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**(U) SURVIVABILITY?  
IT COULD BE A MATTER OF HYDRAULIC FLUID!**

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ABSTRACT

**(U)** Hydraulic fluids perform their jobs in modern systems quietly, efficiently and usually without notice. However, their failures are spectacular and all too often tragic. Like fuels, hydraulic fluids are flammable. Historically, military ground equipment has relied on petroleum based fluids as both the operating systems and environments precluded using either water based or other commercial fire resistant hydraulic fluids. As the sophistication of hydraulic systems has increased, so has the probability of, and the associated damage due to fires, increased. The high number of incidents of hydraulic fluid fires occurring in Israeli M60 tanks during the 1973 Arab-Israeli war led to a push for developing fire resistant or nonflammable fluids.

**(U)** In the 1960's, synthetic hydrocarbons were investigated and developed for use as the fire resistant aviation hydraulic fluid, MIL-H-82382 [1] by the Air Force. In response to the fluid vulnerability problem experienced by the Israeli forces, a corrosion-inhibited version, MIL-H-46170, [2] was developed for ground vehicle use. These synthetic hydrocarbon based fluids, while flammable, have significantly higher flash points than petroleum base fluid and resist pool burning when a flame source is removed.

**(U)** Development of a truly nonflammable hydraulic fluid continued and centered on a chloro-trifluoro ethylene (CTFE) fluid that eventually led to adoption of a nonflammable fluid, MIL-H-53119. [3] However, it was much more costly than other fluids, was very dense, and attacked copper alloys in the hydraulic systems. As these factors would necessitate some system design changes, MIL-H-53119 was left for consideration in future vehicle systems.

**(U)** TARDEC is conducting very promising research on a hydraulic fluid additive to further increase fire resistance of synthetic base fluids. Preliminary results have shown that as little of two percent of the additive can effectively suppress hot surface ignition of current MIL-H-46170 fluids.

**1 (U) INTRODUCTION**

**(U)** The Chief of Staff of the Army recently announced a new initiative for the future Army. This new vision for a strategically responsive force, the brigade combat team, has become the centerpiece for this initiative. As recent events have demonstrated, the current Army structure with its emphasis on heavy armor and the included necessary logistical tail is too

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costly in terms of strategic mobility to generate the desired rapid response to widely diverse conflicts. A decrease in armor protection means a concomitant lost in crew survivability unless other measures are taken to enhance the survivability for the to-be-developed combat fighting vehicle (CFV). As improved survivability is a major requirement for the brigade combat team and the CFV, one way to achieve this is to reduce hydraulic fluid flammability.

(U) This presentation lays out an approach to this problem.

### 2.0 (U) BACKGROUND:

#### 2.1 (U) RECOGNIZING THE FIRE THREAT

(U) The Middle East conflicts in 1973 initially revealed the magnitude of the hydraulic fluid's contribution to the fire threat for armored vehicles. Rupturing of hydraulic fluid lines under pressure generated a fine spray that was easily ignited by hot pieces of projectiles or incendiary fragments. The U.S. manufactured M 60 main battle tanks used by the Israeli military were more prone to these fires than were Russian tanks used by Arab nations.

(U) At the end of the conflict, strong complaints by the Israeli military regarding their significant M 60 losses due to fires led to a DOD task force being established to correct this deficiency. The DOD task force was asked to come up with a replacement fluid for the highly volatile and flammable MIL-H-6083 [4] hydraulic fluid (i.e., also known by its military symbol OHT) that was used in all ground vehicles and equipment. The replacement fluid had to be one that had fire retardant qualities.

#### 2.2 (U) THE INTERIM FIX

(U) The DOD task force initially considered a variety of fluid candidates such as glycol water emulsions, phosphate esters, poly-alpha olefins, also known as synthetic hydrocarbons, silicone fluids, halogenated hydrocarbons, etc. all of which were reported to possess fire retardant qualities. The replacement fluid had to be one that would properly function (i.e., be compatible) with the existing hydraulic and gun recoil systems. The poly-alpha olefins (PAO) became the fluid of choice that best met the requirements. Further, ballistic testing on pressurized hydraulic cylinders demonstrated that the PAO was up to 70% more fire resistant than the flammable OHT [5]. Using the PAO as a base, a new "less flammable" hydraulic fluid was developed and became MIL-H-46170 (also known by its military symbol FRH).

(U) FRH was first introduced into M 60's in 1974 and then into M 1's (Abrams tanks) when fielded in early 1980. Although the FRH did offer an increase in safety because of its higher flash point (i.e., 400° F for FRH versus 180° F for OHT), FRH did not completely resolve the hydraulic fluid fire threat. Therefore it was viewed as only an interim fix. The original directive calling for changeover from OHT to FRH had identified other armored vehicles (e.g., self-propelled artillery, carrier, command post, etc.) in addition to main battle tanks. Unfortunately, these other armored assets were never changed to FRH and have continued to use the flammable OHT.

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**3.0 (U) APPROACH:**

**3.1 (U) THE FUTURE OF HYDRAULIC SYSTEMS –**

**(U)** Some persons might question the future of hydraulics. Vehicular electric drives are being seriously evaluated for use in combat and tactical vehicles. However, their use is for future vehicles. The legacy fleet, which will be with us until 2030 or beyond, uses hydraulic fluid in traditional hydraulic systems and also as a recoil/equilibrating fluid. For these reasons hydraulics are not going away, and it behooves us to give the crews every bit of survivability of which we are capable.

**4.1 (U) HISTORY:**

**(U)** The genesis of the proposed effort to develop a hydraulic fluid having greater fire retardancy is found in efforts by the Tank and Automotive Research, Development and Engineering Center (TARDEC). On-board fire suppression systems, by design, are to extinguish any fire the moment it starts and have been an integral element of survivability for armored vehicles. In the past, on-board fire suppression systems used HALON 1301, a proven and effective fire suppressant. In the late 1980's, the Montreal Protocol Treaty identified chlorofluorocarbons such as HALON 1301 to be depleting the ozone layer, and required these substances to be phased out of production during the early 1990's. Other suppressants have since been developed, but these do not appear to be equivalent to HALON 1301 leaving a question as to their ability to suppress hydraulic fluid fires. There have continued to be additional concerns with fire suppressant systems such as the responsiveness of sensors in detecting a flame, protection against multiple hit scenarios, system malfunctioning, possible loss of pressurized suppressant, etc. The bottom line is if the sensors fail to function or the system does not immediately operate, there is no backup and the presence of either FRH or OHT will more than likely "add fuel to the fire." Because of these nagging uncertainties, there has been a continuing effort to develop a non-flammable hydraulic fluid.

**3.3 (U) HYDRAULIC FLUID FORMULATIONS AND PROPERTIES**

**3.3.1 (U) CURRENT:**

**(U)** Non-Flammable Fluid --In the mid 1980's, an Army requirement for a non-flammable hydraulic fluid led to the development of MIL-H-53119 (also known by its military symbol CTFE) in the early 1990's. The non-flammable hydraulic fluid was based upon Chlorotrifluoroethylene chemistry. Although it has no affinity for water absorption, it has some corrosive tendencies toward some common non-ferrous alloys used in most hydraulic systems of the present fleet. A Break Even Cost Analysis generated to consider introducing CTFE into the M1 fleet provided some interesting statistics on the numbers of non-combat fires occurring in M1s directly attributable to hydraulic fluid [6]. For the period covering 1980 to 1990, there were fifty-one (51) non-combat fires caused by the hydraulic fluid with the total cost for these fires being \$4,521,697.00.

**(U)** However, all was not rosy for CTFE, some systems modifications were required prior to its proposed use in hydraulic and gun recoil systems as a function of its greater density and because of CTFE's incompatibility with certain seals and non-ferrous parts. As a result of this retrofit requirement and costs associated with the changeover, CTFE was "put on the shelf" to be considered for future vehicle systems design.

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3.3.2 **(U)** EXPLORATORY:

**(U)** This program will focus on modifying the current standard hydraulic fluids described immediately below.

3.3.2.1 **(U)** Enhanced FRH -- The Fuels and Lubricants Team of TARDEC conducted some limited testing and experimentation in adding small amounts (2% to 10%) of CTFE to five formulations of hydraulic fluid to improve their fire resistance. It was found that CTFE had limited solubility in PAO's. While adding CTFE to the formulations of hydraulic fluid increased the fire resistance somewhat, increases in foaming and other property changes were noted. The report concluded that further studies be conducted to evaluate the undesirable properties of CTFE [7].

**(U)** More recently some limited testing has been conducted at the TARDEC Fuels and Lubricants Research Facility (TFLRF) at Southwest Research Institute, using small amounts of halogenated compounds blended into FRH. This exploration has produced surprising results in reducing the flammability of FRH. These halogenated compounds are of the type that do not violate the Montreal Protocol Treaty and are acceptable for use. It was found that as little as 2-5% of a halogenated compound blended into FRH was sufficient to suppress any potential for the fluid to burn. Although this preliminary testing has shown extremely promising results, additional work is needed to insure this small amount of halogenated compound will not change any of FRH's performance characteristics. If successful, introduction of this "Enhanced FRH" in combination with the on-board fire suppressant systems will certainly go a long way towards guaranteeing increased crew and vehicle survivability necessary for the new concept, the brigade combat team and the CFV, and for all other armored vehicle systems.

3.3.2.2 **(U)** Improved OHT -- Work has also been performed by TARDEC and TFLRF directed toward developing improved fire retardancy in OHT while retaining its excellent low temperature properties [8]. This reformulation effort has the objective of providing increased survivability potential to the current OHT users (see Interim Fix above) This is a low risk effort in that several candidate fluids have been submitted that met the required chemical and physical properties for the improved OHT. It is envisioned that the same process used for FRH that of adding small amounts of halogenated compounds will be able to further increase the fire resistant properties of OHT once the question of reformulation is settled.

**(U)** There exists a high probability that the requirements for Improved OHT could be incorporated into the Enhanced FRH. This would result in having only one fluid for ground vehicles and equipment, which would certainly simplify logistics. This approach will be pursued in the future.

3.4 **(U)** ADDRESSING FLAMMABILITY

**(U)** The term halon used in this report simply refers to compounds containing halogen substituents, *i.e.*, fluorine, chlorine, bromine, or iodine. If other specific compounds are referenced, special note will be listed.

**(U)** To choose the optimal application, it is necessary to measure the flame-inhibiting characteristics under several conditions. Although previous studies have been performed on the flame-inhibiting characteristics of halons, the one area of research relatively devoid of data is the condition in which the halon is dissolved in the fluid. When the halon is dissolved in the fluid, its vapors can create a blanket over the fluid that is often very effective in rendering the fluid air

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mixture above the fluid nonflammable. The emphasis in carrying out this concept is to determine the effectiveness of halons as vapor-blanketing agents in fluid spill fires.

**3.4.1 (U) Halon Compounds as Additives**

**(U)** Halons are known to be extremely effective in flame inhibition and reducing fires. However, the widespread use of halons is coming under increasingly rigid controls over manufacturing and application. Some halon fire-fighting agents can have a negative impact on the environment and, therefore, are being phased out by federal agencies. The stability of the halons provides for compatibility and low toxicity; their thermal and chemical activities provide efficient suppression for widely varying fire scenarios.

**3.4.2 (U) Fire Suppression Mechanism**

**(U)** The development of a flame retardant additive for hydraulic fluids will be conducted using a similar approach several years ago on hydrocarbon fuels [9]. That is to investigate the efficiency of the candidate agents on the flash point of the fluid. The reasoning is that, if the flash point of the fluid can be eliminated, then the fire point (continued burning following the flash point) will not occur. In effect, the residual burning of the fluid will be prevented. As an example of this approach, Table 1 lists the agents that were evaluated in the fuel study. It can be seen that compared to bromochloromethane, some agents are up to nine times more effective. It should be mentioned that the flash point (*i.e.*, open flame ignition source) is only one type of ignition source, whereas there are other scenarios such as hot surface (ballistic or exhaust manifold) that should also be addressed.

**(U)** In order to better understand the approach illustrated in Table 1, the following discussion is presented.

**(U)** The experimental procedure begins with dissolving a measured amount of halon in the fuel and determining if there is a flash point. The flash point and fire point measured with the Cleveland open-cup tester were both 74°C. If the mixture flashes, the procedure is repeated using a higher concentration of halon until the mixture is unable to ignite. Table 1 gives the results of the flash point measurements on all the halons examined except trifluoroiodomethane. The table lists the boiling point, the concentration of halon in the liquid fuel required to prevent flash, the calculated volume percent of halon in the vapor phase, and a halon effectiveness parameter,  $e$ , defined later in this section.

**(U)** Twenty-one halons ranging widely in boiling point and composition were examined. The objective was to determine the effectiveness of the halons in preventing ignition (flash) of the fuel vapors. Two definitions of halon effectiveness are given in Table 1. The first definition (column 4, Table 1) is based on the understanding that halons prevent fire by a vapor-blanketing mechanism [10]. In that case, effectiveness is defined as the volume percent of halon vapor required in the vapor space to prevent ignition of fuel. The lower the volume percent halon required to prevent ignition, the greater the effectiveness.

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**Table 1. (U) Flame Inhibition Efficacy of Halons Determined by Flash Point Test**

Halon Description	Halon Boiling Point, °C	No Flash Halon Conc., wt%	Vol% Halon in Vapor Space Calc.*	Efficacy (e) Relative to CH <sub>2</sub> ClBr
Bromochloro Methane (CH <sub>2</sub> ClBr)	68.0	2.13	2.0	1.00
Carbon Tetrachloride (CCl <sub>4</sub> )	78.6	10.39	6.0	0.25
Methylene Chloride (CH <sub>2</sub> Cl <sub>2</sub> )	40.5	6.25	20.3	0.22
Methylenebromide (CH <sub>2</sub> Br <sub>2</sub> )	98.2	2.29	0.6	1.25
1,1,2-Trichloro-1,2,2-Trifluoroethane (C1CF <sub>2</sub> CFC1 <sub>2</sub> )	47.5	3.39	4.2	0.91
Ethyl Bromide (C <sub>2</sub> H <sub>5</sub> Br)	38.4	2.21	6.3	0.81
Trichloro-Ethylene (C1CH=CC1 <sub>2</sub> )	85.7	36.25	16.7	0.06
Chloroform (CHCl <sub>3</sub> )	61.3	8.13	9.8	0.24
Bromochlorotrifluoro Ethane (CHClBrCF <sub>3</sub> )	50.2	1.15	1.3	2.83
Dichlorotrifluoro Ethane (CHCl <sub>2</sub> CF <sub>3</sub> )	24.0	2.00	5.6	1.26
Ethyl Iodide (C <sub>2</sub> H <sub>5</sub> I)	71.2	6.90	4.8	0.37
Methyl Iodide (CH <sub>3</sub> I)	42.5	1.00	1.9	2.34
Methylene Iodide (CH <sub>2</sub> I <sub>2</sub> )	181.0	13.83	0.2	0.32
Difluorotetrachloro Ethane (C <sub>2</sub> F <sub>2</sub> Cl <sub>4</sub> )	91.0	8.03	2.3	0.42
Difluorodibromo Methane (CF <sub>2</sub> Br <sub>2</sub> )	22.5	0.38	0.9	9.14
Dichlorobromo Methane (CHCl <sub>2</sub> Br)	87.0	2.55	0.8	1.35
Trichloro Fluoromethane CFC1 <sub>3</sub> (	23.7	1.71	6.2	1.33
Dibromofluorochloro Methane (CFC1Br <sub>2</sub> )				

Dibromotetra-	79.5	1.79	0.7	1.57
Fluoroethane (C <sub>2</sub> F <sub>4</sub> Br <sub>2</sub> )	47.0	0.61	0.6	7.00
	56.0	0.90	0.5	6.21

\* Calculated assuming the halon/fuel mixture is an ideal solution.

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(U) In the second definition (column 5, Table 1), the effectiveness,  $e$ , is expressed as

$$e = \frac{M_w}{100w} \quad (\text{Eq. 1})$$

where  $M_w$  is the molecular weight and  $w$  is the weight percent halon dissolved in the fuel. Equation 1 conveys that  $e$  is inversely proportional to the molar concentration of halon in the fuel.

(U) Both definitions of halon effectiveness are relevant. The volume percent of halon required in the vapor space is of interest because it can be compared with previously measured volume percents of halon vapors required to prevent ignition of premixed gas-phase fuel/air mixtures [11]. The definition expressed by Equation 1 is more practical because it is a direct measure of the effectiveness of halons dissolved in fuel.

(U) The volume percent halon given in column 4 of Table 1 to prevent ignition is the concentration in the vapor space calculated at 57.2°C (*i.e.*, 3°C above the flash point of the fuel). The volume percent of halon in the vapor space is expressed as

$$C_H = 100 \frac{P_v}{P_t} \quad (\text{Eq. 2})$$

where  $P_t$  is the total pressure, and  $P_v$  is the partial pressure of halon vapor above the fuel expressed as

$$P_v = X_{\text{Halon}} P_{\text{Halon}} \quad (\text{Eq. 3})$$

where  $X_{\text{Halon}}$  is the mole fraction of halon in the fuel, and  $P_{\text{Halon}}$  is the vapor pressure of the pure halon calculated *via* the Clausius-Clapeyron equation [12]. Equation 3 is an expression of Raoult's Law [12], which assumes that the halon/fuel mixture is an ideal solution. At first glance, this assumption appeared to be reasonable for most of the halons except for perfluorohexane, which had only limited solubility in jet fuel. To calculate  $P_{\text{Halon}}$ , the heat of vaporization,  $H_{\text{vap}}$ , (Where  $H_{\text{vap}}$  represents the unknown heat of vaporization.) of the halon is required. Because several of the heats of vaporization were not known, a correlation of  $H_{\text{vap}}$  with the boiling point  $T_{\text{bp}}$  of the halon was developed from the data that were available. Figure 1 shows a linear correlation of the known heats of vaporization,  $H_{\text{vap}}$ , with boiling points,  $T_{\text{bp}}$ , of the halons. The correlating equation expressed as

$$H = 23.21 T_{\text{bp}} - 611.7 \quad (\text{Eq. 4})$$

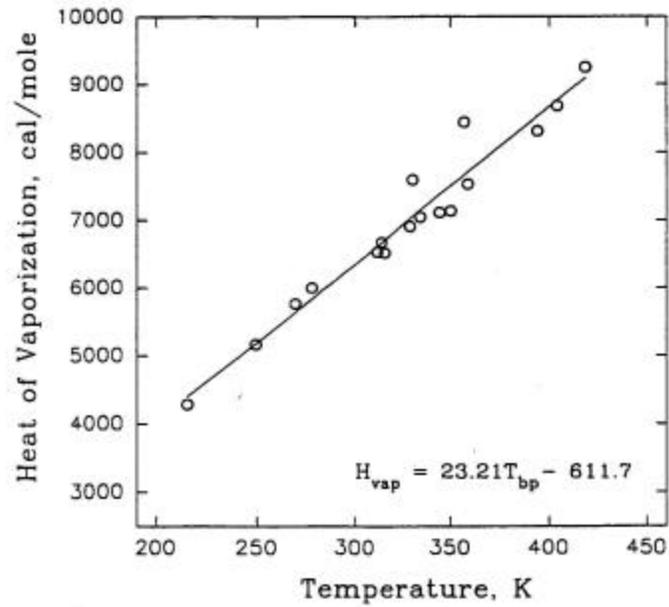
was used in the Clausius-Clapeyron equation to calculate  $P_{\text{Halon}}$ . Column 4 of Table 1 gives the results of the calculations in terms of volume percent of halon in the vapor space above the fuel.

(U) Figure 2 compares the halon vapor concentrations listed in Table 1 with the halon vapor concentrations required to suppress ignition of premixed fuel/air mixtures [11]. The flammability limit data<sup>(7)</sup> were obtained by determining the minimum volume percent of halon

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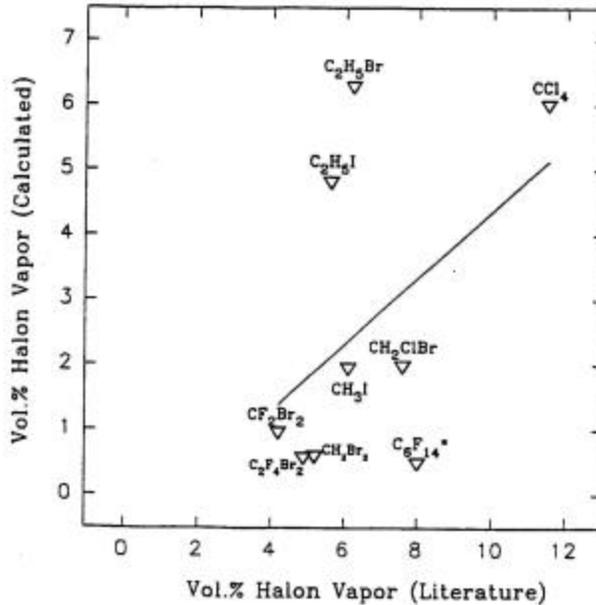
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(U) FIGURE 1.



Correlation of the heat of vaporization of halons with their boiling point temperature

(U) FIGURE 2.



**Comparison of halon vapor concentrations calculated assuming Raoult's law with values from the literature determined in flammability limit studies**

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vapor required to prevent ignition of a heptane/air mixture. These measurements were performed over a range of equivalence ratios to determine the optimum condition for ignition and flame propagation.

**3.4.2 (U) FLAMMABILITY TESTING**

**3.4.2.1 (U) Flammability Tests**

**3.4.2.1.1 (U) Flash & Fire Points by the Cleveland Open Cup Method (ASTM D 92)**—This test method determines the flash and fire point of petroleum products with flash point over 79°C and less than 400°C. The test sample is heated in an open cup at a constant rate of increase in temperature. At specified intervals a flame is passed at a height of 2 mm above the top edge of the test cup taking approximately one second to cross the test cup. The interval for crossing the cup with the flame is once for every two degrees of temperature rise. The flash point is that temperature at which the fluid produces enough vapors to ignite and instantaneously spread over the entire surface of the fluid but not continue burning. The fire point is the temperature at which the fluid will produce enough vapors to flash and then sustain a flame. A rule of thumb is that the fire point is usually occurs about 10°C higher than the flash point. Record the temperatures at which each phenomenon occurs.

**3.4.2.1.2. (U) Auto-ignition Temperature of Liquid Chemicals (ASTM E 659)**-- This test method determines the hot and cool-flame temperatures of liquid chemicals. The auto-ignition temperature is also referred to as the spontaneous ignition temperature, self-ignition temperature or autogenous ignition temperature. It is the lowest temperature at which the substance will produce a hot-flame ignition in air without the aid of an external spark or flame. In this test a sample of liquid is heated in air in a laboratory flask in a dark room for 10 minutes or auto-ignition occurs. The temperature at

which the auto-ignition flame occurs and the elapsed time from application of heat to the sample to ignition (ignition delay time) is recorded.

3.4.2.1.3 (U) High Temperature-High Pressure Spray Ignition (Federal Test Method 791, Method 6052.1)—This test method is to determine the relative flammability of liquids. It is a basically simple test wherein the test liquid under 1,000-psig pressure is sprayed through a nozzle and then the flame of an acetylene torch is inserted into the cone of the sprayed liquid at the nozzle, Figure 3. The acetylene flame is moved away from the nozzle until the spray ignites. The distance from the nozzle to the ignition point, whether or not the spray ignites easily and whether the flame extinguishes when the torch is removed are recorded.

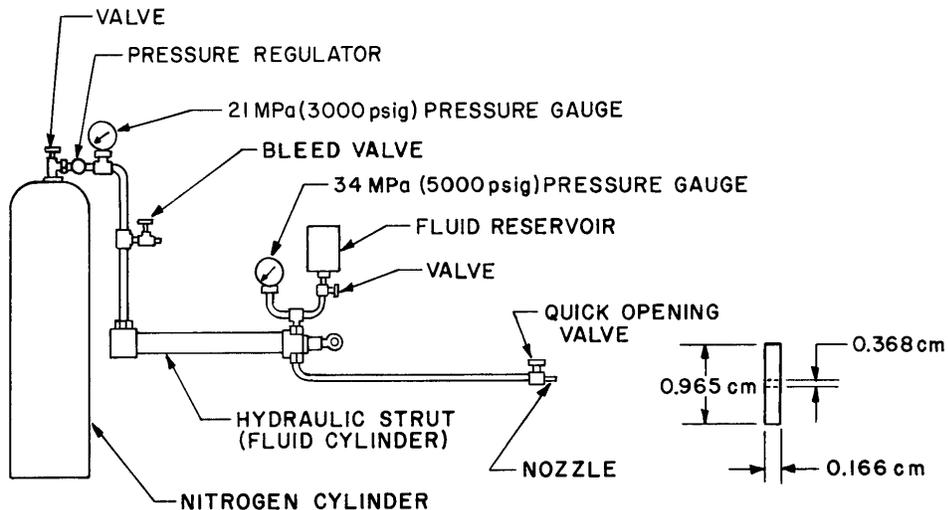
3.4.2.1.4 (U) Hot Manifold Ignition Test (Federal Test Method 791, Method 6053.1)—This test method is to determine the relative flammability of a liquid in contact with a hot surface. The fluid is dropped on a simulated manifold that is heated by an electric “Globar” type element, located inside the manifold to a temperature of 704°C (1300°F) Figure 4. The fluid is dropped on the heated manifold at a rate of 10 mL in 40 -60 seconds. The results are reported as, *a* flashes or burns on the manifold but not after dripping from the manifold, *b* does not flash or burn on the manifold but does after dripping from the manifold, or *c* Does not flash or burn on the manifold or after dripping from the manifold.

3.4.2.1.5 (U) Horizontal Flame Propagation Test--This test is to determine how fast the flames of a burning pool can be expected to spread. A series of tests will be conducted in a controlled-temperature, horizontal/flame propagation channel. The device, which is illustrated in Figure 5 comprises a test liquid channel 8.5-cm wide, 4 cm deep, and 61 cm long (inside dimensions),

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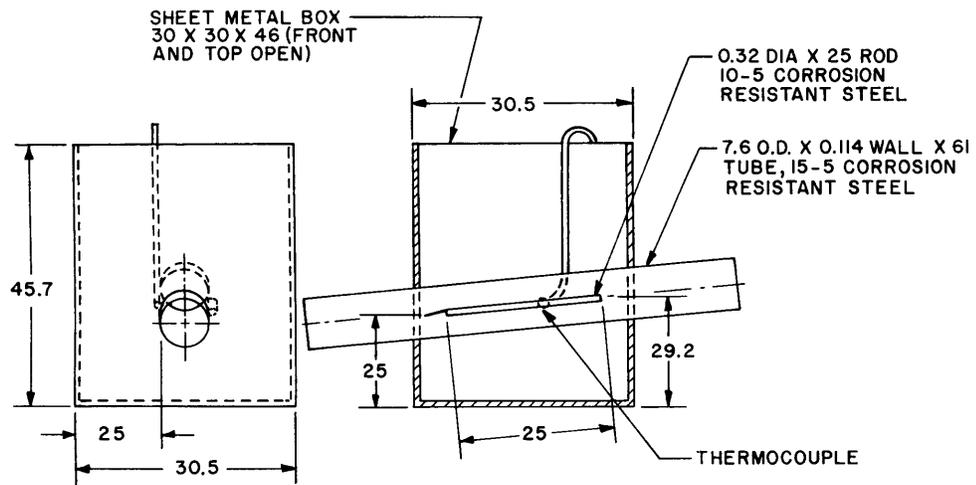
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Figure 3



Spray test setup.

Figure 4



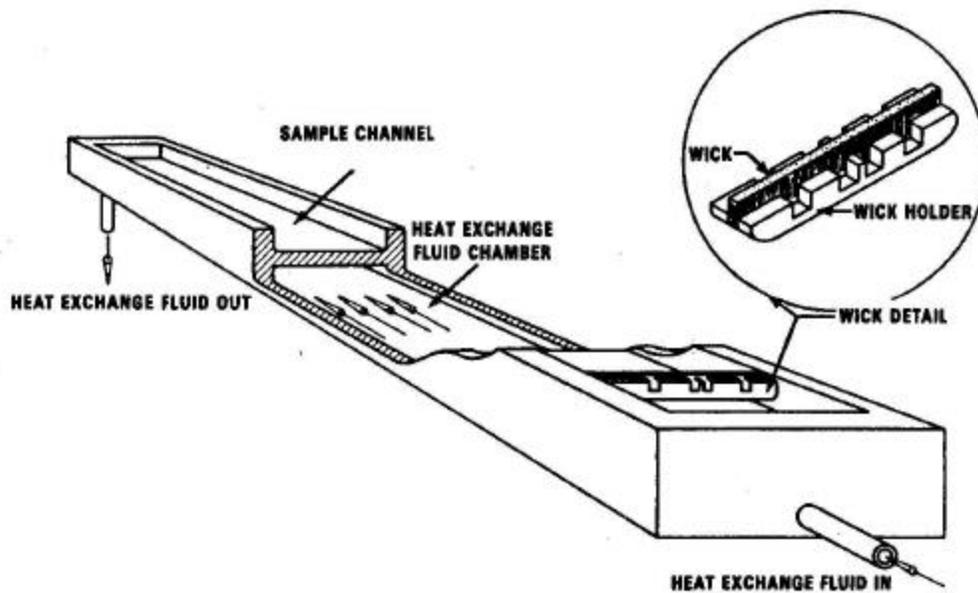
NOTE: DIMENSIONS IN CENTIMETERS.

Simulated manifold test setup.

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Figure 5



## **Illustration of Controlled-Temperature Horizontal Flame Propagation Channel**

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open on top. A closed, heat-transfer fluid chamber of identical, but inverted, dimensions forms the base of the channel. In these experiments, the fluid will be preheated in a closed vessel, while the channel was equilibrated. In each experiment, the channel is fully filled with the test fluid, and the illustrated wick was placed in the liquid 15 cm from one end of the channel. The wick was then lighted at one end, and the time required for the flame to depart from the wick (induction period) and the additional time required for it to traverse the length of the channel are recorded.

### **3.4.2.2 (U) ADDRESSING CONCERNS**

**(U)** While fire prevention is paramount in this concept, the selection of additives and their method of application will be influenced by economic and environmental concerns. Therefore, an important element in this program will be to coordinate the research with changes in suppressant agent development and availability as mandated by government regulations. It should be noted that the additives to be evaluated are liquid. They are used in low concentrations and in closed systems. These additives should not be confused with fire suppression system agents such as HALON 1301 since those agents are gaseous and are sprayed into open systems.

4.1.1.1.1**(U)** Environmental Impact Halons, as a result of their chemical stability, may enter the stratosphere. There, photolytic and chemical activities release the halogens, bromine and chlorine that catalytically destroys the Earth's protective ozone layer. The Chief of the U.S. Environmental Protection Agency (USEPA) announced in April 1991 that the Earth's ozone layer

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is thinning twice as fast as previously believed. The release into the Earth's atmosphere of compounds containing halogens can lead to a decrease in the stratospheric levels of ozone [13]. Increases in CFC and halon atmospheric trace gases can contribute to what has been called the *greenhouse warming effect* because these compounds allow the sun's energy to reach the surface of the earth, thereby warming it, while preventing much of that energy from being reradiated to outer space. Models with which these effects are calculated are not within the scope of this paper.

3.4.2.2.2 **(U)** Health Impact The ozone layer consisting of a triatomic form of oxygen, exists in the Earth's stratosphere and acts as a barrier to harmful solar rays, filtering out a large fraction of solar UV-B radiation to keep it from reaching the Earth's surface. Short wavelength UV-B radiation causes adverse biological impacts including increased risk of skin cancer, cataracts and crop damage. Other health ramifications of the additives can not be predicted such as toxicity, carcinogenicity and mutagenicity but will be addressed in the development of this project.

## **4. (U) CONCLUSION/RECOMMENDATIONS**

### **4.1 (U) CONCLUSION**

**(U)** A strong probability exists that the fire retardancy of hydraulic fluid can be improved through the use of halogenated additives. The preliminary work indicates that as little as 2 - 5 percent of such a halogenated additive combined with the current or improved U. S. military specification hydraulic fluids can virtually eliminate flammability up to 1,000-1,200 °F, an over 100 %

increase in the flashpoint. This would reduce the likelihood of crew compartment fires in combat vehicles and thus the crew survivability.

#### 4.2 (U) RECOMMENDATION

(U) It is recommended that the gain in survivability offered by this increase in the flashpoint of hydraulic fluid be further pursued.

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