

# Fire Protection in Military Ground Vehicles

Steven E. Hodges  
Alion Science and Technology

## ABSTRACT

Fire protection, active and passive, has been, and is, an important area of concern during the design, development and deployment phases for all modern ground vehicles. All US military vehicles carry handheld fire extinguishers, and many tactical and all combat vehicles have automatic fire protection systems that protect the crew, engine, and in some cases, external components such as fuel tanks and wheels, from potentially catastrophic combat events involving fire. Vehicle designs also mitigate fire hazards by separating the vehicle occupants from the most flammable materials, e.g., fuel and ammunition, as much as practical. Explosion protection of the crew and passengers in military vehicles is a unique application with unique requirements that must balance suppression actions with safety limits. This paper presents an overview of general guidelines related to protecting military ground vehicle crews from injury due to fire, and lessons learned from the experiences of fielded systems.

**CITATION:** Hodges, S., "Fire Protection in Military Ground Vehicles," *SAE Int. J. Trans. Safety* 4(2):2016, doi:10.4271/2016-01-1404.

## INTRODUCTION

When combustible fluids and flammable materials are stored in close proximity to potential ignition sources, as they inevitably are in ground vehicles, fires are a real and present danger. Modern military vehicles use diesel or JP8 fuels which are, due to the relatively high flash point temperature, much less of a fire hazard than gasoline, the fuel used in earlier vehicles. Nevertheless, all fuels, hydraulic fluids and most lubricants are flammable and the risk of fire in modern military vehicles remains significant.

'Peacetime' fires in military ground vehicles are similar to commercial vehicle fires:

- Fuel, hydraulic fluid, or lubricating oil component failures can lead to leakage of flammable liquids that are ignited by contact with hot surfaces and/or sparks.
- Electrical component failures or corrosion can lead to overheated circuits that ignite wire insulation or oily contaminants and other combustible materials.
- Overheated brake components and trapped road debris can cause fires in the wheel well. (Wheel well fires can also occur if a vehicle operates too long on 'run-flats' designed to offer temporary support when the main tires are deflated.)

As is the case with heavy-duty vehicles, hand-held fire extinguishers (HFEs) are deployed on all military vehicles. If used properly, HFEs are generally effective in suppressing and extinguishing small, slow-growth peacetime fires, but cannot be relied on to protect against fast-growing, explosive fires that can occur in combat. Protection against combat fires requires a fast and automatic system.

The first automatic fire extinguishing systems (AFES) deployed by the US Army in ground vehicles were developed for the Abrams, Bradley Fighting Vehicles (BFV), Field Artillery Ammunition Support Vehicles (FAASV), and later the Stryker family of vehicles. More recently, a variety of similar fire protection systems have been deployed on mine-resistant ambush-protected (MRAP) and uparmored high-mobility multi-wheeled (UAH) vehicles.

The threat the AFES was designed to protect against was a penetration of the vehicle that involved fuel or other petroleum, oil, or lubricant (POL). The penetrating threat entered the vehicle so that a POL reservoir was involved, resulting in a spray of flammable fluid that was ignited by residual threat elements causing an explosion (technically a fast deflagration). During Operation Desert Storm, the Abrams and BFV AFES were reported to be effective in protecting vehicle crews from such combat-initiated POL-fueled fires (1).

What is a combat fire? The Abrams specification (see Table I in ref. 2) requires that the fire sensor respond with an alarm signal when exposed to a 'fireball' explosion, defined as follows:

"The radiation level equal to or equivalent of that produced by a fuel oil fire ball explosion which grows from 1.0 inch or less to 4.0 feet or larger in diameter instantaneously at 5 feet and less from the sensor."

Subsequent tests on the BFV and other platforms confirmed this definition of a combat explosion as reasonable, and it is currently routinely simulated by a fuel-spray fire during AFES verification tests (3). In these tests, the "fireball generator" (FBG) is oriented to simulate a threat penetration deemed realistic by the platform program management team and/or independent evaluator. Current live-fire test methodologies are routinely reviewed to insure that they reflect realistic scenarios to adequately evaluate systems intended to

protect against the newer threats. For example, recently, simulations of field-expedient Molotov cocktails (FEM) have been included in validation testing of tactical vehicle fire protection.

As a result of the new threats encountered during the wars in Iraq and Afghanistan, ones that pose significant risk of fires, in addition to an AFES, vehicles have added passive fire protection systems such as powder panels or blankets that enclose and protect fuel tanks. Some vehicles also use active fire extinguishing systems to protect their external fuel tanks and/or the tires. Self-sealing fuel tanks have been developed and are deployed on some vehicles.

High-level attention to 'lessons learned' relevant to fire protection is not new. In 1986 an Army blue ribbon panel focused on vehicle fires and recommended particular attention to defining realistic operational requirements and ensuring that fire protection systems be functional when needed. The 1995 Design of Combat Vehicles for Fire Survivability Handbook (MIL-HDK-684) details lessons learned at that time. Topics covered include: bilge design, engine type, design and location of fuel cells and fuel lines, space heaters, and routing of hydraulic lines. (4)

Lessons learned during recent asymmetric Middle East conflicts led, among other things, to successful development and deployment of external fuel tanks with add-on fire protection. The protective wraps around fuel tanks were initially retrofitted, and later installed during manufacturing.

More recently, due to the combination of urgent needs and the lack of centralized vehicle fire protection oversight, a wide variety of components and systems, many with similar or same capabilities, have been deployed. The large number of part numbers has made logistical and training support costs notably high and made vehicle down-time more likely. And the variation in the performance and safety of fire protection system has also increased, due, for example, to new suppliers who are unfamiliar with military applications.

Advancements in vehicle development, especially those associated with the power train and fuel, may involve relatively new fire hazards that often require somewhat unique mitigation means. Recent collaborative efforts to understand emerging electric vehicle fire hazards (e.g., those associated with certain battery technologies) and develop applicable safety standards are notable examples. Clearly the need for vehicle fire research, in all applications, continues.

## FIRE PROTECTION SYSTEM DESIGN

No safety system can be effective unless it is designed with a well defined threat, or set of threats, in mind. Fire protection systems are no exception (4). Hence, the first step in designing a fire protection system to protect the crew in a ground vehicle from combat threats is to understand the nature of the threat, and how it may cause a catastrophic fire.

In addition to being effective against fire threats, the fire protection systems must meet the general environmental and operational vehicle requirements. After the fire protection and general requirements are defined for a target vehicle, qualified components must be integrated into systems on the vehicle and then the system's performance must be validated. The key design and development steps are:

1. Define requirements
2. Component verification
3. Integration of qualified components onto the vehicle
4. Validation of system performance

## Requirements

The detailed requirements for each platform vary. Tracked and wheeled vehicles have different operating and mission profiles; however, there are many similarities, both generally and specifically related to fire protection. A recent specification supporting the BFV modernization program is fairly comprehensive (5).

## General

The general requirements for sub-systems aboard a vehicle apply to the fire protection systems. These requirements include:

- Human engineering factors/ergonomics
- Safe-use criteria
- Mechanical and thermal abuse
- EMI and EMC immunity and effects
- Nuclear survivability
- Space and weight claims
- Integration compatibility
- Reliability
- Commonality
- Maintainability
- Availability and cost

## Unique to Fire Protection

The general requirements for sub-systems aboard a vehicle do not usually include requirements that are essential for adequate fire protection performance. Fire Protection specific requirements generally include:

- Fire suppression capability and performance
- Appropriate suppression agent(s)
- Adequate and safe agent concentration levels
- Manual release; mechanical and/or electrical
- Backup power (independent, not co-located with, vehicle power)
- Automatic fuel and/or air flow shutoff(s)
- Attitude insensitivity

Table 1. Selected Requirements for Crew Compartment AFES.

| Parameter                            | Requirement                                                                                                                                                                                               |
|--------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Fire Suppression                     | Extinguish all flames without reflash                                                                                                                                                                     |
| Skin Burns <sup>a</sup>              | Less than second degree burns<br>( $<2400^{\circ}\text{F-s}$ over 10 sec or heat flux $< 3.9 \text{ cal/cm}^2$ )                                                                                          |
| Toxic Gases <sup>a</sup>             | Acid Gases ( $\text{HF} + \text{HBr} + 2\cdot\text{COF}_2$ ) $< 746 \text{ ppm-min}$ (5 min dose)<br>Other toxic gases (eg, $\text{CO}_2$ , $\text{CO}$ , $\text{NOX}$ , $\text{HCN}$ ) are also measured |
| Overpressure <sup>b</sup>            | Lung damage $<11.6 \text{ psi}$ ; Ear damage $\leq 4 \text{ psi}$                                                                                                                                         |
| Oxygen <sup>b</sup>                  | Levels at breathing locations of at least 16%                                                                                                                                                             |
| Agent <sup>c</sup>                   | Concentration within occupational safety limits                                                                                                                                                           |
| Discharge Impulse Noise <sup>d</sup> | No hearing protection limit: $<140 \text{ dBp}$<br>Single hearing protection limit: $<165 \text{ dBp}$                                                                                                    |
| Discharge Forces <sup>e,f</sup>      | Not to exceed 8 g and $<20 \text{ psi}$ at 5 inches                                                                                                                                                       |
| Fragmentation <sup>g,h</sup>         | Ejected non-agent particles $<300 \text{ micrometers}$<br>Non-Shatterable Cylinders (NONSHAT)                                                                                                             |

- (a) Per reference (6).  
 (b) Per reference (7).  
 (c) See reference (8).  
 (d) See reference (9).  
 (e) Extrapolated from reference (6).  
 (f) See reference (10).  
 (g) Section 3.4.1.3 in reference (11).  
 (h) Section 3.3.9 in reference (12).

### Crew Compartment AFES

The AFES that protects the crew compartment is unique in that this military application is the only one that offers explosion protection to an occupied area. In this application the fire protection system must extinguish a POL-fueled fire before the crew is incapacitated. Thus there is a tradeoff between what is most effective at suppressing an explosion and what is safe for occupants (per human injury criteria). Table 1 summarizes the requirements that are generally most significant in designing and verifying the crew compartment AFES.

### Engine AFES

Current Army vehicles typically require that the engine AFES "... protect the engine compartment against petroleum, hydraulic fluid and other slow growth fires, as well as explosive hydrocarbon fires from threat weapon penetrations or explosions with an automatic first shot and a delayed or manually activated second shot to extinguish the fire without reflash...." The time within which the AFES must perform varies. Some applications require that the engine AFES act within 10 seconds of detection, and others require extinguishment without reflash within 10 seconds of fire detection or within 60 seconds of ignition, whichever occurs first. (13)

### Tire Fire Suppression

Several wheeled vehicles have tire fire suppression systems installed. The design goals of the tire fire protection system are to (14):

- Fully extinguish the fires within 25 seconds of ignition
- Minimize flame spread to external vehicle stowage

- Require no occupant action for extinguisher function
- Disperse extinguishant only in the area in and around the fire
- Present no hazard to personnel around the vehicle
- Require no scheduled maintenance for at least four years
- Provide manual backup operation capability

### Fuel Tank Fire Protection

Fuel tanks are generally protected using passive means such as armor and, recently using dry chemical 'powder pack' jackets. Dry chemical powder packs protect the fuel tank by dispersing fire extinguishing agent when they are penetrated. Some vehicles have recently implemented so-called 'crashworthy bladders' to minimize leakage in the event of the failure of the fuel tank enclosure due to a non-penetrating event, e.g., an underbody blast that does not breach the floor. In some vehicles the fuel tanks are mounted externally in ways that minimize the risk of a catastrophic fuel fire inside the vehicle (e.g., with an air gap between the fuel tank and the vehicle hull).

### Ammunition Fire Protection

Currently, while possibly mitigating secondary fires, active extinguishing systems are not effective against ammunition fires directly. Ammunition fires are best addressed via passive approaches including storing the ammunition separately from the crew, in a compartment with blow-off panels that, when a fire occurs, relieve pressure build-up to reduce the risk to the crew and vehicle (15).

## Component Verification

### Qualification

As a basic requirement, components used in fire protection systems need to be qualified to the relevant portions of the vehicle specification, including the general, e.g., environmental, and AFES-specific requirements, e.g., fire extinguishing performance.

### Highly Accelerated Life Tests (HALT)

Above and beyond qualification, as a means to reduce risks of failure once integrated onto a vehicle, it is desired that components be subjected to highly accelerated life tests (HALT) before they are integrated onto a vehicle. The HALT results should clearly identify:

- The margin by which the component exceeds the minimum qualification levels
- Weak links in the component design

The HALT environment typically subjects the component being tested to simultaneous mechanical and thermal abuse. The environmental excursions are expected to exceed those required by the specification, generally to the point where the component fails. This approach allows the component detailed design to be improved efficiently (16).

### System Integration

Different vehicle platforms have varying POL reservoir locations, capacities, geometries, layout and stowage. The AFES must be integrated on each vehicle so that it is optimized for that vehicle and