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2017 Fire Protection Informational Exchange Meeting

by J Kevin Boyd and Steve McCormick

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2017 Fire Protection Informational Exchange Meeting

by J Kevin Boyd

Weapons and Materials Research Directorate, ARL

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US Army Tank Automotive Research, Development and Engineering Center

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14. ABSTRACT US Department of Defense platforms have many components other than stored munitions that are the source of, and are vulnerable to, fires caused by a wide variety of threats. Vulnerabilities resulting from a fire can turn a survivable event into a catastrophic loss of crew and equipment. This report documents the results of an information exchange meeting held May 10-11, 2017 at the US Army Research Laboratory, which brought together interested parties across the armed services to outline, as a community, the current state of the art in fire protection research and engineering and determine where future efforts would be most advantageous. The forum provided the opportunity to strengthen old collaborations, begin new partnerships, and serve as a resource to highlight to potential customers and/or management the importance of continuing efforts in this field.					
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1. Introduction

US Department of Defense (DOD) platforms can be vulnerable to fires from the stowed energetics on the platforms. Historically, the main concern has been fuel and ammunition due to the large volume of these stowed energetic materials. Hydraulic and lubricating oils are also of concern and more recently, energy-dense lithium (Li)-ion batteries. Advancements in vehicle development, new threats, emerging technologies, and regulatory changes can introduce new fire hazards. As a result, research and development efforts in vehicle fire protection can vary widely over time.

This report documents a 2-day Fire Protection Information Exchange Meeting held May 10–11, 2017 at Aberdeen Proving Ground, Maryland. The meeting was jointly hosted by the US Army Research Laboratory (ARL) and the US Army Tank Automotive Research, Development and Engineering Center (TARDEC). The purpose of the meeting was to provide a community forum to discuss current and emerging fire hazards on military platforms and methods to prevent or extinguish those fires. This is third fire protection meeting the 2 organizations have hosted.^{1,2} The community agreed that these meetings should be held every 18 months.

Over 100 people attended the meeting, which included presentations from the following:

US Government

- ARL
- TARDEC
- Office of the Assistant Secretary of the Army for Acquisition, Logistics and Technology (ASA-ALT)
- US Army Aberdeen Test Center (ATC)
- US Environmental Protection Agency (EPA)
- US Naval Research Laboratory (NRL)
- US Naval Air Systems Command (NAVAIR)
- National Transportation Safety Board (NTSB)
- US Army Natick Soldier Research, Development and Engineering Center (NSRDEC)
- US Marine Corps (USMC)

Industry and Academia

- Alion Science and Technology
- California Institute of Technology (Caltech)
- Jensen Hughes
- Kidde
- Meggitt Polymers and Composites
- Southwest Research Institute (SwRI)
- University of Cincinnati
- University of Maryland
- UTC Aerospace Systems

Foreign contributors

- Ministère de la Défense

Other participants who attended, but did not present, include:

- US Army Research, Development and Engineering Command (RDECOM)
- US Army Aviation and Missile Command (AMCOM)
- Naval Sea Systems Command (NAVSEA)
- Naval Surface Warfare Center (NSWC)
- Program Executive Office Land Systems (PEO-LS)
- US Army Medical Command (MEDCOM) Public Health Center (APHC)
- Industry and Academia
 - 3M
 - A-Gas Americas
 - ADI Technologies Inc.
 - AMEREX Defense
 - AMETEK Ameron LLC
 - AMPAC- Halotron
 - Boeing

- Catholic University
- The Chemours Company
- Emerson/Spectrex
- ESSPI
- FireTrace
- Halon Alternatives Research Corporation (HARC)
- Hazard Protection Systems Inc.
- High Impact Technologies
- Magam Safety
- Rodgard
- SURVICE Engineering Company
- Wesco

2. Presented Talks Summary

The agenda for the meeting is in Appendix A, and a list of the participants and their contact information is in Appendix B.

2.1 US Army TARDEC

2.1.1 Steve McCormick

Steve McCormick provided an overview of military vehicle fire protection. Ground vehicle fire statistics were given along with current areas of research in vehicle fire protection. Approximately 1.5% of all attacks on vehicles from 2007 to 2012 led to fires, producing 220 casualties. Accidental fires are also a concern resulting in 40 casualties from 2002 to 2012. Areas of research include:

- Development and evaluation of alternative, more environmentally friendly, fire suppressants to replace Halon 1301, hydrofluorocarbon (HFC)-227ea, and HFC-125;
- Fuel tank protection technologies to provide multi-hit survivable fuel tanks;
- Development of fuel tank protection standards;

- Li-ion battery protection to protect the crew and vehicle from the heat and potential toxic gases from a Li-ion battery thermal event; and
- Development of computational fluid dynamics (CFD) simulations to address peacetime and combat fire threats for ground vehicles.

Also discussed were 2017 Congressional Taskers on fuel tank protection and fire suppressant and fuel tank standards.

2.1.2 Dr Vamshi Korivi

TARDEC's fire suppression modeling effort was presented by Dr Vamshi Korivi. TARDEC has developed a unique physics-based modeling and simulation capability using CFD techniques to optimize automatic fire extinguishing system (AFES) designs and complement vehicle testing for both occupied and unoccupied spaces of military ground vehicles. The modeling techniques are based on reduced global kinetics for computational efficiency and are applicable to fire suppressants used in Army vehicles. These CFD simulations enable the Army to assess AFES designs in a virtual world at less cost than physical-fire tests. This methodology is applied to vehicle crew compartments for multiple scenarios using HFC-227ea + sodium bicarbonate (SBC) powder, which is the suppressant combination used in most US combat and tactical vehicles with crew fire protection systems. Predicted and test results match qualitatively very well for overall suppression time as well as for soldier survivability from thermal injury, blast overpressure, and inhalation toxicity risks. This fire suppression modeling methodology is now being applied to the geometrically more complex military vehicle engine compartments with HFC-125 fire suppressant that is widely used for unoccupied spaces.

2.2 US Army TARDEC/Alion Science and Technology

2.2.1 Dr Steve Hodges

Dr Steve Hodges spoke about the use of SBC dry powder agent to enhance the performance of gaseous fire extinguishing agents. In the 1990s it was demonstrated that SBC was a more effective fire suppression agent (by weight) than HFC-227ea by a factor of 2 to 10. In 2000, TARDEC reported that HFC-227BC, a mix of HFC-227ea and SBC, was an effective Halon 1301 replacement. Exploratory tests conducted by TARDEC showed that using SBC alone risked reflash, and that using a mix of SBC dry chemical and a gaseous agent performs better than either agent alone. Experiments by NRL show that nanoparticle SBC performs better in handheld fire extinguishers than larger, regular SBC. The low global warming

potential (GWP) fire suppression agent development project plans to test SCBs in full-scale AFES tests involving 3-D fuel-spray fires.

2.2.2 Dr Doug Mather

Dr Doug Mather spoke about the strategies used for evaluating alternate materials as replacements for the high-GWP extinguishing agents currently deployed in ground and aviation weapon systems. A review of recent agent development programs for HFC SBC blended agents was discussed, as well as strategies for evaluating short atmospheric lifetime fluorocarbon candidates. Test methods used in the evaluation included: 5/8ths cup burner, pan fire testing with JP8, hidden fire test chamber with n-heptane, and 8-ft³ chamber testing. Commercial and noncommercial short atmospheric lifetime candidate compounds were examined mixed with SBCs.

2.3 US Army Aberdeen Test Center

Dan Kogut presented on ATC's test strategy for the evaluation of low-GWP alternative fire suppressants. Testing included brill cell and tube furnace tests to determine the products of combustion, and test chamber and pan fire testing to assess agent characteristics and abilities. Due to limited quantities of some agents, ATC developed an 8-ft³ enclosed chamber to test the extinguishing abilities of the agents. Once the minimum effective extinguishing concentration was determined in the 8-ft³ chamber, SBC was blended into the agent to characterize the potential effectiveness of a particular compound as a total flooding agent. ATC constructed a hidden fire test chamber to use as a direct comparison for previous testing conducted by Kidde (Mebane, North Carolina) and the Federal Aviation Agency (FAA). The test is used to determine the effectiveness of an agent at extinguishing fires outside the direct path of discharge. As the testing at ATC progresses, if a particular agent or agent blend is deemed viable, additional testing to include handheld fire extinguisher optimization, pan fire testing, AFES testing, and larger scale total flood testing may be conducted.

2.4 US Army Natick Soldier Research, Development and Engineering Center

Thomas Tiano presented on NSRDEC's flame- and thermal-resistant materials development program. The goals are 2-fold: perform a front-end analysis (FEA) for flame-resistant (FR) clothing and develop technologies for FR fabrics that will replace or supplement the fabric presently used in the FR Army combat uniform (ACU). A result of the FEA is a database that consolidates the FR needs of soldiers based on burn injury data and threat exposure based on environment, mission, and

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current and near-future threats. Flame-resistant material test methods were discussed along with the results from testing several FR fabrics. This effort will improve the performance-to-cost ratio of current FR military materials in ACUs such as the FR-ACU.

2.5 US Army Research Laboratory

2.5.1 ARL Vehicle Technology Directorate: Dr Jacob Temme

Dr Jacob Temme presented on the effects of fire-mitigating fuel additives on fuel sprays and combustion. The Army has a wide range of propulsion systems including rotary, piston, and gas turbine engines. The large quantities of combustible fuels for the propulsion systems in combat vehicles make them susceptible to fires. ARL is collaborating with Caltech on investigating the spray and combustion behavior of megasupramolecules. Megasupramolecules are ultra-long polymers that inhibit ignition of fuel spray/mist during an accidental release. In initial diesel engine tests there was no loss of performance when these additives were added to the fuel. The collaborative effort will investigate why these molecules inhibit ignition in some cases but not others. Experiments will be conducted to measure the detailed spray breakup and atomization, spray vaporization, autoignition events, and forced ignition events of fuels with this additive.

2.5.2 ARL Weapons and Materials Research Directorate: Dr Barrie Homan

Dr Barrie Homan gave an overview of ARL's fire protection mission program. ARL's efforts are currently focused on the characterization of fuel spray from fuel tanks due to ballistic events. The hydrodynamic ram induced aerosolized spray is highly combustible and a major source of fire. This capability is of interest to TARDEC for the development of a CFD capability for modeling suppression events in ground combat vehicles. Stereo imaging of the fuel spray is showing promise as a characterization technique. An algorithm is being developed to process the stereo images and has provided a reasonable reproduction of ground-truth data. Further improvements to imaging and processing techniques are underway. A 300-ft³ ground vehicle mockup has been built and will initially be used to examine the flame growth from ballistic events inside a ground combat vehicle. Follow-on studies will examine the effectiveness of AFES systems and extinguishing agents, and examine Li-ion battery reactions in a confined space.

2.5.3 ARL Weapons and Materials Research Directorate: Kevin Boyd (Li-ion Battery Vulnerabilities)

Kevin Boyd presented his work on Li-ion battery vulnerabilities. A proof-of-principle fire suppression system was discussed in which an extinguishing agent flooded a battery compartment at the first sign of thermal runaway. There was a significant reduction in the overall severity of the fire event; however, there were still a large amount of combustion products. The combustion products from 2 Li-ion battery chemistries were sampled in a confined space to assess their toxicology. Smoke and combustion products quickly filled the space. Preliminary toxicology analysis shows that depending on the battery chemistry, the combustion products ranged from a nuisance level to deadly for a crew. It was concluded that Li-ion batteries should be in a robust battery compartment that is vented to the outside of any confined space.

2.5.4 ARL Weapons and Materials Research Directorate: Kevin Boyd (Refrigerant Flammability Evaluation)

Kevin Boyd presented the results of ARL's refrigerant flammability evaluation. The goal is to examine the flammability of low-GWP refrigerants when subjected to ballistic events. Initial experiments were conducted with bulk samples of refrigerants and the lessons learned were then applied to system level evaluations. Bulk samples of R134a, R1234yf, and R290 (propane) were evaluated. Fires were observed with R290, but not with R134a or R1234yf. R134a and R1234yf were then evaluated in a mobile air condition system configuration. No fires were observed with R134a, but fires were observed with R1234yf in the system configuration. Follow-on evaluations will be conducted to examine the effect of compressor oil on fires with R1234yf.

2.6 US Marine Corps

Jaspal Brar presented USMC topics relating to AFES-related mishaps that caused death or injury. AFES bottles are under very high pressure and when they are inadvertently discharged without being constrained, the stored energy can cause the bottles to fly through the air striking individuals with considerable force. Injuries and fatalities have occurred when proper safety precautions are not followed. Other topics included seized antirecoil plugs, and the inability to install antirecoil plugs due to plumbing or adjacent components being in the way. Antirecoil plugs prevent a bottle from accidentally discharging. Engineering and design suggestions included reducing sharp corners that may result in death when struck by a bottle, safety provisions for removing AFES bottles, improved bottle bleed-down

procedures, and improved electromagnetic interference protection. An analysis of 88 fire events in mine-resistant ambush-protected vehicles was also given.

2.7 US Naval Research Laboratory

2.7.1 Dave Kessler

Dave Kessler presented his work on modeling the dispersion of the fire suppression agent ejected from the AFES in the US Marines' medium tactical vehicle replacement (MTVR) by performing simulations coupling 1-D network models of multiphase pipe flow and 3-D compressible flow. The 1-D multiphase simulations model the flow within the AFES piping network and provide inlet conditions at the discharge nozzle for 3-D simulations of the compressible gas dynamics of the flow exiting the nozzle region and dispersing throughout the MTVR. The geometry of the distribution nozzle causes the flow to accelerate to supersonic speeds. The result is a strong, narrow jet directed into the MTVR dashboard, which leads to a unique dispersion pattern dictated by the cabin geometry. Two thermodynamic models of the discharge suppressant material were presented: a single-phase model with instantaneous evaporation at the nozzle and a homogeneous multiphase model. A comparison of the jet structure obtained using the 2 approaches was presented and the merits of each were discussed.

2.7.2 Bill Szymczak

Bill Szymczak spoke about NRL's work to bring the impulsive acoustic noise level of the AFES in the MTVR down to a level where hearing protection is no longer required (140 dBP). Two significant noise sources were identified: the tank squib valve (~160 dBP) and the supersonic discharge flow (~154 dBP) at the nozzle. An AFES laboratory simulator was developed to emulate these noise sources and develop mitigation techniques. A Sorbothane (Kent, Ohio) sealed valve enclosure was experimentally shown to reduce the noise level by approximately 20 dBP. The supersonic flow was modeled to optimally design a manifold with volume expansion, perforated screen barriers, and multiple nozzles. The experimental results show manifold flow noise reductions on the order of approximately 12 dBP. These attenuated impulsive noise levels now fall in a range where hearing protection may no longer be required.

2.8 US Naval Air Systems Command

2.8.1 Mike Cosgrove

Mike Cosgrove spoke about NAVAIR's effort to find a replacement for Halon 1211 in flight line fire extinguishers. Halon 1211 has been banned by new environmental regulations. Multiple alternative agents were evaluated and the Navy initially selected Purple-K with carbon dioxide as an alternative; however, it is now causing unexpected levels of collateral damage. As a result, the Navy is now implementing a performance-based clean agent requirement for flight line fire extinguishers. Clean agents will be rolled out on an attrition basis until funding is available for large-scale replacement.

2.8.2 Ryan Arthur

Ryan Arthur spoke about the Navy's new gas analyzer capability for fire suppression testing. Mr Arthur gave an overview of NAVAIR's aircraft fire protection team that is responsible for providing the engineering technical expertise for all US Navy on-aircraft fire protection systems. NAVAIR recently procured a fire extinguisher gas chromatograph (FGC) that is used to measure fire suppressant concentrations for system qualification purposes. The FGC works by continuously pulling sample gasses from up to 12 locations and using individual detectors to measure the concentration of a suppressant agent. This equipment can be used for developmental testing in a lab environment or system qualification on aircraft during flight. Although it was designed for uses in aircraft engine and auxiliary power unit bays, its capabilities could extend to testing ground vehicles and larger bays that use gaseous fire suppression agents.

2.9 US National Transportation Safety Board

Joseph Panagiotou gave an overview of the NTSB's history, structure, and mission. The NTSB investigates accidents involving aviation, railroad, marine, highway, pipeline, and hazardous materials. Recent fire issues in the various modes of transportation were discussed.

2.10 US Environmental Protection Agency

Margaret Sheppard from the Stratospheric Protection Division of the EPA gave an overview of its Significant New Alternatives Policy (SNAP) Program. Section 612 of the Clean Air Act directs the EPA to evaluate and list substitutes for ozone-depleting substances (ODSs) that reduce overall risk to human health and the environment. In addition to ozone depletion potential and GWP, the EPA considers

flammability, toxicity, local air quality, ecosystem effects, and occupational and consumer health safety. SNAP has reviewed 400+ alternatives since 1994. There were a total of 75 listings for fire suppression, with 70 acceptable substitutes and 5 unacceptable. Federal acquisition regulation was discussed as it relates to HFCs. When feasible, the federal government will procure alternatives to high-GWP HFCs and will refer to SNAP for the current list of acceptable alternatives. Next steps include expanding the SNAP acceptable list, developing the next SNAP notice for acceptable listings, and developing the next SNAP rule to include alternatives that are acceptable with use restrictions.

2.11 Meggitt Polymers and Composites

Randy Fontinakes from Meggitt summarized his company's products and testing of self-sealing technologies to prevent fuel loss and passive fire suppressant blankets to prevent fuel fires from ballistic events. Test results for 20-mm and 25-mm armor piercing threats showed sealing of the bullet perforations in the tank. Container construction suggestions include using particular tank materials such as steel and aluminum (no titanium) as well as external (to the tank) treatments that can maximize the performance of self-sealing bladders. Also, for fire suppression it was suggested that the best results are achieved with a passive fire suppression blanket (not panel).

2.12 Jensen Hughes

2.12.1 Gerard Back

Gerard Back presented the efforts by Jensen Hughes (Baltimore, Maryland) on Li-ion battery shipping and storage container development for the Navy. Mr Back first gave an overview of Li-ion battery construction, hazards, and types of reactions. The Navy tested over 30 different types of batteries including 5 specific to the military. Container designs were discussed to include the joint modular intermodal container (JMIC) and the JMIC charging station (Garrett Container Systems Inc, Accident, Maryland), and the Quadcon storage compartment and work station (CMCI, Charleston, South Carolina). Fire suppression systems for containers were also discussed, as was a fire containment cover made by AmSafe Bridport (Bridport, United Kingdom).

2.12.2 Brian Lattimer

Brian Lattimer presented modeling and experimental methods in the study of fire spread through aluminum structures. Ships are constructed from lightweight materials such as aluminum and fiber-reinforced composites that behave differently

than steel in a fire. Fire spread to spaces adjacent to a burning compartment is a primary hazard consideration onboard ships. Real-time models such as the Fire and Smoke Simulator are available to predict fire dynamics and material response during fires. Sequentially coupled models such as the Fire Dynamics Simulator for fire behavior and Abaqus for structural and thermal response assist in better understanding behavior and providing higher fidelity predictions. Full-field measurements are used to provide the nonuniform detail required to understand behavior and validate models.

2.13 ASA-ALT/Jensen Hughes

Dr Daniel Verdonik gave a regulatory overview of the drivers for low GWP agents and refrigerants and what has changed in the past 18 months. He provided a history of the treaties and international agreements that are driving the current concern of ozone depletion and global warming trends. The United Nations Framework Convention on Climate Change (UNFCCC) was ratified in 1992. It led to the development of the Kyoto Protocol that addressed the use of GWP-classified substances. The Kyoto Protocol expired, and in 2015 the parties to the UNFCCC approved a new international climate change treaty: the Paris Agreement. The Paris Agreement was ratified by 114 countries and entered into force in November 2016.

In 1989 the Montreal Protocol was entered into force regulating the production, and sharing of production, of ODSs and now, high GWP HFCs that are/were the alternatives to ODSs. On October 15, 2016, the Montreal Protocol was amended to add high GWP HFCs to the list of controlled substances. This is known as the Kigali Amendment; it gradually phases down the global production of high GWP HFCs. Of military importance are the 100% phaseout of halons and hydrochlorofluorocarbon (HCFC)-123 in HCFC Blend B, the 100% phaseout of chlorofluorocarbons (CFCs)/solvents and HCFCs, and the 85% phasedown of HFCs. The US military has reserves of halons, CFCs, and HCFCs and additional production can be requested through the Montreal Protocol “Essential Use” process. Some issues going forward with the Kigali Amendment are that it has not been ratified by the US, and what happens if it is not? Also, military and industry needs are diverging and as a result, industry may not make the type and amount of agents needed for military use.

2.14 Southwest Research Institute

2.14.1 Dr Nicholas Mueschke

Dr Nicholas Mueschke with the Southwest Research Institute (San Antonio, Texas) presented his work on gaseous detonations in semiconfined environments. New power sources and technologies such as Li-ion batteries and hydrogen fuel cells can generate or vent flammable fuel-air gas mixtures. Depending upon the mixture, conditions, ignition, and confinement, the resulting fuel-air combustion may result in a detonation and impart significant blast loads on the environment surrounding the explosion. The research examined simulated release and subsequent detonation of hydrogen and methane fuel-oxidizer mixtures into a semiconfined structure. Different volumes of gas mixtures were detonated in various configurations. Dynamic pressure loading on the structure was recorded using high-rate pressure sensors. High-speed video was also used to record the detonation event and measure detonation wave velocities. Data from these novel experiments are validating new computational tools used to directly model the detonation of gases and the resulting overpressures that surrounding structures will experience.

2.14.2 Dr Marc Janssens

Dr Marc Janssens spoke about recent developments in risk-informed performance-based (RIPB) fire protection of nuclear power plants (NPP) and potential DOD applications. An overview was given on SwRI's involvement in fire protection and also on changes made by the Nuclear Regulatory Commission that led to an RIPB fire protection program. RIPB fire protection involves extensive use of fire modeling tools ranging from relatively simple algebraic equations and correlations to complex CFD codes. It also involves experiments to obtain material properties and other input data for fire models and model validation. The steps involved in the transition from a deterministic to an RIPB fire protection program were reviewed, as well as examples of fire modeling and experimental programs. Analogous DOD facilities to an NPP may include command and control centers, air traffic control facilities, munitions storage areas, fuel depots, and other critical facilities.

2.15 UTC Aerospace Systems

Greg Chambers spoke about the ground vehicle fire extinguisher safe valve developed by UTC Aerospace Systems (Charlotte, North Carolina). An inadvertent AFES bottle valve actuation can create a hazard if the antirecoil cap is not installed during extinguisher handling. The sudden release of high-pressure stored energy will result in violent extinguisher movement, which can cause injury or death. Accidental valve actuation can occur when safety procedures are not followed and

from a lack of training. The safe valve prevents the valve from fully opening unless installed in a vehicle bracket, preventing inadvertent thrust and subsequent damage and personnel injury.

2.16 California Institute of Technology

Dr Julia Kornfield presented on megasupramolecules, a new class of additives for lubricants, hydraulic fluids, and fuels. After 9/11, members of Caltech and the NASA Jet Propulsion Laboratory began looking at ultra-long polymers for mist control in fuels. TARDEC joined the collaboration in 2011 while looking for ways to prevent explosively formed fuel-mist fires. Megasupramolecules increase the droplet size of a fuel mist. The larger droplets result in less fuel vapor available for ignition during an accident or attack with an improvised explosive device. When ignition does occur, it results in a small, self-quenching fire and little or no pool fires versus the large, self-supporting fire with untreated fuel. Megasupramolecules differ from the previous state of the art in that they are resistant to nonintentional degradation, soluble over a wide temperature range, permit dewatering and filtering, and burn in an unmodified internal combustion engine. Threat readiness level (TRL) testing by TARDEC showed that megasupramolecules have the potential to provide beneficial effects on compression ignition, viscosity index, and lubrication. To advance from TRL 2 to TRL 6, a 50% reduction in flame propagation after ballistic damage to a fuel tank or fuel/hydraulic line should be demonstrated.

2.17 University of Cincinnati: Engineering and Scientific Innovations, Inc.

Dr Peter Disimile spoke of efforts in the development of an intelligent, high-speed fireball suppression technology. Current aviation systems typically work by flooding the volume of interest with a suppression agent in a one-time event. Simply flooding the compartment can require longer times and result in inefficient use of agent materials. Dr Disimile outlined an “ideal” solution that encompasses rapid fire detection to a measured and dynamic release of agent that addresses the shortcomings of current systems.

2.18 University of Maryland

James Quintiere spoke on the flammability requirements for military vehicle ceiling cushioning material. The materials are located in the crew compartment of a military vehicle and subjected to accidental or war fire ignition scenarios. A test protocol was discussed to measure the fire thermal and toxicity hazards of the

materials. The approach is to not adapt standard relative ranking tests without relevance to the actual fire scenario. Material fire properties are used to judge the performance of the materials in a fire scenario; the methodology can be improved with new information. An example process for the evaluation of gray foam was given.

2.19 Ministère de la Défense (French Ministry of Defence)

Camille Riera from the French Directorate General of Armaments (DGA) was scheduled to present; however, she was not able to attend the meeting. With her permission the authors have included her presentation in this report. An overview of the DGA is included in the presentation and also the capabilities of the DGA's Aeronautical Systems (AS) Fire Laboratory. The DGA is responsible for equipping the armed forces, preparing for the future of defense systems, and promoting defense equipment exports. The DGA conducts testing and assessment of equipment and military technologies. The DGA AS material and technologies group conducts fire behavior testing to include regulatory testing for aircraft and full-scale testing for the French Navy, Ground Forces, Firefighters, and Air Force.

3. References

1. Homan BE, Boyd KJ, McCormick S. Systems fire protection workshop report. Aberdeen Proving Ground (MD): Army Research Laboratory (US); 2013 Apr. Report No.: ARL-TR-6398.
2. Homan BE, Boyd KJ, McCormick S. Fire protection information exchange. Aberdeen Proving Ground (MD): Army Research Laboratory (US); 2016 July. Report No.: ARL-MR-0932.

Appendix A. Agenda

Table A-1 Day 1 agenda

Day 1	Title	Speaker	Organization
	Opening remarks	Kevin Boyd/Steve McCormick	ARL/TARDEC
1	Overview of US military vehicle fire protection	Steve McCormick	TARDEC
2	Ground combat vehicle fuel system survivability technical capabilities to avoid fires from high level threats	Randy Fontinakes	Meggitt
3	Megasupramolecules as fuel additives	Dr Julia Kornfield	Caltech
4	Fuel additives	Dr Jacob Temme	ARL-VTD
5	Virtual fire suppression framework for ground vehicles using computation fluid dynamics	Dr Vamshi Korivi	TARDEC
6	Fuel spray characterization studies	Dr Barrie Homan	ARL
7	Intelligent high-speed fire ball suppression technology	Dr Peter Disimile	University of Cincinnati
8	Li-ion battery storage container development	Jerry Back	Jensen Hughes
9	Li-ion battery assessments	Kevin Boyd	ARL-WMRD
10	Evaluation of gaseous detonations in semiconfined environments	Dr Nicholas Mueschke	SWRI
11	NSRDEC update on the development of flame resistant uniforms	Thomas Tiano	NSRDEC
12	USMC hot topics related to AFES systems	Jaspal Brar	USMC
13	Making AFES handling safer	Greg Chambers	Kidde
14	Assessment of the dynamics of fire suppression agents discharged from the AFES within the cabin of the medium tactical vehicle replacement platform	Dave Kessler	NRL
15	Impulsive noise mitigation of marine vehicle fire suppression systems	Bill Szymczak	NRL
16	National Transportation Safety Board overview	Joseph Panagiotou	NTSB

Table A-2 Day 2 agenda

Day 2	Title	Speaker	Organization
17	Opening remarks	Kevin Boyd/Steve McCormick	ARL/TARDEC
18	Halon 1211 flight line extinguisher replacement	Mike Cosgrove	NAVAIR
19	The new Navy gas analyzer capability for fire suppression testing	Ryan Arthur	NAVAIR
20	Regulatory overview of low GWP agents and refrigerants	Dr Dan Verdonik	ASA-ALT/ Jensen Hughes
21	Recent environmental regulations issued by EPA concerning fire protection and alternative fire suppressants under review by the EPA's Significant New Alternatives Policy (SNAP) Program	Margaret Shephard	EPA
22	Using sodium bicarbonate dry powder to enhance the performance of gaseous extinguishing agents	Dr Steve Hodges	TARDEC/ Alion S&T
23	Strategy for low global warming potential fire suppressants identification	Dr Doug Mather	TARDEC/ Alion S&T
24	Low global warming potential fire suppressant testing and evaluation	Dan Kogut	ATC
25	Flammability of low GWP refrigerants to ballistic threats	Kevin Boyd	ARL
26	Fire spread through aluminum structures	Brian Lattimer	Jensen Hughes
27	Recent developments in risk-informed performance-based fire protection of nuclear power plants and potential applications for DOD	Dr Marc Janssens	SWRI
28	Test protocol for assessing the fire hazard of ceiling materials	Dr James G Quintiere	University of Maryland
...	Questions and Comments	All	...
...	Future Plans	All	...

Appendix B. Contact List

Table B-1 US Government

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Table B-1 US Government (continued)

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Table B-2 Companies

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Appendix C. Attached Briefings*

* This appendix appears as multiple pdf attachments.

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Table C-1 List of attached presentations and documents

Arthur_DoD Systems Fire Protection Meeting - NAVAIR Fire Extinguisher Gas Chromatograph Brief
Arthur_Flight Line Fire Suppression Alternatives 2017 MAY 11
Back_DoD Battery Presentation 5-10-17 Battery Shipping and Storage
Boyd_Li-Ion Battery Evaluation
Boyd_Refrigerant Evaluation
Brar_USMC AFES Brief - 05-11-2017
Chambers_Kidde GV Safe Valve for FMv2 3-26-1
Disimile_ESI Fireball Suppression5_May2017
Hodges_Dry Chemical Blends in AFES May 2017
Janssens_2017_Fire_Protection_Information_Meeting
Kessler_presentation_MTVR
Kogut_Systems Fire Protection Brief - ATC - Final
Kornfield Fire Protection Megasupramolecules_ May 2017
Lattimer_Fire Spread in Aluminum Structures
Mather_Low Global Warming Alternative Fire Suppressants - Strategy
McCormick_Overview of US Military Vehicle Fire Protection
Mueschke_2017 Fire Protection Information Exchange
Panagiotou_NTSB overview for Info exchange meeting
PPT RIERA DGA AS
Quintiere-MilitaryVehicleInteriorsPres-May 11 2017
Sheppard_EPA Presentation for DoD Fire Protection Info Exchange_051117 for distribution
Spray characterization HOMAN - Final
Szymczak_Fire Symposium
Temme_Fire protection slides
Tiano_FR protection information exchange FY17
Vamshi_Presentation
Verdonik_Regulatory Drivers for Low GWP Agents 2017-0511 final

List of Symbols, Acronyms, and Abbreviations

1-D	1-dimensional
3-D	3-dimensional
ACU	Army combat uniform
AFES	automatic fire extinguishing system
AMCOM	US Army Aviation and Missile Command
APHC	US Army Public Health Center
ARL	US Army Research Laboratory
AS	Aeronautical Systems
ASA-ALT	Office of the Assistant Secretary of the Army for Acquisition, Logistics and Technology
ATC	US Army Aberdeen Test Center
Caltech	California Institute of Technology
CFC	chlorofluorocarbons
CFD	computational fluid dynamics
DGA	Directorate General of Armaments
DOD	US Department of Defense
EPA	US Environmental Protection Agency
FEA	front-end analysis
FAA	US Federal Aviation Agency
FGC	fire extinguisher gas chromatograph
FR	flame resistant
GWP	global warming potential
halon	halogenated hydrocarbon
HARC	Halon Alternatives Research Corporation
HFC	hydrofluorocarbons
HCFC	hydrochlorofluorocarbons

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JMIC	joint modular intermodal container
Li	lithium
MEDCOM	US Army Medical Command
MTVR	medium tactical vehicle replacement
NAVAIR	US Naval Air Systems Command
NAVSEA	US Naval Sea Systems Command
NPP	nuclear power plants
NRL	US Naval Research Laboratory
NSRDEC	US Army Natick Soldier Research, Development and Engineering Center
NSWC	Naval Surface Warfare Center
NTSB	National Transportation Safety Board
ODS	ozone-depleting substance
PEO-LS	Program Executive Office Land Systems
RDECOM	US Army Research, Development and Engineering Command
RIPB	risk-informed performance based
SBC	sodium bicarbonate
SNAP	Significant New Alternatives Policy
SwRI	Southwest Research Institute
TARDEC	US Army Tank Automotive Research, Development and Engineering Center
TRL	threat readiness level
UNFCCC	United Nations Framework Convention on Climate Change
USMC	US Marine Corps

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5 (PDF)	PEO GCS SFAE GCS AAM M MILNER SFAE GCS HBCT B T DENOMY SFAE GCS BCT E R ZEBRON SFAE GCS AFVS J SCHIRMER	3 (PDF)	JENSEN HUGHES M MCGINLEY J BACK B LATTIMER
5 (PDF)	RDECOM RDNS OOI T M TIANO AMSRD FEA E HANGELAND K WATTS B CONWAY AMSRD OPG B KRZEWINSKI	4 (PDF)	SWRI D GROSCH M BLAIS M JANSSENS N MUESCHKE
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1 (PDF)	CALTECH J KORNFIELD		
1 (PDF)	UNIVERSITY OF VIRGINIA L MA		
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