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Smoke and Gases Produced by Burning Aircraft Interior Materials

D. Gross, J. J. Loftus, T. G. Lee, and V. E. Gray

Building Research Division
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National Bureau of Standards
Washington, D.C.



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Contents

	Page
1. Introduction	1
2. Test methods	1
2.1. Material identification	1
2.2. Smoke measurements	2
2.3. Gas analysis	3
3. Test results and analysis	3
3.1. Material identification	3
3.2. Smoke measurements	4
3.3. Gas analysis	8
4. Discussion	9
5. Conclusions	11
6. References	11
7. Appendix 1. Gas analysis	12
7.1. Colorimetric indicator tubes	12
7.2. Specific ion electrode	13
8. Appendix 2. Materials description	16
9. Appendix 3. Summary of test results—smoke and gas concentration ...	21
10. Appendix 4. Typical smoke accumulation curves for selected materials	26

Smoke and Gases Produced by Burning Aircraft Interior Materials*

D. Gross, J. J. Loftus, T. G. Lee, and V. E. Gray

Measurements are reported of the smoke produced during both flaming and smoldering exposures on 141 aircraft interior materials. Smoke is reported in terms of specific optical density, a dimensionless attenuation coefficient which defines the photometric obscuration produced by a quantity of smoke accumulated from a specimen of given thickness and unit surface area within a chamber of unit volume. A very wide range in the maximum specific optical density was observed. For the majority of materials, more smoke was produced during the flaming exposure test. However, certain materials produced significantly more smoke in the absence of open flaming.

During the smoke chamber tests, indications of the maximum concentrations of CO, HCl, HCN, and other selected potentially toxic combustion products were obtained using commercial colorimetric detector tubes. A study was made of the operation, accuracy, and limitations of the detector tubes used. Measurements of the concentrations of HCl were also made using specific ion electrode techniques.

Qualitative identification of the major components of the original test materials was accomplished primarily by infrared absorption spectrophotometry.

Key Words: Aircraft materials; combustion products; fire tests; interior finish; smoke; toxic gases.

1. Introduction

Regulatory safeguards for reducing the fire hazard of transport aircraft interior materials are contained in the Federal Aviation Regulations (FAR-Part 25, amended October 24, 1967) of the Federal Aviation Administration (FAA), which specify the use of flame-resistant materials. However, no requirements exist relating to the production of smoke and potentially toxic products.

Recent accidents involving fire, and the development of new materials and test methods, suggested that additional technical information should be assembled. Accordingly, the FAA stud-

ied the flammability and smoke characteristics of over 100 representative interior materials [1]¹, and performed full-scale fire tests within an airplane fuselage with complete cabin furnishings and interior decor under conditions simulating normal operation [2]. The present laboratory studies are a part of FAA Project No. 510-001-11X, Hazardous Combustible Characteristics of Cabin Materials, and were undertaken with the primary objective of providing measurements on the generation of smoke and decomposition products using a recently developed smoke test chamber [3].

2. Test Methods

2.1. Material Identification

Qualitative identification of the major components of the materials prior to test was accomplished primarily by infrared absorption spectrophotometry. This involved preparing a specimen in either film or solid pellet form, with or without potassium bromide, suitable for obtaining an infrared absorption spectrum. In some cases, solvent extraction and separation were necessary in order to obtain a suitable film. Except

for wools, which were identified by nitration tests, and other spot tests which were employed for cellulosic materials, most materials were identified by comparison of their infrared absorption spectra with reference spectra of known compositions. When some estimate of the percentage composition of blends or mixtures was possible, this was included and listed in order of major to minor components. For fabric blends, valid quantitative estimates are usually very difficult to make. Poly (vinyl chloride) (PVC) and poly (vinylidene chloride) polymers are difficult to detect specifically

*The work reported in this paper was sponsored by the Federal Aviation Administration, Washington, D.C. under Contract No. FA66NF-AP-7, Project No. 510-001-11X.

¹ Figures in brackets indicate the literature references on page 11.

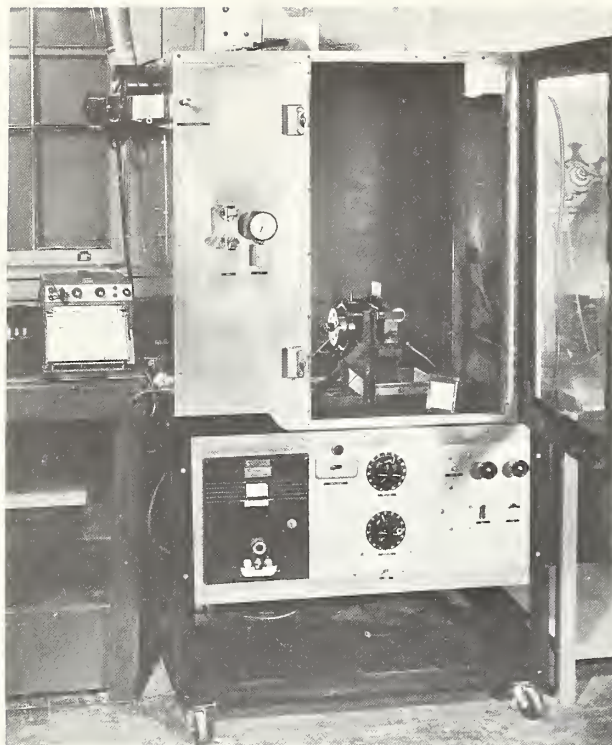


FIGURE 1. Smoke test chamber.

by infrared techniques because they have weak absorption bands and because pigments, fillers and polymer components with which they are mixed generally have overlapping spectral bands. As much as 20 to 40 percent of PVC or poly (vinylidene chloride) could go undetected.

Generic names are given in all cases, even though the spectra for some materials were so similar to reference spectra identified by trade name from the literature that very little doubt existed as to source.

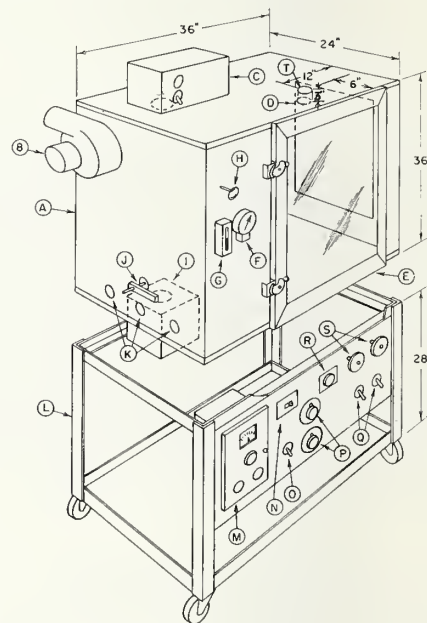
2.2. Smoke Measurements

The smoke level was determined by measuring the progressive attenuation of a light beam passed through the smoke aerosol within an enclosed smoke chamber (see figs. 1 and 2). Smoke is reported in terms of specific optical density, a dimensionless attenuation coefficient which defines the amount of smoke accumulated from a specimen of unit surface area in terms of its photometric obscuration over unit path length within a chamber of unit volume. For the typical application in which the material is to be used as an interior finish (e.g. on walls, ceilings, floors), the fire-exposed surface area of the specimen governs its smoke-production behavior. Specimen thickness (unit weight) correspond to the materials as supplied and used. The basis and limitation of the method were described in detail in a recent paper

[3], which also discussed the general relationship between the measured specific optical density and the level of smoke through which a light (or lighted exit sign) may be seen.

The tests involved a thermal irradiation exposure of 2.5 W/cm^2 ($2.2 \text{ Btu/ft}^2 \cdot \text{s}$)² normal to the exterior surface of a 3×3 in specimen and were performed under both flaming and non-flaming (smoldering) exposure. To induce open flaming in the former case, a small pilot (0.35 SCFH natural gas diffusion flame in a $\frac{1}{16}$ in i.d. tube) was applied at the base of the specimen. These conditions were selected to provide a wide range of smoke levels for different types of materials. The size of the specimen and the volume of the chamber were such that complete oxidation of practically all materials could occur without appreciable decrease in oxygen content. Materials were furnished by FAA and were tested using a typical section in the thickness supplied.

Optical density, defined as $D = \log \frac{100}{T}$ (where T = percent light transmission), is the single most characteristic measure of the obscuring quality of a smoke. Specific optical density, D_s , is a property of a specimen of given thickness



- | | |
|---------------------------|----------------------------|
| A-Chamber | K-Service openings |
| B-Exhaust blower | L-Support frame |
| C-Photometer light source | M-Temperature controller |
| D-Blowout panel | N-Main power switch |
| E-Hinged door with window | O-Internal light switch |
| F-Air pressure gage | P-Autotransformers |
| G-Gas flowmeter | Q-Gas, air shut-off valves |
| H-Blower and damper lever | R-Electric ignitor switch |
| I-Photometer | S-Gas, air control valves |
| J-Pilot burner lever | T-Gas sampling port |

FIGURE 2. Smoke chamber assembly.

² 1 British thermal unit (Btu) = 1055 watt second (W·s).

and represents the optical density measured over unit path length (L), within a chamber of unit volume (V), produced from a specimen of unit surface area (A). Thus, $D_s = D \frac{V}{AL} = \frac{V}{AL} \log \frac{100}{T}$.

For the test chamber, $V = 18 \text{ ft}^3$ (0.510 m^3), $A = 0.0456 \text{ ft}^2$ (0.00424 m^2), and $L = 3 \text{ ft}$ (0.914 m). Ideally, the change in D_s with time during the smoke accumulation process will depend only upon the thickness of the specimen, its chemical and physical properties, and the exposure conditions. The results are reported in terms of (a) maximum (total) smoke accumulation, D_m , (b) maximum rate of smoke accumulation (over a 2-min period), R_m , and (c) the time period, t_c , to reach a "critical" specific optical density of 16, under the test conditions.

However, there are definite limitations to the use of specific optical density for extrapolation and comparison with other box volumes, specimen areas and photometric systems, and for extension to human visibility. The degree to which such extensions are valid depend upon a number of major assumptions: the smoke generated is uniformly distributed and is independent of the amount of excess air available and of any specimen edge effects; coagulation and deposition of smoke is similar regardless of the specimen size, or the size and shape of the chamber; for any given smoke the optical density is linearly related to concentration; and human and photometric vision through light-scattering smoke aerosols, expressed in terms of optical density, are similar.

2.3. Gas Analysis

Indications of the concentrations of gaseous products were obtained by drawing a sample of the gas mixture in the smoke test chamber through commercial colorimetric gas detector tubes and

reporting results on the basis of the manufacturers calibrations for the selected gases [4]. Essentially, a colorimetric tube is a small-bore glass tube containing a chemical packing which changes color when exposed to a specific component of a gas mixture, and the length of color stain is related to the concentration of that component for a given quantity and rate of flow of gas. Layers of precleaning granules and a plug to absorb interfering gases and to control the sample flow rate are generally provided. Sampling was done several times during each smoke test using a small syringe or bellows pump designed to aspirate a measured volume of gas each stroke. The gas detector tube was inserted into the smoke chamber from the top, and was situated 3 in below the top surface of the chamber (approximately 25 in above the level of the specimen). In some instances an attempt was made to extend the range of these indicators by drawing less than the recommended gas volume through them and reporting results on the basis of individual laboratory calibrations, as reported in a later section. More detailed discussion of product gas analysis by colorimetric detector tubes and by specific ion electrode are presented in appendix 1.

Indicator tubes were used to detect CO, HCN, HCl, HF, SO₂, NO + NO₂, NH₃, Cl₂ and COCl₂, since these gases have generally been considered toxicologically hazardous compared with other possible components. However, these are not necessarily the only potentially toxic components released. No attempts were made to determine high concentrations of CO₂ or low concentrations of O₂, or to consider the type, size, or concentration of smoke particles in toxicological terms. Information on the analytical limits for the tubes used, and references to the toxic hazard limits of these gases are discussed in appendix 1. Where HCl was one of the products, in many cases the gas was also absorbed in water and analyzed by a chlorine ion electrode to provide a more accurate indication at high concentrations.

3. Test Results and Analysis

3.1. Material Identification

Appendix 2 is a list of materials, showing numerical designation, thickness, unit weight, type, use, and approximate chemical composition of the major components. Of the 141 materials studied, these may be divided into the following groups:

Sheet materials	46
Laminates	21
Fabrics	38
Rugs	10
Pads, Insulation, and Assemblies	24
Films	2

Of the 38 fabrics composed of woven fibers, only a few were essentially natural fibers (cotton

and wool), a few were composed of a mixture of natural and artificial fibers, but the bulk of the fabrics were made from 100 percent artificial fibers, including acrylics, modacrylics, polyesters, polyamides (nylon-type), vinyl, and glass.

Of the sheet and laminate materials, approximately one-half were composed entirely or predominantly of poly vinyl chloride (PVC), and the remaining sheet and laminate materials were composed of acrylonitrile-butadiene-styrene (ABS), methyl methacrylate, and other copolymers, blends, and varieties of polymers. The rugs tested included wool, modacrylics, polyamide (nylon and aromatic types), and polypropylene. Of the pads used for seats, there were several urethane foam materials and one rubber (chloroprene). The materials used as ceiling or bulkhead insulation in-

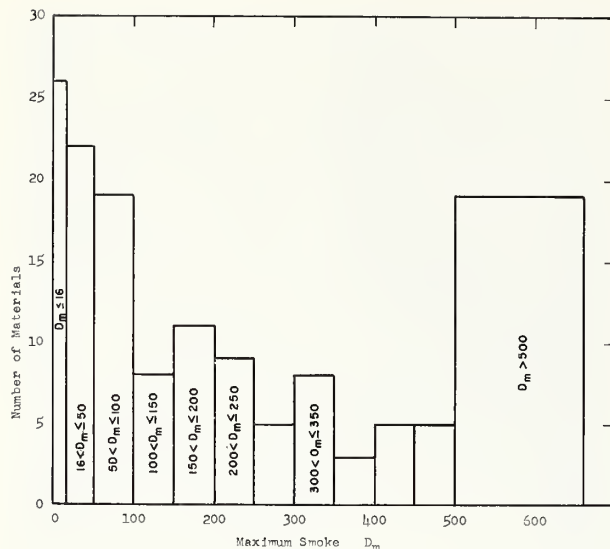


FIGURE 3. Frequency distribution of maximum smoke values. Flaming exposure—140 materials.

cluded mainly glass fiber materials or a paper honeycomb sandwich.

3.2. Smoke Measurements

Smoke measurements are summarized in appendix 3 in terms of the maximum smoke accumulation (D_m), the maximum rate of smoke accumulation (R_m) and the time (t_c) to reach a specific optical density of 16 for both flaming and smoldering exposure. These results represent averages of duplicate tests (with few exceptions). For D_m values up to 200, the standard deviation was 11.8 for flaming and 9.2 for nonflaming tests. Smoke buildup curves for typical flaming and smoldering tests on selected types of materials are shown in appendix 4.

A wide range of D_m values was measured. Slightly more than 15 percent of the materials produced smoke corresponding to a $D_m = 16$ or less, for both flaming and smoldering exposures. These included materials composed of glass, asbestos, aromatic polyamide, polyimide plus others, but many of these materials were very thin (light-weight). D_m values in excess of 200 were recorded for flaming and smoldering exposures on approximately 20 percent of the materials.

For flaming exposure of 140 materials, frequency distribution histograms of the maximum smoke values are shown in figure 3 for all materials, and in figure 4 within the classification groups: (a) fabrics, (b) rugs, (c) sheets, films, and laminates, and (d) pads, insulations, and assemblies.

Of the materials in the $D_m \leq 16$ category, 16 were fabrics, 6 were sheets or films, and 4 were glass or asbestos fiber insulations.

With one exception, all materials in the $D_m \leq 16$

category under flaming conditions were also $D_m \leq 16$ under nonflaming conditions.

Figures 5, 6, and 7 comprise a complete histogram showing smoke and toxic gas concentrations for flaming and nonflaming exposures on each material based on the data in appendix 3. Materials have been arranged according to classification by groups, by composition, and by generally increasing weight within each subgroup.

It should be noted that only the "front" side of a material was exposed, and that specimens exhibited a very wide range in their physical and thermal behavior during flaming and nonflaming exposure. Materials which melted at fairly low temperatures, including nylon, polysulfone, and polyethylene, flowed to the bottom or dripped off the sample holder in varying degrees, resulting in less smoke. Some materials evaporated fairly rapidly before extensive decomposition or combustion took place. All urethane foam materials produced more smoke under smoldering exposure than with flaming exposure, except in one instance where the material was noted to shrink into a corner of the holder and was, therefore, subjected to less radiation. Rubber (chloroprene), ABS, methacrylate, and PVC materials nearly always produced more smoke under flaming exposure. Under thermal radiation exposure alone, elastomers generally formed a bell-shaped protrusion at their center through which gaseous products streamed out rapidly. The maximum smoke level depends upon the thickness (and density) of the specimen, and for some materials D_m may be expected to increase with thickness but not always in direct proportion [3].

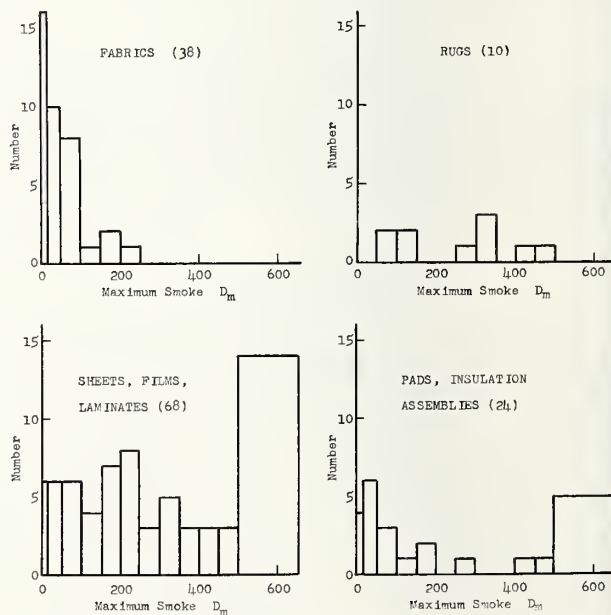


FIGURE 4. Frequency distribution of maximum smoke values by groups. Flaming exposure—140 materials.

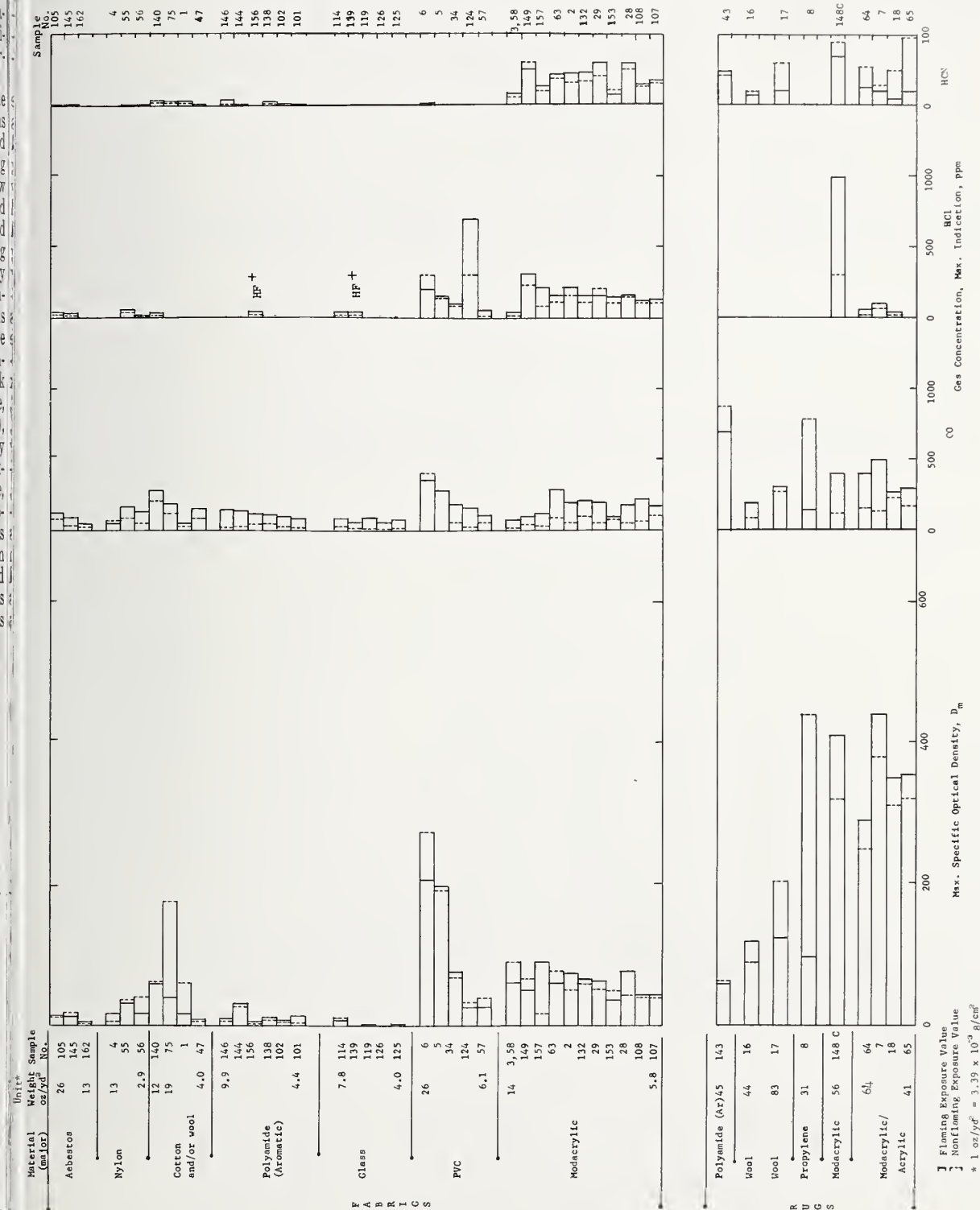


FIGURE 5. Smoke and gas concentrations for individual materials—fabrics, rugs.

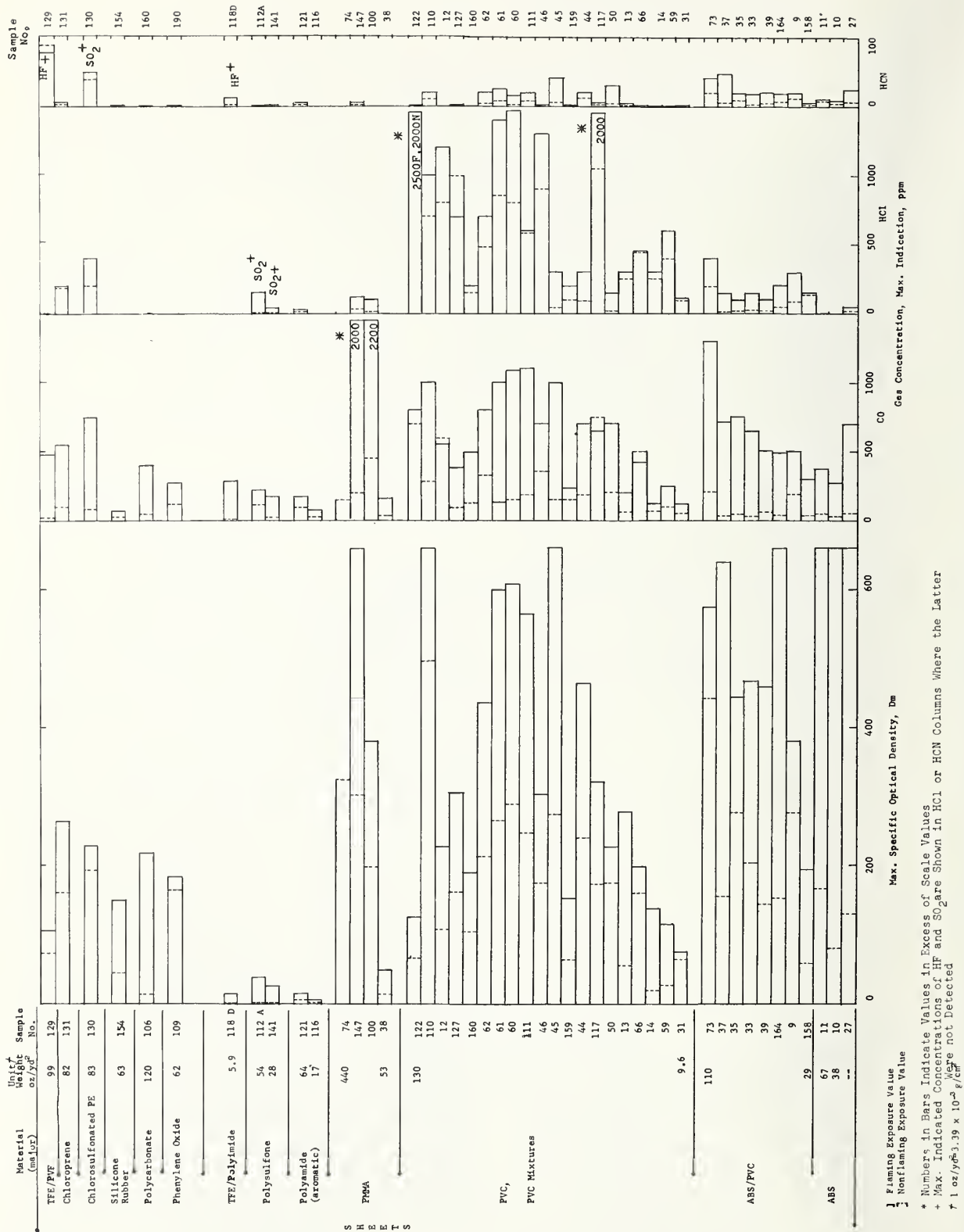


FIGURE 6. Smoke and gas concentrations for individual materials—sheets.

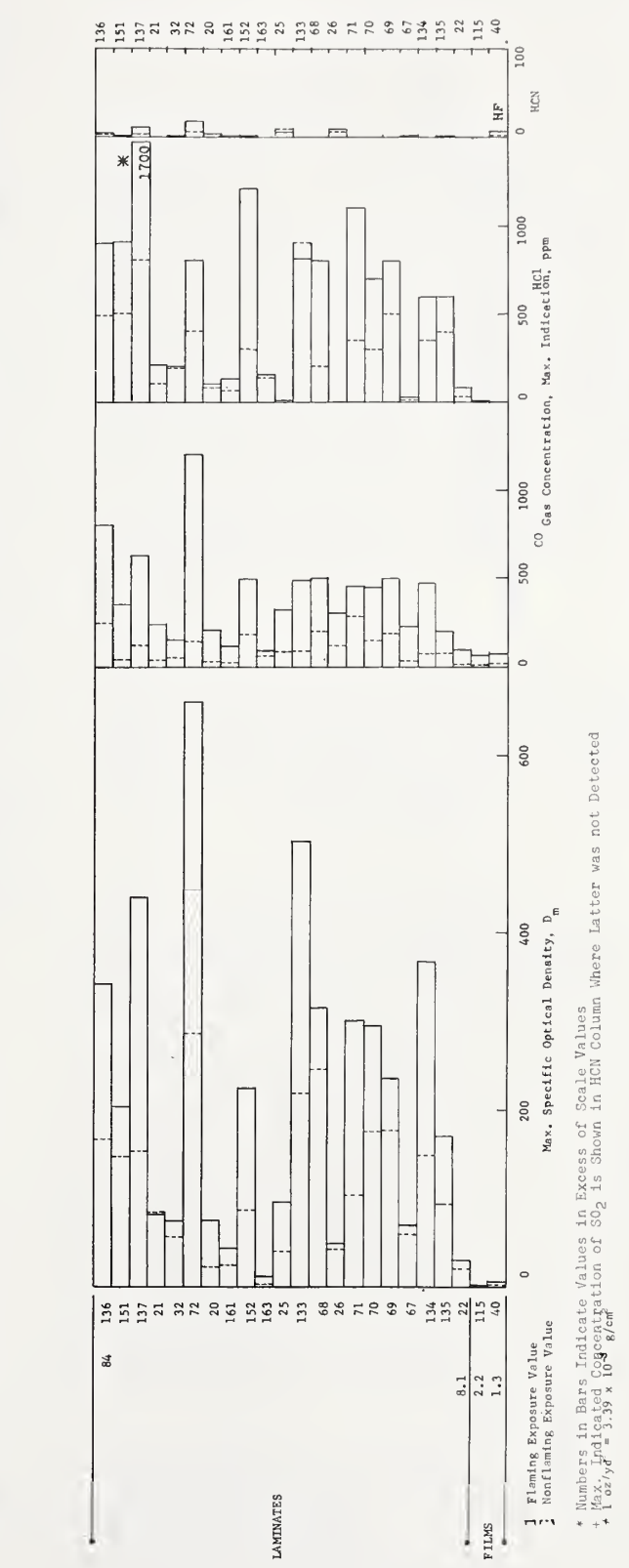
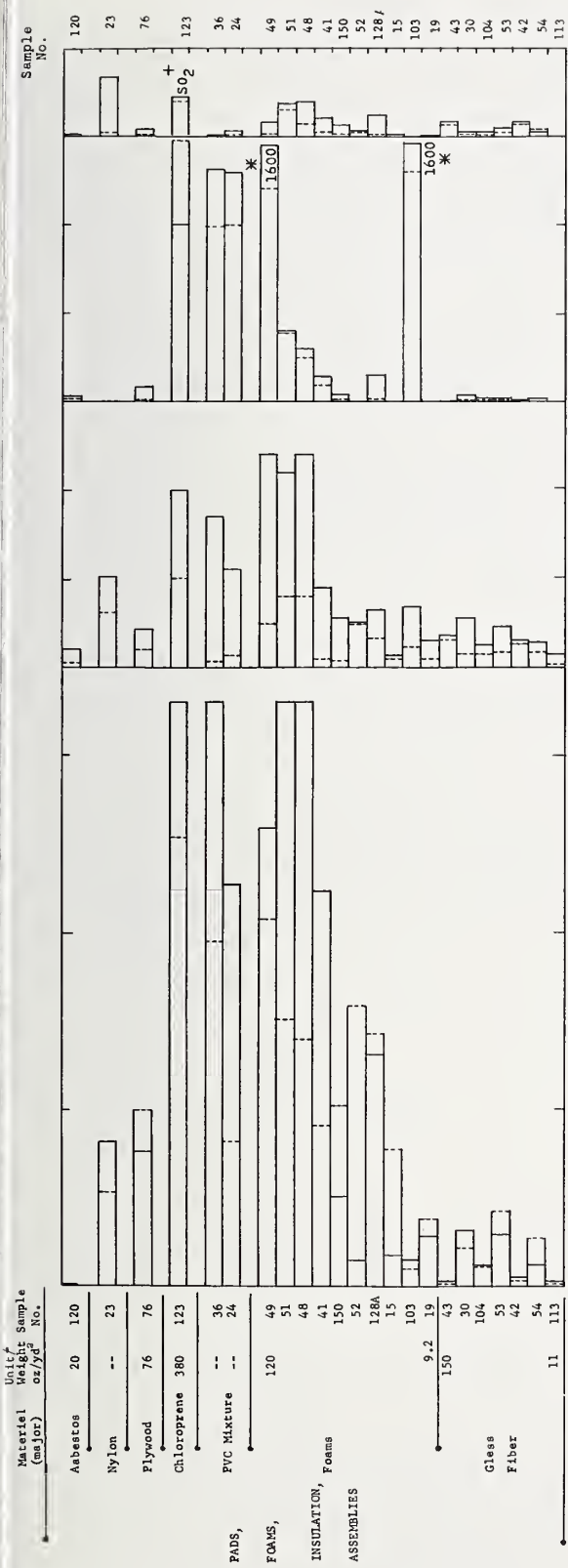


FIGURE 7. Smoke and gas concentrations for individual materials—semblies, laminates, films.

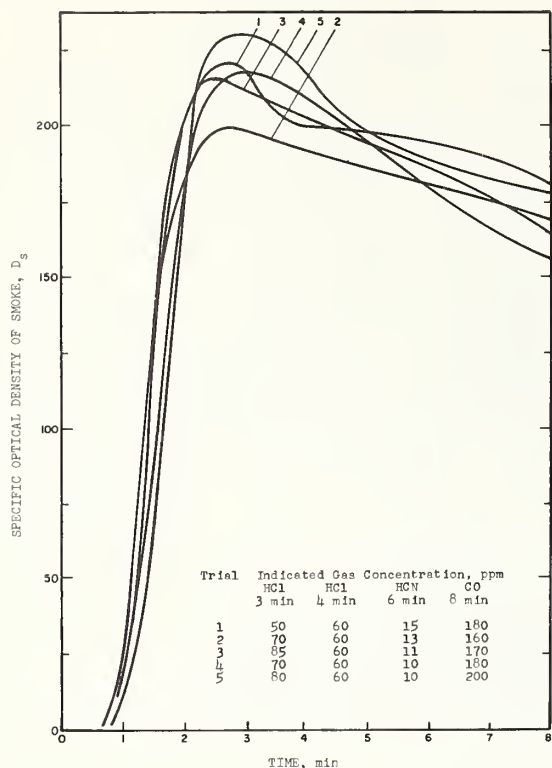


FIGURE 8. Reproducibility of smoke and gas concentration indications. Sample No. 44 (PVC/PVA/ABS) nonflaming exposure.

3.3. Gas Analysis

"Maximum" indicated concentrations of gases are listed in appendix 3 along with the smoke data. These values are based on the average of two separate determinations, except that additional tests were made where large discrepancies (greater than a factor of 2) between duplicate values were obtained. Unlike the measurement of optical density of smoke, which is recorded continuously to obtain a maximum, the concentrations of selected components was measured periodically. Particularly for components which change rapidly, therefore, the indicated concentration values may not necessarily be the true maximum values. For the materials tested, the highest indicated concentrations were 2200 ppm CO, 2500 ppm HCl, and 90 ppm HCN. These concentrations refer to the same exposed area of specimen and chamber volume used, but to a wide range of specimen weights.

Since the primary objective of this study was to ascertain approximate values, no extensive efforts were made to improve reproducibility. As a test of reproducibility for a PVC material (specimen No. 44), 5 separate smoldering exposure tests were conducted with the results shown in figure 8. This figure shows the five replicate smoke curves and a tabulation of indicated gas concentrations at spe-

cific times during each test. The measurement ranges were on the order of ± 20 percent for CO and HCN and ± 30 percent for HCl, and such variations may be considered typical of the maximum indicated concentration values under the test conditions.

Because the plastic materials studied were from many manufacturers and generally contained plasticizers, fillers, and other additives, it is difficult to relate quantitatively gaseous product concentrations with polymer composition. In general, HCl was produced by polyvinyl chloride and modacrylic materials, HF from polyvinyl fluoride, HCN from wool, urethane, ABS, and modacrylics and SO₂ from polysulfone and rubber materials. CO was produced by almost all the samples in varying amounts depending on the type of material.

It has been shown [5] that the amount of a given gas produced during pyrolysis and its rate of generation are strongly temperature dependent. Thus, any materials or processes which affect the temperature profile across the specimen (e.g. fillers and plasticizers which produce surface crusting, intumescence, etc.), could readily influence the concentration of gaseous products. For certain materials, higher concentrations of some gases may be produced under conditions of insufficient air, e.g. 10 percent oxygen [6].

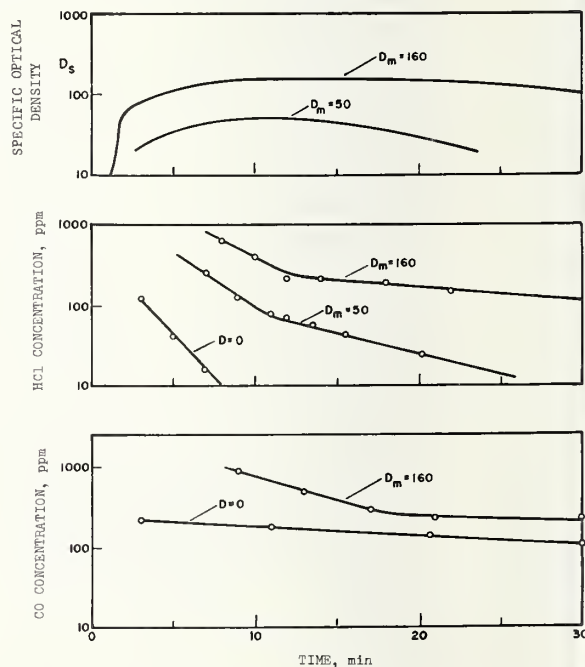


FIGURE 9. Comparative decay in HCl and CO concentrations for several smoke density levels.

Top: Smoke, nonflaming exposure, 2 selected PVC/PVA materials

Center: HCl concentration. Prior to taking readings, 220 cm³/min of H₂ was introduced in chamber over 3-min period

Bottom: CO concentration. Prior to taking readings, 190 cm³/min of C was introduced in chamber over 3-min period

Sampling was performed sequentially, proceeding generally from HCl and HF to HCN to CO, and was initiated when optical density of the smoke approached its peak. This procedure was followed because of the fairly rapid decay in halogen acid concentration resulting from adsorption on (and reaction with) moisture, smoke particles, and chamber surfaces. To facilitate subsequent data comparison, sampling for HCl and HF was generally initiated at the beginning of the minute close to the maximum smoke level, and at 2-min intervals thereafter for other gases.

Gas temperature at the sampling tube inlet generally ranged from 46 to 52 °C (115 to 126 °F), the higher temperatures occurring during flaming tests on heavier materials. Due to the cooling effect of the precleaning layers of the indicator tubes, the temperature of the gases passing the indicating layers were within the prescribed maximum temperature limits. The sampling rate was generally unaffected by either the elevated temperature of gases or by heavy smoke particle concentrations.

Hydrogen chloride is generally released rapidly during combustion or pyrolysis of polyvinyl chloride, modified acrylics and other retardant-treated materials [7, 8]. Maximum levels were generally higher under flaming compared to smoldering exposure conditions presumably due to the higher temperature involved and the resultant greater rate of release. The HCl concentration changed rapidly as a result of its high reactivity, solubility in water, and adsorption on smoke particles and wall surfaces. The type of surface as well as the total area of the interior walls have a pronounced influence on the adsorption and settling (or decay) rate of HCl and smoke. To illustrate the decay of both HCl and CO, a suitable concentration of the pure component was metered into the bottom of the chamber under both smoke-free ($D = 0$) and smoke-filled conditions. Figure 9 shows the indicated concentrations of HCl and CO. In these tests involving smoldering specimens only, the gas concentration levels are obviously higher because a portion of the gas is introduced by combustion. The decay rates are also higher.

4. Discussion

In the work described in this report, it was presumed that the test specimens were representative in thickness and density of the materials intended for actual use as interior finishes. For a few materials supplied in thicknesses greater than 1 in, the test specimen was trimmed to a thickness of 1 in to fit the size of the specimen holder. It should be evident that the density of smoke, the concentration of gaseous products, and the heat release characteristics are properties of the specimen as tested and will be different for other thicknesses and densities.

Limitations were previously noted to the use of specific optical density for extrapolating the smoke density measured in the laboratory test to other enclosure volumes and surface areas. Within these limitations, the relationship between the measured

value of D_s and the geometrical factor $\frac{V}{LA}$ for

various values of light transmission (or optical density) is shown in figure 10. The optical density level through which a lighted exit sign may be seen can vary over wide limits depending on the

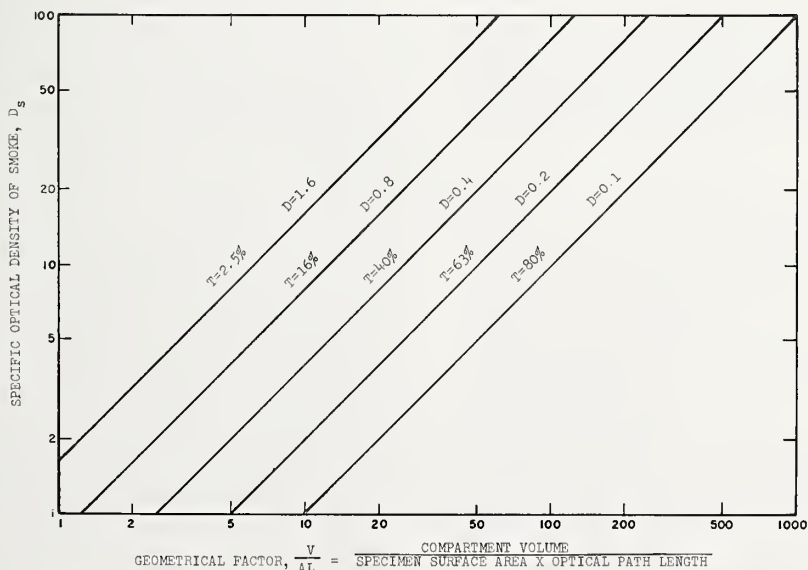


FIGURE 10. Specific optical density versus geometrical factor for five selected light transmission values.

general illumination level, on the contrast threshold and the extent to which the observer's eyes have been dark-adapted, as well as on the irritating nature of the smoke. In figure 10, five lines are shown for transmission values ranging from 80 to 2.5 percent (optical density 0.1 to 1.6) corresponding to a wide range of visual limits [3].

Using this figure, sample computations have been made in Table 1 for 3 selected values of D_s . If it is assumed that a lighted exit sign can be seen when the transmission is down to 40 percent (optical density 0.4), and an aircraft cabin has a volume of 10,000 ft³ within which smoke is uniformly dispersed, then Table 1 shows the estimated area A of material, the smoke from which may just begin to limit seeing the exit sign at various distances L .

Up to this point, only geometrical factors have been considered, but time is certainly important, and the choice of a critical specific optical density for each material can presumably also be based on a prescribed time period which is sufficiently long to permit escape or defensive action. From appendix 3, it may be noted that the time periods to attain a critical specific optical density of 16 ranged from 0.2 to over 20 min. It was previously noted [3] that a specific optical density of 16 could represent a possible critical limit.

Although the three factors, total smoke accumulation (D_m), maximum rate of smoke accumulation (R_m), and the time period to reach a "critical" optical density (t_c), are directly related to the smoke obscuration hazard, their relative weighting is not entirely obvious. One suggestion for a single overall hazard index based on the results of this test was made in the appendix of reference 3. However, it should be emphasized that additional experimental verification would be desirable prior to establishing rigorous smoke hazard limits for interior materials.

This study was concerned with the limited problem of measuring the optical density of smoke as it relates to the obscuration of human vision. No attempt was made to evaluate complications due to eye irritations, to respiratory effects from

TABLE 1. Critical (projected) surface area of material burned in 10,000 ft³ volume (for optical density = 0.4)

Specific optical density D_s	$\frac{V}{AL}$ (for OD = 0.4)	Light distance L	Specimen area A
10	25	3 ft	133 ft ²
10	25	10	40
10	25	30	13.3
10	25	100	4
50	125	3	26.7
50	125	10	8
50	125	30	2.67
50	125	100	0.8
100	250	3	13.3
100	250	10	4.0
100	250	30	1.3
100	250	100	0.4

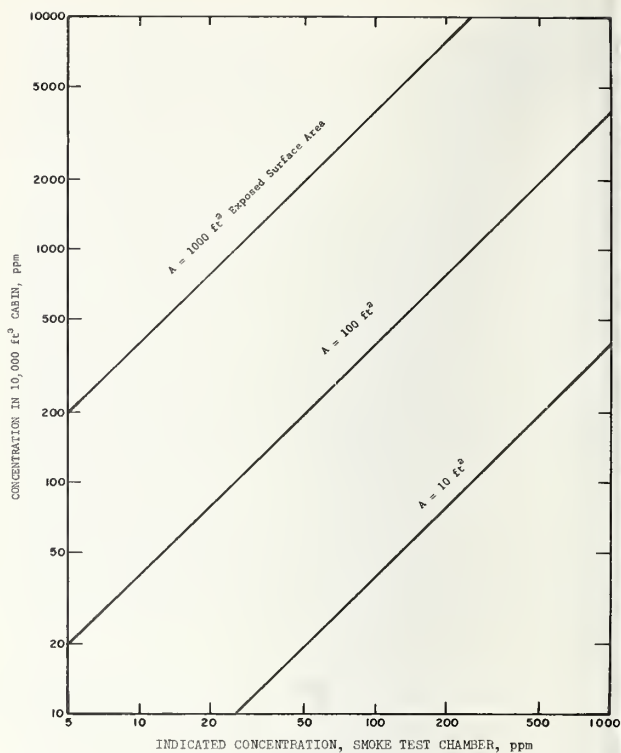


FIGURE 11. Gas concentration in 10,000 ft³ cabin based on indicated concentration in smoke test chamber.

inhaled smoke particles, or to hysteria or associated physiological or psychological factors.

The indicated concentrations of gaseous products listed in appendix 3 represent values measured at the sampling location and are associated with the prescribed exposure conditions on a specimen of given exposed area ($2\frac{9}{16}$ in square) within a totally enclosed chamber of 18 ft³ volume. Specimens were tested in the thickness and weight supplied, which varied over a wide range. Concentration measurements were made periodically from the time when the optical density of the smoke approached its peak. Any realistic evaluation of the gas concentrations likely to be encountered in a real fire situation must take into account actual areas and thicknesses of the materials exposed and the volumes in which the gases are dispersed. Also of importance are the rate of fire growth, the effects of adsorption and reaction, the extent of ventilation, dilution, and/or application of extinguishing agents, and other factors outside the scope of this study. Where specimen area and chamber volume are the only variables and uniform mixing is assumed, an approximate relationship between the gas concentration measured in the smoke chamber and the projected concentration within a much larger chamber, such as an aircraft cabin, is given by

$$C_{\text{cabin}} = C_{\text{test}} \frac{V_t A_c}{A_t V_c}$$

This simply scales concentration (C) in direct proportion to the area A of specimen involved and in inverse proportion to the chamber volume V . As an example, the gas concentration in a 10,000 ft³ cabin is shown in figure 11 for a series of lines corresponding to surface areas of 10, 100, and 1,000 ft².

It should be noted that such scaled estimates assume similar (or uniform) distribution of the gaseous components, and large differences may result in the case of active gases and vapors which tend to be adsorbed on surfaces, e.g. HF

and HCl, and gases and vapors which tend to stratify in layers.

Finally, it should be noted that relationships between the indicated concentrations measured in the smoke chamber and physiological or toxicological effects are also outside the scope of this study. The table of toxicological data, assembled from open literature sources has been included for reference purposes only. Information on the combined, or synergistic, effects of several noxious components (including smoke particles) is apparently very limited.

5. Conclusions

Based upon the tests performed and an evaluation of the results, the following conclusions have been reached:

1. Materials currently used as interior furnishings for aircraft cabins, and those being considered for future use, vary considerably in their production of smoke and potentially toxic products under simulated fire conditions.
2. The laboratory test method for generating smoke and measuring its optical density appears to be a useful tool for the quantitative classification of materials, and for the possible establishment of revised fire safety standards and criteria for controlling smoke production. Optical density is the single most characteristic measure of the visual obscuring quality of a smoke.
3. For evaluating smoke production, both smoldering and active flaming conditions should be considered. For the majority of materials, more smoke was produced during the flaming exposure test. However, certain materials produced significantly more smoke in the absence of open flaming.
4. Within the limitations and assumptions cited, the specific optical density of smoke measured

in the laboratory may be extrapolated to cabin volumes and surface areas of combustible furnishings in order to provide guidelines for cabin area limitations, or to estimate time periods available for escape or defensive action.

5. Indications of the concentrations of potentially toxic combustion products can be conveniently and inexpensively obtained during the smoke production test using calibrated commercial colorimetric tubes; however, these are suitable only where interferences by other gases are absent, and where precision is not of primary importance. The specific ion electrode is also a convenient method of measuring the concentrations of halogen acid gases. Furthermore, if an attempt is made to relate the indicated concentrations measured in the smoke chamber in terms of toxicological limits, caution must be exercised. It is essential that proper consideration be given to (a) scaling of the areas and volumes in the proposed situation, (b) the integrated dosage where concentration varies with time, (c) the synergistic effects of several components (and smoke particles), and (d) the effects of relative humidity, elevated temperature, stratification, adsorption on surfaces, and physiological factors not considered in this study.

6. References

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7. Appendix 1. Gas Analysis

7.1. Colorimetric Indicator Tubes

The manufacturer provided general information on the detector tubes regarding their measuring range, interfering reactions, reuse and the effects of temperature and relative humidity. The upper and lower limits of the measuring ranges of these tubes and some references to the toxicological limits of these gases are summarized in table 2. With good quality control during manufacture and frequent calibration, specific tubes can give meaningful results. However, certain shortcomings may be noted. These include:

1. Variation of packing density within the tube and nonuniformity of indicator gel among the tubes. Since the adsorption rate of a sample gas by the gel depends primarily on the reacting surface area available per length of tube, a variable packing density would affect reproducibility.
2. Certain gases and vapors are not adsorbed by the precleaning layer but react similarly with the indicator as the gas of interest to produce an unexpected interference.
3. The transition zone of the discolored stain front makes it difficult to judge the exact demarcation line and thus introduces errors.

These shortcomings can be minimized, for example, by frequent calibration to establish probable sources of errors, by knowing the specific interfering gases in the sample not absorbed by the precleaning layer and the sensitivity of the tube to these gases, and by determining the concentration of the interference gas, if any, found in the sample. With cumulative experience on using the tubes both during calibration and sampling, the error in judging the line of demarcation of the discolored section by an operator can be minimized. The merit of the colorimetric tubes as in any other analytical method should be judged by performance on a specific gas. Sensitivity, accuracy, and interference effects depend on the chemical system used in the tube and they are

obviously different for different gases. An extensive review of some of the techniques and problems associated with these tubes is given by Kusnetz, et al. [9].

The advantages of the indicator tubes are convenience and simplicity, yielding immediate results with the avoidance of transfer vessels and other sampling problems. In the hands of an experienced operator, reasonable accuracy can be attained.

Of the colorimetric tubes used, tubes for four compounds have been calibrated and examined for interferences and temperature effect. For calibration purposes low concentrations of HCl or HCN were prepared from a flow dilution system suggested by Saltzman [10]. The system consists of an asbestos plug which serves as a flow-limiting device [11], and a mixing chamber as shown in figure 12. Tubing to the asbestos flowmeter is 1 mm i.d. polytetrafluoroethylene tubing to minimize dead volume. The pressure regulating cylinder was filled with concentrated H₂SO₄. Flows were calibrated by attaching a graduated 0.1 ml pipet to the meter outlet and timing with a stopwatch the movement of a drop of mercury past the graduations. Flow rates as low as 0.01 cm³/min can be achieved with good long term stability.

The degree of dilution of pure HCl from the tank was controlled by the asbestos plug and the diluting gas metered by a rotameter. Mixture concentration could be varied from 10 to 1000 ppm. A needle valve controlled the flow rate to the indicator tube. The pressure drop across the colorimetric indicator during calibration was balanced by applying an appropriate vacuum at the other end of the tube. This arrangement avoids creating any disturbance to the diluting system when the tube is inserted to start a calibration.

Low concentrations of HCN were generated by aeration of a 4.6 molar solution of KCN in a midjet impinger. A thermostated water bath surrounding the bubbler and air supply condenser maintained a temperature of 30 °C (86 °F). The system produced an output of 100 ppm and further dilution was necessary for lower concen-

TABLE 2. Measuring range of colorimetric indicator tubes and toxicological data for selected gases

		CO	CO ₂	HCl		HCN	NO ₂	NO + NO ₂	NH ₃	Cl ₂	COCl ₂	HF	SO ₂
				Type A	Type B								
Indicator tube data	Nominal range, lower	10	—	2	2	2	0.5	0.5	25	0.2	0.25	0.5	5
	upper	3,000	—	30	500	150	50	10	700	30	75	15	150
	Recommended upper temp. Limit (tube and test gas) °C	90	—	40	45	30	40	40	40	50	35	40	40
Toxicological data*	M.A.C.**	50	5,000	5		10	5		50	1	0.1	3	5
	Irritation on brief exposure	ppm		35			25		500	30	5	30	20-50
	Immediate danger to life (2 to 5 min)	ppm	10,000	70,000	1000-2000	200-300	200		>2000	1000	50	50-250	500

* Based on the following references:

Henderson, Y., Haggard, H. W.: Noxious Gases. (Reinhold Publishing Corp., New York 1943).

Elkins, H. B.: The Chemistry of Industrial Toxicology (John Wiley & Sons, Inc., New York 1959).

American Conference of Governmental Industrial Hygienists, Document of Threshold Values, Cincinnati, Ohio 45202 (1966 edition).

** Maximum average atmospheric concentration for 8-hr daily exposure adopted by American Conference of Governmental Industrial Hygienists, 1966.

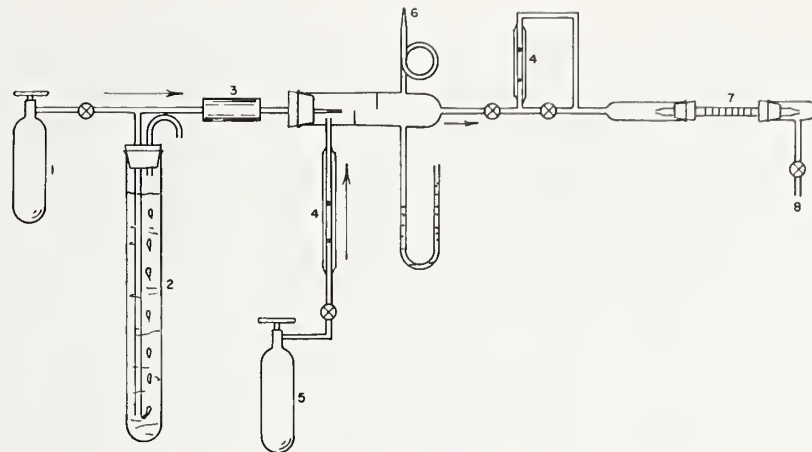


FIGURE 12. Flow dilution and calibration arrangement.

- | | | | |
|-----------------------|------------------|------------------|----------------------|
| 1. Gas of Interest | 3. Asbestos Plug | 5. Diluting Gas | 7. Colorimetric Tube |
| 2. Pressure Regulator | 4. Rotameter | 6. Mixture Waste | 8. Vacuum Source |

trations. Both HCl and HCN systems were very stable and consistent.

A static method using an FEP polytetrafluoroethylene 5-mil-thick collapsible bag was used to generate low concentrations of nonreacting gases. Under this arrangement, the sample gas was deposited by a gas-tight microsyringe and diluted with air or other gases from a 1-liter syringe. This method is not applicable to HCl or HCN because of losses resulting from adsorption, but gave satisfactory results with CO from 10 to 1000 ppm.

7.2. Specific Ion Electrode

A permeable membrane electrode for chloride ions (after Pungor) described recently [12] was

used in a system to determine the HCl concentration in a gas sample potentiometrically. This method has higher accuracy, range, and reliability than that of colorimetric indicator tubes. Its working range is between 20 and 20,000 ppm for a 100 cm³ gas sample. For lower concentrations, a larger sample must be used.

In practice, the highly water-soluble HCl gas and vapor in the 100 cm³ sample was totally absorbed when the sample flowed at a rate of 100 cm³/min through polytetrafluoroethylene tubing (5.3 mm i.d.) containing about 40 mg of loosely packed glass wool wetted with 0.1 cm³ water. The exposed glass wool was carefully transferred to a polytetrafluoroethylene cup of small

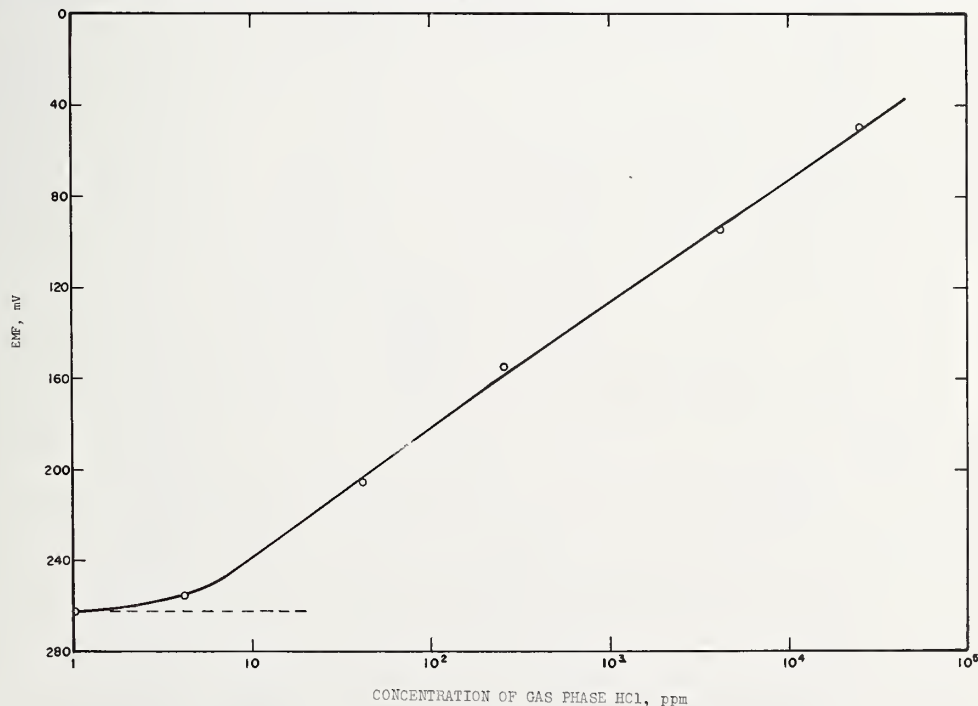


FIGURE 13. Measured emf as a function of HCl concentration in gas phase based on HCl in 100 cm³ sample absorbed by 1 cm³ of water.

TABLE 3. *Interfering components on colorimetric tubes**

Tube	Nominal concentration range	Indicating reagents	Interfering components	Noninterference
HCl** Type A	ppm 2-30	Organic metal salt to react with Cl.	H ₂ S > 20 ppm, no HCl sensitivity. (Cl ₂ , NO ₂ , NO) ≥ HCl, reading will be low. HF > 3 x HCl, reading will be high. H ₂ O > 70% RH, reading will be low. H ₂ O < 30% RH, reading will be high.	HCN, CO, SO ₂ , SO ₃ .
HCl Type B	2-500	Congo red on beaded alkali salt.	Any strong acid gas.	
HCN**	2-150	Hg salt to release acid gas.	H ₂ O > 90% RH NH ₃ > 1000 ppm H ₂ S > 300 SO ₂ > 200 Other acid gases in high concentrations (above adsorption limit of precleaning layer). NO ₂ > 50 ppm HCl > 5000 CO > 5000	
CO**	10-3000	Iodine pentoxide. Selenious dioxide. Sulfuric acid.	Saturated and unsaturated hydrocarbons > 4000 ppm. Hydrocarbons to CO ratio > 30.	H ₂ O, HCl, and HCN adsorbed by precleaning layers. (Watch precleaning layer saturation by color change.)
NH ₃	25-700	Gold chloride.	Aliphatic amines. H ₂ S > 50 ppm.	Hydrocarbons.
HF	1-15	Alizarin-zirconium complex.	None known. Specific for HF.	HCl, SO ₂ , NO ₂ , CO.
NO + NO ₂	0.5-10	Diphenylbenzidine.	HCl NO ₂ > 270 Cl ₂ NO ₂ > 2	
SO ₂	5-1500	Iodate.	Reducing compounds	

* Data based on manufacturer's information.

** The lack of mutual interference among HCl, HCN and CO for these tubes for concentration up to 1000 ppm HCl, 100 ppm HCN, and 1000 ppm CO was confirmed by NBS results.

internal volume. Water was added to make a total solution of 1 cm³ before insertion of the specific ion electrode, and a low-leakage, small-diameter-tip, conventional calomel-KCl reference electrode. A high impedance differential voltmeter or an expanded scale pH meter may be used to measure the emf between the electrodes. The specific electrode has a sensitivity limit of 10⁻⁵ mole per liter for chloride ion in solution and an equilibrium response time of about 1 min. It consists essentially of a polymeric silicone rubber membrane impregnated with particles of silver chloride precipitate. The membrane covers the tip of a small diameter glass tube filled with a chloride solution. Figure 13 shows the calibration curve of emf in mV and HCl concentration in ppm calculated on the basis of a 100 cm³ gas sample absorbed in a 1 cm³ solution. The curves were based on measurements made with solutions of known HCl concentrations.

Known interferences of bromide or iodide ions may be considered negligible if their concentrations are less than one-tenth of the chloride ion concentration [12]. In most fire gas or smoke chamber analyses no interference would be expected. In cases where the concentration of bromide ions is likely to be the same order as that of chloride, a bromide specific electrode can be used. This electrode is not affected by chloride ion concentrations as high as 50 times that of bromide.

Table 3 shows the type of indicator reagents used in the detector tubes. It also lists the known components and concentrations which would cause sufficient interference to give erroneous readings.

The precleaning layer serves to remove the interfering components and the table shows the maximum concentrations that can be tolerated. The data are based on information furnished by the tube manufacturer as well as NBS data showing the lack of mutual interference among the major components of HCl, HCN and CO. Except for H₂S which apparently poisons the reactive surface in the HCl tube, other interferences did not significantly alter the usefulness of those colorimetric tubes in the present smoke chamber study.

Table 4 shows some of the basic and calibration data for the colorimetric indicator tubes used. Included are the concentration ranges for which the tubes are rated and the sample volume and measured sampling rate for which the predetermined scale calibration holds. The length of indicating layer compared with the maximum of the concentration range indicates the resolution of the tube. The transition zone is a subjective estimate of the length between complete color change to no change which affects the reading error. The calibration ratios were based on the average of three separate runs for each of the stated concentrations. The method of preparation of an actual concentration of a single component in an atmospheric air mixture was given in the previous section. Unlike a previous study where several disinterested observers were asked to judge the demarcation front of the color change [9], the present results were based on the observation of one individual only. With the exception of the type B HCl tube which was +90 percent in error, all other errors fell within a ± 20 percent range.

TABLE 4. Colorimetric indicator tubes

Basic data (supplied by Mfr.)				Calibration data (NBS)						
Tube	Concentration Range	Sample volume	Sampling rate	Packing length		Transition zone		Concentration		
				Precleaning	Indicating	Length	Error	Actual	Indicated ^b	Error
	ppm	cm ³	seconds per stroke	mm	mm	mm	%	ppm	ppm	%
HCl Type A	2-30	1000	11	30	60	4	± 7	5 25 86 200	30 95 180	+20 +10 -10
	^a 10-300	100								
HCl Type B	2-100 20-500	500 100	30	0	65	2	± 3	300	570	+90
CO	10-300 100-3000	1000 100	27	40	50	2	± 4	50 100 200 500 1000	120 220 500 1000	+20 +10 0 0
HCN	2-30 10-150	500 100	10	30	50	6	± 8	5 30 75	35	+20
HF	1-15 ^a 5-150	1000 100	5	0	60	3	± 5	16	14	-13
NO + NO ₂	0.5-10 ^a 5-50	500 100	9	30	60	5	± 8			
SO ₂	5-150 50-1500	1000 100	12	0	65	4	± 6			
NH ₃	25-700	1000	9	0	75	3	± 4			

^a Concentration range extended by use of individual calibration (not furnished by the manufacturer).

^b Average readings of three separate tubes.

8. Appendix 2. Material Description

Abbreviations

Code	Designation	Composition
F1,F2—Fabric (uncoated, coated)	C Coated	ABS Acrylonitrile/butadiene/styrene
R1,R2—Rug (unpadded, padded)	UC Uncoated	PETP Polyethylene terephthalate polyester
S1,S2,S3—Sheet (flexible, semi-rigid, rigid)	F Flexible	PMMA Poly methyl methacrylate
L1,L2,L3—Laminate (flexible, semi-rigid, rigid)	SR Semi-rigid	PVA Poly vinyl acetate
	R Rigid	PVC Poly vinyl chloride
	P Padded	
	UP Unpadded	
	FR Fire-retardant treated	

No.	Code	Thickness	Unit* weight	Color and surface	Designation	Present or intended use	Material identification
		<i>Inch</i>	<i>oz/yd²</i>				
1	F-1	0.035	11	Light-blue	Fabric (UC)	Drapery	Wool/cotton (75:25).
2	F-1	0.030	9.6	Light-blue	Fabric (UC)	Drapery	Modacrylic.
3	F-1	0.055	14	Blue (multi-color pattern)	Fabric (UC)	Drapery	Modacrylic/nylon/cotton.
4	F-1	0.050	13	Tan Corduroy	Fabric (UC)	Upholstery	Polyamide (nylon type).
5	F-2	0.030	12	Blue Matte	Fabric (C)	Upholstery	Polyvinylchloride/methyl methacrylate/ester plasticizer on cotton.
6	F-2	0.045	26	Gold Matte	Fabric (C)	Upholstery	Polyester plasticizer (phthalate-type), possible PVC, on cotton.
7	R-2	0.33	62	Blue/gray Loop	Rug (P)	Flooring	Pile: Modacrylic/acrylic. Backing: Polyester fiber. Pad: Polyester urethane foam.
8	R-1	0.18	31	Blue/green Loop	Rug (UP)	Flooring	Pile: Copolymer poly(propylene-butylene). Center: Cellulosic. Backing: Polyethylene.
9	S-1	0.046	46	Tan Matte	Sheet (F)	Panel and door covering	PVA/ABS, china clay pigmented possible PVC.
10	S-2	0.045	38	Dark gray Matte	Sheet (SR)	Food trays, window frames	ABS (~25%:10%:65%).
11	S-3	0.080	67	Green Polished	Sheet (R)	Food trays, window frames	ABS (~25:10:65).
12	S-3	0.080	81	Tan Matte	Sheet (R)	Ceilings, seat panels	Copolymer: PVC/poly methyl methacrylate (~95:5).
13	S-2	0.030	26	Gold Shiny	Sheet (SR)	Trim	PVC and polyvinyl acetate base with some ABS plastic added. Film: Polyethylene terephthalate (PETP) polyester.
14	S-2	0.020	20	White/green Smooth	Sheet (SR)	Sides, ceiling, seat panels	Polyvinyl chloride/vinyl acetate (~89:11).
15	S-1	4.0	110	White Open cell	Foam (F)	Seat cushion padding	Polyether urethane.
16	R-1	0.22	44	Blue Loop	Rug (UP)	Flooring	Wool.
17	R-2	0.43	83	Multi-color Loop	Rug (P)	Flooring	Pile: Wool. Back: Polyester. Pad: Urethane foam.
18	R-1	0.22	59	Black/gray Loop	Rug (UP)	Flooring	Modacrylic/acrylic.
19	S-1	0.21	9.2	Green Open cell	Pad (F)	Carpet underlay	Polyester urethane foam.
20	L-3	0.042	68	Gold Embossed	Laminate (R)	Panels—Over-head and sides	Face: Polyvinyl acetate with trace of ABS covered with PETP polyester. Back: Aluminum sheet.
21	L-3	0.044	79	Tan Dull, brushed	Laminate (R)	Panels—Over-head and sides	Face: Vinyl chloride/acrylate copolymer (80:20). Back: Aluminum sheet.
22	L-1	0.009	8.1	Aluminum Matte, shiny	Laminate (F)	Window shades	Face: PETP Polyester. Back: Vinyl acetate, PVC copolymer.

* 1 oz/yd² = 3.39x10⁻³ g/cm².

Materials Description—Continued

No.	Code	Thickness	Unit weight	Color and surface	Designation	Present or intended use	Material identification
		<i>Inch</i>	<i>oz/yd²</i>				
23	A	Irregular		White Smooth	Assembly (molded)	Assist handles	Polyamide (nylon type).
24	A	Irregular		Green Smooth	Assembly (molded)	Seat track covers	Polyvinyl chloride, ABS terpolymer (94:6).
25	L-3	0.035	39	Gray Glossy	Laminate (R)	Galley area	Face: Melamine formaldehyde. Back: Urea formaldehyde.
26	L-3	0.032	35	Blue Glossy	Laminate (R)	Galley area	Face: Melamine formaldehyde. Back: Urea formaldehyde.
27	S-2	Irregular		White	Sheet (SR)	Passenger service units	Rigid part: ABS (40:40:20) possible PVC. Flex part: Plasticized PVC possible some vinyl acetate.
28	F-1	0.028	8.0	Tan/gold trace	Fabric (UC)	Drapery	Modacrylic.
29	F-1	0.030	9.3	Turquoise, gold trace	Fabric (UC)	Drapery	Modacrylic.
30	A	0.41	62	Tan Matte	Assembly (honeycomb)	Ceilings, bulkheads	Face: Coated glass fabric (Polyester or cross-linked Acrylic). Core: Paper honeycomb. Back: Plastic-impregnated glass fabric
31	S-1	0.010	9.6	White Matte	Sheet (F)	Lowered ceilings	Vinyl chloride/acrylate, possible Polyvinyl acetate.
32	L-3	0.045	75	Light blue Matte	Laminate (R)	Lowered ceilings	Vinyl chloride/acrylate copolymer film on aluminum sheet.
33	S-3	0.093	91	White Matte	Sheet (R)	Hatrack	ABS (40:40:20), possible PVC.
34	F-2	0.010	10	Tan Smooth	Fabric (C)	Underside hat-rack bullnose	Vinyl chloride/Acrylate copolymer on glass fabric (28%) plus pigment (13%).
35	S-3	0.095	90	Gray Dull	Sheet (R)	Toilet floor pans	ABS (40:40:20), possible PVC.
36	A	0.063		Tan Smooth	Assembly (molded)	Ceiling panel joint	Plasticized PVC. Plasticized di-(2 ethyl-hexyl) phthalate.
37	S-3	0.097	92	White Matte	Sheet (R)	Magazine rack	ABS (40:40:20)/PVC.
38	S-3	0.063	53	Clear Polished	Sheet (R)	Window pane	Methyl methacrylate/Methyl acrylate copolymer (90:10).
39	S-3	0.064	62	Tan Matte	Sheet (R)	Control panel	ABS (40%:40%:20%), possible PVC.
40	S-1	0.002	1.3	Clear Smooth	Film (F)	Protective coating	Polyvinyl fluoride.
41	A	0.35	95	Tan	Assembly (molded)	Bullnose	Face: ABS. Back: Polyether urethane foam.
42	A	1.3	35	Yellow Fibrous	Pad	Insulation	Glass fiber (plus organic binder).
43	A	2.5	150	Yellow Fibrous	Assembly	Insulation	Glass fiber with lead sheet.
44	S-1	0.046	44	Tan Matte	Sheet (F)	Seat panels	PVA/ABS, china clay pigmented, possible PVC.
45	S-3	0.063	60	Tan Matte	Sheet (R)	Seat panels	PVC/ABS.
46	S-3	0.057	55	White Matte	Sheet (R)	Seat panels	PVC/PMMA (90:10).
47	F-1	0.012	4.0	White Matte	Fabric (UC)	Lining for seat pads	Cotton.
48	A	0.57	82	Tan Matte	Assembly	Seat panels	Face: PVC/ABS. Back: Polyurethane.
49	A	0.52	120	White Matte	Assembly	Seat panels	Face: PVC/PMMA (90:10). Back: Urethane foam—polyether type.
50	S-3	0.60	35	White Open cell	Sheet (R)	Seat construction	Urethane foam—polyether type.
51	S-2	1.0	88	White Closed cell	Foam (SR)	Seat construction	Plasticized foam containing PVC/PVA and nitrile groups.
52	S-1	4.0	90	White Open cell	Pad (F)	Seat construction	Urethane foam—polyether type (FR).
53	A	3.0	44	Tan Smooth	Assembly	Insulation	Face: Filled rubber on Nylon 6-6 fabric. Back: Glass fiber batt.

Materials Description—Continued

No.	Code	Thickness	Unit weight	Color and surface	Designation	Present or intended use	Material identification
		<i>Inch</i>	<i>oz/yd²</i>				
54	A	1.3	28	Blue Smooth	Assembly	Insulation	Face: Organic-filled nylon fabric. Back: Glass fiber batt.
55	F-2	0.004	4.2	Tan Smooth	Fabric (C)	Cover for insulation batt	Polyethylene film over nylon fabric (filled rubber).
56	F-2	0.004	2.9	Light blue Smooth	Fabric (C)	Cover for insulation batt	Organic-filled nylon 6-6 fabric.
57	F-2	0.006	6.1	Green Smooth	Fabric (C)	Bulkhead assembly lining	Plasticized PVC on Glass fabric.
58	F-1	0.054	14	Bluish multi-colored weave	Fabric (UC)	Drapery	Modacrylic/nylon/cotton.
59	S-1	0.020	16	White/color pattern	Sheet (F)	Partitions	PVC/PVA (89:11).
60	S-3	0.060	64	Gold Glossy	Sheet (R)	Side panels	Plasticized PVC/PVA with ABS.
61	S-3	0.060	62	Blue Glossy	Sheet (R)	Side panel	PVC/PVA (Small amount of ABS).
62	S-3	0.069	70	White with pattern	Sheet (R)	Window panel	Polyvinyl butyral film on PVC/PVA (90:10).
63	F-1	0.030	9.5	Yellow/gold trace	Fabric (UC)	Drapery	Modacrylic/polyester.
64	R-1	0.33	64	Blue/green Loop	Rug (UP)	Flooring	Modacrylic/acrylic.
65	R-1	0.23	41	Brown/white/black loop	Rug (UP)	Flooring	Modacrylic/acrylic.
66	S-1	0.032	25	Tan/yellow Burlap	Sheet (F)	Sidewall	Plasticized PVC.
67	L-2	0.022	24	White Burlap	Laminate (SR)	Baggage liner	Polyester plastic filled glass fiber fabric.
68	L-2	0.038	34	Blue/white/yellow Simulated fabric	Laminate (SR)	Sidewall, partition liner	Face: PVC/PVA (89:11). Back: Cotton fabric and paper
69	L-2	0.026	24	Blue/white Simulated fabric	Laminate (SR)	Sidewall, partition liner	PVC/PVA.
70	L-2	0.031	28	Gray Glossy	Laminate (SR)	Sidewall, partition liner	Face: Acrylate. Back: PVC/PVA.
71	L-2	0.033	31	Tan/white Embossed	Laminate (SR)	Sidewall, partition liner	PVC/PVA (93:7).
72	L-3	0.075	71	Red Matte	Laminate (R)	Door liners	Face: PVC/PVA. Back: ABS/PVC.
73	S-3	0.11	110	Gray Glossy	Sheet (R)	Cockpit liner	ABS/PVC.
74	S-3	0.50	440	Clear Glossy	Sheet (R)	Window panes	Methyl methacrylate.
75	F-1	0.060	19	Turquoise Corrugated	Fabric (UC)	Upholstery	Cotton/nylon (small amount of polyester).
76	A	0.38	76	White Smooth	Assembly (honeycomb)	Ceiling panel	Face: Acrylic/vinyl coating over plywood (paper). Core: Paper with cresolfomaldehyde resin adhesive.
100	S-3	0.18	180	Clear Polished	Sheet (R)	Window panes	Methyl methacrylate.
101	F-1	0.015	4.4	White	Fabric (UC)	Drapery	Polyamide (aromatic-type).
102	F-1	0.015	6.1	Green	Fabric (UC)	Drapery	Polyamide (aromatic-type).
103	S-3	1.0	28	White Porous	Foam (R)	Foam insulation	Chlorinated PVC.
104	A	1.0	42	White Embossed	Assembly	Wall Insulation	Glass fabric (100%). Bonded to glass-fiber batt.
105	F-2	0.033	26	Aluminum Glossy	Fabric (C)	High temperature liner	Aluminum on asbestos.
106	S-3	0.13	120	Clear Glossy	Sheet (R)	Window panes fabricated parts	Poly (diphenylol propane) carbonate.

Materials Description—Continued

No.	Code	Thickness	Unit weight	Color and surface	Designation	Present or intended use	Material identification
		<i>Inch</i>	<i>oz/yd²</i>				
107	F-1	0.013	5.8	White	Fabric (UC)	Drapery	Modacrylic (100%).
108	F-1	0.013	5.9	Orange	Fabric (UC)	Drapery	Modacrylic (100%).
109	S-3	0.080	62	Yellow Glossy	Sheet (R)	Paneling	Poly (phenylene oxide).
110	S-3	0.13	110	Dark gray Matte	Sheet (R)	Paneling	PVC/PMMA plus ABS.
111	S-3	0.060	57	Green Matte	Sheet (R)	Paneling	PVC/PMMA plus ABS.
112A B	S-2	0.060 0.020	54 18	Clear Glossy	Sheet (SR)	Fabricated parts	Polysulfone.
113	S-1	0.30	11	White Fluffy	Pad	Seat padding, wall insulation	Glass fiber (100%).
114	F-2	0.010	7.8	White Matte	Fabric (C)	Headliner	Glass fabric coated with acrylic (aromatic plasticizer).
115	S-1	0.0015	2.2	Clear Smooth	Film (F)	Protective cover	Poly (difluoroethoxyethylene).
116	S-2	0.020	17	Tan Smooth	Sheet (SR)	Panel sub-strate	Polyamide (aromatic type).
117	S-3	0.045	50	White Glossy	Sheet (R)	Paneling	PVC/poly(vinylidene chloride).
118A B C D	S-1	0.002 0.005 0.003 0.005	2.1 5.4 3.5 5.9	Amber Clear Glossy	Sheet (F)	High temperature insulation	Polytetrafluoroethylene films over polyimide.
119	F-2	0.007	5.0	Blue	Fabric (C)	Headliner	Glass fabric (97%) with organic finish.
120	S-2	0.23	20	Gray Fibrous	Pad	Insulation	Asbestos fiber.
121	S-3	0.063	64	Tan Smooth	Sheet (R)	Panel substrate	Polyamide (aromatic type).
122	S-3	0.11	130	Gray Glossy	Sheet (R)	Paneling	Polyvinylchloride.
123	S-1	4.0	380	Black Open cell	Foam (F)	Seat padding	Chloroprene.
124	F-1	0.012	9.2	Maroon Glossy	Fabric (UC)	Wall covering	Plasticized poly(vinylidene chloride).
125	F-2	0.005	4.0	Light green Glossy	Fabric (C)	Headliner	Glass fabric (97%) with organic finish.
126	F-2	0.006	4.2	Light gray Glossy	Fabric (C)	Headliner	Glass fabric (83%) with organic finish.
127	S-2	0.034	29	Blue Matte	Sheet (SR)	Paneling	Face: Plasticized PVC/PVA (90:10). Back: Polyamide (Aromatic type).
128A B	S-1	4.0 4.0	89 67	White Open cell White Open cell	Foam (F)	Seat padding	Polyether urethane (FR). Polyether urethane.
129	S-1	0.071	99	Black Smooth	Sheet (F)	Elastomer, seals	Copolymer of tetrafluoro-ethylene/vinylidene fluoride.
130	S-1	0.067	83	Tan Smooth	Sheet (F)	Elastomer, gaskets	Chlorosulfonated polyethylene.
131	S-1	0.065	82	Black Smooth	Sheet (F)	Elastomer, hoses	Chloroprene.
132	F-1	0.028	8.7	Green	Fabric (UC)	Drapery	Modacrylic and metallized fiber (94:6).
133	L-1	0.040	36	Copper Glossy	Laminate (F)	Dado paneling	Face: Plasticized PVC/PVA. Back: Polyamide (aromatic type) paper.
134	L-1	0.032	27	Light tan Glossy	Laminate (F)	Hatrack	Face: Plasticized PVC/PVA and cotton fiber. Back: Polyamide (aromatic type) paper.
135	L-2	0.029	26	Blue/white pattern Smooth	Laminate (SR)	Paneling, Bulkhead dividers	Face: PVC/PVA (90:10). Back: Polyamide (aromatic type) paper.
136	L-3	0.099	84	Lt. gray/gold pattern Rough	Laminate (R)	Flooring	Plasticized PVC/PVA. Top coating—mostly plasticized.
137	L-3	0.074	72	Clear/white/blue Smooth	Laminate (R)	Window reveals, dado Seat backs	Plasticized PVC/PVA (90:10) over pigmented ABS, asbestos-filled.

Materials Description—Continued

No.	Code	Thickness	Unit weight	Color and surface	Designation	Present or intended use	Material identification
		<i>Inch</i>	<i>oz/yd²</i>				
138	F-1	0.015	5.8	Green Smooth	Fabric (UC)	Drapery (FR)	Polyamide (aromatic type) cotton (50%:50%).
139	F-2	0.007	6.6	White Smooth	Fabric (C)	Headliner, baggage liner	Glass fabric (60%) coated with polyvinylidene fluoride.
140	F-1	0.024	12	White/blue Smooth	Fabric (UC)	Matress ticking (FR)	Cotton.
141	S-2	0.031	28	Cream semi-clear Glossy	Sheet (SR)	Fabricated parts (FR)	Polysulfone.
142	S-3	1.0	12	White Fine grain	Foam (R)	Insulation	(Urea formaldehyde).
143	R-1	0.30	45	Green Loop	Rug (UP)	Flooring	Polyamide (Aromatic type).
144	F-1	0.035	11	Green/white/orange	Fabric (UC)	Upholstery	Polyamide (Aromatic type).
145	F-2	0.031	18	Silver Reflective	Fabric (C)	Insulation, baggage liner	Aluminum/polyester film on asbestos fabric.
146	F-1	0.035	9.9	White	Fabric (UC)	Upholstery, drapery	Polyamide (more Aromatic groups than 144 and 144).
147	S-3	0.23	210	Clear Glossy	Sheet (R)	Window panes, fabricated parts	Poly methyl methacrylate.
148	R-1	0.25	56	(A) Blue (B) Brown (C) Green Loop	Rug (UP)	Flooring	Pile: Modacrylic (100%).
149	F-1	0.15	10	Cream Fluffy	Fabric (UC)	Blanket	Modacrylic (100%).
150	S-1	4.0	89	White Open cell	Foam (F)	Seat padding (FR)	Polyether urethane.
151	L-3	0.054	75	Light tan Matte	Laminate (R)	Paneling	Plasticized PVC/PVA on aluminum sheet.
152	L-2	0.057	52	Light blue Matte	Laminate (SR)	Paneling	Face (blue): PVC/PVA (89:11). Back (tan): PVC/PMMA (90:10).
153	F-1	0.033	6.8	White Open weave	Fabric (UC)	Casement drapery	Modacrylic/rayon/poly(vinylidene chloride) 20%.
154	S-1	0.11	63	Red Closed cell	Sheet (F)	Padding	Silicone rubber.
155	S-3	0.060	53	Clear Glossy	Sheet (R)	Window panes Fabricated parts	Polycarbonate.
156	F-2	0.007	6.3	White Smooth	Fabric (C)	Headliner	Poly(vinylidene fluoride) coating, on Polyamide (aromatic type) fabric.
157	F-1	0.035	10	White	Fabric (UC)	Drapery	Modacrylic (100%).
158	S-2	0.028	29	Cream Glossy	Sheet (SR)	Panels, fabricated parts	PVC/ABS (94:6).
159	S-2	0.034	34	Olive Glossy	Sheet (SR)	Panels, fabricated parts	PVC/acrylic (90:10).
160	S-3	0.055	65	White Glossy	Sheet (R)	Panels, fabricated parts	Styrene/polyester, fiberglass—reinforced (25%) TiO ₂ pigment.
161	L-3	0.032	57	Wood grain pattern Smooth	Laminate (R)	Panels, interior finish	PVC/acrylic on aluminum sheet.
162	F-1	0.020	13	White	Fabric (UC)	High-temperature insulation fabric	Asbestos/glass/polyamide (aromatic type).
163	L-2	0.031	39	Wood grain pattern Smooth	Laminate (SR)	Panels, interior finish	PVC/PVA (95:5) on filled asbestos (71%).
164	S-3	0.070	60	White Glossy	Sheet (R)	Fabricated parts	ABS.

Appendix 3.

Summary of Test Results; Smoke and Gas Concentration

Sample number	Specimen weight	Test Exposure <i>F</i> = Flaming <i>N</i> = Nonflaming	Smoke			Gas concentration							
			Maximum specific optical density <i>D_m</i>	Maximum rate <i>R_m</i>	Time to <i>D_s</i> = 16 <i>t_c</i>	Maximum indication, Colorimetric tube							
						CO	HCl	HCN	Others				
						ppm	ppm	ppm	ppm				
1	^g 2.2	<i>F</i> <i>N</i>	14 60	2 19	NR 1.2	50 30	0 0	6 5					
2	1.8	<i>F</i> <i>N</i>	72 50	29 24	0.5 0.7	200 45	200 S 150 S	45 35					
3	2.8	<i>F</i> <i>N</i>	60 89	20 35	1.0 0.9	80 20	40 25	15 10					
4	^a 2.6	<i>F</i> <i>N</i>	16 6	4 < 1	15.0 NR	30 70	0 0	0 0					
5	4.4	<i>F</i> <i>N</i>	193 191	185 30	0.3 1.4	270 80	150 S 150 S	0 0					
6	5.0	<i>F</i> <i>N</i>	204 272	163 28	0.3 1.5	350 400	200 S 300 S	3 2					
7	12.2	<i>F</i> <i>N</i>	439 375	200 140	0.8 1.2	500 125	90 30	20 30					
8	7.0	<i>F</i> <i>N</i>	96 418	50 60	1.8 2.0	140 800	0 0	2 2					
9	9.1	<i>F</i> <i>N</i>	380 276	178 67	0.5 1.2	500 180	300 S 80 S	20 12					
10	7.1	<i>F</i> <i>N</i>	>660 76	340 6	0.6 4.3	260 25	0 0	10 8	NO + NO ₂ : 30				
11	11.8	<i>F</i> <i>N</i>	>660 167	280 8	0.7 3.5	360 40	0 0	10 9					
12	15.1	<i>F</i> <i>N</i>	229 107	61 17	1.0 3.0	550 600	1200 S 800 S	0 0					
13	5.4	<i>F</i> <i>N</i>	289 55	120 4	0.6 6.5	200 60	300 S 250 S	3 2					
14	4.0	<i>F</i> <i>N</i>	139 20	96 4	0.6 3.8	120 60	300 S 250 S	0 0					
15	^b 2.6	<i>F</i> <i>N</i>	35 156	6 9	1.4 0.5	50 50	0 0	2 2					
16	9.4	<i>F</i> <i>N</i>	123 87	23 6	1.6 2.1	190 90	0 0	15 20					
17	15.2	<i>F</i> <i>N</i>	129 206	50 40	2.2 2.0	320 300	0 0	15 60	NO + NO ₂ : 25				
18	11.6	<i>F</i> <i>N</i>	350 312	170 59	1.2 2.1	270 240	30 6	8 50					
19	1.7	<i>F</i> <i>N</i>	58 77	10 13	1.9 0.6	150 45	0 0	2 0					
20	13.0	<i>F</i> <i>N</i>	76 22	14 2	5.2 21.6	210 20	100 80	2 0					
21	14.9	<i>F</i> <i>N</i>	81 82	26 17	2.1 5.0	230 30	200 100	0 0					
22	1.3	<i>F</i> <i>N</i>	28 24	4 4	1.5 5.7	90 10	70 30	0 0					
23	^a 50.0	<i>F</i> <i>N</i>	162 105	11 3	5.6 13.6	500 30	0 0	65 2	NO + NO ₂ : 50				
24	11.4	<i>F</i> <i>N</i>	454 167	160 40	0.7 1.8	550 60	1300 S 1000 S	4 1					
25	7.2	<i>F</i> <i>N</i>	94 44	9 6	3.5 4.5	320 80	0 0	10 4					
26	6.7	<i>F</i> <i>N</i>	50 43	4 6	3.7 3.6	300 130	0 0	8 7					
27	4.6	<i>F</i> <i>N</i>	>660 126	260 5	0.8 5.3	700 50	50 20	25 8					
28	1.5	<i>F</i> <i>N</i>	76 48	23 20	0.4 0.8	170 60	150 150	60 50					
29	1.6	<i>F</i> <i>N</i>	66 52	23 17	0.5 0.9	200 40	150 200	60 40					

See footnote at the end of table.

Summary of Test Results; Smoke and Gas Concentration—Continued

Sample number	Specimen weight	Test Exposure <i>F</i> = Flaming <i>N</i> = Nonflaming	Smoke			Gas concentration					
			Maximum specific optical density <i>D_m</i>	Maximum rate <i>R_m</i>	Time to <i>D_s</i> = 16 <i>t_c</i>	Maximum indication, Colorimetric tube					
						CO	HCl	HCN	Others		
	<i>g</i>			<i>min⁻¹</i>	<i>min</i>	<i>ppm</i>	<i>ppm</i>	<i>ppm</i>	<i>ppm</i>		
30	12.3	<i>F</i> <i>N</i>	63 45	11 14	0.6 1.9	280 75	45 8	7 1			
31	1.8	<i>F</i> <i>N</i>	72 68	21 4	0.2 3.6	110 50	110 90	1 1			
32	14.7	<i>F</i> <i>N</i>	74 58	15 6	3.5 7.7	150 50	200 200	0 0			
33	17.6	<i>F</i> <i>N</i>	458 207	190 48	0.7 2.4	650 30	150 30	20 5			
34	2.0	<i>F</i> <i>N</i>	74 68	16 11	0.4 1.3	180 55	80 60	1 1			
35	17.4	<i>F</i> <i>N</i>	446 277	200 74	0.6 2.1	750 35	100 30	20 12			
36	^a 17.7	<i>F</i> <i>N</i>	>660 390	240 40	0.5 2.6	850 30	1300 S 1000 S	0 0			
37	18.2	<i>F</i> <i>N</i>	641 156	220 37	0.7 2.9	700 40	150 20	50 5			
38	10.7	<i>F</i> <i>N</i>	50 12	16 2	1.6 NR	160 30	0 0	0 0			
39	12.2	<i>F</i> <i>N</i>	460 146	190 26	0.6 2.3	500 60	110 25	20 6			
40	0.2	<i>F</i> <i>N</i>	4 1	<1 <1	NR NR	60 20	0 0	0 0			HF: 7 HF: 0
41	15.3	<i>F</i> <i>N</i>	448 181	170 38	0.4 1.5	450 45	150 100	20 5			
42	^c 4.8	<i>F</i> <i>N</i>	10 8	2 <1	NR NR	150 130	0 0	13 14			
43	^c 21.3	<i>F</i> <i>N</i>	8 4	<1 <1	NR NR	180 160	0 0	18 15			
44	10.3	<i>F</i> <i>N</i>	466 240	230 120	0.4 1.1	700 180	300 S 80 S	20 12			
45	12.2	<i>F</i> <i>N</i>	>660 276	260 65	0.4 1.7	1000 150	300 40	40 6			
46	12.2	<i>F</i> <i>N</i>	303 172	120 35	0.8 2.0	700 350	1300 S 900 S	1 0			
47	0.7	<i>F</i> <i>N</i>	8 8	1 <1	NR NR	150 80	0 0	1 0			
48	16.9	<i>F</i> <i>N</i>	>660 280	180 130	0.5 1.4	1200 400	300 250	40 15			
49	21.2	<i>F</i> <i>N</i>	518 414	220 100	0.7 1.4	1200 250	1600 S 1200 S	15 2			
50	^a 6.2	<i>F</i> <i>N</i>	229 164	110 59	0.2 0.4	700 200	150 0	30 3			
51	17.0	<i>F</i> <i>N</i>	>660 302	250 50	0.2 0.6	1100 400	400 400	38 30			
52	^c 4.6	<i>F</i> <i>N</i>	30 318	8 46	2.5 0.5	250 250	0 0	3 2			
53	5.9	<i>F</i> <i>N</i>	60 87	23 34	0.2 0.6	230 90	15 8	10 5			
54	4.1	<i>F</i> <i>N</i>	24 56	7 26	0.8 0.4	140 80	8 1	6 7			
55	0.9	<i>F</i> <i>N</i>	30 35	6 5	2.9 3.1	160 80	50 35	2 1			
56	0.6	<i>F</i> <i>N</i>	18 40	3 3	5.2 7.8	120 50	9 5	3 1			
57	1.0	<i>F</i> <i>N</i>	27 40	7 4	1.3 3.9	100 60	40 12	1 1			
58	2.6	<i>F</i> <i>N</i>	58 89	22 35	1.0 1.0	80 20	40 25	15 10			
59	3.0	<i>F</i> <i>N</i>	115 28	64 8	0.4 1.8	250 100	600 400	0 0			

Summary of Test Results; Smoke and Gas Concentration—Continued

Sample number	Specimen weight	Test Exposure <i>F</i> = Flaming <i>N</i> = Nonflaming	Smoke			Gas concentration			
			Maximum specific optical density D_m	Maximum rate R_m	Time to $D_s = 16$ t_c	Maximum indication, Colorimetric tube			
						CO	HCl	HCN	Others
	<i>g</i>			min^{-1}	<i>min</i>	<i>ppm</i>	<i>ppm</i>	<i>ppm</i>	<i>ppm</i>
60	12.8	<i>F</i> <i>N</i>	609 290	260 47	0.5 1.2	1100 150	1500 S 800 S	15 4	
61	12.7	<i>F</i> <i>N</i>	600 267	250 77	0.5 1.4	1000 130	1400 S 850 S	25 8	
62	13.2	<i>F</i> <i>N</i>	436 216	180 33	0.5 1.6	800 320	700 S 450 S	20 5	
63	2.0	<i>F</i> <i>N</i>	60 78	20 22	0.5 0.7	280 80	150 100	45 40	
64	12.1	<i>F</i> <i>N</i>	295 254	140 92	0.6 1.3	380 160	30 0	25 55 d	
65	8.3	<i>F</i> <i>N</i>	355 327	310 86	0.7 2.0	300 170	0 0	17 110 d	
66	5.0	<i>F</i> <i>N</i>	199 180	180 44	0.4 1.4	420 500	450 450	0 1	
67	4.7	<i>F</i> <i>N</i>	69 60	28 6	0.4 4.2	230 30	20 8	0 0	
68	6.7	<i>F</i> <i>N</i>	311 246	160 19	0.6 2.4	500 200	800 S 200	0 0	
69	5.3	<i>F</i> <i>N</i>	234 178	200 33	0.4 1.2	500 190	800 S 500	0 0	
70	5.5	<i>F</i> <i>N</i>	295 178	250 26	0.4 1.2	450 150	700 S 300	1 1	
71	6.0	<i>F</i> <i>N</i>	300 104	230 25	0.4 1.0	450 280	1100 S 350	1 1	
72	14.1	<i>F</i> <i>N</i>	>660 286	260 45	0.6 1.6	1200 130	800 S 400	17 7	
73	20.8	<i>F</i> <i>N</i>	574 442	180 58	0.6 2.0	1300 200	400 200	40 20	
74	86.9	<i>F</i> <i>N</i>	328	5	9.0	140	0	0	
75	3.9	<i>F</i> <i>N</i>	39 175	13 29	0.9 1.2	180 120	0 0	5 5	
76	16.0	<i>F</i> <i>N</i>	151 200	35 70	1.2 1.4	220 100	80 5	7 3	
100	32.9	<i>F</i> <i>N</i>	383 203	120 12	1.9 6.0	2200 400	100 8	0 0	
101	0.9	<i>F</i> <i>N</i>	10 0	<1 0	NR NR	70 10	0 0	1 1	
102	1.0	<i>F</i> <i>N</i>	8 5	1 <1	NR NR	95 10	0 0	2 0	
103	5.7	<i>F</i> <i>N</i>	30 20	6 2	1.5 6.8	330 110	1600 S 1300 S	2 1	
104	9.4	<i>F</i> <i>N</i>	25 25	4 5	2.8 3.0	130 70	15 12	5 4	
105	5.2	<i>F</i> <i>N</i>	11 10	2 1	NR NR	110 75	35 13	1 0	
106	18.4	<i>F</i> <i>N</i>	210 12	70 1	2.8 NR	400 50	0 0	0 0	
107	1.2	<i>F</i> <i>N</i>	39 41	15 10	0.4 0.8	160 90	120 100	35 30	
108	1.2	<i>F</i> <i>N</i>	39 41	11 13	0.6 0.6	220 60	110 100	30 30	
109	12.4	<i>F</i> <i>N</i>	183 168	66 5	0.9 18.2	270 120	0 0	1 0	
110	23.2	<i>F</i> <i>N</i>	>660 498	220 68	0.6 2.3	1000 280	1000 S 700	20 10	
111	11.0	<i>F</i> <i>N</i>	566 248	310 42	0.5 1.8	1100 180	600 S 600 S	19 8	
112A	11.2	<i>F</i> <i>N</i>	40 4	12 <1	2.6 NR	220 30	0 0	0 0	SO ₂ : 150 SO ₂ : 0

Summary of Test Results; Smoke and Gas Concentration—Continued

Sample number	Specimen weight	Test Exposure <i>F</i> = Flaming <i>N</i> = Nonflaming	Smoke					Gas concentration								
			Maximum specific optical density <i>D_m</i>		Maximum rate <i>R_m</i>		Time to <i>D_s</i> = 16 <i>t_c</i>		Maximum indication, Colorimetric tube							
									CO		HCl		HCN		Others	
	<i>g</i>				<i>min</i> ⁻¹		<i>min</i>		<i>ppm</i>		<i>ppm</i>		<i>ppm</i>		<i>ppm</i>	
113	1.9	<i>F</i> <i>N</i>	4	4	< 1	< 1	NR	NR	60	5	0	0	0	0		
114	1.6	<i>F</i> <i>N</i>	9	11	3	2	NR	NR	70	20	25	17	0	0		
115	0.5	<i>F</i> <i>N</i>	0	0	0	0	NR	NR	60	5	0	0	0	0	HF: 0 HF: 0	
116	2.3	<i>F</i> <i>N</i>	6	3	< 1	< 1	NR	NR	70	15	0	0	0	0		
117	9.5	<i>F</i> <i>N</i>	321	173	100	25	0.6	1.6	650	750	2000 S	1100 S	5	2		
118D	1.1	<i>F</i> <i>N</i>	15	0	< 1	0	NR	NR	280	< 5	0	0	1	0	HF: 11 HF: 0	
119	1.0	<i>F</i> <i>N</i>	1	2	< 1	< 1	NR	NR	80	10	0	1	0	0		
120	3.0	<i>F</i> <i>N</i>	1	1	< 1	< 1	NR	NR	90	10	11	10	0	0		
121	12.2	<i>F</i> <i>N</i>	14	7	< 1	< 1	NR	NR	170	100	15	13	5	1		
122	23.0	<i>F</i> <i>N</i>	125	66	30	13	1.1	3.2	800	700	2500 S	2000 S	1	1		
123	° 20.0	<i>F</i> <i>N</i>	> 660	508	290	120	0.2	0.3	1000	500	1100	1500 S	8	6	{SO ₂ : 45 H ₂ S: 40 SO ₂ : 40	
124	1.9	<i>F</i> <i>N</i>	26	34	8	4	3.9	3.9	150	20	700	300	0	0		
125	0.9	<i>F</i> <i>N</i>	2	1	< 1	< 1	NR	NR	60	10	0	0	0	0		
126	0.9	<i>F</i> <i>N</i>	1	1	< 1	< 1	NR	NR	60	10	0	0	0	0		
127	5.5	<i>F</i> <i>N</i>	309	162	250	45	0.4	1.0	380	100	700 S	1000 S	2	1		
128A	° 4.2	<i>F</i> <i>N</i>	262	286	120	62	0.2	0.7	320	160	150	25	25	2		
128B	° 3.5	<i>F</i> <i>N</i>	41	300	15	54	0.6	0.7	150	190	2	2	2	2		
129	20.1	<i>F</i> <i>N</i>	109	75	40	28	1.2	2.5	480	20	0	0	2	0	HF: 80 HF: 90	
130	16.7	<i>F</i> <i>N</i>	230	196	92	70	0.8	1.1	750	60	400 S	200 S	0	0	SO ₂ : 50 SO ₂ : 40	
131	18.8	<i>F</i> <i>N</i>	233	161	130	42	0.7	1.6	550	100	200	200 S	5	2		
132	1.8	<i>F</i> <i>N</i>	67	62	25	28	0.4	0.6	210	90	150 S	100 S	46	37		
133	7.5	<i>F</i> <i>N</i>	503	218	300	57	0.4	1.3	500	80	800 S	900 S	1	0		
134	5.6	<i>F</i> <i>N</i>	368	150	340	29	0.4	1.5	470	70	600 S	350 S	0	0		
135	5.3	<i>F</i> <i>N</i>	170	94	83	30	0.4	1.0	200	70	600 S	400 S	1	1		
136	18.3	<i>F</i> <i>N</i>	342	169	160	47	0.6	1.2	800	250	900 S	500 S	3	1		
137	14.8	<i>F</i> <i>N</i>	440	154	140	41	0.5	1.7	620	120	1700 S	800 S	10	1		
138	1.0	<i>F</i> <i>N</i>	10	9	2	< 1	NR	NR	100	40	0	0	4	2		
139	1.5	<i>F</i> <i>N</i>	1	1	< 1	< 1	NR	NR	45	< 5	0	0	0	0	HF: 26 HF: 10	
140	2.4	<i>F</i> <i>N</i>	50	51	16	14	0.8	0.9	270	210	17	14	8	5	NO + NO ₂ : 8	
141	5.4	<i>F</i> <i>N</i>	28	1	4	< 1	5.9	NR	180	< 5	0	0	0	0	SO ₂ : 30 SO ₂ : 0	

Summary of Test Results; Smoke and Gas Concentration—Continued

Sample number	Specimen weight	Test Exposure <i>F</i> = Flaming <i>N</i> = Nonflaming	Smoke			Gas concentration							
			Maximum specific optical density <i>D_m</i>	Maximum rate <i>R_m</i>	Time to <i>D_s</i> = 16 <i>t_c</i>	Maximum indication, Colorimetric tube							
						CO		HCl		HCN		Others	
	<i>g</i>			<i>min⁻¹</i>	<i>min</i>	<i>ppm</i>		<i>ppm</i>		<i>ppm</i>		<i>ppm</i>	
143	8.6	<i>F</i>	51	10	3.2	700	880	0	0	48	40	{ NO + NO ₂ : 10 NH ₃ : 60	
144	2.4	<i>F</i> <i>N</i>	32 30	8 8	2.4 3.4	130 20	20	0 0	0 0	3 0	0	NO + NO ₂ : 12	
145	3.6	<i>F</i> <i>N</i>	11 14	2 2	NR NR	80 20	20	25 15	15	1 0	0		
146	2.3	<i>F</i> <i>N</i>	8 6	< 1 < 1	NR NR	140 10	10	0 0	0 0	5 2	2	NO + NO ₂ : 8	
147	42.4	<i>F</i> <i>N</i>	> 660 304	88 15	1.4 4.5	2000 200	200	120 20	20	5 0	0		
148A	11.4	<i>F</i> <i>N</i>	410 314	130 66	0.5 1.5	400 120	1000 S 300 S	70 90	90	1 0	0		
148C	11.5	<i>F</i> <i>N</i>	464 324	190 150	0.5 1.5	500 100	1000 S 250 S	90 90	90	1 0	0		
149	2.3	<i>F</i> <i>N</i>	50 66	20 30	1.2 1.2	80 50	300 S 200 S	50 60	60	1 0	0		
150	^a 4.8	<i>F</i> <i>N</i>	101 205	43 42	0.4 0.4	270 40	40 0	12 2	2	NO + NO ₂ : 12			
151	15.2	<i>F</i> <i>N</i>	202 148	91 45	0.9 2.9	350 40	900 S 500 S	1 0	0				
152	10.5	<i>F</i> <i>N</i>	223 88	76 20	0.6 1.7	500 180	1200 S 300 S	1 1	1				
153	1.5	<i>F</i> <i>N</i>	19 25	6 10	1.1 1.1	80 80	150 90	15 20	20				
154	12.5	<i>F</i> <i>N</i>	151 44	50 10	0.9 2.8	60 10	0 0	0 0	0				
155		<i>F</i> <i>N</i>											
156	1.3	<i>F</i> <i>N</i>	3 2	< 1 < 1	NR NR	100 40	0 0	0 0	0	HF: 35 HF: 24			
157	^a 2.0	<i>F</i> <i>N</i>	90 18	130 4	0.6 4.6	130 20	200 80	25 20	20				
158	5.1	<i>F</i> <i>N</i>	195 59	170 25	0.5 1.2	300 35	150 S 150 S	5 1	1				
159	6.7	<i>F</i> <i>N</i>	154 63	74 20	0.7 1.5	240 50	200 S 100 S	0 0	0				
160	13.1	<i>F</i> <i>N</i>	190 106	70 18	0.7 3.3	500 125	200 150	0 0	0				
161	11.5	<i>F</i> <i>N</i>	43 24	18 8	2.0 4.4	110 25	130 70	0 0	0				
161x	1.5	<i>F</i> <i>N</i>	52 29	20 11	0.3 1.0	120 25	150 80	0 0	0				
162	2.5	<i>F</i> <i>N</i>	1 0	< 1 0	NR NR	30 < 5	0 0	0 0	0				
163	7.5	<i>F</i> <i>N</i>	11 1	< 1 < 1	NR NR	80 60	150 150	0 0	0				
163x	6.3	<i>F</i> <i>N</i>	4 0	< 1 0	NR NR	100 90	80 40	0 0	0				
164	11.8	<i>F</i> <i>N</i>	> 660 152	260 54	0.4 1.7	500 40	200 50	20 10	10				

^a Material not fully exposed because of melting, shrinking, etc.^b Tested in 3/4-in. thickness.^c Tested in 1-in. thickness.^d Probably acrylonitrile vapor indication.

NR Not reached.

S Measured with chloride ion electrode.

Appendix 4. Typical Smoke Accumulation Curves for Selected Materials

$$D_s \text{ Specific optical density} = \frac{V}{AL} \log \frac{100}{T}$$

F Flaming exposure

NF Nonflaming (smoldering) exposure

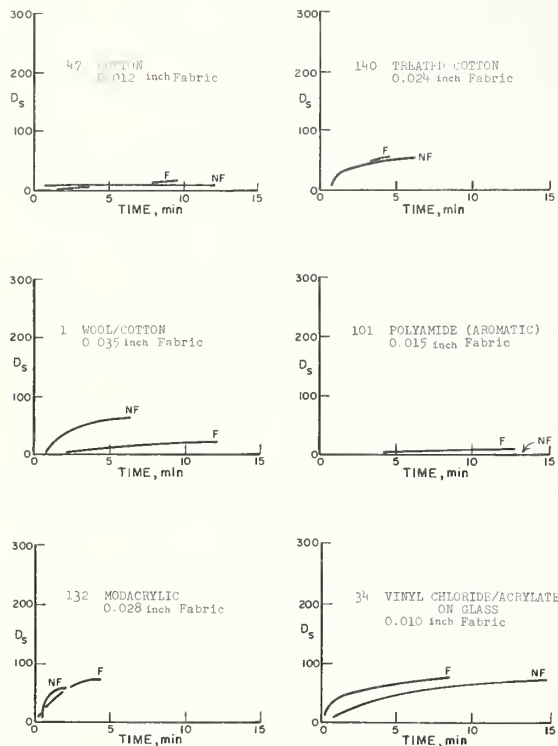


FIGURE 14. Typical smoke curves—fabrics.

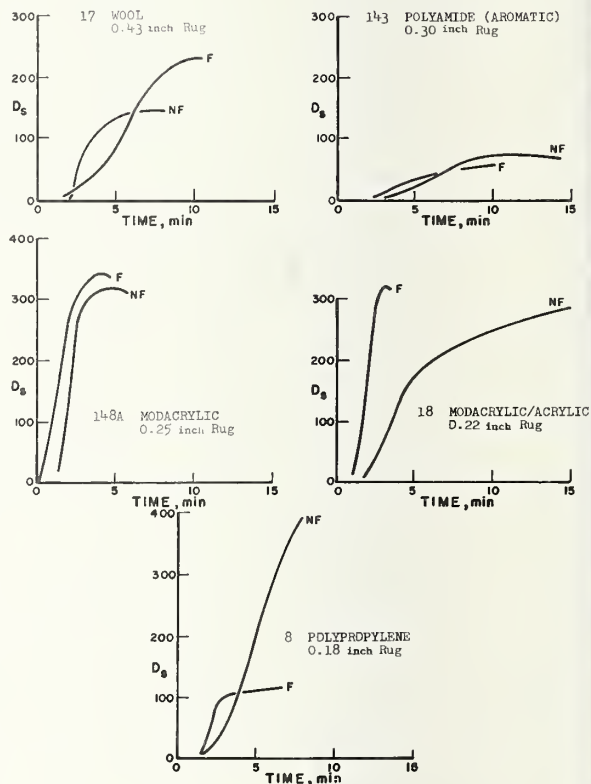


FIGURE 15. Typical smoke curves—rugs.

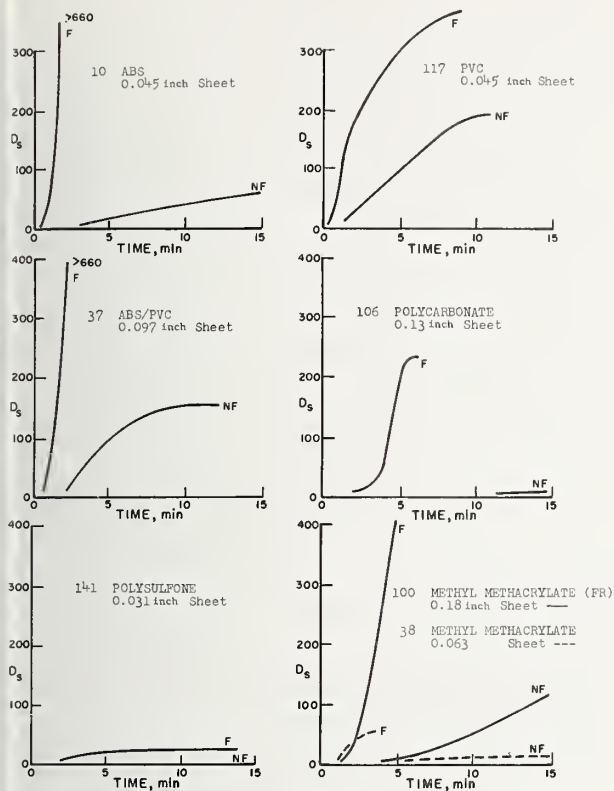


FIGURE 16. Typical smoke curves—sheets.

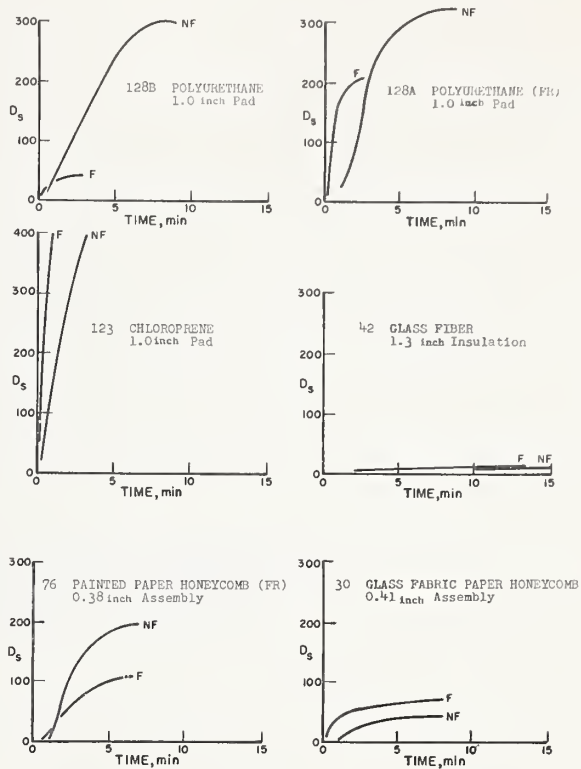


FIGURE 18. Typical smoke curves—pads, insulation, assemblies.

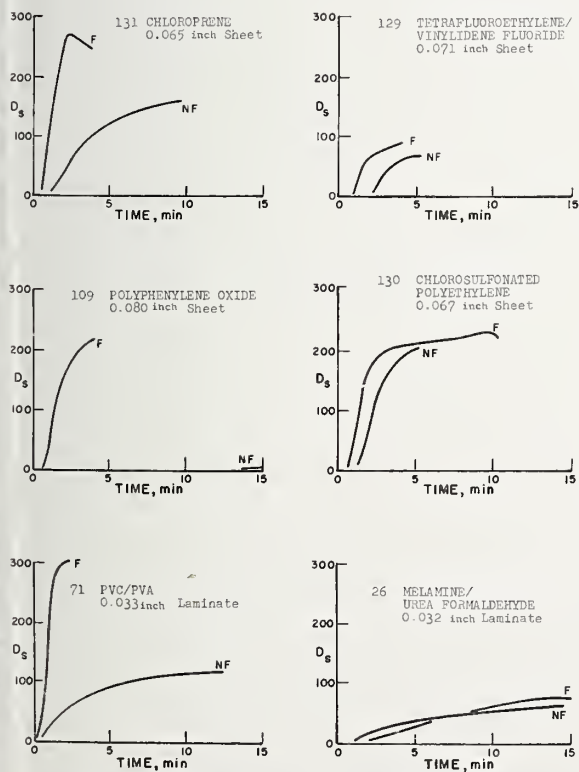


FIGURE 17. Typical smoke curves—sheets, laminates.



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