By Douglas Kulick

Douglas Kulick, Military Systems, Business Development Director, Spectrex Inc. Prior to joining Spectrex, Mr. Kulick was Project Manager at FMC (BAE) and also served as an industrial consultant. Mr. Kulick has had extensive armored vehicle experience serving in the United States Marine Corps as an armor officer.

Spectrex Inc. is a global leader in fire and explosion detection and suppression technologies and systems integrated in military vehicles worldwide. Spectrex also develops hazard detection and suppression systems such as Flame Detectors and Open Path Gas Detectors designed to the highest safety requirements for high-risk industrial applications and for commercial businesses.

INTRODUCTION

More than 30,000 light tactical vehicles are protected by Automatic Fire Extinguishing System (AFES) and are deployed in various combat zones. Such vehicles are the High Mobility Multi-purpose Wheeled Vehicle (HMMWV, aka Hummer) and the Mine Resistant Ambush Protected (MRAP, various types) that are in active duty in Iraq and a few thousands of the recent addition of M-ATV in the Afghanistan arena.

The M-ATV is the most recent protected light vehicle developed for the Afghanistan combat environment which is protected by the well-tested and modern AFES system. The Marine Corps had recently defined the need and performance requirements to improve the HMMWV Automatic Fire Extinguishing System (AFES). This includes the requirement to extinguish peacetime and combat-initiated petroleum, oil and lubricant (POL) fires and to reduce or eliminate secondary fires (re-ignitions).
As a result of the lesson learned in combat duty, the Marine Corps is now considering options to improve the current HMMWV in a project called AFES Replacement (AFES-R).

The system will be used in the crew and cargo compartments of the United States Marine Corps (USMC) armored variants of High Mobility Multi-Purpose Wheeled Vehicle (HMMWV).

Today's battlefield experiences have generated major efforts to enhance the physical vehicle protection and fire detection and extinguishing systems upgrading. The effort to provide fire survivability addressed several areas including:

- Soldier Survivability
- Vehicle Survivability
- Safety
- AFE System Survivability

The fire detection and suppression systems were installed in various critical parts of the vehicles, protecting the engine and crew/cabin compartments, the wheels and tires as well as under the vehicle. Each subsystem is specifically designed and tailored to the vehicle's interior/exterior shape and volume and contains a specific fire extinguishing agent designed to extinguish the fire scenario expected in each area.

SOLDIER SURVIVABILITY

The Automatic Fire Extinguishing System (AFES) cannot protect the troops if it does not detect a fuel fire at all or detects it very late when it engulfs large portions of the vehicle. The extinguishing process can produce very irritant decomposition products (mainly HF) proportional to the speed and efficiency of extinguishment that may affect the soldiers in the vehicle. For troops to stay inside a vehicle when hit by an IED or RPG resulting in fire, the Automatic Fire Extinguishing System (AFES) must rapidly and efficiently extinguish the fire. If not:

- Troops who are able to egress will do so however they can, as fast as they can.
- Troops who are wounded or cannot egress may be injured or even die from the exposure to toxic gases or flames.

Troops need to be protected against both explosive and slow-growth type fires.

Most MRAP combat fires are a result of an IED causing slow-growth type fires.

- Slow-growth, secondary fires are usually a result of burning fuel, engine transmission hydraulic fluids, steering fluids and tires.
- A slow-growth fuel fire that develops in a few seconds after an IED event can be uncontrollable if not extinguished quickly.

In a combat or hazard zone, the vehicle and its system design should enable the troops to stay in the vehicle and be better protected from enemy fire than the threats that may result in unwanted egress that exposes the troops to the life-threatening enemy fire.

SOLDIER SAFETY

All types of fuel fires must be rapidly detected and extinguished to provide conditions that will not result in any risk to the troops or loss of confidence that may later result in unwanted egress from the vehicle.

Fires must be suppressed quickly and efficiently to prevent skin burns and the formation of high concentration of poisonous irritant decomposition products like HF, CO, HCN, etc. There needs to be no physical impact (pressure or blow) on the crew during the extinguishing agent discharge (particularly for personnel sitting next to or in front of the discharge nozzle).

The US Army has reviewed and refined its requirements for fire detection and suppression systems for the Up-Armeded HMMWV (M1114), the MRAP and the JLTV vehicle according to the present battlefield threats. Fast detection of the fire at its incipient stage is mandatory, especially in order to eliminate the occurrence of skin burns, prevent a secondary fire and the formation of decomposition by-products. Deploying the suppression means fast enough to completely extinguish the fire, prevent its re-ignition and at the same time provide a safe environment to the crew in order to facilitate their continued mission is a complicated task.

Re-ignition and secondary fire can occur where the fuel fumes or vapors that are present in the protected volume after the extinguishing action are ignited by a hot spot, usually as a result of the heat which is emitted by the original fire.

The phenomenon described as a secondary fire occurs when a prolonged fire is extinguished, and in places where the extinguishing concentration evaporates, there is a re-flash. It's an obvious fact that the longer the fire is burning with no detection and activation of the suppression action, the greater the likelihood of re-ignition. Therefore, to "reduce the risk of secondary fire" faster and more sensitive detection systems are needed.

Specifications defined by the services...
for the JLTV family of vehicles address current capability gaps, to increase the forces’ protection, survivability, fuel-efficiency, capacity, maneuverability and automotive safety all balanced with the total cost of ownership.

The Mine Resistant Ambush Protected (MRAP) vehicles include the RG 33L and CAIMAN vehicles, which are based on the well-proven reliable Family of Medium Tactical Vehicles (FMTV) platform and the combat-proven Low Signature Armored Cab (LSAC). These vehicles provide an enhanced degree of mission flexibility offering both improved survivability and more volume under armor than any other mine protected vehicle, incorporating the latest designs in protection against improvised explosive devices.

**CREW COMPARTMENT**

Explosion, detection and suppression system

- Optical Detector
- Control Box
- Detector Controller
- Emergency Switch
- Extinguisher Cylinder

**MRAP II AFES PERFORMANCE SPECIFICATION**

The MRAP vehicle will be equipped with Automatic Fire Extinguishing Systems (AFES) for the crew area, engine compartments, fuel tanks (passive extinguishment), and cargo compartments if not isolated from the crew area. The systems shall address slow growth and rapidly developing fuel fires generated by various explosive effects. The systems will be able to extinguish petroleum, oil, and lubricant (POL) fires before crew members are incapacitated or significant vehicle damage occurs.

Removal of any individual fire sensor shall not render the remainder of the system inoperative.

The Caiman and RG-33 MRAPs are equipped with AFES providing the capability of early detection of slow-growing fires and/or approaching fires and instantly activating the extinguishing system, thus preventing the occurrence of skin burns. These systems, tested for performance at the Aberdeen Test Center (ATC), are widely deployed and have proven their reliability. In the test data obtained in these test series, it was found that slow-growth fires, if not detected and extinguished automatically in time, would definitely cause injuries to the crew.

In the ATC Crew Compartment Fuel Fire Tests, all pan fires (1x1 ft and 18” diam.) in the crew compartment were successfully extinguished by the on-board Automatic Fire Extinguishing System (AFES) without re-flash and prior to any vehicle damage.

In Tests 1 and 4, the AFES was set to function automatically. The fire during these tests lasted 1.076 and 1.154 sec. (from the pan fire start to the extinguishment), respectively. Each fire was automatically detected and extinguished by the AFES and there were no crew injuries from thermal effects, toxic gases, or from blast overpressure (BOP). No significant vehicle damage resulted from any pan fire test in the crew compartment.

In Tests 2, 3 and 5, the AFES were manually discharged and the tests were conducted while the sensors were covered. During these tests, the crew compartment extinguishers were manually discharged 18.32, 20.573 and 16.90 sec., respectively, after the fire ignition. Temperatures at the crew positions climbed to over 1400 °F. Each fire was extinguished as a result of the manual release of the AFES, with the overall duration of the fire during these tests lasting 18.76, 21.573, and 17.425 sec., respectively.
In conclusion, the tests showed excellent fire detection and suppression of slow-growth fires, which would certainly cause crew injuries, if not for the AFES quick reaction. Secondly, unchecked slow-growth fires are a cause for concern if not detected and automatically suppressed.

**SURVIVABILITY CRITERIA FOR MILITARY FIRE EXTINGUISHING SYSTEMS**

The US Army Tank-Automotive Command worked with the US Army Surgeon General to establish the guidelines shown in Table 1 as the minimum acceptable requirements of the Automatic Fire Extinguishing Systems (AFES) for occupied vehicle compartments. These parameters have been set at levels that do not result in incapacitation of the crewmen from the fire and its extinguishing process, allowing them to take corrective action and to potentially continue their mission.

The standards established by the Army Surgeon General clearly state that time is the enemy of a fire extinguishing system. Once a fireball begins to grow inside of the crew compartment, if not extinguished fast, more extinguishing agent will decompose as part of the chemical action to suppress the fire, production of more toxic gasses, less oxygen, and greater exposure of skin to the fire. In simple terms, the faster the AFES extinguishes the fire, the higher the probability that the crew will not be injured.

**AUTOMATIC FIRE EXTINGUISHING SYSTEMS (AFES)**

**The Detection Subsystem** in laymen terms either sees or feels the fire event. If it’s in an occupied compartment such as the crew compartment, an electro-optical sensor is the quickest means to identify a fire. It acts like an eye. Since the eye can see light at the speed of light, it is almost instantaneous. A special UV/IR combination provides greater sensitivity and higher speed of response while providing a high immunity to false alarms.

The sensors in the engine compartment act like our skin in that a wire sensor (thermistor) senses the changes in temperature and at pre-designated temperature points gives an alarm or activates the extinguisher.

**The Fire Extinguishing Subsystem** consists of an agent, shatterproof pressurized cylinder or by a gas generator, high-speed valve, wiring harnesses, nozzles, and piping. For decades, Halon 1301 was the agent of choice for military applications, but with the approval of the Montreal Protocol, Halons were banned from production and the military community worldwide conducted a wide search to find the “silver bullet” that would be a “drop-in” replacement of Halon 1301. After an exhaustive search, they did not find the “silver bullet,” however they did find several acceptable replacements.

**FIRE EXTINGUISHING AGENTS**

A published report written by Mr. Steve McCormick, Fire Research Team Leader, US Army TARDEC and Mr. David Koehler, Manager, Army ODC Elimination Program, states the following concerning their search for a Halon replacement:
“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.”

Other agents, such as sodium bicarbonate based dry powder, can be used in the engine compartment as in the Abrams M-1 Series Tank. HFC-227ea will be used in vehicles that shut the engine off prior to agent discharge (including the M2/M3 Bradley Fighting Vehicle) because of its ease of retrofit. Powdered Aerosols have been selected for the engine compartment of MATV vehicles. In a recent paper presented at SUP-DET 2010, the US Army presented findings of more than 150 live fire tests using nine agents and four extinguishing technologies. The basic conclusion is that no alternative agent can yet be considered a “drop-in” replacement for Halon 1301 or HFC 227 BC for the application of fire extinguishing in military ground vehicles. An interesting finding was that a blend of Halon 1301 and dry powder can be about twice as effective as Halon 1301 alone.

### ARMORED PERSONNEL WHEELED VEHICLES PROGRAMS

The M1114 HMMW up-armored vehicles are equipped with a system that protects both crew and cargo areas. The system comprises three optical detectors, two HFC 227 cylinders and a controller. The experience from the battlefield has driven the USMC to issue a recent solicitation for the replacement of the current AFE system, in order to provide upgraded systems that will provide a cooling effect and reduce the risk of secondary fires. Most MRAP variants are equipped with AFE systems that protect the troop and engine compartments. Some variants also include systems that protect the wheel-bay and external areas of the vehicle. The Caiman and the RG 33 MRAPs include an AFES crew compartment system comprising one detector-controller, one optical detector and two HFC 227 cylinders. This system ensures rapid detection

<table>
<thead>
<tr>
<th>TABLE 1. CREW SURVIVABILITY CRITERIA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
</tr>
<tr>
<td>Fire Suppression</td>
</tr>
<tr>
<td>Skin Burns</td>
</tr>
<tr>
<td>Overpressure</td>
</tr>
<tr>
<td>Agent Concentration</td>
</tr>
<tr>
<td>Acid Gases HF</td>
</tr>
<tr>
<td>Oxygen Levels</td>
</tr>
</tbody>
</table>

*NOAEL - No Observed Adverse Effects Level
NOTE: Often the Skin Burns Requirement is converted to a fire out time of 250 milliseconds or less. (250/1000th of a second)

<table>
<thead>
<tr>
<th>TABLE 2. CREW MEMBER ACID-GAS EXPOSURE CRITERIA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Authority</td>
</tr>
<tr>
<td>US Army Surgeon General</td>
</tr>
<tr>
<td>Walter Reed (Sept ’89)</td>
</tr>
<tr>
<td>USMC EFV/AAV (’99)</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

Exposure criteria and other safety requirements have been recently updated by the US military forces and are more detailed, taking into account brief exposures to HF acid which is created during the extinguishing process of the Halon alternatives that contain fluoride like FE 227.
of slow-growing fires and/or approaching fires followed by immediate activation of suppression means, thus preventing occurrence of skin burns and minimizing the toxic by-products.

The Oshkosh M-ATV vehicles are equipped with AFES crew compartment detection systems featuring one controller, one optical fire detector and one HFC 227 extinguisher cylinder. The performance parameters are similar to the MRAP Caiman and RG-33 systems.

KEY FEATURES OF MODERN AFES

Various technologies are currently evaluated for external vehicle fire protection, whether for protecting the vehicle’s surface or its “soft belly” before it is engulfed in flames that may cause irreparable damage. Improvements in conventional crew and engine compartments have been introduced to meet the new critical design parameters for the Future Combat Vehicle and other new armored and tactical vehicles.

Key features of these modern AFES include:

- Valve and dispersion special design that provides for:
  - Rapid, efficient and homogenous dispersion of the extinguishing agent throughout the protected volume
  - Dispersion mechanism (deflector) that ensures rapid drop in pressure at a short distance from the valve outlet and substantially increased safety to personnel during cylinder discharge, compared to the previously used high pressure pointed discharge nozzle
  - Sensitivity of the optical detectors that ensures optimal detection coverage of the protected volume including detection of penetration in less than 3 milliseconds as well as detection of small and slow-growth fires (size of 8 in. pan fire located anywhere in the crew compartment), all combined with increased detector immunity to false alarm
- Preferably a double-shot system providing a second shot suppression to address the high likelihood of a vehicle being hit twice once acquired as a target by the enemy in the battlefield
- Embedded diagnostics that detect and isolate all essential system critical performance functions of each one of the optical flame detectors, extinguisher valves and the system control unit
- Embedded prognostics that enhance the availability of the system and its components and reduce support costs by predicting critical performance failures in advance of their occurrence
- Microprocessor-based control units providing for:
  - Visual alarm, fault, status indications and operational switches on panel or detailed indication by LCD display (as an option)
  - RS-485/422 serial communication port connects to external control

SYSTEM CONSIDERATIONS

Crew System Considerations:

Vehicle operational requirements
- Access to ammo storage and other stored items
- No interference with weapon systems and other vehicle systems
- No interference when entering/exiting vehicle
- Withstand vehicle operating environment – vibration, shock
- Vehicle maintenance routine

Agent discharge and dispersion
- Discharge will not cause threat to crew – design appropriate valve outlet
- Secure homogenous and effective dispersion throughout the protected volume

Crew safety
- Appropriate anti-recoil device
- Divert discharge from direct impact on crew

Engine System Considerations:

- Protect dispersion nozzles from dirt
- Locate extinguisher beyond engine compartment bulkhead
- Consider airflow, sources of fire hazards
- Consider airflow and need for engine shut down before agent discharge
system for test, maintenance, diagnostics and troubleshooting
- TCP/IP Ethernet port interfaces with LAN for integration into vehicle communication infrastructure (option)
- Built-in event recorder (option)

Novel environment friendly fire extinguishing agents and new methods of dispersion are considered for the modern AFES. Fire suppression solutions may include:

- Small particles or dry powder “shot” directly at the incoming fire threat to counter/diminish the fire ball that may hit the vehicle’s surface
- Dry powder in direct stream or through piping and nozzles discharge. The powder dispersion in cloud form or surface area coverage to protect the vehicle surface
- Surface-acting wetting agents (chemical agents) such as foam or fuel and rubber decomposing material by itself or in combination with dry powder for the wheels compartment
- Total flooding and streaming agents discharged from hybrid systems

The mechanisms by which these fire suppression agents extinguish the fire are complicated and usually more than one mechanism applies for fast and successful fire suppression. Some of the most effective fire extinguishing mechanisms identified so far include:

- Dry powders (various particle sizes) that act chemically and physically on the fire propagating species in the gaseous phase, disrupting the flame front and causing fire suppression
- Wetting agents/foams that act chemically on the burning surface to prevent further burning
- Water-based agents with additives (loaded streaming agents) that act chemically and physically to suppress the fire and cool down the fuel surface

As technology changes, leading companies with their aggressive research and development programs are up to the challenge that will provide innovative fire protection strategies and products for the modern vehicles on today’s battlefield. 

### SYSTEM TECHNOLOGIES

#### Optical Flame Detection:

Spectral analysis of fire phenomena discriminates between slow-growth fuel fires, ammunition fires and high-energy penetration (HEAT and Kinetic charges). The spectral analysis is performed in the UV and IR spectral bands that are emitted by the various combustion processes. Optical detectors based on this technology include the well-known UV/IR – featuring fast response, high reliability, enhanced immunity to false alarms, and dual IR and the Triple IR (IR3) – featuring increased sensitivity to small fires, highest reliability and best immunity to false alarms.

#### Logic and Control:

Microprocessor-based electronics enable flexibility to fit specific system configurations and operating logic. Control panel includes mode selector, indication and warning signals, and Built-In-Test capabilities. Modern RS-485 serial communication port enables connection to a main control system and can be used for maintenance and troubleshooting. The control unit can also interface with a Local Area Network (LAN) via TCP/IP Ethernet port, enabling integration of the system into an existing vehicle communication infrastructure.

#### Extinguishing Technologies:

Chemical and physical-acting fire suppression agents featuring clean gaseous agents (Halon Alternatives) such as HFC-227ea combined with scrubbing agents such as BS (Sodium Bicarbonate) for reduced toxic by-products and increased extinguishing efficiency. These agents are rapidly and effectively discharged from pressurized cylinders that feature squib-activated valves and dispersion nozzles that provide homogeneous total flooding of the protected volume. Novel concepts in fire suppression employing propellant- extinguishing technologies either as stand-alone systems or as propelling means for conventional extinguishing agents. These novel concepts are provided in cooperation with leading propellant industries.