

# REVIEW OF THERMAL DECOMPOSITION PRODUCT FORMATION FROM HALOCARBON FIRE SUPPRESSION AGENTS: SUPPRESSION OF CLASS A FIRES

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## INTRODUCTION

During the past several decades the use of the highly efficient, clean, nontoxic fire suppression agent Halon 1301 in total-flooding applications has prevented the loss of human life. Billions of dollars worth of equipment worldwide are protected by Halon 1301. However, due to its implication in the destruction of stratospheric ozone, the production of Halon 1301 was halted on January 1, 1994.

HFC-227ea, marketed under the tradename FM-200<sup>®</sup>, is an effective replacement for Halon 1301, providing rapid extinguishment of flames through a combination of physical and chemical mechanisms. The physical contribution to flame suppression stems mainly from the heat absorbing ability of the agent, which results in a lowering of the flame temperature and a slowing of the radical chain reactions occurring in the flame. HFC-227ea also acts chemically by removing key chemical species involved in the flame chain reactions, breaking the chain reactions responsible for flame propagation.

HFC-227ea, characterized by high fire suppression efficiency, low toxicity, low residue formation following extinguishment, low electrical conductivity, and long-term storage stability, produces no corrosive or abrasive residues upon extinguishment. HFC-227ea is suitable to protect areas such as libraries and museums, where the use of water or solid fire-extinguishing agents can cause secondary damage exceeding that caused by direct fire damage. Because it is electrically nonconducting, it is suitable for the protection of electrical and electronic equipment.

Applications of HFC-227ea for the protection of Class A hazards are discussed in this paper. The performance of HFC-227ea in the suppression of test fires of typical polymeric Class A materials is discussed, as well as the performance of HFC-227ea in full-scale Class A testing on typical electronic data processing (EDP) and anechoic chamber hazards. The effects of the post-extinguishing atmosphere on personnel and equipment are also detailed.

## CLASS A AND CLASS B HAZARDS

HFC-227ea is currently employed worldwide for the protection of both Class A (cellulosic fuel) and Class B (liquid and gaseous fuel) hazards. However, as was the case for Halon 1301, the vast majority (> 90%) of fire suppression applications of HFC-227ea involve the protection of Class A hazards, for example, those found in electronic data processing (EDP) and telecommunication facilities. In applying HFC-227ea to a particular hazard, it is important to understand the

fundamental differences between Class **A** and Class **B** fires. In 1972 Hekstad [1] proposed that fires grow according to a power-law relation of the form

$$Q = \alpha t^n$$

where  $Q$  is the heat release in kW,  $\alpha$  is the fire intensity coefficient in kW/s<sup>n</sup>,  $t$  is the time in seconds, and  $n = 1, 2, 3$ . It has been shown [2-4] that for a wide range of fuels,  $n=2$ , and the growth of most flaming fires is hence described as "T-squared growth." T-squared fires have been further categorized as slow, medium, fast and ultrafast growth fires. The heat release rates for typical Class **A** fuels are much lower than for Class **B** fuels, and Class **A** fires are characterized by relatively slow growth. Rapidly growing Class **B** fires, for example, methanol pool fires, will require more rapid detection to limit fire damage and the production of combustion and decomposition products than will the slower growing Class **A** fires.

With regard to suppression agent discharge times, Echternacht [5] points out that shorter discharge times are more crucial for Class **B** hazards, in which a flame could spread rapidly over a large area and develop high levels of heat, than for Class **A** hazards such as a computer facility where the fire would not be expected to spread rapidly. In his examination of the suppression of Class **A** and **B** fuels with Halon 1301, Ford [6] also noted that Halon 1301 systems protecting slow-burning flammable solids do not require the same rapid detection and rapid agent discharge capabilities as those placed upon Halon 1301 systems protecting flammable liquid hazards.

For halocarbon suppression agents such as HFC-227ea, flame extinguishment is due primarily to the absorption of heat by the agent. The halocarbon agent absorbs heat from the flame, slowing the combustion reaction rate and lowering the flame temperature, eventually to the point where the flame temperature is below the minimum temperature required to sustain flame propagation. For the slower growing Class **A** fires, the heat release at any given time from ignition is much smaller than for typical Class **B** fuels, and hence less heat must be absorbed to afford extinguishment. This is consistent with the observation that the extinguishment of Class **A** fuels with the halocarbon agents requires less agent than the extinguishment of Class **B** fuels.

Recognition of the fundamental differences between Class **A** and Class **B** fires, and the implications of such differences in system design, have led to recent changes in fire suppression related standards with regard to the establishment of minimum design concentrations. In the past, agent requirements for Class **A** protection were linked to n-heptane (a Class **B** fuel) requirements, solely on a historical basis. With the recognition that no technical justification exists for relating Class **A** requirements to Class **B** requirements, current fire suppression related standards such as NFPA 2001 and ISO 14520 now require that base agent requirements for Class **A** protection be based upon testing of Class **A** materials, and that base agent requirements for Class **B** protection be based upon testing of Class **B** materials. In addition, listing and approval agencies such as Underwriters Laboratories are currently rewriting their fire suppression standards to reflect the recognition of the fundamental differences between Class **A** and Class **B** fires.

### TYPICAL CLASS A HAZARDS

The vast majority (> 90%) of fire suppression applications of HFC-227ea involve the protection of Class **A** hazards, for example, those found in electronic data processing (EDP) and telecom-

munication facilities. Fire hazards in such facilities are characterized by low fuel loads and include wire insulation, PC boards, electronic components, transformers, insulating materials and plastic housings. As indicated by Meacham [7], fires in such facilities are of low energy output, often less than 5 to 10 kW.

Detection capabilities in such facilities are such that fires are detected in their incipient stages, and there is an industry-wide desire to detect fires at as small a size as possible. Some telco companies desire to detect at a fire size of 1 kW, whereas others have indicated that detection at a fire size of 0.1 kW is desirable for sensitive equipment [8]. Meacham [9] has categorized the type of detection required based upon the level of damage tolerable and considers fires larger than 10 kW to result in a major loss (Table I).

TABLE I. CLASSIFICATION OF LOSS AS A FUNCTION OF FIRE SIZE.

Acceptable Loss	Fire Size
Major loss	> 10 kW
Large loss	5 - 10 kW
Moderate loss	2 - 5 kW
Small loss	< 2 kW

### MID-SCALE SUPPRESSION TESTING

Hughes Associates, Inc., have determined the minimum extinguishing concentrations of HFC-227ea for a number of polymeric materials in both laboratory and mid-scale tests [10]. The purpose of the tests was to establish minimum concentration values for Class A fuels, analogous to the minimum extinguishing concentrations determined for Class B fuels using the cup-burner technique. The tests were conducted in two test compartments: a large chamber 19.25 by 11.25 by 11.8 ft high (2555 ft<sup>3</sup>) and a nominal 8 by 8 by 8 ft (512 ft<sup>3</sup>) room. The fuel array consisted of four 3/8 in thick polymer specimens 8 in wide by 16 in long, spaced as shown in Figure 2. The fuel array was adequately shielded via a series of baffles to prevent the extinguishment of the test fires by transient high agent concentrations or turbulence due to the agent discharge. The fuel array was placed inside a partial metal enclosure 32 in high, 24 in deep, and 15 in wide. The metal enclosure is closed at the top and two sides parallel with the fuel array, and is raised off the floor 3.5 in. This enclosure is further baffled with two 12 in high by 3 in sq baffles. Ignition of the fuel array was accomplished by an electric glocoil igniter placed between the two innermost plastic panels; once flaming combustion was noted, a 90 sec preburn period was allowed before releasing the agent. During the preburn the inlet and exhaust vents to the enclosure were open; just prior to agent discharge, the vent dampers were closed.

The Class A materials utilized in the study included black and clear polymethylmethacrylate (PMMA), high and low density polyethylene (HDPE, LDPE), polyvinyl chloride (PVC), acrylonitrile-butadiene-styrene (ABS), flame retarded and untreated polypropylene (PP), and also pine boards. All of these materials burned relatively well with fire sizes ranging from 10 kW to 30 kW at the time of agent discharge. The minimum extinguishing concentrations measured in the tests are summarized in Table 2, where it is noted that fires of all materials were extinguished at HFC-227ea concentrations of 5.5% v/v or less. (Note that tests at concentrations lower than 5.0% were not conducted.)

TABLE 2. MINIMUM HFC-227EA EXTINGUISHING CONCENTRATIONS FOR CLASS A MATERIALS.

Test Material	Ext. conc., % v/v
PMMA(black)	5.5
PMMA (clear)	5.5
PVC	<5.0
<b>ABS</b>	<5.0
PP	<5.0
Pine	<5.0

Hughes Associates, Inc., has also examined the extinguishment of fires involving continuously energized cables [11]. Tests included ohmic heating, conductive heating, and PC board failure tests. These tests demonstrated that fires initiated by, and involving, energized electrical circuits can be controlled by HFC-227ea at concentrations below 7%.

Robin et al. [12], have examined the extinguishment of PVC cable fires in various configurations in both ladder and ventilated trough cable trays, and found that extinguishment of these fires occurs readily at HFC-227ea concentrations of 5.8 % v/v.

## FULL-SCALE FIRE SUPPRESSION TESTING

### EDP/Telecommunication Facilities

The fire hazard associated with EDP and telecommunication facilities involves low fuel loads, such as wire insulation, PC boards, electronic components, transformers, insulating materials, and plastic housings. As discussed by Meacham [7] fires of such materials are of low energy output, often less than 5 to 10 kW. Tests conducted by Hughes Associates, Inc., [13] have examined the extinguishment of Class A fires by HFC-227ea under conditions typical of those encountered in EDP and telecommunication facilities. The tests were conducted in a 2562 ft<sup>3</sup> enclosure equipped with an ionization detector located 14 ft from the fuel source, representing a worst case with a 20-foot on center detector spacing. Delay times of 10 and 30 sec following detection were employed before discharge of the suppression system; all tests employed 7% v/v HFC-227ea.

The test fuels included shredded paper, PC boards, PVC coated wire cables, and magnetic tape, representing the most common fuel sources expected to burn in a computer room. The wastebasket fires consisted of 200 grams of newsprint, shredded into 6 mm strips, 30 to 61 cm in length and packed into a polyethylene wastebasket. The fuel was ignited with a match thrown on top of the paper. The heat release rates ranged from 11 to 36 kW (9 kW average). All test fires were extinguished within 8 to 15 sec from the end of agent discharge.

The PC board fires consisted of two Zenith Data Systems 85-3334 boards vertically mounted onto frames 2.9 cm apart; ignition was via a Glo-Coil. The heat release rates varied from 8 to 15 kW (1 kW average). All test fires were extinguished within 2 to 7 sec from the end of agent discharge.

The magnetic tape fires consisted of 26.7 cm (10.5 in) round reel tapes in a 120-tape rack library, stacked 4 tapes per row, 3 rows high. Ignition was via a Glo-Coil. Heat release rates ranged from 21 to 35 kW (23 kW average). All test fires were extinguished within 6 to 11 sec from the end of agent discharge.

The PVC cable fires consisted of 100 pair PVC telephone cable, ignited by a 5.1 cm<sup>2</sup> pen of *n*-heptane. The heat release rates ranged from 3 to 6 kW (4 kW average). All test fires were extinguished within 6 to 10 sec from the end of agent discharge.

The development of electronic equipment, which operates in the high radio frequency ranges, requires testing in an electronically isolated environment free from reflected signals. Anechoic chambers play a major role in the development of sophisticated electronic equipment in the aerospace, communications, and digital electronics industries, and can range in size from several cubic feet to volumes large enough to house an entire satellite or aircraft. The walls, ceiling, and floor of such chambers are lined with a material designed to absorb radio frequency energy. This material is typically a polyurethane foam, impregnated with carbon and formed into pyramidal or wedge shapes, with each pyramid ranging from a few inches to several feet from tip to base.

Hughes Associates, Inc., [14] under contract to Great Lakes Chemical Corporation, has investigated the performance of HFC-227ea in anechoic chamber applications in a test enclosure of dimensions 7.2 by 7.2 by 9.9 ft (512 ft<sup>3</sup>). The test fire consisted of two slabs of anechoic chamber lining material 5.5 by 13 by 2.5 in, arranged on a single level and ignited via a Glo-Coil; a 2-min preburn was allowed in the tests. The fires were rapidly extinguished at an HFC-227ea concentration of 5.8% v/v. Identical testing of anechoic cones from a different manufacturer in a large enclosure (1562 ft<sup>3</sup>) produced similar results, although some smoldering was observed at an HFC-227ea concentration of 5.8% v/v; increasing the HFC-227ea concentration to 6.0% v/v eliminated smoldering.

## EFFECTS OF DECOMPOSITION PRODUCTS

As was the case for Halon 1301, the thermal decomposition product of primary concern for HFC-227ea is the associated halogen acid, HF. For Class A fires typical of those expected to be encountered in computer and EDP facilities, modeling and test data have shown that the amount of HF produced following extinguishment by HFC-227ea is of the same approximate magnitude as the total decomposition products (HF plus HBr) formed from Halon 1301 [15].

Figure 1 shows the HF formed during extinguishment of various Class A fires with 7% v/v HFC-227ea. It should also be kept in mind that the UL and Hughes EDP experiments were carried out under worst case conditions.

### Effects on Humans

Figure 2 shows the average HF concentration resulting from extinguishment of Class A test fires at 7% FM-200<sup>®</sup> with a 10 sec discharge and 30 sec delay, as measured in the Hughes study [13]. Also shown in Figure 1 is the approximate LC<sub>50</sub> for mammals, derived from Sax [16], and the Dangerous Toxic Load (DTL) for humans based upon the analysis of Meldrum [17]. The DTL was derived by Meldrum based upon an evaluation of HF exposure data for mice, which show

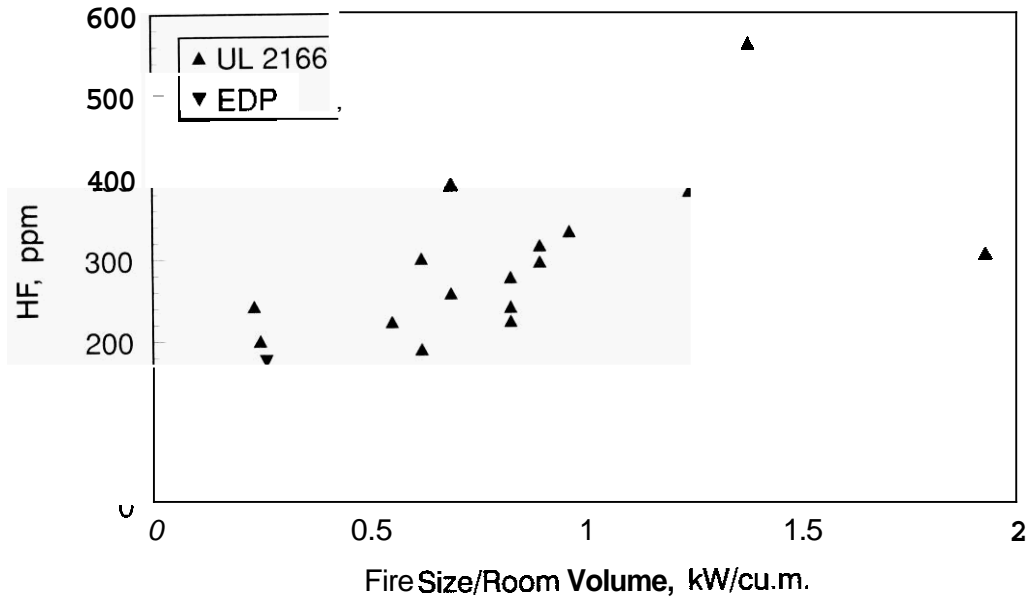


Figure 1. Production of HF from HFC-227ea

the greatest sensitivity to HF exposure of all mammals tested, and corresponds to exposure levels at which severe distress would be expected for all exposed personnel. As seen in Figure 2, the HF levels produced from the extinguishment of typical Class A fuels under realistic conditions were well below both the estimated mammalian LC<sub>50</sub> and DTL curves. Peatross and Forssell [18] in their analysis of the data concluded that it was obvious that this type of fire presented no toxic threat.

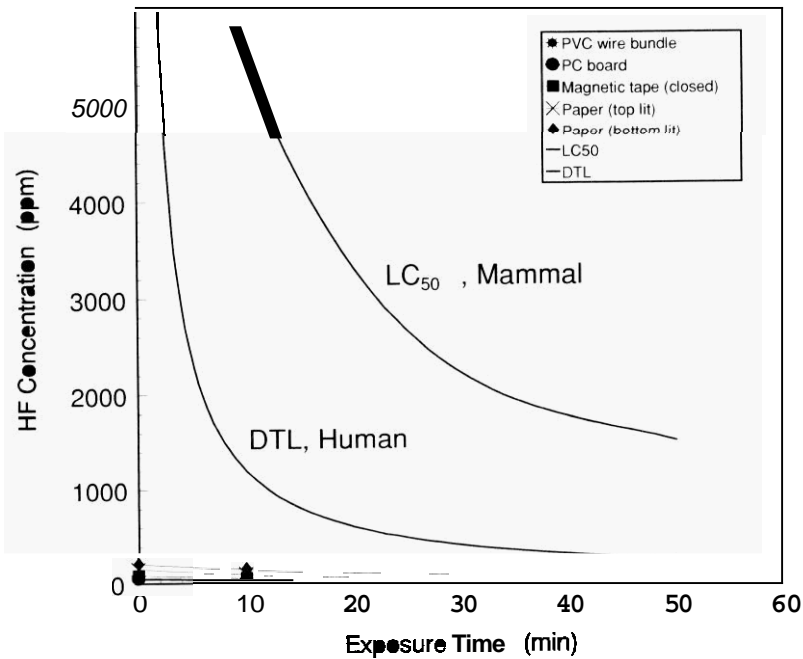


Figure 2. Hazard assessment of HF concentrations-extinguishment of typical EDP hazards with 7% FM-200.

## Effects on Equipment

The threat to electronic and other equipment from exposure to the halogen acids is a function of several variables, including the decomposition product concentration, the exposure time to the halogen acids, the deposition rate of acids on the equipment surface, the relative humidity and temperature, the sensitivity of the equipment, and the combined effects with smoke. Pedley [19] at NASA reported the results of exposure of a variety of electronic equipment to HF and HBr. Tests included measurement of corrosion rates for metals exposed to HF and HBr, effects of HF and HBr on nonmetallic parts, and effects of HF and HBr on unpowered and powered electronic equipment, printed circuit boards, and conformal coatings. For atmospheres of 500 ppm HF and 200 ppm HBr, no damage to powered electronic equipment occurred and no damage to the various conformal coatings was observed. The NFPA 2001 Technical Committee, following their review of the available data concluded that damage was not likely for exposures of 500 ppm HF for 30 min. As seen from Figure 1, HF levels produced upon extinguishment of typical Class A fires under real-world conditions is significantly below the levels examined by Pedley.

## CONCLUSION

Over 90% of clean agent fire suppression applications involve the protection of Class A hazards, and fires in these hazards are characterized by low fuel loadings and low energy output, with fire sizes often in the range of 5-10 kW. Mid- and large-scale testing have demonstrated that HFC-227ea, at its minimum design concentration of 7.0% v/v, is effective at extinguishing fires typical of those expected to occur in EDP facilities, telecommunication facilities, and anechoic chambers. The levels of HF produced following extinguishment of typical Class A fires with HFC-227ea were found to be well below the estimated mammalian  $LC_{50}$  and the human Dangerous Toxic Load (DTL), and do not appear to present a threat to electronic equipment.

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