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2018 Fire Protection Informational Exchange Meeting

by J Kevin Boyd and Steven McCormick

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2018 Fire Protection Informational Exchange Meeting

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14. ABSTRACT
Historically, stowed ammunition and fuel were major fire vulnerability concerns for military ground vehicles. Now, however, tires, plastics and composites, crew clothing, and other combustible components such as the electrolytes in lithium-ion batteries and refrigerants are also of significant concern. 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 at the CCDC Army Research Laboratory during 10–11 October 2018. The purpose of the meeting was to bring together fire investigators and interested parties across the 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 collaborations, begin new partnerships, and serve as a resource to highlight to potential customers and/or management the importance of continuing research efforts in this field.

15. SUBJECT TERMS
fuel fire, fire suppression, automatic fire extinguishment system, AFES, halon, hydrodynamic ram, lithium ion battery, fires, hydrofluorocarbons, HFC, global warming potential, GWP, Montreal Protocol, suppression agents, flammable fuels, ozone-depletion potential, ozone-depleting substance, ODS, refrigerants

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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 fires from fuel and ammunition due to the large volume of these stowed energetics. However, tires, plastics and composites, hydraulic and lubricating oils, crew clothing, and more recently, energy-dense lithium (Li)-ion batteries and flammable refrigerants have also become of greater concern. In addition to fires, advancements in vehicle development, new threats, emerging technologies, and regulatory changes can introduce new fire hazards. As a result of the wide range of topics relating to vehicle fires, research and development efforts in vehicle fire protection can vary widely over time.

This report documents a two-day Fire Protection Information Exchange Meeting held 10–11 October 2018 at Aberdeen Proving Ground, Maryland. The meeting was jointly hosted by the US Army Combat Capabilities Development Command (CCDC) Army Research Laboratory (ARL) and CCDC Ground Vehicle Systems Center (GVSC). The purpose of the meeting is to provide a forum for the Defense community to discuss current and emerging fire hazards on military platforms and methods to prevent or extinguish these fires. Military and industry fire protection investigators came together to discuss research efforts and explore opportunities for collaboration. Along with the military services, other government agencies, industry, and several allied militaries participated. This is the fourth fire protection meeting the two organizations have hosted.[1–3]

After this meeting was held, the Research Development and Engineering Command (RDECOM) moved from under the Army Materiel Command (AMC) to the Army Futures Command (AFC). As a result, the names of several of the organizations that participated in this meeting have changed. The organizational names used in this report will be the new names under the AFC, with the exception of the presentations in Appendix C that retain the organizational names used under AMC. The name changes are shown in Table 1.

Table 1 Organizational name changes under AFC

Organizational name under AMC	Organizational name under AFC
RDECOM	CCDC
ARL	CCDC ARL
Tank Automotive Research Engineering and Development Center (TARDEC)	CCDC GVSC
Natick Soldier Research Development and Engineering Center (NSRDEC)	CCDC Soldier Center (SC)
ARL Survivability Lethality Analysis Directorate (SLAD)	CCDC Data & Analysis Center (DAC)

The meeting was broken down into three broad categories:

1) Engineering/Full-scale Testing

   Discussions focused on hardware development and testing of new/existing designs and technologies.

2) Science and Technology

   Discussions focused on the efforts to better understand the mechanisms leading to fires in DOD vehicles and systems and research in alternate extinguishing agents.

3) Environmental and Health Effect Issues

   Discussions focused on environmental issues such as no ozone-depleting potential/low global-warming potential (GWP) halon alternatives and alternatives to current hydrofluorocarbon (HFC) refrigerants, and the toxicity and health issues related to fire protection in military vehicles.

The meeting included presentations from the following organizations:

- Government presenters
    - CCDC ARL
    - CCDC GVSC
    - Aberdeen Test Center (ATC)
    - US Naval Research Laboratory (NRL)
    - CCDC SC
- Industry and Academia presenters

- Alion Science and Technology
- Applied Research Associates, Inc.
- Fireaway, Inc.
- Fluid Efficiency
- Hutchinson Defense and Mobility
- Jensen Hughes
- Kidde Aerospace
- Survice Engineering
- University of Virginia

- Foreign contributors
  - French Directorate General of Armaments (DGA)
- Other participants
  - Assistant Secretary of the Army for Installations, Energy and Environment (ASA-IEE)
  - Headquarters, CCDC
  - CCDC DAC
  - Air Force Civil Engineering Center (AFCEC)
  - Aviation and Missile Command (AMCOM)
  - Naval Air Systems Command (NAVAIR)
  - Naval Sea Systems Command (NAVSEA)
  - Naval Surface Warfare Center (NSWC)
  - Program Executive Office Land Systems (PEO LS)
  - US Army Medical Command (MEDCOM)
  - AMEREX Defense
  - AMETEK Ameron LLC
  - AMPAC Halotron
  - Battelle Memorial Institute

- Boeing
- The Chemours Company
- Dupont
- Emerson/Spectrex
- Etrier LLC
- FireTrace Aerospace
- Halon Alternatives Research Corporation
- Hazard Protection Systems, Inc.
- High Impact Technology, LLC
- Honeywell
- Martec Marine and Technologies
- WAYSMOS USA
- 3M

2. Presented Talks

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

2.1 Engineering/Full-Scale Testing

2.1.1 External Fuel Tank Protection from Overmatching Ballistic Threats

Seth Copeland presented on CCDC ARL's fuel tank protection effort. The goal of the effort is to allow a damaged vehicle to exit from a dangerous scenario after the fuel tank has been impacted by an overmatching threat. Baseline evaluations were conducted to determine a surrogate tank geometry and wall thickness for the evaluation of mitigation techniques; a 12-inch-diameter by 18-inch-long tank with a wall thickness of 3/16 inch was selected. Both inner-tank liners and overwraps were evaluated versus a shaped-charge threat. The liners and wraps reduced the fuel spray from the tank compared to the baseline tank; in addition, the overwrap significantly reduced the threat's entry-hole size. Next, reactive inner liners combined with an overwrap were examined. The reactive inner liner and overwrap showed potential to deliver a clogging agent to the threat entry and exit holes.

Future efforts will continue to explore reactive inner liners and overwraps with both clogging materials and fire-suppression agents.

2.1.2 Aramid Fabric Overwraps of Steel Fuel Tanks Subjected to Shaped-Charge Attack

Dr Brian Scott from CCDC ARL spoke on his efforts examining aramid fabric fuel tank overwraps to reduce the adverse effects of a shaped-charge jet attack on a fuel tank. The overwraps were not intended to defeat the shaped charge, but rather to reduce the threat's hole size, self-seal the holes created by the jet, and prevent ignition of the fuel vapor. Baseline evaluations were conducted on a bare steel tank with a 1.6-mm wall thickness. Evaluations were then conducted using the 1.6-mm-thick tank wrapped with either a 40-ply Kevlar wrap, 20-ply Kevlar wrap, a 20-ply fabric with a felt and rubber slab, or a 20-ply rubber-coated fabric and felt. Performance ranking based on the minimum-sized hole in the exit side of the tank and/or average hole diameter in the fabric showed that the 20-ply rubber-coated fabric plus felt performed best, followed by the 40-ply fabric, then the 20-ply fabric plus felt plus rubber slab, and lastly, the 20-ply fabric. All of the overwrapped tanks had reduced entry- and exit-hole sizes when compared to the baseline tank.

2.1.3 Safetank Fuel Tank Self-Sealing for Tactical Vehicles: State of the Technology and Opportunities in Lightweight, High-Performance Self-Sealing for Kinetic Energy and Fragment Threats

Paul Ardovini presented on Hutchinson Defense & Mobility's Safetank Fuel Tank Self-Sealing for Tactical Vehicles (Hutchinson Industries, Trenton, New Jersey). Self-sealing protection for fuel tanks provides enhanced mobility and safety options for tactical and combat vehicles. Fuel tank damage and the resulting loss of fuel reduces operating range, can disable the vehicle and put the crew at risk of a fire,and diverts resources from crew protection and the recovery of crews and vehicles. The Hutchinson Safetank system addresses the challenges of practical fuel tank construction materials and vehicle space and weight constraints with options to balance weight and cost impact with varying threats and post-threat performance. The flexibility of the Safetank materials and manufacturing options, along with innovative energy-absorbing options, enable the use of lighter-weight tank materials and provide high self-sealing performance to improve crew safety and greater mobility in hostile environments. Safetank is successfully installed and deployed on multiple tactical and security platforms such as the Mine-Resistant Ambush-Protected Vehicle, US Marine Corps Light-Armored Vehicle, and Special Operations Command Ground Mobility Vehicle. (This presentation is not included in Appendix C.)

2.1.4 DGA Fire Laboratory Overview

Antoine Orth from the French Directorate General of Armaments (DGA) gave an overview of the DGA and 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 and the DGA AS conducts fire behavior testing to include regulatory testing for aircraft and full-scale testing for the French Navy, ground forces, firefighters, and Air Force.

2.1.5 Preliminary Analysis of Flame-Resistant (FR) Uniform Needs Based on Burn Injuries

Thomas Tiano presented on CCDC SC's flame- and thermal-resistant materials development program. The Front-End Analysis for the FR clothing effort was initiated in FY17 with the purpose of providing a scientifically based understanding of FR protection needs for soldiers. This is being accomplished by examining injury data related to operationally based scenarios and military occupational specialties (MOSs). When completed, this analysis will aid program managers and program executive officers in determining the appropriate level(s) of FR protection for each MOS based on the specific knowledge and assessment of MOS-specific threats and injury data.

2.1.6 Fiber Optic Fire Protection

John Porterfield spoke about United Technology Corporation Aerospace Systems' fiber optic overheat and fire detection system (UTC Aerospace Systems, Charlotte, North Carolina). Current state of the art includes eutectic, thermistor, pneumatic, and twisted pair thermal detection. Fiber optic overheat and fire detection can improve on these systems. Benefits include smaller size, lighter weight, faster response time, electromagnetic interference immunity, and higher reliability. Also, fiber optic fire detection is potentially cost neutral to current technologies.

2.1.7 Li-ion Battery Fire Tests

Jerry Brown representing Fireaway Inc. (Minnetonka, Minnesota) spoke about the company's Stat-X fire suppression system. The Stat-X aerosol suppression system is a total flooding system for enclosed spaces. It is listed for Class A, B, and C fire hazards. Test results for Li-ion battery fires showed that Stat-X was effective in extinguishing fires from a 75-amp-hour nickel manganese cobalt (NMC) Li-ion pouch and with a 9-volt DC Li-ion NMC 2×2 four-cell battery pack.

2.1.8 Discussion on Requirements for Ground Vehicle Fuel Tanks

Steve McCormick from the CCDC GVSC led a group discussion on ground combat and tactical vehicle fuel tank requirements. The discussion centered on self-sealing technologies. Topics of discussion included:

- Due to the wide range of ground vehicles and vehicle requirements, multiple standards may be required.
- The Navy is publishing a report on the history of self-sealing and working on improving self-sealing specifications for aircraft. This information may be useful in developing a ground vehicle requirement.
- Self-sealing technologies were initially developed for aircraft. However, the ground vehicle environment may cause issues with current self-sealing technologies.
  - Vibration may cause small leaks in a self-sealed bladder.
  - Temperature extremes may affect sealing capabilities.
  - Self-sealing coatings exposed to road debris may be damaged.
  - High-energy threats can overmatch current self-sealing technologies.
- Multi-tier self-sealing requirements for various levels of threats may be required:
  - Stop leak
  - Leak with some conditions
  - Extreme leak with some conditions

2.1.9 Discussion on Unmanned Vehicle Fire Protection

Kevin Boyd from ARL led a discussion on fire protection for unmanned ground-combat vehicles. Topics of discussion included the following:

- For unmanned systems, the automatic fire extinguishing system (AFES) does not need to account for crew safety needs
  - Noise and concentration are not a risk
- A zero-delay deployment system that automatically deploys when a fuel tank is impacted by an overmatching threat
- Agents

    - Need to be clean for electronics
    - Higher concentration may be okay; do not need to have a toxicity limit
    - Lower concentration of oxygen
        - Inerting system to reduce the chance of starting a fire
        - Inert confined space in an unmanned vehicle
- Fuel power systems
    - Traditional engines for short term
    - Batteries in the future
    - Hydrogen fuel cell in the future
        - Different fire protection strategies will be required
- Location of fuel tanks
    - Which is best for unmanned—behind armor or outside?
        - Outside tank location is a concern for human egress from the vehicle in the event of fire but is not a concern with unmanned
        - Behind armor provides greater fuel tank protection from overmatching threats
- Multiple AFES deployment events are possible with unmanned vehicles
    - There are crew safety concerns for a manned platform, not a problem for unmanned
- Sensors
    - May need more information since there are no humans in an unmanned vehicle—like remote access to the sensor data
- Two systems—one for when the vehicle is manned and one for unmanned
    - Are multiple systems too complex?
    - Will this cause issues? (Unmanned system deploys when manned?)
    - What are the reasons for a second system?
        - It may be too complex for unmanned in some aspects and too simple in other areas such as concentration, toxicity, and locations
    - How to deal with part-time manned vehicles

        - Modular kit for unmanned versus manned applications

- Small versus large vehicles
    - Different requirements for a large ground-combat vehicle versus a mule-like vehicle

2.2 Science and Technology

2.2.1 Overview of CCDC ARL's Fire Protection Program

Kevin Boyd gave an overview of CCDC ARL's fire protection mission program. CCDC ARL's fire protection program is focused on the response of fuel tanks to overmatching ballistic threat. The fuel tank response from a ballistic event is threat dependent. The main threats of concern for ground vehicles are high-energy threats such as shaped charges and improvised explosive devices. The goals of the program are to mitigate the effects of ballistically induced hydrodynamic ram (HD-Ram), characterization of HD-Ram induced fuel spray, and understanding flame growth and propagation from ballistic events.

2.2.2 CCDC ARL's Ground Vehicle Testbed and Fuel Spray Characterization Studies

James Anderson presented on CCDC ARL's Fuel Spray Characterization and Ground Vehicle Testbed studies. Fuel spray from the ballistic impact of a fuel tank is HD-Ram dependent. Understanding the formation of the fuel spray and the size, velocity, and distribution of the particles will facilitate development of more efficient mitigation techniques. A two-camera stereo-imaging technique has been developed to successfully characterize droplets down to 100 microns in diameter. A 300-ft^3 ground-vehicle mockup has been built and will initially be used to examine the flame growth from ballistic events inside a vehicle crew compartment. The mockup has eight 10- × 10-inch viewing ports and one large 46- × 16-inch window. Two-camera pyrometry will be used to measure spatial flame growth and temperatures in the mockup. Follow-on studies will examine the effectiveness of AFES systems and extinguishing agents, and examine Li-ion battery reactions in a confined space.

2.2.3 Hydrodynamic Ram Simulations of Thin-Walled Liquid-Filled 7-L and 15,000-L Containers

Dr Suthee Wiri from Applied Research Associates, Inc. (Albuquerque, New Mexico) presented on simulation results for the response of liquid-filled containers impacted by fragments. Peridynamics, an extension of continuum mechanics, was used to study container response. Experiments were conducted on 7-L tanks filled with water; the containers were impacted by one, four, and seven fragments. The results for simulations with the 7-L tank were in agreement with the experimental results; the spray pattern, hydraulic pressure, and deformation of the container matched the experimental results. Simulations were also conducted for a 15,000-L tank with low- and high-kinetic energy threats. The results showed that the peridynamic approach can simulate HD-Ram effects with different container shapes and sizes.

2.2.4 4-D Flame Visualization in Fire Protection: Challenges and Opportunities

Dr Lin Ma from the University of Virginia (UVA [Charlottesville, Virginia]) presented on his group's recent progress in the area of four-dimensional (4-D) flame visualization. Due to continued advancements in imaging and computing technologies, it has become feasible to attempt a long-desired experimental capability—visualization measurements that can resolve both the temporal and all three spatial scales (i.e., 4-D measurements) of highly turbulent flames. Example measurements from the UVA group included 4-D measurements of turbulent flow structures, chemical species, and velocity with temporal resolution up to 20 kHz and sub-millimeter spatial resolution in all three directions. Besides demonstrating the feasibility and potential of 4-D visualization, these results also elucidate several opportunities for both fundamental and applied research under the context of fire protection.

2.2.5 Megasupramolecules (MSMs) as Fuel Additives

Dr Jeremy Wei from Fluid Efficiency (Pasadena, California) presented on MSMs, a new class of additives for lubricants, hydraulic fluids, and fuels. After 9/11, members of Caltech University began looking at ultra-long polymers for mist control in fuels. After 15 years of research, MSMs were developed that survive real-world conditions and prevent explosions by increasing the droplet size of a fuel mist. The larger droplets result in less fuel vapor available for ignition during an accident or attack. When ignition does occur, it results in a small self-quenching fire and little or no pool fire versus the large self-supporting fire with untreated fuel. MSMs differ from previous state of the art; they are resistant to nonintentional degradation, soluble over a wide temperature range, they permit dewatering and filtering, and they burn in an unmodified internal combustion engine. Threat-readiness level testing by CCDC GVSC shows that MSMs have the potential to provide beneficial effects on compression ignition, viscosity index, and lubrication. Currently Fluid Efficiency is planning to scale up production to deliver pilot quantities of MSMs for field tests.

2.2.6 Crew Compartment Free Volume Uncertainty Based on Suppressant Concentration Measurements

Dr Vamshi Korivi from the CCDC GVSC presented a summary of the findings and lessons learned from testing and crew compartment volume calculations. Using standards for fire suppressant agent properties given by the National Fire Protection Association, the free air volume of an enclosed compartment can be determined from agent concentration measurement data, the amount of suppressant discharged, and the ambient temperature. For a tactical ground vehicle, HFC-227ea measurement data were used to determine the crew compartment volume and the resultant volume was in agreement with the volume calculated using a solid model (CAD) of the vehicle. Similar high-speed concentration test data with Halon 1301 for the crew compartment of a larger ground vehicle yielded a volume that was significantly lower than the volume calculated using CAD. This discrepancy in the free air volume comparison motivated a methodical study using a cuboid box with a known volume to determine, under different conditions, the uncertainty of the volume calculated using suppressant concentration data.

2.2.7 Evaluation of Commercial Surfactants through Fire Suppression, Foam Degradation, and Fuel Transport to Develop a Fluorine-Free AFFF Replacement

Katherine Hinnant spoke about NRL's effort to develop a fluorine-free aqueous film-forming foam (AFFF) replacement. Mechanisms of foam fire suppression were evaluated for various commercial fluorine-free surfactants. Fast fire suppression is dependent on a foam's ability to block fuel vapors traveling between the burning fuel pool below and the flame above, and maintaining physical coverage over the fuel pool. Fuel transport through the foam is influenced by diffusion properties between surfactants in the foam and fuel as well as the foam layer thickness, which is impacted by foam degradation. Surfactants were evaluated as individual components and in a reference formulation mixed with a hydrocarbon surfactant and solvent. None of the surfactants have matched the foam degradation or fuel transport performance of commercial AFFF. More research is needed into surfactant synthesis and the role of fuel in extinction to bridge the performance gap between fluorine-free surfactants and AFFF.

2.3 Environmental and Health Effect Issues

2.3.1 Regulatory Overview of Low-GWP Agents and Refrigerants

Patrick Taylor of Jensen Hughes (Baltimore, Maryland) gave a regulatory overview of the drivers for low-GWP extinguishing 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, which 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. Meanwhile, the Montreal Protocol entered into force in 1989 to regulate the production and sharing of ozone-depleting substances (ODS) and now high-GWP HFCs that are/were the primary alternatives to ODS. On 15 Oct 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% phase-out of halons and hydrochlorofluorocarbons (HCFC)-123 in HCFC blend B, the 100% phase-out of chlorofluorocarbons (CFCs)/solvents and HCFCs, and the 85% phase-down 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; as a result, industry may not make the type and amount of low-GWP agents that will be needed for future military uses.

2.3.2 Low-GWP Fire Suppressants

Steve McCormick and Dan Kogut spoke on a joint CCDC GVSC/AMCOM program to evaluate alternate materials for the high-GWP extinguishing agents currently deployed in ground and aviation weapon systems. The results of laboratory, medium-scale, and full-scale extinguishing tests of low-GWP agents against fuel fires were presented. These results are intended to guide future research and procurements, and to assess the need for regulatory exemptions and/or reserves of high-GWP agents where low-GWP agents are not feasible. The scope includes ground vehicle crew and engine compartments, aviation engine and auxiliary power unit compartments, and portable extinguishers. The new agents must meet the requirements unique to military applications (e.g., vulnerability to ballistic threats and explosion suppression in occupied area). A benefit of identifying low-GWP agents will be the cost avoidance associated with the reduced availability and thus higher costs of current high-GWP agents after expected production phase-downs.

2.3.3 Evolution of Combustion Byproducts from Gaseous Fire Suppression Agents

Dr Steve Hodges spoke about an interesting observation made during a study of fire suppression agents with lower GWP than currently used agents. It was found that the byproducts from low-GWP FK-5-1-12 evolved quite differently than the byproducts from higher-GWP Halon 1301 and HFC-227BC. Continuous sampling gas phase Fourier transform infrared spectrometers were used to analyze combustion products in near real time. It was found that Halon 1301 and HFC-227BC produced significant levels of carbonyl fluoride (COF_2) which then decayed into hydrogen fluoride (HF); however, the levels of byproducts remained below acceptable levels. FK-5-1-12 on the other hand produced very high levels of HF and COF_2 simultaneously and the levels of byproducts remained above acceptable limits. Overall, this result suggests that chemicals, such as FK-5-1-12, that are designed to be more reactive, thus yielding shorter atmospheric lifetimes and therefore lower GWPs, generate much higher byproduct levels during the fire suppression process than more stable, and thus likely higher GWP, compounds.

2.3.4 Ballistic Fire Evaluation of R1234yf Refrigerant

Kevin Boyd presented on a CCDC GVSC-funded effort to evaluate the flammability of R1234yf when subjected to ballistic events. R1234yf is a potential replacement for R134A in mobile air conditioning (MAC) systems. R134A is nonflammable while R1234yf is flammable but has a low burn velocity (< = 10 cm/s). In standard ASTM E681 refrigerant flammability tests, no fires were observed with R1234yf; however, in the ballistic evaluations, fires were observed with R1234yf in a simulated MAC system. MAC systems use oil for lubrication of a compressor, and 4 oz of compressor oil were used in the simulated MAC system. Follow-on experiments were conducted with 0 and 1 oz of oil to determine what effect, if any, the oil had on the fires. Mixed results were observed; with no oil, one large fire event, similar to what was observed with 4 oz of oil, was observed along with two short-duration fires. With 1 oz of oil, no fires were observed. The conclusions from the effort were that R1234yf presents a fire hazard in military MAC systems versus R134A, and the ASTM E681 standard refrigerant flammability test is not adequate for military applications.

3. References

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3. Boyd KJ, McCormick S. 2017 fire protection information exchange meeting. Aberdeen Proving Ground (MD): Army Research Laboratory (US); 2018 May Report No.: ARL-MR-0978.

Appendix A. Agenda

Day 1	Title	Speaker	Organization
	Opening Remarks	Kevin Boyd/Steve McCormick	CCDC ARL/GVSC
1	Overview of CCDC ARL's Fire Protection Program	Kevin Boyd	CCDC ARL
2	CCDC ARL's Ground Vehicle Mockup and Fuel Spray Characterization Studies	James Anderson	CCDC ARL
3	External Fuel Cell Protection From Overmatching Ballistic Threats	Seth Copeland	CCDC ARL
4	Aramid Fabric Overwraps of Steel Fuel Tanks Subjected to Shaped-Charge Attack	Dr Brian Scott	CCDC ARL
5	Hydrodynamic Ram Simulations of Thin-Walled Liquid-Filled 7- and 15,000-L Containers	Dr Suthee Wiri	Applied Research Associates, Inc.
6	Safetank Fuel Tank Self-Sealing for Tactical Vehicles: State of the Technology and Opportunities in Lightweight, High-Performance Self-Sealing for Kinetic Energy and Fragment Threats	Paul Ardovini	Hutchinson Defense & Mobility
7	4-D Flame Visualization in Fire Protection - Challenges and Opportunities	Dr Lin Ma	University of Virginia
8	Discussion - Requirements For Ground Vehicle Fuel Tanks	Steve McCormick	CCDC GVSC
9	DGA Fire Laboratory Overview	Antoine Orth	French MOD
10	Preliminary Analysis of FR Uniform Needs Based on Burn Injuries	Thomas Tiano	CCDC SC
11	Megasupramolecules as Fuel Additives	Dr Jeremy Wei	Fluid Efficiency
12	Fiber Optic Fire Protection	John Porterfield	Kidde
13	Discussion - Fire Protection for Unmanned Ground-Combat Vehicles	Kevin Boyd	CCDC ARL
Day 2	**Title**	**Speaker**	**Organization**
	Opening Remarks	Kevin Boyd/Steve McCormick	CCDC ARL/GVSC
14	Regulatory Overview of Low-GWP Agents and Refrigerants	Patrick Taylor	Jensen Hughes
15	Low-GWP Fire Suppressants	Steve McCormick/ Dan Kogut	CCDC GVSC/ATC
16	Evolution of Combustion Byproducts from Gaseous Fire Suppression Agents	Dr Steve Hodges	CCDC GVSC
17	Crew Compartment Free Air Volume Uncertainty Based on Suppressant Concentration Measurements	Dr Vamshi Korivi	CCDC GVSC
18	Evaluation of Commercial Surfactants through Fire Suppression, Foam Degradation, and Fuel Transport to Develop a Fluorine-Free AFFF Replacement	Katherine Hinnant	NRL
19	Ballistic Fire Evaluation of R1234yf Refrigerant	Kevin Boyd	CCDC ARL
20	Li-ion Battery Fire Tests	Jerry Brown	Fireaway Inc.
	Questions and Comments	All	

Appendix B. Contact List

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Appendix C. Presentations*

* This appendix appears as multiple pdf attachments.

Table C-1 List of attached presentations and documents

Anderson_FuelSpray_Mockup
Boyd_ARL Vehicle Fire Protection Overview
Boyd_RefrigerantEval2018FPM
Brown_Stat-X Suppression
Copeland_Fuel Tank Protection
Hinnant_Commercial Surfactants
Hodges_Evolution of Byproducts
Korivi_Volume Uncertainty
Lin Ma_4D Flame Visualization
McCormick_Kogut_Low GWP Fire Suppressants
Orth_DGA Fire Lab
Scott_Aramid Fabric Overwraps of Steel Fuel Tanks Subjected to SC
Taylor_Regulatory Update for Low GWP Agents
Tiano_Fire Resistant Uniforms
Wei_Megasupramolecules
Wiri_HRAM Simulations

List of Symbols, Abbreviations, and Acronyms

4-D	four-dimensional
AFC	Army Futures Command
AFCEC	Air Force Civil Engineering Center
AFES	automatic fire extinguishing system
AFFF	aqueous film-forming foam
AMC	US Army Materiel Command
AMCOM	US Army Aviation and Missile Command
ARL	US Army Research Laboratory
AS	Aeronautical Systems
ASA-IEE	Assistant Secretary of the Army for Installations, Energy and Environment
ATC	US Army Aberdeen Test Center
CAD	computer-aided design
CCDC	Combat Capabilities Development Command
CFC	chlorofluorocarbons
COF_2	carbonyl fluoride
DAC	Data & Analysis Center
DC	direct current
DGA	Directorate General of Armaments
DOD	US Department of Defense
FR	flame resistant
FY	fiscal year
GVSC	Ground Vehicle Systems Center
GWP	global warming potential
HCFC	hydrochlorofluorocarbons
HD-Ram	hydrodynamic ram
HF	hydrogen fluoride
HFC	hydrofluorocarbons

Li	lithium
MAC	mobile air conditioning
MEDCOM	US Army Medical Command
MOS	military occupational specialty
MSM	megasupramolecules
NAVAIR	US Naval Air Systems Command
NAVSEA	US Naval Sea Systems Command
NMC	nickel manganese cobalt
NRL	US Naval Research Laboratory
NSWC	US Naval Surface Warfare Center
ODS	ozone-depleting substances
PEO LS	Program Executive Office Land Systems
RDECOM	US Army Research Development and Engineering Command
SC	Soldier Center
UNFCCC	United Nations Framework Convention on Climate Change
UVA	University of Virginia

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