Final Technical Report
Fires Experienced and Halon 1301 Fire Suppression Systems in Current Weapon Systems
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This project was not sponsored nor performed under the auspices of any particular program office, and is intended to serve only as a research tool to assist in improving the quality and relevance of current fire protection research to the operational military aircraft community. It is not an official or formal trade study or assessment of the merits of modifying the existing fire protection system design of the platforms specifically, nor is it intended to be such. Interpretations and simplifications have been made by the investigators in executing this project, to comply within the project scope and purposes for the R&D community and sponsors.

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The goal of the Next Generation Fire Suppression Technology Program (NGP) is to develop and demonstrate retrofitable, economically feasible, environmentally-acceptable, and user-safe processes, techniques, and fluids that meet the operational requirements currently satisfied by halon 1301 systems in aircraft, ships, land combat vehicles, and critical mission support facilities. The results will be specifically applicable to fielded weapon systems and will provide dual-use fire suppression technologies for preserving both life and operational assets.

The purposes of this project were: to characterize and tabulate the nature, frequency, consequences (including personnel injuries), and severity of fires previously and currently attacked using halon 1301; to derive a small set of representative (model) fires (using the analyses described above) for other elements in the Program; and to compile characteristics and limitations of the systems that new fire suppression technologies will replace or into which they will be retrofitted. The descriptions of the environments of the current systems compiled during this program will serve as boundary conditions for the new technologies to be developed in subsequent Elements of the NGP.

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1.0 Executive Summary

The goal of the Next Generation Fire Suppression Technology Program (NGP) is to develop and demonstrate retrofitable, economically feasible, environmentally-acceptable, and user-safe processes, techniques, and fluids that meet the operational requirements currently satisfied by halon 1301 systems in aircraft, ships, land combat vehicles, and critical mission support facilities. The results will be specifically applicable to fielded weapon systems and will provide dual-use fire suppression technologies for preserving both life and operational assets.

The purposes of this project are:

- To characterize and tabulate the nature, frequency, consequences (including personnel injuries), and severity of fires previously and currently attacked using halon 1301.
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- To compile characteristics and limitations of the systems that new fire suppression technologies will replace or into which they will be retrofitted. The descriptions of the environments of the current systems compiled during this program will serve as boundary conditions for the new technologies to be developed in subsequent Elements of the NGP.

There are a large number of platforms that have halon 1301 fire-suppression systems. Obtaining information on all of these would be difficult, costly, and unnecessary. Therefore, the Military Services identified a small subset of these platforms whose halon systems are representative of the range of fire suppression needs:

- Ground vehicles: M992 (FAASV), M1 tank, and M2/M3 (BFSV)
- Aircraft: C-130, F/A-18 C/D, C-17, H-60, CH-47, F-16
- Ships: DDG 51, LHD 1/LHA 1

In order to characterize and tabulate the nature, frequency, consequences (including personnel injuries), and severity of fires previously and currently attacked using halon 1301, the Safety Centers of the Services and the Survivability/Vulnerability Information Analysis Center (SURVIAC) were contacted for both noncombat and combat data, respectively. Items such as fire zone, fire incidence rate, hazards to be protected against by halon 1301 system, flame suppression time requirements, and the current system tests were investigated.

Ground vehicles experience a wide variety of fires. The nature of these fires in peacetime is somewhat different from that experienced in combat. In peacetime, the significant contributors to crew compartment fires include the fuel in the hull cells next to the driver, hydraulic fluid in the turret hydraulic system, hydraulic fluid in the main gun recoil mechanism, the fuel-fed personnel heater, and ammunition stowed in the turret and the hull. The most common types of fires to occur in combat vehicles are the mist fireball explosion, pressurized hydraulic spray fires, and dry bay fires. Combat fires are initiated by a variety of weapons (mines, air attack weapons). Hot fragments or incendiaries produced from ballistic impacts ignite the fuel and hydraulic components where the fluids may be released in a spray of droplets. From 1988 through mid-1991, there were 178 peacetime incidents. The automatic fire extinguishing system was effective thirty-four percent (61 out of 178) of the time for the M1/M1A1. The frequency of fire incidents is a function of the exposure of the vehicle to combat. The single most lethal damage mechanism to ground vehicles in combat is fire. Fires can be initiated by a variety of weapons, and in all cases, they can cause a rapid kill of the vehicle and its crew. Internally stowed munitions such as gun rounds and missiles, fuel tanks, and hydraulic systems all provide substantial fire sources. Because fire can kill so quickly, rapid-reacting fire suppression systems have been developed.

The majority of peacetime aircraft dry bay fires are due to an equipment failure in a fuselage dry bay or failure of the engine or starter that results in damage to a fuselage dry bay. A large number involved wing fire damage due to equipment failures. Combat dry bay fires are usually created when a ballistic projectile impacts a dry bay in flight, rupturing fuel system components and generating tremendous ignition energy. Although this is the assumed primary initiation means, other initiation sources such as overheated, shorting electrical circuits in avionics bays, some other form of impact (i.e., bird strike), or burning stored munition propellants can also be responsible in rare instances. Data from Southeast Asia (SEA) suggest that fifty-eight percent of the twenty-four C-130 incidents were related to dry bay fires. The C-130 incidents were reported in which engines and/or adjacent bays were damaged by gunfire, creating numerous ignition sources, leaking fuel, and resultant fires in the leading and trailing edges. Dry bay fires can result in loss of aircraft assets either in combat or noncombat operations.

Aircraft engine nacelles have fluid lines that are routed within the enclosure on the exterior of the machinery, to provide fuel, oil or hydraulic/brake fluid for the machinery (all of which are flammable). In a typical peacetime fire scenario, one of the fluid lines leaks, and sprays or streams the flammable fluid onto the hot machinery, which results in a fire. Most engine nacelle incidents occurred during peacetime. Nonetheless, the potential of a combat-induced engine nacelle fire definitely exists and is currently being considered in several ballistic engine nacelle programs. However, fire protection systems are certified to the safety hazard and not to a combat induced hazard. Peacetime aircraft engine nacelle fire incidents are maintained by the Safety Centers of the various Services. SURVIAC maintains numerous combat databases. Data from these repositories are discussed in this report. Aircraft engine nacelle fires can result in loss of aircraft assets either in combat or noncombat operations.

Ullage (the void space above the fuel level in a fuel tank) in aircraft fuel tanks can have a potentially explosive fuel-air mixture. If initiated by a combat threat, an explosion can result. Fuel tank explosions are a result of ullage deflagrations where the combustion overpressure generated exceeds the structural strength of the tank. With large ignition sources, combustion will occur and overpressures will vary according to the threat level, tank volume, and oxygen concentration. If the combustion wave propagates throughout the ullage with near stoichiometric fuel/air mixture, a pressure increase of over 790 kPa (100 psig) (eight times atmospheric pressure) is theoretically possible. Fuel tank explosions are not frequent during peacetime. They are more a function of a combat incident. Historically, fuel fire and explosion is a major cause of aircraft losses in combat. Data from Southeast Asia show over half of the aircraft combat losses involved fuel fires and explosions. While other factors might also have contributed to the loss (e.g., pilot killed, loss of control, etc.), this fact, nonetheless, indicates the fuel system is a very significant contributor to an aircraft's vulnerability. Therefore, to increase survivability, various techniques are used to reduce the vulnerability of the aircraft's fuel system to this significant threat effect.

Fires in MMRs, AMRs, engine enclosures, and generator rooms result from the ignition of a pressurized fuel (diesel/hydraulic or lubricating oil) leak or ignition of fuel-soaked insulating material. Leaks onto hot surfaces result in three-dimensional spray fires with cascading liquid flow on complex surfaces and into flaming pools. Fires in FLSRs and paint issue rooms result from burning fuel cascading over highly obstructed and fuel loaded shelves and into flaming pools. The LHD class has high pressure steam plants. The steam plants have high temperature piping that can provide possible ignition and reignition sources. Further, these pipes are slow to cool. While turbine and diesel propulsion plants have high temperature surfaces, these cool much faster. Unvented high-pressure steam remains in the steam plant piping after engine shut down. Peacetime fire incidents data are discussed in this report. No combat data were available. The Navy started installing halon on ships in the 1970s following several disastrous machinery spacey fires where fuel and lube oil were released under pressure.

Previous research, development, testing and evaluation have led to the identification of ways to provide halon-equivalent fire protection for some platforms. However, some of the most important platforms (and the types of fires most commonly experienced) remain. They are:

- Crew compartments of ground vehicles (In the case of ground combat vehicles, the justification for the cost of automatic halon fire-extinguishing systems rests on the ability of these systems to extinguish the mist fireball explosion. This is a rapid growth fire caused by the release and ignition of large quantities of fuel or hydraulic fluid, mist, vapor, spray, etc. in an occupied compartment.),
- Dry bays in aircraft (An in-flight fire in a dry bay typically occurs when a ballistic projectile impacts the dry bay, rupturing fuel system components and generating tremendous ignition energy.),
- Engine nacelles in aircraft (Engine nacelle fire protection systems are designed to protect against fire events such as those caused by ruptured or leaking fuel, hydraulic fluid, or oil lines within the nacelle. In these circumstances, flammable fluid can leak onto the hot engine case or accessory components and ignite.),
- Storage compartments in ships (Fires in shipboard flammable liquid storerooms (FLSRs) and paint issue rooms result from burning fuel cascading over highly obstructed and fuel loaded shelves and into flaming pools.),
- Machinery spaces in ships (Fires in shipboard main machinery rooms (MMRs), auxiliary machinery rooms (AMRs), engine enclosures, and generator rooms result from the ignition of a pressurized fuel (diesel/hydraulic or lubricating oil) leak or ignition of fuel soaked insulating material. Leaks onto hot surfaces result in three-dimensional spray fires with cascading liquid flow on complex surfaces and into flaming pools.), and

- Fuel tanks in aircraft (Ullage, the void space above the fuel level in a fuel tank, in aircraft fuel tanks can have a potentially explosive fuel-air mixture. If initiated by a combat threat, an explosion can result.).

During the course of the NGP, a large number of experiments will be conducted and considerable effort will be devoted to computer modeling of the fire phenomena in order to ensure the applicability of the new fire suppression technologies. A small set of model fires has been constructed to enhance the effectiveness of these studies. These model fires capture the essence of the fires actually experienced by the weapons systems. The mist fireball explosion captures the essence of both the ground vehicle crew compartment and the dry bay fires. An appropriate laboratory apparatus for studying this model is an opposed flow diffusion flame (OFDF). This spray flame simulates fires that might occur in engine nacelles and dry bays. An appropriate laboratory apparatus for studying this model is the Dispersed Liquid Agent Fire Suppression Screen (DLAFSS). The obstructed pool fire simulates fires that might occur behind clutter in engine nacelles, storage compartments and shipboard machinery spaces. Appropriate laboratory apparatus for studying this model are the Transient Application, Recirculating Pool Fire apparatus (TARPF) and the cup burner. The inert atmosphere simulates conditions that are desirable in fuel tank ullage, where an ignition source should not generate a sustained ignition of a fuel/air mixture. An appropriate laboratory apparatus for studying this model is ASTM E 2079.

Characteristics and limitations of the systems that new fire suppression technologies will replace or into which they will be retrofitted were compiled. The descriptions of the environments of the current systems compiled during this program will serve as boundary conditions for the new technologies to be developed in subsequent Elements of the NGP. The system configuration (number of fire zones, extinguisher requirements, distribution system requirements, modification potential, etc.), system schematic, and the current halon 1301 system activation/sequence of events were examined.

1.1 Task Objectives

The objectives of this project are:

- To characterize and tabulate the nature, frequency, consequences (including personnel injuries), and severity of fires previously and currently attacked using halon 1301.
- To derive a small set of representative (model) fires (using the analyses described above) for other elements in the Program.
- To compile characteristics and limitations of the systems that new fire suppression technologies will replace or into which they will be retrofitted. The descriptions of the environments of the current systems compiled during this program will serve as boundary conditions for the new technologies to be developed in subsequent Elements of the NGP.

1.2 Technical Problems

There is a need to find replacement extinguishing agents to the currently used halons because production has been banned due to environmental concerns. However, to date such replacement chemicals have shown reduced performance relative to halons. Development of appropriate new technologies requires knowledge of the fires of concern and the characteristics and limitations of the systems they will replace or into which they will be fit.

1.3 General Methodology

To accomplish the stated objectives, a methodology was developed which characterized the nature of fires attacked using halon 1301, derived a small set of model fires, and compiled the characteristics and limitations of the existing systems.

In order to characterize and tabulate the nature, frequency, consequences (including personnel injuries), and severity of fires previously and currently attacked using halon 1301, the Safety Centers of the Services and the Survivability/Vulnerability Information Analysis Center (SURVIAC) were contacted for both noncombat and combat data, respectively. Items such as fire zone, fire incidence rate, hazards to be protected against by halon 1301 system, flame suppression time requirements, and the current system tests were investigated.

A small set of model fires has been constructed to enhance the effectiveness of these studies. These model fires capture the essence of the fires actually experienced by the weapons systems. These were developed with the assistance of the basic research community and the test community.

Characteristics and limitations of the systems that new fire suppression technologies will replace or into which they will be retrofitted were compiled. These were developed using various resources: program offices, technical manuals, and previous studies.

1.4 Technical Results

The descriptions of the environments of the current systems compiled during this program will serve as boundary conditions for the new technologies to be developed in subsequent Elements of the NGP.

1.5 Important Findings and Conclusions

This effort resulted in numerous important findings and conclusions, which will be useful to future fire research. These included: generation of model fires to be used in computer modeling, types of fires encountered, hazards to be protected against by the halon 1301 system, methods used to certify current halon 1301 systems, characterization of the current system and the fire zone which it protects, and the modification potential for retrofit platforms.

1.6 Significant Hardware Developments

None.

1.7 Special Comments

None.

1.8 Implications for Further Research

With limited resources in the future, considerable effort will be devoted to computer modeling of the fire phenomena. In order to ensure the applicability of the new fire suppression technologies, a small set of model fires was constructed to capture the essence of the fires actually experienced by the weapons systems.

2.0 Bibliography

None.

3.0 Detailed Description of the Project

3.1 Introduction

3.1.1 Goal of the Next Generation Fire Suppression Technology Program (NGP)

Unwanted fires are a principal cause of the loss of military ground vehicles, aircraft, and ships. Halon 1301, CF_3Br, had become the fire suppressant of choice for nearly all of these platforms. Unfortunately, this chemical has been found to be a potent depleter of stratospheric ozone, and its production has ceased under both international treaty (the 1987 Montreal Protocol for Substances That Deplete the Ozone Layer and its subsequent amendments) and U.S. legislation (the Clean Air Act of 1990).

Prior Department of Defense research, development, testing and evaluation has identified alternative approaches for some of the applications of halon 1301. However, replacement technologies have been particularly difficult to find for some critical applications. The Next Generation Fire Suppression Technology Program (NGP) was initiated in 1997, with the goal to develop and demonstrate retrofitable, economically feasible, environmentally-acceptable, and user-safe processes, techniques, and fluids that meet the operational requirements currently satisfied by halon 1301 systems in aircraft, ships, land combat vehicles, and critical mission support facilities. The results will be specifically applicable to fielded weapon systems and will provide dual-use fire suppression technologies for preserving both life and operational assets. [1]

3.1.2 Purposes of This Project

The purposes of this project are:

- To characterize and tabulate the nature, frequency, consequences (including personnel injuries), and severity of fires previously and currently attacked using halon 1301.
- To derive a small set of representative (model) fires (using the analyses described above) for other elements in the Program.
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3.1.3 Sources of Data on DoD Fire Experience

For details concerning the sources of data used for this effort, please address requests to:

U.S. Army	U.S. Air Force	U.S. Navy	
U.S. Army Research Laboratory AMSRL-WM-TB Aberdeen Proving Ground, MD 21005	46 OG/OGM/OL-AC 2700 D Street Building 1661 Wright Patterson AFB, OH 45433-7605	U.S. Naval Research Laboratory Code 6185 Bldg. 207, Rm. 307 4555 Overlook Avenue, S.W. Washington, DC 20375-5342	U.S. Naval Air Systems Command Code 4.3.5.1 Building 2187 Patuxent River, MD

3.1.4 Model Platforms

Previous research, development, testing and evaluation have led to the identification of ways to provide halon-equivalent fire protection for some platforms. The remaining applications are fire suppression in:

- Crew compartments of ground vehicles,
- Dry bays in aircraft,
- Engine nacelles in aircraft,
- Storage compartments in ships, and
- Machinery spaces in ships.

In addition, halon 1301 is used to inert the ullage in some aircraft fuel tanks.

There are a large number of platforms that have halon 1301 fire-suppression systems. Obtaining information on all of these would be difficult, costly, and unnecessary. Therefore, the Military Services identified a small subset of these platforms whose halon systems are representative of the range of fire suppression needs:

- Ground vehicles: M992 (FAASV), M1 tank, and M2/M3 (BFSV)
- Aircraft: C-130, F/A-18 C/D, C-17, H-60, CH-47, F-16
- Ships: DDG 51, LHD 1/LHA 1

3.1.4.1 Ground Vehicles

Engine compartment fires in ground combat vehicles are being addressed by a separate Army program; hence, the NGP is only explicitly addressing crew compartments of ground combat vehicles now protected by halon 1301. However, new fire suppression technology developed under the NGP may well be applicable to such types of fires.

The single most lethal damage mechanism to ground vehicles in combat is fire. Fires can be initiated by a variety of weapons, and in all cases, they can cause a rapid kill of the vehicle and its crew. Internally stowed munitions such as gun rounds and missiles, fuel tanks, and hydraulic systems all provide substantial fire sources. Because fire can kill so quickly, rapid-reacting fire suppression systems have been developed.

The particular requirements that exist for an agent in ground vehicles are that it suppress fires quickly in a highly cluttered volume and allow safe occupation of the space by personnel after discharge. The principal cause of incapacitation and death of combat vehicle occupants from peacetime fires is not burning but carbon monoxide (CO) poisoning. Since lethal CO concentrations can form quickly in the enclosed space of these vehicles, the fire must be suppressed within about 250 milliseconds (ms). The interior of a typical ground vehicle is filled with people, equipment, and structures that interfere with line of sight from the agent dispensers to some possible fire point sources. This means that the agent must be three-dimensional, that is, able to fill an irregular volume despite obstructions. The crew must remain in the vehicle after discharge, so the concentration of the fire suppression and its combustion byproducts must be lower than the concentrations acutely hazardous to humans. The replacement agent must meet all these requirements. [2]

3.1.4.1.1 Field Artillery Ammunition Support Vehicle: M992 (FAASV)

The FAASV is an aluminum, tracked resupply vehicle for the Palladin 155 mm self-propelled Howitzer. The vehicle is powered by a conventional diesel engine. The crew compartment is a large aluminum box that contains ninety 155 mm Howitzer projectiles, the required propellant charges, and two Copperhead 155 mm warheads. There is a hydraulic system to aid in the movement and transfer of the ammunition into and out of the vehicle. The hydraulic fluid reservoir in the crew compartment contains approximately 50 liters (L) of hydraulic fluid. There are also several additional liters of fluid in the rest of the system. The composite (fiberglass) fuel cell is separated from the crew compartment by an aluminum bulkhead. Fuel may enter the crew compartment as a result of a projectile penetrating the bulkhead. The M992 FAASV has a halon 1301 extinguishing system for both the engine and crew compartments.

3.1.4.1.2 Abrams M1 Main Battle Tank

The M1 tank is a steel, tracked battle tank. It is propelled by a turbine engine with multifuel capability. The tank has a four-man crew in a small, crowded compartment. The crew, except for the driver, is located in the turret that rotates with the main gun. The driver is in a small subcompartment in the hull of the vehicle. Movement between these two compartments is restricted to certain turret positions. The driver is located between two polyethylene fuel tanks in the front of the vehicle. A 1.3 cm (one-half inch) thick bulkhead separates the driver from the fuel tanks. There is an elaborate hydraulic system in the turret of the vehicle. The pumps and reservoirs are in the hull. The M1 tank has a halon 1301 extinguishing system for both the engine and crew compartments.

3.1.4.1.3 Bradley Fighting Vehicle, M2 and M3 (BFVS)

The Bradley is an aluminum, tracked fighting vehicle powered by a conventional diesel engine. The crew compartment is an aluminum box designed to carry five soldiers when used in the scout mode or an infantry squad of soldiers when used in the armored personnel mode. The main fuel cell is on the floor in the crew compartment, directly under the turret basket. This molded nylon fuel cell is partially protected by an externally mounted steel plate, covering the bottom front half of the vehicle. A second, smaller nylon fuel cell is attached to the hull wall on the right-hand side, just below the turret ring. This second fuel cell is emptied first; therefore, the probability of its involvement in fuel fires would be lower than for the primary fuel cell. There is a small hydraulic system in the crew compartment. This system is used to lift and lower the rear exit ramp. This system is not considered to be a fire problem due to the small amount of hydraulic fluid involved and its placement in the vehicle. [3] The Bradley has a halon 1301 extinguishing system for both the engine and crew compartments.

3.1.4.2 Aircraft

There are three aspects of an aircraft that are vulnerable to fire and for which halon 1301 systems are currently used: fire suppression in dry bays and engine nacelles and inerting against fire initiation in the ullage of fuel tanks. There is limited use of other halons (1011 – CH_2BrCl and 1202 – CF_2Br_2) for total flooding. These are also ozone-depleting chemicals, and their replacement is included under the NGP umbrella.

Fire extinguishing systems are used on military and commercial aircraft to protect engine nacelles (the region surrounding the exterior of the jet engine case and shrouded by an outer cover, and typically ventilated) and dry bays (which can include wing leading/trailing edges, landing gear, avionics, and weapons bays). Halon-based inerting systems are also provided on some aircraft to provide inerting in fuel tank ullage. Auxiliary power units (APUs), which provide ground, supplementary or emergency power, are also frequently protected using extinguishing systems, either as stand-alone units or in conjunction with the engine nacelle fire-extinguishing system. Each of these systems is fixed in configuration. Engine/APU extinguishing systems and inerting systems are typically activated remotely to totally flood the compartment in question with fire extinguishant, whereas dry bay fire extinguishing systems are activated automatically upon detection of a ballistically-induced fire/explosion event.

The Military Services have identified four fixed-wing and two rotary wing platforms for inclusion in this project. The fixed wing aircraft of interest for the NGP are the F/A-18, C-17, C-130, and F-16. The rotary aircraft of interest for the NGP are the H-60 and CH-47 helicopters.

3.1.4.2.1 C-130

The C-130 Hercules primarily performs in the intratheater portion of the airlift mission. The aircraft is capable of operating from rough dirt strips and is the prime transport for paradropping troops and equipment into hostile areas. [4] For fire protection, the C-130 utilizes three halons (1301, 1011, and 1202) onboard. The distribution system for the halon 1202 engine system is significantly different from the halon 1301 system. The high rate discharge (HRD) halon 1301 system utilizes open-end nozzles and relies on the high velocity of the agent discharge for proper dispersal within the nacelle. Consequently, high vapor pressure agents such as halon 1301 are best suited for HRD applications. In contrast, the conventional system utilizes perforated tubing for agent distribution with consequent penalties of restricted flow and general high total system weight. Low vapor pressure agents such as halon 1011 are best suited for the latter application. Halon 1202, an intermediate volatility extinguishant, has been used successfully in both types of systems. The C-130 has long and unique distribution system runs since the bottles are housed under the left wing and distribution lines must be routed from the bottles to the left engines on the left side wing, plus they must pass through the fuselage to the engines on the right wing. [5]

3.1.4.2.2 F/A-18

The F/A-18 C/D is a single- and two-seat, twin-engine multimission tactical aircraft. It is the first tactical aircraft designed from its inception to carry out both air-to-air and air-to-ground missions. [6] A single-shot halon 1301 HRD-type fire extinguishing system on the aircraft provides fire protection for both engine nacelles, both airframe mounted accessory drive (AMAD) bays, and APU compartment.

3.1.4.2.3 C-17

The C-17 Globemaster III is the newest, most flexible cargo aircraft to enter the airlift force. The C-17 is capable of rapid strategic delivery of troops and all types of cargo to main operating bases or directly to forward bases in the deployment area. The aircraft is also able to perform tactical airlift and airdrop missions when required. [4] The C-17 has a stand alone APU and has a large halon 1301 discharge system. It has larger engines than fighter aircraft. The fire suppression bottles are located on the wing and result in the bottles being exposed to vast temperature extremes.

3.1.4.2.4 H-60

Over 1,500 Army BLACKHAWKs, made to fly soldiers into combat, now serve with active duty and National Guard units around the world. [7] The H-60 is a representative rotary aircraft widely used by all three Services. A dual-shot halon 1301 HRD-type fire extinguishing system on the aircraft provides fire protection for both engine nacelles and the APU compartment. The dual-shot functionality allows activation of both bottles on either engine nacelle and the APU compartment.

3.1.4.2.5 CH-47

The primary mission of the Chinook is the transportation of troops, artillery, ammunition, fuel, water, perimeter protection/barrier materials, supplies and equipment to the battlefield. Other roles include medical evacuation, aircraft recovery, parachute drop, search and rescue missions, disaster relief, fire fighting and heavy construction. [6] A dual-shot halon 1301 HRD-type fire extinguishing system on the aircraft provides fire protection for both engine nacelles. Similar to the H-60, the dual-shot functionality allows activation of both bottles on either engine nacelle.

3.1.4.2.6 F-16

The F-16 Fighting Falcon is a single-engine, compact, multirole fighter aircraft. It is highly maneuverable and has proven itself in air-to-air combat and air-to-surface attack. It provides a relatively low-cost, high-performance weapon system for the United States and allied nations. [4]. The F-16 is one of two aircraft that uses halon 1301 as fuel tank inertant.

3.1.4.3 Watercraft

There are a number of types of watercraft using halon 1301, and the fire suppression system designs and use protocols can vary significantly from ship to ship within a given type. The Navy has selected two generic classes of ships for inclusion in this project, as they represent different continuing challenges for halon retrofit.

3.1.4.3.1 DDG 51 (Arleigh Burke) Class: Aegis Guided Missile Destroyer

The DDG 51 is representative of the newer ships where halon 1301 was the suppression agent of choice during the design of the ship. The following compartments are protected by halon 1301: MMRs, AMRs, FLSRs, paint issue rooms, pump rooms, and generator room. There is enough space onboard to accommodate a two-shot halon 1301 system for each MMR, AMR and generator room.

3.1.4.3.2 LHD 1 (WASP)/LHA 1 (Tarawa) Class: Amphibious Helo/Landing Craft Carriers

The LHDs can be separated into LHD-1 through LHD-4, and LHD-5. While LHD-5 compartments are likely to have dampers in the ventilation ducts, the other ships probably do not. The following compartments are protected by halon 1301: MMRs, AMRs, FLSRs, paint issue rooms, pump rooms, and generator room. [8]

3.2 Fire/Explosion Events Encountered on Current Weapons Platforms

3.2.1 Ground Vehicle Crew Compartments

3.2.1.1 Fire Zone Definition

3.2.1.1.1 M992 FAASV Ammunition Resupply Vehicle

The principal combustibles in the M992 ground vehicle crew compartment are ammunition (ninety 155 mm Howitzer projectiles, and two Copperhead 155 mm warheads), hydraulic fluid (approximately 50 L (13.2 gal)), and personnel heater. Batteries are less of a threat, but cause a large portion of fires of fires in peacetime/training environments. Minor contributors to the fire threat include various filters (fuel, air, oil), rubber lines, insulation and seals. [2]

3.2.1.1.2 M1 Tank

The principal combustibles in the M1 ground vehicle crew compartment are hull fuel (969 L (256 gallons)), hydraulic system (75.7 liters (20 gallons)), recoil mechanism (24.6 L (6.5 gal) hydraulic fluid), ammunition, and personnel heater. Batteries are less of a threat, but cause a large portion of fires in peacetime/training environments. Minor contributors to the fire threat include various filters (fuel, air, oil), rubber lines, insulation and seals. [2]

3.2.1.1.3 M2, M3 Bradley Fighting Vehicles

The principal combustibles in the M2/M3 ground vehicle crew compartment are fuel (662 liters (175 gallons)), ramp hydraulics, batteries (4), turret batteries (2), ammunition, and personnel heater. Minor contributors to the fire threat include various filters (fuel, air, oil), rubber lines, insulation and seals. It is also possible that electrical fires could be initiated by electrical components (i.e., generator, etc.) shoring in the engine compartment. [2]

3.2.1.2 Fire Incidence Rate

3.2.1.2.1 Noncombat Fire Data

3.2.1.2.1.1 Engine Compartment

Examination of fire data from the Army Safety Center shows that most of the accidental or peacetime fires experienced by ground vehicles have been in engine compartments. These fires are usually caused by ignition of fuel, oil or hydraulic fluid on a hot surface. There may be a leak or a pressurized spray of a flammable liquid near a hot exhaust manifold, engine combustor, etc. The AFES have not been very successful in extinguishing these fires. In most cases, the crew has used both the first and second engine compartment shots, and then whatever portable extinguishers were available. Then the local Fire Department was called to inject foam into the engine compartment. This has extinguished even the worst engine compartment fires.

The Army has already developed low cost alternatives to halon 1301 systems for engine compartment fires. Thus they are not addressed by the NGP.

3.2.1.2.1.2 Crew Compartment

In peacetime, the significant contributors to fire in the M992 FAASV crew compartment include ammunition stowed in the turret and hull, the fuel-fed personnel heater, fuel in the hull cells next to the driver, and the hydraulic fluid in the turret hydraulic system, in the main gun recoil mechanism, and in the ammunition handling system. Minor contributors to the fire threat include seat cushions, canvas equipment covers, personnel uniform items, vehicle logbooks and manuals, and electrical components which short out. [2] Since both personnel and ammunition in the crew compartment are exposed, fires must be extinguished immediately.

The M1/M1A1 crew compartment faces a fire threat from fuel or hydraulic lines which might fail or from electrical shorts which might occur in various components located in the turret and driver's compartment. Additionally, the possibility exists that ammunition stowed in the M1/M1A1 could be ignited. [2]

An examination of data from peacetime fire incidents experienced by ground vehicles reveals several facets pertinent to this study. In Table 1, peacetime fire incident data for the M1/M1A1 tank for the years 1988, 1989, 1990 and the fires six months of 1991 have been summarized. These data show that the AFES system was only activated 71 percent of the time for M1/M1A1 fires and was adequate to extinguish the fire by itself only 34 percent of the time. Thirteen percent (13 percent) of the fires involved V-Packs which are part of the engine air cleaner system and, because they are fibrous material, are very difficult to extinguish. In fact, they often have to be fully immersed in water to be extinguished. Halon 1301 is generally ineffective against the V-Packs because they are smoldering type fires and it is difficult to apply Halon in the necessary concentrations for the required period of time. Fires which occurred in the battery compartment accounted for 15 percent of the total fires. Halon 1301 is also ineffective versus this type of fire.

Table 1. M1/M1A1 Fire Incident Data.

Year	Total Cases	Number Detected	AFES Activated	V-Pack Involved	Batteries Involved	AFES Effective
1988	51	28	43	12	6	21
1989	55	24	43	4	9	19
1990	41	22	28	4	7	16
1991*	21	9	12	4	5	5
Total	178	83	126	24	27	61

* First six months

The significant contributors to fire in the M2/M3 crew compartment include the fuel in the cell under the turret, hydraulic fluid in the ramp hydraulic system, batteries under the driver and under the turret, the fuel-fed personnel heater, and ammunition stowed in the turret and the hull. Minor contributors to the fire threat include seat cushions, canvas equipment covers, personnel uniform items, vehicle logbooks and manuals, and electrical components which might short out. [2]

A detailed breakdown of peacetime fire data for 74 additional incidents which occurred during the period 1988 to 1990 was also examined. These data, summarized in Table 2, covered various tanks (no M1/M1A1), infantry vehicles, and self propelled artillery vehicles. The data included the location of these fires (engine compartment, crew compartment, and other) and type of fire (diesel fuel, hydraulic oil, transmission oil, electrical, engine oil and other). A breakdown of this type of data for the M1/M1A1 tank only exists for these first six months of 1991; therefore, it was not included.

Table 2. Detailed Breakdown of Ground Vehicle Fire Incidents, 1988-1990.

	Tanks			**Infantry Vehicles**			**SP Arty**	**Total**		
Type	Engine	Crew	Other	Engine	Crew	Other	Engine	Engine	Crew	Other
Fuel	16		1	2	2	3	1	19	2	4
Engine	5							5		
Hyd Oil	1							1		
Trans Oil				2				2		
Electrical	10	3	2			3		10	3	5
Other	12	4	3	1	1	2		13	5	5
Total	44	7	6	5	3	8	1	50	10	14

These data provide several interesting insights into peacetime fires in ground vehicles. First, they show that regardless of vehicle type, engine compartments were the most common location for fires (68 percent). Of the engine compartment fires at least 27 out of 50 (54 percent) were hydrocarbon fires (Class B) and ten (20 percent) were electrical fires (Class C). The remaining 26 percent of the fires were of an undetermined type. Further, at least 45 percent of all fires were hydrocarbon fires (Class B) and 25 percent of all fires were electrical in nature.

The fire incident data led to several conclusions about peacetime fires in ground vehicles. First, engine compartment fires clearly offer the largest peacetime threat. It therefore seems appropriate that the engine compartment is receiving the highest priority for replacement of halon 1301. Next, most fires are of the hydrocarbon type, so the replacement agent which is selected should be very effective against Class B fires. There is a problem with smoldering Class A type fires (V-Packs), and therefore a coating agent should be considered. Finally, a significant percentage of fires are electrical. This means that an ideal would be one which can suppress and/or extinguish Class C fires.

3.2.1.2.2 Combat Fire Data

Fires can be started due to weapon attack on a fuel cell, hydraulic fluid reservoir, or pressurized hydraulic lines. The types of fires may be pool fires or spray fires.

3.2.1.2.2.1 Engine Compartment

In combat, the most significant cause of fire is from ballistic impacts against fuel components. Fires in this case are characterized by fuel being released into the engine from damaged fuel cells, fuel lines, fuel pumps and similar components. A fire may be ignited by hot fragments and incendiary from the threat or by fuel which contacts hot engine surfaces. In either case, the optimum fire extinguishing agent should be able to not only suppress the immediate fire but also prevent reignition either by cooling of hot surfaces or by placing a barrier of agent between the hot surfaces and the fuel.

3.2.1.2.2.2 Crew Compartment

There are no data available describing a combat-induced mist fireball explosion in a crew compartment and the role of halon 1301 in attempting to extinguish the fire. The reports which describe the testing of the halon 1301 system against mist fireball explosions in crew compartments are classified or of limited distribution. However, models have been fabricated which describe the essential physio-chemical features which have been elucidated by crew compartment fire tests.

Since the fuel main tank is positioned so low in the hull on the M2, M3 Bradley Fighting Vehicles, it would probably not be struck by flat trajectory rounds. The most likely attack modes are mines and air-attack weapons. The external steel plate under the front half of the hull will provide only limited protection against large antivehicle mines. Many air-attack weapons are capable of defeating the armor of aluminum vehicles. [2]

The most significant threat to the crew compartment during combat is from ammunition fires caused by ballistic impacts. No currently available replacement agent will be capable off rapidly suppressing such a fire. In recognition of this problem, the M1/M1A1 tank ammo is all stowed in special compartments behind blast doors designed to contain any ammunition fires and prevent their spread to the crew or engine compartments. The remaining possibilities of fire in combat derive from ballistic impacts to the fuel and hydraulic components where the fluids may be released in a spray of droplets and are ignited by hot fragments or incendiary.

Data on fires that occurred as a result of combat incidents are not releasable. It is expected that such data would show a larger percentage of fires to have occurred in the crew compartments due to ballistic impacts on hydraulic components, fuel system components and ammunition. As a percentage of all fires, electrical fires could be expected to increase somewhat because of shorts occurring in severed wiring. Smoldering Class A fires would be a problem not only in V-Packs but also in items such as seat cushions and crew personnel equipment (i.e., packs, sleeping backs, etc.). [2]

3.2.1.3 Hazards to be Protected against by Halon 1301 Systems

The available data show that ground vehicles experience a wide variety of fires. These include:

- Class A fires involving air filters, canvas, paper,
- Class B hydrocarbon fuel fires fed by vehicle fuel, hydraulic fluid, lubricants, and miscellaneous materials such as paint,
- Class C electrical fires including batteries, and
- Class D ammunition fires.

Also, the nature of these fires in peacetime is somewhat different from that experienced in combat. It may be difficult to find a single agent which can handle all of these fires under all conditions; the best solution may be a combination of agents or protection concepts. For example, one method might be best for the fully developed Class A/B fires in the engine compartment, a second for electrical fires, a third for smoldering Class A fires, and a fourth for crew area protection involving fires initiated by ballistic impacts. [2]

The most common types of fires to occur in combat vehicles are the mist fireball explosion, pressurized hydraulic spray fires, and dry bay fires.

<u>Mist Fireball Explosion</u>

The mist fireball explosion occurs when a weapon perforates the armor (outer skin) of a vehicle and then passes through a fuel cell or hydraulic reservoir which is in an occupied compartment. As the penetrator traverses through the fuel cell, energy is transferred to the liquid. A pressure wave is formed at the tip of the penetrator, and a cavity is formed at the tail of the penetrator as it moves through the liquid. When the cavity collapses, a pressure wave is formed in the wake of the penetrator.

In the case of a kinetic energy penetrator (a bullet or metallic fragment), the pressure in the liquid due to the cavity collapse can exceed the pressure at the front of the penetrator. Thus, when a liquid filled metallic container (fuel cell) is perforated by a bullet or fragment, the container usually bulges outward at both the entrance and exit holes.

In the case of a shaped charge jet traversing a fuel cell, the pressure from the high-speed jet on the material at the entrance hole of the container is larger than the pressure due to cavity collapse. The container bulges outward only at the jet exit hole. The container usually bulges inward at the jet entrance hole.

The pressure waves (and the interaction of their reflections off the container walls) cause fuel to spurt out both the entrance and exit holes of the fuel cell. The fuel (or hydraulic fluid) exits as a mist consisting of vapor, droplets, and streams of liquid. The mist continues to spurt fuel from the holes as long as the pressure waves are present throughout the liquid.

In many cases the seams of the fuel cell may be split allowing a pool of fuel to form while the mist is present in the compartment. The pool of fuel is important for the formation of a sustained fire in the vehicle.

The ignition source required for igniting the fuel mist will normally not be provided by a shaped charge jet or bullet. The shaped charge jet is moving so fast that there is insufficient contact time between the jet and the fuel air mixture for ignition to occur. A bullet is normally not hot enough to serve as an ignition source. A tracer, a pyrophoric, or incendiary component of a kinetic energy penetrator may ignite the mist if the component remains in the vicinity of the fuel-air mixture. The spall ejected from metal which has been struck by the penetrator is the usual ignition source.

The fuel mist which comes out of the container is in the (approximate) form of an expanding cone. In general, it travels in the path of the penetrator. Thus, a fuel cloud follows the penetrator. When the penetrator strikes an object, perhaps the far wall of the vehicle, the penetrator, in perforating the wall, will eject hot spall from the wall material. This spall will move back into the interior of the vehicle along the approximate path of the penetrator. When the fuel mist and the hot spall collide, the mist fireball explosion occurs. A large portion of the volume of the compartment may be involved in the fireball. The pressure associated with the fuel explosion is enough to force open hatches of a combat vehicle.

The initial fireball may be sufficient to transfer ignition to the pool of fuel that can form if the seams of the container split or if the entrance and exit holes in the container are large enough. Combustion of the pool of fuel will cause a sustained fire in the vehicle. This normally leads to the loss of the vehicle. The conditions which lead to the mist fireball explosion can occur at both the entrance hole of the liquid container and the exit hole.

In general, large (overmatching) weapons, thin-walled liquid containers, high liquid temperatures and metallic surfaces in the compartment favor the mist fireball explosion. Easily ruptured containers and warm surfaces in the compartment favor formation of a sustained fire.

The Army has determined that if the mist fireball explosion can be suppressed within 250 ms from the time the weapon strikes the vehicle, there will not only be no sustained fire, but personnel present in the compartment will receive no worse than first degree burns (comparable to a mild sunburn) on exposed skin. Therefore, the requirement is that the mist fireball explosion be extinguished within 250 ms. Current halon 1301 automatic fire extinguishing systems can meet this requirement, often exceeding it by 100 ms.

<u>Pressurized Hydraulic Spray Fires</u>

The pressurized hydraulic spray fire occurs when a pressurized hydraulic fluid line is ruptured by a weapon attack or simply fails due to negligence or fatigue. The high pressure (up to 27.6 MPa (4,000 pounds per square inch (psi))) spray is readily combustible even at temperatures well below the flash point of the fluid. Since low viscosity is a requirement of a good hydraulic fluid and since low viscosity fluids readily produce fine sprays, all flammable hydraulic fluids can readily generate a blow-torch-like flame when ignited.

The supply of hydraulic fluid in an aircraft or ground vehicle will normally be many gallons. The burning spray will continue as long as the pumps can maintain pressure, or until the reservoir is depleted of fluid unless pressure fuses are present in the system. This entails great danger to personnel if the spray is in an occupied compartment. Even in an unoccupied compartment, the fire can cause severe damage. Both aircraft and ground vehicles are at risk.

There are no data on the maximum time personnel may be exposed to sprays of burning hydraulic fluid, but it assumed that these fires must be extinguished within the 250 ms requirement for the mist fireball explosion fires.

Pressurized fuel systems normally have pressures much lower than those employed in hydraulic systems. While a combustible spray will be formed if a pressurized line is ruptured, the rate of flow of the fuel should be much less than that of hydraulic fluid. Therefore, while there is a severe fire problem with the leak, if ignited, the problem should be less severe than with hydraulic fluid. Therefore, the 250 ms extinguishment time is presumed sufficient for fires involving leaks of pressurized fuel in occupied compartments.

Dry Bay Fires

Dry bays are found on both aircraft and ground vehicles. This is a compartment that does not have any flammable material stored in it. However, a flammable material such as a fuel cell or hydraulic fluid is adjacent to the dry bay separated by only a bulkhead. The dry bay fire is similar to the mist fireball explosion even though it occurs in a compartment which does not contain a fuel cell or hydraulic fluid. A shaped charge jet, bullet, or fragment which attacks the fuel cell or hydraulic fluid system can also perforate the bulkhead, allowing combustible fluid to enter the dry bay. The liquid will be in the form of a mist. This mist can be ignited by hot spall, pyrophoric, incendiary or tracer components of the projectile. This scenario also occurs when the attacking weapon enters the dry bay first and then perforates the bulkhead and the fuel cell. An overpressure is created in the fuel cell and fuel is spurted into the dry bay through the entrance hole.

The explosion of the mist can create pressures high enough to cause major structural damage to lightweight structures such as aircraft. There is a high probability of a sustained fire due to the flow of combustible liquid into the dry bay. This flow can be through the hole in the bulkhead caused by the penetrator, or the flow may be through a bulkhead ruptured by the pressure of the mist explosion. The sustained fire, with or without structural damage, can result in loss of an aircraft or ground vehicle.

In the case of an occupied dry bay, it is necessary to extinguish the fire within 250 ms, for the safety of personnel. However, this time may be too long in the case of aircraft. Damage to the structure may occur even if the fire is extinguished within 250 ms.

3.2.1.3.1 M992 FAASV Ammunition Resupply Vehicle

The fuels used in the M992 (FAASV) are JP-8, diesel, and Jet A1. Under operating conditions, fuel temperature can reach 70 ºC (158 °F). A typical flash point for JP-8 and Jet A1 is approximately 50 ºC (122 °F), but can be as low as 38 ºC (100 °F). For diesel fuel, a typical flash point is approximately 65 ºC (149 °F), but can be as low as 53 ºC (127 °F). Conventional hydraulic fluid is used in this vehicle. The flash point is 93 ºC (199 °F) or higher. The expected working temperature of this fluid is approximately 77 ºC (171 °F). Sprays of this material are extremely flammable even at temperatures below the flash point.

3.2.1.3.2 M1 Tank

The fuels used in the M1 tank are JP-8, diesel, and Jet A-1. Under operating conditions, fuel stored in the front of the vehicle is at ambient temperature which can be as high as 63 ºC

(145 °F). A typical flash point for JP-8 and Jet A1 is approximately 50 ºC (122 °F), but can be as low as 38 ºC (100 °F). For diesel fuel a typical flash point is approximately 65 ºC (149 °F), but can be as low as 53 ºC (127 °F). The hydraulic fluid used in this vehicle is "fire resistant", its flash point being approximately 215 ºC (420 °F). The expected working temperature of this fluid is approximately 77 ºC (171 °F). Sprays of this material are extremely flammable even at temperatures well below the flash point.

3.2.1.3.3 M2, M3 Bradley Fighting Vehicles

Fuels used in the Bradley fighting vehicles are JP-8, diesel, and Jet A-1. Under operating conditions, the fuel in the smaller tank is used before the fuel in the larger tank. The halon systems are not capable of extinguishing fires of the ammunition stored on the vehicle. Therefore, only hydrocarbon fires are addressed by the halon system. Therefore, the fuel fires in the crew compartment would probably involve the main tank.

3.2.1.4 Flame Suppression Time Requirements

As noted above, full fire suppression within 250 ms is required for crew compartment of fire to other combustibles, such as ammunition, and to prevent second-degree burns on exposed skin of the crew. A knockdown of the fire is not acceptable since manual follow-up would take too long.

For the FAASV and the M1, reflash is not considered to be a problem because there are no hot surfaces in the crew working area, and the halon is retained for eight seconds until the exhaust fan automatically engages. By this time the hot spall will have cooled sufficiently to provide only a poor ignition source. The main gun ammunition with combustible cartridge cases is stored in a separate compartment, sealed from the crew compartment of the tank. A fire of short duration in the crew compartment is not considered to be a likely ignition source for the ammunition. However for the M2/M3, reflash is considered to be a problem in the case of attack by a land mine. In all probability there will be an external fuel fire under the vehicle and unless the vehicle can drive away or be removed from the fire, the fire will likely enter it. Therefore, the fire extinguishing system must inert the crew compartment until the vehicle can be moved away from the fire. [3]

3.2.1.5 Current System Tests

The crew compartment fire suppression test fixture was built from a combat vehicle hull and turret to evaluate the performance of high speed automatic fire extinguishing systems (FES) for occupied areas. It is equipped with instrumentation to determine suppression speed and the ability of the FES to protect the crew from burns, blast pressure and toxic chemical injuries.

A range of ballistic threats can be used to simulate battle damage. Armor protection and other material, such as fuel tanks or hydraulic reservoirs, are positioned in the path of the penetrator for testing. Combustible fluids can be pressurized and heated to any desired condition. A remote controlled pressurizing blower is provided for ventilation and NBC overpressure system simulation. To reduce test setup and post-test repair time, the fixture is fitted with replaceable components including armor windows, hydraulic reservoirs and fuel tanks.

FES performance and crew survivability is assessed by a comprehensive instrumentation suite which includes high speed video/film, transient pressure, temperature and toxic combustion products measuring devices inside the normally occupied spaces.

http://www.atc.army.mil/brochures/fireprot/images/imagename.jpgViewing ports have been cut into the sides of the test bed through which video and high-speed cameras view and record the events. Fine-wire thermocouples and heat flux gages are suspended inside the crew compartment to measure time versus temperature and time versus energy transients. Infrared sensors have been installed to monitor and record fire intensity levels, and may be used to discharge extinguishing agents upon reaching a pre-determined intensity level. Piezo-electric pressure gages are used to measure crew area air pressure during the events.

Toxic fumes instrumentation is under development to measure oxygen depletion and toxic fumes by-products resulting from the decomposition of fluorinated extinguishing agents and the combustion of hydrocarbon fuels.

Extinguisher locations and distribution system designs can be easily changed as required to improve performance. Simulated "clutter" (equipment, ammunition containers, dummies, etc.) can be positioned as desired to increase realism. Test scenarios can be defined and extinguishers may be activated by fire sensors or at a pre-selected time after initiation of the threat. Multi-shot systems can also be evaluated.

A backup CO_2 extinguishing system is provided for asset protection, in the event that the test system fails to extinguish a test fire.

The standardized fuel cell for the testing has been determined to be a 2.5 ft^3, reinforced aluminum fuel tank are fabricated from 0.32 cm (1/8 in.) thick aluminum sheets. The fuel tank is placed on the rear, right sponson of the crew compartment, as close to the right side wall of the vehicle as possible. Ten gallons (37.9 L) of JP-8 fuel, heated to approximately 76.7 °C (170 °F), is poured into the tank. A replaceable aluminum armor window has been bolted onto the side of the test bed vehicle adjacent to the fuel cell. A shape-charge munition is placed outside the removable window, pointed in the direction of the fuel cell and center of the crew compartment. Initiation of the warhead allows the shape-charge jet to penetrate the wall and fuel cell, initiating the fuel-mist fire inside the crew compartment. Extinguishing agent is discharged based on a pre-determined time delay following initiation of the warhead.

Fire suppression testing with shape-charge munitions is ultimately the final test of whether or not an extinguishing system is effective in combating explosively-formed fuel-mist (EFFM) fires.

Unfortunately, tests conducted with shape-charge munitions are expensive, time consuming and destructive. Aberdeen Test Center (ATC) personnel have developed a ballistic fireball simulator (BFSim) to be used to test candidate fire suppression systems and agents by expediting hardware evaluation and reducing test time and costs when compared to actual ballistic tests.

http://www.atc.army.mil/brochures/fireprot/images/imagename.jpgThe BFSim uses high-pressure nitrogen gas (up to 8.27 MPa (1200 psi)) to rapidly force hot JP-8 (82.2 °C (180 °F plus)) through a small diameter, multi-orifice spray nozzle into the crew area of the test bed vehicle. The fuel is sprayed into the test bed compartment then ignited with a high energy spark device. The spray is initiated and ignited at the desired location (generally either the entry point or the opposite wall) after a pre-determined delay. The time delay between spray start and ignition can be varied, along with the configuration of the nozzle and spray pressure. As the fireball expands, an IR detector senses the fire, and discharges the fire extinguishing system at a pre-set intensity. The fuel spray is stopped at a pre-set time. The simulator decreases test turn around time by eliminating damage from explosive charge, while providing a credible challenge to automatic fire extinguishing systems. The BFSim crew test bed is outfitted with the same instrumentation as for the ballistic test.

When promising results are obtained for the BFSim tests, final testing is conducted against an actual ballistic threat. [9]

General purpose outdoor test ranges designed for very large scale fire, vulnerability, survivability, explosive and lethality tests. The real estate area covers 132 Acres (535,000 m^2). Current crew compartment tests are performed at the Poverty Island Outdoor Range Complex. The structure consists of outdoor test pads with hardened instrumentation enclosures and means for liquid test effluent collection. There are no size and weight limitations. Fire and explosion limitations are dependent to atmospheric weather conditions. Several thousands of pounds of explosive and several hundreds of gallons of fuels can be addressed. [10]

The crew compartments of the M992, M1, and the M2/M3 range in volume from 7.1 to 19.8 m^3 (250 to 700 ft^3) and employ from 7 lb of halon 1301 in a single shot to 21 lb in each of two shots.

The Army Surgeon General has established the guidelines shown in Table 3 as the minimum acceptable requirements of automatic fire extinguishing systems for occupied vehicle compartments. These parameters have been established at levels that would not result in incapacitation of the crew from the fire and its extinguishment, allowing them to take corrective action and potentially to continue their mission.

Table 3. Crew Survivability Criteria.

Parameter	Requirement
Fire Suppression	Extinguish all flames without reflash
Skin Burns	Less than second degree burns (<1316 °C-s (2400 °F-s) over 10 heat flux <16.3 J/cm^2 (3.9 cal/cm^2)
Overpressure	Less than 80 kPa (11.6 psi)
Agent Concentration	Not to exceed LOAEL (Lowest Observed Adverse Effects Level)
Acid Gasses	Less than 1000 ppm peak
Oxygen Levels	Not below 16 percent

The crew test fixture was constructed from an excess ground vehicle hull and turret. The fixture had an interior volume of approximately 12.7 m^3 (450 ft^3). Three "tin" mannequins and a four-unit TOW missile rack were added to simulate partial vehicle stowage. The cargo and turret hatches and ramp door were secured during each test while the driver's hatch was allowed to pop open to relieve internal overpressures while minimizing airflow.

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

Two test scenarios conducted include fuel spray fires and ballistic penetrations. The spray fire was generated with approximately 1.1 L (0.3 gal) of JP-8 of JP-8 heated to 82.2 to 87.8 °C (180 to 190 °F) and pressurized to 8.27 MPa (1200 psi) using a specially designed nozzle. Fuel flow continued for approximately 1.2 s with the igniter energized for the duration of the spray to simulate the reignition sources present during the ballistic event. The spray fires were monitored with three one-micron infrared detectors. The extinguishing system was activated automatically after an 11 s delay from the time the fire energy reached a predetermined threshold. Ballistic fires were generated by firing a 6.9 cm (2.7 in.) shaped charge through an 70.8 liters (18.7 gallon (2.25 ft^3)) capacity aluminum fuel cell filled with 41.6 L (11 gal) of JP-8 heated to 73.9 °C (165 °F). The fire extinguishing system was activated 25 ms after warhead initiation to eliminate the variability of the detection system. [11]

3.2.2 Aircraft Dry Bays

The use of dry bay fire protection systems on selected aircraft is warranted due to the combat threat environment and the mission profile of the aircraft. These systems have been verified recently by live fire testing using ballistic threats to assure performance in the actual fire extinguishing of such events. Generally, rotary-wing dry bays are much smaller than fixed-wing dry bays with the exception of the CH-47.

3.2.2.1 Fire Zone Definition

Dry bays are defined as void volumes within the mold line of the aircraft, excluding air inlets, engine compartments, and exhaust nozzles. Dry bays can include wing leading/trailing edges, landing gear wheel wells, avionics equipment and weapons bays, and related zones where a catastrophic rupture of flammable fluid and an ignition supply, such as from a ballistic impact, can create a sustained fire. Dry bays frequently contain fluid lines (fuel, hydraulic, coolant), bleed air ducts, and electrical cables and may contain avionics, flight control actuators, hydraulic accumulators and liquid oxygen dewars. [12]

The four common types of dry bays and their physical characteristics are categorized in Table 4 and Table 5. Two of the four bay types are located in the wing. Wing leading edge/trailing edge (forward and aft portion of the wing) bays are characteristic of both fighter/attack and transport aircraft, while midchord (compartment between fuel cells in wing) bays are found primarily in transport aircraft. The two types of fuselage bays, fuel cell boundary bays and equipment bays, are characteristic of fighter/attack aircraft. Equipment bays can be subdivided into forward equipment bays, aft equipment bays, ammunition storage bays and engine accessory bays.

Table 4. Categorization of Wing Dry Bays.

Types	Leading Edge/Trailing Edge	Midchord
Characteristics	long, narrow	rectangular, nearly cubic
	relatively uncluttered with sections isolated by ribs	relatively uncluttered, open volume
	contain hydraulic lines, control cables and wire bundles, and bleed air ducting	contain fuel lines, fuel system components
		located between fuel tanks or with one side wall common to fuel tank
	common to both fighter/attack and transport aircraft	found primarily in transport aircraft

Table 5. Categorization of Fuselage Dry Bays.

Types	Fuel Cell Boundary	Equipment
Characteristics	shallow bays separated at close intervals by rigs and stringers	size and shape varies with contents and location; usually large; sometimes partitioned with bulk heads, ribs, and stringers
	vary from empty to almost full	medium to dense clutter
	contain lines, wiring and control cables	usually ventilated
	located below or beside fuel tank	subtypes: • forward equipment bay located between cockpit and forward fuel tank • ammunition storage bay usually located between fuel tanks • engine accessory bay located below and beside engines and aft fuel tank • aft equipment bay located between engines
	common to fighter/attack aircraft	common to fighter/attack aircraft

3.2.2.2 Fire Incidence Rate

3.2.2.2.1 Noncombat Fire Data

Noncombat fire data were examined to identify fires that resulted from failure of or damage to dry bay equipment. These data were divided into six typical dry bay configurations: fuselage, engine pylon (mainly on transport aircraft; suspends the engine from wing; contains fuel lines going to the engine), wing leading edge (forward portion of the wing), wing root (point of attachment of wing to the fuselage), tail (contains hydraulic lines for actuators) and wheel well (contains tires, hydraulic lines, etc.). The majority of mishaps occur due to an equipment failure in a fuselage dry bay or failure of the engine or starter that results in damage to a fuselage dry bay. Of the remaining mishaps, a large number involved wing fire damage due to equipment failures. [13] These may include overheating, shorting electrical circuits in avionics bays, some other form of impact (i.e., bird strike), or burning stored munition propellants can also be responsible in rare instances [12].

3.2.2.2.2 Combat Fire Data

Combat fires are usually created when a ballistic projectile impacts a dry bay in flight, rupturing fuel system components and generating tremendous ignition energy. [12]

Figure 1 illustrates the sequence of events by which a dry bay fire can be ignited from the impact of an armor piercing incendiary (API) or high explosive incendiary (HEI) projectile into a wing leading edge.

During a projectile or fragment entry into an aircraft, the skin surface is usually torn and radial cracks may form. This effect is referred to as skin petaling. The damaged skin surface can protrude into the aircraft (entrance damage), or into the surrounding airflow (exit damage), creating a flame-holding region for any fires that develop. Projectile penetration into an aircraft can also result in pieces of the skin surface material, referred to as spall, being ejected at high speeds along the path of the projectile. Spall can also become penetrators and may introduce additional fluid into the dry bay.

If the proper skin thickness and impact obliquity angles are present, impact of the HEI projectile with the target skin will initiate the projectile’s fusing sequence, which in turn will detonate the projectile’s high explosive. An approximate 425 μs delay will occur after impact before the selected projectile detonates. This delay allows the projectile to travel farther into the target before it explodes, thereby increasing its damage capability. The detonation breaks the projectile shell apart and expels a large number of small fragments capable of penetrating electric wire bundles and perforating fuel tanks, hydraulic lines and coolant lines. The fragments penetrate into adjacent fuel tanks and hydraulic and coolant lines, thereby releasing combustible fluids into the dry bay. These fluids can be ignited by either the incendiary (ignited aluminum particles) of the projectile or sparking due to fragment impacts on metallic surfaces. They also may perforate the aircraft skin(s) allowing airflow (containing oxygen) to enter into the dry bay. Overpressures created from the detonation of the projectile can significantly damage adjacent fuel tanks, crush and/or sever hydraulic and coolant lines, as well as remove aircraft skin.

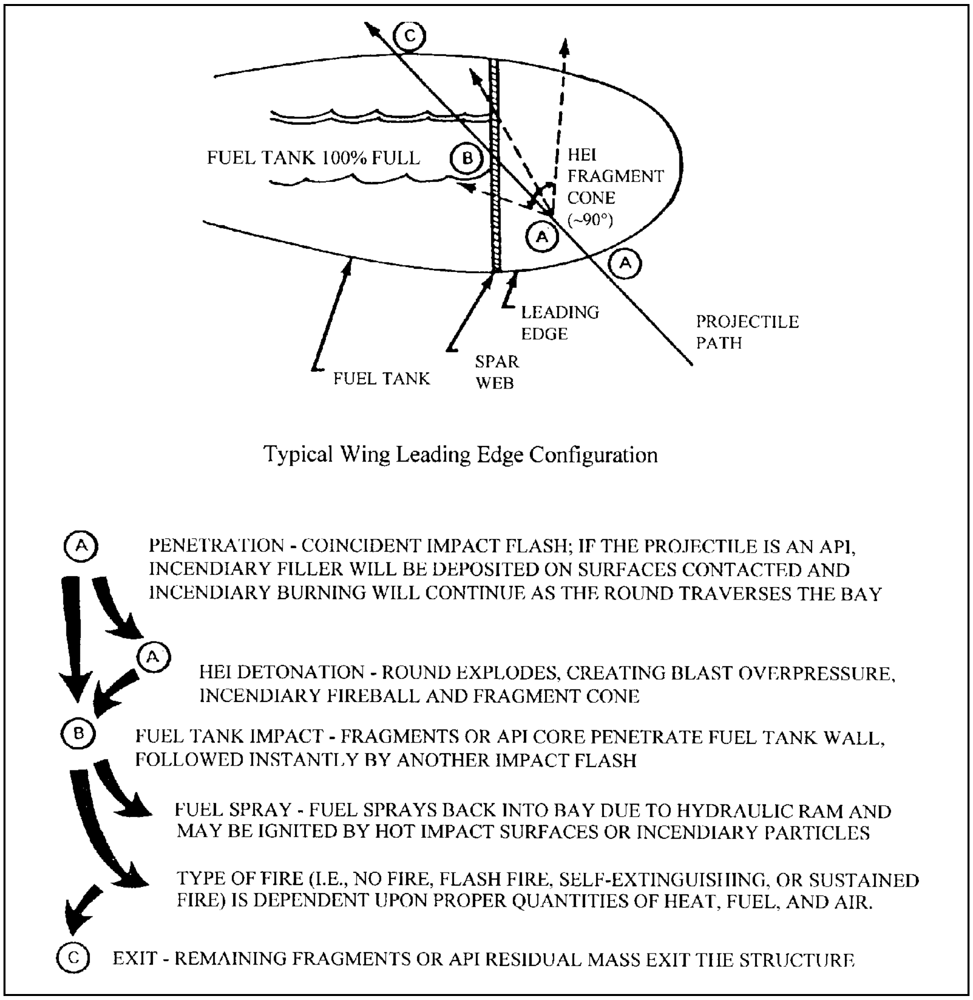

Figure 1. Projectile Penetration of a Wing Leading Edge

Warhead fragments damage aircraft components primarily through penetration and perforation effects in the same manner as small armor piercing projectiles. Depending upon the material impacted, a fragment typically generates incandescent particles or vapors, known as impact flash or vaporific flash, which can ignite nearby combustible fluids. The intensity of the flash is dependent on the material type and thickness of the impact panel and the mass, material type, and striking velocity of the warhead fragment. An impact velocity of greater than 1220 m/s (4,000 ft/s) is typically required before vaporific flash is experienced. A fragment impacting the skin at sufficiently high speed can also result in breakup of the fragment into a number of smaller fragments which individually are inherently less lethal than the original fragment. However, light aircraft components (i.e., hydraulic lines) may be vulnerable to these smaller fragments. In either case, a single fragment, or a number of smaller fragments, could penetrate the tank wall and release a spray of fuel into the dry bay. Interaction of the vaporific flash, fuel spray, and available oxygen can result in a dry bay fire. [14]

Data from Southeast Asia (SEA) suggest that 58 percent of the 24 C-130 incidents were related to dry bay fires. The C-130 incidents were reported in which engines and/or adjacent bays were damaged by gunfire, creating numerous ignition sources, leaking fuel, and resultant fires in the leading and trailing edges. [13]

Since the C-17, F-16, H-60, and F-18 platforms were not in service during SEA, no SEA combat data exist.

No discernable dry bay fire incidences in the SEA data for the CH-47 platform were located.

3.2.2.3 Hazards to be Protected Against by Halon 1301 Systems

The principal modes of failure of the fuel system are fire and explosion. The most critical hydraulic system failures were those in which damage to lines or pumps resulted in fires. Fuel system related losses were classified as direct fires and explosions, vapor mist explosions in the ullage, liquid fed fires in the dry bays, indirect fires caused by leakage from damaged lines, or from fuel tanks damaged by hydrodynamic ram effects. Protection of dry bays is equal in importance in vulnerability reduction to direct protection of the fuel system from fire and explosion.

3.2.2.4 Flame Suppression Time Requirements

Fluid ignition requires the interaction of an ignition source, a flammable fluid, and oxygen. However, fluid ignition is a time-based event, and each ingredient must be introduced in the proper sequence and with the proper quantity for a sufficient duration to assure ignition occurs. If the proper conditions are present, three to five ms are required to initiate a dry bay fire. [14]

Given an ignition source in a flammable mixture, the flame front starts at the source and propagates throughout the mixture until it reaches either a solid boundary or a mixture that will not support combustion. The velocity at which the flame front travels depends upon the amount and rate of energy released. A relatively large and rapid energy release by the combustion process causes a supersonic wave or flame front with a rapid rise and large increase in the pressure, called the overpressure. This phenomenon is referred to as a detonation. A relatively small and slow energy release causes a subsonic flame front with a slow rise and low increase in the overpressure. This is called a deflagration. Aviation fuels typically deflagrate with overpressure normal less than 1.38 MPa (200 psi). Detonations and deflagrations may or may not lead to a fire. When the combustion overpressure is sufficiently large enough to damage or destroy portions of the aircraft structure, the combustion process is referred to as an explosion. [15] Dry bay fires are typically the result of a deflagration. Because of this, successful fire suppression efforts should be accomplished within approximately 200 ms.

Live fire test data typically show dry bay fires to be quenched within 200 ms. Fast quenching is preferred due to the effect of agent dilution by the entering airflow induced by the battle damage. However, there is no set specification for fire suppression time. [16]

Recommendations for these requirements were developed in the *Aircraft Engine Nacelle/APU and Dry Bay Fire Extinguishing System Design Model*.

3.2.2.5 Current System Tests

Dry bay fire protection systems are a relatively new concept that will be fielded on selected aircraft in production now or in the future that warrant its use due to the combat threat environment and the mission profile of the aircraft. These systems have been verified recently by live fire testing using various ballistic threats to assure performance in the fire extinguishing of such events.

Rapid fire detection and discharge of fire suppression chemicals provide the potential for the greatest success of effective fire suppression against ballistic threats. The speed of response of both the sensor and the suppressor enable the concept to effectively respond to projectile-induced fires. [13]

3.2.3 Aircraft Engine Nacelles

3.2.3.1 Fire Zone Definition

The engine nacelle is defined as the region surrounding the exterior of the jet engine case, shrouded by an outer cover, and typically ventilated. [5] The engine nacelle varies in shape and size, but is typically annular with a length and diameter of the same order as the engine it encases. Fuel and hydraulic lines, pumps, and lubrication systems are located within the nacelle volume. Ventilation is provided to prevent the buildup of combustible vapors, and drain holes are located on the underside to reduce the amount of fluid that could pool in the event of a leak. [17] APUs are machinery units that provide supplemental, auxiliary, or emergency power to all or some subsystems of the aircraft. [12]

3.2.3.2 Fire Incidence Rate

3.2.3.2.1 Noncombat Fire Data

3.2.3.2.1.1 C-130

The data given for the C-130 are peacetime incidents from the *Incident Data Analysis Report*, July 1994, Booz•Allen & Hamilton Inc. These data were made available by the USAF Safety Center and cover the time period of 1983 through 1993. There were 115 reported incidents (An incident is not necessarily a confirmed fire.) with 94 confirmed fires. In eleven of these incidents, halon 1011, 1201, or 1301 was used for extinguishment. There were eleven confirmed fires. Of these, seven occurred inflight and four occurred on the ground. [18]

3.2.3.2.1.2 F-18

The F/A-18 fire history was obtained from *Fixed-Wing Aircraft Fire Protection, halon 1301 Fire Suppression Systems Effectivity Analysis,* September 30, 1994, NAWCADLKE-MISC-05-SR-0146. Excerpts from this report are given below.

Thirteen percent of F-18 fire incident aircraft were lost or destroyed due to fire. Eighty-six percent of all aircraft losses (6 of 7 losses) were due to engine fires. Forty-seven of 54 F-18 fire incident aircraft (87 percent) were not destroyed by fire incidents (An incident is not necessarily a confirmed fire.).

The F-18 engine halon fire suppression was used in 17 of 55 F-18 fires and was successful in extinguishing 12 fires. Therefore, the overall effectivity of F-18 engine halon 1301 fire suppression system was 71 percent, when the system was utilized. The engine halon fire suppression system was used only in engine fires; no fire suppression was attempted in any fire occurring in the AMAD bays. Only in-flight engine fires were extinguished. The effectivity of the engine halon fire suppression system during in-flight fires was eighty percent, and this effectivity was the same for each engine. No ground engine fires were extinguished in two attempts using the engine halon fire suppression system.

In the five fires in which the engine halon fire suppression system failed to extinguish fires, three of the fires resulted in loss of aircraft, and two were extinguished by ground efforts after the aircraft landed. One of these two fires occurred in the AMAD bay and was fed by a massive fuel leak in the bay.

Based on the data contained in the F-18 aircraft fire incident narratives, 48 of 55 F-18 aircraft fires (87 percent) were extinguished. Twenty-two percent of these fires were extinguished by the F-18 engine halon fire suppression system. Analysis of the Safety Center data indicates that this system is an effective fire protection system when used.

- The F-18 engine halon fire suppression system extinguished 71 percent of F-18 aircraft fires.
- The F-18 engine halon fire suppression system extinguished 80 percent of F-18 aircraft in-flight fires.
- One area in which the engine halon fire suppression system has been unsuccessful is in extinguishing ground engine fires. The system was used unsuccessfully in two ground engine fires. Analysis of the Safety Center data also revealed several trends regarding F-18 aircraft fires:
  - Eighty-six percent of all aircraft losses were the result of engine fires.
  - Eighty-two percent of all fires occurred in areas protected by the F-18 engine halon fire suppression system. This supports the conclusion that the system is implemented to provide fire protection in those areas most susceptible to fire.
  - Seventy-three percent of all fires were engine fires. Inflight engine fires also accounted for 78 percent of all in-flight fires.

- There were four fires that occurred in the AMAD bays, plus an additional fire that occurred in both an engine and AMAD bay. Even though the AMAD bays are protected by the engine halon fire suppression system, no fire halon suppression was attempted in any of these fires. The fire that occurred in both an engine and AMAD bay caused the engine system halon bottle to vent rendering the aircraft without any fire protection agent.
- Eighty-two percent of fires occurred in flight, and seventy-eight percent of in-flight fires were engine fires. Eighty-seven percent of all fires and of all in-flight fires were caused by material failures. Areas susceptible to material failures included high-pressure compressors, afterburner liners and spraybar pigtails, and the AMAD bay (hydraulic pump failures and source of several fuel leaks).

The overwhelming fraction of peacetime aircraft losses comes from inflight engine fires. [19]

3.2.3.2.1.3 C-17

The C-17 made its maiden flight on Sept. 15, 1991, and the first production model was delivered to Charleston Air Force Base, S.C., on June 14, 1993. The 17th Airlift Squadron, the first squadron of C-17s, was declared operationally ready Jan. 17, 1995. The Air Force is programmed to receive a total of 120 C-17s by the year 2005. [4]

No aircraft have been lost or destroyed by fire. There have been no engine fires reported. [20]

3.2.3.2.1.4 H-60

The H-60 fire history was obtained from *Rotary-Wing Aircraft Fire Protection, halon 1301 Fire Suppression Systems Effectivity Analysis*, May 26, 1994, NAWCADLKE-MISC-05-SR-0132. Excerpts from this report are given below.

Five of the six H-60 aircraft fires were successfully extinguished; another H-60 aircraft was lost at sea.

The H-60 engine halon fire suppression systems were utilized successfully in two of three APU ground fire incidents (An incident is not necessarily a confirmed fire.). The reserve capability was utilized unsuccessfully in the incident that the engine halon fire suppression system failed to extinguish an APU fire. Therefore, when used to extinguish APU ground fires, the H-60 engine halon fire suppression system was 67 percent effective. No fire suppression was attempted in either of the two in-flight engine fires, one of which resulted in loss of aircraft.

Based on the data contained in the H-60 aircraft fire incident narratives, five of six H-sixty aircraft fires (eighty-three percent) were extinguished. Fifty percent of these fires were extinguished by the H-60 halon fire suppression systems. However, all extinguished fires were APU fires that occurred on the ground. Analysis of the Safety Center data indicates that the halon fire suppression systems were 75 percent effective when used.

Three of the six H-60 fire incidents occurred in the APU. Two occurred during maintenance activities and one occurred during preflight checks. Two of these APU fires were the result of residual fuel in the APU combustion section from previous start attempts. The manner in which these fires occurred suggests that procedures for performing maintenance or start-up could be addressed to promote less reliance on the halon fire suppression systems by preventing fires as part of the procedures [21].

3.2.3.2.1.5 CH-47

Noncombat data regarding aircraft lost, destroyed or not destroyed by fire, how fires were extinguished, incidents where halon fire suppression systems were not utilized or unknown, and where and why CH-47 fires occurred were not available at the time of this report.

3.2.3.2.1.6 F-16

The data given are peacetime incidents from the *Incident Data Analysis Report*, July 1994, Booz•Allen & Hamilton Inc. These data were made available by the USAF Safety Center and cover the time period 1983 through 1993. There were 149 incidents (An incident is not necessarily a confirmed fire.) with 111 confirmed fires. There were 56 total incidents that occurred in the engine, jet fuel starter, or tailpipe areas. There were 49 confirmed fires. Of these, 29 incidents occurred inflight with 22 being confirmed fires. Of these, 27 incidents occurred on the ground, and all were confirmed fires. [18]

3.2.3.2.2 Combat Fire Data

Most engine nacelle incidents occurred during peacetime. However, the potential of a combat-induced engine nacelle fire definitely exists and is currently being considered in several ballistic engine nacelle programs. It is important to note that the current halon 1301 engine nacelle fire extinguishing systems are certified only to a safety related hazard not a threat-induced one.

3.2.3.3 Hazards to be Protected against by Halon 1301 Systems

Engine nacelle fire protection systems are designed to protect against events such as ruptured or leaking fuel, hydraulic fluid, or oil lines within the nacelle. In these circumstances, flammable fluids can leak onto the hot engine case or accessory components and ignite. These systems can also protect against the results of catastrophic events such as thrown turbine blades that instantaneously rupture fuel sources or overheating components that can initiate fluid fire scenarios. The first step in such cases is to shut down the engine, when the proximity fire detector confirms a fire is present and the pilot is satisfied that a true fire event has occurred. Even with the engine shut down and flammable fluid supply turned off, up to a minute or more of fuel and other flammable fluids flowing into the fire zone can occur, sometimes under high-pressure, depending upon the location and nature of the failure and the capability to remotely arrest the flow near the point of damage. Under these conditions, a supply of fuel can be maintained for a lengthy period to create robust fire conditions that, left unchecked, can heat and burn through surrounding structure and threaten the welfare of the aircraft, creating fire conditions in collateral areas before the fuel is drained, thereby weakening key structures. In addition, impacts into the engine nacelle by ballistic projectiles in combat can also create failure conditions and resultant fires (provided that the engine case is not penetrated, which could result in catastrophic engine failure becoming the more immediate threat). [12] An additional fire hazard associated with the aircraft engine nacelle arises from the fact that even after extinguishment is achieved, a substantial potential exists for reignition of the fire from hot surfaces. Hot surface reignition remains a threat as long as fuel vapor and air can come in contact with sufficiently hot surfaces. Suppression of the hot surface reignition fire hazard in the engine nacelle requires an additional amount of agent over that required for flame extinguishment in order to maintain extinguishment until the hot surfaces cool. [17]

APUs are used to provide supplemental, auxiliary, or emergency power to all or some of the subsystems of the aircraft, either on the ground or in flight. These units function and generate power independently from the normal aircraft engine systems. The power units may be miniature turbines or other power generating equipment, but are typically smaller than the normal jet engine propulsion systems. These compartments must be protected against potential fires, since the possibility of fuel, hydraulic fluid, or oil leakage onto the hot power unit and equipment or catastrophic unit failure can create fire scenarios just as in the engine nacelles. For many military aircraft, the engine fire protection system is plumbed to be alternatively used in the auxiliary power unit compartment, since in most cases the engine fire protection system's capacity is more than adequate for the smaller volume of the APU bay. In some cases, however, the APU compartment may have a larger free volume than an individual engine nacelle or otherwise require a greater quantity of extinguishant than the nacelle, so great care must be taken to assure that sufficient capacity is designed for either use. APU compartments can be ventilated, so provision must be made for dilution of extinguishant by ventilation airflow during discharge. In many cases, however, the ventilation system is designed to be closed during discharge, hopefully sealing off the compartment. For many military transport and most commercial aircraft, an independent fire protection system is designed for a remote APU compartment, which may be located within the cabin or cargo section, or in the tail section. These systems must then be designed separately from engine nacelle systems.

An engine nacelle or auxiliary power unit has hot operating components and uses fuel or flammable fluids under normal operating conditions. The zones are considered primary fire zones, because merely a failure in a flammable fluid system, which can rupture and spray fluid, can result in ignition on a normally hot component surface, initiating a fire. [12]

3.2.3.3.1 Effect of Airflow

An engine nacelle fire is typically a turbulent diffusion flame stabilized behind an obstruction in a moderately high-speed airflow (that range from 0.57 kg/s (1.25 lb/s) to 1.25 kg/s (2.75 lb/s)). The fuel source for a fire in the nacelle is most often leaking pipes carrying jet fuel or hydraulic fluid; the fire can usually be described as either a spray fire or a puddle or pool fire.

Pool fires are more difficult to extinguish than spray fires. In addition, it has been observed that under conditions of increasing airflow velocities, the required concentration of extinguishing agents for both pool and spray fires decreases. These results have been rationalized in terms of flame stability and structure; the pool fire flames are believed to have a "premixed" structure and are more stable than the "diffusion" structure spray flames, and both types of flame are believed to be less stable (more easily extinguished) at high airspeeds. Premixed flames require higher extinguishing concentrations than diffusion flames. [22]

Typically, there is airflow through the nacelle to provide cooling of hot surfaces and to sweep out combustible vapors. While serving these important functions, the airflow also dilutes the extinguishing agent after a discharge, and carries it out of the nacelle rapidly. The number of air exchanges per unit time (volumetric air flow/net volume) depends on the aircraft design and may be as high as one per second. Clearly, the amount of agent required to achieve a specified concentration in the nacelle depends on the airflow and the nacelle free volume. The nacelle free volume is defined as the total nacelle volume minus the volume due to clutter.

3.2.3.3.2 Pool Fires

A pool fire resulting from a puddle of jet fuel or hydraulic fluid can pose the most serious fire hazard under certain conditions in an engine nacelle. In airflow, the stability of a pool fire, which incorporates a premixed flame, can be greatly enhanced if an obstacle at the leading edge of the pool is present. In some nacelle configurations, obstacles in the form of structural ribs or other bluff bodies are present at locations where combustible liquids could form a puddle. Fire suppression tests in configurations such as these have shown that the stabilizing effect of a baffle in front of a pool fire can be very significant. Test results show that under similar air flow and baffle height conditions, a baffle-stabilized pool fire is dramatically more difficult to extinguish than a baffle-stabilized spray fire where the baffle is located in the middle of the flow field.

3.2.3.3.3 Spray Fires

A fuel spray represents a unique combustion situation that incorporates a diffusion flame. A ruptured high-pressure fuel, lubricant, or hydraulic fluid line can supply a steady flow of fuel for a fire stabilized behind obstacles in the engine nacelle. Small droplets quickly evaporate and the momentum from the spray efficiently entrains the air necessary for combustion. Extinguishment of the burning spray occurs when a critical amount of agent becomes entrained within the combustion zone. Flame stability in this case is also influenced by parameters other than the rate of agent entrainment such as the airflow rate and temperature, the fuel type, the pressure, and the type of agent employed.

3.2.3.3.4 Hot Surface Ignition

After suppression of a nacelle fire, hot fuel vapor may exist at levels that are flammable, leading to the possibility of reignition of the fire. A puddle of hydraulic fluid or jet fuel from a leaking fuel line will vaporize as heat is transferred from a nearby hot metal surface. Under normal engine operating conditions, hot metal surfaces that could cause reignition exist along the interior wall of the nacelle that separates the jet engine combustor from the nacelle. In addition, hot metal surfaces may be engendered by the heat of the fire itself. Reignition then arises from contact of the reactive fuel/air mixture with the hot metal surface.

Conditions that lead to hot surface reignition fires are controlled by the time and temperature history of the reactive mixture and to a lesser extent, by the type of metal surface and the chemical composition of the fuel. Test have shown that when a hot (700 °C (1300 °F)) metal surface is present, fire suppression requires almost an order of magnitude more agent than if the hot surface is not present, presumably due to reignition. Strategies to prevent reignition include removing fuel vapor, reducing surface temperatures either through design changes or active cooling, and inerting the fuel/air mixture with additional suppressant.

3.2.3.3.5 Clutter

The total mass of agent to be stored in the engine nacelle fire extinguisher is normally based on the amount needed to quench the worst case anticipated fire hazard. For engine nacelles with ribs and other obstructions, this is a baffle-stabilized pool fire. But engine nacelle fires can occur either in the form of a pool or a spray. In either type of fire, flame stability is enhanced by flow field obstacles (or clutter), which act as flame holders. It is well known that if a flame is established behind a flow obstacle or bluff body, a recirculation zone will form. The presence of the recirculation zone enhances flame stability, although flame “blow-out” will occur if air flows past the obstacle at sufficiently high velocities.

Also by definition, a smooth nacelle has no circumferential ribs protruding into nacelle free volume; ribs are often incorporated into the nacelle to provide structural rigidity. A rough nacelle has circumferential ribs protruding less than 15 cm (6 in) into the nacelle; a deep frame nacelle has circumferential ribs greater than 15 cm (6 in) protruding into the nacelle, or a configuration with cavities 15 cm (6 in) or more in depth. A smooth nacelle may contain clutter such as electronic housings, hydraulic and fuel lines, transducers, and clamps that may create flow disturbances.

The time required for an agent to entrain into the recirculation zone is a key parameter in the effectiveness of suppression with respect to baffle-stabilized flames. This characteristic mixing time or residence time is extremely important in developing fire protection strategies and system designs, because it influences the free-stream agent concentration and duration required to obtain extinction of the flame. Agent entrainment into a baffle-stabilized combustion zone is governed by the free-stream flow velocity, the baffle size and shape, and the free-stream agent concentration/duration. The agent concentrations required for suppression of baffle-stabilized fires can be a factor of two larger than agent concentrations required to extinguish cup burner flames burning the same fuel [17].

3.2.3.4 Flame Suppression Time Requirements

This specification is verified by experiment under realistic conditions. [12] Actual suppression test requirements do not exist. It is believed that if extinguishment can occur within seconds that the success rate is increased.

3.2.3.5 Current System Tests

All of these engine nacelle systems are "certified," or approved, in a given design configuration for a particular fire zone application and aircraft. The current specifications for halon 1301 require a minimum of six percent concentration by volume in air be present simultaneously at all points in the engine nacelle for a minimum of 500 ms. This specification is verified by experiment under realistic conditions. [12]

3.2.4 Aircraft Fuel Tanks

3.2.4.1 Fire Zone Definition

Ullage (the void space above the fuel level in a fuel tank) in aircraft fuel tanks can have a potentially explosive fuel-air mixture. If initiated by a combat threat, an explosion can result. Currently two aircraft systems (F-16 and F-117) use halon 1301 to inert these fuel tanks and prevent these phenomenon from occurring. [24]

Several other fuel tank inerting approaches exist. These include utilization of foam, nitrogen inertion, and a solid propellant gas generator system. Foams are a fully passive system used to suppress flame spread in the fuel tank ullage. The nitrogen inerting system is a moderate weight active explosion-proofing mechanism that operates on the principle of oxygen dilution of the ullage and the fuel at a level below the concentration required to propagate fire. One example of a nitrogen inerting system is the on board inert gas generating system (OBIGGS). OBIGGS filters N_2 directly from engine bleed air. OBIGGS eliminates the need to service either nitrogen or halon bottles. The use of liquid nitrogen (LN_2) inerting is another nitrogen inerting system. A third example of a nitrogen inerting system involves the use of gaseous nitrogen (stored in bottle form). Solid propellant gas generators might also provide a solution to the fuel tank inerting problem. A solid propellant gas generator system used for extinguishing a fuel tank explosion is in the early stages of conceptual development. [25]

3.2.4.2 Fire Incidence Rate

3.2.4.2.1 Noncombat Fire Data

Fuel tank explosions are not frequent during peacetime. They are more a function of a combat incident.

3.2.4.2.2 Combat Fire Data

Historically, fuel fire and explosion is a major cause of aircraft losses in combat. Data from Southeast Asia show over half of the aircraft combat losses involved fuel fires and explosions. While other factors might also have contributed to the loss (e.g., pilot killed, loss of control, etc.), this fact, nonetheless, indicates the fuel system is a very significant contributor to an aircraft's vulnerability. Therefore, to increase survivability, various techniques are used to reduce the vulnerability of the aircraft's fuel system to this significant threat effect. [24]

No Southeast Asia data exist for the F-16 or the F-117, since neither existed during that conflict. No combat data for aircraft whose fuel tanks were inerted by halon 1301 (F-16 or the F-117) were available.

3.2.4.3 Hazards to be Protected Against by halon 1301 System

Fuel tank explosions are a result of ullage deflagrations where the combustion overpressure generated exceeds the structural strength of the tank. With large ignition sources, combustion will occur and overpressures will vary according to the threat level, tank volume, and oxygen concentration. If the combustion wave propagates throughout the ullage with near stoichiometric fuel/air mixture, a pressure increase of over 790 kPa (100 psig) (eight times atmospheric pressure) is theoretically possible. The current halon inerting system must also provide protection from in-tank arcing due to lightning, electrostatic discharge, and combat threats.

3.2.4.4 Flame Suppression Time Requirements

The current halon 1301 inerting systems provide protection for about 8 minutes. After that time the bleed-air into the ullage will have diluted the inertant below its effective concentration. Therefore, the pilot activates the system by releasing the halon shortly before entering combat. To prevent the deflagration pressure from returning the fuel tank, the quenching must occur within about 200 ms, similar to the required time limit for the mist fireball suppression in dry bay fires. However, in the inerting case, the agent is already deployed. Thus detection and dispersion time intervals do not consume part of the total suppression time requirement.

3.2.4.5 Current System Tests

The Air Force Research Laboratory uses the W-Tank (380 liter (100 gallon rectangular tank)) to certify fuel tank inerting systems.

Tank overpressure is the criterion used to determine the effectiveness of the inerting agent, as it is the sudden pressure pulse that can result in failure of the fuel tank. The inertant physically extracts heat. By the dilution provided by the inertant, there is less fuel and air to react.

Many common parameters that affect tank overpressure are given below.

- Fuel temperature--affects ullage fuel vapor composition;
- Ullage temperature--affects reaction rate, vapor transfer to ullage;
- Ullage pressure--affects final peak pressure value;
- Total energy release of ignition source--affects time to peak pressure, energy required to be dissipated via greater inertant;
- Inertant type--affects estimated heat extraction rate of reaction (physically and possibly chemically); and

- Inertant concentration--affects rate of heat extraction. [26]

3.2.5 Shipboard Machinery and Storage Spaces

3.2.5.1 Fire Zone Definition

The following compartments are protected by halon 1301: main machinery rooms (MMRs), auxiliary machinery rooms (AMRs), flammable liquid storerooms (FLSRs), paint issue rooms, pump rooms, and generator room for both the DDG 51 (Arleigh Burke) Class: Aegis Guided Missile Destroyer and the LHD 1 (WASP)/LHA 1 (Tarawa) Class: Amphibious Helo/Landing Craft Carriers.

3.2.5.2 Fire Incidence Rate

3.2.5.2.1 Noncombat Fire Data

The Naval Research Laboratory (NRL) identified forty-two halon 1301 fire suppression incidents between 1982 and 1997 primarily from NAVSEA on Navy Safety Center investigation reports. Of the 42 incidents, 26 provided detailed accounts, twelve provided no information, and four provided few details, but said that the fires had been extinguished with halon. Although for the majority of the fire incidents a single shot of halon 1301 extinguished the fire, two incidents (out of 26) required a second shot of halon to achieve suppression. In incidents that required additional agents (halon, AFFF, or other) release, it was found that fuel soaked lagging was often a key contributor to agent failure. There were also six reflash incidents. Two of the fires used the secondary halon for suppression and occurred in a Gas Turbine Module (GTM) and in a diesel generator compartment. AFFF hoses were used on the remaining fuel of the reflash incidents by the ship fire party during reclamation procedures. One of these fires occurred in a main machinery room and the other three occurred in a diesel generator compartment. The occurrence of reflashing is due to the reduction of agent concentration due to compartment leakage, agent decomposition.

There were four incidents, which occurred in GTMs, where both the fires and second shots were ineffective in extinguishing the fire. All four incidents occurred in GTMs that were protected by 27.2 kg (60 lb) of halon 1301 per shot. NAVSEA recognized the limitations of the GTM total flooding system and increased the total flooding agent capacity by over 50 percent per shot, to 43.1 kg (95 lb) of halon 1301 per shot. Other modifications were also made. All GTMs currently under construction (e.g.; DDG-51 Class ships) are being built with the 43.1 kg (95 lb) per shot halon 1301 system. A large number of GTMs, however, are still protected by CO_2. Because the objective of this report is to identify halon 1301 discharges, no CO_2 GTM fire suppression data have been collected.

An update to the NRL study was also available. This report identified an additional six reported halon 1301 discharge incidents. A total of five of the discharges were to achieve fire suppression. The primary shot of halon was sufficient for three of the fires in which other agents were required for suppression or reflashes occurred. A reflash occurred in one fire which was suppressed with AFFF and one used AFFF in conjunction with a halon discharge to suppress the fire. One halon discharge was used to protect a paint locker space which had a fully involved fire exterior of the space.

The total estimated quantity of halon discharged from 1982 to 1997 for suppression is 16,500 kg (36,000 lb), and for accidental, malicious, and other types of non-fire related discharges is 6,500 kg (14,000 lb). [27]

It may be sufficient (but not desirable) in the case of multiple simultaneous incidents for some of the smaller unoccupied compartments protected by halon for the fire to be controlled and isolated. They would be dealt with after larger operational issues have been addressed.

Table 6 summarizes halon 1301 use from 1982 to 1997, excluding agent used during ship acceptance testing. Table 7 summarizes halon 1301 fire suppression performance.

Table 6. Shipboard Halon 1301 Discharges

Reported halon 1301 Discharge Incidents*	Number of Incidents	Estimated Halon Discharged in kg (lbs)
Fire Suppressions	42	16,500 (36,000)
Accidental discharges/ other	14	6,500 (14,000)
Total Reported Incidents	56	23,000 (50,000)

* An incident may involve a single or dual shot discharge.

Table 7. Shipboard Halon 1301 System Performance.*

halon 1301 Suppression Performance	Number of Incidents	Fire Location (Compartment or Enclosure)
Suppressions by primary halon, no reignitions	14	Diesel Generator (SSDG), GTM, Paint Locker
Reflashes suppressed by secondary halon	2	SSDG, GTM
Reflashes suppressed by AFFF	4	MMR, SSDG
Suppressions by secondary halon (not suppressed by primary)	2	GTM, SSDG
System Failures (unsuccessful fire suppression) **	4	GTM

* Only the 26 incidents where sufficient data were available are used in this table.
** Unsuccessful fire suppressions after two shots were discharged.

3.2.5.2.2 Combat Fire Data

These data were not compiled.

3.2.5.3 Hazards to be Protected Against by halon 1301 System

Fires in MMRs, AMRs, engine enclosures, and generator rooms result from the ignition of a pressurized fuel (diesel/hydraulic or lubricating oil) leak or ignition of fuel-soaked insulating material. Leaks onto hot surfaces result in three-dimensional spray fires with cascading liquid flow on complex surfaces and into flaming pools.

Fires in FLSRs and paint issue rooms result from burning fuel cascading over highly obstructed and fuel loaded shelves and into flaming pools. [8]

The LHD class has high pressure steam plants. The steam plants have high temperature piping that can provide possible ignition and reignition sources. Further, these pipes are slow to cool. While turbine and diesel propulsion plants have high temperature surfaces, these cool much faster. Unvented high-pressure steam remains in the steam plant piping after engine shut down.

3.2.5.4 Flame Suppression Time Requirements

Current suppression times are of the order of minutes.

The fire suppression system has a reignition protection of 15 minutes hold time (minimum time from agent discharge to compartment reentry). Reflash in machinery spaces as well as other compartments is a serious consideration. During reclamation procedures, agent concentration will decrease and additional oxygen will be available.

3.2.5.5 Current System Tests

The Navy utilizes the following intermediate and full-scale test facilities to assist in the development of fire suppression systems.

The Full Scale Fire Test Facility (ex-USS Shadwell, LSD-15) is a 139.3 m (457 ft), 8,165,000 kg (9,000 ton) landing ship dock, located at the U.S. Coast Guard's Fire and Safety Test Detachment, Little Sand Island, Mobile, Alabama. All aspects and ship systems important to damage control are maintained on the ship, i.e., ventilation, fire main, heating and air conditioning, electrical, lighting, and internal communication systems. Three damage control lockers are also maintained. [28]

The Chesapeake Bay Fire Test Facility is concerned with all aspects of shipboard fire safety, particularly as related to fight decks, submarines and interior ship conflagrations. The emphasis is on providing facilities for intermediate scale, credible evaluations of firefighting agents, systems and training concepts under more realistic, shipboard conditions. In many cases, the facility provides a vital link between laboratory testing and full scale, proof of concept on the ex-USS SHADWELL. [29]

Halon concentration uniformity is frequently not well characterized. Based on NRL testing aboard the *ex*-USS SHADWELL, variations of at least ± 20 percent are to be expected; typical variation can be far broader. Agent distribution tests in a Cruiser (CG 47 - TICONDEROGA Class) Main Machinery Room (MMR) measured agent concentration variation as a whole number factor. [8]

3.3 Model Fires And Flames For Use In Research On Alternatives To halon 1301

During the course of the NGP, a large number of experiments will be conducted, both at laboratory scale and in realistic test fixtures. Further, considerable effort will be devoted to computer modeling of the fire phenomena in order to ensure the applicability of the new fire suppression technologies.

To aid this, we have constructed a small set of model fires. These capture the essence of the fires actually experienced by the weapons systems, as documented earlier in this paper.

3.3.1 Mist Fireball Explosion

This captures the essence of both the ground vehicle crew compartment and the dry bay fires. An appropriate laboratory apparatus for studying this model is an opposed flow diffusion flame (OFDF). [30]

3.3.2 Spray Flame

This simulates fires that might occur in engine nacelles and dry bays. An appropriate laboratory apparatus for studying this model is Dispersed Liquid Agent Fire Suppression Screen (DLAFSS). [31]

3.3.3 Obstructed Pool Fire

This simulates fires that might occur behind clutter in engine nacelles, storage compartments and shipboard machinery spaces. An appropriate laboratory apparatus for studying this model is the Transient Application Recirculating Pool Fire (TARPF) apparatus. [32]

3.3.4 Inert Atmosphere

This simulates conditions that are desirable in fuel tank ullage, where an ignition source should not generate a sustained ignition of a fuel/air mixture. An appropriate laboratory apparatus for studying this model is ASTM E 2079. [33]

3.4 Description of Representative Halon 1301 Systems In Current Weapons Platforms

This section compiles characteristics and limitations of the systems that new fire suppression technologies will replace or into which they will be retrofitted. The descriptions of the environments of the current systems compiled during this program will serve as boundary conditions for the new technologies to be developed in subsequent Elements of the NGP.

3.4.1 Ground Vehicle Crew Compartment Halon 1301 System Configurations

3.4.1.1 M992 FAASV Ammunition Resupply Vehicle

3.4.1.1.1 System Configuration Description

The M992 FAASV has a halon 1301 extinguisher system for both the engine and crew compartments. There are six which serve the crew compartment. Two crew compartment bottles may be activated manually. Manual activation is accomplished using pull handles located in the driver's compartment and outside the vehicle. There are four optical sensors in the crew compartment which sense the flash from a ballistic event and activate the extinguishers. [2]

Table 8 displays the fire suppression system configuration for the M992 FAASV Ammunition Resupply Vehicle.

Table 8. M992 FAASV Ammunition Resupply Vehicle Fire Suppression System Configuration.

	M992 FAASV Ammunition Resupply Vehicle	
	Crew Compartment	
	Vehicles 1-344	Vehicles 345 and greater
GENERIC		
Number of vehicles	664 (fielded units at the end of 1999)	
Service cycle refill (years)	n.a.	
Fire types (pool fires, mist…)	Mist fireball explosion, pressurized hydraulic spray fire, dry bay fire	
Estimated halon use/year/vehicle (kg (lb))	n.a.	n.a.
FIRE ZONE		
# of fire zones	3 (hydraulic reservoir, fuel cell, pressurized hydraulic lines)	
Fire Zone size (L, W, D) (cm, cm, cm (in, in, in))	n.a.	n.a.
Fire zone volume (cm^3 (in^3))	n.a.	n.a.
Fire zone free volume (m^3 (ft^3))	n.a.	n.a.
EXTINGUISHANT		
# of halon systems	2 (two 4.5 kg (10 lb) bottles for each independent discharge)	3 (three 3.2 kg (7 lb) bottles for each independent discharge)
Extinguisher trigger mode	Automatic	
Extinguisher volume (cm^3 (in^3))	Range from 204 to 1224 in^3	
Size of extinguishant container (cm, cm, cm (in, in, in))	n.a.	n.a.
Storage compartment for extinguishant bottle (cm, cm, cm (in, in, in))	n.a.	n.a.
Free volume in storage compartment (cm^3 (in^3))	n.a.	n.a.
Normal charge and pressure of extinguisher container (MPa (psi))	n.a.	n.a.
Max extinguisher container pressure (MPa (psi))	n.a.	n.a.
Extinguisher container percent filled (%)	n.a.	n.a.
Extinguisher container orientation (upright with valves at bottom)	upright	
Extinguisher container weight without Halon (kg (lb))	n.a.	n.a.
Halon wt (kg (lb))	4.5 kg (10 lb)	3.2 kg (7 lb)
Extinguisher container location (inside/outside fire zone)	Two bottles are attached to the bulkhead at the front of the compartment and two are located approximately in the middle of the crew compartment.	Two bottles are attached to the bulkhead at the front of the compartment and four are located approximately in the middle of the compartment.
Strategy for use	Vehicles numbered 1 – 344 use a	Vehicles numbered 345 and

	M992 FAASV Ammunition Resupply Vehicle	
	Crew Compartment	
	dual-shot system for the crew compartment. Each independent discharge involves two 4.5 kg (10 lb) halon bottles (9 kg (20-lb) total). For each activation, one of the bottles attached to the bulkhead and one of the bottles in the middle of the compartment are discharged.	above also have a two-shot system for the crew compartment, however, each independent discharge uses three 3.2 kg (7 lb) bottles (9.5 kg (21-lb) total). For each activation, one of the bottles attached to the bulkhead and two of the bottles in the middle of the crew compartment are discharged.
# of shots	2	
Manual/automatic	Automatic	
Procedure for activation	4 optical sensors	
Time to release halon 1301	The system specification does not list the interval from detection of the fire until start of discharge. The halon will probably be fully discharged within 100 ms.	
DISTRIBUTION SYSTEM		
Extinguisher dispersion method	Cone placed in front of discharge nozzle.	
Extinguisher discharge rate (kg/min (lb/min))	n.a.	n.a.
Distribution system plumbing	The only plumbing associated with the fire extinguishment system is a cone placed in front of the discharge nozzle to improve the halon distribution. There is no additional plumbing.	
Inner diameter (cm (in))		
Length (cm (in))		
Shape (bends, elbows)		
# and nature of nozzles/pipe terminations		
MODIFICATION POTENTIAL		
Potential for increased number or increased size of storage bottles	It may be possible to find room for larger and/or more numerous bottles if an agent less volume efficient than halon were used.	
Restriction on alternative fluids (very/modestly/slightly)	n.a.	
Access of current distribution plumbing for retrofit (Please rate with percent of ease (e.g., 20 percent of the plumbing is difficult to access, 80 percent of the plumbing is easy to access.))	n.a.	
Access & available space for additional distribution plumbing or nozzle modification (Please rate with percent of ease (e.g., 20 percent of the plumbing is difficult to access, 80 percent of the plumbing is easy to access.))	The crew working volume is very large. The halon distribution system was changed to modify distribution of the agent. It is possible to add nozzles although they are not used in the current systems because of time delays associated with most nozzles.	
How tight is the bottle space?	n.a.	
Is the plumbing readily accessible for replacement?	n.a.	
Is the plumbing readily accessible for adding another distribution part?	n.a.	
Is the plumbing readily accessible for changing the pipe end?	n.a.	
Extinguisher Growth Potential	n.a.	
OTHER		
Suppression success fraction	n.a.	
Extinguisher system manufacturer	n.a.	
Evidence of halon distribution characteristics (from certification tests)—design concentration required for extinguishment	7 percent - Halon concentration will be a function of location within the compartment.	
Range of expected operating temperatures for the bottle and the plumbing (ºC (ºF))	Any system in a vehicle must survive –45 ºC (-49 ºF). The system must function properly at –32 ºC (-26 ºF) and above. The bottles are all in the crew compartment, and thus are not exposed to the high temperatures associated with engine compartments. The maximum temperature to which the bottles will be exposed is approximately 63 ºC (145 ºF).	

n.a. – not available

3.4.1.1.2 System Schematic

Figure 2 displays the fire suppression system configuration for the M992 FAASV Ammunition Resupply Vehicle.

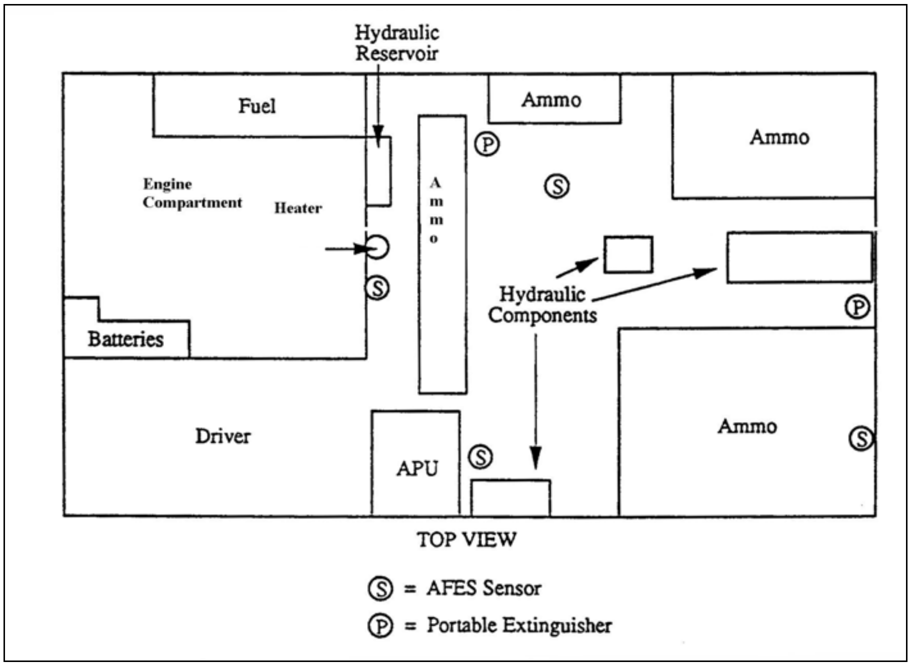

Figure 2. M992 FAASV Ammunition Resupply Vehicle Fire Extinguishing System Schematic

3.4.1.1.3 Sequence of Events

Fires are detected automatically through use of discriminating dual-band infrared sensors. When a weapon, e.g., a shaped charge jet defeats the armor and penetrates the crew compartment, the hot spall from the armor and ionized hot air emit intense electromagnetic radiation. (The adjective "discriminating" implies that when the sensor sees the intense electromagnetic radiation, the fire detection shuts down for 5 ms.) The fire sensor sees this and shuts down to allow the initial radiation to decay. The sensor then reactivates and if it still sees a strong signal, it causes the rest of the extinguishing system to function, releasing halon. The assumption is that the long-term signal is caused by the combustion of hydrocarbon components while the initial signal will be present whether or not the weapon has encountered a source of hydrocarbons. Thus, the sensor discriminates between the initial event of penetration and the presence of a fire. Once the reactivated sensor detects the fire, a signal is sent to the control box, which operates the solenoidal valve of the halon reservoir. If the shaped charge jet passes through the fuel cell and into the crew compartment, the mist fireball is expected to be several feet in diameter by the time the fire suppression system releases halon. A similar situation applies to the hydraulic system that is in the crew compartment.

3.4.1.2 M1 Tank

3.4.1.2.1 System Configuration Description

The M1/M1A1 tank has a halon 1301 extinguisher system for both the engine and crew compartments. One bottle serves the crew compartment. Each bottle contains 7.0 pounds of halon 1301. The bottle may be activated either manually or automatically. Manual activation is accomplished using pull handles located in the driver's compartment. There are three optical sensors in the turret and one in the driver's compartment. These sensors are designed to sense the flash from a ballistic event and activate the extinguishers. Table 9 displays the fire suppression system configuration for the M1 Tank.

Table 9. M1 Tank Fire Suppression System Configuration.

	M1 Tank
	Crew Compartment
GENERIC	
Number of vehicles	403 USMC
Service cycle refill (years)	n.a.
Fire types (pool fires, mist…)	Mist fireball explosion, pressurized hydraulic spray fire, dry bay fire
Estimated halon use/year/vehicle (kg (lb))	n.a.
FIRE ZONE	
# of fire zones	3 (hydraulic reservoir, fuel cell, pressurized hydraulic lines)
Fire Zone size (L, W, D) (cm, cm, cm (in, in, in))	n.a.
Fire zone volume (cm^3 (in^3))	n.a.
Fire zone free volume (m^3 (ft^3))	n.a.
EXTINGUISHANT	
# of halon systems	3
Extinguisher trigger mode	Automatic
Extinguisher volume (cm^3 (in^3))	Range from 204 to 1224 in^3
Size of extinguishant container (cm, cm, cm (in, in, in))	n.a.
Storage compartment for extinguishant bottle (cm, cm, cm (in, in, in))	n.a.
Free volume in storage compartment (cm^3 (in^3))	n.a.
Normal charge and pressure of extinguisher container (MPa (psi))	n.a.
Max extinguisher container pressure (MPa (psi))	n.a.
Extinguisher container percent filled (%)	n.a.
Extinguisher container orientation (upright with valves at bottom…)	upright
Extinguisher container weight without Halon (kg (lb))	n.a.
Halon wt (kg (lb))	3.2 kg (7 lb)
Extinguisher container location (inside/outside fire zone)	Stored within the crew compartment.
Strategy for use	The entire series has the same size and location of halon bottles. Two of these bottles are used for independent releases within the engine compartment. The third bottle is used for the single-shot crew fire extinguishment. This bottle has a nozzle designed to ensure simultaneous flow of halon to the front of the vehicle where there two fuel cells are and to the rotatable turret basket which houses the other three crew members and an extensive hydraulic system.
# of shots	3
Manual/automatic	Automatic with manual 3rd shot (used by crew)
Procedure for activation	4 optical sensors

	M1 Tank
	Crew Compartment
Time to release halon 1301	The system specification lists the interval from detection of the fire until start of discharge as 10 - 15 ms. The halon will be fully discharged within 100 ms.
DISTRIBUTION SYSTEM	
Extinguisher dispersion method	Nozzle
Extinguisher discharge rate (kg/min (lb/min))	n.a.
Distribution system plumbing	The only plumbing associated with the fire extinguishing system is a nozzle used to direct the halon discharge. There is no additional plumbing.
Inner diameter (cm (in))	
Length (cm (in))	
Shape (bends, elbows)	
# and nature of nozzles/pipe terminations	
MODIFICATION POTENTIAL	
Potential for increased number or increased size of storage bottles	The crew working volume is very small. It has been repeatedly stated that there is insufficient room in the crew compartment for additional bottles or larger bottles.
Restriction on alternative fluids (very/modestly/slightly)	n.a.
Access of current distribution plumbing for retrofit (Please rate with percent of ease (e.g., 20 percent of the plumbing is difficult to access, 80 percent of the plumbing is easy to access.))	n.a.
Access & available space for additional distribution plumbing or nozzle modification (Please rate with percent of ease (e.g., 20 percent of the plumbing is difficult to access, 80 percent of the plumbing is easy to access.))	It should be possible to modify nozzle design although any time delays associated with different nozzles may not be acceptable, especially if the fire is not extinguished within 250 ms.
How tight is the bottle space?	n.a.
Is the plumbing readily accessible for replacement?	n.a.
Is the plumbing readily accessible for adding another distribution part?	n.a.
Is the plumbing readily accessible for changing the pipe end?	n.a.
Extinguisher Growth Potential	n.a.
OTHER	
Suppression success fraction	n.a.
Extinguisher system manufacturer	n.a.
Evidence of halon distribution characteristics (from certification tests)—design concentration required for extinguishment	7 percent - Halon concentration within the crew compartment probably varies by a factor of at least two.
Range of expected operating temperatures for the bottle and the plumbing (ºC (ºF))	Any system in a vehicle must survive –45 ºC (-49 ºF). The system must function properly at –32 ºC (-26 ºF)and above. The bottles are all in the crew compartment, and thus are not exposed to the high temperatures associated with engine compartments. The maximum temperature to which the bottles will be exposed is approximately 63 ºC (145 ºF).

n.a. – not available

3.4.1.2.2 System Schematic

Figure 3 displays the fire suppression system configuration for the M1 Tank.

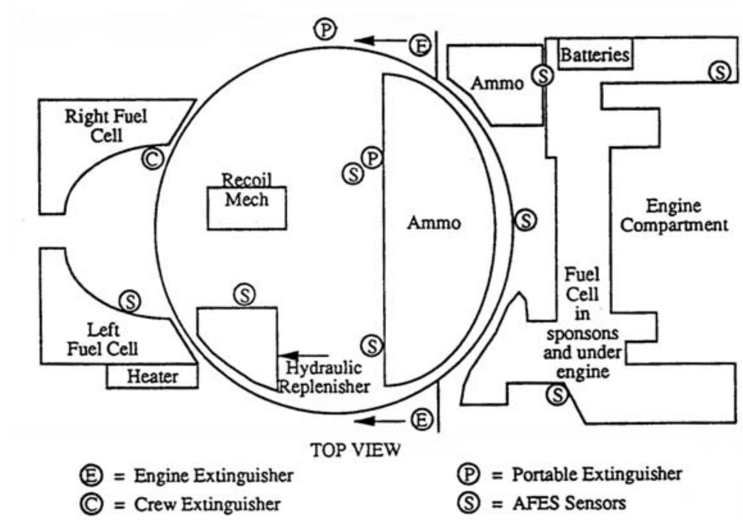

Figure 3. M1 Tank Fire Extinguishing System Schematic

3.4.1.2.3 Sequence of Events

These fires are also detected automatically through use of dual-band infrared sensors. When a weapon, e.g., a shaped charge jet defeats the armor and penetrates the crew compartment, the sensor sees the event and sends a signal to the control box which operates the solenoidal valve of the halon reservoir, releasing the halon. If the shaped charge jet passes through the fuel cell and into the crew compartment, the mist fireball is expected to be several feet in diameter by the time the fire suppression system releases halon. A similar situation applies to the hydraulic system that is in the crew compartment.

3.4.1.3 M2, M3 Bradley Fighting Vehicles

3.4.1.3.1 System Configuration Description

The Bradley Fighting Vehicle has a halon 1301 extinguisher system for both the engine and crew compartments. There is one fire extinguishing bottle which serves the engine compartment. That bottle is located forward of the driver in the crew compartment and contains 7.0 lb of halon 1301. The engine fire bottle is manually activated from the driver's position or by a pull handle outside of the vehicle. There are two bottles each with 5.0 lb of halon 1301 to serve the crew compartment. These bottles may be activated either manually or automatically. There are four optical sensors in the crew compartment. These sensors are designed to sense the flash from a ballistic event and activate the extinguishers. These also are two portable extinguishers in the crew compartment each with 2.75 lb of halon 1301.

Table 10 displays the fire suppression system configuration for the M2, M3 Bradley Fighting Vehicles.

Table 10. M2, M3 Bradley Fighting Vehicles Fire Suppression System Configuration.

	M2, M3 Bradley Fighting Vehicles
	Crew Compartment
GENERIC	
Number of vehicles	1602
Service cycle refill (years)	n.a.
Fire types (pool fires, mist…)	Mist fireball explosion, pressurized hydraulic spray fire, dry bay fire
Estimated halon use/year/vehicle (kg (lb))	n.a.
FIRE ZONE	
# of fire zones	3 (hydraulic reservoir, fuel cell, pressurized hydraulic lines)
Fire Zone size (L, W, D) (cm, cm, cm (in, in, in))	n.a.
Fire zone volume (cm^3 (in^3))	n.a.
Fire zone free volume (m^3 (ft^3))	n.a.
EXTINGUISHANT	
# of halon systems	2
Extinguisher trigger mode	Automatic
Extinguisher volume (cm^3 (in^3))	Range from 204 to 1224 in^3
Size of extinguishant container(cm, cm, cm (in, in, in))	n.a.
Storage compartment for extinguishant bottle (cm, cm, cm (in, in, in))	n.a.
Free volume in storage compartment (cm^3 (in^3))	n.a.
Normal charge and pressure of extinguisher container (MPa (psi))	n.a.
Max extinguisher container pressure (MPa (psi))	n.a.
Extinguisher container percent filled (%)	n.a.
Extinguisher container orientation (upright with valves at bottom…)	upright
Extinguisher container weight without Halon (kg (lb))	n.a.
Halon wt (kg (lb))	2.8 kg (5 lb)
Extinguisher container location (inside/outside fire zone)	Both the M2s and M3s have the same size and location of halon bottles. The bottles stored within the crew compartment, closely spaced, immediately adjacent to each other, approximately in the middle of the compartment.
STRATEGY FOR USE	
# of shots	n.a.
Manual/automatic	n.a.
Procedure for activation	4 optical sensors
Time to release halon 1301	The system specification lists the interval from detection of the fire until start of discharge as 10 - 15 ms. The halon will be fully discharged within 100 ms.
DISTRIBUTION SYSTEM	
Extinguisher dispersion method	One discharges toward the front, the other toward the rear of this compartment. The halon discharges are unrestricted; no nozzles are used. This is intended to produce the shortest discharge time.
Extinguisher discharge rate (kg/min (lb/min))	n.a.
Distribution system plumbing	There is no plumbing associated with the fire extinguishing system in the crew compartment.
Inner diameter (cm (in))	
Length (cm (in))	
Shape (bends, elbows)	
# and nature of nozzles/pipe terminations	
MODIFICATION POTENTIAL	
Potential for increased number or increased size of storage bottles	The crew compartment is of medium size, but can be crowded with soldiers. Examination of the interior indicates that it may be possible to use larger fire extinguishing bottles.
Restriction on alternative fluids (very/modestly/slightly)	n.a.

	M2, M3 Bradley Fighting Vehicles
	Crew Compartment
Access of current distribution plumbing for retrofit (Please rate with percent of ease (e.g., 20 percent of the plumbing is difficult to access, 80 percent of the plumbing is easy to access.))	n.a.
Access & available space for additional distribution plumbing or nozzle modification (Please rate with percent of ease (e.g., 20 percent of the plumbing is difficult to access, 80 percent of the plumbing is easy to access.))	It should be possible to add nozzles to the discharge valves, although any time delays associated with additional plumbing may not be acceptable.
How tight is the bottle space?	n.a.
Is the plumbing readily accessible for replacement?	n.a.
Is the plumbing readily accessible for adding another distribution part?	n.a.
Is the plumbing readily accessible for changing the pipe end?	n.a.
Extinguisher Growth Potential	n.a.
OTHER	
Suppression success fraction	n.a.
Extinguisher system manufacturer	n.a.
Evidence of halon distribution characteristics (from certification tests)—design concentration required for extinguishment	7 percent - Halon concentration within the crew compartment probably varies by a factor of at least two.
Range of expected operating temperatures for the bottle and the plumbing (ºC (ºF))	Any system in a vehicle must survive –45 ºC (-49 ºF). The system must function properly at –32 ºC (-26 ºF)and above. The bottles are all in the crew compartment, and thus are not exposed to the high temperatures associated with engine compartments. The maximum temperature to which the bottles will be exposed is approximately 63 ºC (145 ºF).

n.a. – not available

3.4.1.3.2 System Schematic

Figure 4 displays the fire suppression system configuration for the M2, M3 Bradley Fighting Vehicles.

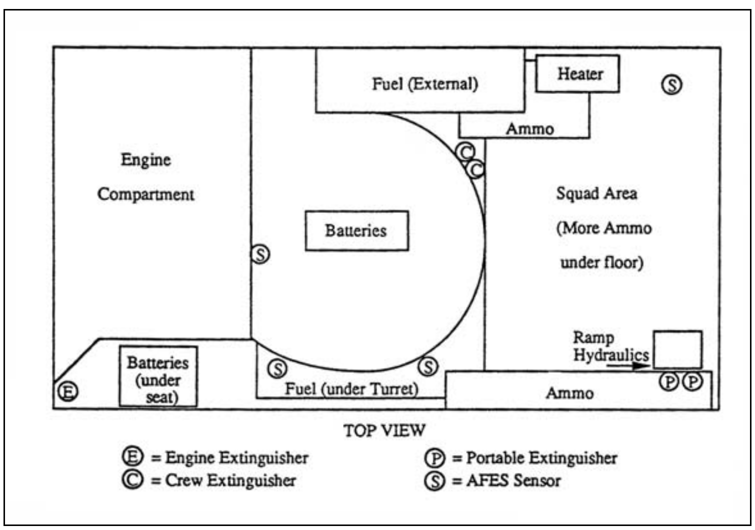

Figure 4. M2, M3 Bradley Fighting Vehicles Fire Extinguishing System Schematic

3.4.1.3.3 Sequence of Events

As above, fires are detected automatically through the use of discriminating dual-band infrared sensors. When a mine penetrates the crew compartment and ruptures the main fuel cell, a large quantity of fuel (liquid, droplets, mist, and vapor) will be ejected from the tank and into the crew compartment. Both hot metal spall and remnants of the explosive fireball will act as ignition sources, igniting the fuel. The discriminating sensors will sense the initial event, but then delay activation of the halon fire suppression system for approximately 5 ms until the system is certain that there is truly a fire. The initial event is so large that closed hatches or the ramp may be blown open. The halon that is released may be entrained in the fire plume exiting the hatch openings. There is a danger that the halon can be swept out of the vehicle before achieving fire suppression. This is an absolutely worst-case scenario. Most events in which an antivehicle mine would attack a Bradley would not produce as large an initial event as described above. It is expected that in most cases the crew compartment halon system will be able to extinguish fires caused by land mines within the 250 ms time frame. Since most air-attack weapons are not nearly as strong as large land mines, it is expected that the halon system in the crew compartment will be able to extinguish resulting fires within the accepted time frame.

3.4.2 Aircraft halon 1301 System Configurations

3.4.2.1 C-130 System Configuration Description

3.4.2.1.1 System Configuration Description

The C-130 fire extinguisher system provides fire protection for each of the four engines and the auxiliary power unit. For fire protection, the C-130 utilizes three halons (1301, 1011, and 1202) onboard. The distribution system for the halon 1202 engine system is significantly different than the halon 1301 system. The high rate discharge (HRD) halon 1301 system utilizes open-end nozzles and relies on the high velocity of the agent discharge for proper dispersal within the nacelle. Consequently, high vapor pressure agents such as halon 1301 are best suited for HRD applications. In contrast, the conventional system utilizes perforated tubing for agent distribution with consequent penalties of restricted flow and general high total system weight. A low vapor pressure agents such as halon 1011 are best suited for the latter application. Halon 1202, an intermediate volatility extinguishant, has been used successfully in both types of systems. The C-130 has long and unique distribution system runs since the bottles are housed under the left wing and distribution lines must be routed from the bottles to the left engines on the left side wing, plus they must pass through the fuselage to the engines on the right wing. [5] The agent is contained in two bottles and the capacities of the bottles depend upon the agent (1011 – 9 kg (20 lb), 1202 – 9 kg (20 lb), 1301 – 10 kg (22 lb)). Each bottle is marked to identify the type of agent it contains. The bottles are discharged one at a time, and the agent is directed to any one of the engines or auxiliary power unit. The outlets for the agent are perforated tubing. Two rings encircle each engine, and a single tube is located above the auxiliary power unit. The controls for the system are located on the fire emergency panel on the pilot’s overhead pane. Specific C-130 fire system details are in Table 11.

Table 11. C-130 Fire Suppression System Configuration.

	C-130 (Halon 1011)		C-130 (Halon 1202)		C-130 (halon 1301)	
	Engine Bay	**APU**	**Engine Bay**	**APU**	**Engine Bay**	**APU**
GENERIC						
Number of aircraft	Active force, 300; ANG, 80E's and 166Hs; reserve 140					
Service cycle refill (years)	5		5		5	
Fire types (pool fires, mist…)	Spray/pool		Spray/pool		Spray/pool	
Estimated halon use/year/aircraft (kg (lb))	39					
FIRE ZONE						
# of fire zones	2		2		2	
Fire Zone size (L, W, D) (cm, cm, cm (in, in, in))	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Fire zone volume (cm^3 (in^3))	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Fire zone free volume (m^3 (ft^3))	1.9 (66)	1.9 (66)	1.9 (66)	1.9 (66)	1.9 (66)	1.9 (66)
EXTINGUISHANT	Usually, C-130s are shipped with Halon 1011. After this is expelled, they are refilled with either Halon 1202 or for newer models/versions halon 1301.					
# of halon systems	2		2		2	
Extinguisher trigger mode	Pilot activated	Pilot activated	Pilot activated	Pilot activated	Pilot activated	Pilot activated
Extinguisher volume (cm^3 (in^3))	8800 (536)	8800 (536)	8800 (536)	8800 (536)	15,500 (945)	15,500 (945)
Size of extinguishant container (cm, cm, cm (in, in, in))	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Storage compartment for extinguishant bottle (cm, cm, cm (in, in, in))	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Free volume in storage compartment (cm^3 (in^3))	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Normal charge and pressure of extinguisher container (MPa (psi))	4.1 (600)					
Max extinguisher container pressure (MPa (psi))	4.4 (640) (except on hot days where the pressure may exceed 6.9 MPa (1000 psi))					
Extinguisher container percent filled (%)	50					
Extinguisher container orientation (upright with valves at bottom…)	Valves @ bottom					
Extinguisher container weight without Halon (kg (lb))	9 (20)	9 (20)	9 (20)	9 (20)	10 (22)	10 (22)
Halon wt (kg (lb))	8.6 (19)	8.6 (19)	8.6 (19)	8.6 (19)	8.6 (19)	8.6 (19)
Extinguisher container location (inside/outside fire zone)	Outside					
STRATEGY FOR USE						
# of shots	2	2	2	2	2	2
Manual/automatic	Manual, discharge one at a time					
Procedure for activation	Fire warning light is activated, pilot initiates firing of pyrotechnic squib which releases the contents of the bottle, the agent travels through the system plumbing to the engine nacelle/APU and is discharged as a gas.					
Time to release halon 1301	10 seconds					
DISTRIBUTION SYSTEM						
Extinguisher dispersion method	Manifold					
Extinguisher discharge rate (lb/min)	The contents of the bottle are discharged in less than 10 seconds.					
Distribution system plumbing	The distribution system is complex. The bottles are stored under the left wing. The plumbing is routed to the left engine and through the aircraft to the right engine. There would involve a significant effort to redesign the plumbing system. The system was designed for a liquid agent (such as Halons 1011, 1211, and 1202) and not for a gaseous agent (halon 1301). The optimal design for a halon 1301 system would require short plumbing runs and larger diameter tubing. However, the distribution system for the C-130 utilizes long runs and a smaller diameter tubing (for optimization of the liquid agents utilized).					
Inner diameter (cm (in)_	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

	C-130 (Halon 1011)		C-130 (Halon 1202)		C-130 (halon 1301)	
	Engine Bay	**APU**	**Engine Bay**	**APU**	**Engine Bay**	**APU**
Length (m (ft))	24-27 (80-90)	n.a.	24-27 (80-90)	n.a.	24-27 (80-90)	n.a.
Shape (bends, elbows)	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
# and nature of nozzles/pipe terminations	Outlets for agent are perforated tubing. Tubing is scattered throughout the each engine compartment, a single tube is located above APU.		Outlets for agent are perforated tubing. Tubing is scattered throughout the each engine compartment, a single tube is located above APU.		Outlets for agent are perforated tubing. Tubing is scattered throughout the each engine compartment, a single tube is located above APU. Normal halon 1301 systems have pipe terminations discharging into engine compartment. However, this system was not designed that way and the agent amount was increase to compensate.	
MODIFICATION POTENTIAL						
Potential for increased number or increased size of storage bottles	The exact reasoning for storage of the bottles under the left wing is unknown in the original design. However, this design has been maintained for subsequent aircraft modifications. There is room for larger bottle. The fixtures, which support these bottles, would need to be redesigned. There may not be room for the addition of more bottles. The potential might exist to store additional bottles on the other side of the aircraft. The optimal solution would allow for 1 bottle to be assigned to each engine.					
Restriction on alternative fluids (very/modestly/slightly)	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Access of current distribution plumbing for retrofit (Please rate with percent of ease (e.g., 0%-very difficult, 50%-relatively easy, 100 percent easy).)	Open access doors on nacelle/APU		Open access doors on nacelle/APU		Open access doors on nacelle/APU	
Access & available space for additional distribution plumbing or nozzle modification (Please rate with percent of ease (e.g., 0%-very difficult, 50%-relatively easy, 100 percent easy).)	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
How tight is the bottle space?	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Is the plumbing readily accessible for replacement?	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Is the plumbing readily accessible for adding another distribution part?	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Is the plumbing readily accessible for changing the pipe end?	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Extinguisher Growth Potential	200%	200%	200%	200%	200%	200%
OTHER						
Suppression success fraction						
Extinguisher system manufacturer	Walter Kidde	Walter Kidde	Walter Kidde	Walter Kidde	Walter Kidde	Walter Kidde
Evidence of halon distribution characteristics (from certification tests)—design concentration required for extinguishment	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Range of expected operating temperatures for the bottle and the plumbing (°C (°F))	-54 to 71 (-65 to 160)	-54 to 71 (-65 to 160)	-54 to 71 (-65 to 160)	-54 to 71 (-65 to 160)	-54 to 71 (-65 to 160)	-54 to 71 (-65 to 160)

n.a. – not available

3.4.2.1.2 System Schematic

The C-130 utilizes three halons (1301, 1011, and 1202) onboard. The distribution system for the halon 1202 engine system is significantly different than the halon 1301 system. The

C-130 has long and unique distribution system runs since the bottles are housed under the left wing and distribution lines must be routed from the bottles to the left engines on the left side wing, plus they must pass through the fuselage to the engines on the right wing. [5] Figure 5 displays the fire suppression system configuration for the C-130 [34].

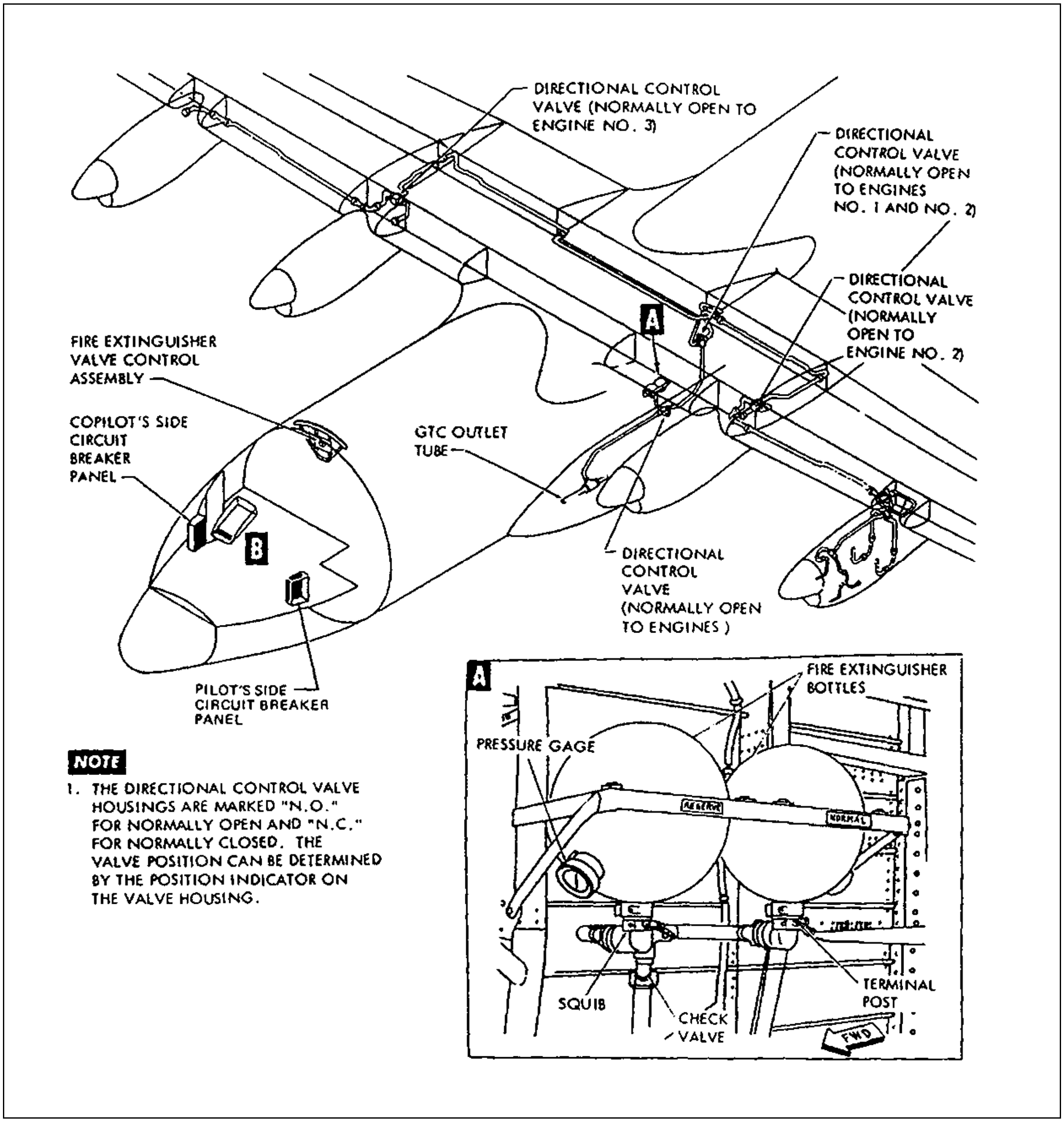

Figure 5. C-130 Fire Extinguishing System Schematic.

3.4.2.1.3 Sequence of Events

The storage containers (or “bottles”) of fire extinguishant for engine fire protection systems are typically remotely located from the engine nacelle (although not always)--sometimes up to 15.2 m or 18.3 m (50 or 60 feet) away from the engine nacelle itself. The first step in such cases is to shut down the engine, when the proximity fire detector confirms a fire is present and the pilot is satisfied that a true fire event has occurred. The bottle is typically activated, at the initiation of the pilot, by the firing of a pyrotechnic squib that severs a rupture disk and releases the contents of the bottle. The extinguishant must then travel some distance through a series of pipes to the nacelle in question. A bottle may be plumbed to more than one engine nacelle, and some configurations will cross-feed two different bottles to the same two nacelles to provide "two-shot" protection to the nacelle needing extinguishment. Typically, APU systems are plumbed from the engine nacelle systems. Once the extinguishant reaches the nacelle, it discharges as a fluid either at one or more remote locations in the nacelle (for high volatility extinguishants such as halon 1301) or through a series of perforated holes in a complex network of distribution tubing within the nacelle (such as with low volatility extinguishants halon 1202, 1211, and 1011). [12] In most cases, the fluid exits as a two-phase fluid (in the same distribution pipe), then flashes. The momentum allows the extinguishant to fill the "nooks and crannies" of the fire zone.

3.4.2.2 F/A-18 C/D

3.4.2.2.1 System Configuration Description

The approach to fire protection in F-18 aircraft consists of a single-bottle fixed halon 1301 fire suppression system designed to provide fire protection for the left and right engines and the left and right airframe mounted accessory drive (AMAD) bays. A potential for false discharges exists on the ground. [19] Specific F/A-18 fire system details are in Table 12.

Table 12. F-18C/D Fire Suppression System Configuration.

	F-18C/D	
	Engine Bay	**APU**
GENERIC		
Number of aircraft	1001	
Service cycle refill (years)	5	
Fire types (pool fires, mist…)	Spray/pool	
Estimated halon use/year/aircraft (kg (lb))	n.a.	
FIRE ZONE		
# of fire zones	3 (2 engines/AMAD, 1 APU)	
Fire Zone size (L, W, D) (cm, cm, cm (in, in, in))	n.a.	n.a.
Fire zone volume (cm^3 (in^3))	n.a.	n.a.
Fire zone free volume (m^3 (ft^3))	1.14 (40.4)	n.a.
EXTINGUISHANT		
# of halon systems	1	
Extinguisher trigger mode	Pilot activated	
Extinguisher volume (cm^3 (in^3))	3031 (185)	
Size of extinguishant container (cm, cm, cm (in, in, in))	11.4 cm (4.5 in.) dia, 46 cm (18 in.) long; cylindrical	
Storage compartment for extinguishant bottle (cm, cm, cm (in, in, in)) see drawing	206 x 12.7 x 20.3 (81 x 5 x 8)	
Free volume in storage compartment (m^3 (in^3)) see drawing	0.048 (2953)	
Normal charge and pressure of extinguisher container (MPa (psi))	4.3 (625) @ 22.2 °C (72 °F)	
Max extinguisher container pressure (MPa (psi))	6.2 (900) @ 16 °C (60 °F)	
Extinguisher container percent filled (%)	50	
Extinguisher container orientation (upright with valves at bottom…)	Lateral configuration	

	F-18C/D	
	Engine Bay	**APU**
Extinguisher container weight (kg (lb)) without Halon	2.7 (~6 lb)	
Halon wt (kg (lb))	2.5 (5.5)	
Extinguisher container location (inside/outside fire zone)	Outside	
STRATEGY FOR USE		
# of shots	1 shot discharges into engine nacelle and AMAD bay or APU.	
Manual/automatic	Manual	
Procedure for Activation	Fire warning light is activated, pilot initiates firing of pyrotechnic squib which releases the contents of the bottle, the agent travels through the system plumbing to the engine nacelle/APU and is discharged as a gas.	
Time to release halon 1301		
DISTRIBUTION SYSTEM		
Extinguisher dispersion method	Cut off pipe	Cut off pipe
Extinguisher discharge rate (kg/sec (lb/s))	0.99 (2.2)	
Distribution system plumbing	Single pipe discharged into engine and AMAD simultaneously. APU has discharge port, but the first fire occurrence in either the engine/AMAD or APU bays will utilize all Halon	
Inner diameter (cm (in)) see drawings: none given	n.a.	n.a.
Length (cm (in)) see drawings: none given	n.a.	n.a.
Shape (bends, elbows) see drawings: nothing specific given	n.a.	n.a.
# and nature of nozzles/pipe terminations	cut off pipe	cut off pipe
MODIFICATION POTENTIAL		
Potential for increased number of increased size of storage bottles.	n.a.	n.a.
Restriction on alternative fluids (very/modestly/slightly)	modestly	modestly
Access of current distribution plumbing for retrofit (Please rate with percent of ease (e.g., 0%-very difficult, 50%-relatively easy, 100 percent easy).)	20%	20%
Access & available space for additional distribution plumbing or nozzle modification (Please rate with percent of ease (e.g., 0%-very difficult, 50%-relatively easy, 100 percent easy).)	20%	20%
How tight is the bottle space?	Only 12.7 cm (5 in.) in height available for growth.	
Is the plumbing readily accessible for replacement?	n.a.	n.a.
Is the plumbing readily accessible for adding another distribution part?	n.a.	n.a.
Is the plumbing readily accessible for changing the pipe end?	n.a.	n.a.
Extinguisher Bottle Growth Potential	12.7 cm (5 in.) in height	
OTHER		
Suppression success fraction	Historical reports show 80 percent success.	
Extinguisher system manufacturer	Pacific Scientific	
Evidence of halon distribution characteristics (from certification tests)	Yes	Yes
Range of expected operating temperatures for the bottle and the plumbing (°C (°F))	-54 to 71 (-65 to 600)	-54 to 71 (-65 to 600)

n.a. – not available

3.4.2.2.2 System Schematic

Figure 6 through Figure 8 display the fire suppression system configuration for the F-18C/D [35].

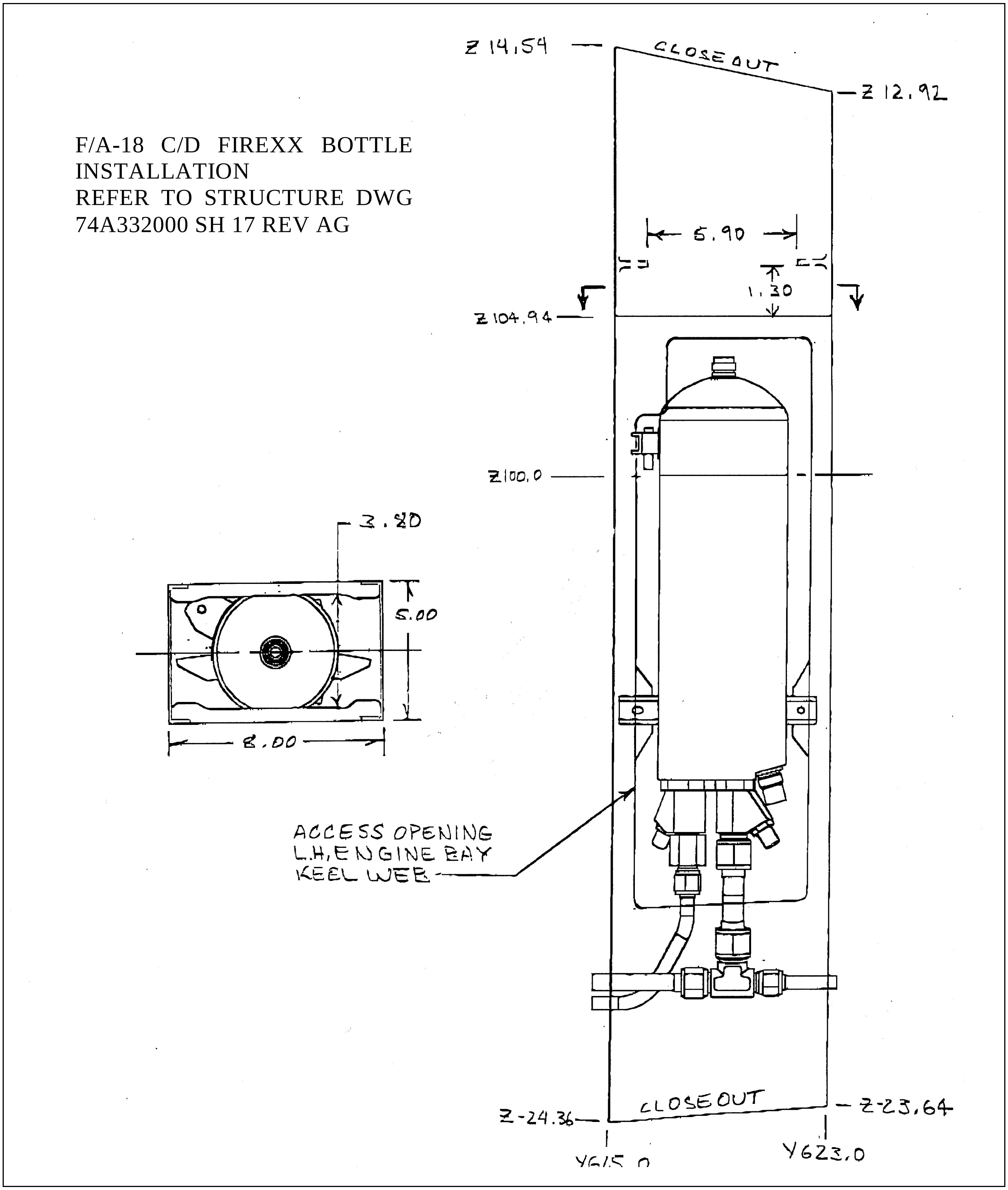

Figure 6. F/A-18C/D FIREXX Bottle Installation.

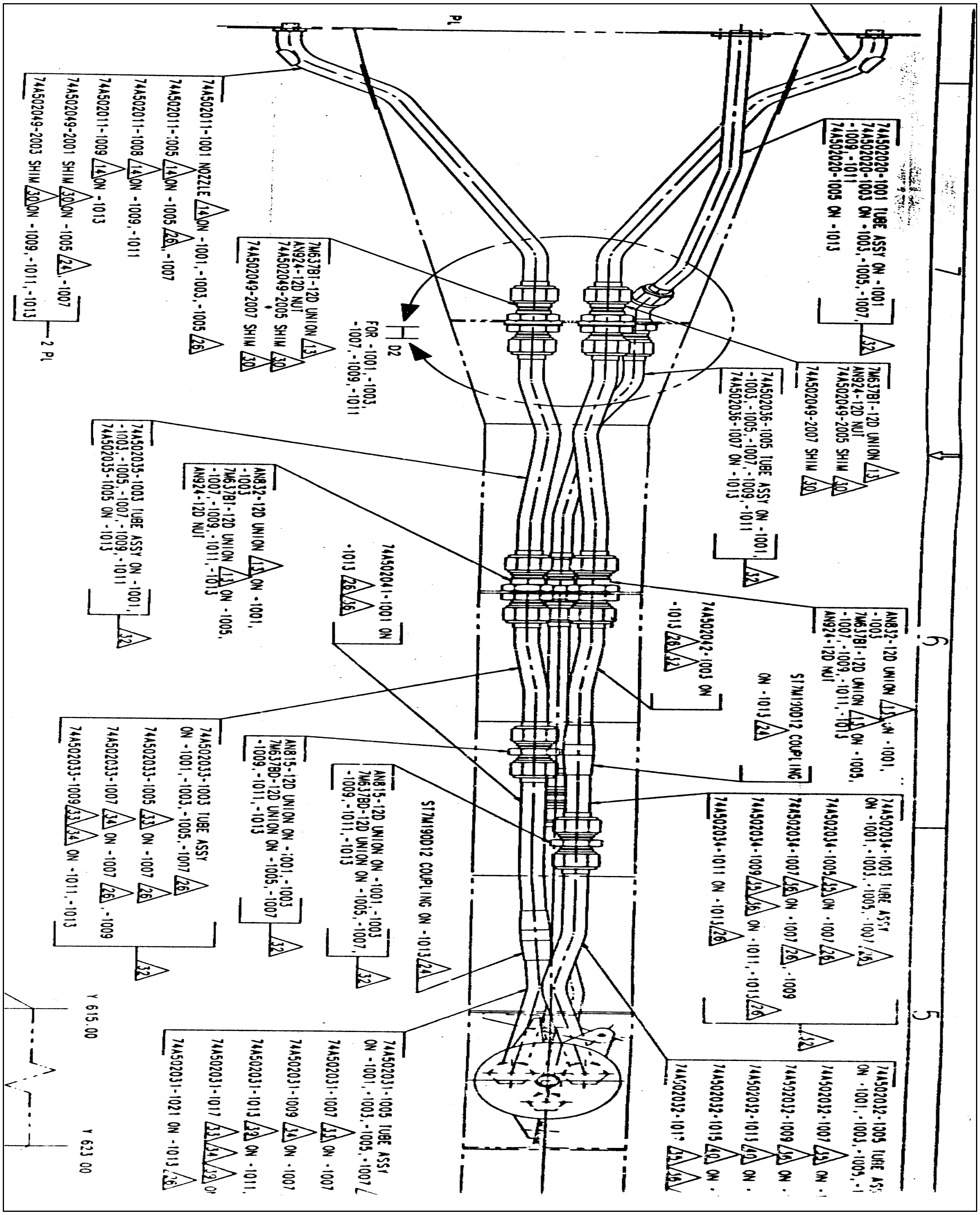

Figure 7. F/A-18C/D Halon Bottle And Discharge Piping Installations Bottom View.

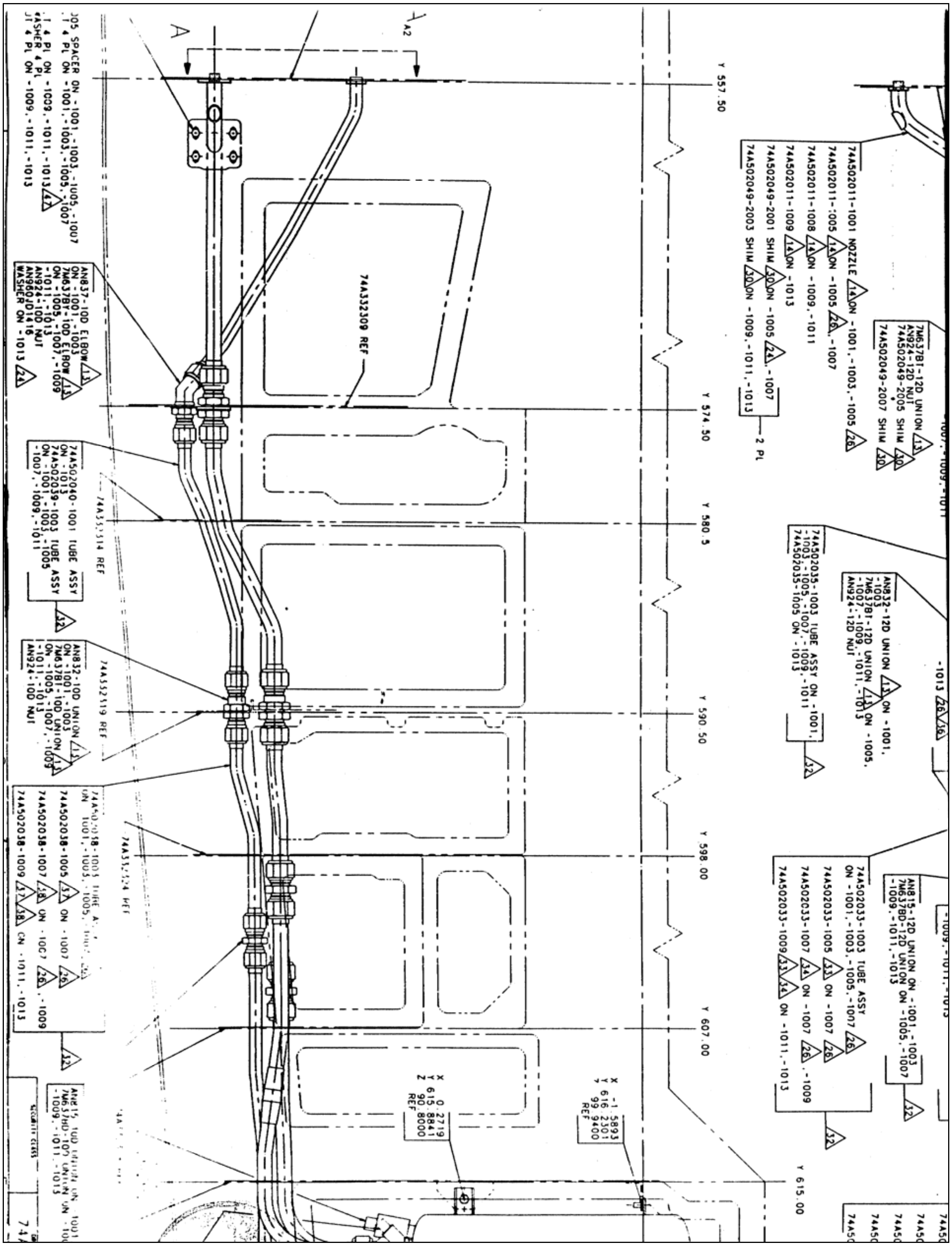

Figure 8. Halon Bottle and Discharge Piping Installations Side View.

3.4.2.2.3 Sequence of Events

The storage containers (or “bottles”) of fire extinguishant for engine fire protection systems are typically remotely located from the engine nacelle (although not always)--sometimes up to 15.2 m or 18.3 m (50 or 60 feet) away from the engine nacelle itself. The first step in such cases is to shut down the engine, when the proximity fire detector confirms a fire is present and the pilot is satisfied that a true fire event has occurred. The bottle is typically activated, at the initiation of the pilot, by the firing of a pyrotechnic squib that severs a rupture disk and releases the contents of the bottle. The extinguishant must then travel some distance through a series of pipes to the nacelle in question. A bottle may be plumbed to more than one engine nacelle, and some configurations will cross-feed two different bottles to the same two nacelles to provide “two-shot” protection to the nacelle needing extinguishment. Typically, APU systems are plumbed from the engine nacelle systems. Once the extinguishant reaches the nacelle, it discharges as a fluid either at one or more remote locations in the nacelle (for high volatility extinguishants such as halon 1301) or through a series of perforated holes in a complex network of distribution tubing within the nacelle (such as with low volatility extinguishants halon 1202, 1211, and 1011). [12] In most cases, the fluid exits as a two-phase fluid (in the same distribution pipe), then flashes. The momentum allows the extinguishant to fill the "nooks and crannies" of the fire zone.

3.4.2.3 C-17

3.4.2.3.1 System Configuration Description

Fire extinguishing is provided for all four engines (with four 9.5 kg (21 lb) bottles) and for the APU compartment (with one 1.13 kg (2.5 lb) bottle). Pulling out the applicable handle assembly on the glareshield panel discharges the agent from the extinguishers. The engine fire extinguisher system distribution lines on each wing are routed so the agent from each extinguisher can be discharged to either or both engines. Fire extinguishing is provided for the APU by a fixed halon 1301 high rate discharge fire extinguishing system in the APU compartment. Specific C-17 fire system details are in Table 13.

Table 13. C-17 Fire Suppression System Configuration.

	C-17	
	Engine Bay	**APU**
GENERIC		
Number of aircraft	23	
Service cycle refill (years)	n.a.	
Fire types (pool fires, mist…)	Spray/pool	
Estimated halon use/year/aircraft (kg (lb))	n.a.	n.a.
FIRE ZONE		
# of fire zones	2	1
Fire Zone size (L, W, D) (cm, cm, cm (in, in, in))	n.a.	n.a.
Fire zone volume (m^3 (ft^3))	n.a.	n.a.
Fire zone free volume (m^3 (ft^3)) (net volume)	7.45 (263)	0.623 (22)
EXTINGUISHANT		
# of halon systems	2	1
Extinguisher trigger mode	Remote	Remote
Extinguisher volume (cm^3 (in^3))	10,300 (630)	1400 (86)

	C-17	
Size of extinguishant container (cm, cm, cm (in, in, in))	27.7 (10.9 in.) diameter	14.2 (5.6 in.) diameter
Storage compartment for extinguishant bottle (m^3 (ft^3))		0.42 (15)
Free volume in storage compartment (cm^3 (in^3))		0.43 (260)
Normal charge and pressure of extinguisher container (MPa (psig)) (@ 21 °C (70 °F)) with GN_2)	5.6 (800)	4.24 (600)
Max extinguisher container pressure (MPa (psig)) (Burst range of safety disc)	13.2 – 15.6 (1900-2300) @ 96 °C (205 °F)	11.96 – 13.3 (1720-1920)
Extinguisher container percent filled (%)	67%	69%
Extinguisher container orientation (upright with valves at bottom…)	Valves at bottom	
Extinguisher container weight (kg (lb)) without Halon	5.8 (12.8)	1.5 (3.2)
Halon wt (kg (lb))	9.5 (21.0)	1.1 (2.5)
Extinguisher container location (inside/outside fire zone)	Outside	
STRATEGY FOR USE		
# of shots	2	1
Manual/automatic	Manual	Manual
Procedure for Activation	Fire warning light is activated, pilot initiates firing of pyrotechnic squib which releases the contents of the bottle, the agent travels through the system plumbing to the engine nacelle/APU and is discharged as a gas.	
Time to release halon 1301	n.a.	n.a.
DISTRIBUTION SYSTEM		
Extinguisher dispersion method (@ 21 °C (70 °F))	5.6 MPa (Gas N_2 @ 800 psig)	4.24 MPa (Gas N_2 at 600 psig)
Extinguisher discharge rate (kg/min (lb/min)) (95 percent in 0.9 seconds)	544 (1200)	72 (158)
Distribution system plumbing	Bottle to pylon stub: 6061ALT6; all else: CRES.	CRES 321
Inner diameter (cm (in))	From bottle to pylon stub, 3.8 (1.5) ID; all else, 3.8 (1.5), 2.5 (1.0), and 1.9 (0.75) ID. Wall thickness, 0.24 (0.095)	1.27 (0.5) ID. Wall thickness, 0.071 (0 .028)
Length (cm (in))	99.4 (39.14) from outboard bottle to both outlets in core compartments; 41.7 (16.42); from outboard bottle to inboard pylon	Straight length – 12.7 (5) – 78.7 (31)
Shape (bends, elbows)		1 bend, 1.5 radius
# and nature of nozzles/pipe terminations	Two nozzles (1.91 (0.75))	One nozzle (1.27 (0.5))
MODIFICATION POTENTIAL		
Potential for increased number of increased size of storage bottles.	n.a.	n.a.
Restriction on alternative fluids (very/modestly/slightly)	slightly	slightly
Access of current distribution plumbing for retrofit (Please rate with percent of ease (e.g., 0%-very difficult, 50%-relatively easy, 100 percent easy).)	30 percent difficult; 70 percent easy.	30 percent difficult; 70 percent easy.
Access & available space for additional distribution plumbing or nozzle modification (Please rate with percent of ease (e.g., 0%-very difficult, 50%-relatively easy, 100 percent easy).)	30 percent difficult; 70 percent easy.	30 percent difficult; 70 percent easy.
How tight is the bottle space?	n.a.	n.a.
Is the plumbing readily accessible for replacement?	n.a.	n.a.
Is the plumbing readily accessible for adding another distribution part?	n.a.	n.a.
Is the plumbing readily accessible for changing the pipe end?	n.a.	n.a.
Extinguisher Bottle Growth Potential	n.a.	n.a.
OTHER		
Suppression success fraction	n.a.	

	C-17	
Extinguisher system manufacturer	Walter Kidde	
Evidence of halon distribution characteristics (from certification tests)	6 percent by volume for 5.5 seconds at cruising condition.	6 percent by volume for 5.5 seconds at cruising condition.
Range of expected operating temperatures for the bottle and the plumbing (°C (°F))	-60 to 93 (-77 to 200)	-60 to 93 (-77 to 200)
MISCELLANEOUS	130 kPa (4 psig) is max pressure the protected volume can accept in nacelle. Max pressure in plumbing is 14 kPa (2000 psi) allowable. Potential fuels: Jet A and JP-8, Hydraulic Fluid MIL -H-83282, Lube Oil MIL-L-23699.	

n.a. – not available

3.4.2.3.2 System Schematic

Figure 9 displays the fire suppression system configuration for the C-17 [36].

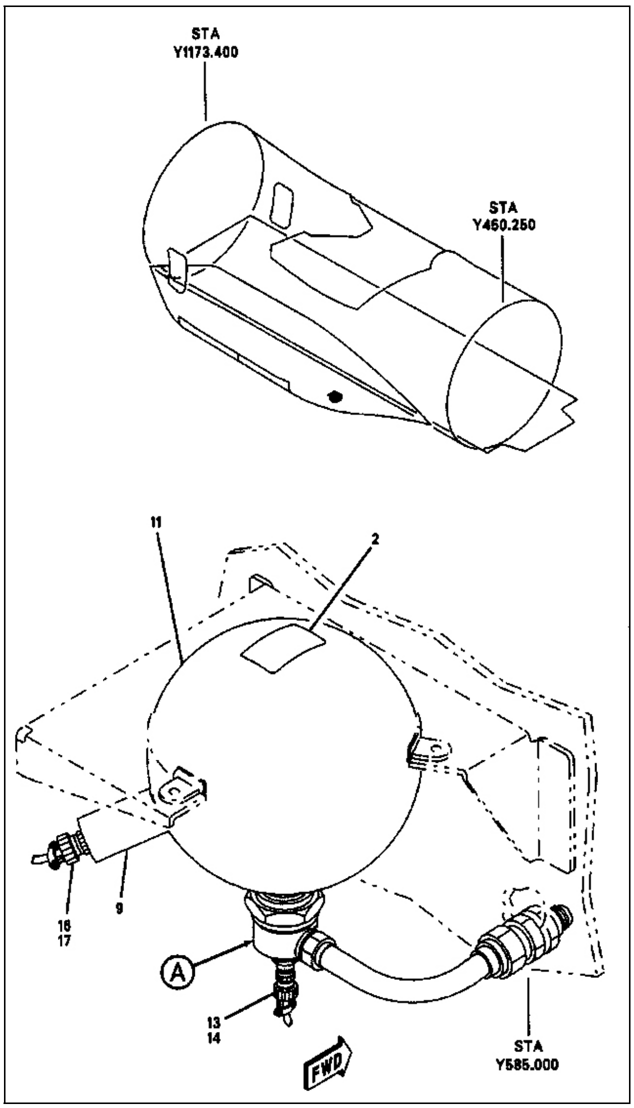

Figure 9. C-17 Fire Extinguishing System Schematic (86 in^3).

3.4.2.3.3 Sequence of Events

The storage containers (or “bottles”) of fire extinguishant for engine fire protection systems are typically remotely located from the engine nacelle (although not always)--sometimes up to 15.2 m or 18.3 m (50 or 60 feet) away from the engine nacelle itself. The first step in such cases is to shut down the engine, when the proximity fire detector confirms a fire is present and the pilot is satisfied that a true fire event has occurred. The bottle is typically activated, at the initiation of the pilot, by the firing of a pyrotechnic squib that severs a rupture disk and releases the contents of the bottle. The extinguishant must then travel some distance through a series of pipes to the nacelle in question. A bottle may be plumbed to more than one engine nacelle, and some configurations will cross-feed two different bottles to the same two nacelles to provide “two-shot” protection to the nacelle needing extinguishment. Typically, APU systems are plumbed from the engine nacelle systems. Once the extinguishant reaches the nacelle, it discharges as a fluid either at one or more remote locations in the nacelle (for high volatility extinguishants such as halon 1301) or through a series of perforated holes in a complex network of distribution tubing within the nacelle (such as with low volatility extinguishants halon 1202, 1211, and 1011). [12] In most cases, the fluid exits as a two-phase fluid (in the same distribution pipe), then flashes. The momentum allows the extinguishant to fill the "nooks and crannies" of the fire zone.

3.4.2.4 H-60

3.4.2.4.1 System Configuration Description

Fire suppression for the H-60 aircraft consists of two halon 1301 bottles, which provide protection for both engines and the APU. The engine system halon bottles are configured to provide a "reserve capability.” for both engines and the APU. For the engines this means that the No. 2 engine bottle provides reserve fire protection capability for the No. 1 engine, and the No. 1 engine bottle provides reserve fire protection capability for the No. 2 engine. For the APU, either bottle can be the primary bottle or the reserve bottle depending upon which bottle is first utilized. [21] Specific H-60 fire system details are in Table 14.

Table 14. H-60 Fire Suppression System Configuration.

	H-60	
	Engine Bay	**APU**
GENERIC		
Number of aircraft	1400	
Service cycle refill (years)	5	
Fire types (pool fires, mist…)	Spray/pool	Spray/pool
Estimated halon use/year/aircraft (kg (lb))	n.a.	n.a.
FIRE ZONE		
# of fire zones	2	
Fire Zone size (L, W, D) (cm, cm, cm (in, in, in))	132, 69, 56 (52, 27, 22)	36, 48, 38 (14, 19, 15)
Fire zone volume (m^3 (ft^3))	0.54 (19)	n.a.
Fire zone free volume (m^3 (ft^3))	0.28 (10.01)	4.5 E-2 (1.6)
Fire zone maximum airflow rate (m^3/min (CFM))	(1770)	(1770)
EXTINGUISHANT		
# of halon systems	1	1

	H-60	
	Engine Bay	**APU**
Extinguisher trigger mode	Pilot activated	Pilot activated
Extinguisher volume (cm^3 (in^3))	1410 (86)	1410 (86)
Size of extinguishant container (cm, cm, cm (in, in, in))	n.a.	n.a.
Storage compartment for extinguishant bottle (cm, cm, cm (in, in, in))	n.a.	n.a.
Free volume in storage compartment (cm^3 (in^3))	n.a.	n.a.
Normal charge and pressure of extinguisher container (kPa (psi))	42.2 (600)	42.2 (600)
Max extinguisher container pressure (kPa (psi))	n.a.	n.a.
Extinguisher container percent filled (%)	50	50
Extinguisher container orientation (upright with valves at bottom…)	upright with valves at bottom	
Extinguisher container weight (kg (lb)) without Halon	n.a.	n.a.
Halon wt (kg (lb))	1.13 (2.5)	1.13 (2.5)
Extinguisher container location (inside/outside fire zone)	outside	Outside
STRATEGY FOR USE		
# of shots	2	
Manual/automatic	Manual	Manual
Procedure for Activation	Confirm fire, trigger No. 1 bottle, then can use No. 2 bottle	
Time to release halon 1301	n.a.	n.a.
DISTRIBUTION SYSTEM		
Extinguisher dispersion method	Manifold	Manifold
Extinguisher discharge rate (m^3/min (CFM))	0.105 (3.7)	(3.7)
Distribution system plumbing		
Inner diameter (cm (in))	n.a.	n.a.
Length (cm (in))	n.a.	n.a.
Shape (bends, elbows)	n.a.	n.a.
# and nature of nozzles/pipe terminations	n.a.	n.a.
MODIFICATION POTENTIAL		
Potential for increased number of increased size of storage bottles.	n.a.	n.a.
Restriction on alternative fluids (very/modestly/slightly)	n.a.	n.a.
Access of current distribution plumbing for retrofit (Please rate with percent of ease (e.g., 0%-very difficult, 50%-relatively easy, 100 percent easy).)	n.a.	n.a.
Access & available space for additional distribution plumbing or nozzle modification (Please rate with percent of ease (e.g., 0%-very difficult, 50%-relatively easy, 100 percent easy).)	n.a.	n.a.
How tight is the bottle space?	n.a.	n.a.
Is the plumbing readily accessible for replacement?	n.a.	n.a.
Is the plumbing readily accessible for adding another distribution part?	n.a.	n.a.
Is the plumbing readily accessible for changing the pipe end?	n.a.	n.a.
Extinguisher Bottle Growth Potential	n.a.	n.a.
OTHER		
Suppression success fraction	n.a.	
Extinguisher system manufacturer	Walter Kidde	Walter Kidde
Evidence of halon distribution characteristics (from certification tests)		
Range of expected operating temperatures for the bottle and the plumbing (°C (°F))	-54 to 177 (-65 to 350)	-54 to 177 (-65 to 350)

n.a. – not available

3.4.2.4.2 System Schematic

Figure 10 through Figure 12 display the fire suppression system configuration for the H-60 [37].

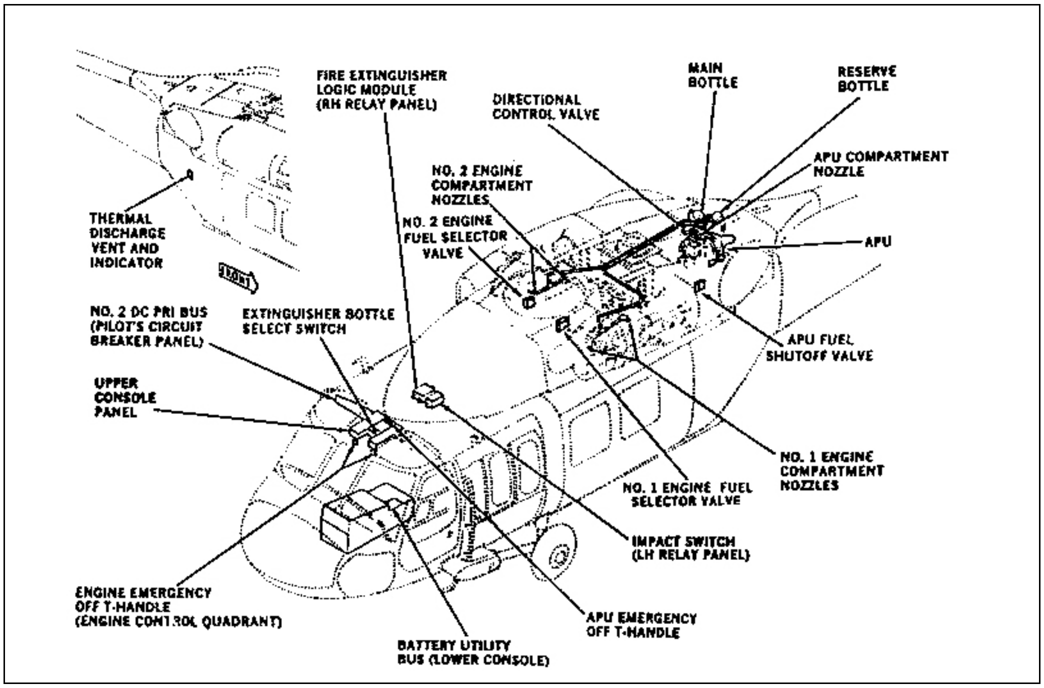

Figure 10. H-60 Fire Extinguishing Components Location.

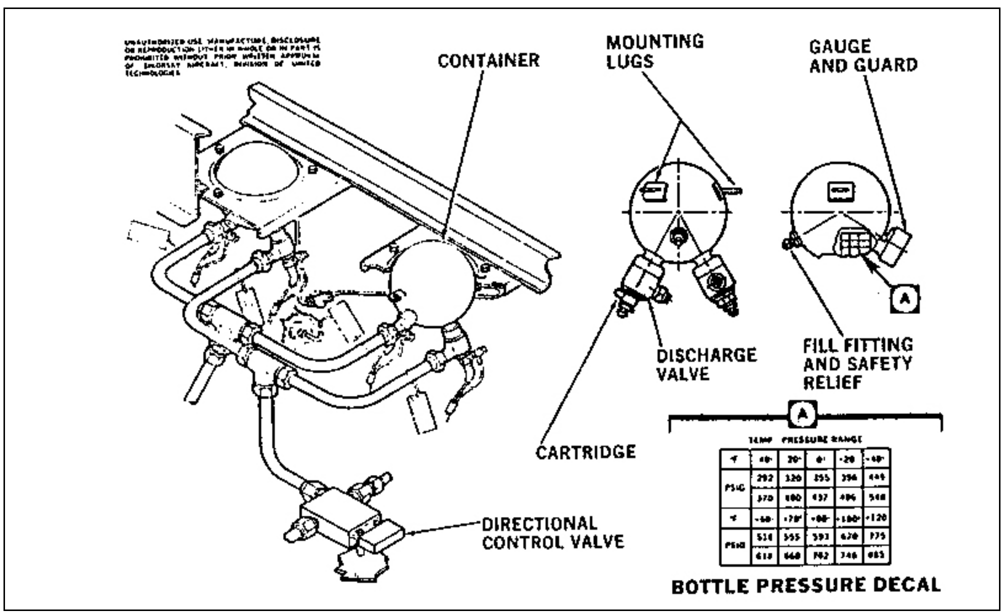

Figure 11. H-60 Engine Fire Extinguisher Installation.

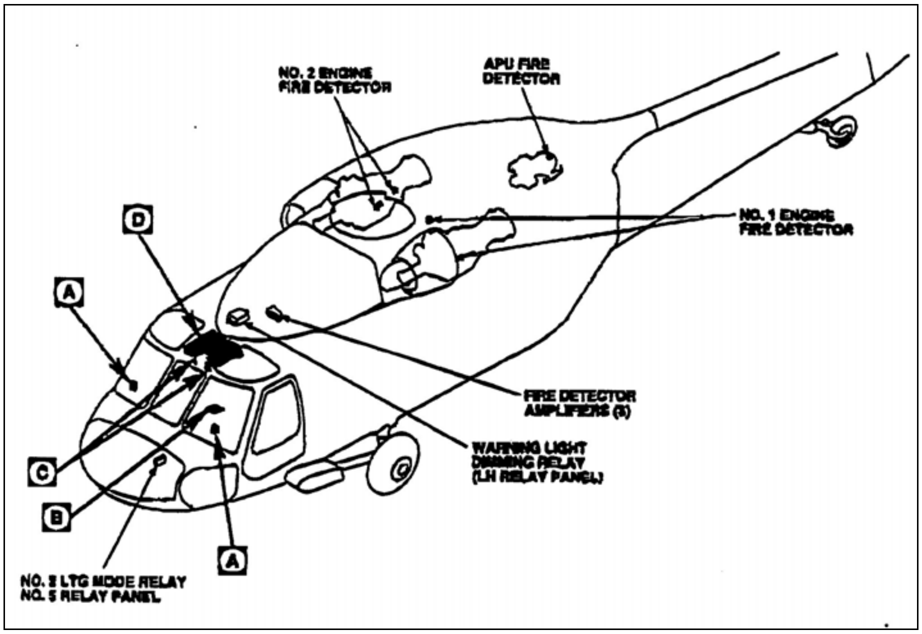

Figure 12. H-60 Engine Fire Extinguisher Installation.

3.4.2.4.3 Sequence of Events

The storage bottles of fire extinguishant for engine fire protection systems are typically remotely located from the engine nacelle (although not always)--sometimes up to 15.2 m or 18.3 m (50 or 60 feet) away from the engine nacelle itself. The first step in such cases is to shut down the engine, when the proximity fire detector confirms a fire is present and the pilot is satisfied that a true fire event has occurred. The bottle is typically activated, at the initiation of the pilot, by the firing of a pyrotechnic squib that severs a rupture disk and releases the contents of the bottle. The extinguishant must then travel some distance through a series of pipes to the nacelle in question. A bottle may be plumbed to more than one engine nacelle, and some configurations will cross-feed two different bottles to the same two nacelles to provide “two-shot” protection to the nacelle needing extinguishment. Typically, APU systems are plumbed from the engine nacelle systems. Once the extinguishant reaches the nacelle, it discharges as a fluid either at one or more remote locations in the nacelle (for high volatility extinguishants such as halon 1301) or through a series of perforated holes in a complex network of distribution tubing within the nacelle (such as with low volatility extinguishants halon 1202, 1211, and 1011). [12] In most cases, the fluid exits as a two-phase fluid (in the same distribution pipe), then flashes. The momentum allows the extinguishant to fill the "nooks and crannies" of the fire zone.

3.4.2.5 CH-47

3.4.2.5.1 System Configuration Description

Fire suppression for the CH-47 aircraft consists of two halon 1301 bottles, which provide dual-shot protection for both engines similar to the reserve capability of the H-60. Specific CH-47 fire system details are in Table 15.

Table 15. CH-47 Fire Suppression System Configuration.

	CH-47
	Engine Bay
GENERIC	
Number of aircraft	463 (AF); 398 (USA)
Service cycle refill (years)	n.a.
Fire types (pool fires, mist…)	Spray/pool
Estimated halon use/year/aircraft (kg (lb))	n.a.
FIRE ZONE	
# of fire zones	2 (1 under each engine)
Fire Zone size (L, W, D) (cm, cm, cm (in, in, in))	99, 56, 66 (39, 22 ,26)
Fire zone volume (m^3 (ft^3))	0.37 (13)
Fire zone free volume (m^3 (ft^3))	0.34 (12)
Fire zone operating temperature range (°C (°F))	-17 to 149 (0 to 300)
Fire zone length/effective diameter ratio (m (ft))	15.24 (50)
EXTINGUISHANT	
# of halon systems	2
Extinguisher trigger mode	Pilot activated
Extinguisher volume (cm^3 (in^3))	62 (86)
Size of extinguishant container (cm, cm, cm (in, in, in))	Spherical with 12.7 cm (5.5 in diameter bottle (2 containers)
Storage compartment for extinguishant bottle (cm, cm, cm (in, in, in))	Not really stored in a compartment. Bottle is between fuselage and APU.
Free volume in storage compartment (m^3 (ft^3))	0.028 (1)
Normal charge and pressure of extinguisher container (MPa (psi))	4.1 (600)
Max extinguisher container pressure (MPa (psi))	4.1 (600)
Extinguisher container percent filled (%)	50
Extinguisher container orientation (upright with valves at bottom…)	Valves at bottom and to the side
Extinguisher container weight without halon (kg (lb))	1.81 (4)
Halon wt (kg (lb))	1.36 (3)
Extinguisher container location (inside/outside fire zone)	Outside (located at stations 482 and 502)
STRATEGY FOR USE	
# of shots	2 (can blow both bottles on either engine)
Manual/automatic	Manual
Procedure for Activation	See fire, detect with wire around engine, light in cockpit goes off, select bottle, select engine, pull "T" handle.
Time to release halon 1301	n.a.
DISTRIBUTION SYSTEM	
Extinguisher dispersion method	Nozzle
Extinguisher discharge rate (m^3/min (CFM))	0.105 (3.7)
Distribution system plumbing	Very simple.
Inner diameter (cm (in))	Majority is 2.54 (1) (ID); goes to 0.952 (0.375); goes to 1.27 (0.5) before it exits the nozzle.
Length (cm (in))	160 (63) for each run
Shape (bends, elbows)	Front bottle has 3 bends and 2 tees on the left and right side.

	CH-47
	Back bottle has 4 bends and 2 tees on the left and right side.
# and nature of nozzles/pipe terminations	2 nozzles on each engine; fitted to fuselage bulkhead
MODIFICATION POTENTIAL	
Potential for increased number of increased size of storage bottles.	n.a.
Restriction on alternative fluids (very/modestly/slightly)	n.a.
Access of current distribution plumbing for retrofit (Please rate with percent of ease (e.g., 0%-very difficult, 50%-relatively easy, 100 percent easy).)	n.a.
Access & available space for additional distribution plumbing or nozzle modification (Please rate with percent of ease (e.g., 0%-very difficult, 50%-relatively easy, 100 percent easy).)	n.a.
How tight is the bottle space?	n.a.
Is the plumbing readily accessible for replacement?	n.a.
Is the plumbing readily accessible for adding another distribution part?	n.a.
Is the plumbing readily accessible for changing the pipe end?	n.a.
Extinguisher Bottle Growth Potential	n.a.
OTHER	n.a.
Suppression success fraction	n.a.
Extinguisher system manufacturer	Walter Kidde
Evidence of halon distribution characteristics (from certification tests)	114-FT-718-3 Report of Test Powerplant Fire Extinguishing System on CH-47C Helicopter, 1969 D234-10090-3.5 APU Fire Extinguishing System Agent Concentration Test and Engine/APU Fire Detector System, 1981
Range of expected operating temperatures for the bottle and the plumbing (°C (°F))	149 (300)

n.a. – not available

3.4.2.5.2 System Schematic

Figure 13 displays the fire suppression system configuration for the CH-47 [38].

3.4.2.5.3 Sequence of Events

The storage containers (or "bottles") of fire extinguishant for engine fire protection systems are typically remotely located from the engine nacelle (although not always)--sometimes up to 15.2 m or 18.3 m (50 or 60 feet) away from the engine nacelle itself. The first step in such cases is to shut down the engine, when the proximity fire detector confirms a fire is present and the pilot is satisfied that a true fire event has occurred. The bottle is typically activated, at the initiation of the pilot, by the firing of a pyrotechnic squib that severs a rupture disk and releases the contents of the bottle. The extinguishant must then travel some distance through a series of pipes to the nacelle in question. A bottle may be plumbed to more than one engine nacelle, and some configurations will cross-feed two different bottles to the same two nacelles to provide "two-shot" protection to the nacelle needing extinguishment. Typically, APU systems are plumbed from the engine nacelle systems. Once the extinguishant reaches the nacelle, it discharges as a fluid either at one or more remote locations in the nacelle (for high volatility extinguishants such as halon 1301) or through a series of perforated holes in a complex network of distribution tubing within the nacelle (such as with low volatility extinguishants halon 1202, 1211, and 1011). [12] In most cases, the fluid exits as a two-phase fluid (in the same distribution pipe), then flashes. The momentum allows the extinguishant to fill the "nooks and crannies" of the fire zone.

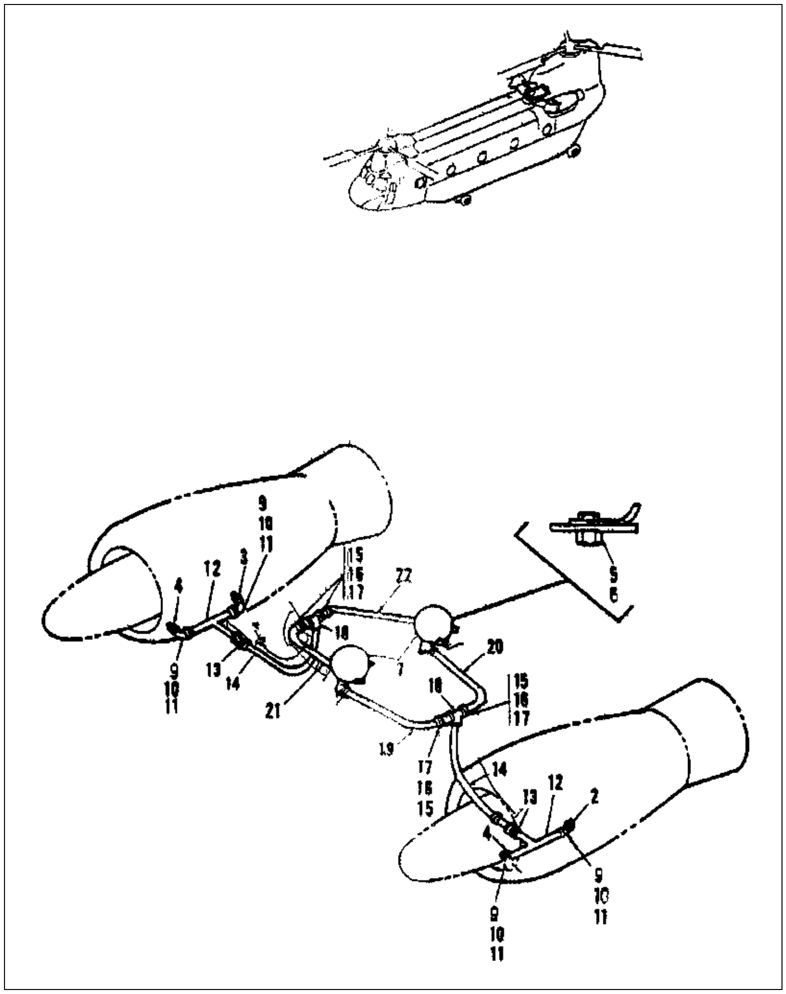

Figure 13. CH-47 Fire Extinguishing System Schematic.

3.4.2.6 F-16

3.4.2.6.1 System Configuration Description

The halon reservoir is located in the left main wheel well. The reservoir stores thirteen pounds of liquid halon. The halon inerting system is set to ensure a nine percent halon by volume concentration, thereby providing a modest margin of safety.

The halon inerting, or fuel tank explosion suppression, system is controlled by the TANK INERTING switch on the cockpit fuel control panel. When the TANK INERTING switch is placed to TANK INERTING, the fuselage and internal wing tanks are placed on a reduced pressure schedule and a valve at the halon reservoir is opened. At each activation of the TANK INERTING switch, halon (if available) is released into the F1, A1, and internal wing tanks for 20 seconds for initial inerting. After the 20 s of initial inerting, a small amount of pure halon will continue to flow into the wings. Thereafter, a continuous metered flow of halon is mixed with pressurization air to maintain the inert condition. The metered flow continues until the system is turned off or master power is turned off. Because of the limited halon supply, the system normally is activated after the external tanks have emptied, but before half of the internal fuel is depleted. The external tanks are not protected by the explosion suppression system. Specific F-16 fire system details are in Table 16. [24]

Table 16. F-16 Fire Suppression System Configuration.

	F-16
	Fuel Cells
GENERIC	
Number of aircraft	Active force, 444; ANG, 305; reserve, 60
Service cycle refill (years)	n.a.
Fire types (pool fires, mist…)	Deflagration
Estimated halon use/year/aircraft (kg (lb))	12
FIRE ZONE	
# of fire zones	1
Fire Zone size (L, W, D) (cm, cm, cm (in, in, in))	n.a.
Fire zone volume (cm^3(in^3))	1966 (120)
Fire zone free volume (cm^3 (in^3))	n.a.
EXTINGUISHANT	
# of halon systems	1
Extinguisher trigger mode	n.a.
Extinguisher volume (cm^3 (in^3))	5200 – 5600 (315-340)
Size of extinguishant container (cm, cm, cm (in, in, in))	n.a.
Storage compartment for extinguishant bottle (cm, cm, cm (in, in, in))	n.a.
Free volume in storage compartment(cm^3 (in^3))	n.a.
Normal charge and pressure of extinguisher container (MPa (psi))	4.1 (600)
Max extinguisher container pressure (MPa (psi))	4.1 (600)
Extinguisher container percent filled (%)	n.a.
Extinguisher container orientation (upright with valves at bottom…)	Upright with valves at bottom
Extinguisher container weight (kg (lb)) without Halon	2.5 (5.5)
Halon wt (kg (lb))	5.9 (13.0)
Extinguisher container location (inside/outside fire zone)	Outside
STRATEGY FOR USE	
# of shots	Multiple
Manual/automatic	Manual activation; automatic metering.
Procedure for Activation	Pilot activated.
Time to release halon 1301	n.a.
How long does the halon last (with tank venting and fuel use)? It is not active when the plane is refueled in flight?	Halon is released into F1, A1, and internal wing tanks for 20 seconds for initial inerting. After 20 seconds, a small amount of pure halon will continue to flow into the wings. A continuous flow of halon is mixed with pressurization air to maintain the inert condition. The metered flow continues until the system is turned off or master power is turned off.
DISTRIBUTION SYSTEM	
Extinguisher dispersion method	n.a.
Extinguisher discharge rate (kg/min (lb/min))	0.91 (2)
Distribution system plumbing	
Inner diameter (cm (in))	
Length (cm (in))	762 (300)
Shape (bends, elbows)	From forward to aft fuselage fuel tanks and across to wing

	F-16
	tanks
# and nature of nozzles/pipe terminations	n.a.
MODIFICATION POTENTIAL	
Potential for increased number of increased size of storage bottles.	n.a.
Restriction on alternative fluids (very/modestly/slightly)	n.a.
Access of current distribution plumbing for retrofit (Please rate with percent of ease (e.g., 0%-very difficult, 50%-relatively easy, 100 percent easy).)	Access to tubing would necessitate opening the fuel tanks
Access & available space for additional distribution plumbing or nozzle modification (Please rate with percent of ease (e.g., 0%-very difficult, 50%-relatively easy, 100 percent easy).)	Access to tubing would necessitate opening the fuel tanks
How tight is the bottle space?	n.a.
Is the plumbing readily accessible for replacement?	n.a.
Is the plumbing readily accessible for adding another distribution part?	n.a.
Is the plumbing readily accessible for changing the pipe end?	n.a.
Extinguisher Bottle Growth Potential	100%
OTHER	n.a.
Suppression success fraction	n.a.
Extinguisher system manufacturer	Walter Kidde
Evidence of halon distribution characteristics (from certification tests)	9 percent by volume
Range of expected operating temperatures for the bottle and the plumbing (°C (°F))	-54 to 71 (-65 to 160)

n.a. – not available

3.4.2.6.2 System Schematic

Figure 14 through Figure 16 illustrate the halon inerting system with the major system components identified along with a general depiction of the associated plumbing, electrical wiring and switches [24].

3.4.2.6.3 Sequence of Events

Halon inerting systems are activated prior to entering combat. The halon inerting, or fuel tank explosion suppression, system is controlled by the TANK INERTING switch on the cockpit fuel control panel. When the TANK INERTING switch is placed to TANK INERTING, the fuselage and internal wing tanks are placed on a reduced pressure schedule and a valve at the halon reservoir is opened. At each activation of the TANK INERTING switch, halon (if available) is released into the F1, A1, and internal wing tanks for 20 s for initial inerting. After the 20 s of initial inerting, a small amount of pure halon will continue to flow into the wings. Thereafter, a continuous metered flow of halon is mixed with pressurization air to maintain the inert condition. [24]

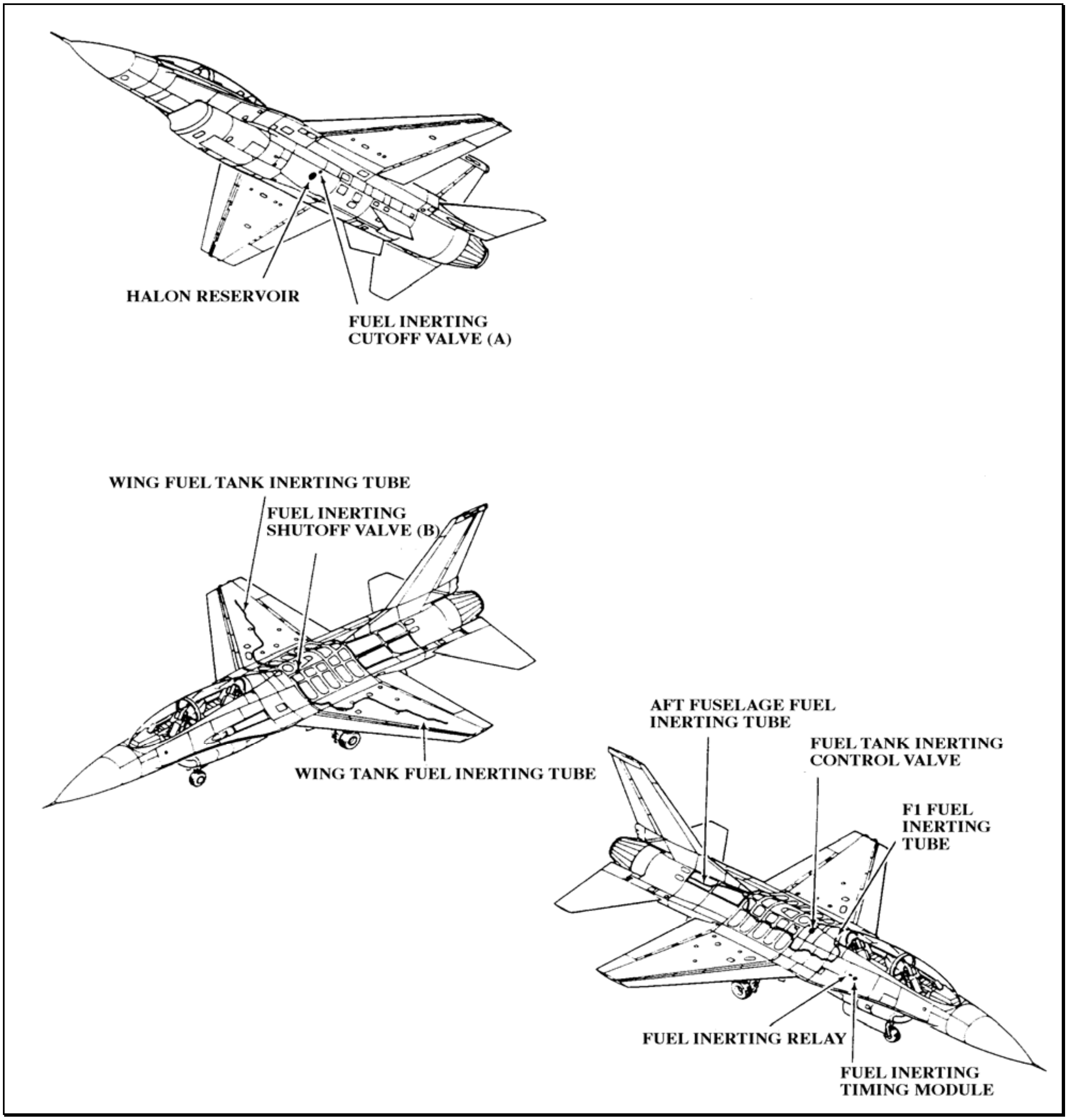

Figure 14. F-16 Fuel Inerting System Schematic.

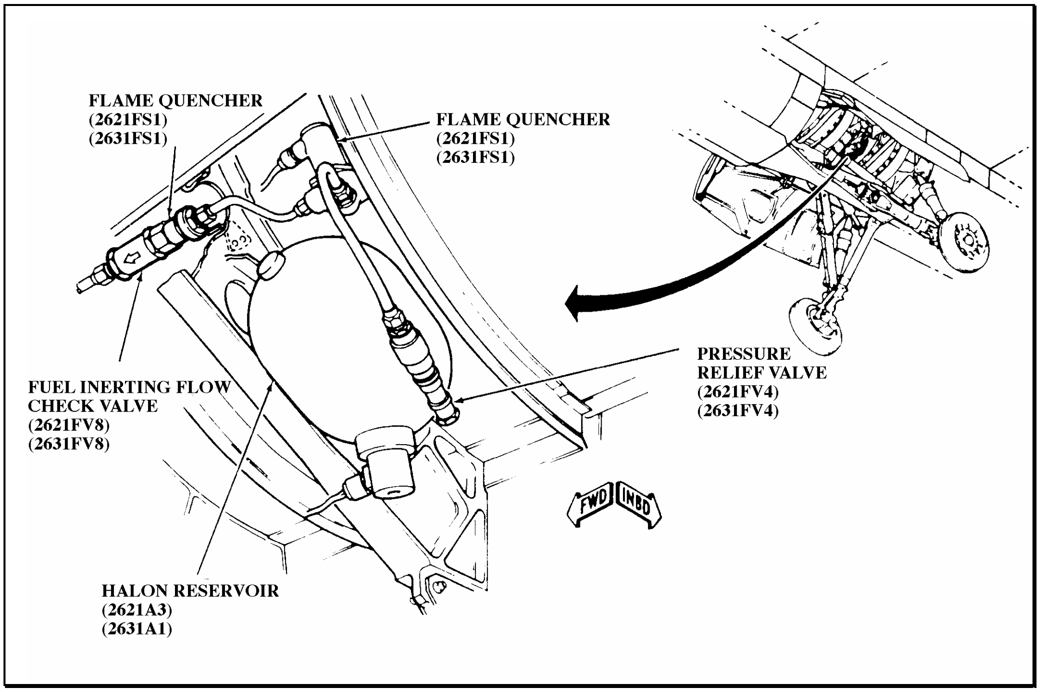

Figure 15. Fuel Inerting Equipment.

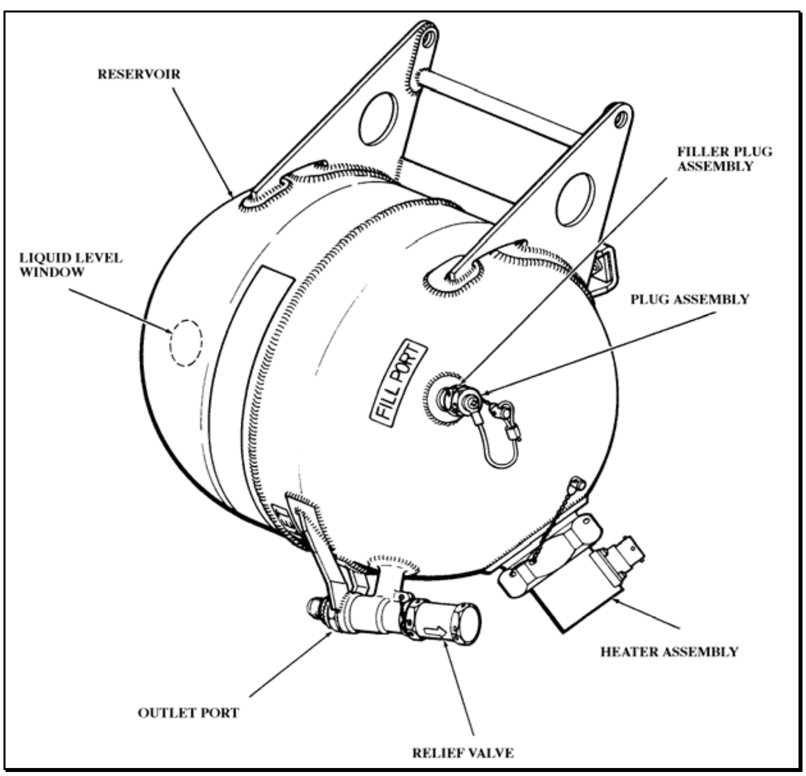

Figure 16. Halon Tank Assembly.

3.4.3 Shipboard Machinery and Storage Spaces halon 1301 System Configurations

3.4.3.1 DDG 51 (Arleigh Burke) Class: Aegis Guided Missile Destroyer

3.4.3.1.1 System Configuration Description

The DDG 51 is representative of the newer ships where halon 1301 was the suppression agent of choice during the design of the ship. The following compartments are protected by halon 1301: MMRs, AMRs, FLSRs, paint issue rooms, pump rooms, and generator room. There is enough space onboard to accommodate a two shot halon 1301 system for each MMR, AMR and generator room. Table 17 displays the breakdown of the DDG 51 (Arleigh Burke) Class: Aegis Guided Missile Destroyer halon 1301 systems including the spaces protected, number of cylinders, and number of shots. All halon 1301 shipboard systems are manually operated, both for occupied and unoccupied compartments. Detection device signal or occupied space sailor fire detection is followed by personnel assessment, evacuation, and system activation, as warranted.

Table 17. DDG 51 (Arleigh Burke) Class: Aegis Guided Missile Destroyer Halon 1301 Systems.

Spaces Protected	Cylinders	Size		Halon Quantity Per System	
		(kg)	(lb)	(kg)	(lb)
* Auxiliary Machinery Room	10	56.7	125	567	1250
* Engine Room – 1	20	56.7	125	1134	2500
* Engine Room – 2	22	56.7	125	1247	2750
* Generator Room	6	43.1	95	258.5	570
* Gas Turbine Module – 1A/B	2	43.1	95	86.2	190
* Gas Turbine Module – 2A/B	2	43.1	95	86.2	190
* Ship Service Gas Turbine Generator – 1	2	43.1	95	86.2	190
* Ship Service Gas Turbine Generator – 2	2	43.1	95	86.2	190
* Ship Service Gas Turbine Generator – 3	2	43.1	95	86.2	190
Flammable Liquid Storeroom	1	27.22	60	27.2	60
Flammable Liquid Issue Room	2	6.8	15	13.6	30
TACTAS room	2	56.7	125	113.4	250
Quantity Halon Installed On Ship				**3792**	**8,360**
On Board Spares				**288**	**635**
Total Halon On Board				**4080**	**8,995**

Notes:
1. Spaces with asterisk (*) have “two shot” systems.
2. All systems are “banked.”

Table 18 displays a description of the DDG 51 (Arleigh Burke) Class: Aegis Guided Missile Destroyer halon 1301 systems.

Table 18. DDG 51 (Arleigh Burke) Class: Aegis Guided Missile Destroyer Halon 1301 System Description.

Platform	Space	Number Of Enclosures In Compartment	Number Of Shots (halon 1301)	Location Of Agent Cylinders	
				Inside Compartment	In Adjacent Compartment
DDG 51	MMR	2 or 3	2	-	Yes
	MMR Gas Turbine Enclosures	-	2	-	Yes
	AMR	1	2	Yes	-
	AMR Enclosure	-	2	-	Yes
	Generator Room	1	1	Yes	-
	Generator Enclosure	-	2	-	Yes
	FLSRs, and other miscellaneous compartment	-	1	Yes	-

Table 19 displays the fire suppression system configuration for the DDG 51 (Arleigh Burke) Class: Aegis Guided Missile Destroyer.

Table 19. DDG 51 (Arleigh Burke) Class: Aegis Guided Missile Destroyer Fire Suppression System Configuration.

	DDG 51 (Arleigh Burke) Class: Aegis Guided Missile Destroyer					
	MMRs	**AMRs**	**FLSRs**	**Paint issue rooms**	**Pump Rooms**	**Generator Room**
GENERIC						
Number of vehicles	Current number of ships/class = 16. Number of ships in class under construction = 37. Quantity of systems/ship = 12. Amount of halon/ship = 4080 kg (8,995 lb) Quantity of 2-shot systems/ship = 9.					
Service cycle refill (years)	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Fire types (pool fires, mist…)	FLSRs and Paint issue rooms: result from burning fuel cascading over highly obstructed and fuel loaded shelves and into flaming pools MMRs, AMRs, Engine Enclosures, and Generator Rooms: result from the ignition of a pressurized fuel (diesel/hydraulic or lubricating oil) leak or ignition of fuel soaked insulating material. Leaks onto hot surfaces result in three-dimensional spray fires with cascading liquid flow on complex surfaces and into flaming pools.					
Estimated halon use/year/vehicle (kg (lb))	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
FIRE ZONE						
# of fire zones	6					
# of enclosures in the compartment	2 or 3	1	--	--	--	1
Fire Zone size (L, W, D) (cm, cm, cm (in, in, in))	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Fire zone volume (cm^3 (in^3))	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Fire zone free volume (m^3 (ft^3))	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
EXTINGUISHANT						

	DDG 51 (Arleigh Burke) Class: Aegis Guided Missile Destroyer					
	MMRs	**AMRs**	**FLSRs**	**Paint issue rooms**	**Pump Rooms**	**Generator Room**
# of halon systems	12 MMR: two shot halon system with the bottles in external manifold banks. LM2500 gas turbine enclosures have their own two shot system. AMR: two shot system, contains an engine enclosure and fuel delivery pipe. The enclosure is tight and halon protected. Enclosure protection is by a two shot system. Generator Room: It has a two shot 1301 system. Contains an engine enclosure that is protected by a 2 shot system. Other: Other spaces are typically protected by single shot systems.					
Extinguisher trigger mode	Manually activated					
Extinguisher volume (cm^3 (in^3))	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Size of extinguishant container (cm, cm, cm (in, in, in))	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Storage compartment for extinguishant bottle (cm, cm, cm (in, in, in))	Systems built in at the time of ship construction are usually banked systems, where bottles are stored as a bank with a discharge manifold feeding nozzles throughout the space.					
Free volume in storage compartment (cm^3 (in^3))	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Normal charge and pressure of extinguisher container (MPa (psi))	4.13 MPa (600 psi)					
Max extinguisher container pressure (MPa (psi))	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Extinguisher container percent filled (%)	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Extinguisher container orientation (upright with valves at bottom…)	Upright with valves at the top					
Extinguisher container weight without Halon (kg (lb))	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Halon wt (kg (lb))	See Table 21					
Extinguisher container location (inside/outside fire zone)	Outside (adjacent)	Inside	Inside	--	--	Inside
STRATEGY FOR USE						
# of shots	2	2	1	--	--	1
Manual/automatic	Manual					
Procedure for activation	All halon 1301 shipboard systems are manually operated, both for occupied and unoccupied compartments. Detection device signal or occupied space sailor fire detection is followed by personnel assessment, evacuation, and system activation, as warranted.					
Time to release halon 1301	Discharge time: 10 seconds maximum. All systems have a time delay (30 or 60 seconds) and a pre-discharge alarm to allow time for ventilation shut down and for personnel egress.					
DISTRIBUTION SYSTEM						
Extinguisher dispersion method	There is probably not significant excess capacity. Smaller systems may employ standard pipe sizes that would allow significant additional fluid to be discharged within the time specifications.					
Extinguisher discharge rate (kg/min (lb/min))	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Distribution system plumbing inner diameter (cm (in))	Plumbing sizes vary from 2.54 cm (1 in.) to over 15.24 cm (6 in.) in diameter Schedule 40 to Schedule 80 pipe depending on compartment size and bottle location. The larger systems have plumbing sized for the amount of agent to be discharged.					
Distribution system plumbing length (cm (in))	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Distribution system plumbing shape (bends, elbows)	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
# and nature of nozzles/pipe terminations	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
MODIFICATION POTENTIAL						

	DDG 51 (Arleigh Burke) Class: Aegis Guided Missile Destroyer					
	MMRs	**AMRs**	**FLSRs**	**Paint issue rooms**	**Pump Rooms**	**Generator Room**
Potential for increased number or increased size of storage bottles	MMR: The bank compartments are crowded with perhaps 10 percent additional capacity. It may be possible to add 50 percent capacity in the MMR itself via modular units. AMR: Retrofit space expansion of 100 percent may be feasible since suppression system can be down rated to a single shot. Generator Room: Some expansion space is available. Other: Several other small usage compartments exist and would need to be considered separately. These involve only one or two cylinders each.					
Restriction on alternative fluids (very/modestly/slightly)	Temperature impacts concentration designs as delivered concentration depends on compartment temperature. Temperature, however, also impacts agent storage. For example, one consideration in selecting HFC-227ea over HFC-23 was that while the same or less weight of HFC-23 was required, its higher vapor pressure at elevated temperatures necessitated employing reduced cylinder fill densities. More cylinders would have been needed at significant increases in system space and weight.					
Access of current distribution plumbing for retrofit (Please rate with percent of ease (e.g., 20 percent of the plumbing is difficult to access, 80 percent of the plumbing is easy to access.))	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Access & available space for additional distribution plumbing or nozzle modification (Please rate with percent of ease (e.g., 20 percent of the plumbing is difficult to access, 80 percent of the plumbing is easy to access.))	The DDG 51 is representative of the newer ships where halon 1301 was the suppression agent of choice during the design of the ship. Therefore, there is enough space onboard to accommodate a two shot halon 1301 system for each MMR, AMR and Generator Room.					
How tight is the bottle space?	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Is the plumbing readily accessible for replacement?	Piping is generally accessible.					
Is the plumbing readily accessible for adding another distribution part?	Additional nozzles could likely be added or nozzles changed particularly with a supplemental modular discharge system.					
Is the plumbing readily accessible for changing the pipe end?	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Extinguisher Growth Potential	MMR: perhaps 10 percent additional capacity or 50 percent capacity via modular units. AMR: expansion of 100 percent may be feasible. Generator Room: Some expansion space is available. Other: Several other small usage compartments exist and would need to be considered separately.					
OTHER						
Suppression success fraction	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Extinguisher system manufacturer	Either Kidde or Ansul.					
Evidence of halon distribution characteristics (from certification tests)—design concentration required for extinguishment	Agent design concentration envelope: 5 percent at 10 °C (50 °F) to 7 percent at 66 °C (150 °F). Acceptance testing: in order for a system to be accepted, during ship commissioning, the average halon 1301 concentration in the compartment must be between 5 percent and 7 percent by volume. The minimum measured value must be above 4 percent. Agent measurements are taken at five to twelve locations depending on compartment type (MMR, AMR, generator room or other).					
Range of expected operating temperatures for the bottle and the plumbing (°C (°F))	The Navy shipboard operating temperature range for total flooding fire protection systems is 10 °C (50 °F) to 66 °C (150 °F). This temperature range covers both the compartments to be protected and the storage of the agent.					

n.a. – not available

3.4.3.1.2 System Schematic

Figure 17 displays the fire suppression system configuration for the DDG 51 (Arleigh Burke) Class: Aegis Guided Missile Destroyer.

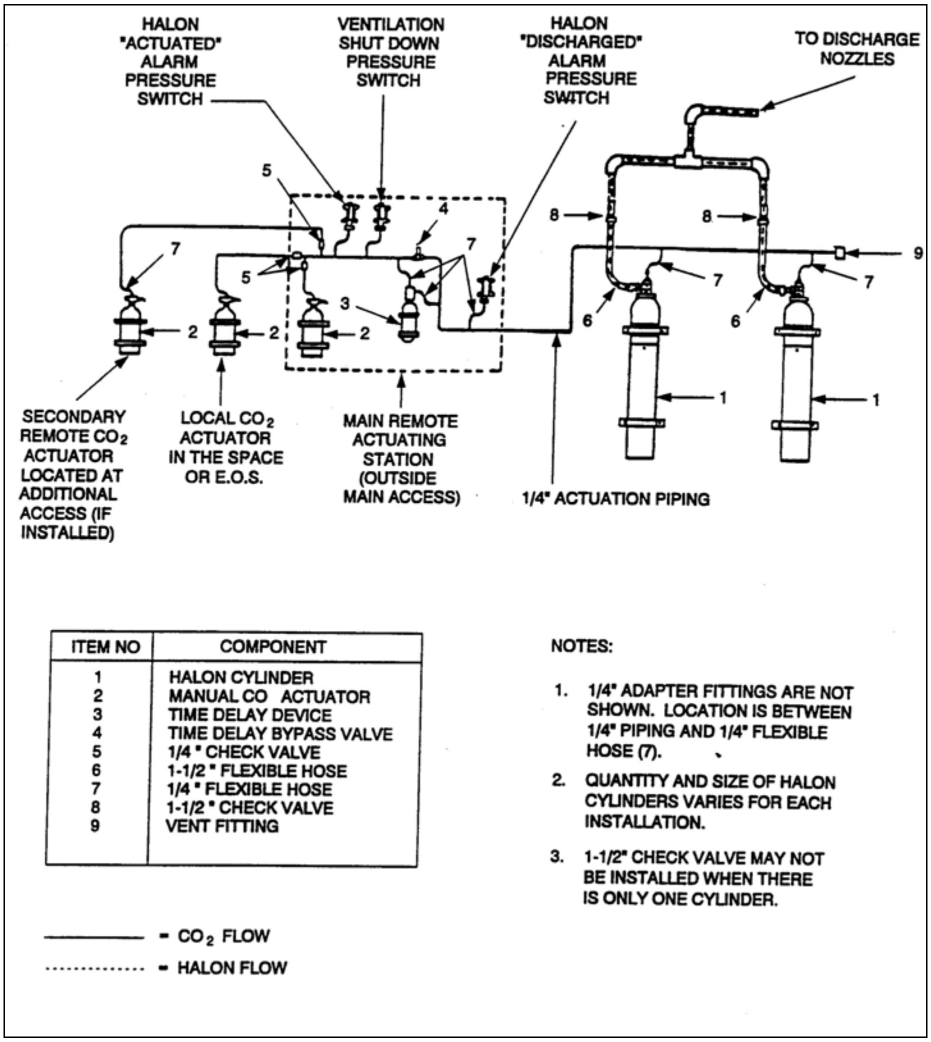

Figure 17. DDG 51 (Arleigh Burke) Class: Aegis Guided Missile Destroyer Fire Extinguishing System Schematic

3.4.3.1.3 Sequence of Events

Time from fire initiation to agent discharge can vary considerably between occupied and unoccupied spaces. All activations are manual and occur after inspection and usually attempts at suppression with water, etc. are made. For occupied spaces, system activation may occur, if warranted, after situation assessment and compartment evacuation. This time interval can be as short as 30 seconds to one minute. For unoccupied spaces, the Damage Control Central will respond to a detector alarm, by sending a dispatcher to investigate the cause of the alarm. The elapsed time from the detector alarm initiation to discharge system activation will be a function of other ongoing activities in Damage Control Central, the availability of a dispatcher, and the proximity of the compartment to be investigated. The shortest times from detector response to suppression system activation are estimated at one and a half to two minutes. Table 20 provides a listing of the sequence of events.

Table 20. System Activation/Sequence of Events.

<table>
<tr><th rowspan="2">Event</th><th colspan="2">Event Initiation and/ or Duration (min:sec)</th></tr>
<tr><th>Unmanned Compartment</th><th>Manned Compartment</th></tr>
<tr><td colspan="3">Dampers are normally open/ fans are normally on</td></tr>
<tr><td>Fire ignition</td><td colspan="2">Variable (prolonged ignition will yield a larger fire, initially)</td></tr>
<tr><td>“Detection”</td><td>High temperature and/or rate of rise detectors</td><td>Manned</td></tr>
<tr><td>Situation Assessment fire</td><td>Damage Control Central responds to detector signal by sending dispatcher to identify threat</td><td>On site personnel</td></tr>
<tr><td>Egress</td><td>-</td><td>0:30-1:00</td></tr>
<tr><td colspan="3">System Activation</td></tr>
<tr><td>Secure fan motors and close dampers (if present)</td><td colspan="2">0:30 - 1:00 (interlocked fan motors and dampers)
<u>Ventilation and Compartment leakage</u> – Compartments protected by 1301 are equipped with ventilation interlocks. In the event of system activation, the ventilation fans are automatically turned off and ventilation dampers, when installed, are automatically shut.</td></tr>
<tr><td colspan="3">Discharge Agent</td></tr>
</table>

3.4.3.2 LHD 1 (WASP) / LHA 1 (TARAWA) Class: Amphibious Helo/Landing Craft Carriers

3.4.3.2.1 System Configuration Description

The LHDs can be separated into LHD-1 through LHD-4, and LHD-5. While LHD-5 compartments are likely to have dampers in the ventilation ducts, the other ships probably do not. Table 21 and Table 22 display the breakdown of the LHA – 4 USS Nassau and the LHD – 3 USS Kearsarge halon 1301 systems including the spaces protected, number of cylinders, and number of shots. All halon 1301 shipboard systems are manually operated, both for occupied and unoccupied compartments. Detection device signal or occupied space sailor fire detection is followed by personnel assessment, evacuation, and system activation, as warranted.

Table 21. LHA – 4 USS Nassau Halon 1301 Systems.

Space	Cylinders	Size		Halon Quantity Per System	
		(kg)	(lb)	(kg)	(lb)
Main Machinery Room #1	19	56.7	125	1077	2375
Main Machinery Room #2	23	56.7	125	1304	2875
Auxiliary Machinery Room	8	56.7	125	453.6	1000
Emergency Diesel Generator Room #1	5	56.7	125	283.5	625
Emergency Diesel Generator Room #2	3	56.7	125	170.1	375
JP-5 Pump Room #1	2	56.7	125	113.4	250
JP-5 Pump Room#2	1	56.7	125	56.7	125
Fuel Pump Room	4	56.7	125	226.8	500
Quantity halon installed on ship				**3685**	**8,125**
On board spares				**1474**	**3,250**
Total halon on board				**5160**	**11,375**

1. All systems are “single shot”.
2. All systems are “modular”.
3. This arrangements (single shot, modular) is typical of ships that received Halon via backfit.

Table 22. LHD – 3 USS Kearsarge Halon 1301 Systems.

Space	Cylinders	Size		Halon Quantity Per System	
		(kg)	(lb)	(kg)	(lb)
Main Machinery Room #1	38	56.7	125	2155	4750
Main Machinery Room #2	46	56.7	125	2608	5750
Auxiliary Machinery Room	20	56.7	125	1134	2500
Emergency Diesel Generator Room #1	5	56.7	125	283.5	625
Emergency Diesel Generator Room #2	3	56.7	125	170.1	375
JP-5 Pump Room #1	4	56.7	125	226.8	500
JP-5 Pump Room#2	3	27.2	60	81.7	180
LCAC Pump Room	3	27.2	60	81.7	180
Paint Mix And Issue Room	1	43.1	95	43.1	95
Cargo Flammable Liquid Room	6	56.7	125	340.2	750
Aviation Flammable Storeroom	2	43.1	95	86.2	190
Supply Department Flammable Liquid Storeroom	4	27.2	60	108.9	240
Ship Store Flammable Liquid Storeroom	2	4.5	10	9.1	20
Aviation Flammable Liquid Issue Room	1	6.8	15	6.8	15
Quantity halon installed on ship				7335	16,170
On board spares				929.9	2,050
Total halon on board				8264	18,220

1. Spaces with asterisk (*) have "two shot" systems.
2. All systems are "banked."

Table 23 displays a description of the LHD 1-4, LHD 5-7, and LHA halon 1301 systems.

Table 23. LHD 1-4, LHD 5-7, and LHA halon 1301 halon 1301 System Description.

Platform	Space	Number Of Enclosures In Compartment	Number Of Shots (halon 1301)	Location Of Agent Cylinders	
				Inside Compartment	In Adjacent Compartment
LHD 1-4	MMR	-	2	Yes	-
	AMR	-	2	Yes	-
	Emergency Generator Room	-	1	Yes	-
	Pump Room	-	1	Yes	-
	FLSRs, and other miscellaneous compartment	-	1	Yes	-
LHD 5-7	MMR	-	2	-	Yes
	AMR	-	1	Yes	-
	Emergency Generator Room	-	1	Yes	-
	FLSRs, and other miscellaneous compartment	-	1	Yes	-
LHA	MMR	-	1	Yes	-
	AMR	-	1	Yes	-
	Emergency Generator Room	-	1	Yes	-
	Pump Room	-	1	Yes	-
	FLSR (CO_2)	-	1	Yes	-

Table 24 displays the fire suppression system configuration for the LHD 1 (WASP) / LHA 1 (TARAWA) Class: Amphibious Helo/Landing Craft Carriers.

Table 24. LHD 1 (WASP) / LHA 1 (TARAWA) Class: Amphibious Helo/Landing Craft Carriers Fire Suppression System Configuration.

	LHD 1 (WASP) / LHA 1 (TARAWA) Class: Amphibious Helo/Landing Craft Carriers					
	MMR	**AMR**	**FLSR**	**Paint issue Rooms**	**Pump Rooms**	**Generator Room**
GENERIC						
Number of vehicles	Current number of ships/class: LHA (5); LHD (4). Number of ships in class under construction: LHA (0); LHD (3). Quantity of systems/ship: LHA (8); LHD (14). Amount of halon/ship: LHA (5160 kg (11,375 lb)); LHD (8314 kg (18,330 lb)). Quantity of 2-shot systems/ship: LHD (3). LHA is a modular system. LHD is a banked system.					
Service cycle refill (years)	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Fire types (pool fires, mist…)	FLSRs and Paint issue rooms: result from burning fuel cascading over highly obstructed and fuel loaded shelves and into flaming pools MMRs, AMRs, Engine Enclosures, and Generator Rooms: result from the ignition of a pressurized fuel (diesel/hydraulic or lubricating oil) leak or ignition of fuel soaked insulating material. Leaks onto hot surfaces result in three-dimensional spray fires with cascading liquid flow on complex surfaces and into flaming pools.					
Estimated halon use/year/vehicle (kg (lb))	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
FIRE ZONE						
# of fire zones	6					
Fire Zone size (L, W, D) (cm, cm, cm (in, in, in))	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Fire zone volume (cm^3 (in^3))	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Fire zone free volume (m^3 (ft^3))	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
EXTINGUISHANT						
# of halon systems	LHA-1 (8); LHD-1 (14)					
Extinguisher trigger mode	Manually activated.					
Extinguisher volume (cm^3 (in^3))	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Size of extinguishant container (cm, cm, cm (in, in, in))	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Storage compartment for extinguishant bottle (cm, cm, cm (in, in, in))	Systems built in at the time of ship construction are usually banked systems, where bottles are stored as a bank with a discharge manifold feeding nozzles throughout the space. LHA is a modular system. LHD is a banked system.					
Free volume in storage compartment (cm^3 (in^3))	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Normal charge and pressure of extinguisher container (MPa (psi))	4.13 MPa (600 psi)					
Max extinguisher container pressure (MPa (psi))	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Extinguisher container percent filled (%)	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Extinguisher container orientation (upright with valves at bottom…)	Upright with valves at the top.					
Extinguisher container weight without Halon (kg (lb))	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Halon wt (kg (lb))	See Tables 32 and 33.					

	LHD 1 (WASP) / LHA 1 (TARAWA) Class: Amphibious Helo/Landing Craft Carriers					
	MMR	**AMR**	**FLSR**	**Paint issue Rooms**	**Pump Rooms**	**Generator Room**
Extinguisher container location (inside/outside fire zone)	Outside (adjacent)	Inside	Inside	--	--	Inside
STRATEGY FOR USE	<u>MMR</u>: LHD 1 to LHD 4 have the halon cylinders in the MMR. LHD 5 has halon stored in dedicated compartments external to the MMR. Additional space in the MMR should be available onboard LHD 5-7. <u>AMR</u>: Early LHDs have two shot that were later down rated as requiring only single shot systems. LHD 1 - 4 have two shot halon systems. LHD 5-7 have a single shot system. The halon cylinders for all LHDs are stored inside the AMRs. LHAs have single shot systems with bottles inside the compartments. <u>Emergency Generator Room</u>: LHDs and LHAs have a single shot. The agent is stored inside the compartment. <u>Other</u>: Other spaces are typically protected by single shot systems.					
# of shots	LHD 1-4: MMR-2, AMR-2, Emergency Generator Room-1, Pump Room-1, FLSR-1 LHD 5-7: MMR-2, AMR-1, Emergency Generator Room-1, FLSR-1 LHA: MMR-1, AMR-1, Emergency Generator Room-1, Pump Room-1, FLSR (CO_2)-1					
Manual/automatic	Manual					
Procedure for activation	All halon 1301 shipboard systems are manually operated, both for occupied and unoccupied compartments. Detection device signal or occupied space sailor fire detection is followed by personnel assessment, evacuation, and system activation, as warranted.					
Time release halon 1301	Discharge time: 10 seconds maximum. All systems have a time delay (30 or 60 seconds) and a pre-discharge alarm to allow time for ventilation shut down and for personnel egress.					
DISTRIBUTION SYSTEM						
Extinguisher dispersion method	Banked system – a discharge manifold feeds nozzles throughout the space. Modular system – cylinders are distributed throughout the space and centrally tripped by a pneumatic activation loop.					
Extinguisher discharge rate (kg/min (lb/min))	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Distribution system plumbing Inner diameter (cm (in))	Plumbing sizes vary from 2.54 cm (1 in.) to over 15.24 cm (6 in.) diameter Schedule 40 to Schedule 80 pipe depending on compartment size and bottle location. The larger systems have plumbing sized for the amount of agent to be discharged.					
Distribution system plumbing Length (cm (in))	Refer to Figure 18.					
Distribution system plumbing Shape (bends, elbows)						
# and nature of nozzles/pipe terminations						
MODIFICATION POTENTIAL						
Potential for increased number or increased size of storage bottles	MMR: LHD 1 - 4 will be the most difficult to retrofit because they have two shot systems in the MMRs hence there is little additional space for more agent. LHD 5 - 7 have the agent stored outside the MMRs, therefore there will available for a modular agent system in side the MMR where the agent used to previously be located (LHD 1 - 4). LHAs will also be difficult to retrofit because they contain the 1 shot suppression system in the MMRs. AMR: There is at least 100 percent space availability. Only a 1 shot protection is required. For LHD 1- 4 the second shot can be eliminated. Generator Room: For all LHDs and LHAs limited space may be available. Several other small usage compartments exist and would need to be considered separately. These involve only one or two cylinders each.					
Restriction on alternative fluids (very/modestly/slightly)	Temperature impacts concentration designs as delivered concentration depends on compartment temperature. Temperature, however, also impacts agent storage. For example, one consideration in selecting HFC-227ea over HFC-23 was that while the same or less weight of HFC-23 was required, its higher vapor pressure at elevated temperatures necessitated employing reduced cylinder fill densities. More cylinders would have been needed at significant increases in system space and weight.					

	LHD 1 (WASP) / LHA 1 (TARAWA) Class: Amphibious Helo/Landing Craft Carriers					
	MMR	**AMR**	**FLSR**	**Paint issue Rooms**	**Pump Rooms**	**Generator Room**
Access of current distribution plumbing for retrofit (Please rate with percent of ease (e.g., 20 percent of the plumbing is difficult to access, 80 percent of the plumbing is easy to access.))	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Access & available space for additional distribution plumbing or nozzle modification (Please rate with percent of ease (e.g., 20 percent of the plumbing is difficult to access, 80 percent of the plumbing is easy to access.))	There is probably not significant excess capacity. Smaller systems may employ standard pipe sizes that would allow significant additional fluid to be discharged within the time specifications.					
How tight is the bottle space?	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Is the plumbing readily accessible for replacement?	Piping is generally accessible.					
Is the plumbing readily accessible for adding another distribution part?	Additional nozzles could likely be added or nozzles changed particularly with a supplemental modular discharge system.					
Is the plumbing readily accessible for changing the pipe end?	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Extinguisher Growth Potential	LHD 1 - 4 MMRs – limited potential. LHD 5 - 7 MMRs have potential due to modular units. LHA MMRs – very difficult. AMR: 100 percent. Generator Room – limited space may be available. Several other small usage compartments exist and would need to be considered separately.					
OTHER						
Suppression success fraction	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Extinguisher system manufacturer	Either Kidde or Ansul.					
Evidence of halon distribution characteristics (from certification tests)—design concentration required for extinguishment	Acceptance testing: in order for a system to be accepted, during ship commissioning, the average halon 1301 concentration in the compartment must be between 5 percent and 7 percent by volume. The minimum measured value must be above 4 percent. Agent measurements are taken at five to twelve locations depending on compartment type (MMR, AMR, generator room or other).					
Range of expected operating temperatures for the bottle and the plumbing (°C (°F))	The Navy shipboard operating temperature range for total flooding fire protection systems is 10 °C (50 °F) to 66 °C (150 °F). This temperature range covers both the compartments to be protected and the storage of the agent.					

n.a. – not available

3.4.3.2.2 System Schematic

Figure 18 displays the fire suppression system configuration for the LHD 1 (WASP)/LHA 1 (Tarawa) Class: Amphibious Helo/Landing Craft Carriers.

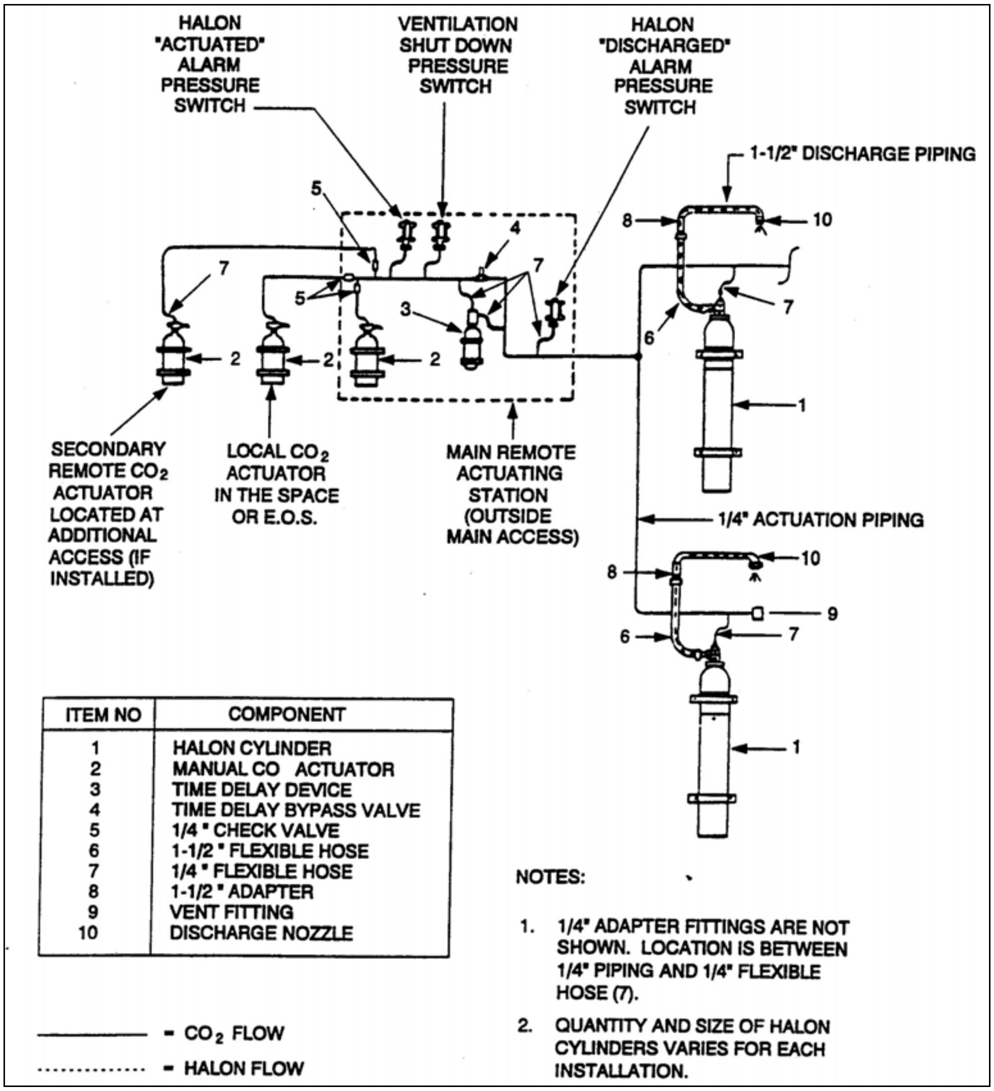

Figure 18. . LHD 1 (WASP) / LHA 1 (TARAWA) Class: Amphibious Helo/Landing Craft Carriers Fire Extinguishing System Schematic.

3.4.3.2.3 Sequence of Events

Time from fire initiation to agent discharge can vary considerably between occupied and unoccupied spaces. All activations are manual and occur after inspection and usually attempts at suppression with water, etc. are made. For occupied spaces, system activation may occur, if warranted, after situation assessment and compartment evacuation. This time interval can be as short as 30 seconds to one minute. For unoccupied spaces, the Damage Control Central will respond to a detector alarm, by sending a dispatcher to investigate the cause of the alarm. The elapsed time from the detector alarm initiation to discharge system activation will be a function of other ongoing activities in Damage Control Central, the availability of a dispatcher, and the proximity of the compartment to be investigated. The shortest times from detector response to suppression system activation are estimated at one and a half to two minutes. Table 25 provides a listing of the sequence of events.

Table 25. System Activation/ Sequence of Events.

Event	**Event Initiation and/ or Duration (min:sec)**	
	Unmanned Compartment	*Manned Compartment*
Dampers are normally open/ fans are normally on		
Fire ignition	Variable (prolonged ignition will yield a larger fire, initially)	
"Detection"	High temperature and/or rate of rise detectors	Manned
Situation Assessment fire	Damage Control Central responds to detector signal by sending dispatcher to identify threat	On site personnel
Egress	-	0:30-1:00
System Activation		
Secure fan motors and close dampers (if present)	0:30 - 1:00 (interlocked fan motors and dampers) Ventilation and Compartment leakage – Compartments protected by 1301 are equipped with ventilation interlocks. In the event of system activation, the ventilation fans are automatically turned off and ventilation dampers, when installed, are automatically shut.	
Discharge Agent		

4.0 Technical Problems

The technical problems associated with this effort related to data (combat, safety, and system configuration) acquisition. In characterizing the severity of fires addressed by these systems, it was necessary to consult the various combat databases. Unfortunately, combat data are not releasable. Also consulted were the safety centers of the various Services. However, sometimes safety center data may be incomplete and/or subjective. Numerous efforts were made to obtain complete system configuration data. Although substantial data were obtained, still data holes exist.

5.0 Recommendations

Since the system configuration data are incomplete, it is recommended that this report be updated as future data are located.

6.0 Conclusions

The goal of the Next Generation Fire Suppression Technology Program (NGP) is to develop and demonstrate retrofitable, economically feasible, environmentally-acceptable, and user-safe processes, techniques, and fluids that meet the operational requirements currently satisfied by halon 1301 systems in aircraft, ships, land combat vehicles, and critical mission support facilities. The results will be specifically applicable to fielded weapon systems, and will provide dual-use fire suppression technologies for preserving both life and operational assets.

Previous research, development, testing and evaluation have led to the identification of ways to provide halon-equivalent fire protection for some platforms. The remaining applications are fire suppression in:

- Crew compartments of ground vehicles,
- Dry bays in aircraft,
- Engine nacelles in aircraft,
- Storage compartments in aircraft and ships, and
- Machinery spaces in ships.

In addition, halon 1301 is used to inert the ullage in some aircraft fuel tanks.

There are a large number of platforms that have halon 1301 fire suppression systems. Obtaining information on all of these would be difficult, costly, and unnecessary. Therefore, the Military Services identified a small subset of these platforms whose halon systems are representative of the range of fire suppression needs:

- Ground vehicles: M992 (FAASV), M1 tank, and M2/M3 (BFSV)
- Aircraft: C-130, F/A-18 C/D, C-17, H-60, CH-47, F-16
- Ships: DDG 51, LHD 1/LHA 1, LCAC

This project accomplished the following:

- Characterized and tabulated the nature, frequency, consequences (including personnel injuries), and severity of fires previously and currently attacked using halon 1301.
- Derived a small set of representative (model) fires (using the analyses described above) for other elements in the Program.
- Compiled characteristics and limitations of the systems that new fire suppression technologies will replace or into which they will be retrofitted. The descriptions of the environments of the current systems compiled during this program will serve as boundary conditions for the new technologies to be developed in subsequent Elements of the NGP.

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