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MEASUREMENT OF TOXIC GASES AND SMOKE FROM AIRCRAFT CABIN INTERIOR MATERIALS USING THE NBS SMOKE CHAMBER AND COLORIMETRIC TUBES

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FINAL REPORT

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Abstract

Twenty-five "self-extinguishing" materials used in wide-bodied aircraft cabin interiors were tested in the National Bureau of Standards Smoke Chamber and analyzed for smoke and toxic gases in the combustion mixture. Concentrations of selected toxic gases were measured at regular intervals during the test, either directly from the chamber or from bag samples, using colorimetric detector tubes.

Data analysis was facilitated by grouping the materials into usage designations and comparing the peak smoke and toxic gas concentrations. Despite the unknown magnitude of interference effects in the combustion mixture, detector tubes appear to offer a convenient and inexpensive method for identifying the presence of selected gases and approximating the relative gas yield of similar cabin materials.

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PREFACE

I would like to thank Joe Spurgeon for his helpful advice in planning this test program, conducting many of the developmental experiments and useful discussions relating to the analysis of the data. I am also grateful to Richard Johnson, Eldon Nicholas, Ross Glidewell, and Frank Coble for operating the National Bureau of Standards smoke density chamber and collecting the detector tube data.

The cooperation of the following airframe and seat manufacturers by furnishing test samples made this study possible: Boeing Company, Douglas Aircraft Company, Lockheed-California Company, Universal Oil Products Company, Aircraft Mechanics, Incorporated, Custom Products Company, Weber Aircraft, Heath Tecna Corporation, Hardman Aerospace, and Flight Equipment and Engineering Corporation.

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INTRODUCTION

PURPOSE.

The purpose of this activity was to measure the concentration history of selected toxic gases, using colorimetric detector tubes, and smoke produced by burning wide-bodied cabin materials in the National Bureau of Standards (NBS) Smoke Chamber.

BACKGROUND.

Federal Aviation Administration (FAA) regulations governing the selection of air transport cabin materials based on flammability criteria have been in existence since 1946. In May 1972, the most recent upgrading of the performance criteria for material flammability was promulgated (reference 1). With this rule change, the vast majority of cabin materials was required to be "self-extinguishing". However, under intense fire-exposure conditions, "self-extinguishing" materials (or any polymeric material for that matter) burn and, depending on the circumstances, can produce levels of smoke and toxic combustion products that are hazardous to exposed individuals. The experience of dense smoke is common to all cabin-fire accidents and has led the FAA to propose regulations to minimize this hazard (reference 2). Moreover, mounting evidence from recent accidents indicating that toxic gas emissions from interior materials may have a significant effect on occupant survivability has prompted the FAA to consider rulemaking to control these emissions (reference 3).

It was proposed by FAA that smoke produced by burning materials be measured using the NBS Smoke Chamber (reference 4). This instrument gained recognition in an FAA-sponsored study when it was used to measure the smoke generation of 141 cabin interior materials under both flaming and non-flaming fire exposure conditions (reference 5). In this study, the concentrations of a small number of selected toxic combustion gases were also measured sequentially, using colorimetric detector tubes starting near the time of maximum smoke accumulation. It was demonstrated that the materials tested produced a wide range of smoke and toxic gas values, with some materials behaving much more favorably than others in this regard: i.e., having both low smoke and toxic gas levels.

DISCUSSION

GENERAL APPROACH.

The general approach taken was to burn representative cabin materials in the NBS Smoke Chamber and simultaneously measure the concentration of smoke and a selected number of toxic gases, using the chamber photometric system and colorimetric detector tubes, respectively. Although the chamber was

not specifically designed for the purpose of combustion gas analysis, this instrument was used for this study for several reasons. First, by testing currently used cabin materials in the smoke chamber, additional data would be provided for the early NBS study conducted in 1968 (reference 5); and secondly, the wide popularity and standardization of this instrument would enable many other testing laboratories to compare results for identical test conditions.

In the earlier NBS study (reference 5), toxic gas measurements were made using colorimetric detector tubes inserted through the top of the chamber and situated 3 inches below the ceiling. Sampling was initiated when the smoke level approached its peak and performed sequentially with the most reactive gases (HCl or HF) measured first and the least reactive (CO) measured last. For the present study, several procedural changes were made.

Sampling was conducted at the geometric center where a representative combustion gas mixture was more likely to exist than at the ceiling. Also, all of the selected toxic gases were measured simultaneously and at regular increments over the test duration. A concentration-time curve could then be constructed for each gas that would provide the peak concentration as well as the gas concentration near the time of maximum smoke accumulation as measured in the early work. All gases except HCl and HF were measured from bag samples; the latter two gases were measured with colorimetric tubes placed directly within the chamber after it was discovered that substantial sampling line and bag wall losses were experienced with these very reactive gases (see later detailed discussion).

Colorimetric detector tubes have the advantages of simplicity, speed, and inexpensiveness, which are all important assets when the testing and analysis of a large number of materials is involved. Unfortunately, the tubes are also fairly imprecise and, more importantly, specific gas tube readings are influenced by other gases. These limitations must be recognized and applied when analyzing combustion gas data obtained with colorimetric tubes.

The nature, quantities, and number of toxic gases produced by a burning polymeric material is strongly dependent upon the combustion conditions and the physical and chemical properties of the material. Many of the early combustion gas studies were for a relatively small number of selected toxic gases (reference 6). However, over recent years researchers in this field have applied advanced and specialized analytical tools to identify and quantitate all gaseous components (see, for example, references 7, 8, and 9). This type of effort to completely define the combustion gas mixture is useful and necessary, but beyond the scope of the present work. Instead, a small number of toxic gases were selected that are most often referred to in the literature (e.g., reference 10). These gases are:

Carbon Monoxide - CO
Hydrogen Chloride - HCl
Hydrogen Cyanide - HCN
Hydrogen Fluoride - HF
Nitrogen Oxides - NO_x
Ammonia - NH_3

Sulfur Dioxide - SO_2
Hydrogen Sulphide - H_2S
Toluene Diisocyanate - TDI (for urethane foams)
Aldehydes

They include all gases measured in the early NBS work (reference 5), except for Cl_2 and $COCl_2$ which were not detected then and thus omitted from the present study.

NBS SMOKE CHAMBER.

A detailed description of the NBS Smoke Chamber can be found in reference 4. A photograph of the chamber with gas sampling attachments used in this study is shown in figure 1. Basically, the chamber is comprised of an 18-cubic-foot (ft^3) (510 liter) enclosed box, vertical specimen holder (2 9/16-inch-square specimen exposure), radiant heater (2.5 watts per square centimeter), 6-tube propane-air burner, and photometric system for measuring light-obscuring smoke. The "modified" burner and holder were consistently used throughout the study (reference 4). Although two nominal exposure conditions are specified and often used, materials were only tested under the more severe flaming condition (combined radiant heat and burner flames) in order to produce higher combustion gas concentrations. This trend was usually observed both in the NBS study (reference 5) and during preliminary testing. Specimens were tested in their end-use thickness, except for the thicker foams which were all tested at a thickness of 1/2 inch.

Several minor modifications had to be made to the chamber for this test program. A number of holes were drilled through the ceiling to provide access for sampling probes. All previously bare metallic interior surfaces were coated with a chemical-resistant epoxy paint. The windows of the photometric system and chamber door were covered with a transparent Teflon® film during testing of materials containing polyvinyl fluoride in order to prevent etching of the glass by hydrogen fluoride.

COLORIMETRIC DETECTOR TUBES.

The variation with time (during the test) of each of the selected toxic gases was measured using commercial colorimetric tubes. Appendix A contains a description of the operational characteristics, known interference effects and performance experience for each tube used. Essentially, a colorimetric tube is a small glass tube packed with a chemical that reacts and changes color when a gas mixture drawn through it contains a specific component. The length of discoloration is related to the concentration of the specific component in the gas mixture and the flow rate and volume taken of the gas mixture. The concentration of the specific gas component is related to the stain length by use of a calibration scale provided by the manufacturer. The gas sample is drawn through the tube using the manufacturer's hand pump. A precleanse layer ahead of the indicating layer is designed to remove interfering gases.

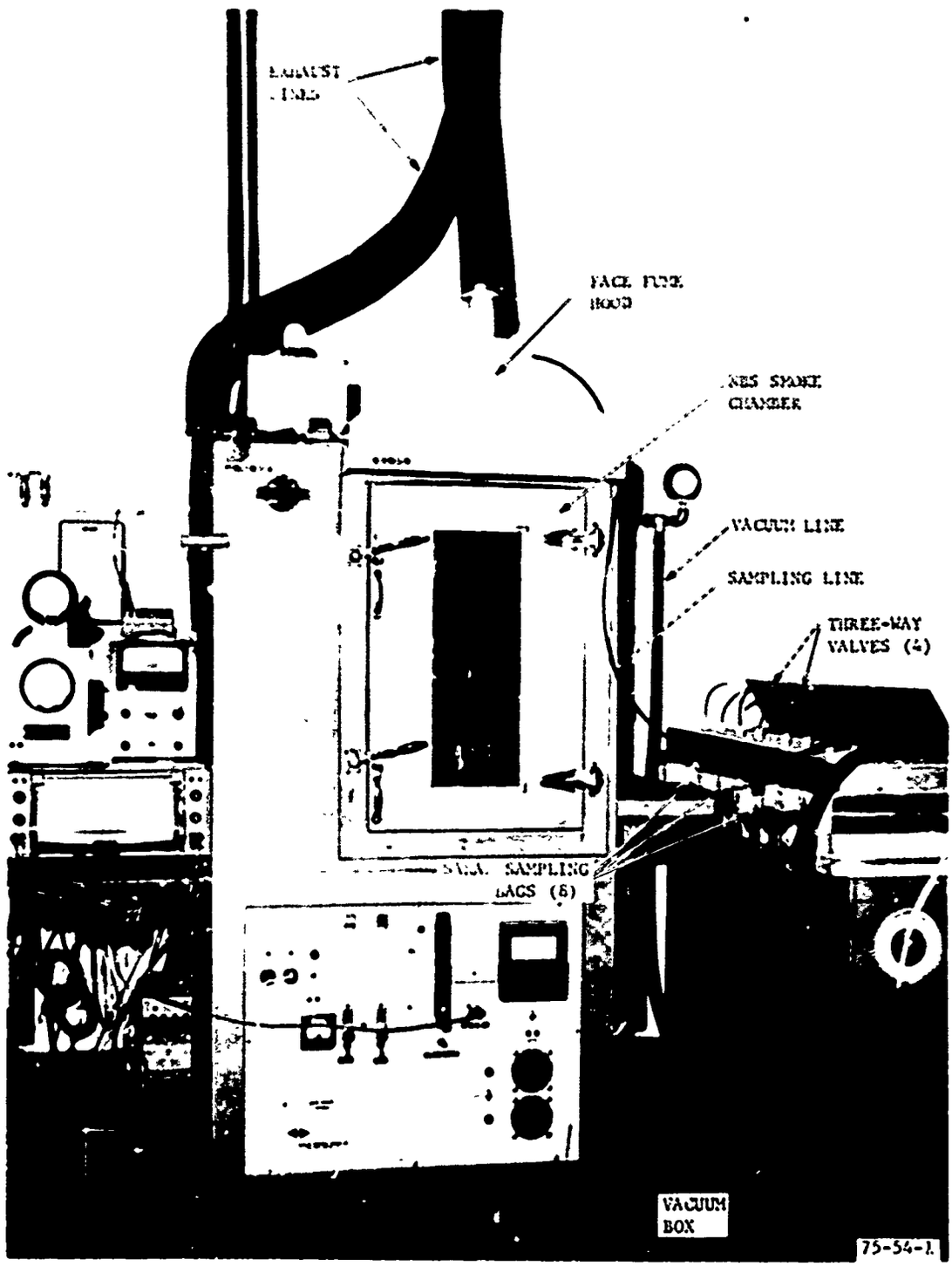


FIGURE 1. NATIONAL BUREAU OF STANDARDS SMOKE DENSITY CHAMBER AND BAG SAMPLING BOX

Since the normal application of colorimetric tubes is for industrial hygiene purposes, their measurement range is usually restricted to the immediate region surrounding (mainly above) the 8-hour threshold limit value (TLV) for substances in workroom air adopted by the American Conference of Governmental Industrial Hygienists (reference 11). However, in a combustion gas mixture the concentration of some toxic components can greatly exceed the TLV. In these cases it became necessary to extend the measurement range by taking a reduced sample volume and assuming an inverse linear relationship between sample volume and concentration. For some tubes the validity of this practice has been substantiated by the manufacturer (e.g., CO, HCN); however, for other tubes (HCl, HF) it was necessary to assume that the manufacturer's calibration could be extrapolated to higher concentrations (appendix A).

Over the last several years there has been a major increase in the accuracy of detector tubes fostered by a certification program under the jurisdiction of the National Institute for Occupational Safety and Health (NIOSH). An important provision of this program is that tube accuracy be within ±25 percent (reference 12). Presently, five of the detector tubes used in this study have been approved by NIOSH in their continuing certification program. This certification is based on the demonstrated measurement accuracy in a mixture containing the specific component alone in air, while the dominant limitation to the use of detector tubes in a multicomponent combustion gas mixture relates to the uncertainty associated with the magnitude of interference effects.

GAS SAMPLING.

One objective of this study was to examine the concentration histories in the NBS Smoke Chamber of each of the 10 selected toxic gases measured using detector tubes. The impracticality of simultaneously measuring 10 different gases by separately aspirating the specified sample volume through each detector tube, using a hand pump requiring a different sampling time for each tube ranging anywhere from 3-4 seconds to several minutes dictated that another approach was needed. It was decided that bag samples should be taken periodically from the chamber and gas analyses performed after the test. This procedure was followed for all gases except HCl and HF because substantial sampling line lag wall losses were found to exist for these reactive gases. As a result their measurement was conducted directly inside the chamber. Each detector tube was placed at the geometric center of the chamber attached to plastic tubing passing through the ceiling to a hand pump. For these tubes the indicated gas concentration was representative of the average level over the sampling time interval, which ranged from 4 to 40 seconds depending on the concentration.

The remaining gases were measured from combustion gas mixtures taken in Saran® (vinylidene chloride-vinyl chloride copolymer) plastic sampling bags. These bags have good chemical resistance, low permeability, and have reasonable cost. Before entering the Saran bags, the combustion gas sample first passed through an 18-inch glass probe within the chamber followed by approximately 6 feet of polypropylene tubing between the chamber and bags. The size of the Saran bags was 12 liters to allow for an adequate combustion gas mixture to enable all gases to be measured with maximum detector tube sensitivity (largest sample volume).

A vacuum box arrangement was designed to transport the combustion gas mixture from the chamber into the Saran bags. Eight bags connected to seperate valve outlets were placed in the 3/4-by-2-1/3-by-4-foot plywood box. By maintaining the box at a vacuum pressure of 8 inches of mercury (in.Hg), it was possible to take a 10-liter (less than 12 liters to keep the bag from bursting) sample in 10 seconds. The pressure differential between the chamber (atmospheric) and vacuum box (-8 in.Hg) propelled the sample into the box. Purging and evacuation of the bags to a "zero" volume before each test minimized any contamination from prior tests or sample dilution. The vacuum box arrangement appears more efficient and less troublesome than a vacuum pump.

TEST MATERIALS.

All test materials are used in the three types of wide-bodied jets and were received from airframe and seat manufacturers. These materials are described in table B-1 of appendix B, showing chemical composition (for composites, description begins with frontface and ends with backface), thickness, unit weight, designation, and cabin use. Descriptive information on makeup and chemical composition of these materials is as provided by the suppliers. Flammability tests were conducted to verify compliance with current FAA regulations (reference 1). All materials were found to meet the flammability acceptability criteria and thus were "self-extinguishing" in a vertical orientation. The window pane (No. 109) and panel adhesive laminate (No. 39) are not required to be "self-extinguishing." The 75 materials tested were divided into the following usage designations:

Panels	13
Panel Components	9
Foams	9
Fabrics	12
Coated Fabrics	4
Flooring	6
Thermoplastics	8
Cargo Liners	5
Transparencies	3
Insulations	4
Elastomers	2

These were selected from the approximately 150 materials obtained primarily to provide a cross section of physical and chemical characteristics for the materials in the more important usage categories (panels, foams, fabrics, and thermoplastics).

TEST RESULTS AND ANALYSIS

CHARACTERISTICS OF TEST APPARATUS AND MEASUREMENT TECHNIQUES.

Before embarking on the analysis of the 75 cabin materials, a series of 10-minute tests were conducted to define the effects or characteristics of certain operating conditions and derive the most appropriate test procedures.

NBS SMOKE DENSITY CHAMBER. For very thin or lightweight materials tested in the NBS Smoke Chamber, when analyzing the combustion gas data one should subtract the background levels caused by the propane/air burner. The effect of burner gases was generally found to be relatively low. Measurements of CO and NO_x were taken at the geometric center of the chamber under the flaming exposure condition (radiant heat and propane/air burner) using a LIRA® infrared analyzer and detector tubes, respectively. The concentrations of both gases increased in a fairly linear manner. The rate of increase of CO and NO_x was 3 and 0.2 parts per million (ppm) per minute, respectively.

A sample taken from the chamber must contain a representative (average) mixture of combustion gases. The effect of sampling probe location during material fire tests was determined for CO and HCl, which were considered as typical nonreactive and highly reactive gases, respectively. The LIRA analyzer was used to measure the concentration history of CO along the vertical center symmetry line and at the corners of three horizontal planes during flaming combustion tests of filter paper. The vertical CO profile at selected times are plotted in figure 2. Across a central region extending from 12 to 30 inches above the floor the concentration was fairly uniform. At the geometric center of the chamber the concentration was also very close to the average value calculated from the seven vertical measurements. The CO concentration in a horizontal plane exhibited a similar invariability, e.g., the coefficient of variation between the four corners and geometric center was less than 5 percent after 3-4 minutes in planes 6 and 18 inches below the ceiling.

Stratification of HCl at the vertical symmetry line was measured during the smoldering combustion of 98 percent polyvinyl chloride (PVC) by simultaneously sampling from three elevations into fritted bubblers. The total quantity of chloride ion collected at each elevation over the 10-minute test was measured using ion selective-electrodes. Table 1 contains this data expressed in terms of weight of chloride per liter of sample volume for three replicate tests. Compared to CO which was found to be fairly uniformly distributed, the stratification of HCl was substantial.

On a time-averaged basis, the concentration of HCl decreased from the ceiling to the floor during two of the three tests; an approximately uniform concentration was evidenced for the remaining test (NO. 1). For all three tests, the concentration at the geometric center (18 inches) was slightly less than, but within 10 percent of, the average concentration. The distribution measurements of CO and HCl demonstrated that a representative (average) gas

concentration existed at the geometric center of the chamber: consequently, all subsequent gas sampling was conducted at this location. Utilization of a fan to more uniformly distribute the gases was ruled out when test results gathered elsewhere demonstrated that this procedure would decrease the yield of some gases, apparently because of wall adsorption effects (reference 13).

TABLE 1. STRATIFICATION OF HYDROGEN CHLORIDE DURING SMOLDERING COMBUSTION OF POLYVINYL CHLORIDE

	Quantity of HCl Collected (micrograms/liter) at Different Probe Depths Below Ceiling		
Test	6 Inches	18 Inches	30 Inches
1	3,160	2,750	3,360
2	4,150	3,360	2,710
3	1,330	1,100	935

Under the nominal NBS Chamber smoldering test condition, HCl wall adsorption losses were found to be insignificant in NAFEC testing of PVC. One-square-foot pieces of Teflon film were placed on the wall behind the heat source and on the opposite wall. After the test the Teflon films were soaked in distilled water and the solution analyzed for adsorbed chloride using ion selective electrodes. Wall losses measured in this manner at the above locations only accounted for 0.9 and 1.1 percent of the total chloride measured, respectively.

The recovery of HCl was examined for a possible effect from the cumulative conditioning of chamber walls from prior testing. Six replicate tests of PVC were conducted under smoldering exposure conditions. Ion selective electrodes were again used to measure chloride collected in 10 consecutive 1-minute fritted impinger samples and also in a filter assembly. A clean chamber wall was used for the first test but the wall was not cleaned for the five subsequent tests. Table 2 contains the total chloride (10 impingers plus filter assembly) and peak chloride (largest impinger level) values obtained.

Although tests 2 and 5 did exhibit large increases in the yield of HCl, no progressive change in HCl recovery was detected within the accuracy of the measurement technique. On this basis, wall conditioning was not considered to be a dominant effect; therefore, no periodic schedule or special precautions for cleaning the chamber were taken.

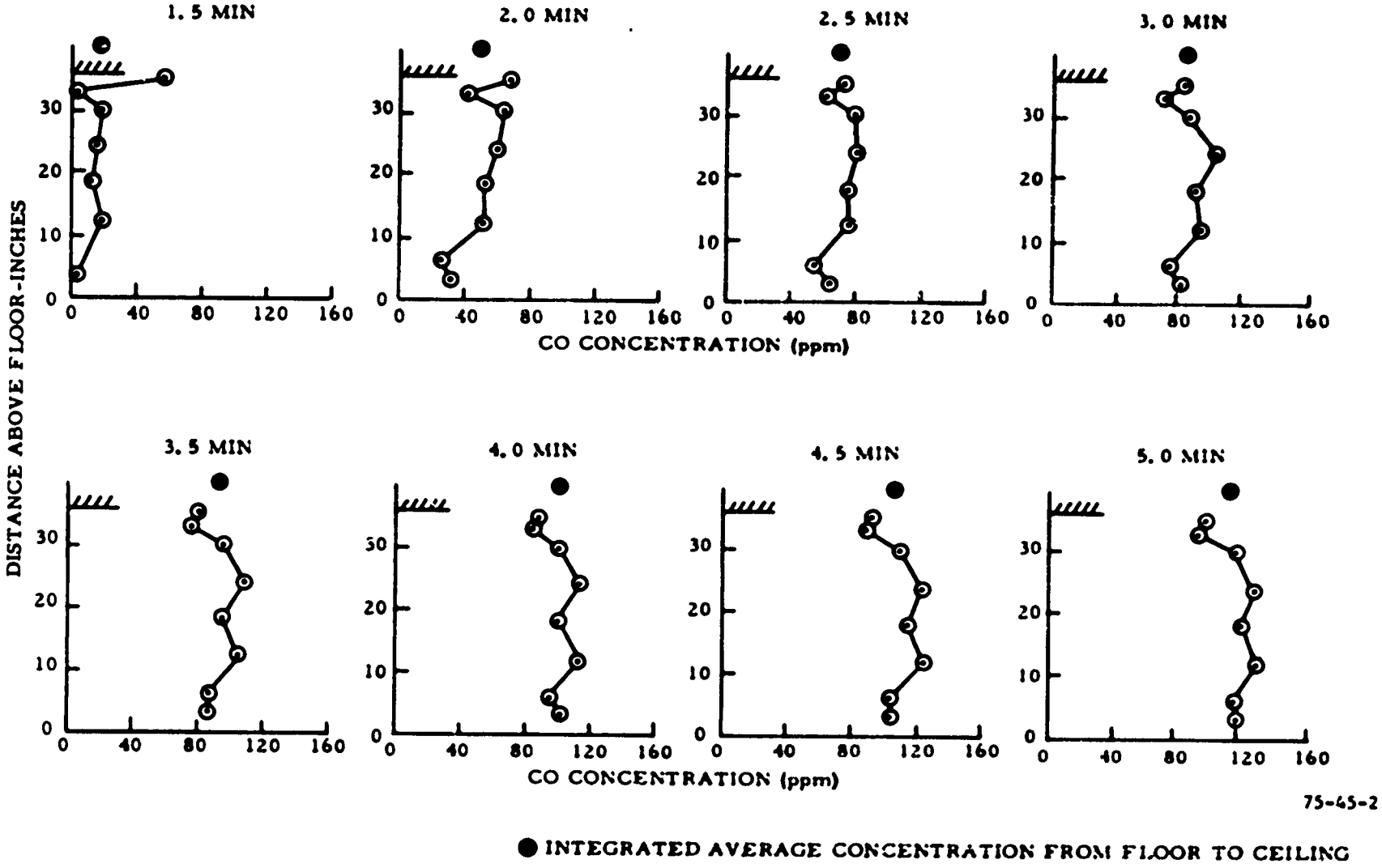


FIGURE 2. STRATIFICATION OF CARBON MONOXIDE IN THE NBS SMOKE DENSITY CHAMBER DURING FLAMING EXPOSURE OF FILTER PAPER

TABLE 2. RECOVERY OF HYDROGEN CHLORIDE (HCl) DURING REPLICATE TESTING OF POLYVINYL CHLORIDE (PVC) UNDER SMOLDERING EXPOSURE CONDITIONS

	Test					
	1	2	3	4	5	6
Total Chloride (micrograms) Collected	7,920	11,800	6,790	6,960	15,500	6,980
Peak Chamber Concentration (ppm)	1,270	1,160	1,290	1,710	4,690	1,180

The reproducibility of gas measurements taken from the geometric center of the NBS Chamber was found to be dependent upon the test material, combustion gas measured, and methodology for gas sampling and analysis. The data contained in table 2 illustrates a case when both combustion gas and sampling methodology affect the reproducibility. From the six replicate tests, the coefficient of variation for total chloride and peak concentration was 38 and 74 percent, respectively. By virtue of its highly reactive nature, the measurements of HCl in the combustion mixture of materials tested in the chamber usually exhibited poor reproducibility. Significant and highly variable HCl losses were also detected in the filter assembly designed to prevent the fritted impingers from clogging; thus the factor of 2 difference in measurement reproducibility between peak and total chloride.

In contrast, the level of a nonreactive gas like CO produced by some materials tested in the NBS Chamber is very reproducible. To illustrate this fact 9 replicate 10-minute tests were conducted on filter paper under flaming exposure conditions. This material was observed to burn slowly and uniformly without any melting or dripping, and as a result, the levels of smoke and CO (LIRA analyzer, geometric center) continued to increase throughout the test. The smoke and CO concentrations measured at 10 minutes for each test and their coefficient of variation is tabulated in table 3. The reproducibility of both measurements was good and slightly better for CO than smoke.

Urethane foam is an example of a material that had a tendency to burn differently in the NBS Chamber from one test to another. Under flaming exposure test conditions, most of the material was consumed during the first minute of the test with a flaming intensity and duration that varied between tests; thereafter, combustion was confined primarily to the sample holder trough where the melted drippings were accumulated (until overflow), and ignited by two propane/air flamelets. Table 4 contains peak smoke, CO (LIRA® analyser) and HCN (detector tubes) data from four replicate tests of urethane foam under flaming exposure conditions.

TABLE 3. REPEATABILITY OF SMOKE AND CARBON MONOXIDE MEASUREMENTS AT 10 MINUTES DURING THE FLAMING COMBUSTION OF FILTER PAPER

	Test									Coefficient of Variation (Percent)
	1	2	3	4	5	6	7	8	9	
Specific Optical Density (D_s)	64	68	60	60	65	74	60	70	58	8.44
Carbon Monoxide Concentration (ppm)	230	245	248	252	259	273	282	267	267	6.21

TABLE 4. REPEATABILITY OF PEAK SMOKE, CARBON MONOXIDE AND HYDROGEN CYANIDE MEASUREMENTS DURING THE FLAMING COMBUSTION OF URETHANE FOAM

	Test				Coefficient of Variation (Percent)
	1	2	3	4	
Specific Optical Density (D_m)	328	310	323	268	8.87
Carbon Monoxide Concentration (ppm)	382	277	258	479	29.3
Hydrogen Cyanide Concentration (ppm)	25	25	22	35	21.2

The variability between tests was significantly greater for CO and HCN than smoke. Generally, higher CO and HCN levels were measured during tests in which the material experienced intense and/or extended flaming, and both gases increased in tandem. The greater precision of the LIRA analyzer compared to the detector tubes was reflected by the greater variability of CO measurements compared to HCN. Obviously, the smokiness of urethane is far less dependent on the combustion characteristics than is the production of CO or HCN; however, very intense and sustained flaming will reduce the overall smoke level (e.g., test 4).

COLORIMETRIC DETECTOR TUBES. A small number of tests were conducted to determine the effect of several factors on the accuracy of the detector tubes. The combustion gas mixture of a urethane foam was analyzed. The results are summarized below:

1. The subjective reading of stain length (concentration) on a used detector tube by two people, independently, was found to be in good agreement (coefficient of variation between 5 and 10 percent at the most sensitive measurement range, i.e., largest sample volume).

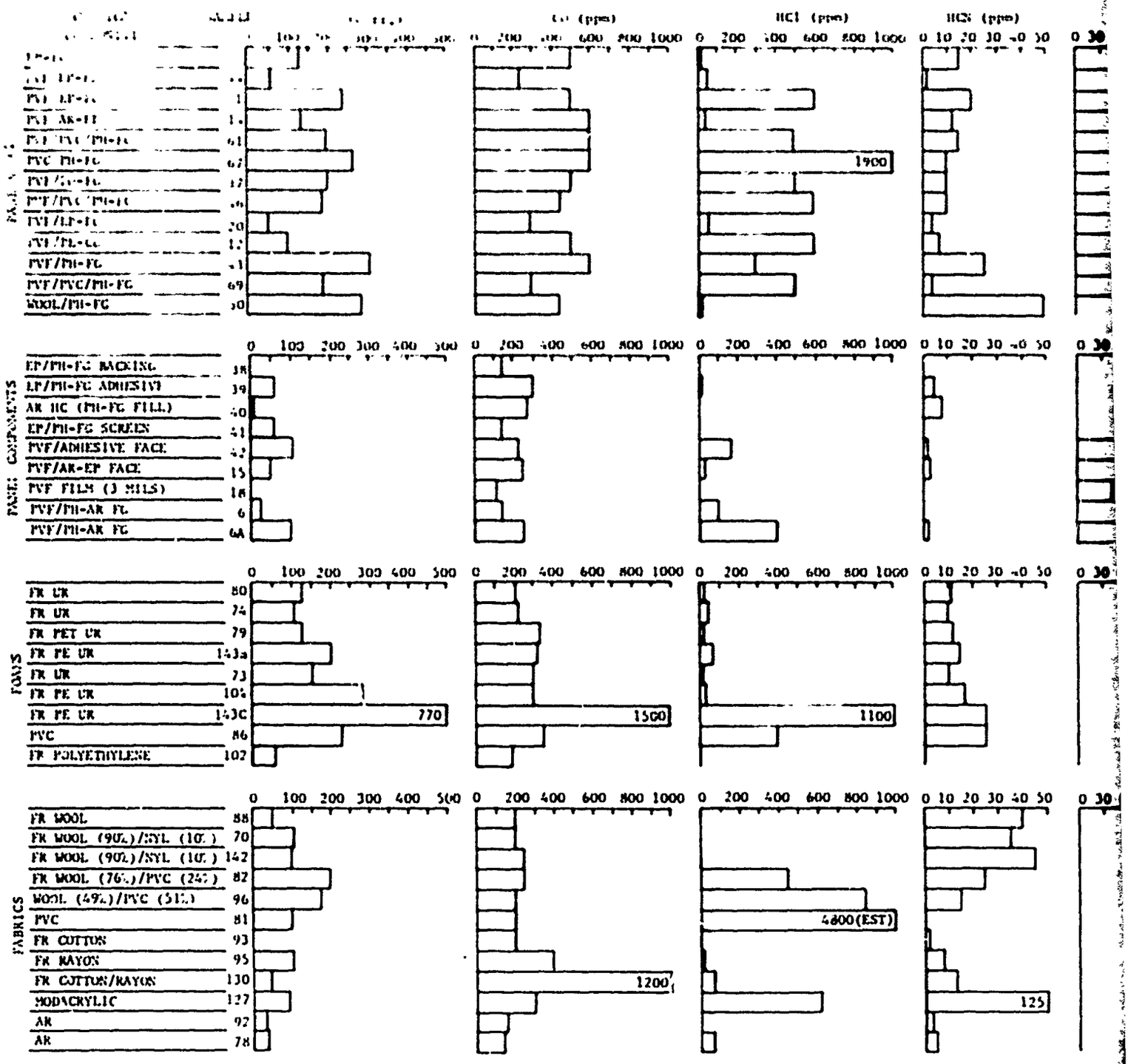
2. This agreement worsens, but not significantly, at the high-scale measurement range because of the loss in distinctiveness of the reduced stain length. The agreement between two readers can decrease to about 10 to 20 percent and depends on the length of the indicating layer and possibly the ratio of sample volume between low- and high-scale operation.

3. Species concentration measurements using detector tubes from different batches are in good agreement (coefficient of variation less than 10 percent). It should be noted that quality control provisions are contained in the NIOSH certification program (reference 12).

SAMPLING SYSTEM. The magnitude of gas adsorption wall losses in the sampling bag and line was determined by comparing detector tube measurements directly from the chamber and from Saran bag samples taken at the same point in time during the test of a material. This comparison was made for the following gases measured and materials tested: CO from paper; HCN, NO_x, and aldehydes (as formaldehyde) from urethane foam; HCl from PVC; SO_2 from polysulfone; and HF from a polyvinyl fluoride (PVF)-coated panel. Within the measurement ($\pm$ 25 percent) accuracy of the detector tubes, there was no consistent difference in indicated gas concentration taken directly from the chamber and from bag samples for all gases except HCl and HF. For the latter gases wall losses were excessive, ranging as high as 90 percent or better for HCl to 100 percent in half of the HF comparative measurements. For this reason HCl and HF measurements were taken with detector tubes inside the chamber, suspended from sampling lines.

A cursory evaluation was made of the time-decay of gas concentration in a Saran bag. CO and HCN detector tube measurements were taken periodically of a urethane foam combustion gas mixture. The indicated gas concentration did not change throughout the 90-minute period analyzed using either new or used sampling bags.

It should be noted that each 10-liter bag sample diluted the combustion mixture in the chamber by about 2 percent. Whether or not this is an additive effect after eight bag samples depends on the concentration history of the gas. For example, in the hypothetical situation of a gas attaining a constant concentration before the first bag sample, the maximum dilution factor would be slightly less than 16 percent after the eighth bag sample. On the other hand, if the gas concentration should increase linearly, the dilution factor after the eighth bag sample would be only slightly greater than 2 percent. The dilution effect of bag sampling was examined by making smoke and CO (LIRA analyzer) measurements during flaming combustion of filter paper both with and without bag sampling. By keeping a running account of the reduced concentration from each bag, it was possible to predict reasonably well the diluted smoke and CO level throughout the test. Since this effect is usually small, especially compared to the detector tube accuracy ($\pm$25 percent), the measured concentration of smoke and toxic combustion gases for the cabin materials is not corrected for sampling bag dilution.


CO (ppm)
HCl (ppm)
HCN (ppm)
0 100 200 300 400 500
0 200 400 600 800 1000
0 10 20 30 40 50
PANEL COMPONENTS
EP/PH-FG BACKING 38
EP/PH-FG ADHESIVE 39
AR HC (PH-FG FILL) 40
EP/PH-FG SCREEN 41
PVF/ADHESIVE FACE 42
PVF/AR-EP FACE 15
PVF FILM (3 MILS) 18
PVF/PH-AR FG 6
PVF/PH-AR FG 6A
FOAMS
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FR UR 74
FR PET UR 79
FR PE UR 143a
FR UR 73
FR PE UR 104
FR PE UR 143C 770 1500 1100
PVC 86
FR POLYETHYLENE 102
FABRICS
FR WOOL 88
FR WOOL (90%)/SYL (10%) 70
FR WOOL (90%)/SYL (10%) 142
FR WOOL (76%)/PVC (24%) 82
WOOL (49%)/PVC (51%) 96
PVC 81 4600(EST)
FR COTTON 93
FR RAYON 95 1200
FR COTTON/RAYON 130
MODACRYLIC 127 125
AR 92
AR 78

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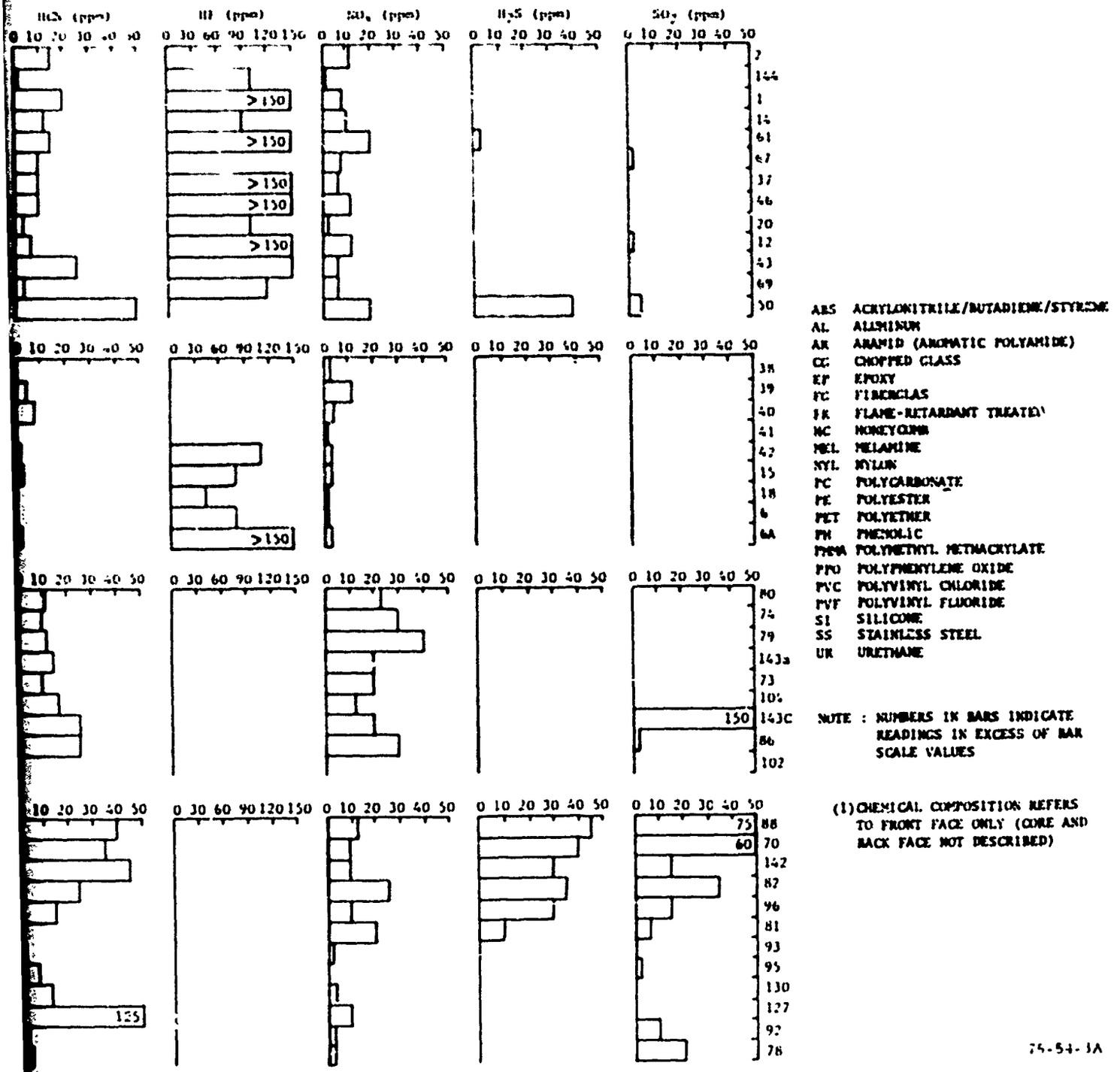


FIGURE 3. PEAK SMOKE AND TOXIC GAS CONCENTRATIONS FOR MATERIALS UNDER FLAMING EXPOSURE FOR A 7-MINUTE TEST (SHEET 1 of 2)

2

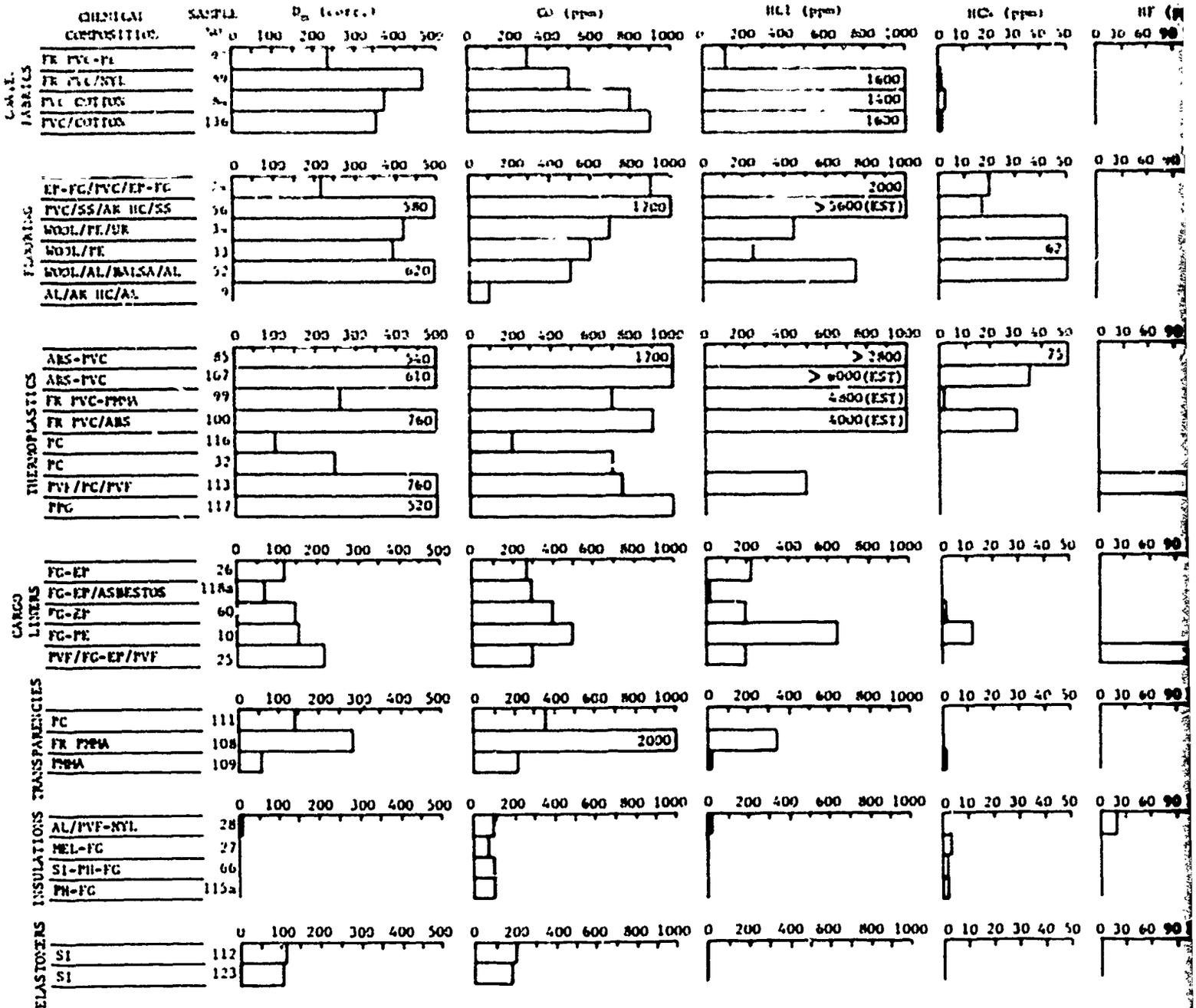
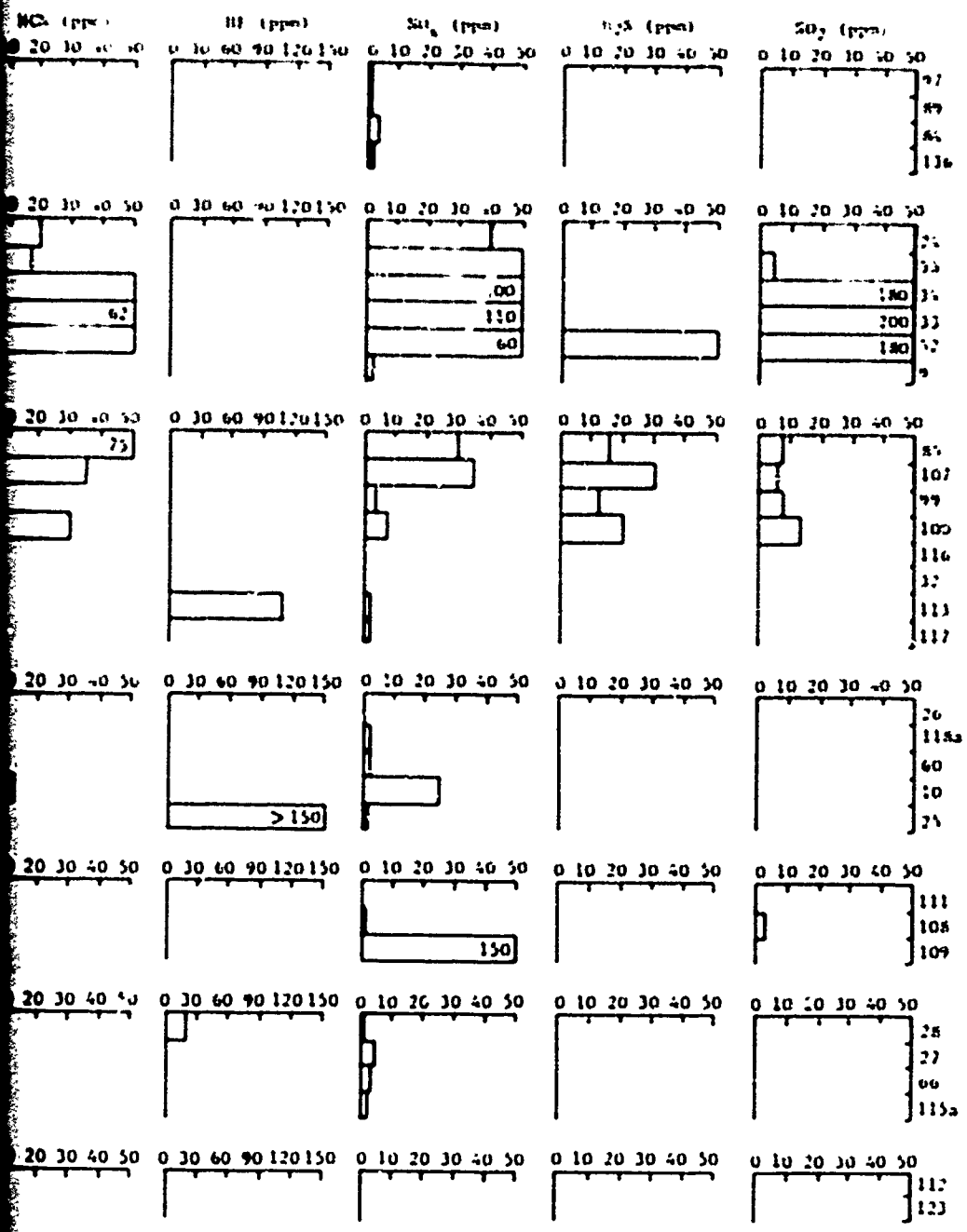


FIGURE 3. PEAK SMOKE AND TOXIC GAS CONCENTRATIONS FOR MATERIALS UNDER FLAMING EXPOSURE FOR A 7-MINUTE TEST (Sheet 2 of 2)



ABS ACRYLONITRILE/BUTADIENE/STYRENE
AL ALUMINUM
AR ARAMID (AROMATIC POLYAMIDE)
CC CROPPED CLASS
EP EPOXY
FG FIBERGLAS
FR FLAME-RETARDANT TREATED
HC HONEYCOMB
MEL MELAMINE
NYL NYLON
PC POLYCARBONATE
PE POLYESTER
PET POLYETHER
PH PHENOLIC
PMMA POLYMETHYL METHACRYLATE
PPO POLYPHENYLENE OXIDE
PVC POLYVINYL CHLORIDE
PVF POLYVINYL FLUORIDE
SI SILICONE
SS STAINLESS STEEL
UR URETHANE

NOTE: NUMBERS IN BARS INDICATE READING IN EXCESS OF BAR SCALE VALUE

75-51-11

UNDER

2

SEVENTY-FIVE WIDE-BODIED CABIN MATERIALS.

The 75 wide-bodied cabin materials described in table B-1 were tested in the NBS Smoke Chamber under the condition of flaming exposure. Only one 7-minute test was conducted per material. Seven bag samples were taken at 1-minute intervals after the beginning of the test. Colorimetric detector tubes were used to analyze the bag samples for CO, HCN, NO_x, H_2S, SO_2, NH_3, TDI (urethane foams only), and aldehydes (as formaldehyde). HF and HCl measurements were made at 1-minute intervals, starting at 1/2 minute into the test, using detector tubes suspended inside the chamber. For both direct and bag measurement methods, if more than one detector tube was available for a particular gas the most sensitive tube was always tried first except when it was likely, from knowing the composition of the material, that high gas concentrations would be present. Anywhere between 1/2 and 2 hours was required to complete a test and analysis, depending on the number of gases detected and the sensitivity (sampling volume, or time) required of each detector tube. Cleaning of the chamber walls or replacement of the sampling bags was performed when contamination seemed excessive (about 3-4 times during the entire program).

Table C-1 (appendix C) summarizes the smoke and toxic gas data. Smoke is reported in terms of the maximum specific optical density corrected for photometer window deposits after the test (D_m (corr.)). The toxic gas measurements are summarized as the peak indicated concentrations with the time of occurrence. Ammonia is not listed in the table because this gas was not detected from any of the materials tested.

As an aid toward facilitating analysis and comparison of test results for different materials, the data contained in table C-1 was prepared into a histogram in figure 3. Materials have been arranged according to usage designations, and within each of these groups, usually by increasing weight (e.g., panels, foams) or into subgroups with similar chemical compositions (e.g., fabrics, thermoplastics).

When analyzing the data contained in figure 3, one should consider the relative toxicity of the different gases. Table 5 contains the dangerous or fatal concentrations of these gases from brief exposure, and the concentrations producing irritation, obtained from reference 14.

Since this data is the best information at the disposal of that author from numerous independent studies with different test protocols and objectives, it should be considered as an approximation.

PANELS. This usage designation refers to the fabricated assemblies used exclusively in wide-bodied jets to construct sidewalls, overhead stowage bins, ceilings, partitions, ets. Because of the large surface area covered by these materials and the critical overhead location of some (e.g., ceiling panels, overhead stowage bins), interior paneling can comprise a major portion of the materials involved in a cabin fire. The overall design adopted by the three manufacturers consists essentially of an aromatic polyamide (aramid) honeycomb core, fiberglas faces, and a PVF finish. Detailed differences in construction however, had a noticeable effect on the performance characteristics.

TABLE 5. APPROXIMATE HARMFUL LEVELS OF SELECTED TOXIC COMBUSTION GASES

	Concentration (ppm)						
	CO	HCN	HCl	HF	NO_2	SO_2	H_2S
Dangerous or Fatal After a Few Minutes	8,000*	280*	1,000	50-200	250	100-250	1,000
Irritation	-	-	35	32	50	20	50
Threshold Limit Value (TLV)**	50	10	5	3	5	5	10

*Described as immediately fatal.
**Maximum average atmospheric concentration for 8-hour daily exposure adopted by American Conference of Governmental Industrial Hygienists (reference 11)

Although the arrangement of the panels in figure 3 is in terms of increasing weight, there is no trend between the amount of smoke and toxic gases produced and sample weight. Carbon monoxide was fairly invariant for the 13 panels tested, ranging from 450 to 600 ppm for all but 3 panels.

Upon examination of the gas concentrations shown in figure 3, HF and HCl appear as the dominant toxic species. However, the large indicated HCl concentrations from panels described as not containing PVC (i.e., Nos. 1, 37, 12, and 43) appear to be primarily the result of a false indication (by the HCl detector tubes) caused by large concentrations of HF. This interference effect is decidedly more pronounced for the type B HCl detector tube than the type A (see appendix A for tube descriptions) as is demonstrated below. Recognizing that HCl concentrations less than 100 ppm were measured with the type A tube and considering that these tube measurements were taken on panels 14, 20, and 144, each of which do not contain PVC in their makeup, it appears that the type A tube will indicate about 1/2 of the HF concentration. Conversely, the only PVF-coated panel not containing PVC that did not saturate the HF detector tube was panel 43. During the analysis of this material, the type B detector tube, which is sensitive to any strong acid gas, indicated double the HF concentration. Thus, the types A and B HCl detector tubes appear to indicate approximatel, half and twice the HF concentration, respectively.

Despite the difficulty in reading the HF detector tube (appendix A), the indicated concentration of this gas was clearly highest for panels coated with the thicker PVF film finishes. Panels 14, 20, and 144 had a 3-mil-thick PVF finish and generated 90-100 ppm of HF. The remaining PVF-coated panels have finishes of 6 or 10 mils and in turn generated higher concentrations of HF, usually in excess of 150 ppm (tube saturation). The concentration of HF measured for the former panels (14, 20, and 144) corresponded approximately to only 25 percent of the HF content in the PVF film, illustrating the

reactive nature of this gas and the need for evaluating its transportability in a real fire situation in order to properly assess its potential danger.

Panel smokiness was related to the construction of the frontface (materials, adhesives, resins), rather than the core which comprises the geometric bulk of the material. The panels finished with 3-mils of PVF (14, 20, and 144) were, besides producing low levels of HF, also relatively low smokers. For these panel constructions, it has been reported that 90 percent of the smoke is produced by the epoxy (reference 15). The remaining PVF-coated panels had thicker layers of PVF and generally produced more smoke, except for panel 12. Despite the thicker PVF coating for this panel, the maximum smoke level was relatively low (D_m (corr)=86). For this reason and the above results for panels 14, 20, and 144, it seems unlikely that the PVF alone from any of the panels contributed significantly to the overall smoke level. Rather, the means of adhering the frontface to the core or possibly other laminating materials not provided in the material description probably were the major smoke generators. Note that removal of the front facing from panel 1 (see panel 2) reduced the smoke level by almost 50 percent. High smoke levels were also experienced by the PVC (67) and wool (50) covered panels.

The variation with time of the smoke and indicated toxic gas emissions (except for HCl which was primarily from HF interferences) by panel 144 is presented in figure 4. Hydrogen fluoride gas produced by the PVF finish experienced by far the most rapid generation rate. This gas decayed to 1/2 of its peak concentration at the end of the test. In contrast, as is experienced generally by all materials tested in the NBS Smoke Chamber, CO increased in an approximately linear fashion over the entire test duration. The concentrations of HCN, NO_x and aldehydes were much lower than either HF or CO and only increased gradually over the length of the test. Although the smoke level was increasing slightly at the end of the test, over 50 percent was produced in the first minute.

PANEL COMPONENTS. A number of panel components were tested to gain a better understanding of the relative contribution of each part to the performance of the final fabricated product. Components are usually not fire tested, since FAA regulations require that the finished product and not the individual components meet certain performance criteria.

The individual components of panel 37 were tested and the smoke and toxic gas levels for these components are compared to the fabricated panel in table 6.

Except for HF and HCl, the summation of the smoke and remaining gas measurements from the components exceeded the values for the assembly. Panel components, often substructure elements in the assembly, usually burn more effectively when subjected directly to the heat source and produce higher smoke and toxic gas levels. An exception is the acoustic skin (frontface) that, when unconstrained, peels away from the heat source before combustion is completed. When this material is instead adhered to a sublayer, it remains in place and burns more effectively. Thus, although the testing of components can be useful for indicating the source of toxic gases or smoke, the contribution of each in the finished assembly can only be correctly measured by testing the entire assembly.

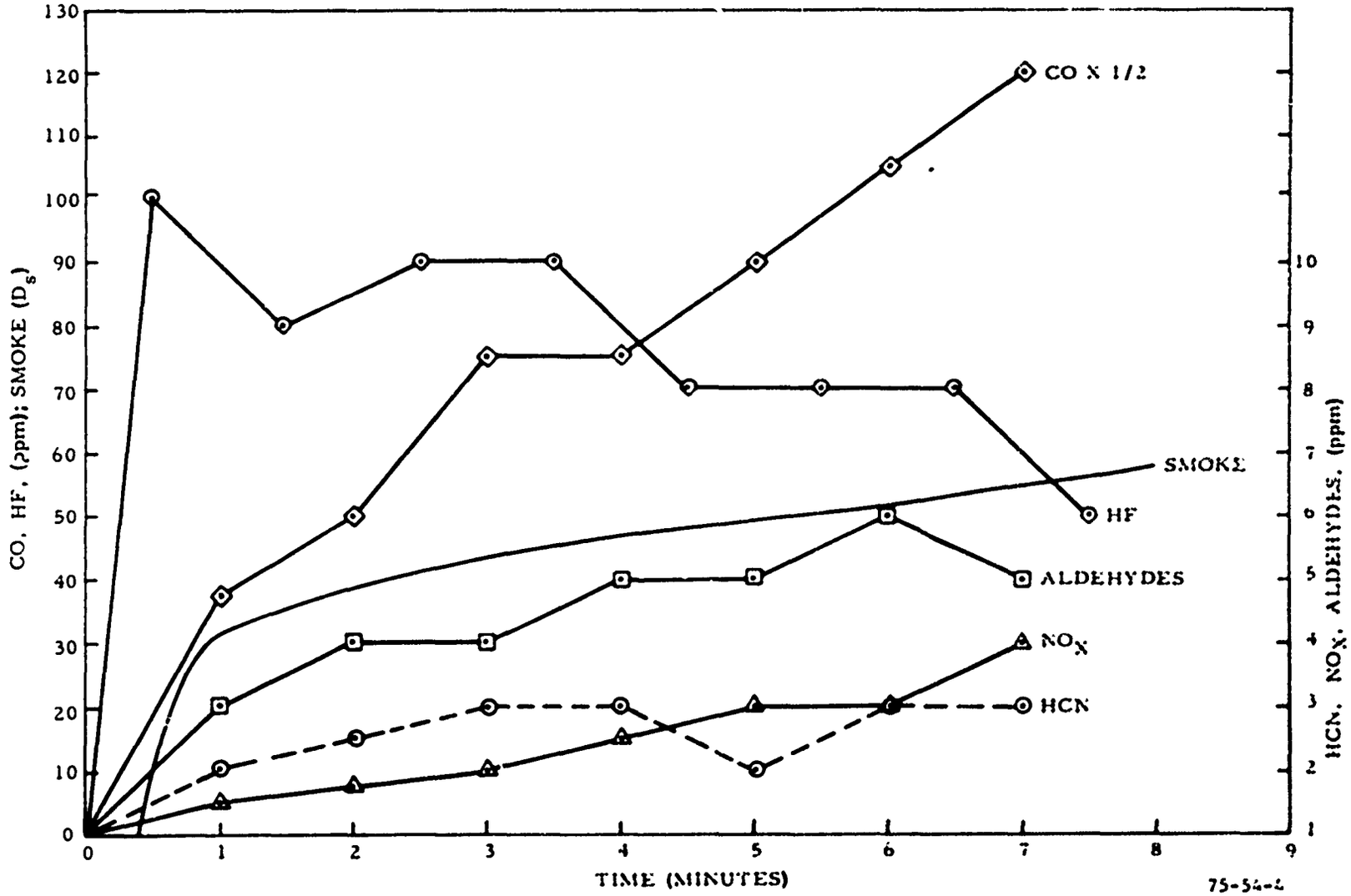


FIGURE 4. SMOKE AND TOXIC GAS CONCENTRATION HISTORIES FOR PVF-COATED, ARAMID HONEYCOMB WALL PANEL 144

TABLE 6. COMPARISON OF SMOKE AND TOXIC GASES FROM PANEL COMPONENTS AND FABRICATED PANEL 37

No.	Description	Weight (gram)		Smoke (D_m (corr))	Peak Toxic Gas Concentration (ppm)				
		Initial	Loss		CO	HCl	HCN	HF	NO_x
38	Backface	3.64	0.17	0	150	0	0	0	1.5
39	Adhesive	3.47	0.88	61	300	2.5	5	0	12
40	Core	2.13	0.48	5	270	0	8	0	5
41	Screen	2.98	0.40	61	140	0	0	0	2
42	Frontface	2.61	1.15	115	230	170	2	110	4
	Summation	14.83	3.08	242	1,090	173	15	110	25
37	Assembly	14.90	2.34	200	500	500	10	>150	7

Additional useful information shown in figure 3 was obtained from the remaining panel components tested. For example, testing 3 mils of PVF (18) stapled to an asbestos block to prevent peeling produced zero smoke, whereas the PVF/aramid-epoxy laminated frontface (15) generated approximately 40 percent of the smoke level produced by the assembly (14), demonstrating the smokiness of the frontface sublayer. Panel components 6 and 6A were designed for usage on ceilings and upper window reveals and partitions, closets, and lower window reveals, respectively. The latter usage areas require a more rugged, wear-resistant surface finish than the former. As such panel component 6 was covered with 6 mils of PVF, whereas panel component 6A contained a 12-mil PVF/PVC covering overlayed with 3 mils of transparent PVC. The data reflected the quantities of finish materials: panel component 6A surpassed component 6 in smoke and HCl by a factor of 4 and HF and CO by a factor of 2. The overriding importance of surface materials and need for optimization is apparent from the preceding discussion.

FOAMS. The analysis of combustion mixtures, using detector tubes, appears to be a simple method of identifying from a group of materials having similar chemical composition any material emitting especially high toxic gas concentrations. A comparison of data for urethane foams in figure 3 illustrates this application of detector tube data. It seems obvious that exceedingly high levels of smoke, CO, HCl and SO_2 were generated by foam 143C. This particular foam was also the only urethane that emitted sulfur compounds, and the level of SO_2 measured was only exceeded by the wool carpets of all the materials analyzed.

Except for materials 104 and 143C, the concentration of NO_x exceeded HCN in the combustion mixtures of urethane foams. As was also observed for other material categories, the relative proportion of NO_x to HCN increases with the degree of flaming of the material. Materials 104 and 143C produced moderate or small flames when tested, as compared to high flames rising 3-4 inches above the top of the specimen holder observed for the remaining urethanes: thus, the level of HCN was higher than NO_x for the former two materials.

It is difficult to interpret the validity of the above simple colorimetric tube measurements of HCN on the basis of a comparison with HCN data on urethane combustion mixtures found in scientific literature. Besides the obvious dependency on analytical methodology or molecular structure, the combustion and test conditions also control the production of HCN. The calculated yield of HCN (appendix D) from the urethane foams varied from 1.2 to 3.0 milligrams per gram (mg/g) of sample. This level is at least a factor of 2 lower than values reported elsewhere; however, the discrepency may be explained in terms of differences in combustion conditions. For example, combustion tube testing of materials 79 and 104 (reference 16) produced approximately twice the HCN yields than measured above, possibly because the carrier airstream sweeps the combustion mixture out of the high-temperature zone and in this manner restricts oxidative reactions. Similarly, the HCN yields produced by flexible urethane foams reported in references 9 and 17 were higher than the above colorimetric tube measurements, possibly because the former tests were conducted at heating rates and oxygen levels different from those used in the NBS Chamber. Thus, the validity of the colorimetric tube measurements for all gases can only be clearly established when the same materials are retested in the NBS chamber using specific analytical techniques.

With the exception of foam 143C, CO levels produced by the urethanes were lower than most other material categories (see figure 3).

Of all the toxic gases detected with colorimetric tubes during the combustion of urethanes, the greatest uncertainty surrounds the measurement of HCl. The peak HCl concentration produced by foam 143C corresponds to 9.5 percent by weight of the material. Although this level of chlorine within the material is below the "average requirement" of 18-20 percent to render polyurethane foams "self-extinguishing" (reference 18), one supplier suggests that 10-20 percent of their flame retardant containing 49 percent chlorine is needed. Therefore, it seems likely that HCl was released by the flame retardant used in foam 143C. For the remaining urethanes tested, the peak HCl concentrations correspond to between 0.25 percent (foam 104) to 1.8 percent (foam 143a) chlorine within the material. It is possible that the materials with a calculated chlorine content of 1-2 percent also contained antimony trioxide, which reduces the level of chlorine needed to render urethanes self-extinguishing by about a factor of 5 (reference 18), as a fire retardant. If the HCl detector tube also indicates the presence of HBr, which is likely, at a reduced sensitivity, this effect in conjunction with the greater effectiveness of bromine as a fire retardant in urethanes (reference 19) may also

explain the low "chlorine" content in the material. Otherwise, the only other likely source of low HCl concentration is in the blowing agent (e.g., trichlorofluoromethane) remaining entrapped in the foam. Because HCl (or HBr) produces irritation at low concentrations (table 5), the use of nonhalogenated fire retardants that remain in the char structure during combustion or that do not increase the toxicity of the foam when burned beyond that of untreated urethane seems desirable.

Low concentrations of TDI were measured in the combustion emissions from six of the seven urethanes tested (table C-1). TDI is a significant irritant described as causing "heavy irritation of eyes, nose, and throat" at a concentration of 0.5 ppm (reference 14). Therefore, notwithstanding the low measured concentrations of TDI, the irritating effect from this gas produced during the combustion of foams 73 and 143a would be roughly comparable to that present from HCl. For the remaining urethanes, HCl would be the major irritant gas.

The maximum smoke level generated by the urethane foams tended to increase with sample density, although this trend was not exactly followed by all materials (figure 3). More importantly, except for foam 73, the rate of smoke production was higher for the denser materials. Thus, from a smoke-hazard standpoint, the utilization, where possible, of low-density urethane seat cushions would be beneficial. In this same regard, since the three polyester-type urethanes generated the highest smoke levels of the seven urethanes evaluated, utilization of polyether-type urethanes also seems to offer a fire safety benefit.

The remaining two foams tested, 86 and 102, were described by the supplier as PVC and polyethylene, and find common usage in aircraft cabins as flotation cushions. An assay of the chlorine content of foam 86 indicated a level of 15 percent, revealing that this material described as a "PVC foam" in reality consisted of only about 26 percent PVC. When tested, in addition to the expected high concentrations of HCl, this material also produced relatively high smoke and CO levels, and most surprisingly, concentrations of HCN and NO_x exceeding the levels generated by most of the urethane foams. In contrast, the polyethylene foam experienced the smallest weight loss and emitted the lowest smoke and CO levels of all the foams that were tested. Moreover, the only additional gases detected were low concentrations of aldehydes, which were probably acetaldehyde (reference 9), one of the least toxic of the aldehyde gases (TLV=100 ppm). Thus, components constructed of polyethylene when compared to "PVC," seem to offer the benefit of significantly reduced smoke and toxic gas emissions in the event of a cabin fire.

Smoke and toxic gas emissions from a urethane foam (143a) are plotted in figure 5 as a function of time. Flaming of this material was observed to cease at about 1 minute, and judging from the first smoke plateau ending at this time, the material probably ignited at about 0.5 minutes. During this 1/2-minute interval of flaming combustion, the total production of NO_x and possibly HCN occurred (the subsequent peaks and dips in HCN likely reflect

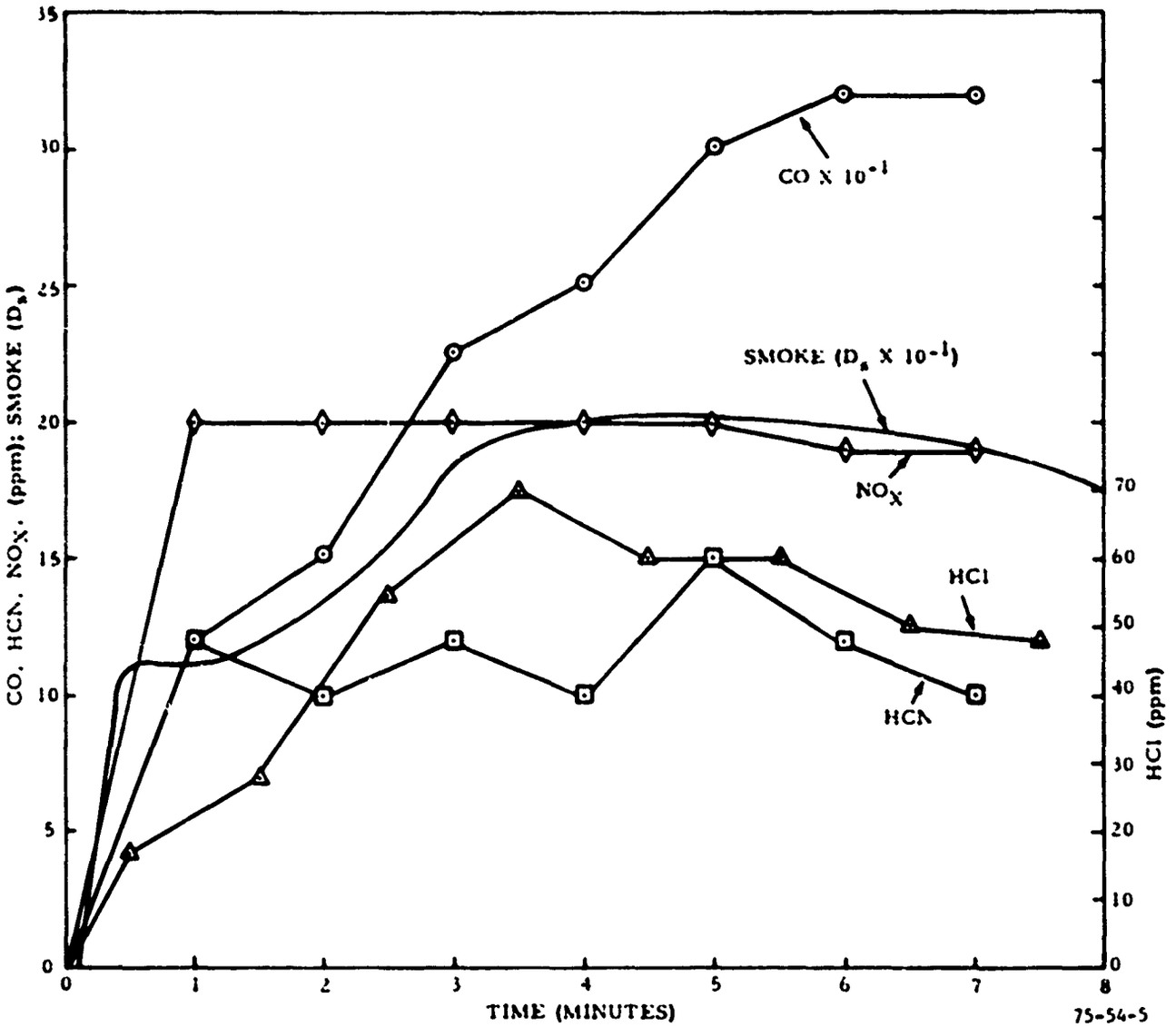


FIGURE 5. SMOKE AND TOXIC GAS CONCENTRATION HISTORIES FOR URETHANE SEAT FOAM 143A

the difficulty in accurately reading the HCN detector tube). The shape of the HCl and smoke curves were fairly similar, indicating the insensitivity of HCl production to the combustion characteristics. Typically, CO increased in an approximately linear fashion over the test duration.

FABRICS. The fabrics chosen for testing included representative samples from each of the various generic descriptions provided by the suppliers. In spite of this wide variety of chemical compositions, smoke production from the fabrics was generally relatively low, probably because of the lightweight construction of these materials. Aldehyde production was also found to be fairly low from this usage designation, ranging from a maximum concentration of 5 ppm for rayon and a cotton/rayon blend to a zero detectable level for the wools, nylons, and aramids.

The peak HCN concentration measured from the flame-retardant treated (FR) wool fabric 88 corresponded to an HCN yield of 6.5 mg/g. This HCN yield was approximately a factor of 2 or more lower than reported in the literature for flaming combustion testing of wool (a similar difference was found for urethane foam--see previous discussion). For example, Sumi and Tsuchiya measured 18 mg/g of HCN from the heaviest sample of wool tested in a 5-liter combustion flask (reference 20). Also, Gordon, et al., burned FR wool samples with a traversing hydrogen flame and measured an average HCN yield of 16 mg/g (reference 17). Again, the above comparisons should not be strictly taken to indicate the inaccuracy of the HCN detector tube since the test conditions differed from the NBS Chamber.

Comparing the wool-containing fabrics with the urethane foams in figure 3 reveals that usually the wools produced higher HCN but lower NO_x levels than the urethanes. Except for wool fabric 82 which produced the highest level of NO_x for the wool-containing fabrics, these fabrics generally flamed very little and this absence of sustained or intense flaming is undoubtedly responsible for the low NO_x concentrations. Conversely, when wool carpets were tested (detailed description later), the increased combustibility related to the separated and looped nature of the woven pile caused these materials to produce "high flames" over a significant duration of the test and the resulting production of NO_x was very high (60-110 ppm).

The presence of significant quantities of H_2S and SO_2 was indicated in the combustion mixtures of the wool fabrics. However, SO_2 concentrations in excess of 20 ppm were measured with the high-range detector tube which, as pointed out in appendix A, also indicates the presence of H_2S with equal sensitivity. After subtracting this interference effect from the high SO_2 readings, the concentrations of H_2S will be higher than SO_2 by as much as a factor of 2. Except for fabric 142, H_2S was more abundant than HCN in the combustion mixture of the wool-containing fabrics.

As might be expected, the toxic gas concentrations from the wool (90 percent)/ nylon (10 percent) blended fabrics 70 and 142 were fairly close to the levels measured from the wool fabric 88. However, the smoke level generated by these blended fabrics was about double that produced by the wool, despite the fact that the blends were much lighter.

Thermal degradation of a pure PVC polymer can be expected to produce a quantitative yield of HCl (i.e., 584 mg/g). This weight of HCl distributed uniformly within the 510-liter volume of the NBS chamber at 95° F corresponds to 795 ppm of HCl for 1 gram of pure PVC. The peak estimated HCl concentration generated by the fabric 81 described as PVC corresponded to 120 percent of the theoretical yield of pure PVC, indicating that the major constituent of this fabric was indeed PVC as reported. The small concentrations of SO_2 and H_2S in the combustion mixture of this material originated most likely from the "sulfur-containing antioxidants and/or polymerization initiators (reference 7)."

It was suggested earlier by analysis of the wool/nylon fabrics that blending materials may increase the smoke production without noticeably altering the toxic gas emissions expected individually from the constituents. Although this seems to be a contradiction, with regard to the emission of smoke the two wool/PVC blended fabrics 82 and 96 did produce significantly higher levels than either the "pure" wool fabric 88 or PVC fabric 81, and this again was despite the fact that the blends were substantially lighter. In order to assess whether toxic gas measurements using detector tubes can correctly rank materials of known composition, it was assumed that the production of HCN and HCl was proportional to the amounts of wool and PVC, respectively, in the blended fabrics. Figure 6 compares the calculated HCN and HCl yields (appendix D) from the wool and/or PVC fabrics with the theoretical values. Aside from the high estimated HCl concentration for the PVC fabric (81), the agreement between measured and theoretical yield for HCN and HCl was remarkably good. It is for the evaluation of similar materials, as demonstrated above, that the use of detector tubes to analyze combustion gas mixtures seems to find its most useful application.

The most abundant toxic gas measured in the combustion mixture of the FR rayon (95) and cotton/rayon (130) fabrics was CO, which for the latter material was anywhere between a factor of 3 to 8 higher than the level measured from the remaining fabrics.

The drapery composed of modacrylic--by definition a copolymer of acrylonitrile (35-85 percent) and vinyl chloride or vinylidene chloride--produced the highest concentration of HCN (125 ppm) measured from any of the 75 materials tested. Additionally, the presence of high HCl concentrations in the modacrylic combustion mixture would appear to make this a relatively toxic material.

The aramid fabrics 78 and 92 generated less smoke (except for the cotton ticking) and CO than any of the remaining fabrics evaluated. The unexpected indication of SO_2 for both materials and HCl for material 78 needs to be verified. It is believed that the low measured concentrations of HCN (0.73 and 1.1 mg/g), compared to the values measured elsewhere under conditions of flaming combustion (references 8 and 17), was a consequence of the relatively good thermal stability of the material, protracting the degradation to the extent that it was incomplete by the end of the 8-minute test.

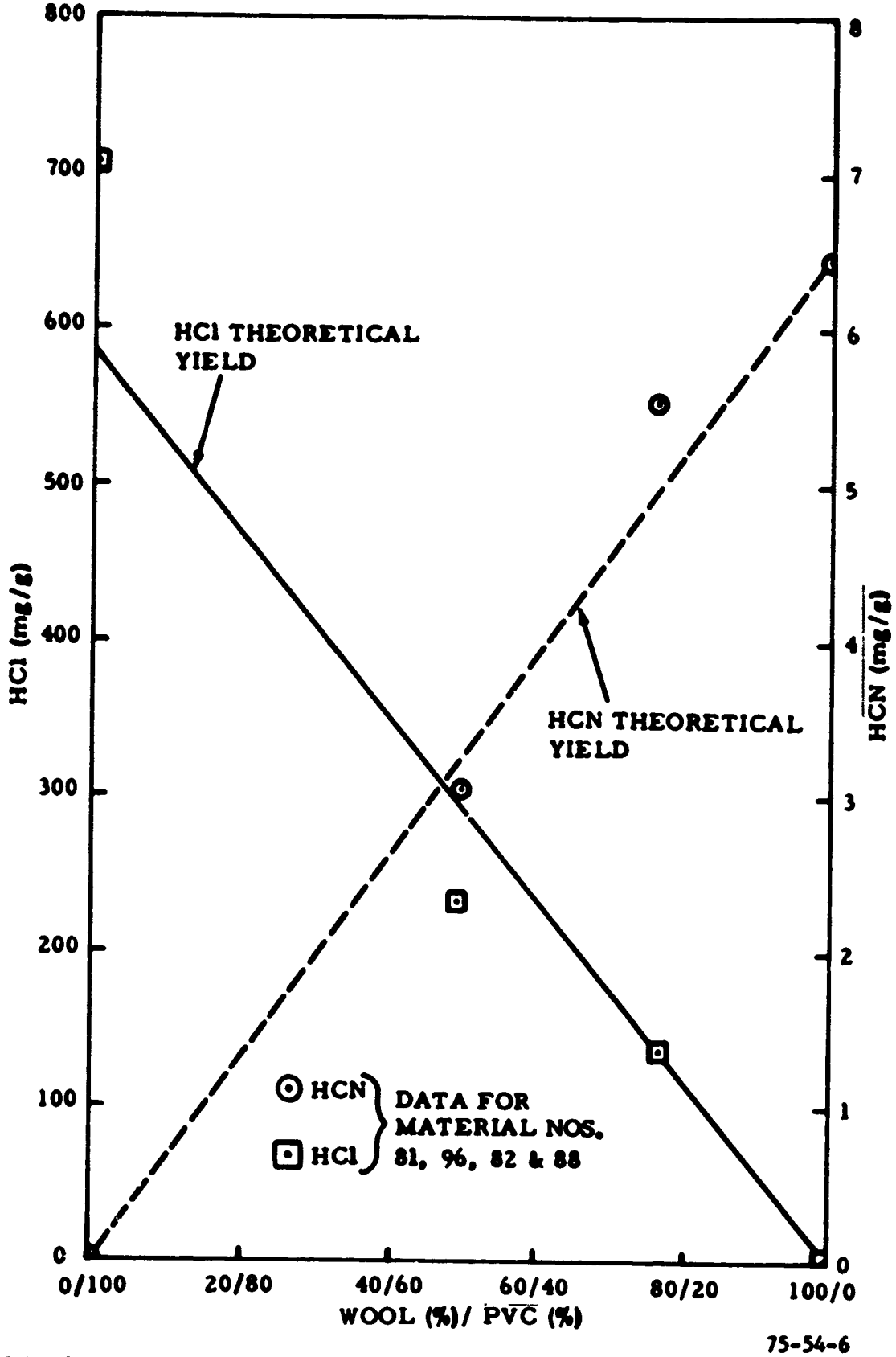


FIGURE 6. PRODUCTION OF HCl AND HCN FROM THE COMBUSTION OF FABRICS CONTAINING WOOL AND/OR PVC COMPARED WITH THE THEORETICAL YIELDS

Figure 7 shows the variation with time of the smoke and toxic gas emissions from the wool fabric 88. Since wool fabrics do not burn readily, the accumulation of smoke and gases within the NBS chamber was gradual, although an early, rapid buildup of smoke was evident when the material flamed briefly. The behavior of wool may be contrasted with urethane foam (figure 5), which degrades quite rapidly. Between these materials the production of HCN and NO_x show the most dramatic differences. These gases were produced primarily during the first minute of the test for the urethane foam, whereas for the wool fabric, the concentrations of both were still increasing at 7 minutes.

COATED FABRICS. The coated fabrics evaluated consisted of one relatively light material used as a seat bottom diaphragm (97) and three heavier arm rest covers of about equal weight. The major combustion products generated by these materials were smoke, CO and HCl, although minor concentrations of HCN and NO_x were also detected (figure 3). Apparently, because of the plasticized PVC coating, the coated fabrics were found to consistently produce more smoke than the uncoated fabrics. CO production by the heavier coated fabrics was also greater than from the uncoated fabrics, except for the cotton/rayon blend (130). Since the peak HCl concentration measured for the lightest coated fabric was more than a factor of 10 lower than the values indicated for the heavier materials, the PVC coating on the former probably constituted a smaller portion of the total material weight than on the latter. Tailoring the PVC coating when possible would, by reducing the potential emissions of HCl, improve the performance of the coated fabrics from a safety viewpoint in the event of a fire.

FLOORING. Smoke levels were generally high for this usage designation composed of some of the heaviest materials tested. The most noteworthy characteristic of the combustion mixture produced by these materials was the consistent presence of relatively high concentrations of NO_x (except for the aluminum-covered structure 9). The amount of NO_x generation seems related to both the intensity of flaming, observed for all flooring materials, and the existence of nitrogen in the material, since the wool floorings produced higher NO_x levels than the floorings covered with nonnitrogen-containing materials (24 and 56). Further investigations are needed to establish the importance of nitrogen oxides emitted by materials undergoing flaming combustion and the dependency of these gases on material composition.

For the wool-covered floorings, the concentration of NO_x was higher than HCN, while just the opposite was found for the fabrics containing wool. The interrelationship between HCN and NO_x and apparent dependency on combustion temperature is another finding that needs further resolution. An analogous interplay seemed to hold for H_2S and SO_2; i.e., the concentration of H_2S was higher than SO_2 for the wool fabrics, while the converse was true for the carpets. It is interesting to note that H_2S was only detected from the wool carpet that was attached to an aluminum substrate (52), where the aluminum acting as a heat sink might have reduced the degradation temperature below that experienced by the other wool carpets (33 and 34).

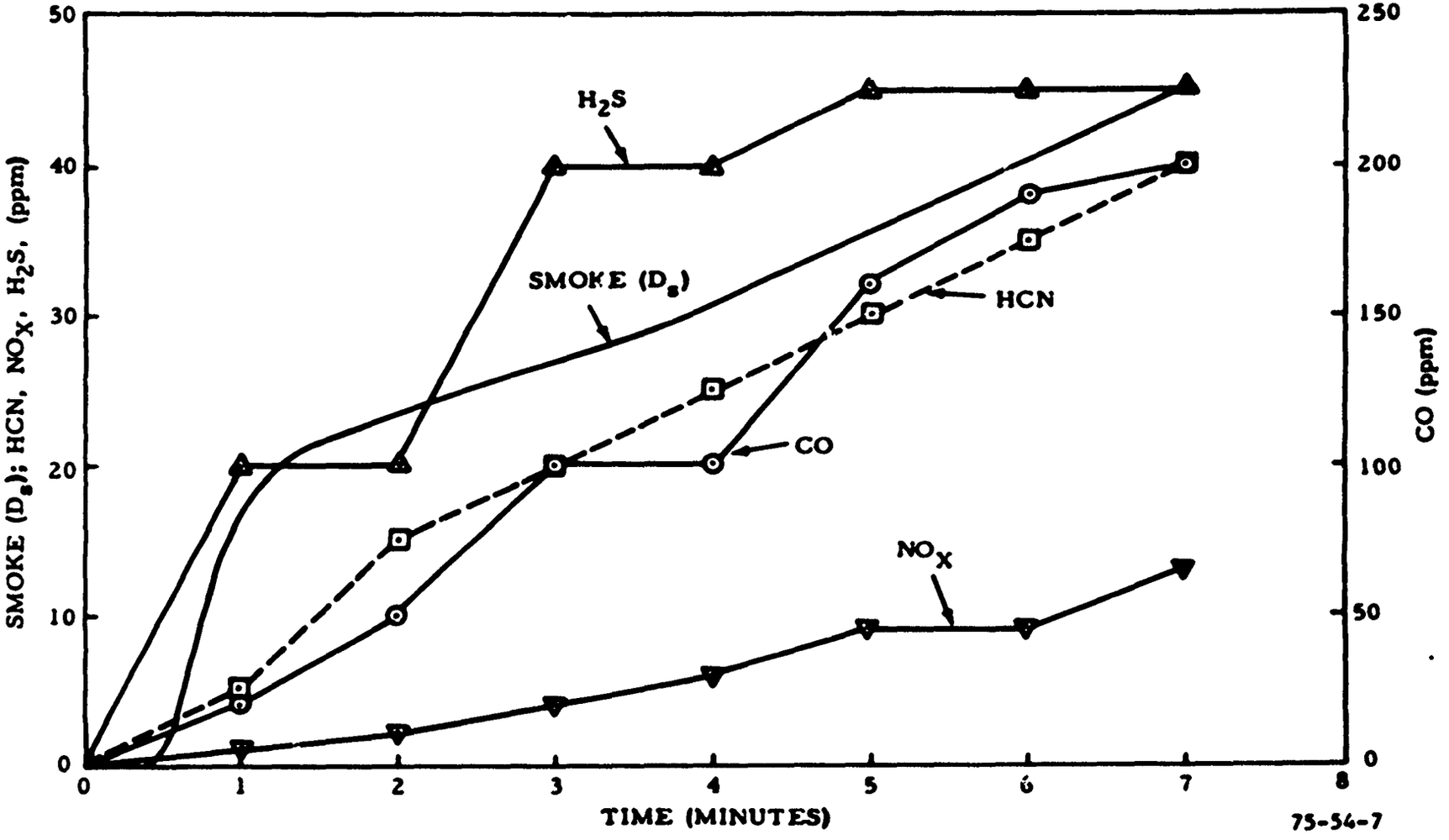


FIGURE 7. SMOKE AND TOXIC GAS CONCENTRATION HISTORIES FOR WOOL UPHOLSTERY FABRIC 88

The large concentrations of HCl detected from the wool carpets, although appearing to be unrealistically high, are primarily combustion products from the treated sublayer materials. Figure 8 is a plot of the smoke and toxic gas concentrations measured from a wool carpet (34) as a function of time. In contrast to the more immediate production of NO_x, HCN and especially SO_2 by the burning wool, the buildup of HCl follows an apparent lag time because of the later involvement of the sublayer materials. The concentration histories in figure 8 may be compared to figure 7 for the wool upholstery fabric. The most striking difference between these plots was that in the case of the fabric the smoke and gas concentrations were still increasing at 7 minutes, while for the much heavier carpet they tended to peak out before this time because of the more rapid consumption rate resulting from flaming combustion.

THERMOPLASTICS. The thermoplastics exhibited the widest range of smoke and toxic gas levels than any of the other usage designations (figure 3). The PVC plastics blended or laminated with acrylonitrite/butadiene/styrene (ABS) or acrylic (85, 107, 99, and 100) produced copious amounts of smoke, CO, HCl and elevated levels of HCN, NO_x, H_2S and SO_2. High levels of aldehydes (50 ppm) were additionally measured from the ABS-containing plastics. It would seem that these materials should be prime candidates for replacement with improved materials. For example, the performance of the above plastics may be contrasted with the plain polycarbonates-materials 32 (flexible) and 116 (rigid). When the polycarbonates were tested, no halogen, nitrogen, or sulfur containing gases were detected (this finding was corroborated in reference 9) and the smoke and CO levels were below those measured for the PVC and/or ABS containing plastics. Moreover, the concentration of aldehydes was zero for material 32 and only 3 ppm for 116, with the latter indication probably from the presence of the relatively non-toxic gas acetaldehyde (reference 9). The polycarbonates therefore appear to be safer than the PVC and/or ABS containing plastics from a smoke and toxicity standpoint.

The major combustion products of polyphenylene oxide (117) were also smoke and CO; however, the levels were greater than measured from polycarbonate. The high concentrations of aldehydes measured was most likely styrene (reference 9), which can also be indicated by the formaldehyde detector tube (appendix A).

CARGO LINERS. The cargo liners used in commercial aircraft are constructed of reinforced plastic (RP) sheets. Of the 4 cargo liners evaluated containing an epoxy resin, the sheet impregnated with asbestos (118a) generated the lowest smoke and HCl levels. However, the release of asbestos was not measured, nor is the acute toxicity known. It appears as if flame retardancy was imparted to the RP sheets by either coating with PVF (25), asbestos impregnation (118a) or use of a halogen-containing treatment (26, 60, and 10). The materials incorporating the latter flame retardant approach generated approximately a factor of 10 higher concentration of aldehyde gases than the former two materials.

TRANSPARENCIES. The transparencies evaluated consisted of two inner window panes (109 and 111) and an outer pane (108), which was approximately five

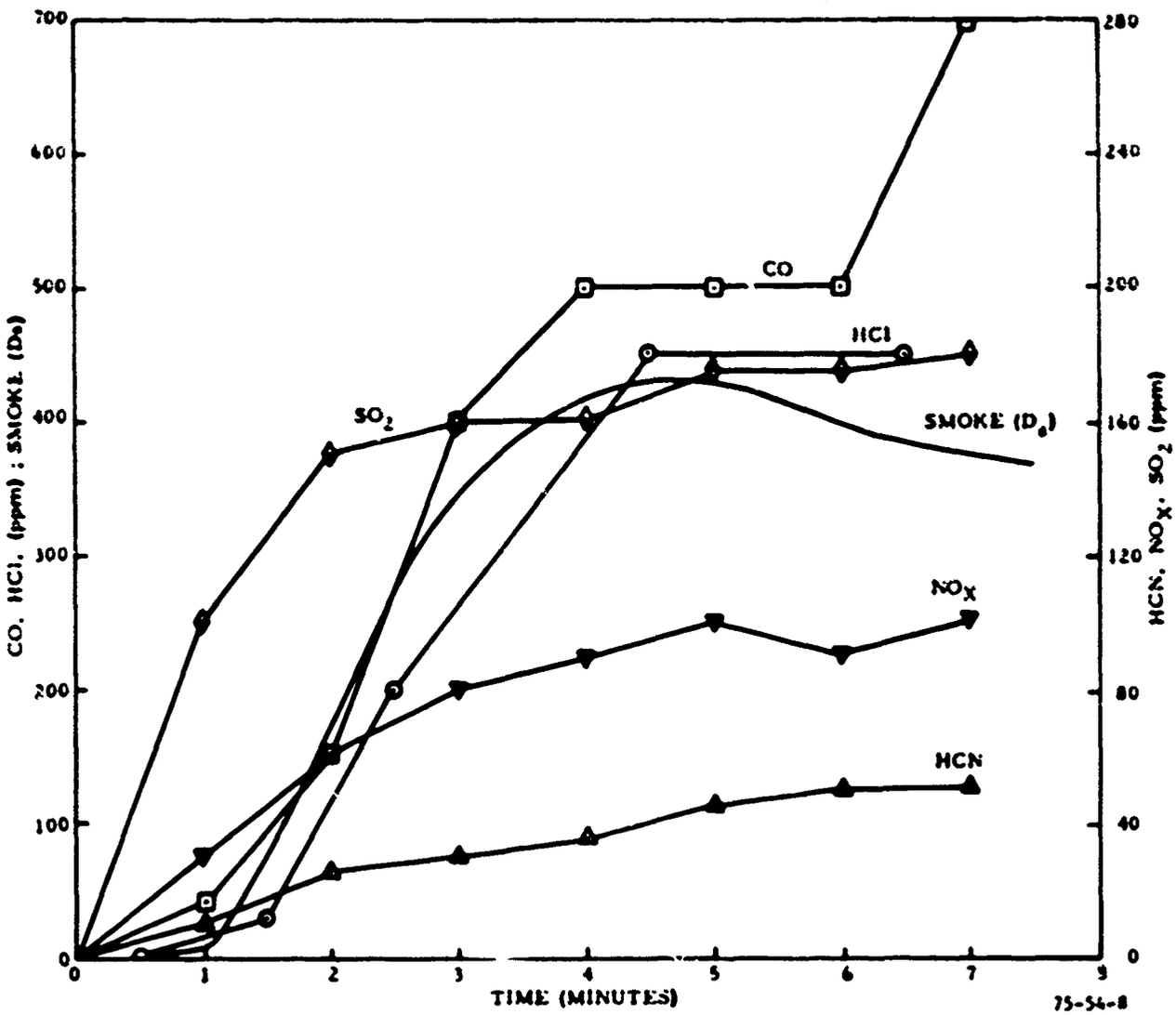


FIGURE 8. SMOKE AND TOXIC GAS CONCENTRATION HISTORIES FOR WOOL CARPET 34

times heavier. The acrylic inner pane produced more CO (2,000 ppm) than any of the other 75 materials tested. Moreover, the acrylic inner pane produced twice as much smoke as did the polycarbonate, and significant quantities of HCl and aldehydes (these gases were not detected from polycarbonate degradation).

The acrylic outer window pane (108) flamed vigorously for most of the test and the production of smoke and CO was very low, considering that this was the heaviest material tested. Despite the absence of nitrogen in this polymer, the concentration of NO_x in the combustion mixture (150 ppm) was higher than from any other material, indicating that NO_x was formed from the fixation of nitrogen in the atmosphere by the intense flames. The only other materials that generated NO_x concentrations above 100 ppm (slightly) were the wool carpets (33 and 34).

INSULATIONS. These materials were the lightest tested and practically produced no smoke or toxic gases, except for some low concentrations of CO. Insulations would seem to be minor contributors to most forseeable cabin fire scenarios, although the total weight of insulation used in an airplane cabin is greater than that for most other usage designations.

ELASTOMERS. Silicone elastomers are likely used in smaller quantities in airplane cabins than any of the other usage designations. These materials burned slowly as evidenced by the slow, progressive accumulation of smoke and CO within the NBS chamber. It is possible that the major toxic combustion gas was formaldehyde, since this detector tube discolored to the specified reddish color (appendix A) as compared to usually yellow for the other materials.

Appendix D contains a comparison of the smoke and toxic gas levels generated during combustion of aviation fuel and several of the cabin interior materials.

SUMMARY OF RESULTS

1. The propane/air burner used in the NBS Smoke Chamber created relatively low concentrations of CO and NO_x, approximately 3 and 0.2 ppm per minute, respectively.

2. A fairly uniform distribution of CO was measured throughout most of the chamber during flaming combustion tests of filter paper.

3. On the basis of samples taken at three elevations, stratification of HCl occurred in the chamber during smoldering combustion tests of PVC, and the concentration at the geometric center was within 10 percent of the average concentration.

4. About 1 percent of the total quantity of HCl measured in the chamber during testing of PVC was detected on Teflon sheets placed on the walls.

5. From six replicate smoldering combustion tests of PVC, the coefficient of variation of total and peak HCl concentration was 38 and 74 percent, respectively.

6. From nine replicate flaming combustion tests of filter paper, the coefficient of variation of specific optical density and CO concentration at 10 minutes was 8.4 and 6.2 percent, respectively.

7. From four replicate flaming combustion tests of urethane foam, the coefficient of variation of the maximum specific optical density, peak CO concentration and peak HCN concentration was 8.9, 29 and 21 percent, respectively.

8. Transferring combustion mixtures containing HCl and HF from the NBS Smoke Chamber into Saran bags resulted in losses in excess of 90 percent of these gases in the air sample.

9. The most prominent toxic combustion gases measured from interior panels appear to be HF and HCl produced by the decomposition of thin film finishes or sublayers constructed of PVF or PVC.

10. The level of smoke and toxic gases generated by interior panels was related to the physical and chemical characteristics of the surface materials and far less dependent on the core or backface construction.

11. The concentration of CO inside the NBS chamber increased in a fairly linear manner with time over the entire test duration, for all materials tested.

12. At the end of a test, the gas concentrations were usually increasing slightly or fairly constant, except for the reactive gases HF and HCl, which attained their maximum level earlier, and CO (see result No. 11).

13. Panel components tested individually behaved differently than when tested as a part of a complete assembly.

14. Fire-retardant urethane seat foams were consumed rapidly by flames and usually produced higher levels of NO_x than HCN.

15. TDI was detected in the combustion mixture of six of the seven urethane foams tested.

16. The total amount and rate of smoke production by urethane foams tended to increase with sample density.

17. The three urethane foams described as polyester types generated higher smoke levels than the other urethanes tested.

18. Although various generic compositions were evaluated, the seat upholstery fabrics (uncoated) generally produced relatively low levels of smoke and aldehydes.

19. The wool fabrics, which burned slowly and with little open flaming, generated higher concentrations of HCN than NO_x and H_2S than SO_2.

20. The production of HCN from wool and HCl from PVC used in blended fabrics woven from these materials was proportional to the constituent weights.

21. A modacrylic drape generated the highest level of HCN (125 ppm) of any of the materials evaluated.

22. The PVC-coated fabrics produced more smoke than the uncoated fabrics.

23. The production of smoke was usually higher for thermoplastics, flooring, and coated fabrics than for materials of other usage designations.

24. The wool-covered floorings, which burned with sustained and high flames, generated higher concentrations of NO_x than HCN and SO_2 than H_2S.

25. The thermoplastics exhibited the widest range of smoke and toxic gas levels than any of the other usage designations.

26. An acrylic inner window pane generated the highest level of CO (2,000 ppm) of any of the materials tested.

27. An acrylic outer window pane generated the highest level of NO_x (150 ppm) of any of the materials tested.

28. Except for low concentrations of CO, the fiberglas insulations generated only trace amounts of smoke and toxic gases.

29. On a per unit area basis some burning cabin materials emitted smoke and CO at a rate comparable to that measured from Jet A fuel.

CONCLUSIONS

Based upon the tests performed and an analysis of the results, it is concluded that:

1. The measurement using commercial detector tubes of combustion gases produced by burning a cabin material in the NBS Smoke Chamber is a simple, rapid, and inexpensive method for identifying the presence of selected toxic gases in the mixture and comparing these gas yields with yields of materials having similar chemical composition.

2. Detector tubes are not appropriate as a primary method for quantitative analysis of combustion products produced by cabin materials having widely different chemical compositions, primarily because of the uncertain magnitude of interference effects on the accuracy of tube readings, and also, because of a limited calibration scale or an indistinct stain length (indication of concentration) for many of the tubes.

3. The NBS Smoke Chamber does not appear to be a sufficiently repeatable method of generating acid combustion gases from the many different types of cabin materials (reference table 2).

RECOMMENDATIONS

Based upon the findings of this test program, it is recommended that:

1. Until evidence to the contrary is developed, the use of the NBS Smoke Chamber to generate toxic gas emissions and commercial detector tubes to measure these gases, in combination, be primarily considered as a convenient method of identifying the presence of selected gases in the combustion products or comparing the relative gas yields of similar cabin materials.

2. Chemical analysis of the combustion mixtures produced by the 75 cabin materials tested during the present study be conducted using a repeatable method of generating toxic combustion gases and specific analytical methods.

3. In coordination with the advanced analyses recommended above, the combustion toxicity of the same materials be studied using animals.

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APPENDIX A

OPERATIONAL AND PERFORMANCE CHARACTERISTICS OF COLORIMETRIC DETECTOR TUBES AND KNOWN INTERFERENCE EFFECTS

The range of the manufacturer's calibration scale (table A-1) for several of the detector tubes, most notably HCl and HF, did not cover the gas concentration levels produced in the NBS Smoke Chamber by many of the cabin materials. For these gases it was necessary to sample the smallest volume possible and assume a linear extension of the measurement range. In spite of this precedure, many of the heavier PVC- and PVF-containing materials still saturated the HCl and HF detector tubes, respectively, precluding any indication of concentration level other than the saturation value (figure 3).

A detector tube measurement took anywhere between 4 seconds and about 4 minutes to make, depending on the sample volume (sensitivity) and tube flow resistance (table A-1). Because of the possibility of lengthy and different measurement times, most gas measurements were taken from a bag sample containing a mixture corresponding to a relatively short time interval (10 seconds) during a test.

For each detector tube used, table A-1 contains a description of the indicating reagents and the known interference effects obtained primarily from reference 5. Undoubtedly, for many of the detector tubes there are numerous chemical compounds produced in a combustion mixture other than the more familiar gases previously studied that will induce a reaction with the indicating layer. From the descriptions provided in table A-1, the HCl detector tubes, being sensitive to any strong acid gas, were perhaps the least specific of the tubes used. This was demonstrated during the test program by the false indication from HF gas produced by the PVF-coated panels. However, the magnitude of similar interferences by other strong acid gases on the HCl detector tube will hopefully be better understood after a reevaluation of some of the materials in the smoke chamber using specific analytical techniques. It should be noted that the gas concentrations tabulated in table C-1 (appendix C) correspond to the maximum length of discoloration of the detector tube, and that the brilliance and color of the indication for any given detector tube sometimes changed for different materials.

Although the HF detector tube is specific, its usefulness is restricted to the limited measurement range and its accuracy is affected by a nonquantitative indication of HF mist. Moreover, the discoloration was sometimes faint and it was difficult to judge with any great confidence the length of discoloration. Other sources of inaccuracy were encountered when using the HCN and CO detector tubes. The discoloration of the HCN detector tube was speckled and diffuse, with a large transitionary zone of partial discoloration, creating some uncertainty regarding the proper selection of the stain length (the maximum was used). With the CO detector tube, the accuracy of the stain length reading changed dramatically when first switching from the low measurement range (10-300 ppm) to the high (100-3,000 ppm). When this scale change became

necessary, the length of the drastically shortened stain resulting from the 10 to 1 reduction in sample volume is difficult to read accurately. Of course, as the gas concentrations and resulting stain lengths increased, the readings became more accurate.

Except from the combustion mixtures of the silicone elastomers, the formaldehyde detector tube discolored faint yellow, indicating the presence not of formaldehyde but instead of other aldehydes or styrenes. Indeed, the purpose of these measurements was to indicate the presence of any aldehydes· however, because of the wide range of toxicity of these gases (e.g., TLV for acrolein and acetaldehyde equals 0.1 and 100 ppm, respectively) the relative toxic importance of the unidentified aldehydes compared with other combustion gases cannot be calculated.

TABLE A-1. OPERATIONAL CHARACTERISTICS OF COLORIMETRIC

Tube	Measurement Range (PPM)	Number of Sampling Pump Strokes[2]	Sampling Time (Secs/Stroke)	Indicating Reagents	Color
CO	10-300 100-3,000	10 1	15-25	Iodine pentoxide, selenium dioxide and fuming sulphuric acid	Brown
HCl (Type A)	1-10 10-100[3]	10 1	6-12	Bromophenol blue	Yellow
HCl (Type B)	0-500 0-2,000[3]	1 1/4	40	Congo red on beaded alkali salt	Blue
HCN	2-30 10-150	5 1	7-12	HCN reacts with mercury chloride to produce acid gas to react with methyl red indicator	Red
HF	1-15 10-150[3]	10 1	4-8	Alizarin-zirconium complex	Light
NO_x (Type A)	0.5-10	5	8-16	Diphenylbenzidine	Bluish
NO_x (Type B)	5-100 25-500[3]	5 1	6-8		
H_2S (Type A)	1-20 10-200	10 1	15-25	Lead compound	Brown
H_2S (Type B)	5-60 50-600	10 1			
SO_2 (Type A)	1-20	10	10-20	Modified iodine-starch	White
SO_2 (Type B)	20-200				
HCHO	2-40 10-200[3]	5 1	4-8	Xylene vapor, sulphuric acid and quinoid compound	Pink
TDI	0.02-2[4]	25	17-40	Reaction of the glutaconic aldehyde with aromatic amines to a polymethine dye	Orang
NH_3	5-70	10	4-8	Acid and bromophenal blue	Blue

1 Data based on information from manufacturer and reference 5.
2 One stroke of hand pump gathers a sample volume of 100 cc.
3 Linear extrapolation of measurement range assumed.
4 A color comparison tube is used to indicate concentrations in the ranges 0.02, 0.1 and 0.2 ppm.

ICS OF COLORIMETRIC DETECTOR TUBES AND KNOWN INTERFERENCE EFFECTS

	Color Change	Interference	Noninterference
lum	Brownish green	Saturated and unsaturated hydrocarbons 4,000 ppm. Hydrocarbons to CO ratio 20.	H_2O, HCl (1,000 ppm) and HCN (100 ppm) adsorbed by precleaning layers
	Yellow grey	Any strong acid gas. HCl mist not measured quantitatively. Chlorine indicated with half of the sensitivity.	H_2S, NO_2
ali	Blue	Any strong acid gas (e.g., nitric acid). Relative humidity greater than 90 percent will result in an indication of HCl below that actually present.	
chloride react er	Red	H_2O: 90 percent RH, SO_2: 200 ppm, CO: 5,000 ppm, NH_3: 1,000 ppm, NO_2: 50 ppm, H_2S: 300 ppm, HCl: 5,000 ppm.	Acid gases adsorbed by precleaning layer
lex	Light yellow	HF mist not quantitatively measured. No known interfering gases.	HCl, SO_2, NO_2, CO
	Bluish grey	HCl/NO_2: 220 Chlorine, ozone.	
	Brown	In the presence of fairly high SO_2 concentrations, the H_2S indication is somewhat high.	SO_2 (alone)
	White	Minus errors in the SO_2 indication occur in the presence of NO_2 (Types A and B).	H_2S concentrations in SO_2 measurement range retained in precleaning layer (Type A).
		H_2S is indicated with the same sensitivity as SO_2 (Type B).	
ed	Pink	Other aldehydes (e.g., acrolein, acetaldehyde) and styrene change indicating layer yellow to brown.	Benzene, toluene, ketones, esters and petroleum distillates
ic dye	Orange		First investigations show no cross sensitivity with the amines.
ue	Blue	Other basic-reacting compounds (e.g., amines).	

ppm.

2

APPENDIX B

DESCRIPTION OF MATERIALS
(TABLE)

TABLE B-1. DESCRIPTION OF MATERIALS

No.	Chemical Composition	Thickness (in)	Unit Weight (oz/yd²)	Designation	Cabin Use
1	PVF/Epoxy-Fiberglas/Aramid Honeycomb/Epoxy-Fiberglas	0.306	48.1	Panel	Ceiling panel
2	Epoxy-Fiberglas/Aramid Honeycomb/Epoxy-Fiberglas (No. 1 without PVF finish)	0.176	29.6	Panel	Ceiling panel
6	PVF/Aramid Fiber-Phenolic	0.048	14.4	Panel component	Face for sidewall or window reveal (upper surface)
6a	PVF/Aramid Fiber-Phenolic	0.050	14.4	Panel component	Face for sidewall or window reveal (lower surface)
9	Aluminum.Aramid Honeycomb/Aluminum	0.171	86.3	Flooring	Floor
10	Fiberglas-Polyester	0.039	15.1	Cargo liner	Side cargo liner
12	PVF/Polyester-Chopped Glass/Aramid Honeycomb/Polyester-Chopped Glass	0.525	90.4	Panel	Overhead stowage door assembly
14	PVF/Nomex-Epoxy/Aramid Honeycomb/Epoxy Fiberglas	0.532	49.7	Panel	Acoustic wall panel
15	PVF/Aramid-Epoxy (Acoustic Skin for No. 14)	0.015	9.75	Panel component	Face of acoustic wall panel
18	PVF (Clear Film)	0.001	1.11	Panel component	Panel finish
20	PVF/Epoxy-Fiberglas/Aramid Honeycomb/Epoxy-Fiberglas/PVF	0.958	82.8	Panel	Partition
24	Epoxy-Fiberglas/PVC/Epoxy-Fiberglas	0.410	117	Flooring	Floor
25	PVF/Fiberglas-Epoxy/PVF	0.051	26.7	Cargo liner	Cargo liner
26	Fiberglas-Epoxy	0.013	16.3	Cargo liner	Cargo liner
27	Melamine-Fiberglas	1.19	5.43	Insulation	Fuselage insulation
28	Aluminized PVF/Nylon Scrim	0.007	1.33	Insulation	Cover for insulation batt
32	Polycarbonate	0.054	47.4	Thermoplastic	Molded part
33	Wool Pile/Polyester Backing/Latex Coating	0.265	51.8	Flooring	Carpet
34	Wool Pile/Polyester Backing/Latex Coating/Urethane Pad	0.345	51.3	Flooring	Carpet
37	PVF/Phenolic-Fiberglas Screen/Aramid Honeycomb filled with Phenolic-Fiberglas Batt/Phenolic-Fiberglas	0.517	77.2	Panel	Center ceiling panel
38	Epoxy Coated Phenolic-Fiberglas (Backing for No. 37)	0.017	18.4	Panel component	Backface of ceiling panel
39	Epoxy Coated Phenolic-Fiberglas (Adhesive used in No. 37)	0.019	17.6	Panel component	Adhesive used in ceiling panel

TABLE B-1. DESCRIPTION OF MATERIALS (Continued)

No.	Chemical Composition	Thickness (in.)	Unit Weight (oz/yd²)	Designation	Cabin Use
60	Aramid Honeycomb filled with Phenolic-Fiberglas Batt (Core for No. 17)	0.431	10.8	Panel component	Ceiling panel core
61	Epoxy Coated Phenolic Fiberglas (Screen used in No. 17)	0.004	11.3	Panel component	Screen used in ceiling panel
62	PVF (Acoustic Skin for No. 17)	0.015	12.7	Panel component	Ceiling panel finish
63	PVF/Phenolic-Fiberglas Screen/ Aramid Honeycomb/Aramid Honeycomb filled with Phenolic-Fiberglas Batt/Phenolic-Fiberglas	0.732	31.8	Panel	Drop ceiling panel
64	PVF/PVC/Phenolic-Fiberglas/ Aramid Honeycomb/Epoxy-Fiberglas	0.500	29.3	Panel	Upper sidewall panel
65	Wool Carpet/Phenolic-Fiberglas/ Aramid Honeycomb/Epoxy-Fiberglas	0.665	33.0	Panel	Lower sidewall panel
66	Wool Carpet/Epoxy Adhesive/Aluminum/ Balsa Wood/Epoxy Adhesive/Aluminum	0.490	198	Flooring	Floor panel
67	PVC/Stainless Steel/Epoxy Adhesive/ Aramid-Phenolic Honeycomb/Epoxy Adhesive/Stainless Steel	0.490	168	Flooring	Floor panel
68	Epoxy-Fiberglas	0.018	22.9	Cargo liner	Cargo liner
69	PVF/PVC/Phenolic-Fiberglas/Epoxy Adhesive/Aramid Honeycomb/Epoxy Adhesive/Phenolic-Fiberglas	0.500	49.1	Panel	Overhead stowage panel
70	Silicone-Treated Phenolic-Fiberglas	1.38	4.09	Insulation	Fuselage insulation
71	PVC/Phenolic-Fiberglas/Aramid Honeycomb/Epoxy-Fiberglas	0.271	48.1	Panel	Door liner
72	PVF/PVC/Phenolic-Fiberglas/Aramid Honeycomb/Epoxy-Fiberglas	0.331	93.0	Panel	Door assembly
73	FR Wool (90 percent)/Nylon (10 percent)	0.037	11.3	Fabric	Upholstery
74	FR Urethane	0.500	17.4	Foam	Seat pad
75	FR Urethane	0.500	12.4	Foam	Seat pad
76	Aramid	0.046	12.1	Fabric	Upholstery
79	FR Polyether Urethane	0.500	13.7	Foam	Seat cushion
80	FR Urethane	0.500	11.1	Foam	Seat cushion
81	PVC (untreated)	0.096	25.1	Fabric	Upholstery
82	FR Wool (76 percent)/PVC (24 percent)	0.039	12.6	Fabric	Upholstery

TABLE B-1. DESCRIPTION OF MATERIALS (Continued)

No.	Chemical Composition	Thickness (in)	Unit Weight (oz/yd²)	Designation	Cabin Use
84	PVC/Cotton (untreated)	0.010	20.9	Coated fabric	Arm rest cover
85	ABS-PVC (untreated)	0.060	14.4	Thermoplastic	Seat side panels and trays
88	PVC (untreated)	0.500	28.8	Foam	Flotation cushion and padding for seat back and arm rest
90	FR Wool	0.031	17.2	Fabric	Upholstery
92	FR PVC/Nylon	0.039	26.1	Coated fabric	Seat arm cap
93	Aramid	0.036	11.8	Fabric	Upholstery
94	FR Cotton	0.032	3.06	Fabric	Upholstery
95	FR Rayon	0.061	13.6	Fabric	Upholstery
96	Wool (49 percent)/PVC (51 percent)	0.064	13.8	Fabric	Upholstery
97	FR PVC-Polyester	0.010	11.6	Coated fabric	Seat bottom diaphragm
99	FR PVC-Polymethyl Methacrylate	0.064	39.6	Thermoplastic	Seat shroud
100	FR PVC/ABS	0.092	66.9	Thermoplastic	Seat shroud
102	FR Polyethylene (rigid)	0.500	13.7	Foam	Flotation cushion
104	FR Polyester Urethane	0.500	40.1	Foam	Seat cushion
107	ABS-PVC	0.127	122	Thermoplastic	Molded part
108	FR Polymethyl Methacrylate	0.034	46.6	Transparency	Scratch shield
109	Polymethyl Methacrylate	0.260	228	Transparency	Window pane
111	Polycarbonate	0.052	46.2	Transparency	Windscreen
112	Silicone	0.094	96.1	Elastomer	Door seals
113	PVF/Polycarbonate/PVF	0.431	151	Thermoplastic	
115a	Phenolic-Fiberglas	1.09	6.40	Insulation	Fuselage insulation
116	Polycarbonate	0.043	36.8	Thermoplastic	Passenger service units and luminaires
117	Polyphenylene Oxide	0.041	31.4	Thermoplastic	Flight station and lavatory parts
118a	Fiberglas-Epoxy/Asbestos	0.020	28.9	Cargo liner	Cargo liner
123	Silicone	0.124	116	Elastomer	Door seals
127	Modacrylic	0.032	9.63	Fabric	Drapery
130	Cotton/Rayon	0.040	15.0	Fabric	Upholstery
136	PVC/Cotton	0.057	28.3	Coated fabric	Upholstery
142	FR Wool (90 percent)/Nylon (10 percent)	0.035	10.3	Fabric	Upholstery

TABLE B-1 DESCRIPTION OF MATERIALS (Continued)

No.	Chemical Composition	Thickness (in.)	Unit Weight (oz/yd^2)	Designation	Cabin Use
163e	FR Polyether Urethane	0.500	11.9	Foam	Seat cushion
163f	FR Polyester Urethane	0.500	16.8	Foam	Seat cushion
164	PVF/Epoxy-Fiberglas/Aramid Honeycomb/Epoxy Fiberglas	0.376	61.3	Panel	Wall panel

ABBREVIATIONS:

ABS - Acrylonitrile/Butadiene Styrene
FR - Flame-retardant treated
PVC - Polyvinyl chloride
PVF - Polyvinyl fluoride

APPENDIX C

MAXIMUM SMOKE LEVEL AND PEAK TOXIC GAS CONCENTRATIONS
UNDER FLAMING EXPOSURE CONDITIONS
(TABLE)

TABLE C-1. MAXIMUM SMOKE LEVEL AND PEAK TOXIC GAS CONCENTRATIONS UNDER FL

	Weight (gm)		Maximum Smoke Level		Peak Toxic							
					CO		HCl		HCN		HF	
Sample Number	Initial	Loss	D_m (corr.)	Time (min)	ppm	Time (min)	ppm	Time (min)	ppm	Time (min)	ppm	Time (min)
1	9.43	..56	239	2.5	500	7	600	4	[illegible]	7	>150	2.5
-	..48	1.58	126	6.8	500	7	12	1.5	15	7	0	1.5
6	11.0	0.77	26	8	140	7	100	3.5	0	-	80	1.5
6a	11.5	1.45	103	7	260	7	400	3.5	1	4	>150	2.5
9	16.5	.208	~0	-	100	7	0	-	0	-	0	-
10	6.91	2.57	152	4	500	4	650	4.5	12	7	0	-
12	16.7	3.92	95	8	500	6	600	2	7	7	>150	2.5
14	9.51	1.79	129	3	600	7	45	1.5	12	7	90	1.5
15***	1.92	0.72	51	3.8	250	8	40	5.5	3	8	80	1.5
18	0.66	0.32	0.9	8	120	7	0	-	0	-	44	7.5
20	16.0	1.23	46	7.9	290	7	>60	1.5	4	7	100	0.5
24	22.8	5.45	219	8	900	7	2000	7.5	20	7	0	-
25	15.1	1.96	217	6.9	300	7	200	6.5	0	-	>150	3.5
26	3.21	1.00	119	5.9	275	7	225	3.5	0	-	0	-
27	0.31	0.05	1.5	8	75	7	0	-	3	7	0	-
28	0.26	0.14	11	8	100	7	8	7.5	0	-	18	3.5
32	8.56	4.08	248	4.8	700	5	0	-	0	-	0	-
33	10.5	6.99	393	5	600	6	250	3.5	62	7	0	-
34	10.4	6.45	424	4.6	700	7	450	4.5	50	6	0	-
37	14.9	2.34	200	3.8	500	7	500	4.5	10	7	>150	5.5
38	3.64	0.17	~ 0	-	150	7	0	-	0	-	0	-
39	3.47	0.88	61	5.8	300	6	2.5	1.5	5	4	0	-
40	2.13	0.48	5	8	270	7	0	-	8	7	0	-
41	2.98	0.40	61	8	140	7	0	-	0	-	0	-
42	2.61	1.15	115	8	230	7	170	4.5	2	4	110	2.5
43	17.0	3.14	306	4.9	600	7	300	4	25	7	150	5.5
46	15.5	2.94	186	5	450	7	600	3.5	10	7	>150	6.5
50	18.2	4.31	285	6.9	450	7	15	9.5	50	6	0	-
52	40.6	8.04	618	7	500	7	>750	6.5	50	7	0	-
56	33.1	11.4	578	5.8	1700	7	>5600 (est.)	4.5	17	7	0	-
60	5.82	1.55	148	5.5	400	6	200	2.5	2	4	0	-
61	13.3	3.36	200	7	600	7	500	1.5	15	7	>150	1.5

EL AND PEAK TOXIC GAS CONCENTRATIONS UNDER FLAMING EXPOSURE CONDITIONS

Peak Toxic Gas Concentrations															
HCl		HCN		HF		NO_x		H_2S		SO_2		Aldehydes[a]		TDI	
	Time (min)	ppm	Time (min)	ppm	Time (min)	ppm	Time (min)	ppm	Time (min)	ppm	Time (min)	ppm	Time (min)	ppm	Time[a] (min)
	4	20	7	>150	2.5	9	7	0	-	0	-	8	3		
	1.5	15	7	0	1.5	12	7	0	-	0	-	30	7		
	3.5	0	-	80	1.5	1	7	0	-	0	-	0	-		
	3.5	1	4	>150	2.5	1.5	7	0	-	0	-	3	3		
	-	0	-	0	-	1.5	7	0	-	0	-	0	-		
	4.5	12	7	0	-	25	7	0	-	0	-	50	3		
	2	7	7	>150	2.5	12	7	0	-	2.5	7	20	7		
	1.5	12	7	90	1.5	10	6	0	-	0	-	10	4		
	5.5	3	8	80	1.5	4	8	0	-	0	-	5	8		
	-	0	-	44	7.5	1	7	0	-	0	-	0	-		
	1.5	4	7	100	0.5	3	6	0	-	0	-	5	3		
	7.5	20	7	0	-	40	7	0	-	0	-	15	7		
	6.5	0	-	>150	2.5	0.5	4	0	-	0	-	5	6		
	3.5	0	-	0	-	0.5	4	0	-	0	-	40	4		
	-	3	7	0	-	5	7	0	-	0	-	0	-		
	7.5	0	-	18	3.5	1	7	0	-	0	-	0	-		
	-	0	-	0	-	0	-	0	-	0	-	3	5		
	3.5	62	7	0	-	110	7	0	-	200	7	30	7		
	4.5	50	6	0	-	100	5	0	-	180	7	50	7	0	*
	4.5	10	7	>150	5.5	7	7	0	-	0	-	5	2		
	-	0	-	0	-	1.5	6	0	-	0	-	0	-		
	1.5	5	4	0	-	12	3	0	-	0	-	2	2		
	-	8	7	0	-	5	7	0	-	0	-	0	-		
	-	0	-	0	-	2	7	0	-	0	-	2	1		
	4.5	2	4	110	2.5	4	5	0	-	0	-	5	4		
	4	25	7	150	5.5	6	7	0	-	0	-	20	7		
	3.5	10	7	>150	6.5	12	6	0	-	0	-	20	7		
	9.5	50	6	0	-	20	7	40	4	5	7	5	6		
	6.5	50	7	0	-	60	6	50	7	180	5	5	5		
	4.5	17	7	0	-	50	6	0	-	5	4	20	2		
	2.5	2	4	0	-	2	7	0	-	0	-	50	5		
	1.5	15	7	>150	1.5	20	6	3	2	0	-	10	7		

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TABLE C-1. MAXIMUM SMOKE LEVEL AND PEAK TOXIC GAS CONCENTRATIONS UNDER FLAMING EXPOSURE C

	Weight (gm)		Maximum Smoke Level		Peak Toxic Gas Conce									
					Cl_2		HCl		HCN		HF		NO_x	
Sample Number	Initial	Loss	D_m (corr.)	Time (min)	ppm	Time (min)	ppm	Time (min)	ppm	Time (min)	ppm	Time (min)	ppm	Ti (m
66	0.60	0.05	~0	-	100	7	0	-	2	4	0	-	4	
67	14.0	3.80	262	4.5	600	7	1900	6.5	10	4	0	-	8	
69	17.2	2.61	184	8	300	7	500	6.5	4	7	120	2.5	6	
70	2.32	1.17	105	8	200	6	0	-	35	7	0	-	10	
71	3.63	3.50	157	7	300	7	20	2.5	10	4	0	-	20	
74	2.42	2.21	110	6	225	6	55	1.5	10	7	0	-	30	
78	2.41	0.63	36	6.6	150	7	70	2.5	5	5	0	-	3	
79	2.53	2.38	159	5	330	7	23	5.5	12	1	0	-	40	
80	2.08	1.76	131	6	210	7	28	1.5	11	1	0	-	23	
81	5.02	3.96	86	1.9	200	7	4800 (est.)	4.5	0	-	0	-	20	
82	2.47	1.65	195	4.7	250	7	450	1.5	25	7	0	-	25	
84	5.30	3.81	381	2.5	800	7	1400	1.5	2	2	0	-	4	
85	11.0	6.67	535	4	1700	7	>2800	5.5	75	5	0	-	30	
86	5.37	1.95	230	4	350	7	400	1.5	25	4	0	-	30	
88	3.37	1.55	49	8	200	7	0	-	40	7	0	-	13	
89	5.28	3.71	473	4	500	7	1600	3.5	1	7	0	-	0.5	
92	2.23	0.48	36	7	160	7	?	-	3	7	0	-	3	
93	0.64	0.40	1	.7	200	7	0	-	2	7	0	-	2	
95	3.15	2.21.	104	3.6	400	7	20	3.5	8	7	0	-	0	
96	2.70	1.45	174	4.4	200	7	850	5.5	15	4	0	-	10	
97	2.24	1.61	240	3.6	300	4	120	1.5	0	-	0	-	0.5	
99	7.82	5.06	262	3.8	700	7	4800 (est.)	2.5	2	4	0	-	4	
100	17.7	10.8	755	8	900	7	4000 (est.)	7.5	30	7	0	-	8	
102	2.85	0.81	63	5.1	200	7	0	-	0	-	0	-	0	
104	7.65	4.82	289	4	300	7	27	7.5	17	2	0	-	13	
107	23.7	13.2	614	7.8	1000	7	>6000 (est.)	7	35	7	0	-	35	
108	9.16	6.35	283	7.7	2000	7	350	3.5	0	-	0	-	1	
109	43.9	36.2	59	4.7	220	7	12	3.5	1	7	0	-	150	
111	9.10	2.92	146	8	350	7	0	-	0	-	0	-	0	
112	16.4	2.19	116	8	200	7	0	-	0	-	0	-	0	

L AND PEAK TOXIC GAS CONCENTRATIONS UNDER FLAMING EXPOSURE CONDITIONS (Continued)

Peak Toxic Gas Concentrations															
HCl		HCN		HF		NO_x		H_2S		SO_2		Aldehydes**		TDI	
ppm	Time (min)	ppm	Time (min)	ppm	Time (min)	ppm	Time (min)	ppm	Time (min)	ppm	Time (min)	ppm	Time (min)	ppm	Time* (min)
0	-	2	4	0	-	4	7	0	-	0	-	0	-	NR	
1900	6.5	10	4	0	-	8	6	0	-	2	7	40	7	NR	
300	6.5	4	7	120	2.5	6	7	0	-	0	-	15	4	NR	
0	-	35	7	0	-	10	5	40	6	60	5	0	-	NR	
20	2.5	10	4	0	-	20	2	0	-	T	-	5	6	>.2	*
55	1.5	10	7	0	-	30	4	0	-	0	-	5	2	>.1 <.2	*
70	2.5	5	5	0	-	3	5	0	-	20	7	0	-	NR	
23	5.5	12	1	0	-	40	4	0	-	0	-	8	7	>.02 <.1	*
28	1.5	11	1	0	-	23	5	0	-	T	-	20	6	>.1 <.2	*
4000 (est.)	4.5	0	-	0	-	20	5	10	3	6	4	3	5	NR	
450	1.5	25	7	0	-	25	7	35	7	35	2	2	4	NR	
1400	1.5	2	2	0	-	4	6	0	-	0	-	15	2	NR	
3000	5.5	75	5	0	-	30	7	15	4	7	2	50	4	NR	
400	1.5	25	4	0	-	30	6	0	-	2.5	4	5	3	NR	
0	-	40	7	0	-	13	7	45	5	75	6	0	-	NR	
1600	3.5	1	7	0	-	0.5	4	0	-	0	-	5	4	NR	
T	-	3	7	0	-	3	7	0	-	10	6	0	-	NR	
0	-	2	7	0	-	2	7	0	-	0	-	3	6	NR	
20	3.5	8	7	0	-	0	-	0	-	2.5	1	5	6	NR	
850	5.5	15	4	0	-	10	4	30	2	15	7	2	4	NR	
120	1.5	0	-	0	-	0.5	7	0	-	0	-	5	7	NR	
4000 (est.)	2.5	2	4	0	-	4	2	12	4	8	7	10	3	NR	
4000 (est.)	7.5	30	7	0	-	8	7	20	7	13	7	50	2	NR	
0	-	0	-	0	-	0	-	0	-	0	-	5	3	NR	
27	7.5	17	2	0	-	13	7	0	-	T	-	5	4	>.1 <.2	*
4000 (est.)	7	35	7	0	-	35	7	30	7	6	4	50	5	NR	
350	3.5	0	-	0	-	1	4	0	-	2.5	4	20	5	NR	
12	3.5	1	7	0	-	150	5	0	-	0	-	30	7	NR	
0	-	0	-	0	-	0	-	0	-	0	-	T	-	NR	
0	-	0	-	0	-	0	-	0	-	0	-	30	7	NR	

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TABLE C-1. MAXIMUM SMOKE LEVEL AND PEAK TOXIC GAS CONCENTRATIONS UNDER FLAMING EX

	Weight (gm)		Maximum Smoke Level		Peak Toxic							
					CO		HCl		HCN		NF	
Sample Number	Initial	Loss	D_m (corr.)	Time (min)	ppm	Time (min)	ppm	Time (min)	ppm	Time (min)	ppm	Time (min)
113	30.7	10.8	764	9.8	750	7	500	7.5	0	-	110	1.5
115a	0.64	0.06	~0	-	100	7	0	-	2	4	0	-
116	6.92	1.99	100	8	210	7	0	-	0	-	0	-
117	6.28	5.15	520	4.5	1000	7	0	-	T	-	0	-
118a	5.70	0.81	72	6	290	6	4	3.5	0	-	0	-
123	23.9	2.85	113	8	190	7	0	-	0	-	0	-
127	1.70	1.26	92	6	300	7	620	5.5	125	4	0	-
130	3.01	2.55	49	2.8	1200	7	75	2.5	13	7	0	-
136	5.46	3.94	360	1.9	900	7	1600	1.5	1	4	0	-
142	1.90	1.22	101	7.4	250	5	0	-	45	6	0	-
143a	2.73	1.35	202	5	320	7	70	3.5	15	5	0	-
143c	8.51	3.44	770	1.8	1500	6	1100	1.5	25	5	0	-
144	8.40	0.95	54	8	240	7	60	1.5	2	3	100	0.5

*TDI measurements of urethane foam combustion mixtures were made only at 2 or 3 minutes
**As formaldehyde
***Only 9-minute test (no 7-minute bag sample)
NM - not measured
T - Trace

PEAK TOXIC GAS CONCENTRATIONS UNDER FLAMING EXPOSURE CONDITIONS (Continued)

Peak Toxic Gas Concentration[a]															
HCl		HCN		HF		NO_x		H_2S		SO_2		Aldehydes[aa]		TDI	
ppm	Time (min)	ppm	Time (min)	ppm	Time (min)	ppm	Time (min)	ppm	Time (min)	ppm	Time (min)	ppm	Time (min)	ppm	Time[a] (min)
	7.5	0	-	110	1.5	2	7	0	-	0	-	5	7	NM	
	-	2	4	0	-	2.5	7	0	-	0	-	0	-	NM	
	-	0	-	0	-	0	-	0	-	0	-	0	-	NM	
	-	T	-	0	-	2	4	0	-	0	-	40	7	NM	
	3.5	6	-	0	-	2	6	0	-	0	-	5	4	NM	
	-	0	-	0	-	0	-	0	-	0	-	10	6	NM	
	5.5	125	4	0	-	10	7	0	-	0	-	1	4	NM	
	2.5	13	7	0	-	3	7	0	-	0	-	5	3	NM	
	1.5	1	4	0	-	3	2	0	-	0	-	5	4	NM	
	-	45	6	0	-	10	7	30	4	15	1	0	-	NM	
	3.5	15	5	0	-	20	1	0	-	0	-	5	[illegible]	>.2	*
	1.5	25	5	0	-	20	3	0	-	150	7	19	2	0	*
	1.5	2	3	100	0.5	1.5	4	0	-	0	-	5	6	NM	

[a] 2 or 3 minutes

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APPENDIX D

CALCULATED YIELD OF TOXIC GASES IN THE SMOKE DENSITY CHAMBER

Many researchers prefer to report the yield of toxic gases from combustion or pyrolysis of a material on a weight basis and normalized by initial sample weight. It was assumed that the peak gas concentration (appendix C, table C-1) uniformly distributed throughout the 18-ft^3 chamber at the initial temperature of 95° F corresponded to the total yield of the gas. Mathematically, the toxic gas yield per initial sample weight (mg/g) is related to the peak concentration (ppm) by the following equation.

$$mg/g = \frac{(.02017)\ (ppm)\ (\text{molecular weight of gas})}{(\text{initial sample weight in grams})}$$

The calculated toxic gas yields using this equation are tabulated in table D-1.

TABLE B-1. CALCULATED YIELD OF TOXIC GASES IN THE SMOKE DENSITY CHAMBER

Toxic Gas Yield Per Sample Weight (mg/g)

Sample Number	CO	HCl	HCN	HF	NO_x^1	H_2S	SO_2	Aldehydes[2]
1	29.9	44.7	1.15	6.41	.844	0	0	.513
2	36.8	1.15	1.04	0	1.45	0	0	2.37
6	7.19	6.69	0	2.54	.044	0	0	0
6a	12.8	25.6	.047	5.27	.121	0	0	.154
9	3.42	0	0	0	.044	0	0	0
10	49.9	69.2	.946	0	3.36	0	0	4.36
12	16.9	26.4	.228	3.63	.447	0	193	726
14	35.6	3.44	.688	3.82	976	0	0	.637
15	73.6	15.3	852	16.8	1.93	0	0	1 58
18	703	0	0	26.9	1.41	0	0	0
20	10.2	2.76	.136	2.52	.174	0	0	129
24	22.3	64.6	.478	0	1.62	0	0	.294
25	11.2	9.75	0	4.01	.031	0	0	.201
26	46.4	51.6	0	0	.145	0	0	2 55
27	83.1	0	3.31	0	9.10	0	0	0
28	217	22.6	0	27.0	3.57	0	0	0
32	46.2	0	0	0	0	0	0	.212
33	32.3	17.5	3.22	0	9.72	0	24.6	1.73
34	36.0	31.8	2.62	0	8.92	0	22.4	2.91
37	19.0	24.7	.346	4.07	.436	0	0	.203
38	23.3	0	0	0	.382	0	0	0
39	48.8	.530	.785	0	3.91	0	0	.349
40	71.6	0	2.05	0	2.18	0	0	0
41	26.5	0	0	0	.423	0	0	.437
42	49.8	47.9	.416	17.0	1.42	0	0	1.16
43	19.9	13.0	.801	3.54	.328	0	0	.713
44	16.4	28.5	.352	2.91	.718	0	0	.782
50	14.0	.607	1.50	0	1.02	7.51	.355	.166
52	6.96	13.6	.671	0	1.37	.846	5.73	.075
56	29.0	125	.780	0	1.43	0	.195	.344
60	38	25.3	.187	0	.319	0	0	5.21
61	25.5	27.7	.615	4.56	1.39	.155	0	.456
64	94.2	0	2.45	0	6.19	0	0	0
67	24.2	99.9	.389	0	.530	0	.185	1.73
69	9.85	21.4	.127	2.82	.324	0	0	.528
70	68.7	0	8.22	0	4.00	11.8	33.4	0
73	66.7	4.05	1.50	0	5.11	0	1	.835
74	52.5	16.7	2.25	0	11.5	0	0	1.25

Toxic Gas Yield Per Sample Weight (mg/g)

Sample Number	CO	HCl	HCN	HF	NO_x^1	H_2S	SO_2	Aldehydes[2]
78	35.2	21.4	1.13	0	1.15	0	15 7	0
79	73.3	6.69	2.58	0	16.2	0	0	1 52
80	57.0	9.95	2.86	0	10.3	0	1	5.83
81	22.5	704	0	0	3.70	1.37	1.54	.342
82	37.2	134	5.52	0	9.39	9.72	.3	.491
84	85.3	194	.706	0	.700	0		1.31
85	87.3	187	3.72	0	2.53	.937	.422	2.75
86	36.8	54.8	2.54	0	5.16	0	.601	.564
88	33.5	0	6.47	0	3.54	9.17	28.7	0
89	53.5	723	.103	0	.068	0	0	.524
92	85.5	1	.723	0	1.24	0	5.79	0
93	176	0	1.72	0	2.90	0	0	2.84
95	71.7	4.67	38	0	0	0	1.62	.942
96	41.8	232	3.03	0	3.44	2.63	7.16	.443
97	75.7	29.4	0	0	.207	0	0	1 35
99	50.6	452	.129	0	.476	1.06	1.32	.765
100	28.7	166	.924	0	.419	.776	.949	1.31
102	29.6	0	0	0	0	0	0	1.06
104	22.1	2.60	1.21	0	1.58	0	1	.396
107	23.8	186	.865	0	1.37	.870	.327	1.28
108	12.3	28.1	0	0	.151	0	.353	1.32
109	2.83	.751	.012	0	3.17	0	0	.414
111	21.7	0	0	0	0	0	0	1
112	6.89	0	0	0	0	0	0	1.11
113	13.8	12.0	0	1.45	.040	0	0	.099
115a	86.3	0	1.75	0	3.62	0	0	0
116	17.1	0	0	0	0	0	0	0
117	83.3	0	1	0	.224	0	0	3.57
118a	28.7	.516	0	0	.326	0	0	.532
123	4.49	0	0	0	0	0	0	.254
127	99.7	268	80.1	0	5.46	0	0	.356
130	225	18.3	2.35	0	.935	0	0	1.01
136	93.1	216	.100	0	.510	0	0	.555
142	74.3	0	12.9	0	4.88	10.8	10.2	0
143a	66.2	18.9	2.99	0	6.80	0	0	1.11
143c	99.6	95.1	1.60	0	2.18	0	22.8	.712
144	16.0	5.20	.128	4.76	.164	0	0	.357

NOTE: [1]As NO_2
[2]As formaldehyde (HCHO)

APPENDIX E

GENERATION OF SMOKE AND TOXIC GASES BY BURNING AVIATION FUEL IN THE SMOKE DENSITY CHAMBER

Burning fuel is the major source of smoke at the scene of an aircraft crash. Whether smoke and gases from burning fuel are a factor in occupant survivability depends to a great extent on the quantities of each that can enter the cabin. In turn, the transfer of smoke and gases into the cabin will depend on many factors; e.g., size of fuel spillage, relation of fuel spillage to access openings, size of openings, wind conditions, etc. If significant quantities of smoke pass into the cabin, it seems likely that for most situations fuel flames would accompany the smoke into the cabin and ignite interior materials. A comparison was made of the contribution of smoke and toxic gases from burning fuel and cabin materials under the condition of equal exposure area. This method of comparison seems reasonable when one considers that for many crash situations fuel smoke and fire enter the cabin through an opened exit or small fuselage rupture.

An 18-ml sample of Jet A aviation fuel in a steel pan (2 9/16 X 2 9/16 X 1 1/2 inches deep) was placed in the NBS Smoke Chamber, directly behind of and at the same elevation as the specimen holder. The preheated fuel was ignited with a match and analyzed in the same manner as the cabin materials. The radiant heater was operated but the propane/air burner was not used.

Duplicate tests demonstrated that the fuel burned in a highly reproducible manner (Dm (corr)=604 and 610). The major combustion products were smoke and CO, although traces of NO_x and SO_2 were also detected (10 ppm and 2.5 ppm, respectively). Figure E-1 compares the smoke buildup from Jet A fuel with that measured for a number of the smokier cabin materials from different usage categories. Although the fuel eventually generated more smoke than did most of the 75 cabin materials evaluated, the generation rate (slope of curve) during the earlier portions of the test was similar to that found for the materials shown in figure E-1. This finding related to consideration of survivability in a post-crash fire is significant since in this situation the first several minutes are the most critical. However, it should also be pointed out that the burning rate of fuel (and smoke production rate per unit area) would increase significantly for fuel pool areas larger than that in the steel pan. The production of CO by the Jet A fuel was comparable to that measured for many of the cabin materials (see figure E-2).

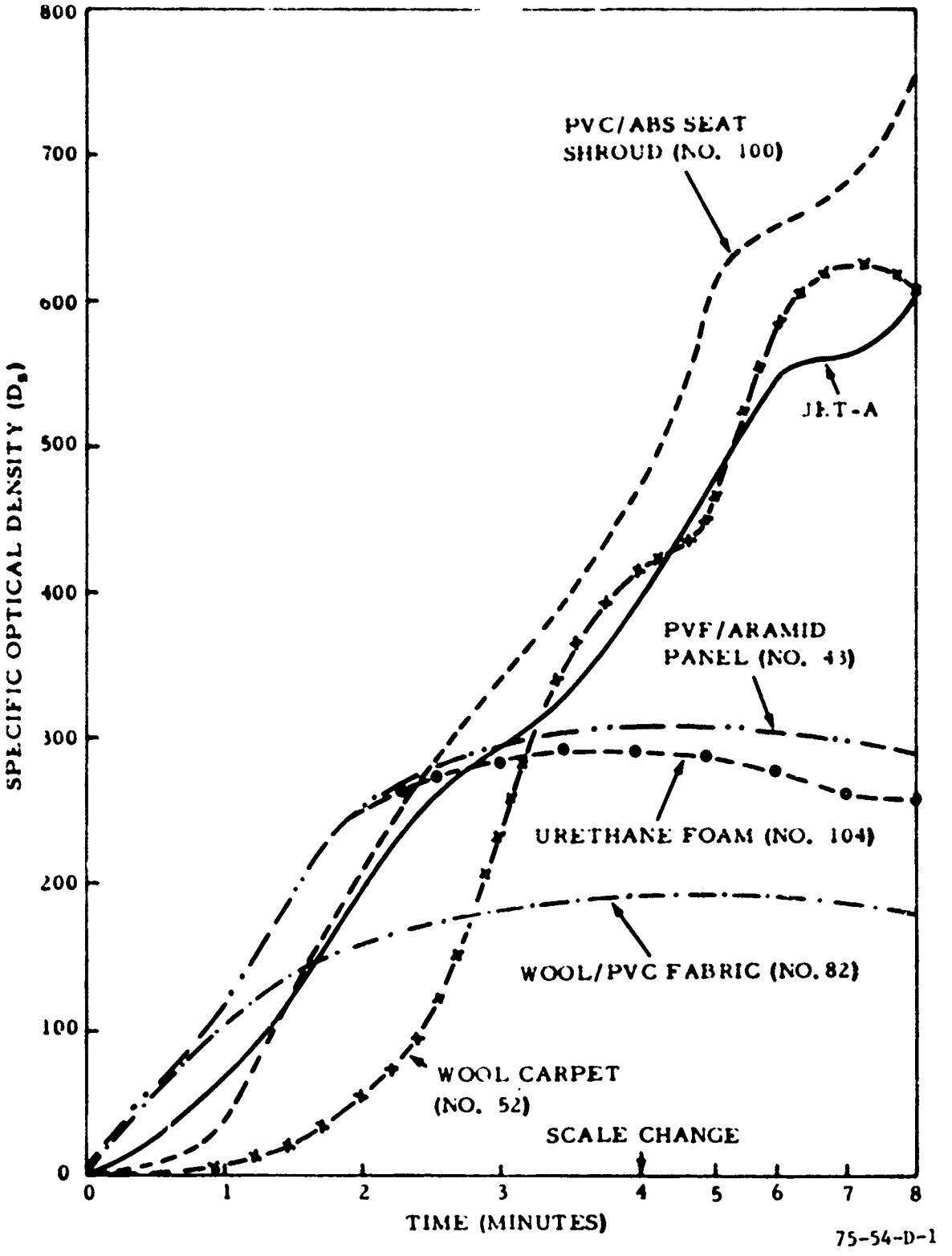

FIGURE E-1. COMPARISON OF SMOKE PRODUCTION FROM AVIATION FUEL AND CABIN INTERIOR MATERIALS

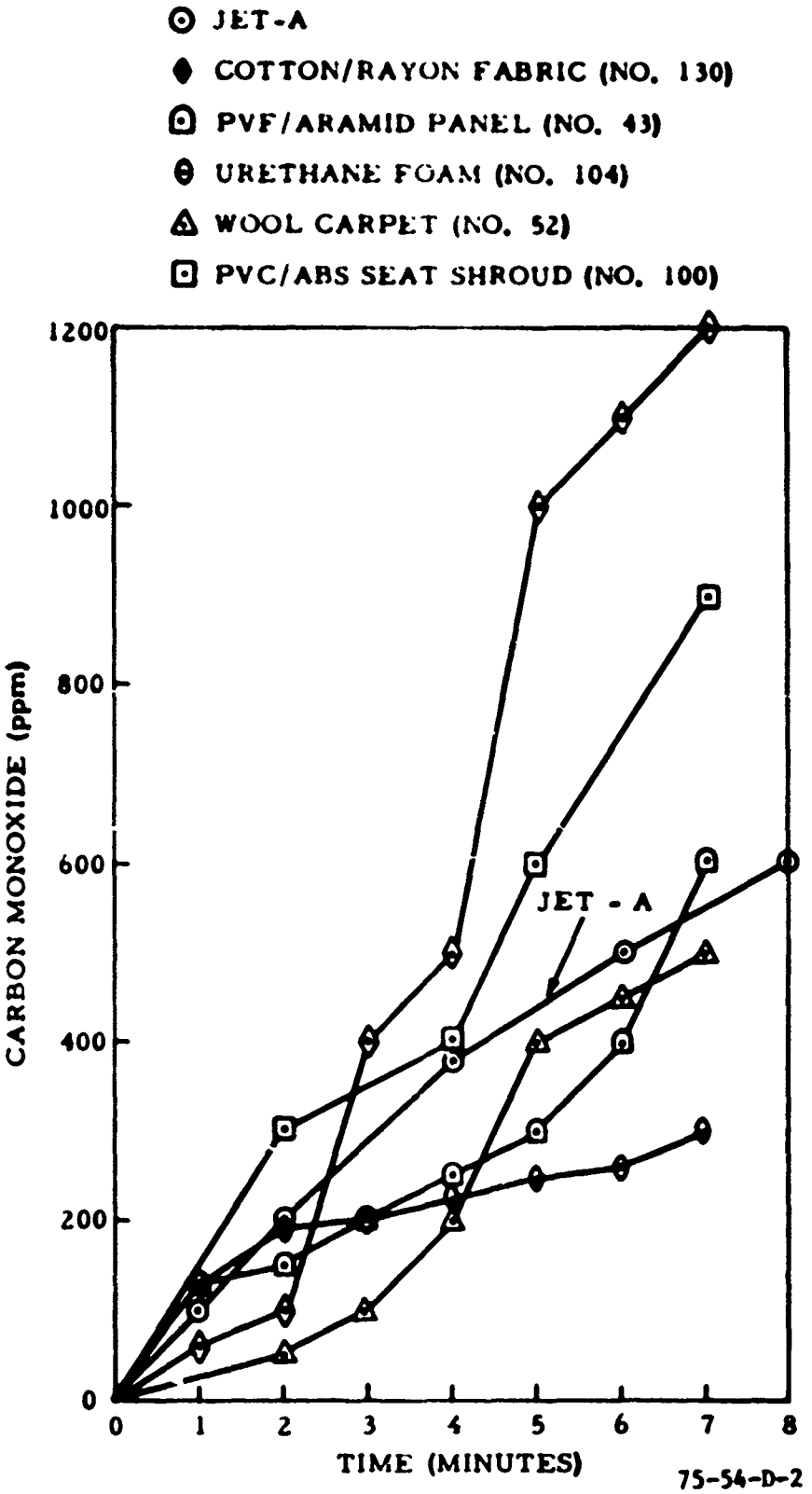

FIGURE E-2. COMPARISON OF CARBON MONOXIDE PRODUCTION FROM AVIATION FUEL AND CABIN INTERIOR MATERIALS