Fire Test Results For
Solid Propellant Inert Gas Generators In The
Walter Kidde Aerospace Dry Bay Fire Simulator

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Abstract

Walter Kidde Aerospace (WKA) has teamed with Atlantic Research Corporation (ARC) to develop solid propellant inert gas generator fire extinguishing systems for aviation applications. One of the aims of the WKA/ARC team has been to develop an inert gas generator composition for dry bay fire protection. WKA has designed a unique dry bay fire simulator and ARC has developed a family of solid propellant gas generators to achieve this goal.

The WKA dry bay fire simulator incorporates many of the important parameters associated with dry bay fire protection including:

- External airflow up to 300 knots
- Internal airflow
- Low temperature test capability
- Bleed air duct rupture simulation
- Realistic fire challenge (fuel spray ignited by incendiary)

The dry bay test vessels are modular in design to allow the simulation of either 'slim' wing leading edge or more 'rectangular' wheel well dry bays. It is believed that the WKA facility offers a realistic, reproducible and inexpensive method of evaluating various fire suppressants under realistic dry bay fire conditions.

Testing in the WKA dry bay fire simulator has shown the inert gases produced by the WKA/ARC gas generators exhibit the excellent three dimensional distribution essential for dry bay fire protection. The inert gas generator compositions developed by the WKA/ARC team have the following characteristics:

- Generate nitrogen, carbon dioxide and water vapor
- Produce high gas yield > 4 moles per 100 g
- Leaves essentially no residue in the container or in the dry bay after discharge

Initial test results suggest the WKA/ARC inert gas generator will offer an effective and environmentally friendly option for dry bay tire protection.

1. Introduction

Studies performed at Wright Patterson Air Force Base in the 1980's showed that Halon 1301 was a suitable agent for dry bay fire protection'. Halon 1301 was an effective suppressant and, due to its high volatility, was capable of good dispersion throughout cluttered dry bays. Unfortunately, due to its adverse environmental properties, Halon 1301 may not be a candidate for dry bay fire protection for much longer. However, recent dry bay fire testing showed that Halon 1301 out-performed all the currently available Halon replacements, therefore, a weight and volume competitive replacement is needed'.

Walter Kidde Aerospace (WKA) has teamed with Atlantic Research Corporation (ARC) to develop fire protection systems based on solid propellant gas generators. The WKA/ARC team believes that solid propellant gas generator technology could offer a number of efficient yet environmentally friendly solutions to the loss of the Halon 1301 particularly in the dry bay application.

To aid the development gas generator technology, WKA has developed a unique dry bay fire simulator to screen prototype extinguishers under realistic dry bay conditions. Initial studies in the dry bay simulator have focused on Halon 1301 and solid propellant **inert** gas generator testing.

2. Background

2.1 The Drv Bav Fire Threat

The primary threat from fire and explosion in military aircraft occurs during combat situations'. The threat mechanisms and damage processes depend upon what type of projectile impacts the aircraft (e.g. high explosive incendiary) and where the first point of impact occurs. Early dry bay studies showed that a 23 mm high explosive incendiary (HEI) impact caused a significant fire event and this fire threat is commonly employed when evaluating alternate agents[3]. The impact events are shown in Figure 1 and are reported to be':-

(I) A delayed-fuse HEI round penetrates the aircraft outer skin generating spall and an impact flash.

(II) After 400 microseconds, the high explosive detonates. This generates a blast pressure wave (up to 100psig) and a pressure pulse due *to* the products of detonation; no residual increase in static pressure is noticed because of the vent left by the round penetration. The detonation causes the projectile casing to fragment and propels burning incendiary throughout the dry bay. The HEI fragments and projectile remnants impact a fuel tank and/or hydraulic lines.

(III) Fuel exits the fuel tank puncture holes and ignites on the burning incendiary. It should be noted that the time between HEI impact and fire ignition can vary between 34 ms and 203 ms[1].

The severity of the dry bay fire threat also depends upon a range of variables including fuselage damage ***area,*** air velocity and orientation over the damage area, air temperature, altitude, dry bay volume and internal damage caused by the round such as bleed air duct rupture. These parameters affect the quantity (number of moles) of oxygen available to support combustion. The fire size will also depend on fuel flow rate, type, temperature and droplet size.

Agent suppression performance will be a function of the severity of the dry bay fire, clutter, detector response time, agent mass and discharge rate and the position of the extinguisher relative to the fire source.

The dry bay fire threat places stringent demands on the fire suppression system and agent.

2.2 Solid Propellant Gas Generators

Solid propellant gas generators produce N,, CO,, and H_2O by the combustion of a solid propellant grain. These inert gases bring about extinguishment by oxygen dilution and heat abstraction. The inert gases generated are environmentally friendly (zero ozone depletion potential) and leave essentially no residue after discharge. In addition, gas generators store the agent in the form of solid grains and therefore no pressure leakage concerns are associated with the use of these systems.

The WKA/ARC team are focusing on the development of gas generator systems for aircraft engine nacelles and dry bay applications. The multi-application potential of gas generator based devices requires discharge times ranging from 100 ins to many seconds. The WKAIARC team use the propellant burning rate law to tailor gas generator discharge times to the needs of the fire challenge:

$$M = k \rho A, P''$$

where:-

M	=	mass burning rate ($g\ s^{-1}$)
P	=	propellant density ($g\ cm^{-3}$)
A_s	=	burning surface area (cm^2)
P	=	chamber pressure (bar)
k & n	=	constants

Usually discharge rates are modified by altering the propellant burning surface area and/or chamber burning pressure. For example, a rapidly acting dry bay gas generator unit will employ propellant in the form of pellets to maximize the burning surface area while an aircraft engine nacelle gas generator needs a much longer discharge time so the propellant burning surface area is reduced by using a single grain.

3. Dry Bay Fire Simulator

3.1 Drv Bav Fire Simulator Capabilities

The **WKA** Dry Bay Fire Simulator (DBFS) aims to model the combat-induced dry bay fire threat as follows:

(i) Simulated external airflow over the damage area: The external airflow system is supplied by eight 8 ft^3 storage tanks pressurized to 500 psig (Figure 2). A 2" x 20" external air flow nozzle can be placed at various angles to the dry bay damage area. Air velocities of 300 to 400 knots can be maintained over the 1 ft^2 damage area for 5 s by means of a pressure regulator. Figure 3 shows the external airflow nozzle in the test position, close to the damage area.

(ii) Simulated bleed air duct rupture: The bleed airflow system is supplied by eight 8 ft^3 storage tanks at a pressure of 100 psig (Figure 2). The bleed airflow outlet protrudes 6" into the dry bay test article and is positioned opposite the 1 ft^2 damage area (Figure 3). The bleed airflow rates from 2 to 25 lb/s are available.

(iii) Dry bay test vessels: Dry bay test vessel volumes from 3 to 24 ft^3 are available. These volumes can be arranged in various configurations to simulate either wing leading edge dry bays or wheel well dry bays. The dry bay test vessels can accommodate 20 % or 40 % clutter packages consisting of 6" x 6" x 12" aviation boxes, 3" diameter pipe and ½" diameter pipe.

(iv) Cooling system: Dry bay fire tests can be performed at low temperatures by sealing the test vessel and recirculating air through a dry ice/alcohol chiller. Air temperatures of -40" F and surface temperatures of -20" F can be achieved.

(v) Ignition energy: A 10 kJ Sobbe chemical igniter can be used to initiate the dry bay fire. The squib is positioned directly in front of the fuel nozzle. The ignition energy is based upon the heat of combustion of the incendiary material contained in a typical HEI round.

(vi) DBFS fire: The DBFS fire threat is supplied by Jet-A fuel flowing through a Spraying System's 7N-26 nozzle (multi-orifice). The multi-orifice nozzle attempts to simulate the 23 HEI fragment/round remnant fuel tank puncture wound. The nozzle is positioned at the rear of the dry bay vessel 10" from the center line of the 1 ft^2 damage area to model a 30° shot angle. The Jet-A fuel is contained in a 2 liter reservoir and heated to 100°F before each test. The fuel is pressurized to 10 psig and this pressure is maintained during discharge by means of a regulated nitrogen cylinder. Fuel flow actuation is controlled by a ½" pneumatic ball valve.

3.2 Instrumentation. Data Collection and Control Svstems

The DBFS uses a range of instrumentation to monitor test conditions including:

(i) A 0 to 15 psig pressure transducer (Omega #236PC15GW) to monitor external air nozzle pressure.
(ii) A 0 to 200 psig pressure transducer (Taber #260) to monitor bleed air nozzle pressure.
(iii) A 0 to 50 psia pressure transducer (Taber #254) dry bay test vessel pressure.
(iv) Pressure transducers (Piezotronic #101A03) to measure Halon 1301 extinguisher gas generator discharge pressure time characteristics.
(v) Fuel flow, ignition and suppressor discharge event markers.
(vi) Fast response (0.005" diameter) type "K" thermocouples to monitor vessel temperature.

(vii) A high-speed camera (Red Lake Laboratories, HYCAM K20S4E) operating at *500* frames per second (fps) and VHS video record tests.

Test data are collected and stored by a WKA designed data collection system based on National Instruments LAB Windows/CVI, sampling at a rate of 1000 **Hz. All** the dry bay events (except the external airflow) are controlled by "Omron" timers (#H5BR-B-AC 100-240) which are programmable in 1 ms steps. The external airflow pressure regulator is controlled by a separate programmable timing system.

A typical suppression test procedure is as follows:
(i) Charge the external airflow tanks to 500 psig.
(ii) Charge bleed air tanks to 100 psig.
(iii) **Cool** test vessel (if necessary).
(iv) Set timing sequence.
(v) Set up data collection system.
(vi) Install gas generator or Halon 1301 suppressor.
(vii) Charge fuel system.
(viii) Install fire igniter.
(ix) Heat fuel.
(x) **Start** video.
(xi) **Start** timers.

Pre-bum times of 50 ms are typically used; these are based on the worst case scenario response time expected for a non-discriminating detector based system.

The unique DBFS offers the capability of examining the fire suppression performance of alternate agents under realistic conditions without the expense of large scale testing.

4. Preliminary Results for Halon 1301 and an Inert Gas Generator in the DBFS

4.1 DBFS Test Conditions

The extinguishing concentrations for Halon 1301 and a WKA/ARC inert gas generator composition (FS-55) were determined for the following test conditions:

Condition 1: External airflow, ambient temperature
Condition 2: External airflow, bleed airflow, ambient temperature
Condition 3: External airflow, low temperature
Condition 4: External airflow, bleed airflow, low temperatures

The following parameters were held constant:

- Volume = 12 ft^3 **(20**" x 18 " **x** 57.6")
- Fire size = 3 MW
- Ignition energy = 10 kJ
- Ignition delay = 100 ms
- Suppressor delay = 50 ms
- Fuel temperature = 100°F

- External air flow = 300 knots
- Damage area = 1 ft^2
- Clutter = **40 %** (total free volume = 0.204 m^3)

Extinguishing concentrations for Halon 1301 and the WKA/ARC inert gas generator were determined for each test condition by varying agent weights, number of devices and their positions. Figure **4** also shows the gas generator and/or Halon 1301 suppressor, instrumentation and clutter locations used in this test series.

4.2 Halon 1301 Radial Suppressor Characteristics

The Halon 1301 suppressor utilized radial discharge ports to ensure good distribution and minimize reaction forces during discharge. The suppressor was tubular and therefore relatively attitude insensitive. Agent discharge times were in the order of 20 ms. The Halon 1301 fill density was 50 % for all tests (based on the density of pure Halon 1301 at 70°F) and the extinguisher pressure was 600 psig at 70°F in all tests.

Figure **4** shows the suppressor location used in all the Halon 1301 tests.

4.3 Solid Propellant Gas Generator Characteristics (FS-55)

The propellant chosen for this test series (FS-55) produced nitrogen, carbon dioxide and water vapor only and had a gas yield of 4.1 moles per 100 g of propellant. The fire suppression tests were performed with re-usable test hardware that utilized radial discharge ports to minimize reaction forces during discharge. Each gas generator could accommodate up to 50 g of propellant and discharge times varied from 50 to 150 ins depending on the firing sequence.

The test vessel could accommodate up to three gas generators in each test; Figure **4** shows the gas generator positions used.

4.4 Results and Observations

Table 1 gives the fire extinguishing concentrations for Halon 1301 and the WKA/ARC inert gas generator **(FS-55)** for test Conditions 1 to 4. Figure 5 plots the relative extinguishing performances for Halon 1301 and gas generator composition FS-55 in the DBFS.

A single Halon 1301 suppressor was sufficient to suppress each fire test condition. Halon 1301 concentrations of 200 g/m^3 (approximately 3 % volume at ambient temperatures) effectively suppressed fires under the test conditions examined. Extinguishing times varied between 300 and 600 ms at this concentration.

Two gas generators were used to extinguish Condition 1 while three were required to suppress Conditions **2,** 3 and **4.** Gas generator fire extinguishing concentrations ranged from **490** g/m^3 to 613 g/m^3 for Conditions 1 to **4.** Extinguishment times varied between 200 and 300 ms. A pressure pulse of **2** psig was typically observed during gas generator discharge.

Table **1: Halon 1301** and Gas Generator Fire Extinguishing Concentrations in the DBFS

Test Conditions	g/m^3	lb/ft^3	Suppressor Qty. and Positions	g/m^3	lb/ft^3	Suppressor Qty. and Positions
Condition 1: external airflow 300 knots; ambient temperature	200	0.012	1 (A)	490	0.031	2 (A,B)*
Condition 2: external airflow 300 knots; bleed airflow = 4 lb/s; ambient temperature	200	0.012	1 (A)	588	0.037	3 (A,B,C)*
Condition 3: external airflow 300 knots; low temperature	200	0.012	1 (A)	613	0.038	3 (A,B,C)*
Condition 4: external airflow 300 knots; bleed airflow = 4 lb/s; low temperature	200	0.012	1 (A)	613	0.038	3 (A,B,C)*

*see Figure 4.

5. Discussion

5.1 Halon 1301

Extinguishing concentrations of 200 g/m^3 (3 % volume) are not unreasonable for a 23 mm HEI-induced dry bay event; testing at Wright Patterson Air Force Base during the 1980's showed success rates of –75 % at this concentration. In addition, Phase IIa of the recent T2 test series at Wright Patterson Air Force Base reported 158 g/m^3 as the average amount of Halon 1301 required to suppress a 23 mm HEI-initiated dry bay event.

5.2 WKAIARC Gas Generator (FS-55)

Gas generator concentrations of 500 to 600 g/m^3 effectively suppressed the DBFS fire challenge. The increased propellant requirements for Conditions 2, 3 and 4 may be due to a combination of factors including:-

(i) The quantity (number of moles) of air available to support combustion increases under conditions of bleed airflow and at low temperatures.

(ii) Water vapor makes up a significant portion of the gas generator exhaust, therefore, performance at low temperatures may have been hampered by increased water condensation.

At the outset of this project it was postulated that the additional volume provided by the 'hot' inert gases produced by the solid propellant grain would give at least equivalent performance to Halon 1301; however, this did not prove to be the case. Testing in the WKA DBFS demonstrated that the gas generator exhaust cools significantly when introduced into the dry bay volume. It is envisaged that this cooling takes place via mixing with the ambient air and the expansion process. The over-riding factor in extinguishing performance appears to be the number of moles of inert gas produced by the gas generator relative to the number of moles of air in the volume to be protected, and <u>not</u> the exhaust temperature. A gas generator discharge test performed at a concentration of 588 g/m^3 supports this hypothesis; only a moderate increase in dry bay air temperature was observed during ($\approx$ 300°F) and after discharge ($<$ 150°F).

A 2 psig pressure pulse was measured during gas generator discharge; this is not surprising as the volume was well ventilated. Previous testing at WKA has shown that over-pressures can be in excess of 30 psig when a fire extinguishing concentration of FS-55 exhaust was discharged into a closed chamber. The potential over-pressurization issue will require careful consideration of volume geometry, ventilation and configuration if a gas generator system is to be employed.

6. Conclusions

(i) The Walter Kidde Aerospace Dry Bay Fire Simulator offers an inexpensive method of evaluating alternate agent concepts under realistic dry bay conditions. Fire suppression concentrations obtained for Halon 1301 were on the order of those found in full-scale testing.

(ii) The performance of the WKA/ARC inert gas generator composition FS-55 was at the level expected for an inert gas. Extinguishing performance was dependant upon the number of moles of inert gas generated by the propellant relative to the number of moles of air in the volume to be protected, <u>not</u> the exhaust temperature.

(iii) Careful consideration of ventilation area is needed to prevent damaging over-pressures.

7. Future Work

The WKA/ARC team is working to further develop a genuine replacement for Halon 1301 for dry bay applications and has been awarded a Defense Advanced Research Projects Agency - Technology Reinvestment Program to test gas generator-based extinguishing systems. The WKA/ARC team plans to examine the performance of gas generator compositions employing chemical additives that inhibit flaming combustion and devices which employ gas generators to expel and vaporize non-ozone depleting vaporizing liquid agents such as HFC-227ea, HFC-236fa and CF_3I.

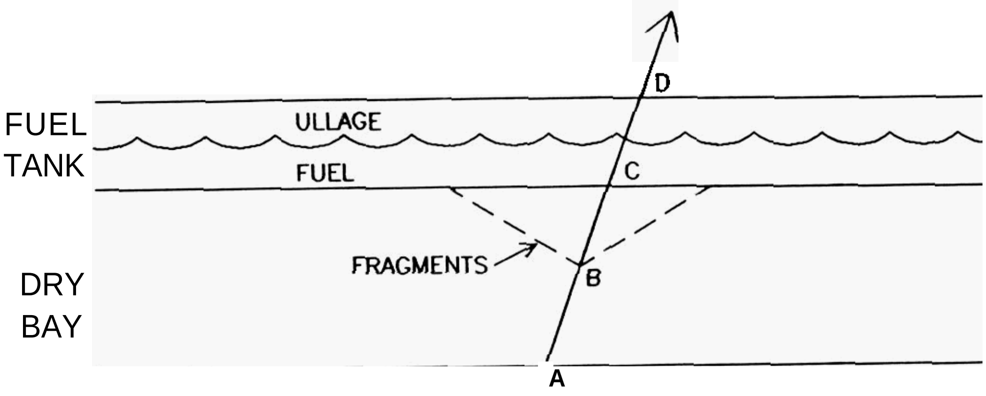
8. References

1. M.F. Robaidek, "Aircraft Dry Bay Fire Protection", Report No. AFWAL-TR-87-3032, Flight Dynamics Laboratory, Wright-Patterson AFB, July 1987.

2. R.L Peters, "Phase II Technology Transition Meeting for Aviation Halon Replacement (27-28 October 1994)", Memorandum for the Technology Transition Team, October 1994.

3. J. Wordehoff, "Onboard fire and explosion suppression for fighter aircraft", NATO Advisory Group for Aerospace Research and Development (AGARD), AGARD Conference Proceedings No. 467., p 23-1.

FIGURE 1: 23mm HEI DRY BAY IMPACT SEQUENCE OF EVENTS



/PROJECTILE PATH [1]

A: PENETRATION – GENERATES IMPACT FLASH

B: HEI DETONATION – ROUND EXPLODES; GENERATES SHOCK WAVE AND TRANSIENT BLAST OVERPRESSURE, PROPELS BURNING INCENDIARY THROUGHOUT BAY

C: FUEL INGITION – FUEL SPRAYS BACK ONTO BURNING INCENDIARY

D: REMAINING FRAGMENTS EXIT

FIGURE 2: PLAN VIEW OF DRY BAY SIMULATOR TEST CELL

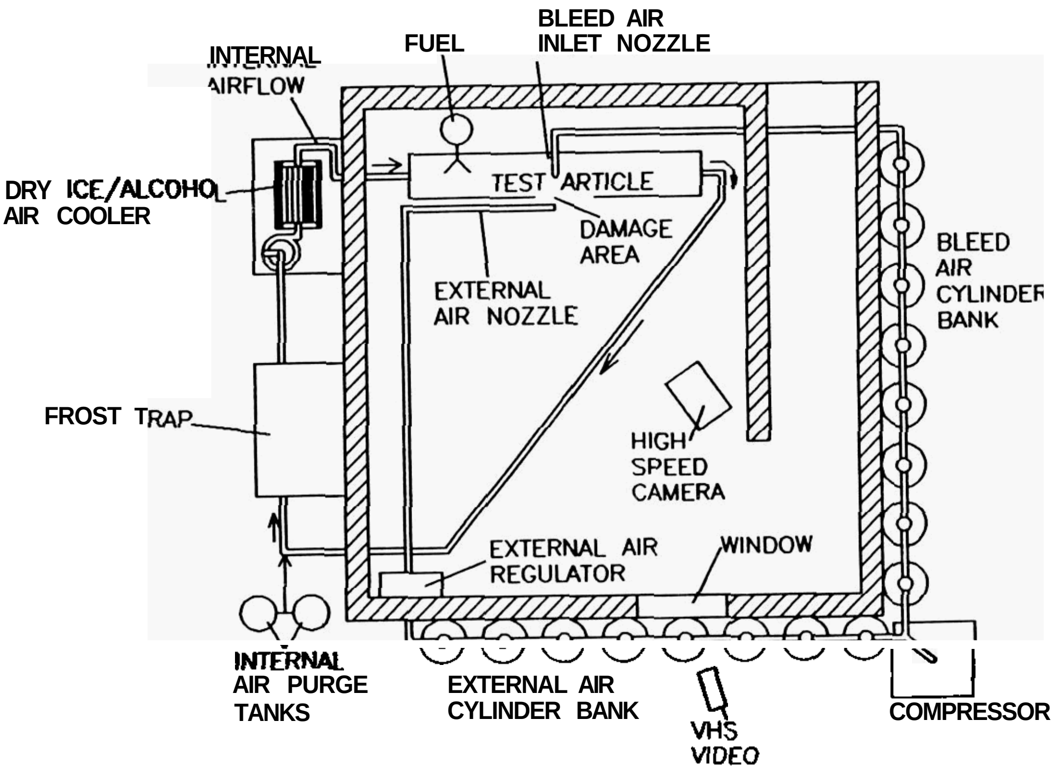
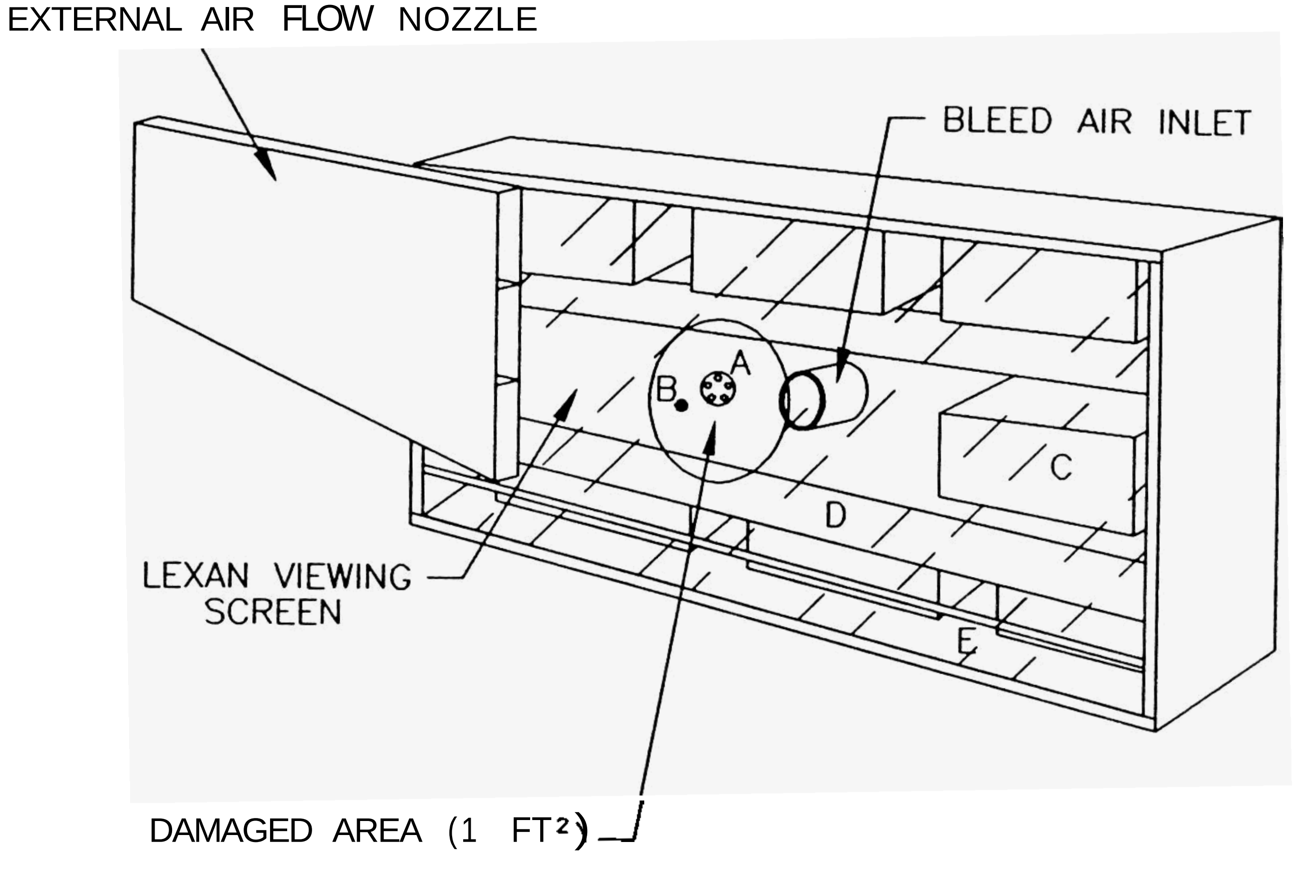
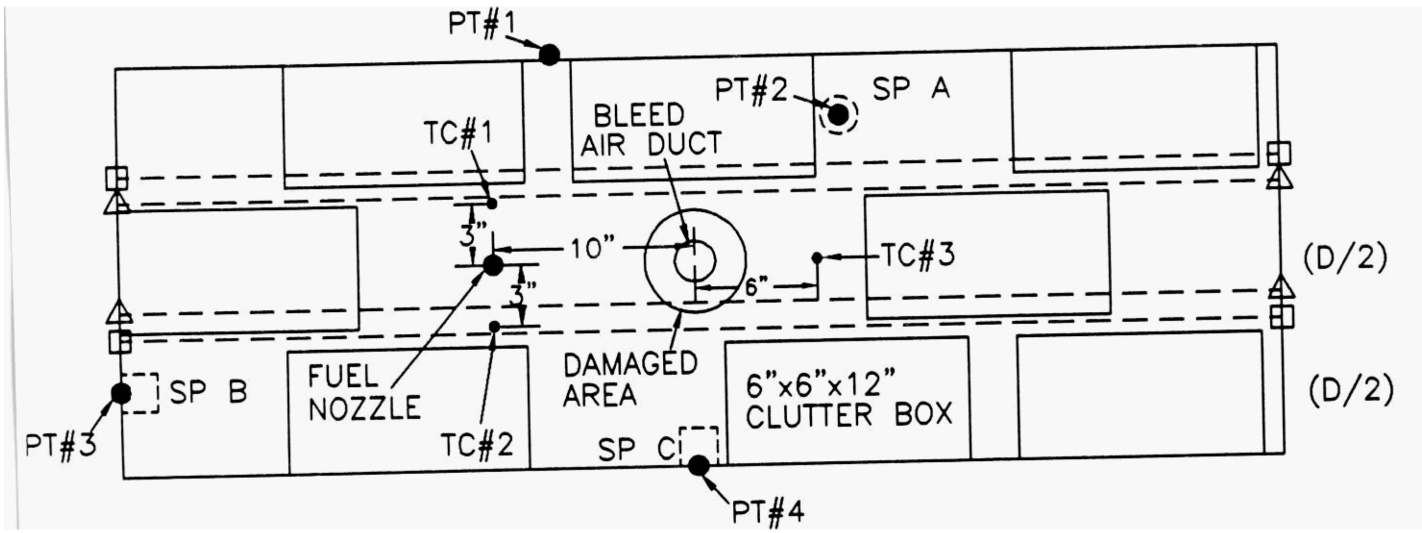


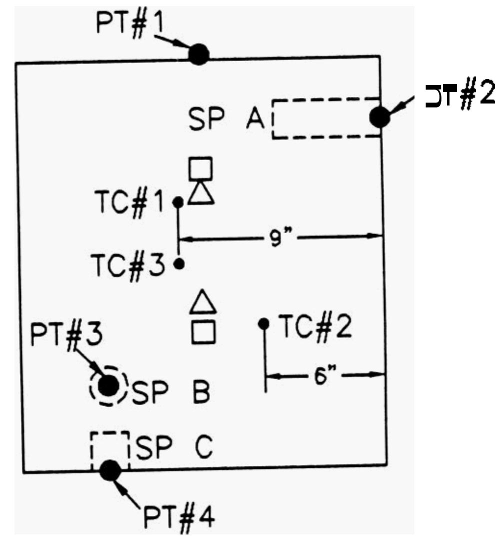
FIGURE 3: 12 FT³ DRY BAY TEST VESSEL CONFIGURATION



A: NOZZLE
B: SQUIB
C: 6"x6"x12" CLUTTER BOX
D: 3" DIAMETER PIPE
E: 1/2" DIAMETER PIPE

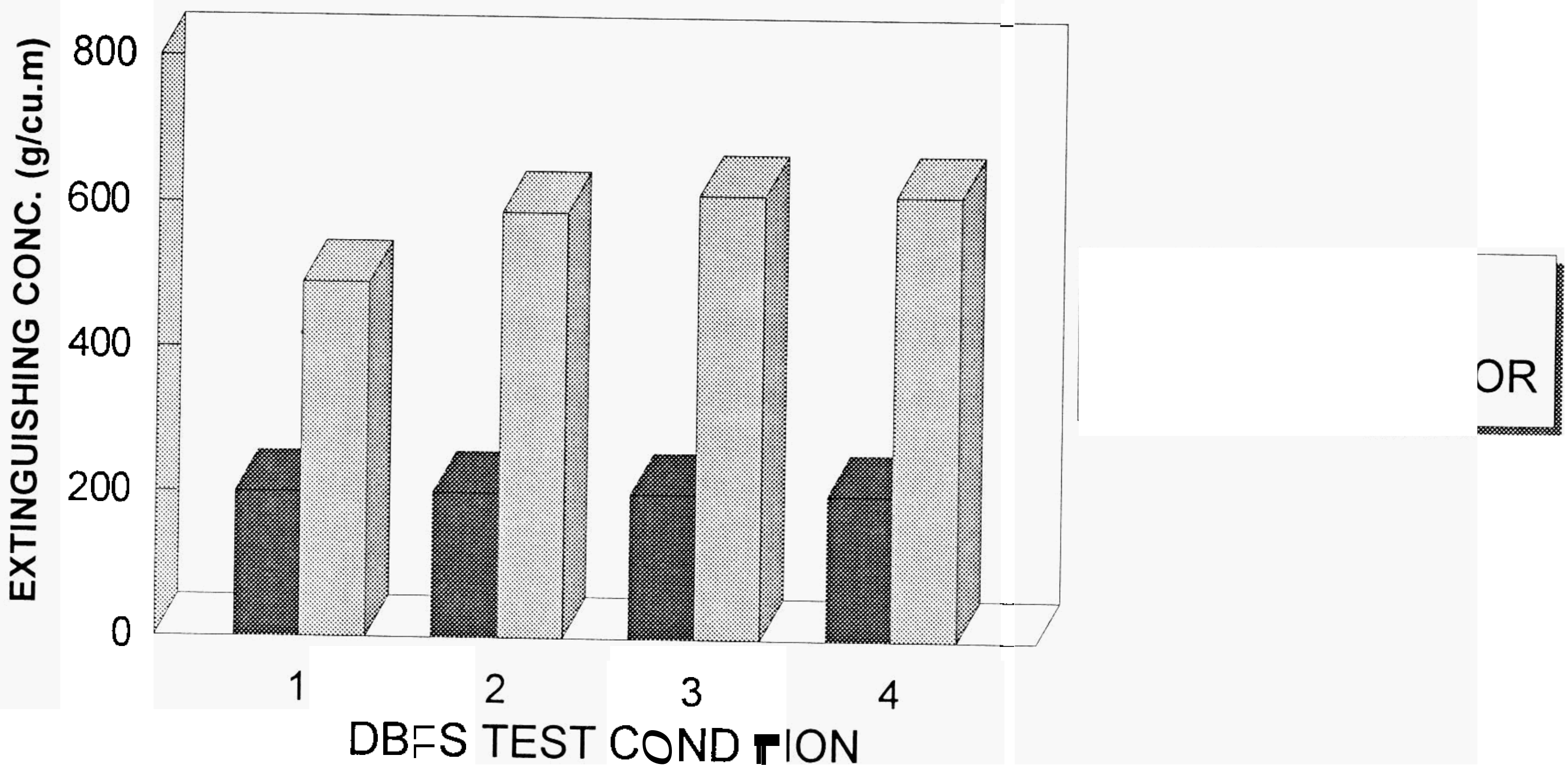
FIGURE 4: SCHEMATIC DIAGRAM OF HALON 1301 AND INERT GAS GENERATOR SUPPRESSOR, DBFS CLUTTER AND INSTRUMENTATION POSTITIONS





△– – – – – – – –△ = 1/2" PIPE
□– – – – – – – –□ = 3" PIPE
20% CLUTTER = 1 LAYER OF 6" X 6" X 12"
40% CLUTTER = 2 LAYERS OF 6" X 6" X 12"
TC = THERMOCOUPLE
PT = PRESSURE TRANSDUCER
SP A = SUPPRESSOR POSITION / 1301 OR GAS GENERATOR 1
SP B = SUPPRESSOR POSITION / GAS GENERATOR 2
SP C = SUPPRESSOR POSITION / GAS GENERATOR 3

FIGURE 5: WKA DBFS HALON 1301 AND GAS GENERATOR RESULTS



CONDITION 1: EX. AIR = 300 KTS; AMB. TEMP., CONDITION 2: EX. AIR = 300 KTS; BLEED AIR = 4 LB/S; AMB. TEMP.
CONDITION 3: EX. AIR = 300 KTS; LOW TEMP., CONDITION 4: EX. AIR = 300 KTS; BLEED AIR = 4 LB/S; LOW TEMP.