CREW COMPARTMENT LIVE FIRE TEST RESULTS WITH HYBRID FIRE EXTINGUISHERS

R. (Mitch) Mitchell
Primex Aerospace Company
Rcdmond, WA 98073-9709, USA

ABSTRACT

Two Hybrid Fire Extinguishers (HFE) have successfully met performance requirements for extinguishing crew compartment fires during testing conducted at Aberdeen Proving Grounds (APG), MD. The two HFE systems were developed at Prirnex Aerospace Company (PAC). Testing was sponsored and funded hy TACOM as part of the halon replacement program The intent of the TACOM crew compartment program is to evaluate technologies that are viable replacements for Halon 1301.

The PAC HFE is composed of (1) an initiator, (2) a solid propellant (FS01-40), and (3) the fire suppression agent (either HFC-227ea or a water-based solution). An electrical or mechanical stimulus ignites a small pyrotechnic charge in the initiator. Hot particles from the initiator then ignite the solid propellant. As the solid propellant burns, pas composed of CO_2, N_2, and H_2O (vapor) is evolved. The propellant gas heats. pressurizes. mixes with. and expels the agent into the crew compartment. The agent is discharged from the extinguisher in less than 100 msec.

The TACOM crew compartment program has two phases: (1) Basic Contracts Requirements (BCR) and (2) Option I. Participation in the Option 1 phase is based upon the success in the BCR phase. In the BCR test series. a set of experiments was designed to evaluate the HFE design parameters deemed important to minimize fire-out time. heal tlux. and acid gas production. Threats tested included spray fires and ballistic projectiles. Test data were compared to contract performance specifications and with baseline Halon I301 data. As a result of the design of experiments. the HFC-227ea HFE demonstrated *superior performance* to Halon 1301 on a weight basis.

The HFE system was selected by TACOM for the follow-on Option I testing. This test series further challenged the extinguisher's capabilities by adding clutter to the fixture and evaluating performance at cold conditions. During ballistic testing. both the water-based and HFC-227ea HFE systems demonstrated *superior performance* to Halon 1301 on the basis of weight. volume. temperature. and extinguisher quantity. Both HFE systems have the potential to meet requirements as a *bolt-Or replacement* for current Halon 1301 systems.

INTRODUCTION

Since 1993, Primex Aerospace Company (PAC) has been introducing novel technology to the fire suppression industry for replacing Halon 1301. PAC Solid Propellant Fire Extinguishers (SPFE) are currently in production on the V-22 and F/A-18E/F aircraft for dry bay fire protection (Figure l). The PAC SPFE discharges a gaseous mixture of carbon dioxide. nitrogen, and water vapor by burning solid propellant (Figure 2). Testing has shown that the SPFE requires a quantity of agent similar to Halon 1301 on a mass basis. Since the density of i- solid propellant is greater than liquid Halon 1301, the SPFE occupies a smaller volume. However, SNAP approval currently limits the propellant (FSOI-40) used in SPFE for use in unoccupied spaces mainly due to oxygen depletion issues. Therefore. PAC has concluded that alternate extinguisher technologies would be better suited for occupied spaces.

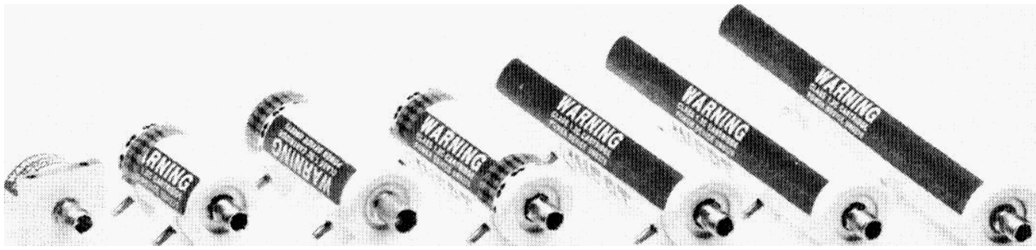

Figure 1. PAC SPFE are currently in production on the V-22 and F/A-18E/F aircraft.

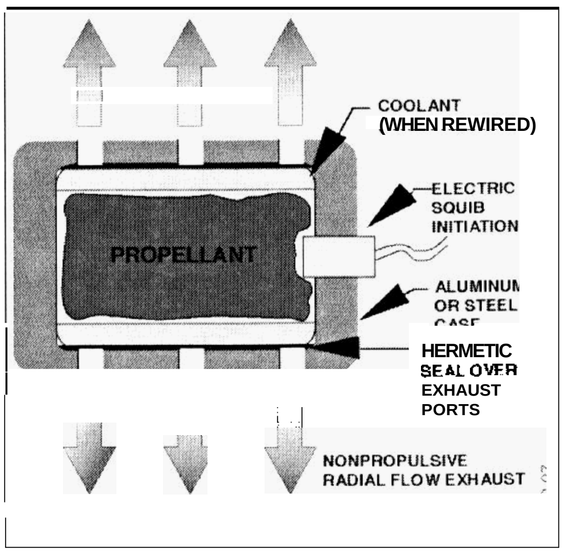

Figure 2. Solid Propellant Fire Extinguisher **(SPFE).**

PAC began developing Hybrid Fire Extinguishers (HFE) in 1994 for fire protection applications. Several HFE versions have been tested in fire fixtures since then. These extinguishers use a small quantity of solid propellant to produce gas, which pressurizes, heats, mixes with, and expels an agent (Figure **3).** HFE agents evaluated to date include CO_2, water (based), HFC-227ea, and PFC-614.

Hybrid technology dates back over 30 years. Typical hybrid applications include inflation systems such as aircraft escape slides (Figure 4), helicopter flotation (Figure 5), and automotive airbag applications.

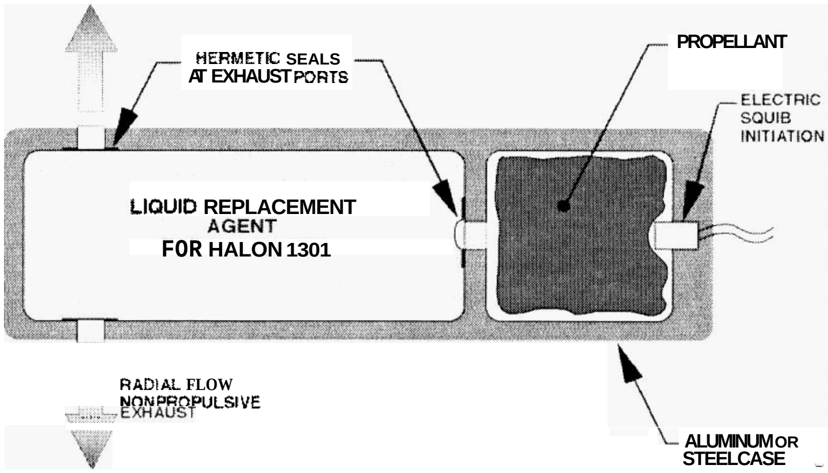

Figure 3. Generic Hybrid Fire Extinguisher (HFE).

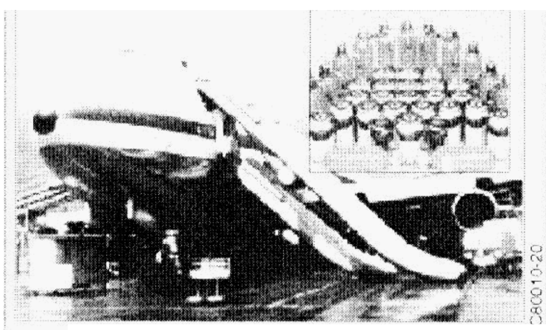

Figure 4. 747 Escape slide.

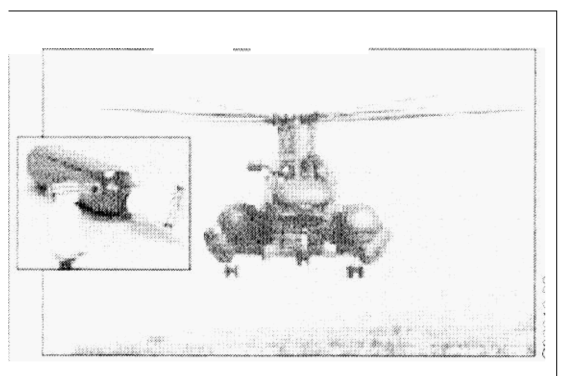

Figure 5. Helicopter flotation.

For *occupied spaces*, a HFE has advantages compared to a SPFE. The high exhaust temperature (>1000 ºF) of solid propellants is not desired. A HFE can provide exhaust temperatures as low as 50 ºF over ambient. Also, the gas expelled from solid propellants typically requires high agent concentrations to extinguish a fire. This can result in a low oxygen concentration. which is not desired in occupied spaces. An HFE can utilize agents with low concentration requirements (typically 7 to 10%) resulting in higher oxygen concentration. An HFE also discharges less particulate dust than a SPFE because less propellant is used.

A HFE has several advantages compared to conventional Halon 1301 and replacement agents. Since the pressurizing gas is stored in solid form until activation, the HFE requires no nitrogen charging. Therefore, the agent storage pressure is much lower. Ambient storage pressure of an HFE charged with HFC-227ea is around 60 psig. This compares favorably to 750 psig for typical nitrogen charged system. As a result, the lower storage pressure reduces leakage potential and improves the safety aspects associated with pressurized devices. In addition, the gross agent storage density can be higher for an HFE because no volume is needed for the nitrogen. As a result, the extinguisher can be packaged in a smaller volume. Extinguisher performance is often a function of how well the agent is distributed. The vapor quality of an agent will affect the ability to achieve homogeneous distribution. The vapor quality X is defined to be the ratio of the mass of the vapor, m_g, to the mass of the mixture, m as follows:

$$X = m_g / m = m_g / (m_g + m_f)$$

Where: m_f is the mass of the liquid, m_g is the mass of the vapor and $m_f + m_g = m$

Some agents such as HFC-227ea and HFC-236fa have been classified as streaming agents due to their high boiling points and low vapor quality. Upon activation, the HFE increases the vapor quality of an agent by heating and pressurizing. This improves the distribution and extinguishing performance of the agent, especially in cold conditions.

Because of the perceived advantages of using a HFE, PAC developed a HFE for the specific purpose of evaluating the design parameters to determine which are important in extinguishing crew compartment and other occupied space fires. Design and development of the HFE was funded by PAC IR&D funds. This extinguisher (Figure 6) was used to support crew compartment testing for TACOM funded under contract number DAAE07-97-C-X131. The important design parameters obtained during testing will be incorporated into a production concept.

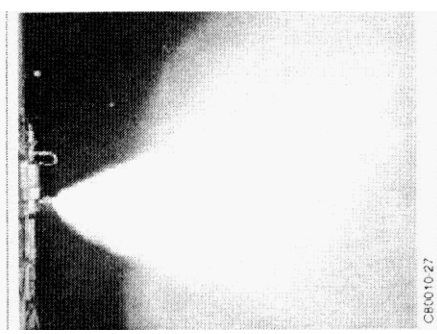

Figure 6. HFE in operation.

TACOM CREW COMPARTMENT TEST PROGRAM OVERVIEW

The TACOM crew compartment test program consisted of two phases: the Basic Contract Requirements (BCR) phase provided initial screening of contractor's extinguisher; a follow-on Option 1 phase was awarded by TACOM based upon the performance achieved in the BCR phase. Aberdeen Test Center (ATC) personnel performed the testing at Aberdeen Proving Grounds, MD.

In both phases, threats tested against included spray fire (fireball) and ballistic (shape-charge) events. Test data were compared to technical requirements and performance demonstrated with conventional Halon 1301 nitrogen-charged extinguishers. ATC personnel performed the Halon 1301 testing using existing 5 lb (144 in^3) and 7 lb (204 in^3) halon extinguishers.

Pertinent test data measured included fire-out time (IR and video), acid gas production, heat flux, temperature. pressure, agent, and oxygen concentration. Test requirements of the contract included (1) fire-out time <250 msec, (2) acid gas production <1000 ppm, (3) heat flux <2400 °F-sec, (4) pressure <1 1.6 psid, and (5) O_2 level >16%, and (6) agent level <NOAEL. Real-time measurements of fire-out time and acid gas production were used to make test configuration decisions.

The test fixture, shown in Figure 7, contains about 450 ft^3 of volume (gross) to be protected. A total of four extinguisher locations were provided but were not always utilized. During the BCR phase, no clutter was utilized. Clutter added to the Option 1 testing included mannequins and TOW missile simulators to further challenge the extinguisher's capabilities.

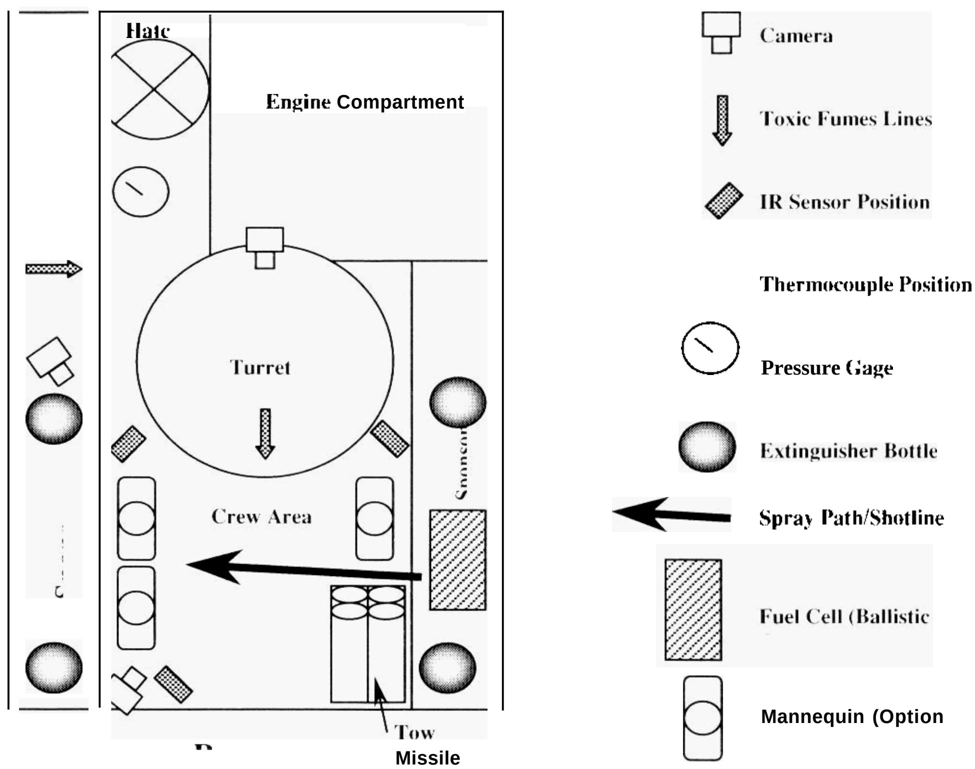

Figure 7. Test fixture.

BCR TESTING

For the BCR phase, PAC was awarded a contract to evaluate two hybrid extinguishers. One HFE used HFC-227ea (FM-200) as the agent while the other contained a water-based agent.

The refurbishable solid propellant cartridge used to heat, pressurize. and expel the agent was designed to accommodate between 150 and 400 grams of FS01-40 propellant. The amount of propellant needed for each HFE was a function of the quantity of agent used. The cartridge was characterized in 25-gram increments to provide uniform performance.

The HFC-227ea HFE was designed to provide a constant 70.5 lbs/ft^3 fill density regardless of agent load. This was achieved by utilizing two different bottle sizes (4 and *6* lbs) with internal sleeves to decrease the volumes as needed. **As** a result, the HFE could discharge 3 to *6* lbs of HFC-227ea in 1 lb increments. The ratio of solid propellant to HFC-227ea was adjusted to provide a consistent exhaust temperature.

Initially, spray fire threat testing was used to determine the critical design parameters associated with extinguishing the fire. This was accomplished by setting up a Design of Experiments (DOE) matrix. **A** baseline total agent weight of 12 lbs of HFC-227ea was used in three extinguishers **(4** lbs agent each) for all DOE tests. Bottle positions 1, 2, and 3 (Figure 7) were used. HFE design variables were changed in each test to affect parameters such as distribution, flame strain. agent vapor quality, and acid gas scavenging.

Figure 8 presents the fire-out times for the DOE tests. Using a total of 12 lbs of HFC-227ea, fire-out times ranged from 289 msec (Test D1) down to 117 msec (Test D13). Tests D8, F10, F3, D10, and D13 demonstrated the best fire-out times.

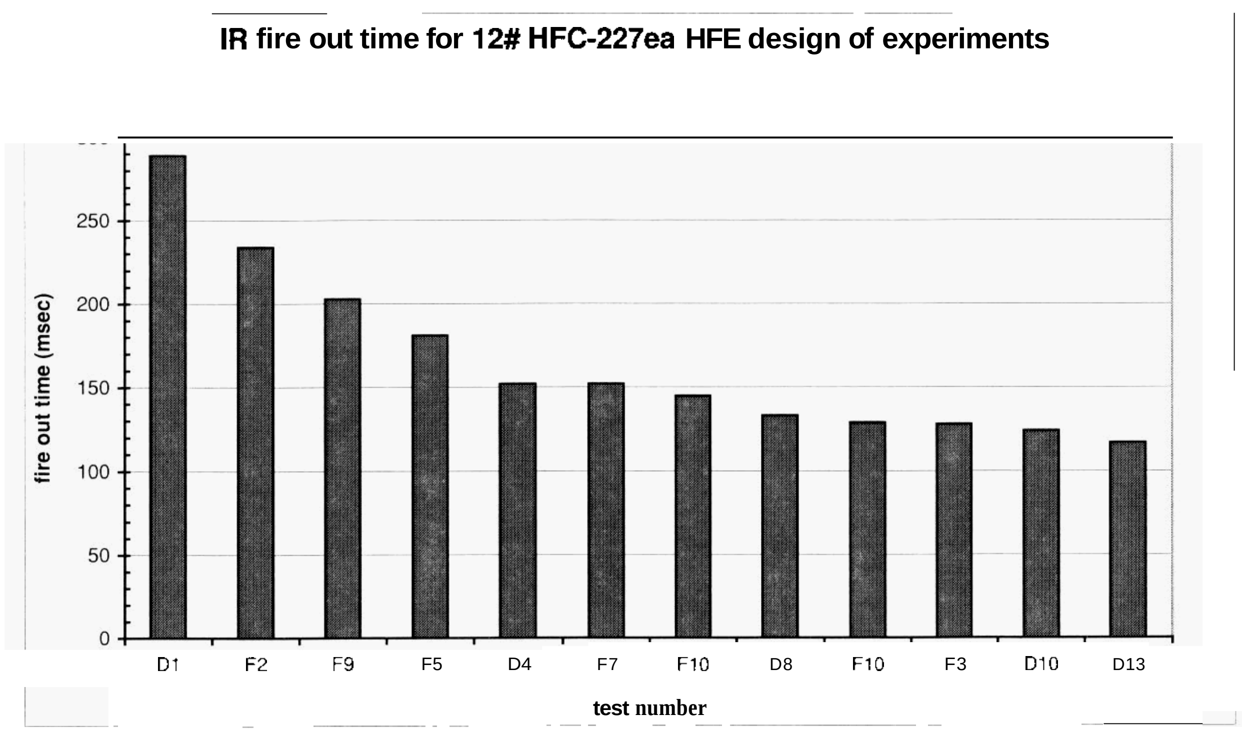

Figure 8. Fire-out times recorded during 12 lb HFC-227ea HFE design of experiments.

Figure 9 presents the acid gas production measured for the spray fire DOE tests conducted. Generally speaking. acid gas production was decreased with a reduced fire-out time. However, the addition of a HF scavenger to the HFE also greatly reduced acid gas production. Tests D13, F7, F5, and **F3** demonstrated the lowest acid gas levels measured. Combining the fire-out time and acid gas data resulted in design configurations for Tests D13 and F3 being selected for ballistic testing.

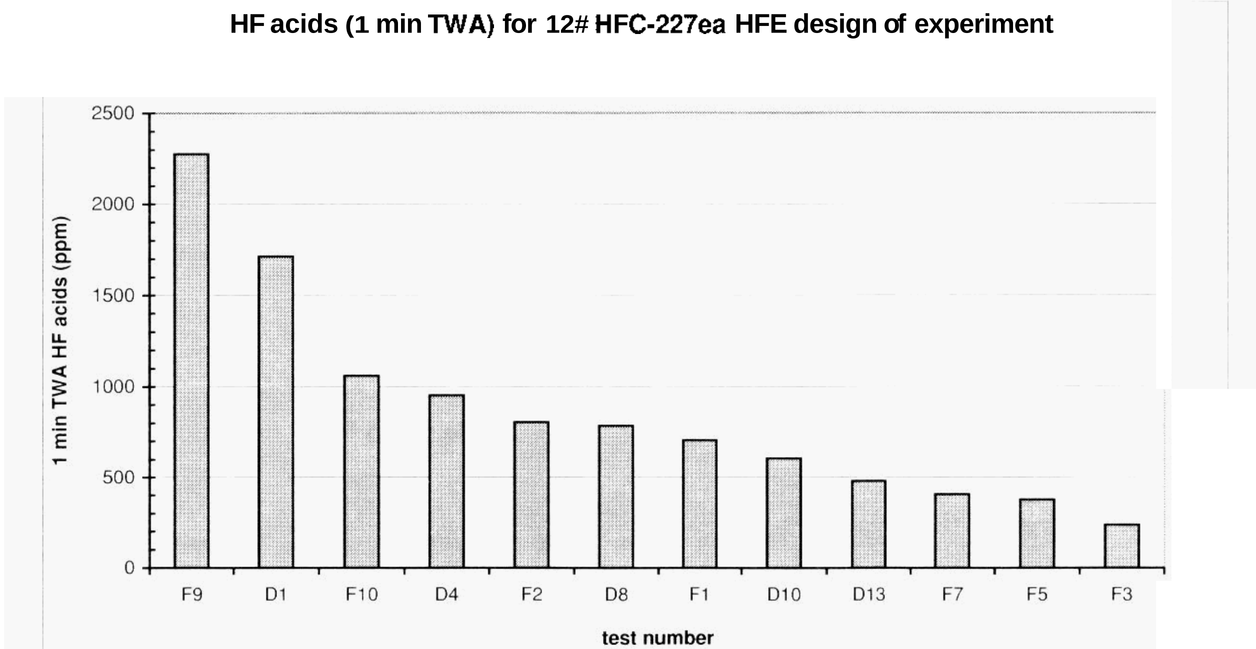

Figure 9. Combined acid gases measured during 12 lb HFC-227ea HFE design of experiments.

At completion of the DOE testing, PAC conducted ballistic testing with the best HFC-227ea HFE configurations. Testing initially used *three* each HFE bottles (4 lbs each) in positions 1, 2, and 3 (Figure 7). Later testing evaluated *two* each HFE bottles (**6** lbs each) in positions 1, and 2. Figure 10 presents the fire-out times for the HFE configurations with a total of 12 lbs of HFC-227ea agent. A test with *three* each HFE bottles (one each 4 lbs, two each 3 lbs) with a total of 10 lbs HFC-227ea was also performed (Figure 10). The performance of the best 10 lb (total) Halon 1301 system with *two* (5 lbs each) and *three* (3.33 lbs each) bottles is shown for comparison. With *three* each bottles, the 10 lbs and 12 lbs (total) HFC-227ea HFEs outperformed 10 lbs of Halon 1301. In this bottle configuration, total volume for the HFE is less than Halon 1301. With only *two* bottles, the HFC-227ea HFE still outperformed Halon 1301. However, the total agent volume of the HFE system is slightly greater than Halon 1301.

Total acid gases were measured for the ballistic tests conducted with the HFC-227ea HFE. Data presented are 1 min Time Weighted Average (TWA) of two sorbent and two impinger analysis techniques. Figure 11 shows that the production of acid gas with the HFE was similar to or lower than Halon 1301. This is largely due to the faster fire-out time and scavenger added to the HFE, which tends to reduce HF production. It should be noted that acid gas production was always higher when using two extinguishers, which is largely due to the longer fire-out time required.

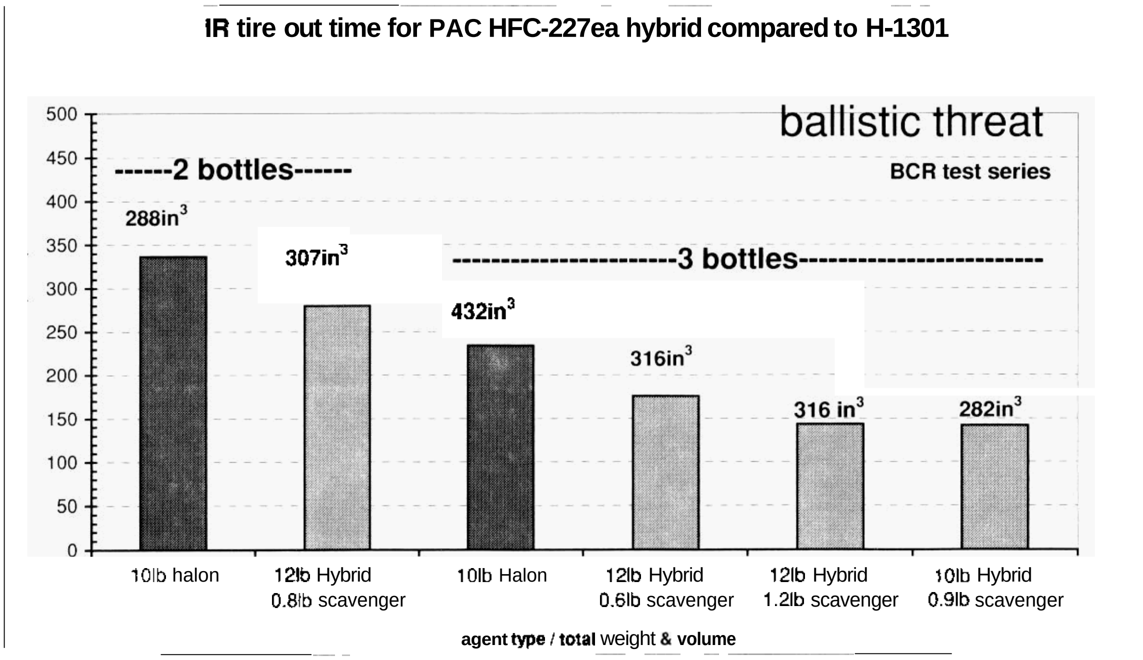

Figure 10. Fire-out times for HFC-227ea HFE during BCR ballistic testing.

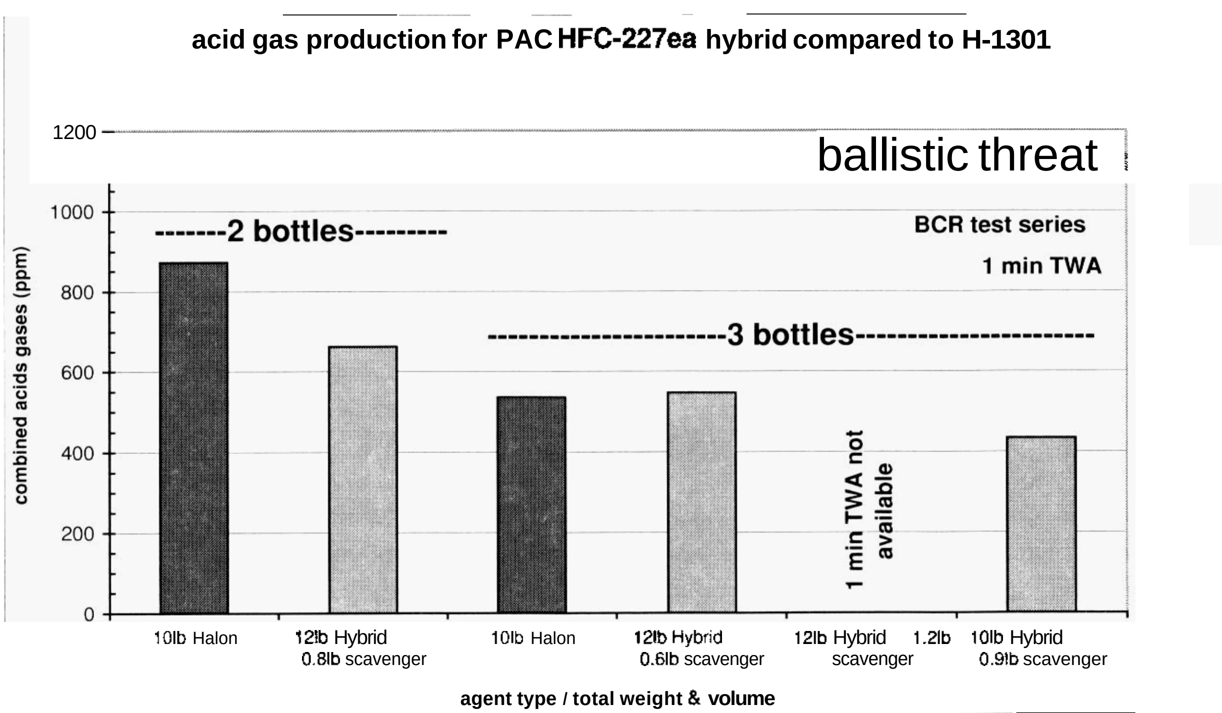

Figure 11. Combined acid **gas** for HFC-227ea HFE during BCR ballistic testing.

OPTION 1 TESTING

As ***a*** result of the successful BCR testing, the PAC HFE was selected by TACOM for additional Option 1 testing. This test series included the addition of clutter and specific tests to evaluate low temperature (-25 ºF) performance.

Aluminum mannequins and TOW missile simulators wcrc added to the fixture as clutter. The placement of the mannequins provided a very difficult scenario to protect against because the mannequins were placed directly in front ofthe extinguishers. This limited the ability of the extinguisher to provide three-dimensional agent coverage. Similarly. the stacked TOW simulators provided areas wherc agent dispersal could he difficult.

Two HFE agents wcrc successfully evaluated during this test series: HFC-227ea and a water-based agent. The water-based agent is composed of water, ***a*** freezing point depressant. and surfactant. The freezing point depressant enables operation of the water HFE down to temperatures of –65°F. A specific gravity of 1.8 was measured for the water-based agent.

Ballistic testing conducted to date (with cluttcr) has indicated that Halon 1301 only meets the contractual specifications when *four* extinguishers are used in positions 1, 2. 3, and 4. However, using positions 1, 2, and 3, ***a*** 16 lb (total) Halon 1301 system extinguished the fire in 344 msec. Since reducing the quantity of extinguishers required is very desirable. PAC focussed efforts on demonstrating success with only *two* or *three* extinguisher locations.

As shown in Figure 12, using three bottles. the HFE had successful fire-out times with ***a*** total of 12 and 18 lbs of HFC-227ea agent. The I2 lb HFE using *three* each 4 lb bottles performs equivalent to 12 lbs of Halon 1301 with *four* each 3 lb bottles. Limiting the HFE system to *two* bottles, 18 lbs of total agent is required meet the <250 msec fire-out time. A HFE system with *two* 7.5 lb bottles of HFC-227ea (15 lbs total) provides identical fire-out time to **a** 16 lb total Halon 1301 system using ***three*** bottles. At the end of the test series. a 12 lb (total) HFE with *three* bottles of HFC-227ea was tested at –25 ºF. A successful fire-out time of 203 msec was recorded.

Figurc 13 presents the HF data for the ballistic tests conducted. Total acid gas production for the Halon 1301 tests are not presently available. Therefore. FTIR analysis of HF gas is provided for comparison purposes. The data presented are time-weight averaged over *2* min. The HFE with scavenger provided ***a*** significant rcduction in HF regardless of the quantity of bottles used.

The PAC water-based HFE was **also** tested using *three* bottles in positions 1.2. and 3. Two identical tests were performed with a total of 10 lbs of water-based agent. Figure 14 presents the fire-out times for the HFE with this agent and provides comparisons to the Halon 1301 systems tested. Both water-based HFE tests yielded identical 230 msec fire-out times. Thus, using *three* bottles. the water-based HFE is equivalent to the same quantity of Halon 1301 using *four* extinguishers.

Since there are no fluorine, chlorine, or bromine compounds in the water-based agent. thcrc are no acid gas byproducts to measure. This was confirmed by FTIR measurements during testing.

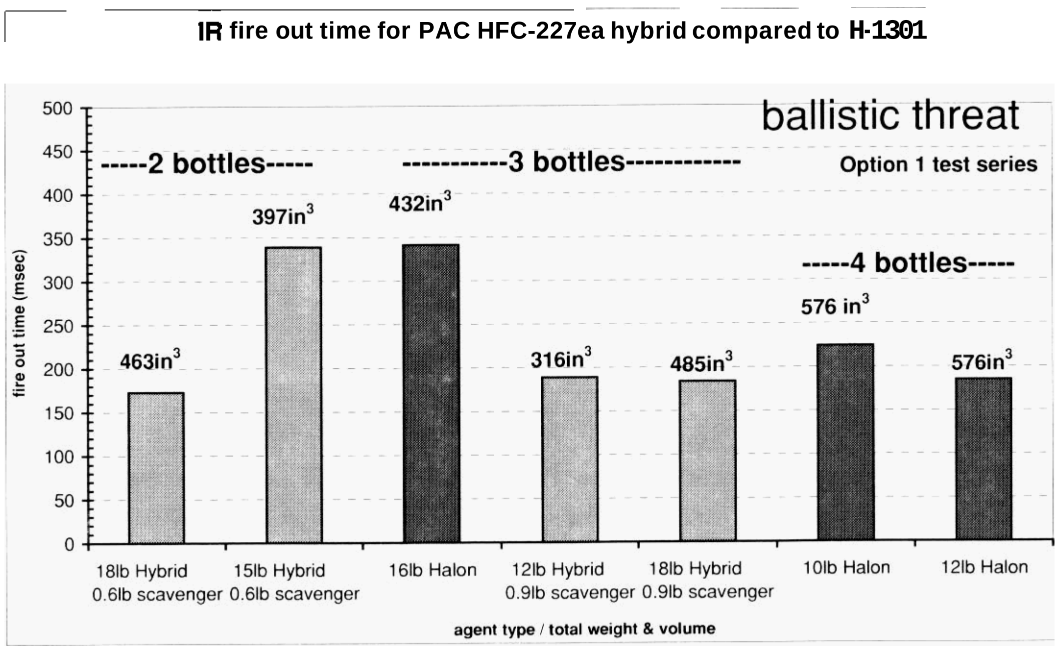

Figure 12. Fire-out times for HFC-227ea HFE during Option 1 ballistic testing.

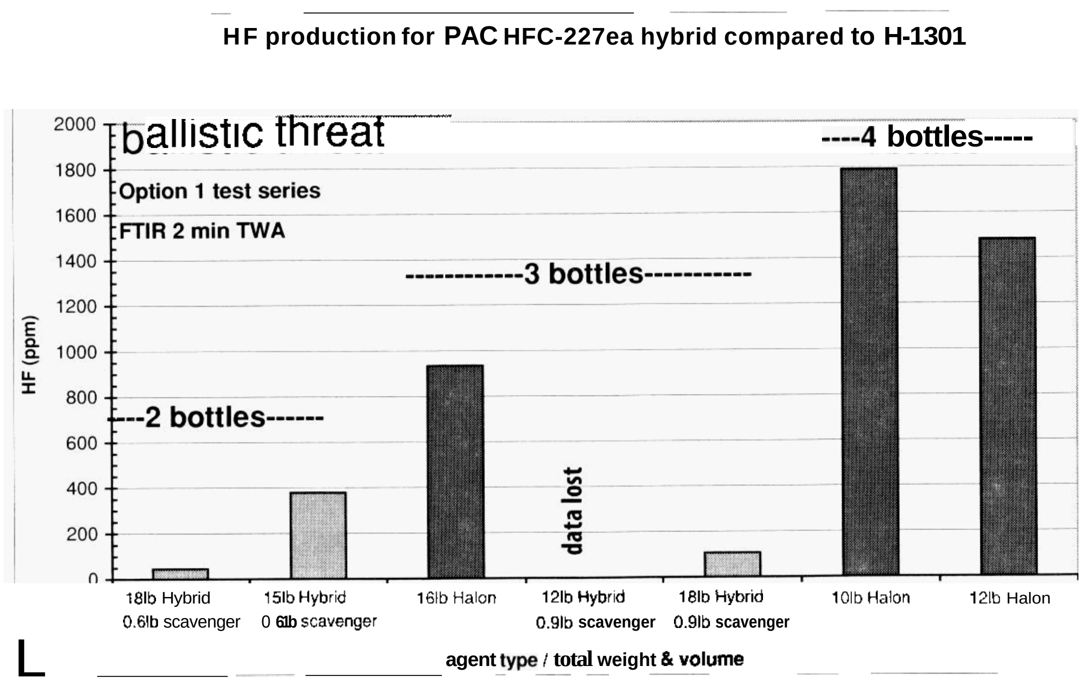

Figure 13. HF production for HFC-227ea HFE during Option I ballistic testing.

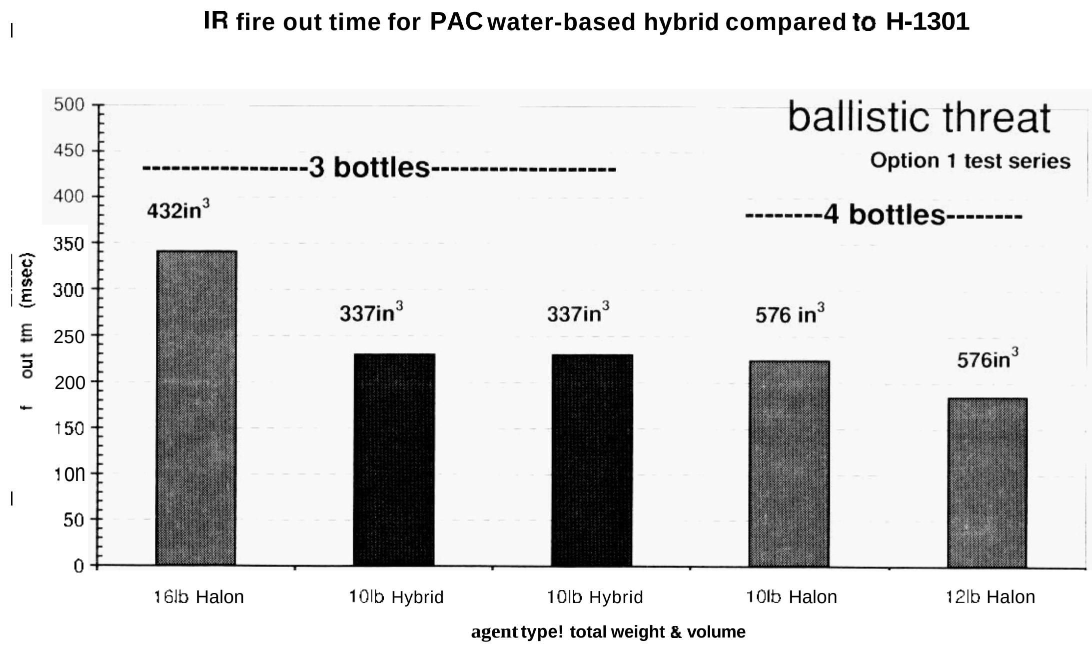

Figure 14. Fire-out times for water-based HFE during Option 1 ballistic tcsting

SUMMARY

The BCR spray fire testing concluded that the HFE design significantly affects the performance. Factors such as agent distribution, llame strain, and vaporization are important parameters. A smaller extinguisher can be used if the HFE is optimized for the specific application. In the BCR ballistic test series where there is no clutter, the HFC-227ea HFE with scavenger demonstrated superior performance to Halon 1301 on a weight and volume basis.

During the Option 1 ballistic test series, the water-based and HFC-227ea PAC HFE showed superior fire-out performance to Halon 1301 on a weight, volume, temperature, and bottle quantity basis. Acid gas levels are *significantly lower* with HFC-227ea HFE and *nonexistent* with the water-based HFE. Compared to Halon 1301 system of equal agent weight, either HFE can provide equivalent fire-out performance *with one less extinguisher*. If the same quantity of bottles and agent is used, significant performance improvements can be realized with a HFE. The TACOM crew compartment test program demonstrated that both PAC HFE systems have the potential to meet the requirements as a *bolt-in replacement* for current Halon 1301 systems.

ACKNOWLEDGMENT

The author acknowledges Steve McCormick and his crew at TACOM for their effort in funding and supporting this project.