# MEASUREMENT OF THERMAL DECOMPOSITION PRODUCTS OF HFC-227EA IN AN ELECTRONIC FACILITY

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## INTRODUCTION

In an electronic environment, corrosion of electronic equipment due to thermal decomposition products (TDP), such as HF, is a major concern after fire suppression by halocarbon agents (such as HFC-227ea). As a part of the NRC study to address the possible corrosion problem in an electronic environment, tests were carried out to determine the amount of HF produced during fire suppression with an HFC-227ea (FM-200) system using realistic fire scenarios. The study involved total-flooding fire suppression of in cabinet cable fires and a small liquid fuel pool fire in a simulated electronic equipment room and measurement of acidic gas products. This paper describes the test conditions and the results of tests, providing concentrations of TDP in various parts of the test compartment during fire suppression with HFC-227ea.

## DESCRIPTION OF TESTS

Full-scale tests were conducted in a 120 $m^3$ compartment (41 $m^2$ floor area, 2.92 m height). The test compartment simulated an electronic facility with various types of electronic cabinets. The compartment was equipped with a piping system for the delivery of HFC-227ea as well as corresponding instruments that monitored and recorded the agent discharge, fire extinguishment processes, and gas compositions in the compartment. A total of six cabinets (two each of three types) were placed in the test room to simulate an electronic facility. The three types of cabinets used in the tests were 'Closed cabinet' with no ventilation openings, 'Ventilated cabinet' with ventilation openings (2% of surface area), and 'Open cabinet' with unlimited ventilation. All cabinets measured 1.8 m high by 1 m wide and 0.46 m deep.

In the test series, liquid fuel pool fires and small cable bundle fires were used to evaluate the fire suppression performance of the agent and to measure the production of thermal decomposition products. Liquid fuel fire (0.7 m heptane fire with 500 kW) was placed in the open area of the compartment, whereas the cable bundle fires (3 kW) were located in the cabinets.

HFC-227ea was used in the full-scale fire tests at 8.6% design concentration. The agent distribution and HF production during fire suppression were measured using a Fourier Transform Infrared (FTIR) Spectrometer. HF concentrations at various locations, including the open area of the compartment and the inside cabinets, for different fire scenarios were measured during fire extinguishment period and for the duration of 10 min after fire extinguishment.

## CABLE BUNDLE FIRE

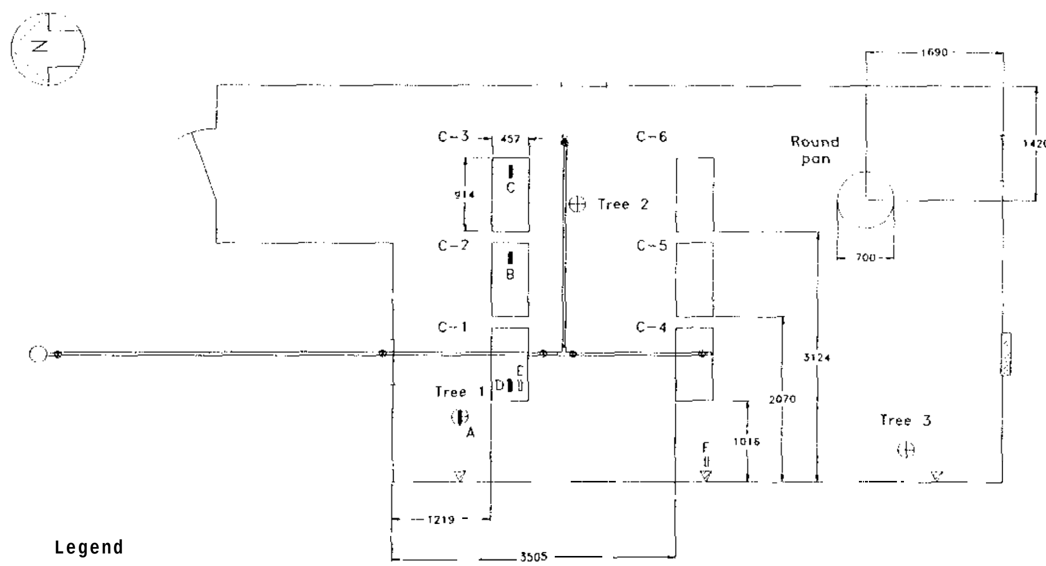
Possible overheating of the cables and ignition into a cable fire in the cabinets was simulated by a small cable bundle fire placed inside the test cabinets. The cable bundle fire was produced by a bundle of cable wires wrapped with a Nichrome wire. The cable bundle consisted of 7 insulation skins of 200 mm long Belden Cable 4, 18 gauge conductor cables wrapped around with 14 gauge Nichrome wire. The Nicrome wire was connected to a 30 amps DC power source and within 20 s, the cable bundle ignited producing a 3 kW fire. The cable bundles were placed in the middle of each type of cabinet used in the tests.

## LIQUID FUEL FIRE

A round pan (RP), 0.7 m in diameter and 0.385 $m^2$ in area, was placed near the corner of the room. The pan contained 2 L of heptane fuel on a water base, and the lip height of the pan above the fuel level was approximately 20 mm. The amount of fuel in the pan provided approximately 720 s of burning time, and the heat release rate of the RP with heptane fuel was approximately 500 kW. During the tests, the round pan was not shielded from the direct spray of the agent discharge.

## TEST PROCEDURE

Figure 1 shows the test scenarios for the cable bundle and pool fires. Cabinet C-1 was the fire cabinet where the cable fire was placed. Three different ventilation conditions were used for Cabinet C-1. In Scenario **1,** the door of Cabinet C-1 was wide open. In Scenario 2, the door of Cabinet C-I was closed and the only ventilation to the cabinet was through leakage around the door. In Scenario 3, Cabinet C-1 had ventilation openings (about 2% of the total surface area of the cabinet) and its door was closed. In the pool fire tests, the 0.7 m diameter heptane pool fire was located in the open area of the test room,




**Legend**

Thermocouple **frees** 1,2,3 — All dims in mm

FTIR sampling port A (on **tree** 1 at ceiling), B & C (in non-fire cabinets C-2 & C-3)
D (in fire cabinet C-1)

CO/CO2/O2 sampling port E (in fire cabinet C-1). F (on west wall at ceiling)

Pressure tap

Figure 1. Set-up for in-cabinet cable bundle fire tests.

For each scenario, a suppression test with HFC-227ea was conducted. In the cable fire tests, 50 s after the electric power to the Nichrome-wire ignitor was turned on, the room door **was** closed and HFC-227ea **was** discharged into the test room. Free-burning tests were conducted for Scenarios 1 and 3 where the cable bundle was left to burn out without suppression. **In** the heptane pool fire tests, a 30 **s** preburn was allowed for the heptane pool fire to develop fully before the agent was discharged.

## MEASUREMENTS

Test data from a wide array of instrumentation were collected by a data acquisition system. The room temperature distributions and the extinguishment times of the fires were measured by thermocouples. The pressure changes in the compartment were monitored by pressure **taps.** The concentrations of **$O_2$,** $CO_2$, and CO in the compartment, **as** well as the concentrations of the agent and its thermal decomposition products in the compartment and in the cabinets, were determined using gas analyzers and a FTIR spectrometer.

A copper sampling port was installed on the middle of the west wall near the ceiling to measure the concentrations of $O_2$, CO, and $CO_2$ in the test room. Two smoke detectors were mounted on the ceiling along the north-south centre line (1 m from the north and south walls, respectively) of the room. Two smoke detectors were installed in the test compartment to measure the time required for the test fire to activate typical smoke detectors. They were both mounted on the ceiling along the north - south centre line of the test room. One detector was installed 1 m from the north (front) wall near the cabinets (above the fire test cabinet with cable bundle fire); the second detector was installed 1 m from the south (back) wall near the round pan fire.

The FTIR spectrometer was used to measure the fire gases in the test compartment and two non-fire cabinets. One gas sampling port was mounted on the northwest thermocouple tree at 2.8 m above the floor in the test compartment. Two gas sampling ports were placed inside Cabinets C-2 and C-3. The three gas sampling lines were heated to reduce the condensation of sample gases. A solenoid valve-switching device was used to connect one gas sampling line to the FTIR spectrometer and the other two sampling lines to exhaust concurrently. The gas samples from the three locations were alternately forwarded to the FTIR spectrometer for measurement. The gas samples flowed through a cylindrical gas cell (10 cm pathlength, 32 mm aperture, 110 mL volume) at a flow rate of 8 L/min. The spectrometer scanned the gas samples in the frequency range of 400 to 4500 $cm^{-1}$ at 1 $cm^{-1}$ resolution. Each spectrum from every single scan was recorded every 2 s.

An additional FTIR spectrometer was used to measure fire gases in fire cabinet (C-1). A dedicated FTIR gas sampling probe was placed inside Cabinet C-I and connected to the FTIR spectrometer through a heated line. A copper sampling probe was also placed at the same position and connected to gas analyzers to measure CO, $CO_2$, and $O_2$. In the cable fire tests, a cable bundle was placed inside Cabinet C-l and two thermocouples were placed above the cable bundle to monitor the flame temperatures.

## RESULTS AND DISCUSSION

A total of 7 tests were conducted. Three tests were conducted allowing cable bundles in open and ventilated cabinets to burn out without suppression. Four suppression tests with cable bundle fires in cabinets with three different ventilation conditions and with the heptane pool fire were conducted. Test results are summarised in Tables 1 and 2.

## CABLE BURN WITHOUT SUPPRESSION

In the free-burning tests, a cable bundle (weight of 33 g) was ignited using electrically heated Nichrome wire. The cable bundle started to burn 18 s after the ignition power was turned on and was left to burn out without suppression. The heat release rate was 3-4 kW.

The cable bundle burned out in 207 to 223 s with less than 5 grams of residue left. The average time for the cable bundle fire to trigger the north smoke detector above Cabinet C-1 was 45 s for the open cabinet scenario and 55 s for the ventilated cabinet scenario. The average time to trigger the south smoke detector was 130 s for the open cabinet scenario and 250 s for the ventilated cabinet scenario. As a result of the cable combustion, CO, $CO_2$, and HCI were produced in the fire cabinet. The peak concentrations were 2000-2200 ppm CO, 0.9-1.2% $CO_2$, and 1200 ppm HCI in the ventilated fire cabinet, and 300 ppm CO, 0.12% $CO_2$, and 150 ppm HCI in the open fire cabinet. The concentrations of combustion products in the open area of the room were very low.

## SUPPRESSION OF IN-CABINET CABLE FIRE

In the cable fire suppression tests, HFC-227ea was discharged into the test room in 10 s. Due to the cooling effect of the agent expansion and vaporization, the room temperature dropped by as much as 29 °C;

TABLE 1. CABLE FREE-BURN TESTS AND RESULTS.

| | | Test | Burn 1 | Burn 2 | Burn 3 |
|---|---|---|---|---|---|
| | | Ventilation condition in Cabinet C-1 | Closed ventilated | Closed ventilated | Open |
| | | Room T (“C) | 20 | 10.5 | 20 |
| | | Room over-pressure (Pa) | 0 | 0 | 0 |
| | | Ignition period (s)[a] | 18 | 18 | 17 |
| | | Free burning time (s)[b] | 222 | 207 | 223 |
| | | First alarm (s)[c] | 64 | 55 | 46 |
| | | Second alarm (s)[c] | 279 | 22s | 131 |
| | | Residue (g, out of 33 g) | < 5 | 4.5 | < 5 |
| Concentrations[d] | Cabinet C-1 | HCl (ppm) | — | 1200 | 150 |
| | | CO (ppm) | 2200 | 2000 | 300 |
| | | $CO_2$ (%) | 0.9 | 1.2 | 0.12 |
| | | $O_2$ (%) | 19.5 | 19.5 | 20.6 |
| | Ro | HCl (ppm) | Not detectable‘ | Not detectable‘ | Not detectable[e] |
| | | CO (ppm) | 50 | < 20 | 80 |
| | | $CO_2$ (%) | 0.04 | 0.02 | 0.05 |
| | | $O_2$ (%) | 20.9 | 20.9 | 20.8 |

[a] Time from ignition power on to cable bundle fully burning

[b] Time from ignition power on to cable bundle self-extinguishment

[c] Time from ignition power on to alarm sounding

[d] Maximum for the HCI, CO, and CO, concentrations; minimum for the $O_2$ concentration

‘Below the lowest detectable limit of the FTS 175 **FTIR** spectrometer

the room pressure went down to as low **as** -82 Pa then went up to +62 Pa. The HFC-227ea concentration in the test room reached a concentration of 8.6% at the end of the discharge.

In the first suppression test (Test 1), the cable fire was in the open cabinet (C-1). The cable fire was extinguished before the end of the discharge. The concentration of HF generated from agent-flame interaction was below 100 ppm in the fire cabinet. The minimum **O,** concentration in the fire cabinet was 18.5% as a result of displacement by the agent and consumption by the combustion.

In the second fire test, the cable bundle fire was in the closed cabinet. Since the fire cabinet was totally closed and had no ventilation openings, the HFC-227ea concentration in the fire cabinet took 190 s to reach its plateau of 8.6% (10 times slower than in Test 1). The cable fire inside the cabinet was extinguished in 64 s, which was before the agent concentration reached the plateau. The maximum concentrations of combustion products in the fire cabinet were 3700 ppm CO, 1.7% CO,, and 2000 ppm HCI, about 10 times as high as those in Test 1. The HF generated from agent-flame interaction reached a peak concentration of 800 ppm in the fire cabinet and then decayed slowly. The minimum **O,** concentration in the fire cabinet was 18.5%.

In the third test, a ventilated cabinet was used. The cable bundle fire in the cabinet was extinguished in 32 s. The maximum concentrations of combustion products in the fire cabinet were 1400 ppm CO, 0.6% CO,, and 450 ppm HCI. The concentration of HF generated from agent-flame interaction was below 100 ppm in the fire cabinet. The minimum **O,** concentration in the fire cabinet was 18.4%.

TABLE 2. FIRE SUPPRESSION TESTS AND RESULTS.

| Test Fire | | | Cable Bundle (Test 1) | Cable Bundle (Test 2) | Cable Bundle (Test 3) | Heptane Pool (Test 4) |
|---|---|---|---|---|---|---|
| Fire location | | | Open Cabinet C-1 | Closed non-ventilated Cabinet C-1 | Closed ventilated Cabinet C-1 | Radar Room |
| Room T (°C) | | | -9; +20 | -8; +20 | -5; +24 | +15;+72 |
| Room over-pressure (Pa) | | | -62; +55 | -82; +62 | -87; +40 | -117; +473 |
| Ignition period (s)[a] | | | 18 | 16 | 18 | 0 |
| Discharge time (s) | | | 10 | 10 | 10 | 9 |
| Ext. time (s)[b] | | | < 10 | 64 | 32 | 9 |
| First alarm (s)[c] | | | 45 | During Discharge | 45 | 2 |
| Second alarm (s)[c] | | | During Discharge | During Discharge | During Discharge | 20 |
| Cable residue (g, out of 33 g) | | | 25 | 13 | 22 | |
| Concentrations in Cabinets and Room[d] | C-1 | Agent (%) | 8.8 | 8.6 | 8.7 | 9.5 |
| | | HF (ppm) | < 100 | 800 | < 100 | 3800 |
| | | HCl (ppm) | 150 | 2000 | 450 | - |
| | | CO (ppm) | 400 | 3700 | 1440 | 2350 |
| | | $CO_2$ (%) | 0.15 | 1.7 | 0.6 | 0.9 |
| | | $O_2$ (%) | 18.5 | 18.5 | 18.4 | 17.2 |
| | C-2 | Agent (%) | 9.9 | 9.8 | 9.4 | 6.3 |
| | | HF (ppm) | ~0 | ~0 | ~0 | 500 |
| | C-3 | Agent (%) | 10.2 | 10.2 | 9.9 | 9.3 |
| | | HF (ppm) | ~0 | ~0 | ~0 | 1800 |
| | Room | Agent (%) | 9.9 | 9.4 | 10.0 | 11.0 |
| | | HF (ppm) | << 100 | << 100 | << 100 | 3900 |
| | | CO (ppm) | | | | |
| | | $CO_2$ (%) | | | | |
| Remark | | | | | | C-1 open |

[a] Time from ignition start to fully burning
[b] Time from discharge activation to fire extinguishment
[c] Time from ignition start to alarm sounding
[d] Maximum for the agent, HF, HCl, CO, and $CO_2$ concentrations; minimum for the $O_2$ concentration
(C-2 was non-ventilated; C-3 had ventilation openings; cabinet doors closed unless otherwise specified.)

The tests showed that the ventilation condition of the cabinet affected the time taken for HFC-227ea to reach the required concentration in the cabinets, and it also affected the extinguishment time of the in-cabinet cable fire. The extinguishment time of the cable bundle tire determined the quantities of the acid gas products generated in the fire cabinet. In the closed fire cabinet, more HF and COF, were generated due to the longer time for agent-flame interaction than in the ventilated or open fire cabinet. The maximum HF concentration was 800 ppm in the closed fire cabinet, which decayed to below 100 ppm in 10 min. In the open or ventilated tire cabinet, the maximum HF concentration was below 100 ppm.

In the non-fire cabinets (C-2 and C-3), the FTIR gas measurement showed neither HF absorption signals nor other byproduct absorption signals. The HF concentration in the non-fire cabinets was too low to be detected, which indicates that migration of gaseous byproducts from the fire cabinet to the adjacent non-fire cabinets was minimal.

The HF concentrations in the test room were much lower than 100 ppm during **all** in-cabinet cable fire tests, which were tolerable for a healthy individual for a short exposure [1].

## SUPPRESSION OF LARGE FIRE

To see the impact of a large fire on electronic equipment, a suppression test of a heptane pool fire was also conducted. **A** round pan (0.7 m in diameter), which contained 2 L of heptane fuel on water base, with a heat release rate of 500 kW was used. The pan was placed on the floor close to the southeast comer of the compartment. The gas measurement showed that, within 8 ***s*** of the discharge, the agent concentration reached a peak value of 9.5% in the open cabinet (C-1). The maximum HF concentration in the room reached 3900 ppm. Measurement in tlie non-fire open cabinet showed peak HF concentration of 3800 ppm, whereas measurement in the ventilated and closed cabinets showed a peak HF concentrations of 1800 ppm and 500 ppm, respectively. When there was a large fire in the room, generation of HF from the fire suppression by HFC-227ea was significant, and a large amount of HF migrated to the non-fire cabinets in the room, indicating potential corrosion problem on the electronic equipments inside the cabinets in the room even when a fire was not located inside the cabinet.

HF can cause sensory and pulmonary irritation, depending on its concentration, exposure duration, and tlie health of individuals. The "Emergency Response Planning Guideline-3" (ERPG-3) value is relevant for firefighting emergency situations. The 10 min ERPG-3 value for HF is 170 ppm, which is the maximum non-lethal concentration for a healthy individual [1]. Exposure risk for people trapped in the room would be a safety concern.

## ELECTRONIC COMPONENT CORROSION STUDY

In a future study, short and long term effects of TDP on electronic components at the concentrations measured in this study will be assessed. In the future study, tests will be conducted using a 1 $m^3$ box to examine the corrosive effect of HF on electronic components. Several different types of electronic components will be placed in the test box with various concentrations of HF. The target concentrations of HF in the test box will range, e.g., 200 ppm, 500 ppm, 1000 ppm, 2000 ppm, 4000 ppm, and 8000 ppm. These concentrations are within the range of HF concentrations measured in this study, except the 8000 ppm. The amount of HF produced during fire suppression depends on the fire size, and it would be necessary to explore the worst case and double the maximum HF concentration measured in the current tests (8000 ppm) would be included in the corrosion study.

Tests will be carried out for various duration, and the test specimen will be examined for corrosion damages after the tests. The test duration will range from 1 to 6 hrs. The test specimen will be examined for surface corrosion **as** well **as** for functionality. The functionality of each test specimen will be checked at regular intervals after the exposure tests over a six-month period.

## CONCLUSIONS

The extinguishment time **of** the cable bundle fire was affected by the ventilation condition of the cabinet, which in turn determined the quantities of acid gas products generated in the fire cabinet. The maximum HF concentration was 800 ppm in the closed fire cabinet; however, it was below 100 ppm in the open or ventilated fire cabinet since it took a longer time to extinguish the fire in the closed fire cabinet than in the ventilated or open fire cabinet. Very little HF moved into the non-fire cabinets (C-2 and C-3) and migration of gaseous byproducts from the fire cabinet to the adjacent non-fire cabinets was minimal. During the in-cabinet cable fire tests, the HF concentration in the test room was much lower than 100 ppm, which was tolerable for a healthy person for a short exposure.

When the test fire was large, however, the HF concentration in the test room was at dangerous levels (10-min average 2000 ppm). Considerable quantities of HF were transported into the non-fire cabinets. Potential corrosion damage by the acid gas to equipment in an electronic environment and exposure risk for people trapped inside would be a safety concern when suppressing a large fire using HFC-227ea. In view of human and property safety, early fire detection must be emphasised so that a small fire can be extinguished before it develops into a large fire.

## ACKNOWLEDGMENTS

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## REFERENCE

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