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Flammability and Toxic-Gas Production of Urethane Foams Used in Anechoic Chambers

Patricia A. Tatem
Frederick W. Williams

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Naval Research Laboratory
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Four types of polyurethane foams for use in anechoic chambers have been evaluated under burning and pyrolysis conditions to determine their flammability and toxic-gas production characteristics. Toxic-gas productions of the foams under continuous exposure to both conditions are comparable. However, there is variation in the ability of the foams to sustain combustion after removal of a heat source. Foams that propagate smoldering present greater heat and toxic-gas hazards than those that do not.

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FLAMMABILITY AND TOXIC-GAS PRODUCTION OF URETHANE FOAMS USED IN ANECHOIC CHAMBERS

INTRODUCTION

In recent years, polymeric materials have been used more and more for structural components and for interior furnishings of buildings. Many of these materials contain halogen, cyanide, and/or other nitrogenous moieties, which can react during combustion or pyrolysis to form toxic products such as hydrogen chloride (HCl) and hydrogen cyanide (HCN). Because of the danger to life and property, the response of these materials to fire needs to be completely understood.

The interior walls and ceiling of many modern anechoic chambers are covered with a nitrogen-containing polymer-polyurethane foam. To serve as a good microwave absorber, the foam is impregnated with carbon and a latex binder to impart good electrical characteristics. The resulting material has low electrical resistance and is thus a good conductor. The foam is further treated with enough of a fire retardant, such as a chlorine-containing compound, to impart fire resistance without degrading electrical properties. When involved in fires, these treated foams may release toxic combustion products containing nitrogen [1, 2] and halogen, whose presence could significantly increase the toxicity of fire gases.

Although knowledge of the fire and toxicity hazards contributed by the treated polyurethane foam in anechoic chambers is limited, two recent fires involving these chambers have indicated the need for flammability and fire-retardance controls in manufacturing these materials. On November 15, 1973, the foam in an anechoic chamber at the Naval Research Laboratory, Washington, D.C., was ignited by an unknown source. The room, along with an associated support room, was severely damaged by the ensuing fire. The usual firefighting efforts were unsuccessful because of the ability of the foam to smolder after the ignition source was removed. High concentrations of HCN and HCl gases produced extremely hazardous conditions for the firefighters; six firemen wearing breathing apparatus were overcome by the toxic gases [3].

On February 5, 1974, an anechoic chamber at the Naval Air Rework Facility in Alameda, California, was completely destroyed by fire when hot slag from a welding torch ignited the chamber's foam. Investigation showed that the absorbent materials used in the chamber were manufactured from a self-extinguishing grade of polyurethane foam, coated with a fire-retardant material [4].

Experience has shown that one must be careful in interpreting the terminology used to describe varying degrees of fire resistance. *Self-extinguishing* materials burn as long as a source of external heat is present but are incapable of sustaining combustion after removal of the heat source. As demonstrated by the fire in Alameda, the fire characteristics of

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a self-extinguishing grade of polyurethane foam can be drastically changed by the processing it undergoes to produce a good microwave absorber. Treatment with *fire retardants* does not produce a nonflammable material; it only *reduces* flammability. A nonflammable material will not burn when exposed to a flame; however, foams that have been painted with a fire-retardant paint can lose their fire-retardant characteristics when the paint is destroyed, either mechanically or by fire. Unless these terms are well understood, the advertising and scientific literature about anechoic-chamber foams can be very misleading.

In an effort to eliminate the fire hazard associated with anechoic chambers, several foams submitted by contractors for use in a new anechoic chamber at NRL were tested for flammability and toxic-product formation under burning or pyrolysis. The two previous fires indicated a need to evaluate the ability of the foams to self-extinguish flame and smoldering after removal of an electrical ignition source, a flaming ignition source, or a flameless (hot-surface) heat source. Tests with these three sources of ignition will give an indication of the hazard once the material is ignited, if the ignition source is detected and eliminated without delay. High toxic-product concentrations during the fires suggested the need for evaluations of toxic-product formation when the material is continuously exposed to a source of ignition.

Four types of foams were tested extensively. As a result of these tests, several performance specifications were devised for fire-retardance and flammability requirements of foams to be considered for use in new chambers. The performance specifications are included as Appendix A; the test numbers in parentheses in the text correlate experimental procedures with these tests. The procedures outlined in the performance specifications do not necessarily duplicate the experimental procedures in the report. The sophisticated and detailed procedures followed for data collection were simplified to produce specification procedures that could be conducted with minimal difficulty and equipment.

EXPERIMENTAL

Materials and Apparatus

The names of the foams tested and their suppliers are given in Table 1.

Tests that required monitoring of combustion-product formation were carried out in the 9.5-ft^3 closed combustion chamber shown in Fig. 1 and described in detail in Ref. 5. The back and bottom of the chamber are equipped with assorted inlets for electrical connections, gas admissions, and product sampling. The chamber atmosphere is continuously sampled via the closed-loop manifold shown schematically in Fig. 2. The gas samples from the chamber flow, in order, through a 0.3-μm soot filter, a bleed valve, and a pressure regulator operated at a pressure differential of about 3.5 lb. The reference side of the regulator is maintained at about 10.7 psi, so that the sample loop is under a slight vacuum during the continuous sampling process. After the regulator the sample flow is divided along two pathways, one leading through a flowmeter into an oxygen analyzer (Beckman Instruments, Model F3) and the other through a flowmeter into CO_2 and CO analyzers (Beckman Instruments, Model 315A). The flow is maintained at 250 cm^3/min into the O_2 analyzer and 900 cm^3/min into the CO_2 and CO analyzers by the individual needle valves ahead of the circulating pump.

Table 1
Anechoic Chamber Foams Tested

Manufacturer	Designation	Date Rec'd by NRL
Rantec, Division of Emerson Electric Co.	Rantec (EHP-5WG-FP)	October 1973
Plessy Environmental Systems	Plessy (Preproduction AF)	October 1973
Eastern Microwave	Eastern (FFP-3)	October 1973
Emerson-Cumming	E-C* (ECCOSORBHPY-12FE)	December 1973

*Original sample received prior to December 1973 was not self-extinguishing. E-C represents newer formulation provided by the supplier and was the Emerson-Cumming material that was eventually subjected to all tests.

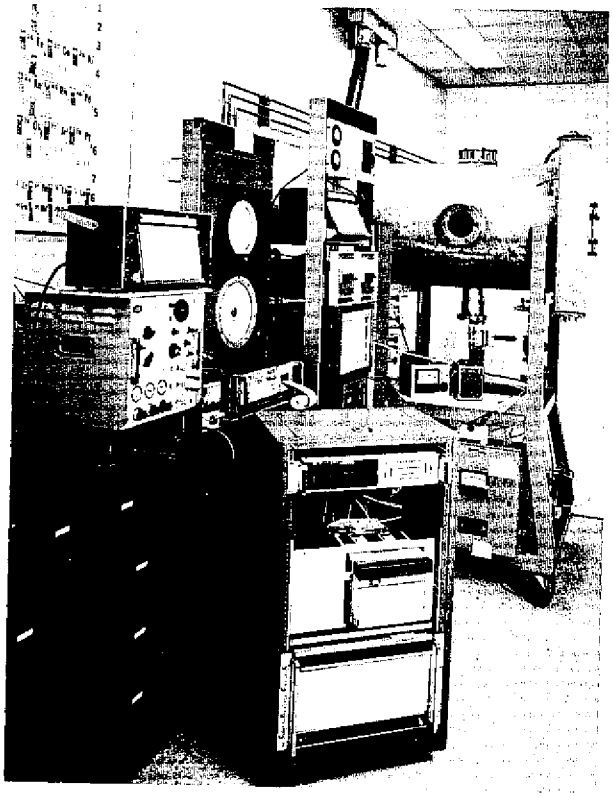

Fig. 1 — Experimental apparatus

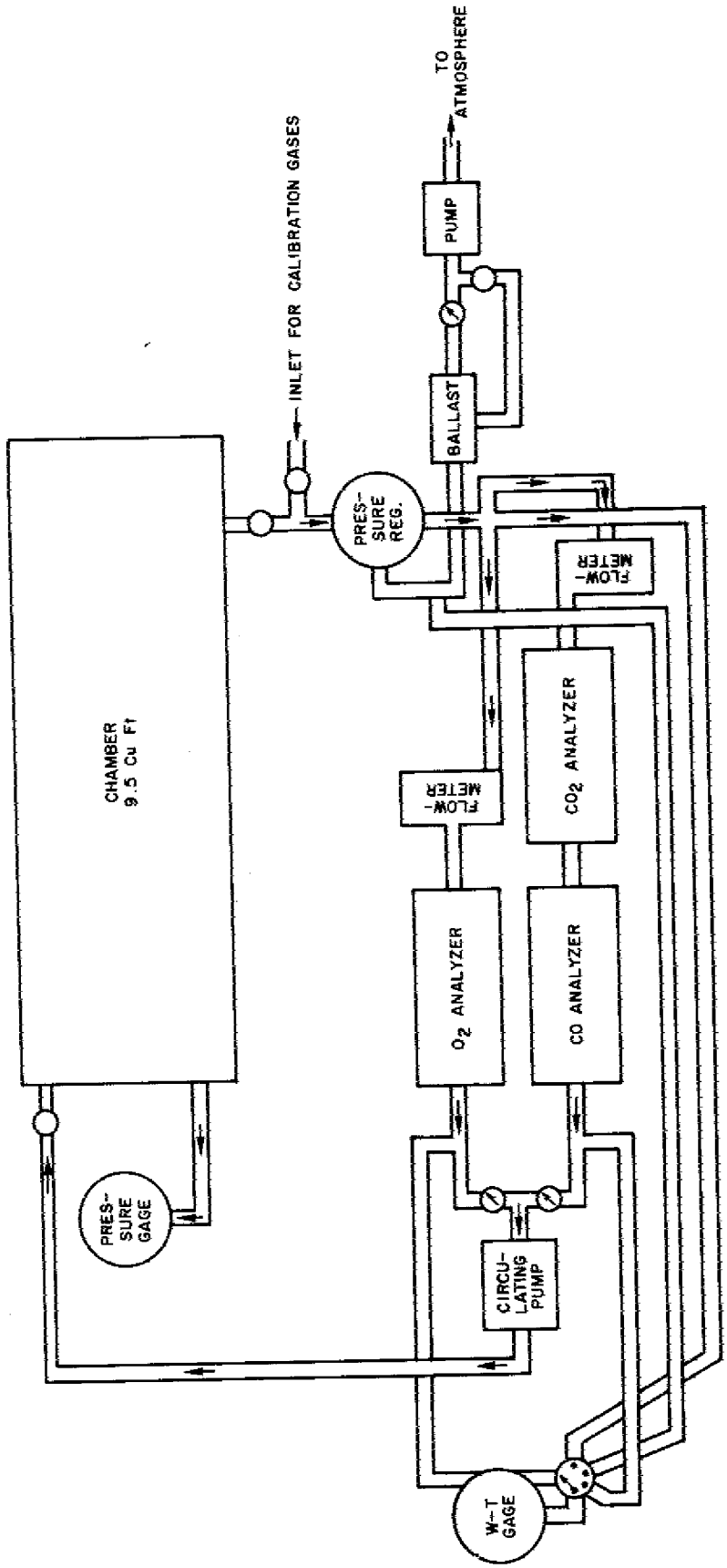

Fig. 2 — Schematic of closed-loop, continuous-sampling system

After leaving the analyzers, the gas flow is recombined at the circulating pump and returned to the chamber. The pressure can be monitored at four points along the sampling manifold—on the reference side of the regulator, in the sample loop immediately after leaving the regulator, after the O_2 analyzer, and after the CO_2/CO analyzers. The closed-loop system operates under a slight vacuum during calibration as well as during sampling, so that no corrections to the analyzer readings are necessary. The CO_2 and CO analyzers have 0-10% and 0-4000 ppm scales, respectively. The O_2 analyzer range is 0-25%. An auxiliary valve in the rear of the chamber provides an outlet for intermittent colorimetric tube sampling (Dräger tubes, Drägerwork Lübeck, 53/55 Moislinger Allee, Lübeck 24, Germany) for HCl and HCN gases. Temperatures are measured with iron-constantan thermocouples referenced to ice water.

The ignition sources used were a power supply (capable of 240 V ac), a hydrogen/air flame ($T \approx 2100°C$), a methane flame ($T \approx 1950°C$), a soldering iron ($T \approx 500°C$), and a 6-in.-long radiative cartridge heater (capable of temperatures up to 600°C). Test leads from the power supply were made of number 12 copper wire from which 1 in. of insulation had been removed at each end. The hydrogen/air flame was produced on a microburner located in the chamber and had a flame height of about 0.5 in. The methane flame was produced on a laboratory Bunsen burner in the hood and had a flame height of about 3 in.

The samples were contained in an alumina combustion boat during the continuous-exposure tests. The boat was in the center of the chamber and could be manipulated with a remote arm. Also in the center of the chamber was a nichrome wire, connected to an external power supply, which served as the ignition source for the hydrogen torch. The same power supply was used for heating the cartridge heater.

Procedures

The samples were subjected to 240 V ac from the power supply under a laboratory hood (Test 1) by inserting the test leads 1 in. apart and 0.5 in. deep in each sample. Current was applied across the foam for 60 s. The foams were inspected for damage at the end of this time and again 30 min later.

Supplementary timed voltage tests were carried out under the hood on specimens of Rantec foam. The same test leads from the power supply were inserted 10 in. apart at opposite ends of the samples and voltages of 40 V, 120 V, and 240 V were applied in turn for 15 min each. Specimens were observed during this period for visible signs of combustion.

Additional tests performed in the laboratory hood (Test 2) involved short exposures (about 30 s) of the foam to the methane flame and the soldering iron. During these exposures, care was taken to assure that the surface of the foam subjected to the ignition source was not covered with a surface fire retardant. Specimens were observed for 60 s after removal of the ignition source for evidence of any visible signs of combustion.

The cartridge heater was inserted snugly into a hole cut into a solid, 40- to 70-g cube of the foam. The specimen was placed in the chamber and the temperature of the heater was increased to a predetermined value (Test 3). The interiors of the E-C samples were hollow, so for these materials the heater was wedged into a corner between the 0.5-in.-thick walls. The power supply to the heater was disconnected after the desired temperature was reached, and the heater was remotely removed from the sample. The temperature of the heater and the concentrations of CO, CO_2, O_2 were monitored continuously.

A known quantity (about 1 g) of each foam was exposed to the hydrogen/air torch for 15-25 min in the chamber (Test 4). The foams were contained in the movable combustion boat, which allowed the entire sample to be heated by the flame from above during the degradation period. The amounts of toxic gases produced were determined at the end of the test period.

One-gram samples of the foams were exposed to the cartridge heater in the combustion boat in the chamber (Test 5). The heater was placed on top of the entire sample in the boat to allow maximum exposure of the foam to the heater. During the course of an experiment, the heater temperature was raised as high as 350°C over a period of 25 min. At the end of the test period, measurements were made of the toxic gases produced.

RESULTS AND DISCUSSION

When subjected to the electrical-resistance test (Test 1), samples of the Plessy and Eastern foams flamed and emitted heavy yellow smoke during the entire test period, even after the power was discontinued. These samples were completely destroyed by the end of the test period. Samples of E-C foam were not availiable for electrical-resistance testing.

Samples of Rantec foam received at different times gave varying responses to the electrical test (Test 1). One sample of Rantec foam (Sample 1) showed no visible response (no smoke, flame, or smoldering) to the electrical test. Sample 2 was completely consumed by flame during the test period, and Sample 3 flamed only during the 60-s period that power was applied. Specimens from Sample 3 showed no signs of smoldering within 60-s after the power was removed. Visual observation of these specimens at the end of the test period indicated that the material had confined the involved area and had not propagated smoldering, thus leaving an intact specimen.

To determine why different Rantec samples responded differently to the electrical tests, resistance measurements were made on each of the Rantec samples. Sample 1 had an extremely high resistance, indicating that the material had not been thoroughly impregnated with carbon and was essentially a nonconductor. Although the resulting material was highly fire resistant, it would not serve as a good microwave absorber. Comparison of Samples 2 and 3 indicated that the latter was intermediate in resistance between Sample 2 and Sample 1. If these resistance measurements are considered in conjunction with the fire retardance of Samples 1 and 2, as indicated by the electrical tests, it is evident that the important factor is that more energy can be put into the foams with lower resistance, that is, the foams of higher carbon impregnation. The amount of carbon also affects the fuel load of the sample; a nonflammable foam becomes flammable with increased carbon

content. However, the resistance of the material cannot be made too high, or the electrical properties of the material will be destroyed, as illustrated by Sample 1.

In the timed voltage tests on Sample 3 flames did not emanate at any time during the 15-min intervals that the voltages were applied across the specimen. During the first 2 min at 240 V, visible smoldering was detected but immediately disappeared.

The flaming and smoldering characteristics determined from Test 2 are summarized in Table 2. Samples of Rantec foam were self-extinguishing and did not propagate smoldering after the ignition source was removed. The original sample of E-C foam was not self-extinguishing, but a newer formulation supplied for further testing proved to be self-extinguishing and did not propagate smoldering after removal of the heat source. Samples of Plessy and Eastern foam self-extinguished with respect to open flame and visible smoldering when the heat source was removed, but damage observed after these tests indicated that nonluminous reaction, and hence toxic-gas production, continued. More sophisticated testing was done to determine the extent of smoldering after a flameless heat source is removed (Test 3).

Table 2
Flaming Characteristics of Anechoic-Chamber Foams (Test 2)

Foam	Acceptable Self-Extinguishment Test	Acceptable Smoldering Test
Rantec	Yes	Yes
Plessy	Yes	No
Eastern	Yes	No
E-C	Yes	Yes

Typical examples of toxic-gas production in the smoldering test (Test 3) are given in Fig. 3. In these examples, the foams were exposed to similar temperatures (300-365°C), but the amounts of toxic products generated after the ignition source was removed differed widely. Toxic-gas production and sample damage varied according to the temperature to which the heater was raised before being removed. After removal of the ignition source, the rate of toxic-gas production depended on the extent of smoldering. If this rate was greater than zero, combustion products were still being formed as a result of propagating smoldering. As the rate approached zero, combustion-product formation was decreasing and smoldering diminishing. A rate of zero was evidence that smoldering had halted.

These tests can be correlated with the ability of the foam to propagate smoldering. For Rantec and E-C foams, the increase in combustion products ceased within 2 to 4 min after removal of the heater if pyrolysis had been initiated, as can be seen in Fig. 3. These foam samples incurred minor damage from smoldering. At temperatures below 225°C for Rantec foam and 300°C for E-C foam, no pyrolysis occurred, as indicated by the absence of gaseous products. In some cases the temperature of the heater was raised as high as 600°C for Rantec and 500°C for E-C before removal; smoldering stopped within the same time period.

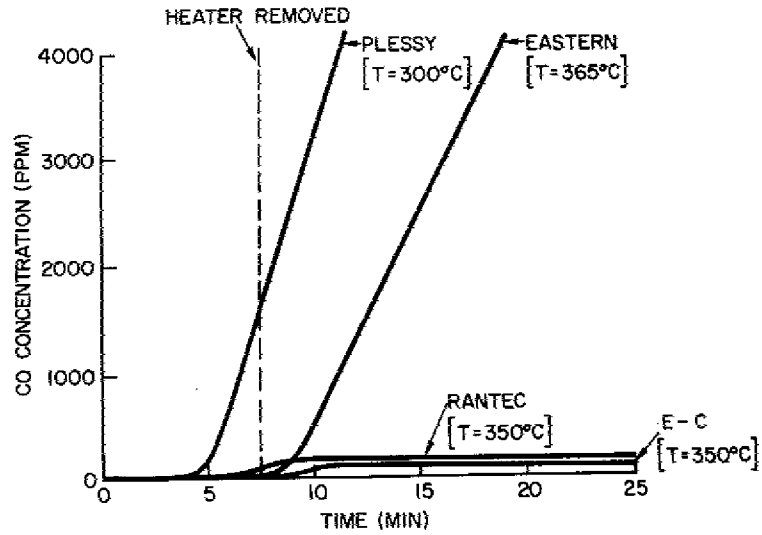

Fig. 3 — Production of CO for foam samples in smoldering test (Test 3)

The hollow interior of the E-C samples suggests that the data from its smoldering tests may not be as definitive as the data from smoldering tests on the other foams. With the heater wedged into a corner between the walls, the contact between the heater and E-C sample was not as effective as with the other foams. For more comparable data, a solid sample of E-C foam should be subjected to the smoldering tests.

For Plessy and Eastern samples (Fig. 3), the concentration of toxic gases increased after removal of the heater (for heater temperatures above 200°C for Plessy or 250°C for Eastern) until CO, HCl, and HCN concentrations were too high to be measured with available instrumentation (CO $>$ 4000 ppm; HCN $>$ 150 ppm; HCl $>$ 20 ppm). For these runs the data collection was terminated 10 to 15 min after the heater was removed from the sample. At this time the CO_2 concentration was still rising and the O_2 concentration falling. The samples were completely destroyed. If the maximum heater temperatures were lower than the temperatures given above, the samples did not propagate smoldering, and damage was not detected.

Rapid deterioration of the atmosphere after the ignition source was removed is immediately evident for the Plessy and Eastern samples. The concentrations of CO and HCN gases produced by these foams within 10 min after reaching 300° and 365°C, respectively, would be enough to cause death in less than an hour. The concentration of HCl gas produced would cause intense discomfort and irritation [6,7].

When the samples were continuously exposed to the hydrogen/air torch (Test 4), the concentrations of combustion products listed in Table 3 were found. Similar results are given in Table 4 for the same samples exposed to the cartridge heater (Test 5). The data in Tables 3 and 4 show that for exposures to intense fire stress (hydrogen torch) and lower temperature pyrolysis (cartridge heater), the yields of toxic products are comparable. Furthermore, as can be seen by comparing the data in each table, each foam produced about the sample quantities of toxic products, with the following exceptions:

1. HCl production was higher for the Plessy samples for both hydrogen/air-torch and cartridge-heater ignition sources.

2. HCN concentration was as high as 5 ppm in only two instances, one involving Plessy foam and the other Eastern foam.

3. CO production by the Eastern sample was the highest for both ignition sources.

Table 3
Atmospheric Analyses Following Exposure to Hydrogen/Air Torch (Test 4)

Foam	Combustion Product	Product Amount*	Weight of Combustion Product per gram of Sample* (mg)
Rantec	HCN	1 ppm	0.24
	HCl	N.D.†	--
	CO_2	0.1%	554
	CO	58 ppm	19
Plessy	HCN	4 ppm‡	0.9
	HCl	>12 ppm	>5.3
	CO_2	0.13%	670
	CO	63 ppm	21
Eastern	HCN	4 ppm‡	1
	HCl	<1 ppm	<0.4
	CO_2	0.11%	560
	CO	75 ppm	25
E-C	HCN	1 ppm	0.24
	HCl	2 ppm	0.7
	CO_2	0.06%	320
	CO	10 ppm	3

*Average values (for duplicate samples).
†Not detectable.
‡The individual values for the duplicate runs were 3 and 5 ppm.

Although the concentrations of toxic gases produced by the 1-g samples of the four foams are well below the levels at which inhalation becomes unsafe [6,7], consideration

must be given to (a) the environment in which these products would be encountered in a real fire situation and (b) the toxic products formed when any of these foams is continuously exposed to fire conditions. First, exposure to these concentrations of CO, HCN, and HCl under normal conditions could be tolerated for several hours without any lasting adverse effects [6,7]. However, in a real fire situation, the environment created by the fire intensifies the hazards of these gases. For example, work done by Stone, et al. supports the hypothesis that HCl may be carried into the lungs by fire-generated soot and water particles [8]. Gas-phase HCl can normally be removed by the defenses of the upper respiratory tract, whereas HCl loosely bound on water or soot particles can gain access to the lower lung. Here HCl may desorb from these particles and invade the tissue of the lungs. The severity of exposure to HCl in this form as opposed to gas-phase HCl is still to be defined by toxicologists.

Table 4
Atmospheric Analysis Following Exposure to Cartridge Heater* (Test 5)

Foam	Combustion Product	Product Amount †	Weight of Combustion Product per gram of Sample † (mg)
Rantec	HCN	3 ppm	0.6
	HCl	2 ppm	0.9
	CO_2	0.02%	110
	CO	15 ppm	5
Plessy	HCN	2 ppm	0.5
	HCl	20 ppm	9
	CO_2	0.04%	215
	CO	35 ppm	12
Eastern	HCN	2 ppm	0.5
	HCl	5 ppm	2
	CO_2	0.04%	215
	CO	130 ppm	44
E-C	HCN	1 ppm	0.24
	HCl	1 ppm	0.4
	CO_2	0%	—
	CO	10 ppm	3

*Smoldering not included.
†Average values (for duplicate samples).

Second, the concentrations given in Tables 3 and 4 are for 1-g samples only. Continuous exposure to any heat source would involve increasing amounts of the material and would generate toxic products from each foam to a concentration that can rapidly cause discomfort or even death in man. Since Rantec and E-C foams will not sustain combustion, removal of the heat source would immediately halt toxic-gas production. Plessy and Eastern foams are capable of propagating extensive smoldering; therefore, removal of the ignition source from these materials would not prevent the continued production of highly toxic gases and further deterioration of the atmosphere.

SUMMARY

This work demonstrates the variation in behavior of anechoic chamber foams under fire and thermal stress. The ability of a foam to self-extinugish external or visible flame does not necessarily indicate that the material is fire safe. The persistence of smoldering combustion can present additional hazards in the form of heat and continued production of toxic gases, even after the visible or flaming fire has subsided. This unseen glowing combustion can rapidly build up toxic gases, rendering an atmosphere unacceptable for prolonged human occupation.

RECOMMENDATIONS

1. The *finished* absorption material used in anechoic chambers should be self-extinguishing. It is not sufficient for a self-extinguishing grade of polyurethane foam to be used as the starting material.

2. Foams to be used in anechoic chambers should be homogeneously impregnated with a fire retardant. Exterior coating of a self-extinguishing polyurethane foam with a fire retardant does not impart the degree of fire retardance acquired by homogeneous impregnation.

3. For added fire protection, all foams considered for use in anechoic chambers should be subjected to and pass the performance specifications given in Appendix A.

4. Every batch of absorber foams produced should be subjected to these tests. Formulations of these absorber foams are changed frequently, and every batch produced must be qualified in order to be classified as safe for use in anechoic chambers.

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Appendix A
PERFORMANCE SPECIFICATIONS FOR ANECHOIC-CHAMBER MATERIALS

TEST 1—RESISTANCE TO ELECTRICAL STRESS

Specimens: Three 2- X 6- X 6-in. samples.

Equipment: A 240-V ac power supply capable of 8-A output; test leads of 10 AWG copper wire with a 90° bend 0.75 from the ends.

Procedure: The insulation is removed from the test leads to expose 0.5 in. of bare wire. The leads are inserted to a depth of 0.5. in the foam, 1 in. apart. The surface area of the specimen in which the test leads are inserted shall not be covered with a surface fire retardant. Power shall be applied to the specimen for 60 s. The specimen fails the test if it does not self-extinguish (no visible flame, smoke, or smoldering) within 60 s after the power has been turned off. The specimen is then left undisturbed for 30 min. At the end of this period, the specimen is inspected and damage to the specimen is rated visually: 1—no damage; 2—Minor damage; 3—extensive damage; 4—total destruction (only char remaining). The specimen is then opened to expose its interior and is inspected for any evidence of remaining combustion (hot embers, smoke, or flame); any visible combustion is reported. Any specimen that is totally destroyed has failed the test. Failure of any specimen rates the material as unsatisfactory.

TEST 2—EASE OF IGNITION AND FLAME PROPAGATION

Specimens: Five cubes, 2 in. or larger on each side.

Equipment: A laboratory ringstand with necessary clamps suitable for supporting and positioning the specimen; a laboratory Bunsen burner adjusted to a height of 3 in. and producing a flame temperature of 2000°C; a timing device permitting measurements of intervals of 1 s or less.

Procedure: The test shall be conducted in a location free of drafts. The specimen is exposed so that the flame is directed at the bottom center of each specimen for 30 s. The bottom of the specimen shall not be covered with surface fire-retardant paint. If the burning part of the specimen melts or shrinks away from the flame, the burner should be moved so that the specimen is continuously in the flame. If the specimen self-extinguishes (no visible flame, smoke, or smoldering) within 60 s after the flame is withdrawn, it has passed the ignition test. For a material to be classified as self-extinguishing by this test, every specimen must self-extinguish within 60 s after flame withdrawal.

TEST 3—SMOLDERING

Specimens: Three 4-in. cubes

Equipment: A radiative cartridge heater, capable of being inserted snugly into a 3-in.-deep hole in the side of the specimen and of reaching a maximum temperature of 600°C.

Procedure: The tests are conducted in a laboratory hood. The temperature of the heater is raised to 600°C before inserting it into the specimen. The heater is left in the specimen for 10 min, then removed. The specimen is left undisturbed for 30 min. At the end of this time, the specimen is inspected and damage to the specimen is rated visually: 1—no damage; 2—minor damage; 3—extensive damage; 4—total destruction (only char remaining). The specimen is then opened to expose its interior and is inspected for any evidence of remaining combustion (hot embers, smoke, or flame); any visible combustion is reported. Any specimen that is totally destroyed has failed the test. Failure of any specimen rates the material as unsatisfactory.

TEST 4—TOXIC-GAS EMISSION IN A FIRE ENVIRONMENT

Specimens: Three 1-g quantities of 0.25-in. cubes.

Equipment: A combustion boat capable of containing 1g of the specimen; a 2000°C hydrogen/air torch adjusted to a height of 0.5 to 1 in. (Either the boat or the flame must be movable to allow exposure of the entire sample to the flame during the test; total involvement of the sample is required.); a closed chamber capable of containing the boat with the specimen and the torch, equipped to remotely ignite the torch and sample the concentrations of CO, HCl, HCN, and O_2 and large enough that the O_2 does not fall below 20 percent during the test; detector tubes or other instrumentation for measuring the concentrations of CO, HCN, and HCl gases at the end of the test.

Procedure: The combustion boat containing the specimen is placed in the closed system. The torch is remotely ignited and directed from an angle above the specimen for 15 min; The flame should be within 0.25 in. of the specimen. During this time, the entire specimen must be exposed to the torch. At the end of the 15-min exposure, the concentrations of HCN, HCl, and CO are measured. Their productions are reported in terms of milligrams of combustion product per gram of specimen. If toxic-gas production exceeds the following limits, the specimen has failed the test.

Combustion Product	Amount of Product per gram Specimen (mg)
HCN	0.3
HCl	0.4
CO	20.0

Failure of any of the specimens rates the material as unsatisfactory.

TEST 5—TOXIC-GAS EMISSION DUE TO A HOT SURFACE

Specimens: Three 1-g quantities of 0.25-in. cubes.

Equipment: The combustion boat, closed chamber (large enough that the O_2 concentration dose not fall below 20 percent during the test) and sampling devices used in Test 4; a radiative cartridge heater capable of generating a temperature up to 350°C. The heater shall be placed on top of the cubes in the boat so that it heats all of the sample during the test.

Procedure: The combustion boat containing the 0.25-in. cubes is placed in the closed system with the heater lying on top of the cubes, so that it heats all of the specimen. The heater is then remotely activated and allowed to heat to 350°C. The specimen is heated at this temperature for 15 min. At the end of the 15-min exposure, the concentrationof CO, HCN, and HCl gases are measured and reported in terms of milligrams of combustion product per gram of specimen. If toxic-gas production exceeds the following limits, the specimen has failed the test.

Combustion Product	Product per gram of Specimen (mg)
HCN	0.6
HCl	0.9
CO	5.0

Failure of any of the specimens rates the material as unsatisfactory.

A summary of the performance tests described above is given in Table A1.

Table A1
Summary of Performance Specification Tests

Test	Equipment for Test	Property Tested	Experimental Conditions	Requirements Under Test Conditions
1. Resistance to electrical stress	Power supply (capable of 240 V ac Test leads	Ability to withstand electrical overload or short	Exposure to 240 V ac for 60 s	Self-extinguish within 60 s after removal of ignition source and intact specimen at end of 30 min
2. Ease of ignition and flame propagation	Bunsen burner Support for specimen Timing device	Ignitability and ability to self-extinguish flame (flaming ignition source)	Exposure to flame for 60 s	Self-extinguish within 60 s after removal of ignition source
3. Smoldering	Radiative cartridge heater (capable of 600°C)	Ability to self-extinguish smoldering (flameless ignition source)	Exposure to 600°C radiative heat source for 10 min	Intact specimen following test
4. Toxic-gas emission in a fire environment	Combustion boat H_2/air flame Closed chamber	Toxic gas production under continuous exposure to flaming ignition source (T = 2000°C)	Exposure to flame for 15 min	HCN concentration <0.3 mg/g HCl concentration <0.4 mg/g CO concentration <20 mg/g
5. Toxic-gas emission due to a hot surface	Combustion boat Radiative cartridge heater Closed chamber	Toxic gas production under continuous exposure to flameless ignition source (T = 350°C)	Exposure to radiative heat source for 15 min	HCN concentration <0.6 mg/g HCl concentration <0.9 mg/g CO concentration <5 mg/g