, and Implications. . Sheinson, R. S. ; Maranghides, A. ; 1997
- Extinction Studies of Hydrofluorocarons in Methane/Air and Propane/Air Counterflow Diffusion Flames: The Role of the CF3 Radical. . Williams, B. A. ; Fleming, J. W. ; Sheinson, R. S. ; 1997
- Flammable Liquid Storeroom Halon 1301 Replacement Testing. Phase 1. Preliminary Results. . Maranghides, A. ; Black, B. H. ; Sheinson, R. S. ; Darwin, R. L. ; 1997

- Flammable Liquid Storeroom Halon 1301 Replacement Testing. Phase 1. Testbed Design and Instrumentation. . Black, B. H. ; Maranghides, A. ; Sheinson, R. S. ; Darwin, R. L. ; 1997
- Real Scale Halon Replacement Testing Aboard the ex-USS SHADWELL: Phase 2. Post Fire Suppression Compartment Characterization. . Sheinson, R. S. ; Maranghides, A. ; Plack, B. H. ; Peatross, M. J. ; 1997
- Extinction Studies of Propane/Air Counterflow Diffusion Flames: The Effectiveness of Aerosols. . Fleming, J. W. ; Reed, M. D. ; Zegers, E. J. P. ; Williams, B. A. ; Sheinson, R. S. ; 1998
- Flammable Liquid Storeroom 1: Halon 1301 Replacement Testing Results. . Maranghides, A. ; Sheinson, R. S. ; Cooke, J., III ; Wellens, J. C. ; Wentworth, B. ; Williams, B. A. ; Darwin, R. L. ; 1998
- Halon 1301 Retrofit Implementation Considerations. . Maranghides, A. ; Sheinson, R. S. ; Darwin, R. L. ; Kay, D. ; Barylski, D. ; 1998
- In-Situ Monitoring of Total-Flooding Fire Tests by FTIR Spectroscopy. . Williams, B. A. ; Thiede, T. ; Maranghides, A. ; Sheinson, R. S. ; 1998
- NRL-Chesapeake Bay Detachment: Full-Scale Fire Test Platform. . Maranghides, A. ; Sheinson, R. S. ; 1999
- Evaluation of Self-Contained Commercial Halon Substitute Systems. . Maranghides, A. ; Sheinson, R. S. ; 2000
- Fire Protection With Water Mist: The NRL Approach. . Sheinson, R. S. ; Maranghides, A. ; Fleming, J. W. ; Williams, B. A. ; 2000
- Nir-Diode Laser Based In-Situ Measurement of Molecular Oxygen in full-Scale Fire Suppression Tests. . Schlosser, H. E. ; Ebert, V. H. E. ; Williams, B. A. ; Sheinson, R. S. ; Fleming, J. W. ; 2000
- Protecting Shipboard Flammable Liquid Rooms With HFP (HFC-227ea). . Maranghides, A. ; Sheinson, R. S. ; 2000
- Water Mist Suppression of Methane/Air and Propane/Air Counterflow Flames. . Zegers, E. J. P. ; Williams, B. A. ; Sheinson, R. S. ; Fleming, J. W. ; 2000
- Use of Water Spray Cooling Systems in Conjunction With HFP (HFC-227ea) to Protect Shipboard Flammable Storage Rooms. . Sheinson, R. S. ; Borman, B. ; Maranghides, A. ; Anleitner, R. ; Gunning, P. ; 2001
- Water Mist Monitoring in Large-Scale Fire Suppression Research: Fundamental Issues. . Fleming, J. W. ; Maranghides, A. ; Sheinson, R. S. ; 2001
- Water Mist Visualization and Droplet size Analysis in Large-Scale Fire Suppression Research. . Anleitner, R. ; Burchell, H. A. ; Fleming, J. W. ; Maranghides, A. ; Montgomery, J. ; Sheinson, R. S. ; 2001
- Fire Suppression Scaling Issues in Different Compartment Sizes. . Ayers, S. ; Sheinson, R. S. ; Maranghides, A. ; Morse, D. ; Szwarc, D. ; 2002

- Future of Aqueous Film Forming Foam (AFFF): Performance Parameters and Requirements. . Sheinson, R. S. ; Williams, B. A. ; Green, C. ; Fleming, J. W. ; Anleitner, R. ; Ayers, S. ; Maranghides, A. ; Barylski, D. ; 2002
- Suppression Effectiveness of Aerosols: The Effect of Size and Flame Type. . Fleming, J. W. ; Williams, B. A. ; Sheinson, R. S. ; 2002
- Combining a Water Spray Cooling System With Heptafluoropropane for Total Flooding Fire Suppression. . Sheinson, R. S. ; Ayers, S. ; Anleitner, R. ; Morse, D. ; Szwarc, D. ; Levenberry, L. ; Maranghides, A. ; 2003
- Essential Uses of Fire Protection Halons. . Hebert, J. ; 1991
- Halon 1301 Use in Oil and Gas Production Facilities: Alaska's North Slope. . Ulmer, P. E. ; 1991
- Halon Alternatives Extinguishment Pathways. . Sheinson, R. S. ; 1991
- Effect of Ignition Source and Strength on Sphere Inertion Results. . Heinonen, E. W. ; 1993
- Importance of Mechanisms. . Finnerty, A. E. ; 1994
- Aircraft Fuel-Tank Ullage Inerting Using First-Generation Halon-Replacement Agents. . Tyson, J. H. ; 1994
- Fluoroiodocarbons as Halon 1211/1301 Replacements: An Overview. . Kibert, C. ; 1994
- Importance of Mechanisms. . Finnerty, A. E. ; 1994
- Inertion of Flammable Refrigerants by HFC-227ea. . Robin, M. L. ; 1995
- Science and Technology Challenges. . Dix, D. M. ; 1995
- Water-Based Fire-Extinguishing Agents. . Finnerty, A. E. ; 1995
- Inertion of Flammable Refrigerants by HFC-227ea. . Robin, M. L. ; 1995
- Powdered Aerosols Performance in Various Fire Protection Applications. . Jacobson, E. ; 1996
- Inerting Hydrocarbon Fuels With Halon Alternatives. . Zlochower, I. A. ; 1996
- Next-Generation Fire Suppression Technology Program. . Gann, R. G. ; 1998
- Crew Compartment Live Fire Test Results With Hybrid Fire Extinguishers. . Mitchell, R. ; 1999
- Next Generation Fire Suppression Technology Program (NGP): Technical Highlights. . Gann, R. G. ; 1999
- Progress Under the Next-Generation Fire Suppression Technology Program (NGP) in 1999. . Gann, R. G. ; 2000
- Reducing Hydrogen Fluoride and Other Decomposition Using Powders and Halocarbons. . Moore, T. A. ; 2000
- Review of Technologies for Active Suppression for Fuel Tank Explosions. . Bennett, G. ; 2000
- Advanced Environmentally Friendly Fire Protection Technology. . Wierenga, P. ; 2001

- Progress Under The Next Generation Fire Suppression Technology Program (NGP) In FY2000. . Gann, R. G. ; 2001
- Assessment of the Fire Suppression Mechanics for HFC-227ea Combined With $NaHCO_3$. . Skaggs, R. R. ; 2002
- Ullage Protection Ownership Cost for KC-130J: Explosion Suppressant Foam (ESF) Vs. On-Board Inert Gas Generation System (OBIGGS). . Bein, D. ; 2002
- Addressing the Need for Halon Replacement. . Sheinson, R. S. ; 2002