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POWDER PACKS— A PASSIVE APPROACH TO EXTINGUISHING FIRE IN COMBAT VEHICLES

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Thin (12.7 and 6.4 mm) panels of fire-extinguishing powder in a honeycomb matrix were tested for their ability to extinguish fires in the FAASV ammunition resupply vehicle. These "powder packs" were applied to the exterior of hydraulic fluid reservoirs and fuel cells for protection from hydrocarbon fires caused by shaped-charge jets penetrating the fluid containers.

It was found that a surround of 12.7-mm-thick panels was required to achieve a sub 250-ms fire-out time with no second-degree burns expected to personnel with hot hydraulic fluid reservoirs. Powder packs as thin as 6.4 mm provided the same protection in the case of hot diesel fuel.

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PREFACE

Although tests have shown that Halon 1301 systems are effective in extinguishing weapon-induced fuel fires in combat vehicles, other approaches to solving the fuel-fire problem are still feasible. The use of "powder packs," thin containers of fire-extinguishing powder attached to the exterior walls of fuel cells, may be indicated when the cost of a halon system is too high. This can be applied in the retrofitting of older vehicles, which are approaching the end of their useful combat lives, but could still benefit from some type of automatic fire-suppression system.

The growing amount of evidence that chloro-fluoro and halon compounds are attacking the Earth's ozone layer may eventually make it difficult to justify using Halon 1301 in our combat vehicles. The U.S. Army should have an alternative method of extinguishing fires in our combat vehicles.

The low cost and the simplicity of powder packs make them attractive both as a field expedient approach and as an original equipment approach to providing fire protection to combat vehicles.

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1. INTRODUCTION

1.1 Background. The U.S. Army is pursuing a policy of equipping new combat vehicles with active fire-protection systems, namely Halon 1301 systems. These systems are specified for combat vehicles because of their ability to extinguish the "mist-fireball explosion" ("SAFE System" 1982). The mist-fireball explosion is encountered when a shaped-charge jet passes through vehicle armor, then through the fuel cell, causing a mist of fuel to form in the open volume of the vehicle. This mist is virtually always ignited by the hot metallic spall, which forms when the jet erodes the vehicle armor or any other metallic structure it penetrates. The rapid flame spread through the fuel mist is accompanied by a significant pressure pulse. The high temperature of the flame and the high pressure can cause serious injuries to personnel inside the vehicle.

Tests (Barger 1969; Hayes 1969; Romanelli 1972) have shown that a properly functioning Halon 1301 automatic fire suppression system can completely extinguish the mist-fireball explosion in 250 ms or less. There is evidence that this rapid quenching of fire will prevent burn injuries to crew members (Romanelli 1972). An automatic fire suppression system is especially important in vehicles that carry fuel cells in the crew compartments (such as the M1, M1A1, M2, M3 and M113 vehicles.) A Halon 1301 system is also capable of extinguishing fires due to burning hydraulic-fluid mists. Vehicles such as the M1, M1A1, M60 and FAASV, which have hydraulic systems in the crew compartments, can benefit from crew compartment automatic fire suppression systems. The M113 and the M60 vehicles are not equipped with automatic fire suppression systems.

It is important that a fuel fire in the crew compartment be suppressed very quickly. Halon 1301 systems are capable of doing this. The very high fire-extinguishing efficiency of Halon 1301 is due largely to its ability to enter directly into the chemistry of the hydrocarbon combustion reactions. Hydrogen atoms are removed from the reaction zone by the action of the halon (Finnerty 1976). Since hydrogen atoms are of paramount importance in the combustion mechanism, their removal effectively destroys the flame zone and stops combustion.

There is a negative side to the use of Halon 1301. Chemical quenching of the fire involves reactions that form toxic products, such as hydrogen fluoride (HF) and hydrogen bromide (HBr) (Porter, Schmidt, and Bishop 1985; Weeks, Mellick, and Steinberg 1972). There is even a suspicion that bromine (Br_2) may be formed (Richards 1976). The amounts of toxic gases formed will be influenced by the size of the fireball, the speed of extinguishment, and the thoroughness of mixing the agent with the air in the crew compartment. The acids (HF and HBr) act as nuclei for condensation of water vapor, causing a fog to form inside the compartment. This fog can cause a total loss of visibility inside the vehicle (Porter, Schmidt, and Bishop 1985). The level of irritation caused by the acids is expected to be very high for personnel. The spill, which may involve many gallons of hot fuel, will only add to the general distress inside the vehicle. The current Army recommendation is that after a fire has been extinguished by Halon 1301, personnel don protective breathing devices or exit the vehicle (Ripple and Mundie 1989).

There are fires, such as ammunition fires, which are not extinguished by Halon 1301 (Finnerty 1982). The high flame temperature associated with these fires may cause excessive amounts of toxic products to form if Halon 1301 is discharged into an ammunition fire (Polyanski 1989a). Unfortunately, the detectors used with the current fire-suppression systems respond to ammunition fires as well as to hydrocarbon fires. Therefore, the Halon 1301 will be discharged into an ammunition fire in the crew compartment of a vehicle (Polyanski 1989a).

1.2 Advantages and Disadvantages of Passive Approaches. There are several advantages in the utilization of passive fire-protection approaches in combat vehicles. Among these are:

- Passive devices are less likely to be compromised by lack of maintenance.

- Failure of the vehicle's electrical system will not render passive devices inoperative.

- Passive devices can be initiated by a penetrator or by spall even before a fuel mist is formed.

- There are no sensors or electrical wires to be cut by a main penetrator or by spall.

- The possibility of the accidental initiation of a device (false alarm) is minor with passive fire-extinguishing approaches.

- Passive approaches involve inherent components of the vehicles. There are no electrical switches to accidentally, or deliberately, turn to the off position.

- There are efficient, nonhalon materials available to use in passive fire-extinguishing devices. Some of the more efficient of these have such low toxicity that they are actually unregulated food additives (potassium bicarbonate is such a material.)

There are also disadvantages in the reliance on passive fire-prevention devices. Among these are:

- Passive devices do not normally respond to accidental fires, such as those that are produced by an accidental fuel leak. A manual extinguisher must also be employed to extinguish accidental fires.

- If the passive devices do not function adequately to prevent fire, it will be necessary to rely on personnel to utilize manual fire extinguishers to fight what may be a large fire.

- There may be difficulty in gaining acceptance of what is essentially a low-technology approach. Many people have been conditioned to believe that only high-technology solutions to problems are desirable.

- The ruggedness of powder packs has not been demonstrated. In order to be useful, they must survive normal wear and tear inside a combat vehicle. This ranges from being leaned against by a soldier to being struck by a rifle butt.

- The long term stability of the powder packs has not been tested. Any water absorption or compacting of the powder would be cause for concern.

BRL-CSTA (Ballistic Research Laboratory-Combat Systems Test Activity) tests were performed on the FAASV to establish conditions under which passive automatic fire-extinguishing devices can extinguish weapon-induced fires in the required timeframe (250 ms). The passive devices consisted of thin containers of fire-extinguishing powder that were arranged so as to surround the exterior of the hydraulic reservoir or to protect the crew compartment side of the fuel cell. Potassium bicarbonate powder was chosen over sodium bicarbonate due to the higher, flame-quenching efficiency of the potassium salt (Nehl 1953). Both materials are considered to be nontoxic (Richards 1976). Both are used as food additives. The only obvious problem areas are those associated with high concentrations of nuisance dusts (coughing, eyes smarting, and visibility loss.) We have found no reports of long-term ill effects from potassium bicarbonate fire-extinguishing powder, even though the U.S. Navy and the U.S. Coast Guard have been using Purple K (potassium bicarbonate) powder fire extinguishers since the 1950s. Available toxicity data is given in Appendix A.

2. MATERIALS AND METHODS

2.1 Powder Packs. The powder packs used in these tests were fabricated at the Ballistic Research Laboratory (BRL). Two thicknesses of containers were tested. Two of the tests involved powder packs that were 12.7 mm thick, and the other two tests used powder packs 6.4 mm thick.

The powder packs were made by placing the appropriate length, width, and thickness of aluminum honeycomb onto a sheet of aluminum foil that was 0.08 mm thick. The honeycomb was glued to the foil using a thin layer of silicone adhesive. After the adhesive had set, the voids in the honeycomb (95% of the total volume) were filled with fire-extinguishing powder. Purple K (potassium bicarbonate) was used in all tests. Aluminum foil was then folded over the top and sides of the honeycomb. Tape was used to seal the foil in place. The completed powder packs were then ready to be glued and/or taped onto the hydraulic fluid reservoirs or to the crew side of the bulkhead, which separates the fuel cell from the crew compartment of the FAASV.* A pictorial of the fabrication of a powder pack is given in Figure 1.

2.2 Setup. The shaped-charge attacks on the FAASV were conducted by the Combat Systems Test Activity (CSTA) at Aberdeen Proving Ground. For the fuel tests, the powder packs were installed on the bulkhead next to the fuel cell. The powder packs were on the crew side of the bulkhead because the powder was intended to protect the crew compartment from the fuel fires which occur when shaped-charge jets cause fuel-mist carrythroughs into the crew section of the vehicle. A photograph of a powder pack installed on the crew side of the bulkhead is given in Figure 2.

* The fuel cell of the FAASV is not actually in the crew compartment. However, there is only a 12.7-mm aluminum bulkhead separating the fuel cell from the crew compartment. A shaped-charge jet attacking the fuel cell can carry fuel mist into the crew compartment.

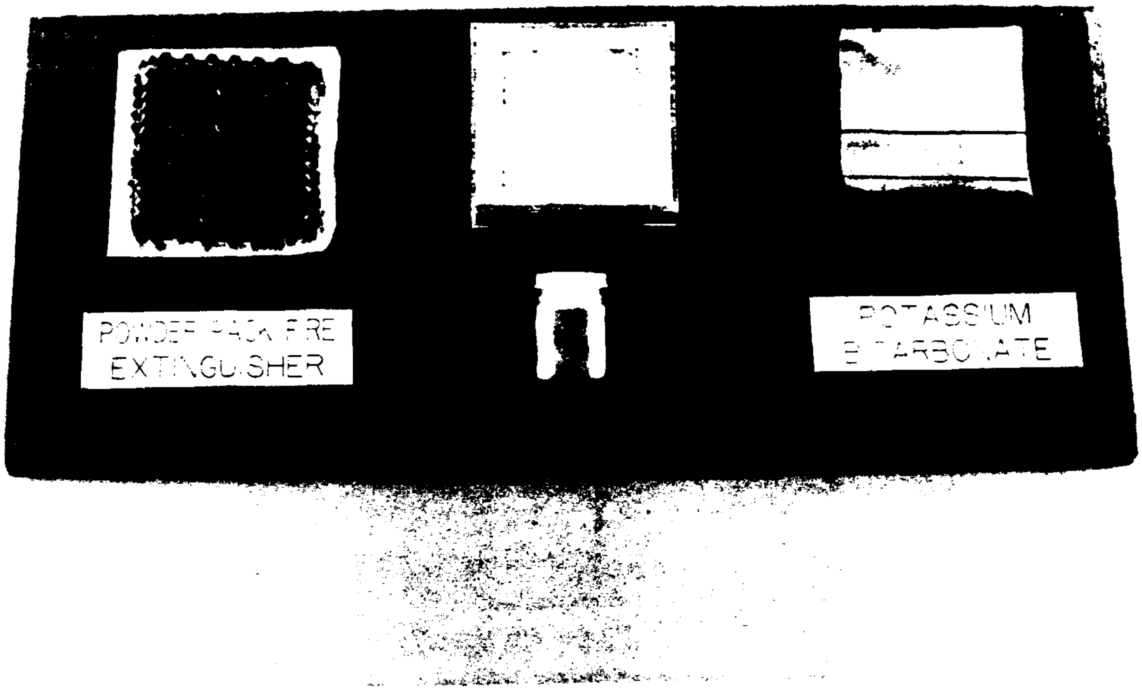

Figure 1. Fabrication of a Powder Pack.

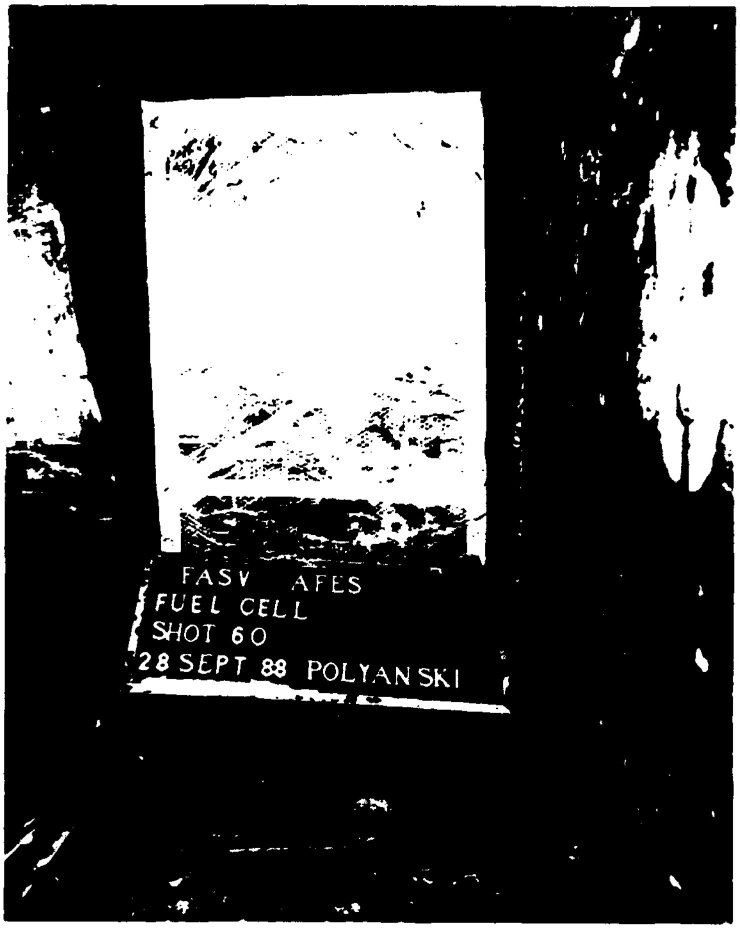

Figure 2. Powder Pack Installed on Bulkhead of FAASV.

Figure 3 shows a hydraulic reservoir bolted into place in the FAASV crew compartment. The fluid lines were not attached to the reservoirs for these tests. Figure 4 shows the reservo' after the powder packs were installed. There was a 25-mm to 50-mm air gap between the vehicle inner wall and the powder pack on the front face of the hydraulic reservoir. The shaped-charge jet entered the vehicle through that inner wall for the hydraulic fluid reservoir tests.

In all four tests the attacking weapon was a 90-mm-diameter shaped charge, identified as an M28A2 warhead. This weapon has long been used as a typically hand-held, HEAT round (Beichler 1956; Hanna and Goodman 1955; Zabel et.al. 1988). The standoff from the vehicle armor (25.4-mm aluminum) was 2 cone diameters (180 mm) in all cases.

2.3 Fluids. Diesel fuel with an average open cup flash point of 87° C was used in the fuel cell tests. The fuel cell was filled with 190 to 208 liters of fuel. The fuel temperature varied between 71° C and 82° C for the tests.

Hydraulic fluid, MIL6080, conventional 93° C flash point red fluid, was used in the hydraulic fluid reservoir tests. Approximately 49 liters of fluid at 65.5° C to 71° C were used for each test. Since the reservoir has a 7.6-cm (3-inch) air gap at the top for 49 liters of cold fluid, less air gap was present for these tests with hot fluid.

2.4 Predicting Second-Degree Burns. The U.S. Army Tank-Automotive Command (TACOM) requires that an automatic fire extinguishing system (AFES) suppress hydrocarbon type fires within 250 ms. The inherent assumption is that any fire suppressed within that timespan will not cause burn injuries to crew members of a vehicle. In an effort to put burn injuries on a more scientific foundation, Walter Reed Army Institute of Research (Ripple and Mundie 1989) recommends, as a criterion, a temperature-time integral. It is recommended that the value of air temperature over body temperature be recorded over a ten-second period using thermocouples.

$$T_{(\text{temp time integral})} = \int_0^t (T_m - 37)\,dt$$

where T is in degrees Celsius, and t is in seconds.

Figure 3. <u>Hydraulic Reservoir Installed in FAASV</u>.

Figure 4. Reservoir with Powder Packs Installed.

An integrated value of 1315° C-second over a ten second-interval is taken as the threshold of second-degree burns on exposed skin. If the integral exceeds 1315° C-second, second-degree burns are predicted for exposed skin.

In the case of skin protected by clothing, the recommendation is for the use of a ten-second temperature integral value of 3300° C-second as the threshold. If this value is exceeded, second-degree burns are likely.

Thermocouples were placed in the FAASV crew compartment at individual crew member positions at eye, waist, and calf levels, except for the left rear and right rear thermocouples.

2.5 Fire-Out Time. The optical sensors presently in the FAASV were included in the powder pack tests. The sensors have two thresholds: SF (small fire) and LF (large fire). For the SF, an alarm is normally sounded, since small fires are not considered life threatening. For the LF, any signal lasting longer than one millisecond will cause discharge of the halon bottles. The halon bottles were not present during the powder pack tests, but the LF and SF signals were recorded. The FOT (fire-out time) from the sensors is defined as the last SF signal out of any sensor minus the first LF signal out of any sensor (Polyanski 1989a).

High-speed cameras (1000 frames per second) were also used in the powder pack tests. Five cameras were positioned inside the crew compartment. The FOT from the high-speed cameras is taken as the time interval of the last frame with visible fire minus the first frame with fire. Each camera can give its own FOT. The longest FOT is taken as the FOT by high-speed cameras, since this usually represents the worst case.

The positions of the optical sensors and high-speed cameras are indicated for each powder pack test in Appendices B and C.

Video cameras were also present inside and outside the vehicle to document the events. The video rate of 30 frames per second does not provide information as precise as the fire sensors and high-speed cameras provide.

3. RESULTS

The results of the diesel-fuel tests with pertinent data are given in Table 1. Only one powder pack was used on the bulkhead for each shot. A detailed description of each test is given in Appendix B.

Both the 12.7-mm-thick and 6.4-mm-thick packs were able to give acceptable fire-out times. In both cases, large amounts of powder were seen coming out of the openings in the vehicles. This is a strong indication that there would be a serious loss of visibility in the vehicle even with a 6.4-mm-thick powder pack.

Table 2 presents the results of the shaped-charge jet firings through the hydraulic fluid reservoirs in the FAASV. In these tests, the four sides and the top of the reservoirs were protected by powder packs. Since the reservoirs are located on a shelf in the vehicle, no powder packs were used under the reservoirs. A detailed description of each test is given in Appendix C. For the hydraulic reservoir in the FAASV, 12.7-mm-thick powder packs were required to achieve an acceptable fire-out time.

The design of the FAASV places the ammunition racks between the reservoir and the main portion of the crew compartment. This restricts the flow of both fluid spray and powder. It is expected that there would be less of a visibility loss at crew locations due to the powder, compared to firings at the fuel cell.

4. DISCUSSION

4.1 Fuel Cell. Since the fuel cell of the FAASV is not really located in the crew compartment, the occurrence of a catastrophic fire in the crew compartment is not likely. It is only the carrythrough fuel mist that would normally be a fire problem for the crew. It was anticipated from previous work (Finnerty 1987b) that a 12.7-mm-thick powder pack would be more than sufficient to give a fire-out time of less than 250 ms. The first test, with the 12.7-mm pack, gave a larger-than-anticipated hole in the aluminum bulkhead. This allowed a considerably greater quantity of fuel to flow into the crew compartment than had been predicted. It was very encouraging to find that the 12.7-mm powder pack was able to completely quench the diesel-fuel fire in 90 ms. This was interpreted as providing a high amount of confidence in meeting the fire-out time. It was also found that the test gave a larger-than-

Table 1. Results of Firings of 90-mm Shaped Charges Through Fuel Cells Into Crew Compartment Protected by Powder Packs.

Thickness of powder pack, mm	Materials of powder pack	Diesel fuel temperature, °C	Maximum fire-out time in crew compartment from high-speed cameras, ms	Maximum fire-out time in crew compartment from fire sensors, ms	Second-degree burns predicted?	Comments
12.7	Aluminum honeycomb filled with potassium bicarbonate fire-extinguishing powder	77	90	107.2	no	Large Fire signal on for only 7.6 ms, indicating either basically a small fire or difficulty sensing any fire due to the amount of powder in air. There was a larger-than-expected hole formed in bulkhead, separating fuel cell from crew compartment. Approximately 100 L of fuel flowed into crew compartment. Powder pack extinguished fire under this unusually severe condition.
6.4	Aluminum honeycomb filled with potassium bicarbonate fire-extinguishing powder	77	110	155.0	no	Large Fire signal on for only 1.1 ms, indicating either a very small fire or difficulty sensing any fire due to the amount of powder in air. The hole in the bulkhead was more of the expected size. Only several liters of fuel flowed into crew compartment. The thin powder pack easily extinguished the fire.

Table 2. Results of Firings of 90-mm Shaped Charges Through Hydraulic Reservoirs Protected by Powder Packs.

Number and thickness of powder packs, mm	Materials of powder pack	Hydrualic fluid temperature, °C	Maximum fire-out time in crew compartment from high-speed cameras, ms	Maximum fire-out time in crew compartment from fire sensors, ms	Second-degree burns predicted?	Comments
5 powder packs, each 12.7 mm	Aluminum honeycomb filled with potassium bicarbonate fire-extinguishing powder	65	199	0	no	There was no Large-Fire signal. Either the fire was very small or there was difficulty sensing any fire due to the amount of powder in air. Fluid exited top of reservoir through vent cap and filler tube. Powder was not released at top. Test just passed 250-ms criterion. Time was required for powder to flow through air to mix with fluid from top. Fluid from entrance and exit holes mixed with powder released from these perforations.
5 powder packs, each 6.4 mm	Aluminum honeycomb filled with potassium bicarbonate fire-extinguishing powder	65	1600	2107.4	no	Fluid exited top of reservoir through vent cap and filler tube. Powder was not released at top. Excessive time was required for powder to flow through air to mix with fluid from top. Fluid from entrance and exit holes mixed with powder from these perforations. Film showed fire was at roof section of vehicle.

anticipated hole in the powder pack. Thus, it appears that, if a more energetic event gives a large fuel spill, it will also cause the release of a large amount of powder to counter the extra fuel. It should be noted that the powder pack was dislodged and thrown approximately 61 cm from the bulkhead.

The test with the 6.4-mm powder pack gave a hole in the bulkhead of the expected size. The hole in the powder pack was also smaller than the case of the 12.7-mm pack. There was still sufficient powder release to quench the fuel fire in about 110 ms. In this case the powder pack was thrown approximately 91 cm from the bulkhead.

It is interesting that when a fuel mist is released at the jet-exit hole, the mist travels along the jet path, as expected. The powder from the damaged powder pack also travels along the jet path (Zabel et al. 1988). The powder is thus preferentially transported to the place where it is needed, the location of the fuel mist. Thus, even if, on the average, there is an insufficient powder release to render the entire compartment nonflammable, there is locally a high powder concentration where there is a high fuel-mist concentration. If it is desired to render the entire volume nonflammable, it is only necessary to increase the thickness of the powder pack. This will automatically release more powder.

4.2 Hydraulic Reservoir. In regard to the hydraulic fluid reservoir, the fluid level was higher than ideal when considering the passage of a shaped-charge jet through the reservoir. The hydrodynamic ram effect associated with the event caused fluid to squirt out of the filler pipe and out of the vent cap on top of the reservoir. There was no initial release of powder at the top to mix with this part of the released fluid. The relatively long fire-out times, especially in the case of the 6.4-mm pack, are probably due to the difficulty of getting the powder to the fluid to quench burning. Ordinarily, fluid mist is released only at the entrance and exit holes of a hydraulic fluid reservoir (Finnerty 1987b). When powder packs are broken open by the penetrator, powder immediately mixes with fluid. Since fluid was released at the top, where there were no broken powder packs, it took a certain amount of time before enough powder mixed with this portion of the fluid to quench the fire. The problem could be easily solved by lowering the fluid level in the reservoir (Finnerty 1987b). However, there was a desire to use the same hydraulic-fluid conditions as has been used on tests with the halon system in the FAASV. It had been anticipated that there would be fluid escaping from the top of the reservoir.

It should be emphasized that, in all cases of fluid containers in combat vehicles, passage of a penetrator through the fluid produces large hydrodynamic ram pressures. Even when there was ullage (headspace above the liquid) present, pressures over 68 MPa (10,000 psi) were measured by Zabel when he fired a 90-mm shaped charge through a fuel cell (Zabel, to be published). The very high pressure can cause failure of any weak part of a fuel cell or reservoir. The expansion of the fluid can cause fluid loss at the top where plates are bolted onto the reservoir. Other sources of fluid losses at the top of the reservoir are the fluid return line (plugged for these tests), the vent, the fill tube, and the electrical pass-through for the fluid level indicator.

If sufficient ullage is present (the exact height of ullage must be determined in a case-by-case approach), damage and fluid loss will be minimized. If no ullage (or insufficient ullage) is provided, massive damage and a large loss of fluid is to be expected. One aspect of passive fire protection is to provide sufficient ullage for containers of flammable fluids. The presence of ullage is only one of the many design features that can be incorporated into fuel and hydraulic fluid containers when the vehicles are initially developed (Finnerty 1987a).

No tests were deemed necessary against pressurized, hydraulic fluid lines since this had already been addressed in a previous project (Finnerty, Meissner, and Copland 1985).

4.3 <u>General Comments on Powder Pack Shots</u>. Both diesel fuel tests introduced large amounts of powder into the crew compartment. This may affect the heat transfer to the thermocouples. For these fuel shots, the powder packs appeared to combat fire very effectively. In both cases, the powder packs were dislodged from the plates to which they had been attached. More powder may have been distributed into the compartment than would have been, had they remained attached to the plates.

The hydraulic reservoir shots are complex as far as how the fluid is introduced into the crew compartment. Fluid can flow/spray through the holes at the front and rear of the reservoir, caused by the passage of the shaped-charge jet. Moreover, there are vents, hoses, and gaskets at the top of the reservoir. Because of hydrodynamic ram pressures generated in the liquid by the passage of the jet, fluid was sprayed out of the top of the reservoir in addition to the fluid that sprayed out of the front and back jet holes. The powder packs covering the front and rear plates of the reservoir were destroyed or badly torn. Most of the powder was discharged from these powder packs. The powder pack covering the top of the reservoir was also twisted, bent, and torn. This powder pack also released fire-extinguishing powder. It appears that the powder released by the top powder pack does not flow with the fluid as well as the powder from the front and rear faces. Fluid sprayed towards the roof of the vehicle burned and caused a long fire-out time. It took a longer than acceptable time for the powder to mix with the spray. Since the fire was confined to the roof section, there was no potential for crew burns associated with this burning fluid.

It is interesting to note that there was no Large Fire signal on the first hydraulic fluid shot. Had halon bottles been present, they would not have discharged. On the second fuel shot, the Large Fire signal was on for no more than 1.1 ms. The halon bottles, had they been present, might not have discharged. The other two shots wculd have involved the halon.

5. CONCLUSIONS

The following conclusions may be drawn from the use of powder packs to protect the FAASV crew compartment from fuel and hydraulic fluid fires:

- Powder packs containing Purple K (potassium bicarbonate) fire-extinguishing powder can provide fire protection.

- Powder packs as thin as 6.4 mm were sufficient to provide crew compartment fire protection against fuel cell shots.

- In the case of hydraulic reservoir shots, 12.7-mm-thick powder packs were required to achieve the required fire-out time of 250 ms. It should be noted that recent data indicate that the 250-ms fire-out time benchmark may not be foolproof in predicting second-degree burns (Polyanski 1989b).

- A generally accepted, nontoxic, nonenvironment-damaging material can be used in the powder packs.

- Sufficient powder is expected to be released so that there will be irritation to eyes and throat with loss of visibility. A change of air will be required to remove the suspended powder from the air. There is little tendency for the powder to simply settle out.

- Designs featuring passive, fire-prevention techniques should be incorporated into all combat vehicles. This is true independent of what type of fire-extinguishing techniques are employed.

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APPENDIX A:
TOXICITY OF "PURPLE K" FIRE-EXTINGUISHING POWDER

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"Purple K" powder is composed of the chemical potassium bicarbonate with approximately 2% silicone agent to ensure that the powder is free flowing. A purple dye is added for ease of identification. Purple K is a widely used fire-extinguishing powder, normally dispensed from pressurized cylinders. Both the U.S. Navy and Coast Guard use it in portable fire-extinguishing systems. It is not intended that the operator of the fire extinguisher be enveloped in a cloud of the agent, although this is a distinct possibility. We have not encountered any reports of health problems due to exposure to such a cloud.

Potassium bicarbonate is an unregulated food additive. While it is expected that exposure to a high concentration of particles in air will cause only difficulty in breathing, coughing, and eye watering with a burning sensation, with no long-term negative effects, this has not been demonstrated. Before use of this material in a crew compartment where personnel may not be able to exit promptly, tests should be carried out which expose animals to high concentrations of the agent.

A copy of the Materials Safety Data Sheet for Purple K fire-extinguishing agent is part of this Appendix.

U.S. DEPARTMENT OF LABOR
Occupational Safety and Health Administration

Form Approved
OMB No. 44-R1387

MATERIAL SAFETY DATA SHEET

Required under USDL Safety and Health Regulations for Ship Repairing, Shipbuilding, and Shipbreaking (29 CFR 1915, 1916, 1917)

SECTION I

MANUFACTURER'S NAME AUTOMATED PROTECTION SYSTEMS INC	EMERGENCY TELEPHONE NO. 1-214-641-9833
ADDRESS *(Number, Street, City, State, and ZIP Code)* 904 FOUNTAIN PKWY GRAND PRAIRIE TX 75050	
CHEMICAL NAME AND SYNONYMS N/A	TRADE NAME AND SYNONYMS PURPLE K DRY CHEMICAL
CHEMICAL FAMILY DRY CHEMICAL EXTINGUISHING AGENT	FORMULA N/A

SECTION II - HAZARDOUS INGREDIENTS

PAINTS, PRESERVATIVES, & SOLVENTS	%	TLV (Units)	ALLOYS AND METALLIC COATINGS	%	TLV (Units)
PIGMENTS	N/A	N/A	BASE METAL	N/A	N/A
CATALYST	N/A	N/A	ALLOYS	N/A	N/A
VEHICLE	N/A	N/A	METALLIC COATINGS	N/A	N/A
SOLVENTS	N/A	N/A	FILLER METAL PLUS COATING OR CORE FLUX	N/A	N/A
ADDITIVES	N/A	N/A	OTHERS	N/A	N/A
OTHERS	N/A	N/A		N/A	N/A

HAZARDOUS MIXTURES OF OTHER LIQUIDS, SOLIDS, OR GASES	%	TLV (Units)
N/A		

SECTION III - PHYSICAL DATA

BOILING POINT (°F.)	N/A	SPECIFIC GRAVITY (H_2O=1)	.926
VAPOR PRESSURE (mm Hg.)	N/A	PERCENT, VOLATILE BY VOLUME (%)	N/A
VAPOR DENSITY (AIR=1)	N/A	EVAPORATION RATE (________ =1)	N/A
SOLUBILITY IN WATER	NEGLIGIBLE		
APPEARANCE AND ODOR	FINE PURPLE POWDER / NO ~~[illegible]~~ ODOR		

SECTION IV - FIRE AND EXPLOSION HAZARD DATA

FLASH POINT (Method used) N/A	FLAMMABLE LIMITS N/A	Lel	Uel
EXTINGUISHING MEDIA N/A			
SPECIAL FIRE FIGHTING PROCEDURES N/A			
UNUSUAL FIRE AND EXPLOSION HAZARDS N/A			

(Continued on reverse side)

SECTION V - HEALTH HAZARD DATA

THRESHOLD LIMIT VALUE Undefined in MG/m^3 (SEE OSHA CLASSIFICATION FOR NUISANCE DUST.)

EFFECTS OF OVEREXPOSURE MINOR SKIN IRRITATION, CONGESTION, BURNING SENSATION AND WATERING OF THE EYES.

EMERGENCY AND FIRST AID PROCEDURES REMOVE CONGESTION RINSE SKIN & EYES WITH WATER.

SECTION VI - REACTIVITY DATA

STABILITY	UNSTABLE		CONDITIONS TO AVOID
	STABLE	X	NONE

INCOMPATABILITY *(Materials to avoid)* NONE

HAZARDOUS DECOMPOSITION PRODUCTS NONE

HAZARDOUS POLYMERIZATION	MAY OCCUR		CONDITIONS TO AVOID
	WILL NOT OCCUR	X	NONE

SECTION VII - SPILL OR LEAK PROCEDURES

STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED

SWEEP UP AND DISCARD CONTAMINATED MATERIAL

WASTE DISPOSAL METHOD

DISCARD IN NON-HAZARDOUS WASTE AREA

SECTION VIII - SPECIAL PROTECTION INFORMATION

RESPIRATORY PROTECTION *(Specify type)* 3M PARTICLE MASK

VENTILATION	LOCAL EXHAUST PROVIDE ADEQUATE VENTILATION	SPECIAL NONE
	MECHANICAL *(General)* EXHAUST FAN IN ENCLOSED AREA.	OTHER NONE

PROTECTIVE GLOVES NOT REQUIRED

EYE PROTECTION SAFETY GOGGLES

OTHER PROTECTIVE EQUIPMENT NONE.

SECTION IX - SPECIAL PRECAUTIONS

PRECAUTIONS TO BE TAKEN IN HANDLING AND STORING NONE

OTHER PRECAUTIONS NONE.

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APPENDIX B:
DESCRIPTION OF THE FUEL-CELL FIRINGS

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Both video and high-speed film cameras were positioned inside the FAASV. A video camera was also positioned to observe the outside of the vehicle. Fire detectors inside the vehicle were activated to observe any fires.

For each firing, a 90-mm HEAT warhead was set up two cone diameters from the vehicle armor (25-mm aluminum). The shotline for both tests was into the right side of the vehicle, 45° from the perpendicular, toward the rear of the vehicle. This allowed the jet to pass through the armor, entering the fiberglass fuel cell and passing through the fuel. When the jet exited the fuel cell, it passed through the 12.7-mm aluminum bulkhead, through the powder pack, and into the crew compartment. The vehicle was essentially empty. No ammo, stowage items, etc., were present.

Both fire-extinguishing powder and fuel mist followed the jet into the crew compartment. Hot metallic spall was produced when the jet struck interior parts of the vehicle and/or the far wall of the crew compartment. While the hot spall provided an excellent ignition source, the fire-extinguishing powder was mixed with fuel spray even before ignition.

Since the hatches of the vehicle were closed before each test, the only light available inside the FAASV was from the jet, the hot spall, and the burning fuel. The fire-out time was taken as the longest time fire was seen inside the vehicle, whether seen by high speed cameras or optical fire sensors.

Test 1. A 12.7-mm powder pack was attached to the 12.7-mm aluminum bulkhead, which separates the fuel cell from the crew compartment. Since the powder pack was intended to protect only the crew compartment from fire, only one pack was used. It was installed on the crew compartment side of the bulkhead so that powder would be released in the crew compartment.

When the shaped-charge device was fired, large clouds of powder were observed (from the video viewing the exterior of the vehicle) exiting the vehicle from all available openings. The powder continued to exit for several minutes (there was no forced ventilation installed in the test vehicle.) It certainly appeared that if no collector had been used to catch fuel, which flowed out of the entrance hole in the armor, there would have been a large ground fire. It is important that a vehicle be capable of driving away from ground fires that result from combat hits. Such fires have been noted even with halon systems.

The fire-out time inside the crew compartment was 90 ms by high-speed camera data and 107.1 ms by optical sensor data, well within the goal of 250 ms. Thermocouple data gave a maximum temperature-time integral of 941° C-second. This yields a prediction of no second-degree burns on exposed skin.

When the interior of the vehicle was examined the next day, considerable powder residue was found on all surfaces. The fire-extinguishing powder does not ordinarily show much tendency to settle out of the air because of the small size of the particles. It is quite possible that, since this vehicle had been used previously for many fire tests, there may have been a film of oil on the interior surfaces. The powder would have a tendency to stick to such a surface in preference to a dry surface.

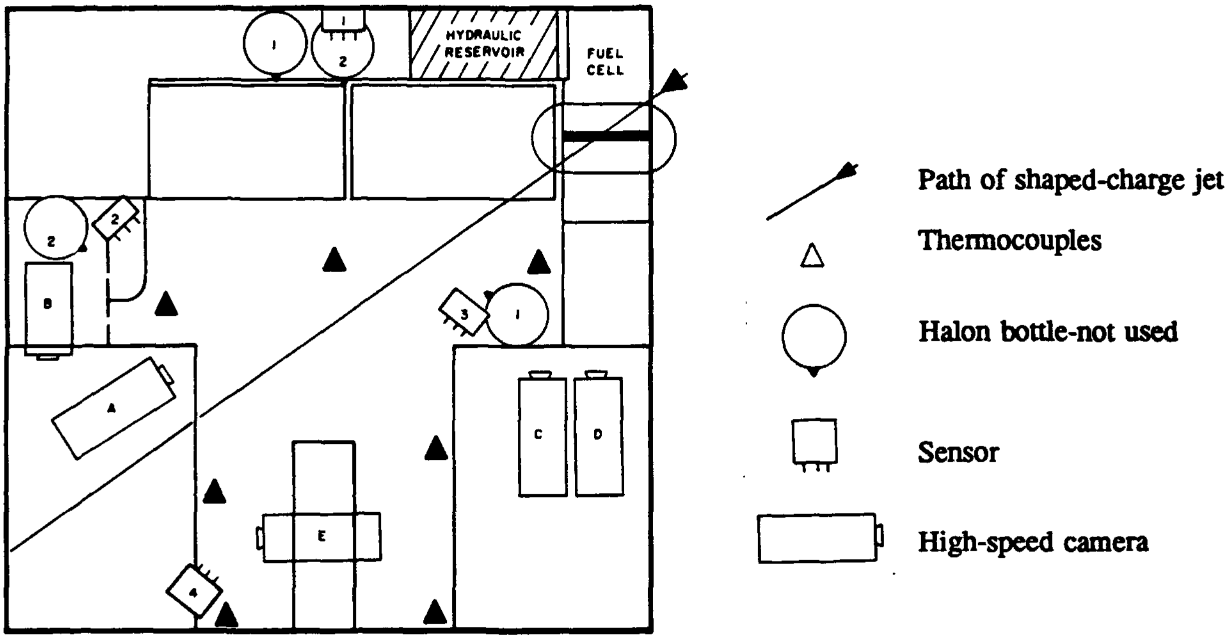
The location of the thermocouples, cameras, sensors, and their data, along with the shot line for the first fuel shot is given in Figure B-1. Views of the powder pack before and after the shot are given in Figures B-2 and B-3.

Test 2. A 6.4-mm-thick powder pack was attached to the 12.7-mm aluminum bulkhead, which separates the fuel cell from the crew compartment. Since the powder pack was intended to protect the crew compartment from fire, only one pack was used. It was installed on the crew compartment side of the bulkhead so that powder would be released in the crew compartment.

When the shaped-charge device was fired, large clouds of powder were observed (from the video viewing the exterior of the vehicle) exiting the vehicle from all available openings. The powder continued to exit for several minutes (there was no forced ventilation in the test vehicle.)

The fire-out time inside the crew compartment was 110 ms from high-speed camera data and 155.0 ms from optical sensor data. This was less than the 250-ms criterion. Thermocouple data gave a maximum temperature-time integral of 646° C-second. The prediction is that there will be no second-degree burns on exposed skin.

The next day a film of powder was observed on all surfaces inside the vehicle, just as in Test 1. Also, as in Test 1, it appeared that a large ground fire would have occurred had a fuel catcher not been used to collect the diesel fuel spilled outside the vehicle. Locations of thermocouples, cameras, sensors, and their data, along with the shot line are given in Figure B-4. Views of the powder pack before and after the shot are given in Figures B-5 and B-6.



12.7-mm powder pack
Sensor fire-out time: 107.2 ms
High-speed camera fire-out time
A - data lost
B - 59 ms
C - 90 ms
D - 52 ms
E - 63 ms
Maximum temperature integral 959°C-sec
Met fire-out time criteria with no second-degree burns.

Figure B-1. Locations of Thermocouples, Cameras, Sensors, and Shot Line for First Fuel Shot.

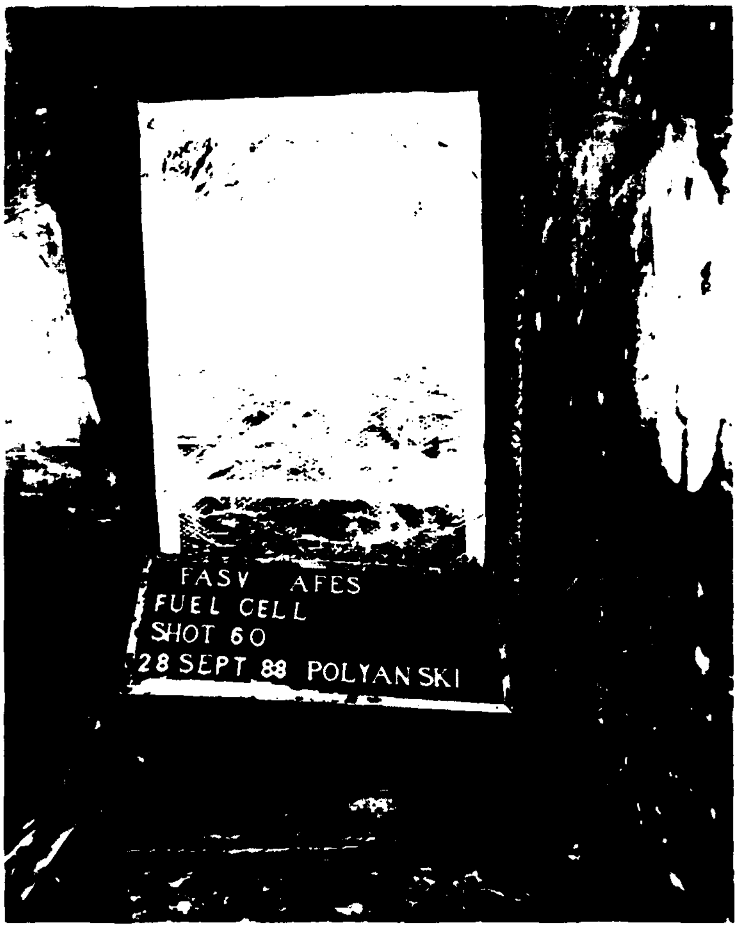
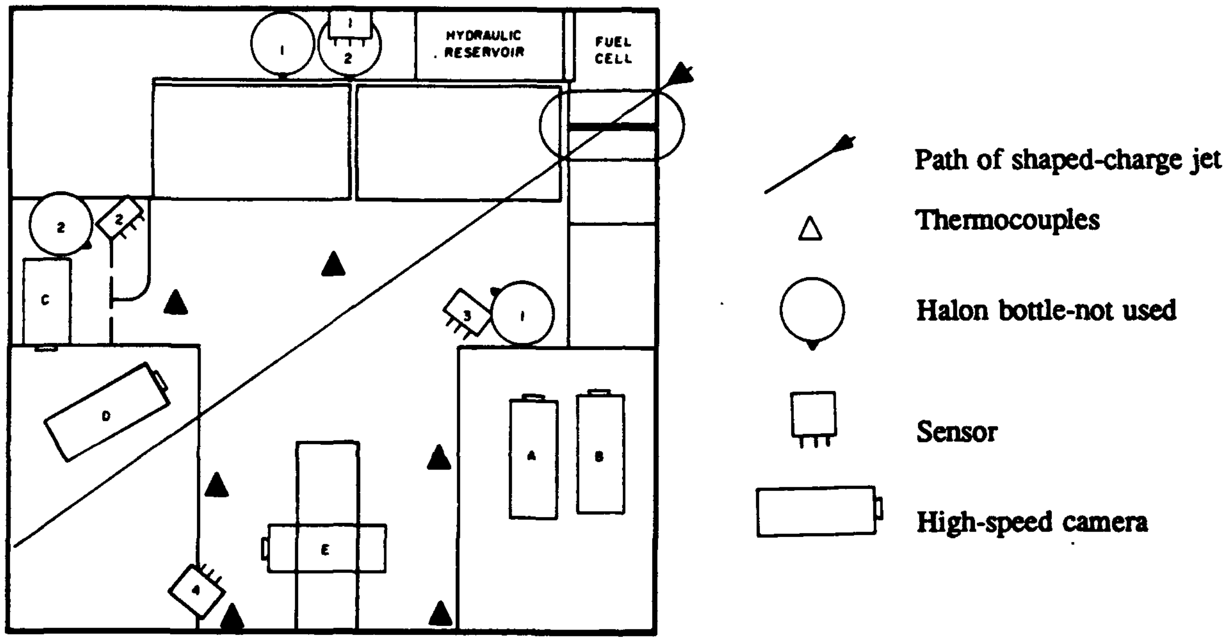


Figure B-2. Powder Pack Before First Fuel Shot.

Figure B-3. Powder Pack After First Fuel Shot.



6.4 mm powder pack
Sensor fire-out time: 155.0 ms
High-speed cameras fire-out times
A - 110 ms
B - 101 ms
C - 49 ms
D - 66 ms
E - data lost
Maximum temperature integral 664°C -sec
Met fire-out time criteria with no second-degree burns.

Figure B-4. <u>Locations of Thermocouples, Cameras, Sensors, and Shot Line for Second Fuel Shot.</u>

Figure B-5. Powder Pack Before Second Fuel Shot.

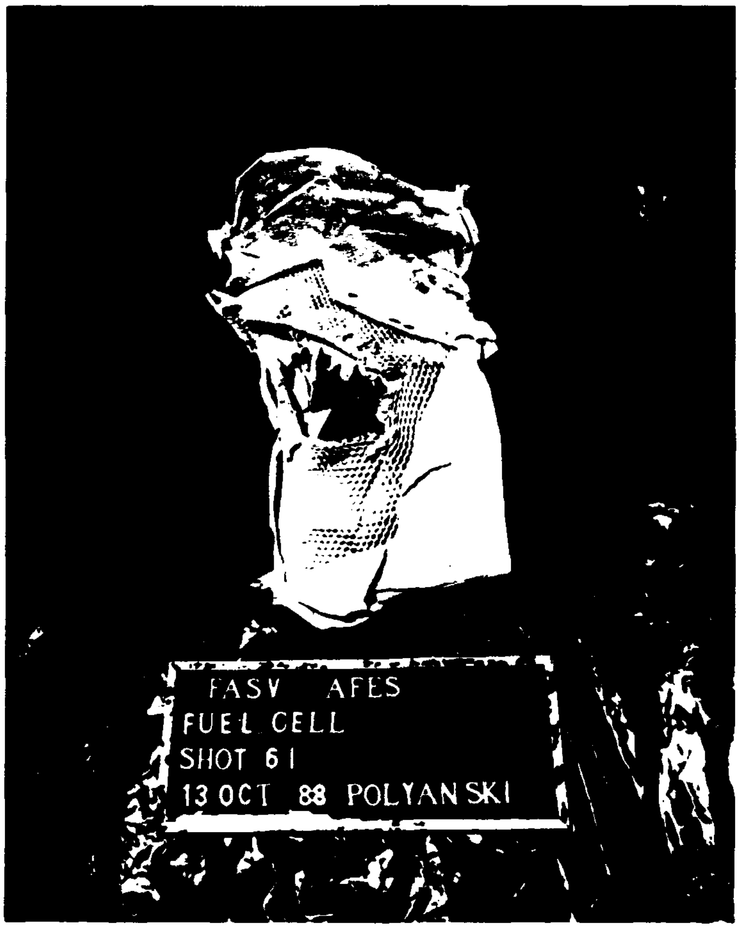


Figure B-6. Powder Pack After Second Fuel Shot.

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APPENDIX C: DESCRIPTION OF THE HYDRAULIC FLUID RESERVOIR TESTS

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Both video and high-speed film cameras were positioned inside the FAASV. Video was also available to observe the outside of the vehicle. Fire detectors inside the vehicle were activated to observe any fires.

For each test a reconditioned hydraulic fluid reservoir was bolted into place on its shelf at the front of the FAASV crew compartment. All openings, except the filler tube and the vent, were sealed shut. The four sides and the top of the reservoir were covered with powder packs of the appropriate thickness. No powder packs were used under the reservoirs, since the reservoirs are normally positioned on a shelf.

Empty steel ammunition racks were installed for each shot. The reservoir side of the racks contain plugs to seal each of the 90 projectile tubes. The racks with plugs effectively confine both fluid spray and released powder to a small volume between the back of the reservoir and the ammunition racks.

For each firing a 90-mm HEAT warhead was set up two cone diameters from the front wall of the vehicle. The shotline for both tests was through the front armor of the compartment (25.4-mm aluminum) into the vehicle, where it passed through approximately 20 mm of air before encountering the reservoir. The reservoir was surrounded on five of its six sides by powder packs. Therefore, the jet had to break through a powder pack before hitting the reservoir. The walls of the reservoir were made of 6.4-mm-thick mild steel. The jet passed through the reservoir, encountering approximately 200 mm of fluid. Upon exiting the reservoir, the jet had to break open a second powder pack on the exit side of the reservoir. The jet then traveled through approximately 64 mm of air before encountering the ammunition racks. The jet passed through the racks and continued across the vehicle.

The video, high-speed film cameras, and fire detectors were all set up to observe the duration of burning of the hydraulic fluid released from the reservoir. The longest time of evidence of fire from any of the three records was taken as the fire-out time.

Test 3. For this test, the five powder packs used to surround the reservoir were each 12.7 mm thick. Approximately 59 liters of hot hydraulic fluid were poured into the reservoir through the filler tube. The fluid was overheated to allow for cooling to 65° C at shot time.

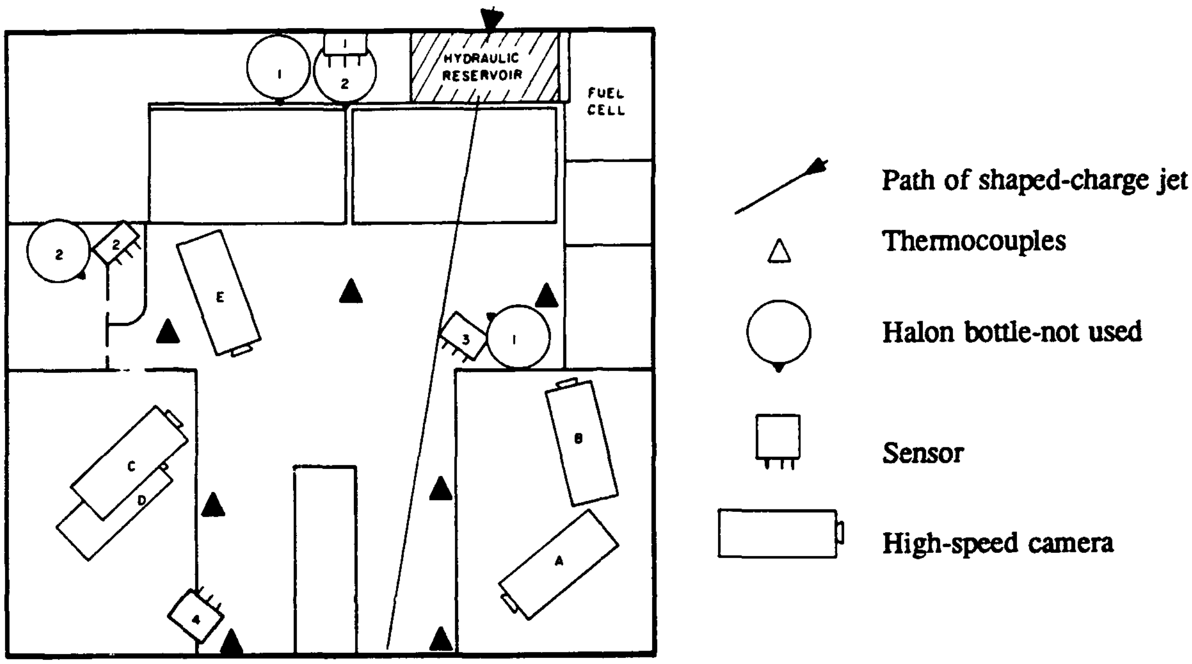
The 90-mm HEAT warhead (M28A2) was positioned and fired. The jet passed through 25.4 mm of aluminum armor, approximately 20 mm of air, and then struck the 12.7-mm powder pack. The jet then went through the 6.4-mm mild steel of the reservoir and approximately 200 mm of hydraulic fluid. The jet then exited through the second 6.4-mm mild-steel wall of the reservoir and broke open the second 12.7-mm powder pack. The jet continued through the empty ammunition rack. Hydraulic fluid and Purple K fire-extinguishing powder were both released at the entrance and exit sides of the reservoir. However, because of hydrodynamic ram pressure, fluid was also released at the filler tube and vent on top of the reservoir. This fluid was ejected upward toward the roof of the vehicle.

The first powder pack struck by the jet, positioned between the front wall of the vehicle and the reservoir, was almost completely destroyed. The powder pack between the reservoir and steel rack, on the jet exit side of the reservoir, was bent, twisted, and torn. The powder pack on the top of the reservoir was also bent, twisted, and torn. The two side powder packs remained intact.

The fire-out time from high-speed camera data was 199 ms. The optical sensors failed to give a LF signal; therefore, they did not see the hydraulic fluid fire. This may have been caused by the unusual location of the hydraulic fluid fire, close to the roof section of the vehicle. The fluid ejected upward did not have much powder with it, due to the limited breaking of the top powder pack. The sensors may not have had a good field of view of this fire. However, the 250-ms criteria was met for fire-out time.

Thermocouple data gave no significant data. This is probably because the burning fluid was mainly close to the roof. The fluid that exited the reservoir, following the jet, was stopped by the ammunition rack. There would have been no second-degree burns on any crew member's exposed skin.

It is interesting to note that there was very little powder in the crew area of the compartment after the test. The ammunition racks effectively confined both hydraulic fluid and powder to the very front of the compartment. External video showed large clouds of powder exiting the front of the vehicle via hatches blown open by the event. There was no external fire. Locations of thermocouples, cameras, sensors, and their data, along with the shot line are given in Figure C-1. Views of the powder pack before and after the test are given in Figure C-2 and C-3.



12.7-mm powder pack
Sensor fire-out time: 0 ms
High-speed cameras fire-out time
A - 71 ms
B - 199 ms
C - 147 ms
D - 136 ms
E - 53 ms
Maximum temperature integral-no significant
temperature data from the thermocouples
Met fire-out time criteria with no second-degree burns.

Figure C-1. <u>Locations of Thermocouples, Cameras, Sensors, and Shot Line for First Hydraulic Fluid Shot</u>

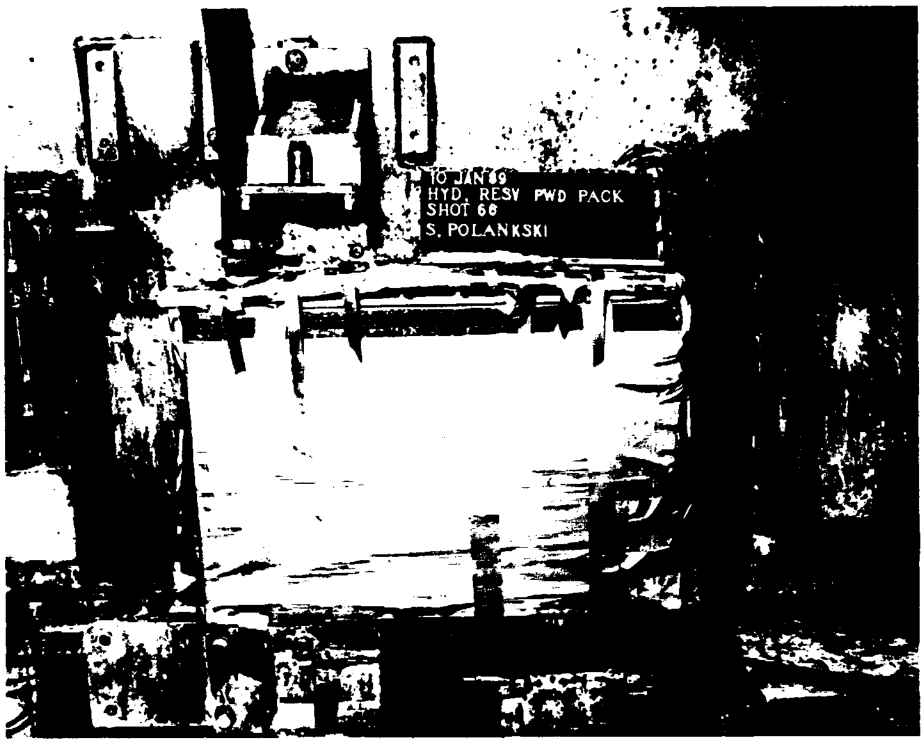


Figure C-2. Powder Packs Before First Hydraulic Fluid Shot.

Figure C-3. Powder Packs After First Hydraulic Fluid Shot.

Test 4. For this test, the five powder packs used to surround the reservoir were each 6.4-mm-thick. Approximately 59 liters of hot hydraulic fluid were poured into the reservoir through the filler tube. The fluid was overheated to allow for cooling to 65° C at shot time.

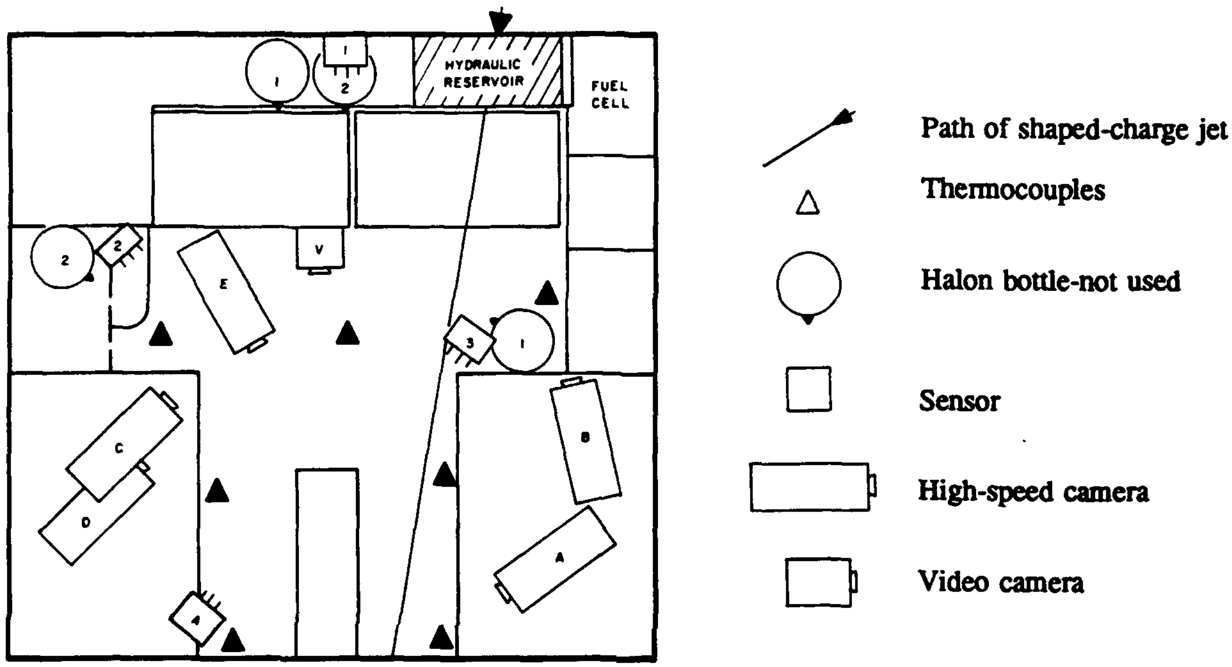
The 90-mm HEAT warhead (M28A2) was positioned and fired. The jet passed through 25.4 mm of aluminum armor, approximately 20 mm of air, and then struck the 6.4-mm powder pack. The jet then went through the 6.4-mm mild steel of the reservoir and approximately 200 mm of hydraulic fluid. The jet then exited through the second 6.4-mm mild-steel wall of the reservoir and broke open the second 6.4-mm powder pack. The jet continued through the empty steel ammunition rack.

The powder pack first struck by the jet was almost completely destroyed. The powder pack on the exit side of the reservoir was bent, twisted, and torn. The powder pack on the top of the reservoir was also bent, twisted, and torn. The two side powder packs remained intact.

This test did not meet the fire-out time criteria of 250 ms. Internal video observed a fire near the roof for approximately four seconds. Fire-out time from the optical sensors was over 2000 ms. This was due to the lack of powder near the roof where the fluid burned. This test of a set of 6.4-mm powder packs was considered a failure.

The thermocouple data were more encouraging. The maximum temperature-time integral was 586° C-second. The assessment was that no crew member would have suffered second-degree burns on exposed skin. Again, it was probably due to the location of the fire near the roof. The ammunition rack effectively prevented most of the hydraulic fluid from reaching crew positions. Figure C-4 gives locations of cameras, thermocouples, sensors and their data, along with the shot line. Views of the powder packs before and after the shot are given in Figure C-5 and C-6.

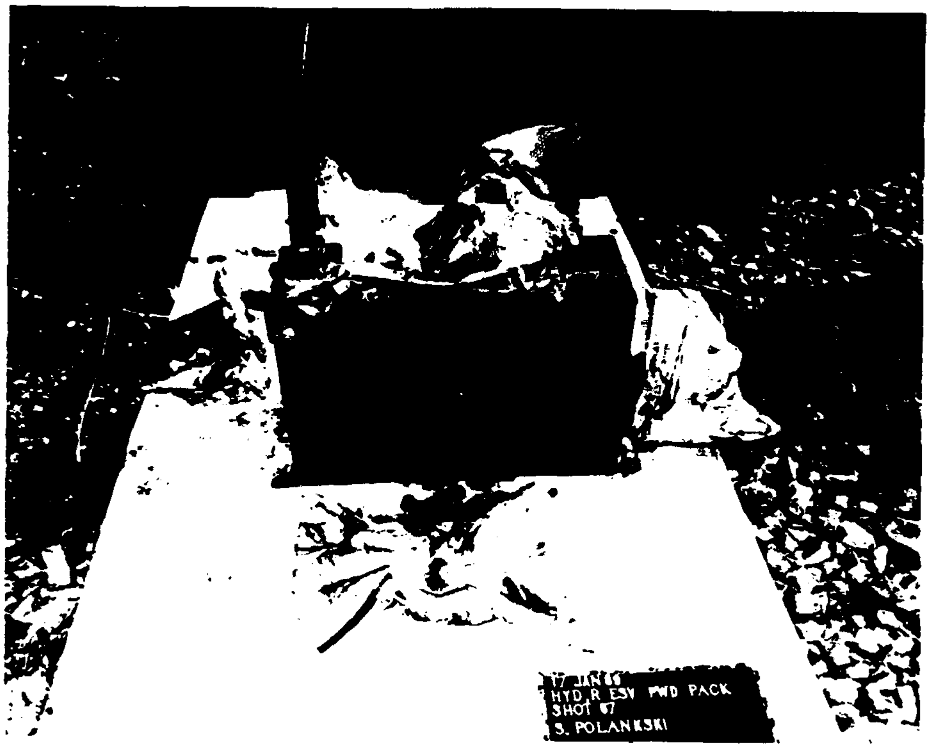
Very little powder was observed in the crew area of the compartment. There was no external fire. External video did show large clouds of powder exiting the front of the crew compartment via hatches blown open by the event.



6.4-mm powder packs
Sensor fire-out time: 2107.4 ms
High-speed cameras fire-out time
A - 82 ms
B - 152 ms
C - 1060 ms
D - 1600 ms
E - 37 ms
Maximum temperature integral 604°C-sec
Did not meet fire-out time criteria, but no second-degree burns.

Figure C-4. Locations of Thermocouples, Cameras, Sensors, and Shot Line for Second Hydraulic Fluid Shot

C-5. Powder Packs Before Second Hydraulic Fluid Shot.



C-6. Powder Packs After Second Hydraulic Fluid Shot.

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