Report No. NA-68-36

(DS-68-16)

FINAL REPORT

141 material

Contract No. FA66NF-AP-7

Project No. 510-001-11X

SMOKE AND GASES PRODUCED BY BURNING AIRCRAFT INTERIOR MATERIALS

JUNE 1968

Prepared for

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
NATIONAL AVIATION FACILITIES EXPERIMENTAL CENTER
Atlantic City, New Jersey 08405

by

Fire Research Section
National Bureau of Standards
U. S. Department of Commerce
Washington, D. C. 20234

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Fire Research Section
National Bureau of Standards
Washington, D. C. 20234

FOREWORD

This report was prepared by the Fire Research Section, National Bureau of Standards for the Federal Aviation Administration. The work effort was part of a program of the Engineering and Safety Division, Aircraft Development Service, Washington, D. C. Engineering liaison and technical review for this project were furnished by the Propulsion Section, Aircraft Branch, Test and Evaluation Division, National Aviation Facilities Experimental Center, Atlantic City, New Jersey.

ABSTRACT

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, $HC\ell$, 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 $HC\ell$ were also made using specific ion electrode techniques.

The elevated temperature thermal degradation of selected materials was studied in a number of ways including thermogravimetry and differential scanning calorimetry.

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

Of the materials tested, a number were found to possess good heat stability properties, and did not generate large quantities of smoke or high concentrations of the combustion products selected for analysis.

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INTRODUCTION

Purpose

This series of laboratory studies was undertaken to measure certain combustible characteristics of cabin interior materials used in aircraft. The scope of this work includes (a) measurement of the smoke and concentrations of certain potentially toxic gases produced by cabin furnishing materials under fire conditions, and (b) characterization of the thermal degradation of these materials at elevated temperatures. These studies are designed to help in understanding the incidence and propagation of fire and smoke in air transports, and to assist in providing a technical basis for defining criteria for fire safety standards.

Background

Regulatory safeguards for limiting 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 obtained information based on laboratory tests of the flammability and smoke characteristics of over 100 representative interior materials [1], as well as by means of 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 objectives of (1) providing measurements on the generation of smoke and decomposition products using a recently developed smoke test chamber [3], and (2) providing basic information on the thermal degradation and heat release properties of selected aircraft interior materials at elevated temperatures.

DISCUSSION

Material Identification

Qualitative identification of the major components of the materials prior to test was accomplished primarily by infrared absorption techniques using a Beckman Model IR-8 Infrared Spectrophotometer. 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) and poly (vinylidene chloride) polymers are difficult to detect specifically 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.

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 quantity 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 watts per square centimeter (2.2 Btu/ft^2 · s)* normal to the exterior surface of a 3 x 3 inch specimen and were performed under both flaming and nonflaming (smoldering) exposure. To induce open flaming in the former case, a small pilot (0.35 SCFH natural gas diffusion flame in a 1/16 inch 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 the sponsor and were tested using a typical section in the thickness supplied.

* 1 British thermal unit (Btu) = 1055 watt-second (W·s)

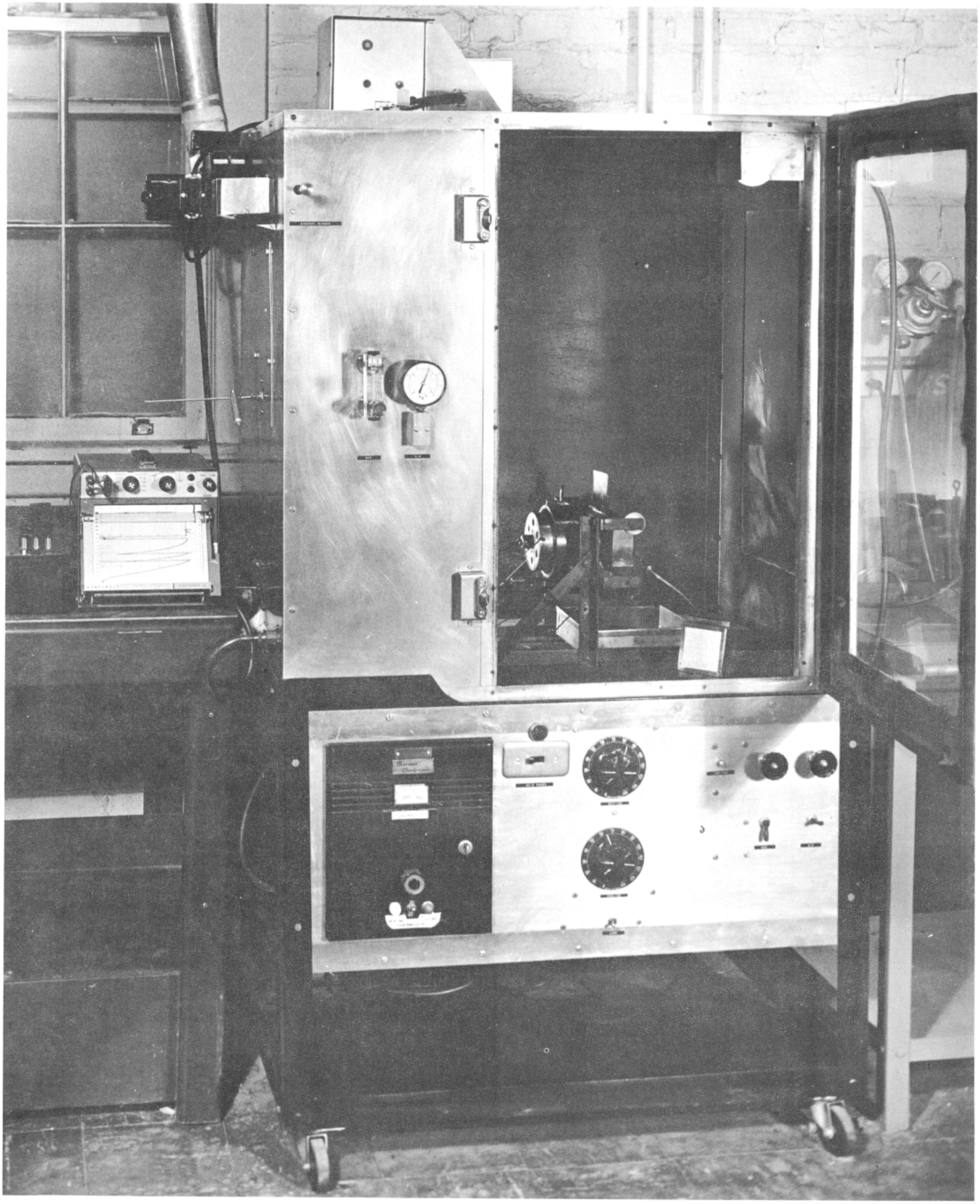


Fig. 1 Smoke Test Chamber

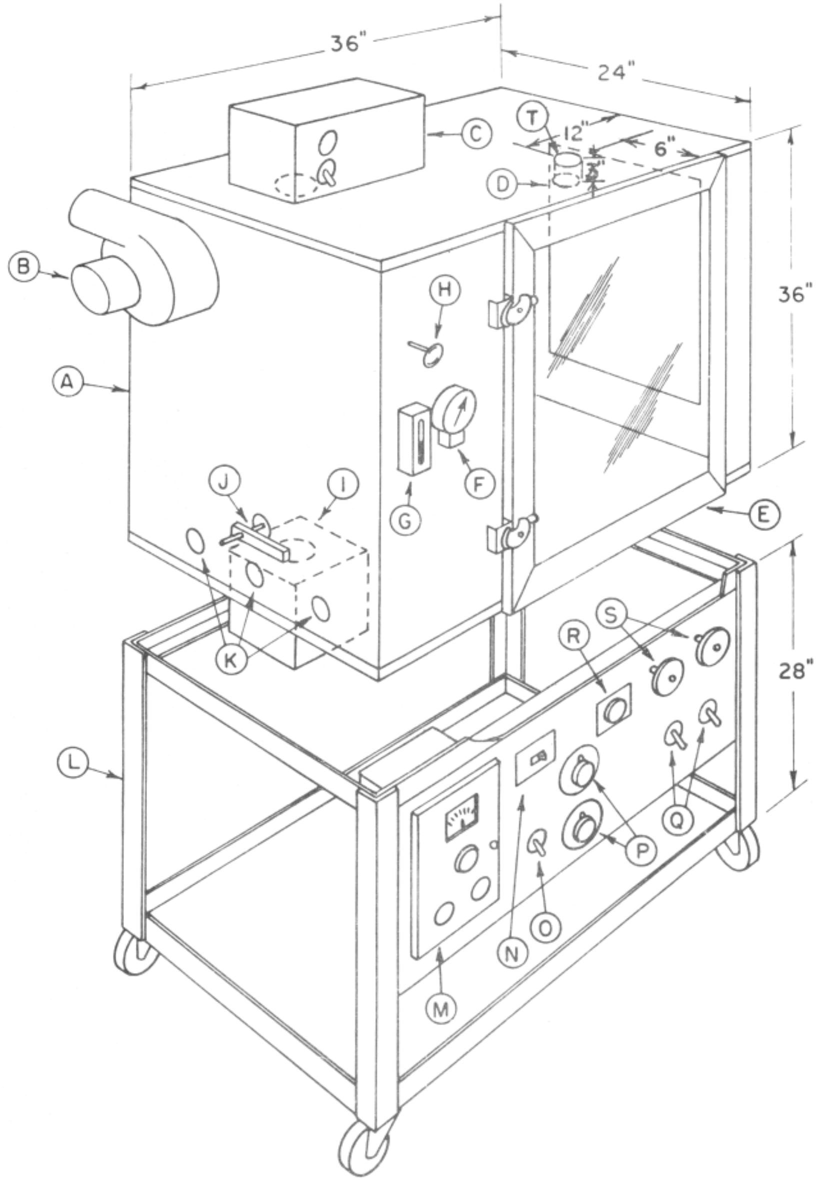


FIG. 2 – SMOKE CHAMBER ASSEMBLY

A-Chamber
B-Exhaust blower
C-Photometer light source
D-Blowout panel
E-Hinged door with window
F-Air pressure gage
G-Gas flowmeter
H-Blower and damper lever
I-Photometer

J-Pilot burner lever
K-Service openings
L-Support frame
M-Temperature controller
N-Main power switch
O-Internal light switch
P-Autotransformers
Q-Gas, air shut-off valves
R-Electric ignitor switch
S-Gas, air control valves
T-Gas sampling port

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, 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, $V = 18$ ft^3, $A = 0.0456$ ft^2, and $L = 3$ ft. 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-minute 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.

Gas Measurement

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]. Where $HC\ell$ was one of the products, in many cases the gas was also absorbed in water and analyzed by a chloride ion electrode. 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 inches below the top surface of the chamber (approximately 25 inches 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 search for CO, HCN, $HC\ell$, HF, SO_2, $NO+NO_2$, NH_3, $C\ell_2$ and $COC\ell_2$, 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 measure high concentrations of CO_2 or low concentrations of O_2, or to consider the type, size or concentration of smoke particles in toxicological terms. Information on the measuring range limits for the tubes used, and references to the toxic hazard limits of these gases are discussed in Appendix 1. For all materials which produced high concentrations of $HC\ell$ (greater than 500 ppm), a specific ion electrode was also used to provide a more accurate indication.

Thermogravimetry and Differential Calorimetry

Two complementary methods were explored for characterizing the elevated temperature thermal decomposition of materials: thermogravimetry, in which a specimen is continuously weighed as it is heated, and differential calorimetry, in which the magnitudes of exothermic and endothermic processes are measured as a function of increasing temperature. In this report reference is made to thermogravimetric analysis (designated TGA), differential thermogravimetric analysis (DTGA) and differential scanning calorimetry (DSC).

To measure weight loss as a function of temperature, an aluminum pan containing the specimen was suspended within an electrically-heated furnace by means of a wire attached to a sensitive weight transducer. See Fig. 3. The heating rate of the furnace was controlled at about 10 °C/min (18 °F/min) to provide sufficient time for the reactions on a 1-inch square specimen to be stabilized. The transducer, Statham Type UC 2 with Type UL 5 microscale accessory, had weight ranges of 3, 6, and 15 g and was accurate to within ±0.15 percent of full scale. It was mounted within an air-purged enclosure to protect it from the heat and gaseous decomposition products. Thermocouples, of No. 24 gage (0.020 inch) chromel-alumel wires, were placed immediately below the specimen pan to provide temperature measurement and control without affecting the weight determination. In addition to a record of weight as a function of time (and temperature), a simple differentiation circuit [5] was used to obtain a simultaneous continuous record of the derivative of the weight-time record.

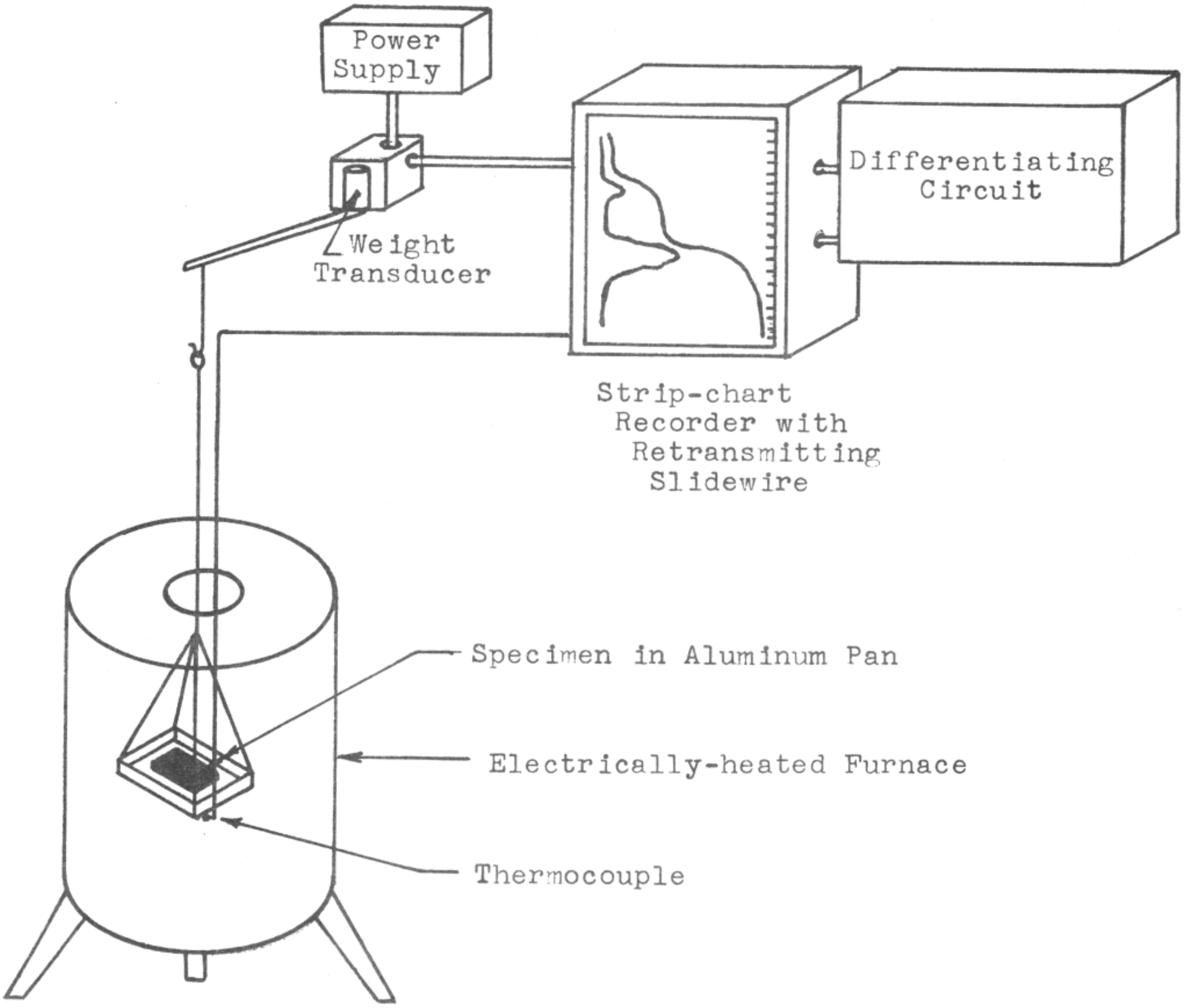


Fig. 3 Schematic of Thermogravimetric Analysis Apparatus

Calorimetric measurements were made on selected materials using a Perkin-Elmer Model DSC-1B Differential Scanning Calorimeter. A record of the exothermic and endothermic reactions occurring during physical or chemical changes in inert (N_2) atmospheres up to 500 °C (932 °F) were obtained at selected heating rates on samples weighing up to 20 mg.

Heat Release

As requested by the sponsor, a measure of the total heat release during flaming combustion of these materials was derived from the stack temperature rise data during radiant panel flammability tests [6] performed by FAA. This data was assembled to explore possible relationships between the total heat released in the radiant panel test and the growth of fires in cabins containing such materials. The radiant panel method involves the determination of the temperature rise within a stack placed over a 6 x 18 inch test specimen which is subjected to a 15-minute surface flammability test exposure, as compared to a completely noncombustible asbestos-cement specimen. In the standard flammability test, only the peak temperature rise is used in calculating a flame spread index. In this instance, the total area under the stack temperature versus time curve was also measured and was taken to be representative of the total heat release during flaming combustion.

TEST RESULTS AND ANALYSIS

Material Identification

Table I (Appendix 3) 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

Identification of the materials was based almost entirely upon infrared absorption spectrophotometry with the following results:

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% 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 tested rugs 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 included mainly glass fiber materials or a paper honeycomb sandwich.

Smoke Measurements

Smoke measurements are summarized in Table II (Appendix 4) 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) and were fairly reproducible. Smoke buildup curves for typical flaming and smoldering tests on selected types of materials are shown in Appendix 2.

A very 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 (lightweight). 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 Fig. 4 for all materials, and in Fig. 5 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. However, of the 22 fabrics, sheets and films, only 3 weighed more than 20 oz/yd^2 (0.068 g/cm^2). 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 6A, 6B and 6C comprise a complete histogram showing smoke and toxic gas concentrations for flaming and nonflaming exposures on each material based on the data in Table II (Appendix 4). Materials have been arranged according to classification by groups, by composition, and by generally increasing weight within each subgroup.

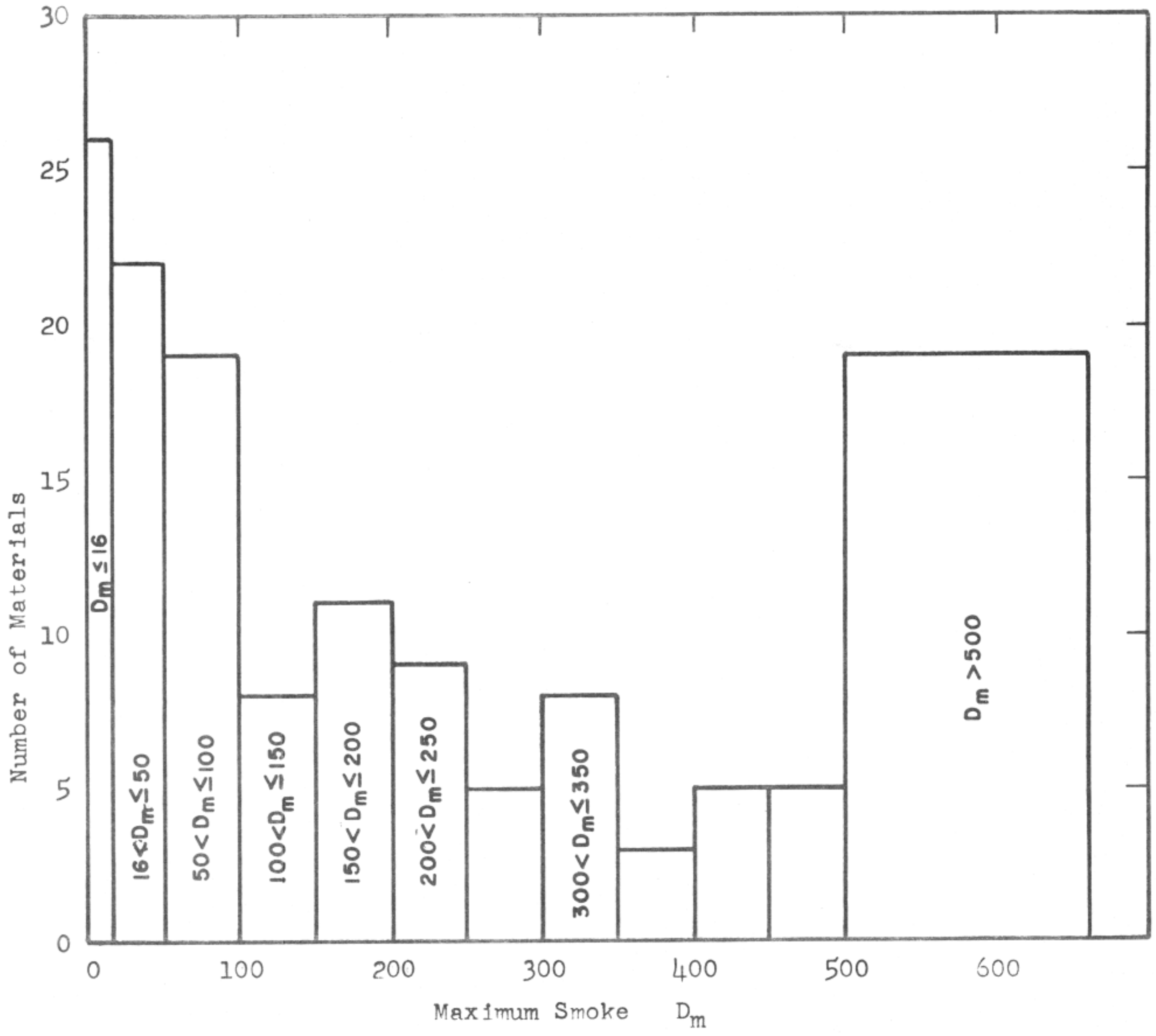


Fig. 4 Frequency Distribution of Maximum Smoke Values

Flaming Exposure -- 140 Materials

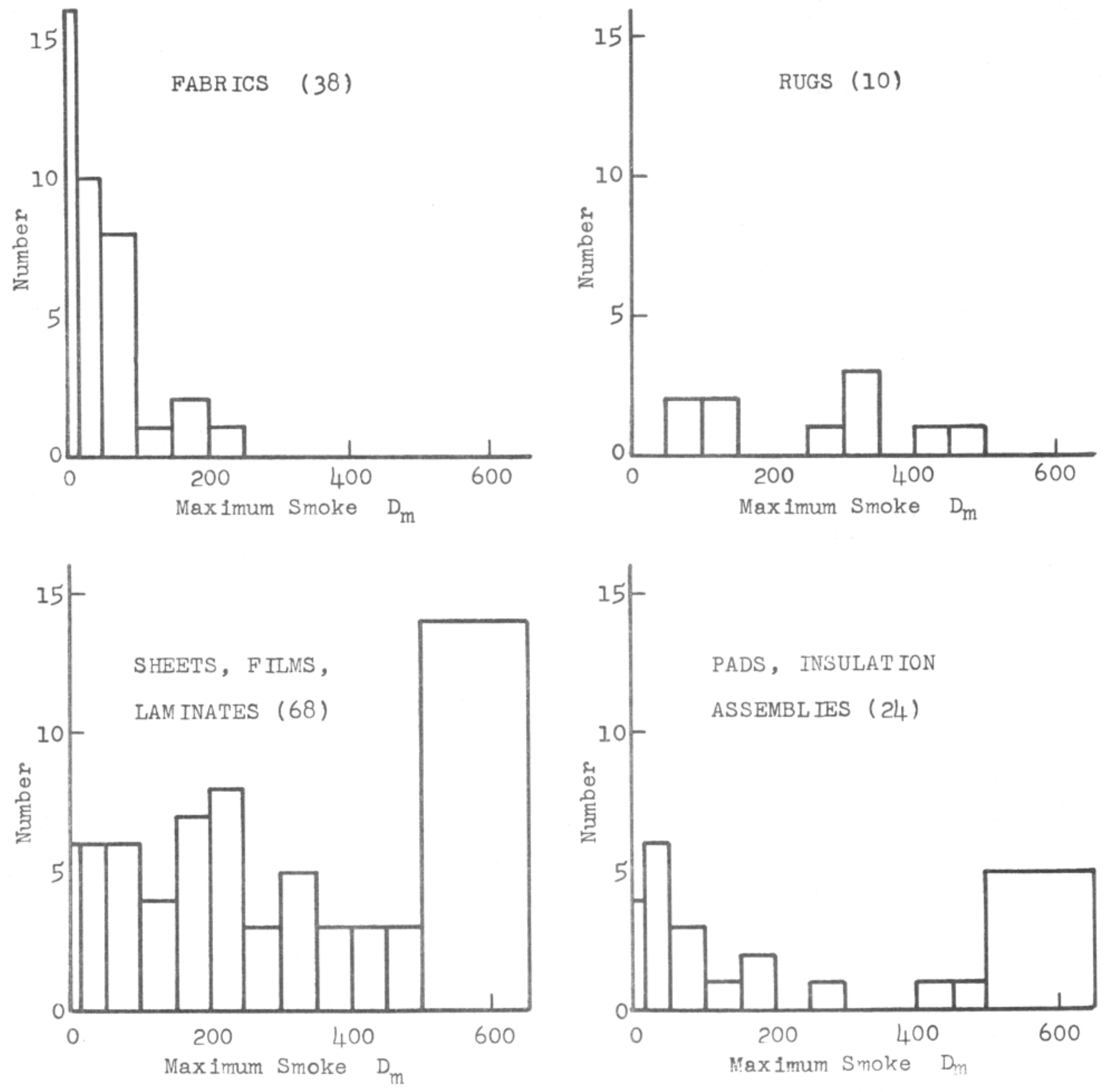


Fig. 5 Frequency Distribution of Maximum Smoke Values by Groups

Flaming Exposure -- 140 Materials

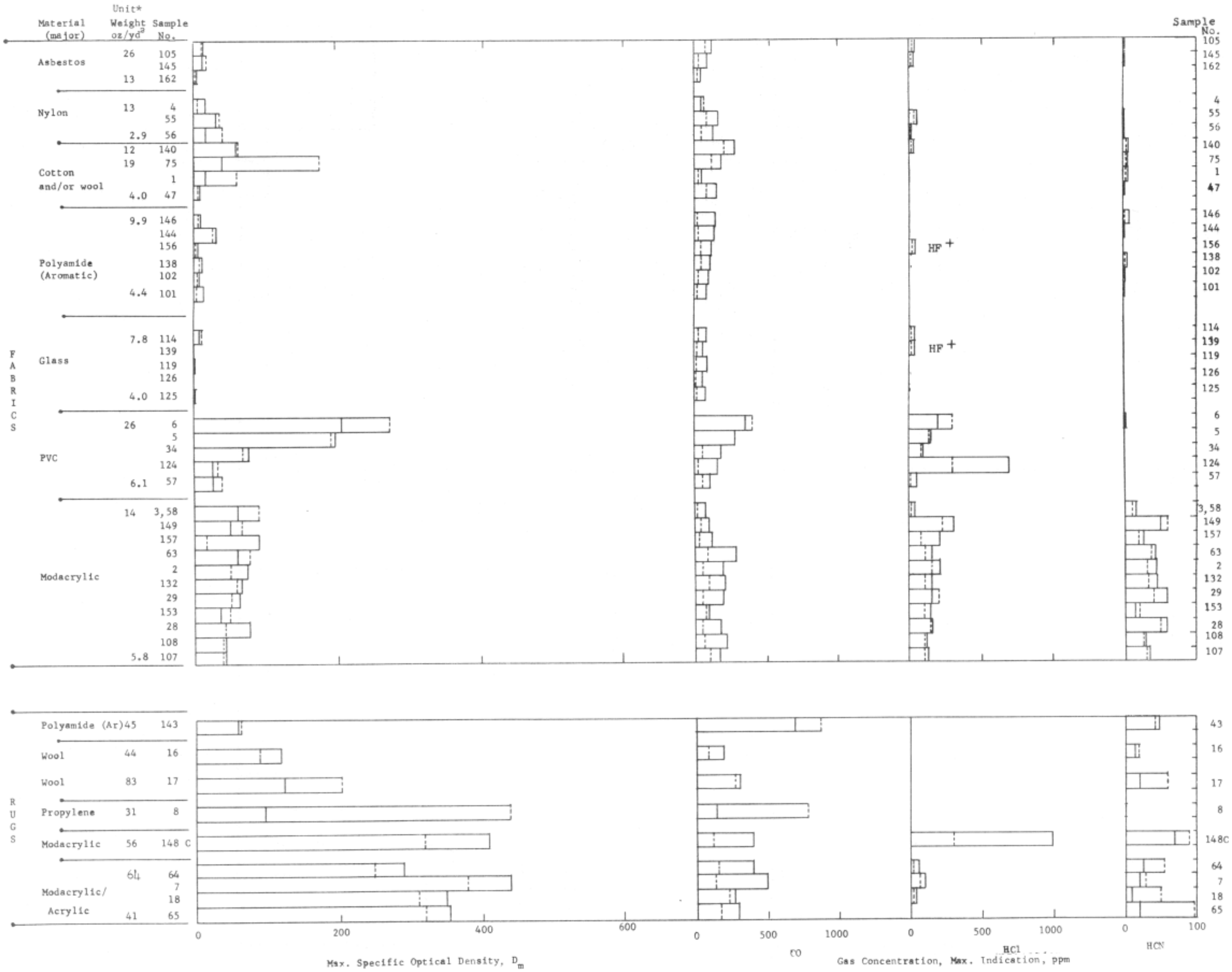


Fig. 6A SMOKE AND GAS CONCENTRATIONS FOR INDIVIDUAL MATERIALS - FABRICS, RUGS

] Flaming Exposure Value
] Nonflaming Exposure Value

* 1 oz/yd^2 = 3.39 x 10^{-3} g/cm^2

\+ Max. Indicated Concentrations of HF is Shown in HCl Column Where Latter was not Detected

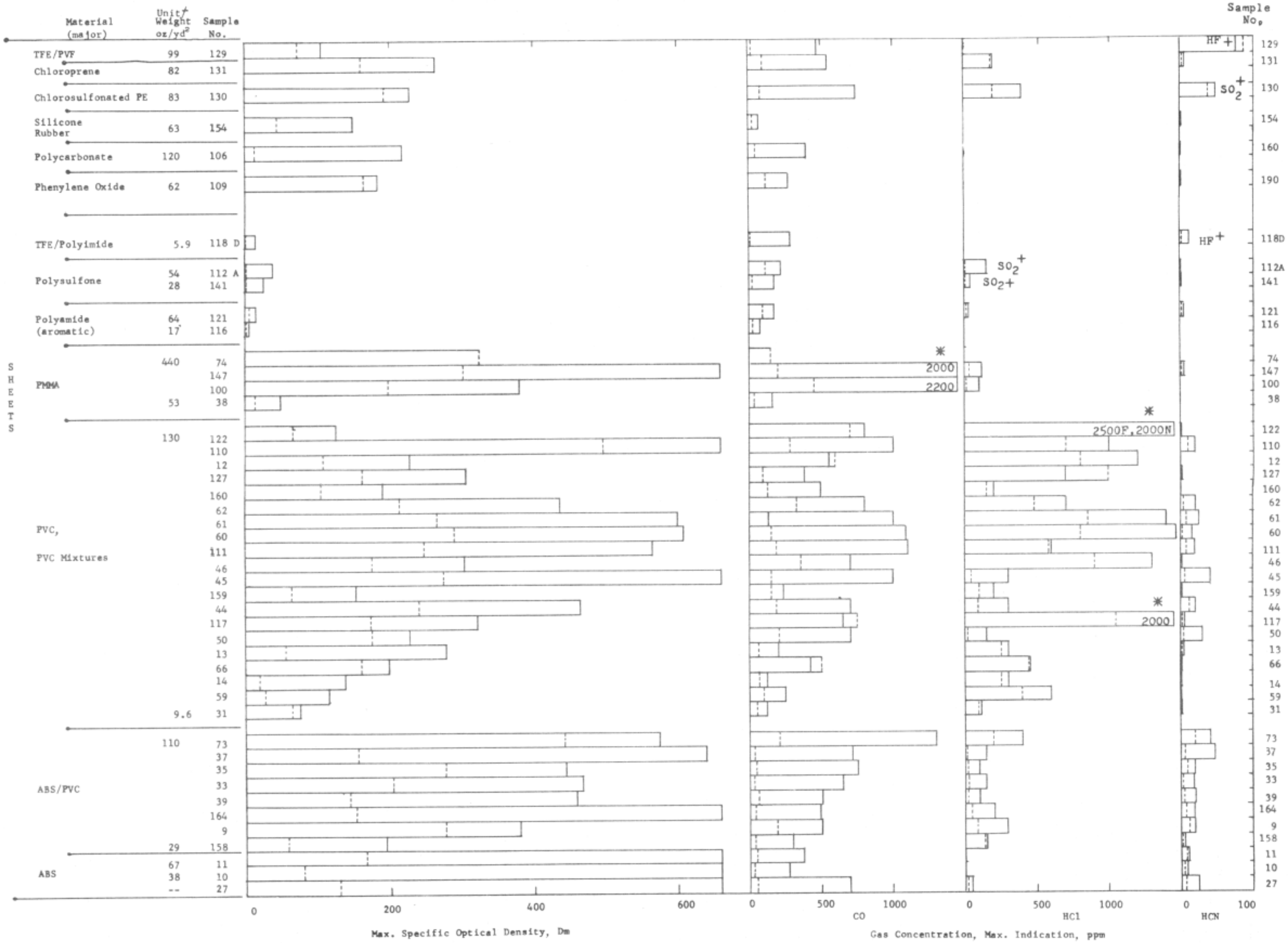


Fig. 6B SMOKE AND GAS CONCENTRATIONS FOR INDIVIDUAL MATERIALS - SHEETS

] Flaming Exposure Value

⁝ Nonflaming Exposure Value

* Numbers in Bars Indicate Values in Excess of Scale Values

\+ Max. Indicated Concentrations of HF and SO_2 are Shown in HCl or HCN Columns Where the Latter Were not Detected

† 1 oz/yd² = 3.39 x 10^{-3} g/cm²

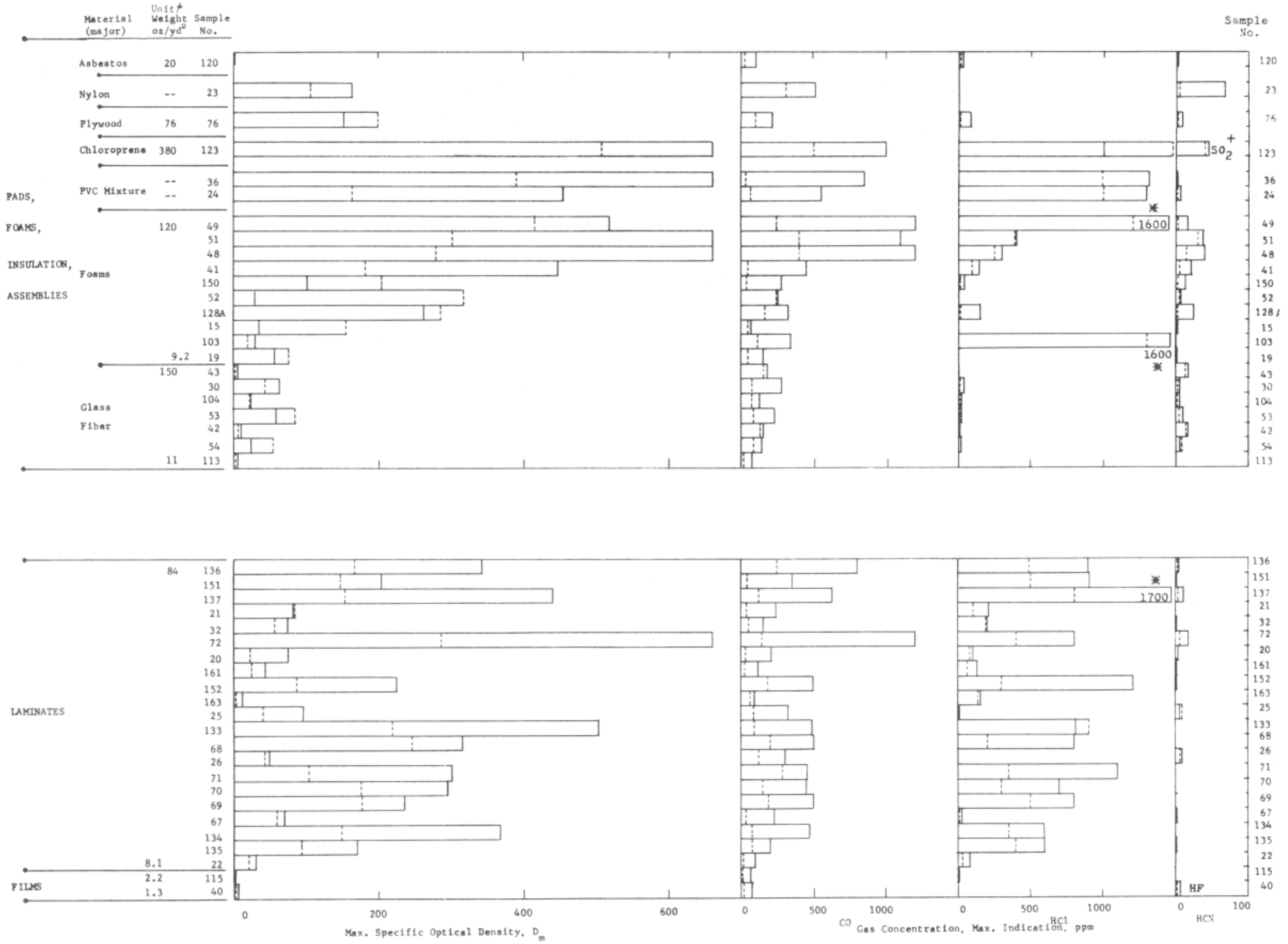


Fig. 6C SMOKE AND GAS CONCENTRATIONS FOR INDIVIDUAL MATERIALS - ASSEMBLIES, LAMINATES, FILMS

] Flaming Exposure Value
⁝ Nonflaming Exposure Value

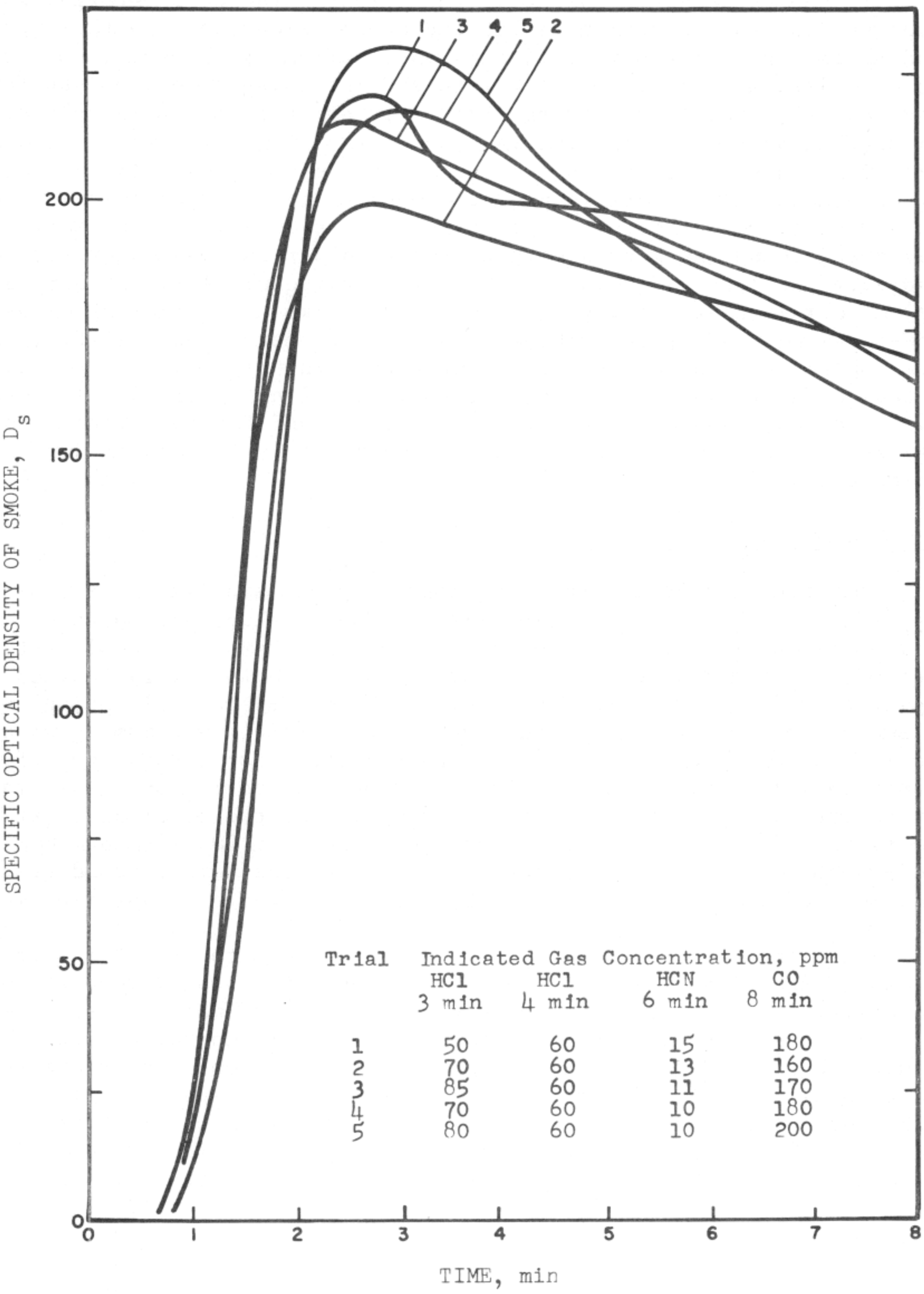
* Numbers in Bars Indicate Values in Excess of Scale Values
\+ Max. Indicated Concentration of SO_2 is Shown in HCN Column Where Latter was not Detected
‡ 1 oz/yd² = 3.39×10^{-3} g/cm²

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 naturally 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].

Gas Measurements

"Maximum" indicated concentrations of gases are listed in Table II (Appendix 4) 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 (greated 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, gas concentration was measured periodically. Particularly for components which change rapidly, therefore, the indicated gas concentration values may not necessarily be the true maximum values. For the materials tested, the highest indicated concentrations were 2200 ppm CO, 2500 ppm $HC\ell$, 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 order of magnitude 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 Fig. 7. This figure shows the 5 replicate smoke curves and a tabulation of indicated gas concentrations at specific times during each test. The measurement ranges were on the order of ±20% for CO and HCN and ±30% for $HC\ell$, and such variations may be considered typical of the maximum indicated concentration values under the test conditions.



Trial	Indicated Gas Concentration, ppm			
	HCl 3 min	HCl 4 min	HCN 6 min	CO 8 min
1	50	60	15	180
2	70	60	13	160
3	85	60	11	170
4	70	60	10	180
5	80	60	10	200

Fig. 7 Reproducibility of Smoke and Gas Concentration Indications
Sample No. 44 (PVC/PVA/ABS) Nonflaming Exposure

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 SO_2 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[7] 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 [8].

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 two-minute 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 [9, 10]. 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 and smoke-filled conditions. Figure 8 shows the indicated

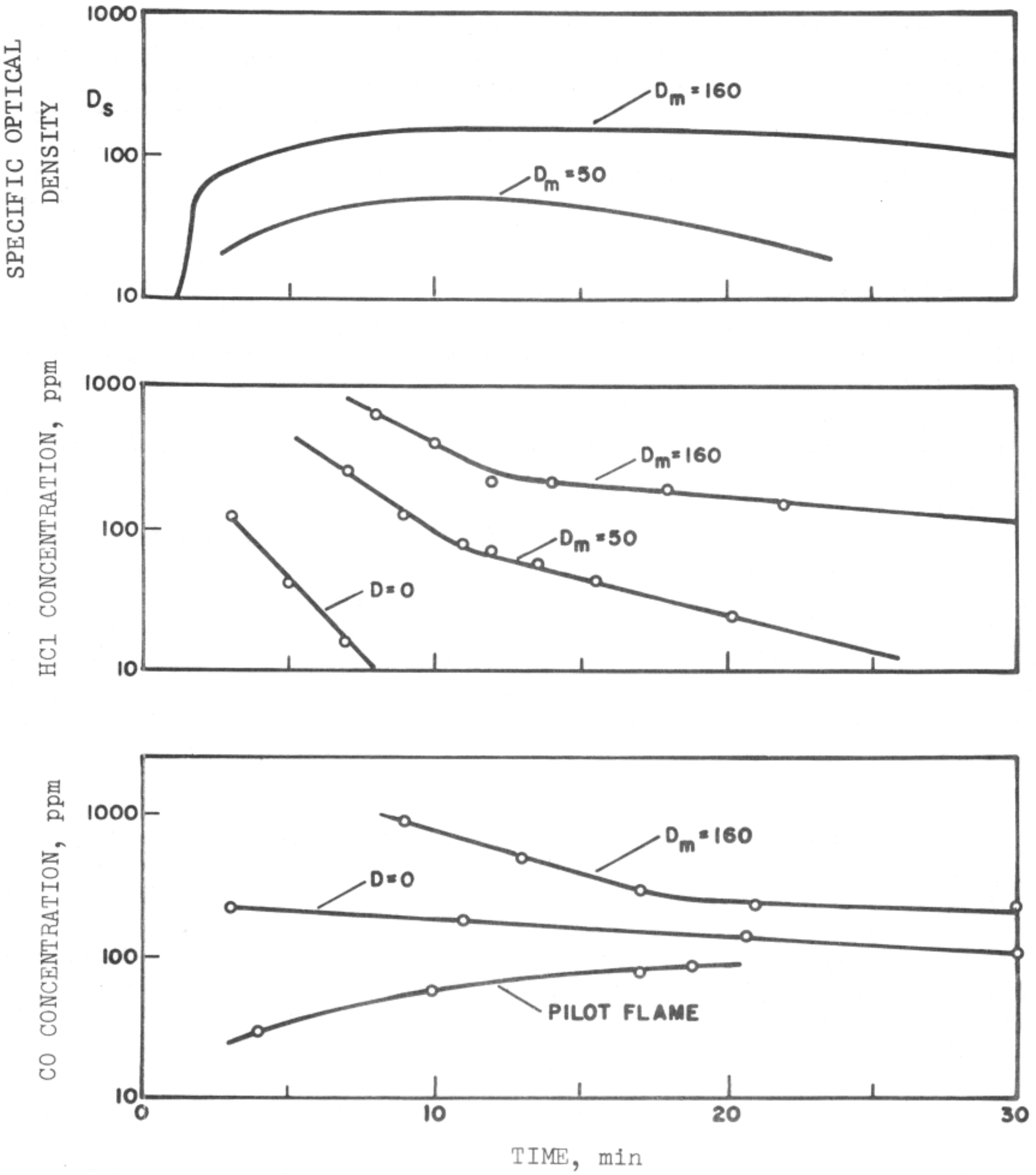


Fig. 8 Comparative Decay in HCl and CO Concentrations for Several Smoke Density Levels

Top: Smoke, nonflaming exposure, 2 selected PVC/PVA materials
Center: HCl Concentration. Prior to taking readings, 220 cm^3/min of HCl was introduced in chamber over 3-min period
Bottom: CO Concentration. Prior to taking readings, 190 cm^3/min of CO was introduced in chamber over 3-min period

concentrations of $HC\ell$ and CO. In the tests involving smoldering specimens, the gas concentration levels are higher because a portion of the gas is introduced by combustion. The decay rates are also higher. A similar decay would be expected to exist following the generation of $HC\ell$ at this level of concentration from a specimen during test exposure.

The effect of a pilot flame on the buildup of CO in flaming exposure tests is shown in the lower figure.

Thermogravimetry and Calorimetry

The thermal decomposition of three selected materials at elevated temperatures is shown in Figs. 9, 10, 11 in terms of weight vs. temperature (TGA), rate of weight loss vs. temperature (DTGA) and the exothermic and endothermic reactions vs. temperature (DSC). Although the DSC is intended for quantitative calorimetry, the calculations were not made for the few selected materials of this preliminary study.

For an acrylonitrile-butadiene-styrene (ABS) copolymer, Specimen No. 10, shown in Fig. 9, the rate of weight loss increased steadily reaching a peak at approximately 350-370 °C (662 to 698 °F) and then decreased gradually up to 500 °C (932 °F). The DSC scan showed a very substantial exotherm extending over a wide temperature range (170 to 440 °C (338 to 824 °F) with a peak at approximately 380-390 °C (717 to 734 °F).

For a plasticized poly (vinyl chloride) sheet, Specimen No. 36, shown in Fig. 10, there was a peak rate of weight loss at about 320 °C (608 °F) followed by additional, but less pronounced weight losses at about 400 °C (752 °F) and 500 °C (937 °F). The DSC scan showed a strong endotherm in the temperature range 265 to 320 °C (509 to 608 °F) followed by a strong exotherm to 335 °C (635 °F).

For a melamine and urea formaldehyde laminate, Specimen No. 26, shown in Fig. 11, there were two significant weight loss ranges at average temperatures of about 320 °C (608 °F) and 500 °C (932 °F). The DSC scan showed an endotherm in the temperature range 40-160 °C (104-320 °F) and an exotherm in the temperature range 160 to 420 °C (320 - 799 °F) with a maximum near 330 °C (626 °F).

Heat Release

As a measure of the total heat released during the radiant panel flame spread test (conducted by FAA), the area under the curve of stack thermocouple temperature versus time in excess of that for noncombustible asbestos-cement board, was measured. These values, expressed in Btu, are listed in Table III, which also lists the maximum rate of heat release measured during the same flame spread test. The magnitude of these values depend upon the specimen thickness, upon the extent of ablation, char formation and similar processes, upon chemical treatments, and upon the ability of a coating to seal and protect the surface from

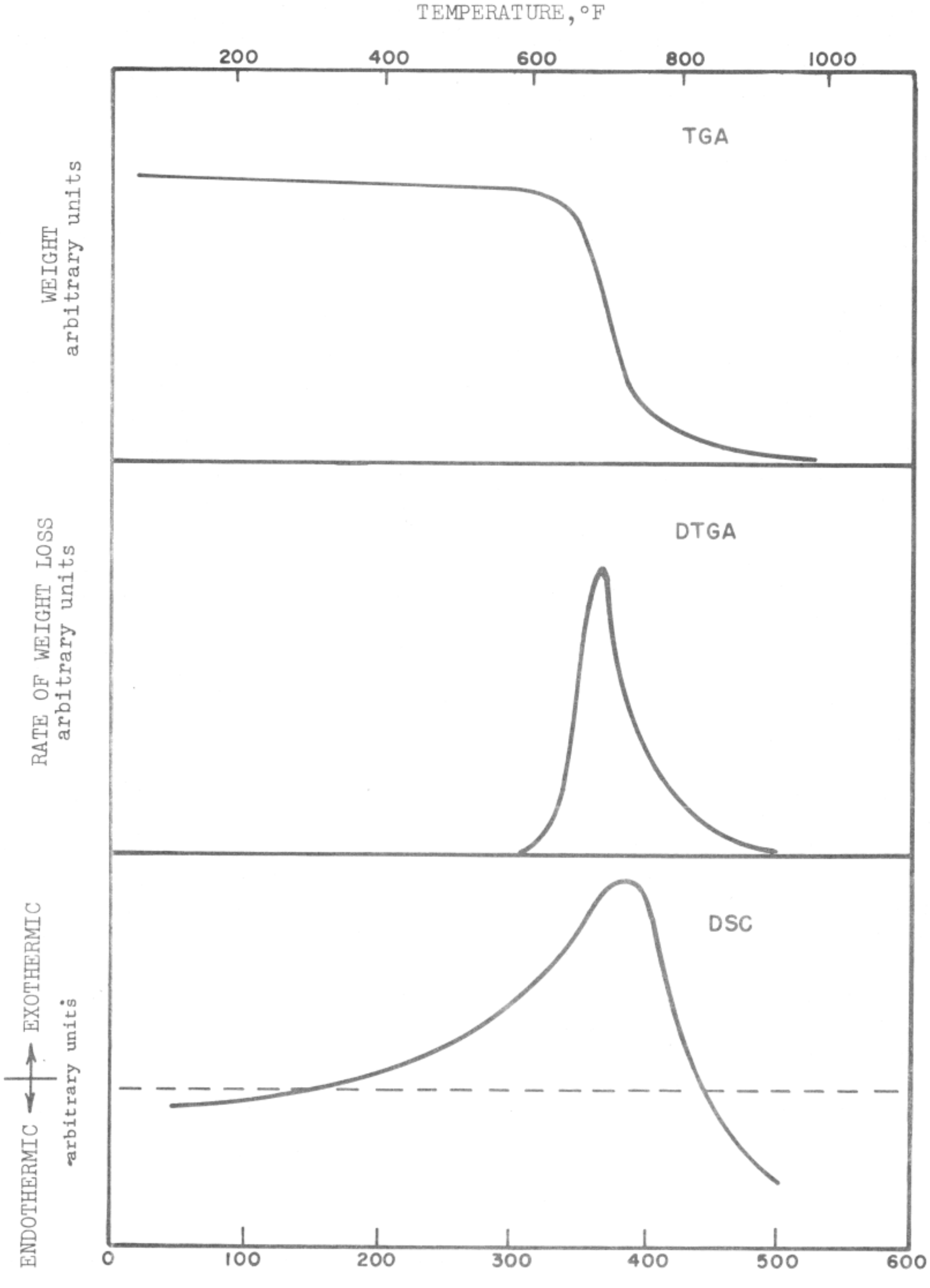


Fig. 9 Thermal Decomposition of Sample No. 10
Acrylonitrile/Butadiene/Styrene (25:10:65) Sheet

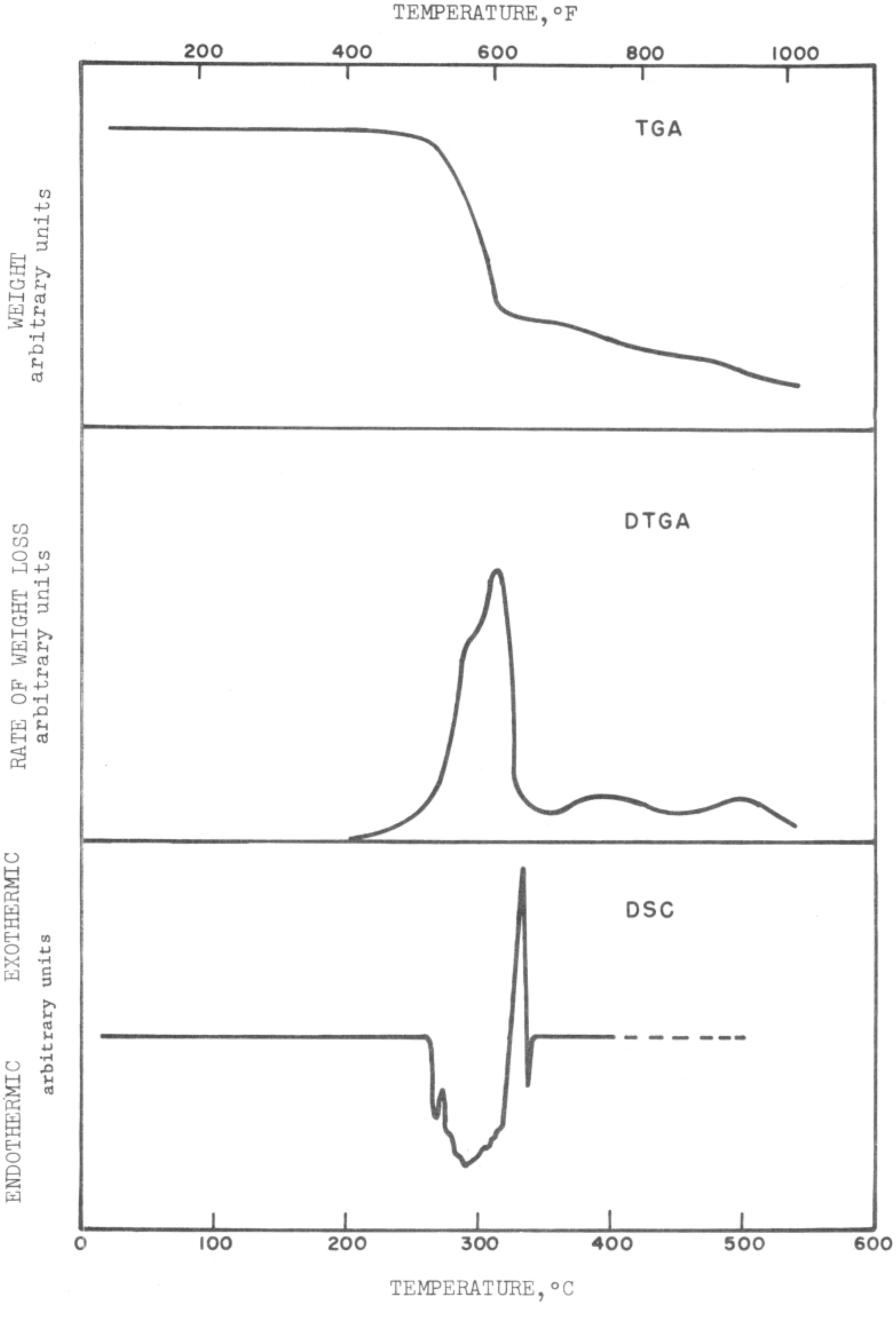


Fig. 10 Thermal Decomposition of Sample No. 36
Plasticized Poly(vinyl chloride) Sheet

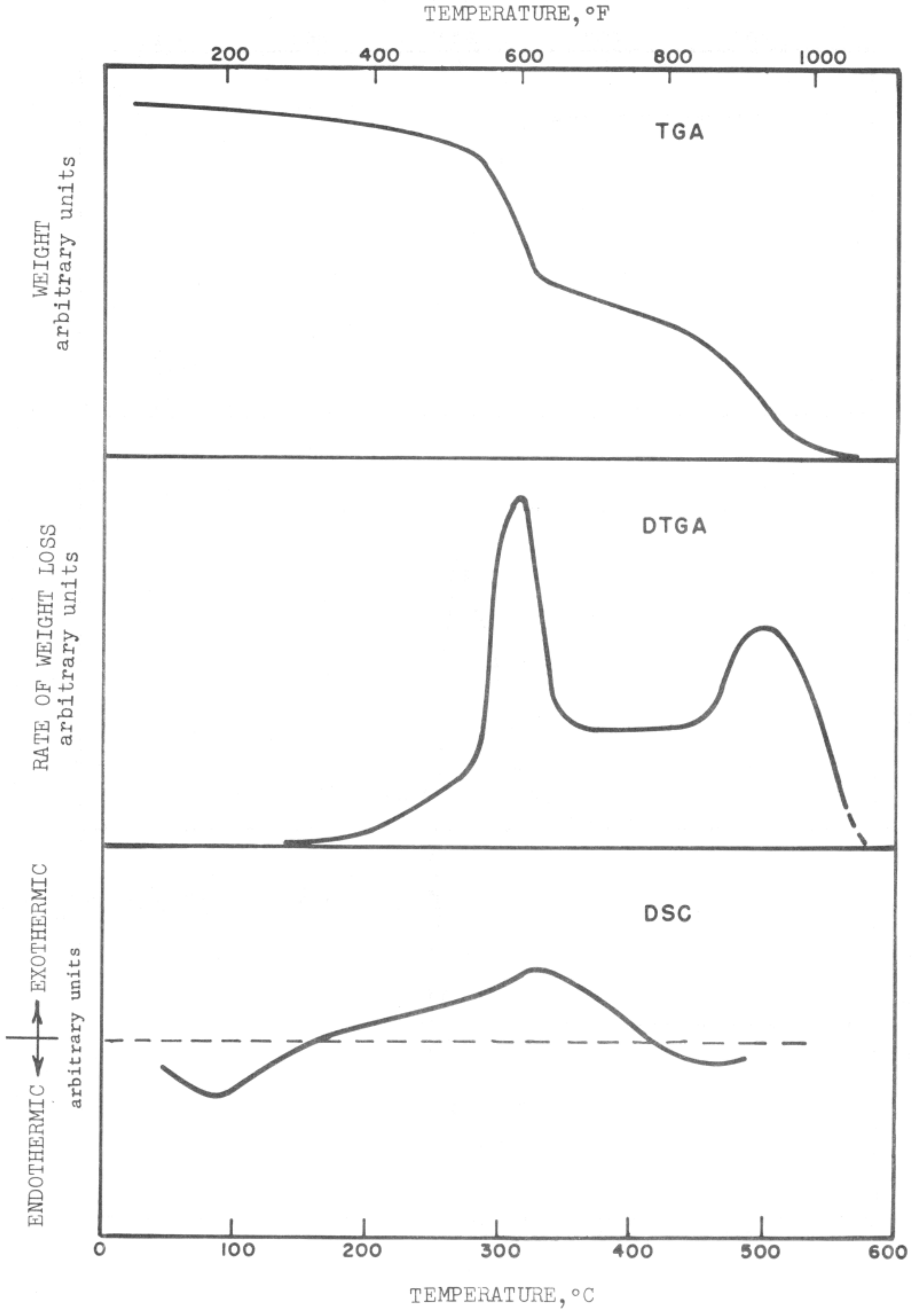


Fig. 11 Thermal Decomposition of Sample No. 26
Melamine/Urea Formaldehyde Laminate

TABLE III

TOTAL HEAT RELEASE AND MAXIMUM HEAT RELEASE RATE
FAA Radiant Panel Data

Material No.	Total Heat Release Btu*	Max. Heat Release Rate Btu/min*	Material No.	Total Heat Release Btu*	Max. Heat Release Rate Btu/min*
1	130	170	39	470	130
2	39	50	40	2	< 5
3	250	175	41	460	250
4	52	41	42	30	< 5
5	300	220	43	52	10
6	300	220	44	310	120
7	1010	480	45	330	130
8	560	330	46	620	80
9	410	120	47	150	30
10	690	310	48	730	200
12	550	65	49	720	170
17	940	140	51	1530	210
18		240	52	190	210
19	140	140	53	80	40
20	77	55	54	100	40
21	250	60	55	130	40
22	58	< 5	57	240	30
25	320	210	58	300	50
26	170	120	59	190	20
28	26	20	60	550	120
29	120	40	61	340	120
30	730	150	62	670	50
31	240	40	63	130	50
32	130	30	64	510	190
33	610	160	65	800	330
34	39	110	66	230	140
35	620	180	67	64	20
36		40	68	270	80
37		40	69	110	60
38	1250	720	70	39	95

*1 Btu = 1055 W·s; 1 Btu/min = 17.6 W

TABLE III (Continued)

TOTAL HEAT RELEASE AND MAXIMUM HEAT RELEASE RATE
FAA Radiant Panel Data

Material No.	Total Heat Release Btu*	Max. Heat Release Rate Btu/min*	Material No.	Total Heat Release Btu*	Max. Heat Release Rate Btu/min*
71	64	30	130	480	40
72	540	90	131	440	40
73	1340	190	132	100	70
74	>2000	950	133	280	170
76	530	70	134	350	180
101	97	10	135	77	50
102	220	30	136	420	60
103	490	50	137	390	60
104	20	25	138	19	10
105	0	0	140	120	20
108	13	20	141	220	20
109	830	160	142	64	70
110	1570	220	143	170	20
111	1030	210	144	90	20
112	600	90	145	0	0
113	50	5	146	110	20
114	0	0	147	4650	500
115	0	0	148A	630	200
116	240	30	149	0	0
117	130	60	150	170	220
118A	50	10	151	290	100
119	77	10	152	760	90
120	0	0	153	60	80
121	220	30	154	600	90
122	580	60	155	100	70
123		670	157	110	30
124	13	10	160	460	70
125	90	10	161	110	40
126	0	0	161X	90	100
128A	220	220	163	20	10
129	370	40	164	720	120

* 1 Btu = 1055 W·s; 1 Btu/min = 17.6 W

progressive decomposition.

The results show that the rate of heat release ranged from 0 up to 950 Btu/min, and the total heat released was as high as 4650 Btu. For the materials tested, approximately one-third released 100 Btu or less

In general, the thicker the material, the greater the heat released, but not in direct proportion Certain materials, notably glass fiber fabrics and insulation, and other lightweight films and fabrics released very little heat under the standard radiant panel test exposure. Polyvinyl chloride and other chlorinated materials were noteworthy in their flame-inhibiting action which reduced or prevented the release of much of the available heat.

For thin materials, the type of backing or substrate and its thermal properties are important in governing flame spread behavior and heat release [11]

Scaling Factors

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 inch, the test specimen was limited to a thickness of 1 inch by 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 Fig. 12. The optical density level through which a lighted exit sign may be seen can vary over wide limits depending on the 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 Fig 12, 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].

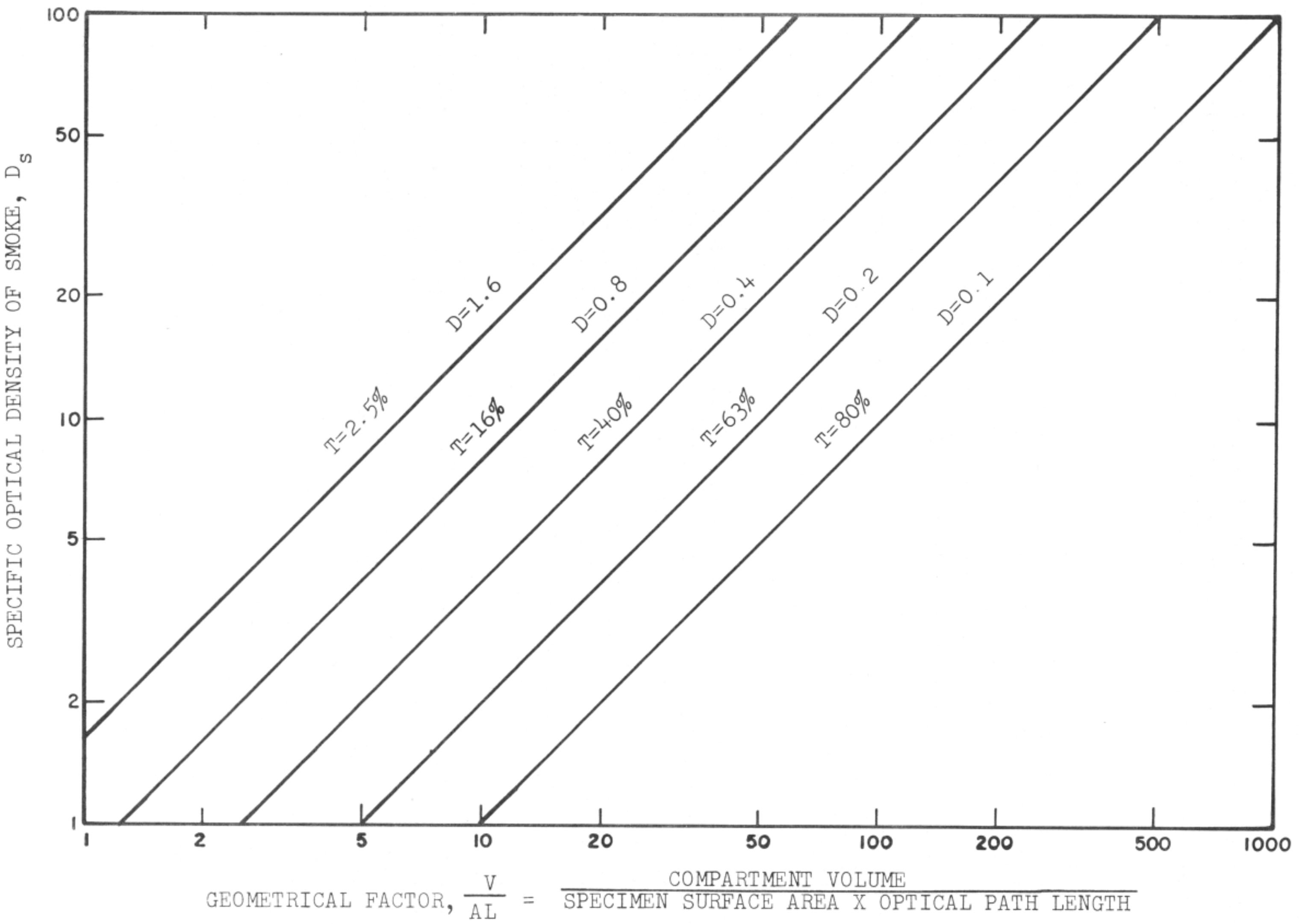


Fig.12 Specific Optical Density vs Geometrical Factor For Five Selected Light Transmission Values

Using this figure, sample computations have been made in Table IV 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% (optical density 0.4), and an aircraft cabin has a volume of 10,000 ft^3 within which smoke is uniformly dispersed, then Table IV 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 Table II, it may be noted that the time periods to attain a critical specific optical density of 16 ranged from 0.2 to over 20 minutes.

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

The indicated concentrations of gaseous products listed in Table II represent values measured at the sampling location and are associated with the prescribed exposure conditions on a specimen of given exposed area (2-9/16 inches square) within a totally enclosed chamber of 18 ft^3 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

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

TABLE IV

Critical (Projected) Surface Area of Material Burned in 10,000 ft^3 Volume (for optical density = 0.4)

Specific Optical Density D_s	$\frac{V}{AL}$ (for OD = .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

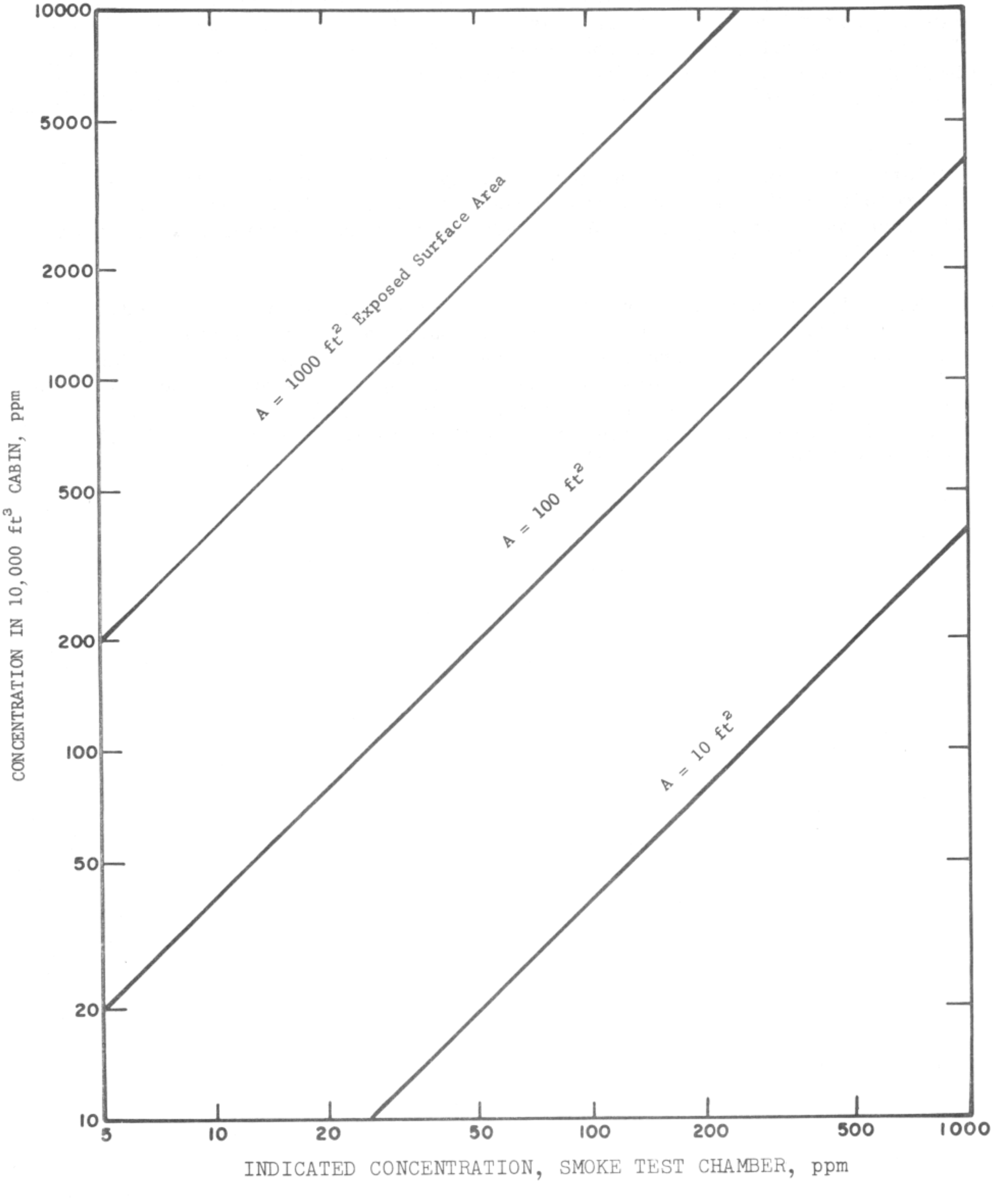


Fig. 13 Gas Concentration in 10,000 ft^3 Cabin Based on Indicated Concentration in Smoke Test Chamber

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 ft^3 cabin is shown in Fig 13 for a series of lines corresponding to surface areas of 10, 100 and 1,000 ft^2.

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 $HC\ell$, 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.

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 decomposition and heat release rates at elevated temperatures, and in their production of smoke and potentially toxic products under simulated fire conditions. Under the conditions studied, certain materials have good heat stability properties and do not generate large quantities of smoke or high concentrations of the gaseous products selected for analysis.

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 on page 5, the specific optical density of smoke measured in the laboratory may be extrapolated to cabin volumes and surface areas 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.

RECOMMENDATIONS

Based upon the work described in this report, and the needs of the Federal Aviation Administration for establishing fire safety standards, it is recommended that:

1. The NBS laboratory test method be used for measuring the optical density of smoke produced by burning aircraft interior materials. Both active flaming and nonflaming (smoldering) exposure conditions should be employed. The selection of the most meaningful smoke criterion, e. g., total smoke accumulation, maximum rate of smoke accumulation, or the time period to a critical optical density -- should be based on information and/or judgments of the operational conditions within actual aircraft.

2. Concurrent measurements of the concentrations of potentially toxic combustion products should be made. Where precision is not of primary importance and interferences (by other gases, high temperature, etc.) are absent, calibrated commercial colorimetric tubes may be used. However, additional studies should be undertaken to establish the accuracy and acceptable conditions for using such tubes. Also, other methods which may provide more accuracy and convenience in the measurement of combustion products should be investigated.

3. Additional studies be undertaken to establish and standardize laboratory methods for measurement of the heat release properties of materials.

4. The laboratory results on smoke production and the evolution of combustion products be verified by large-scale (model) tests with typical materials.

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b. MSA Colorimetric Gas Detector Tubes, Mine Safety Appliances Co., Pittsburgh, Pa.
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APPENDIX 1

GAS ANALYSIS

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 I-1. 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 non-uniformity 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 & vapors are not adsorbed by the pre-cleaning 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 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 probable 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 its 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. [12].

TABLE I-1

MEASURING RANGE OF COLORIMETRIC INDICATOR TUBES AND TOXICOLOGICAL DATA FOR SELECTED GASES

		CO	CO_2	$HC\ell$ Type A	$HC\ell$ Type B	HCN	NO_2	NO+ NO_2	NH_3	$C\ell_2$	$COC\ell_2$	HF	SO_2
Indicator Tube Data													
Nominal Range, Lower	ppm	10	-	2	2	2	0.5	0.5	25	0.2	0.25	0.5	5
Upper	ppm	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. **	ppm	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. Cincinnatic. Ohio 45202 (1966 edition)

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

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 [13]. The system consists of an asbestos plug which serves as a flow-limiting device [14], and a mixing chamber as shown on Fig. 1.1. Tubing to the asbestos flowmeter is 1 mm ID Teflon tubing to minimize dead volume. The pressure regulating cylinder was filled with concentrated H_2SO_4 for metering the HCℓ gas. 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 cm^3/min can be achieved with good long term reproducibility.

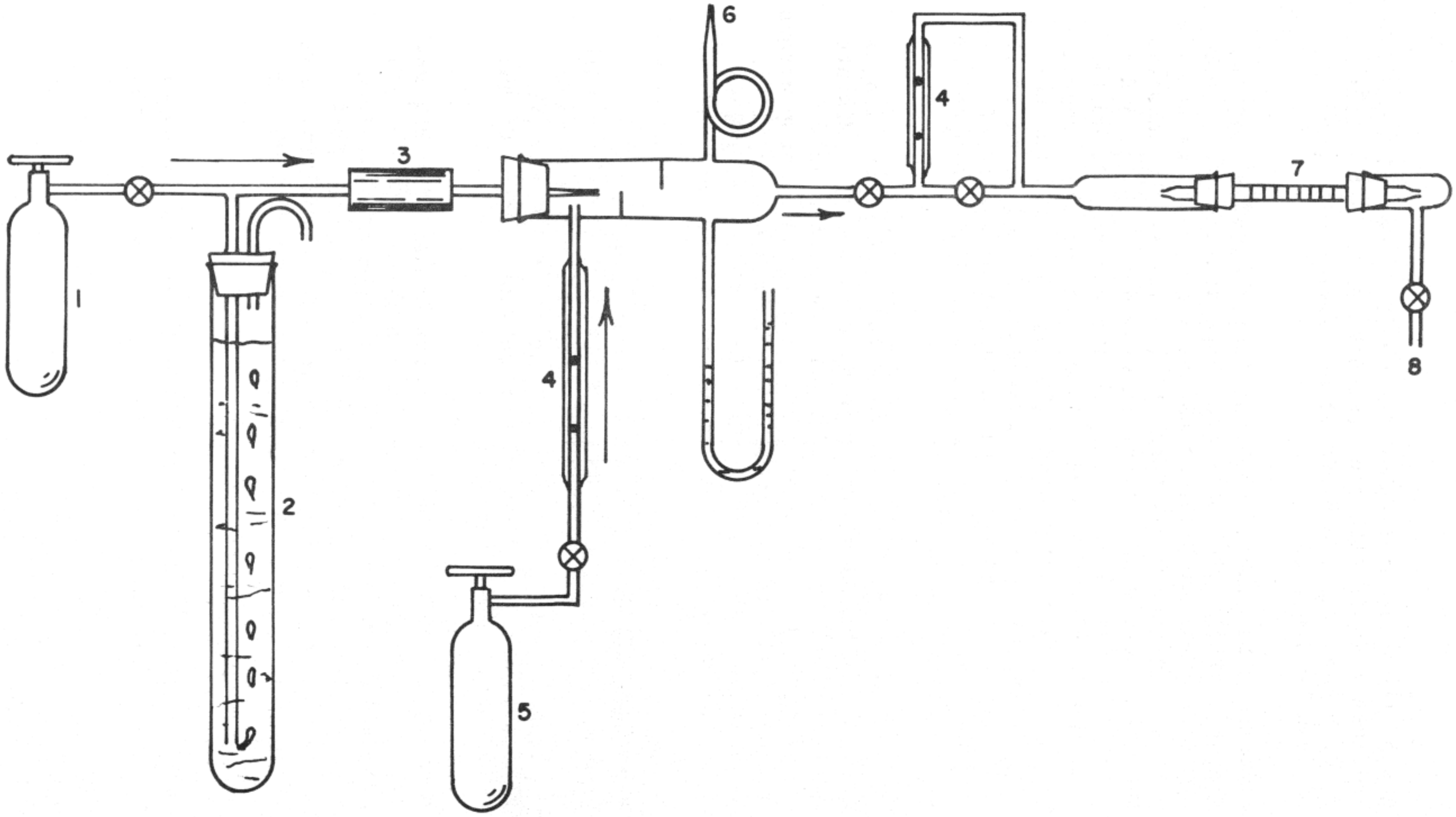
The degree of dilution of pure HCℓ from the tank was controlled by the asbestos plug and the diluting gas metered by a rotameter. Mixture concentration could be varied from 10 to 1000 ppm. A needle valve controlled the flow rate to the indicator tube. The pressure drop across the colorimetric indicator 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 midget 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 concentrations. Both HCℓ and HCN systems were very stable and consistent.

A static method using a FEP Teflon 5-mil-thick collapsible bag was used to generate low concentrations of non-reacting gases. Under this arrangement, the sample gas was deposited by a gas-tight microsyringe and diluted with air or other gases from a one-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.

Specific Ion Electrode

A permeable membrane electrode for chloride ions(after Pungor) was described recently [15] and was used in a system to determine the



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

Fig. 1.1 Flow Dilution and Calibration Arrangement

$HC\ell$ 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 cm^3 gas sample. For lower concentrations, a larger sample must be used.

In practice, the highly water-soluble $HC\ell$ gas and vapor in the 100 cm^3 sample was totally absorbed when the sample flowed at a rate of 100 cm^3/min through Teflon tubing (5.3 mm i.d.) containing about 40 mg of loosely packed glass wool wetted with 0.1 cm^3 water. The exposed glass wool was carefully transferred to a Teflon cup of small internal volume. Water was added to make a total solution of 1 cm^3 before insertion of the specific ion electrode, and a low-leakage, small-diameter-tip, conventional calomel-$KC\ell$ 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. Fig. 1.2 shows the calibration curve of emf in mV and $HC\ell$ concentration in ppm calculated on the basis of a 100 cm^3 gas sample absorbed in a 1 cm^3 solution. The curves were based on measurements made with solutions of known $HC\ell$ 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 [15]. In most fire gas or smoke chamber analyses this problem would not arise. In cases where the concentration of a 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 I-2 shows the type of indicator reagents used in the detector tube. 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 removed. 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 $HC\ell$, HCN and CO. Except for H_2S which apparently poisons the reactive surface in the $HC\ell$ tube, other interferences did not significantly alter the usefulness of those colorimetric tubes used in the present smoke chamber study.

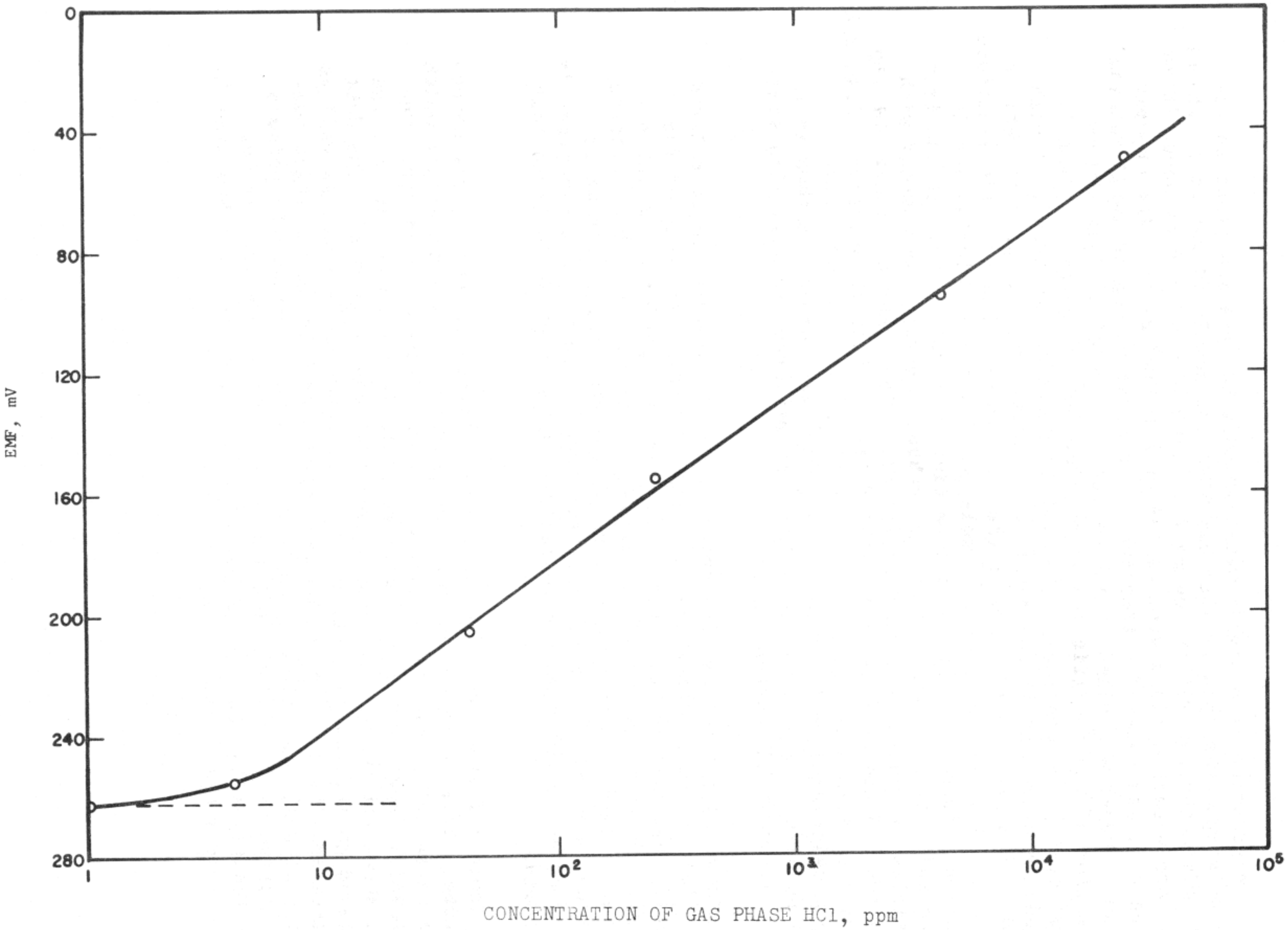


Fig. 1.2 Measured Emf as a Function of HCl Concentration in Gas Phase Based on HCL in a 100 cm^3 Sample Absorbed by 1 cm^3 of Water

TABLE I-2 INTERFERING COMPONENTS ON COLORIMETRIC TUBES*

Tube	Nominal Conc. Range ppm	Indicating Reagents	Interfering Components	Non-Interference
** $HC\ell$ Type A	2 - 30	Organic Metal Salt to react with $C\ell$	$H_2S > 20$ ppm, no $HC\ell$ sensitivity. $(C\ell_2, NO_2, NO) \geq HC\ell$, reading will be low $HF > 3 \times HC\ell$, reading will be high $H_2O > 70\%$ RH reading will be low $H_2O < 30\%$ RH reading will be high	HCN, CO, SO_2, SO_3
$HC\ell$ Type B	2 - 500	Congo red on beaded alkali salt	Any strong acid gas	
** HCN	2 - 150	Hg salt to release acid gas	$H_2O > 90\%$ RH $NO_2 > 50$ ppm $NH_3 > 1000$ ppm $HC\ell > 5000$ $H_2S > 300$ $CO > 5000$ $SO_2 > 200$ Other acid gases in high concentrations (above adsorption limit of precleaning layer)	
** CO	10 - 3000	Iodine Pentoxide Selenious Dioxide Sulfuric Acid	Saturated and unsaturated Hydrocarbons > 4000 ppm Hydrocarbons to CO ratio > 30.	H_2O, $HC\ell$, and HCN adsorbed by precleaning layers (Watch precleaning layer saturation by color change)
NH_3	25 - 700	Gold Chloride	Aliphatic Amines $H_2S > 50$ ppm	Hydrocarbons
HF	1 - 15	Alizarin-Zirconium Complex	None known Specific for HF	$HC\ell$, SO_2, NO_2, CO
$NO+NO_2$	0.5 - 10	Diphenylbenzidine	$\frac{HC\ell}{NO_2} > 270$ $\frac{C\ell_2}{NO_2} > 2$	
SO_2	5 - 1500	Iodate	Reducing Compounds	

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*Data based on manufacturer's information.

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

Table I-3 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. 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 [12], the present results were based on the observation of one individual only. With the exception of the type B $HC\ell$ tube which was +90% in error, all other errors fell within a ±20% range.

TABLE I-3 COLORIMETRIC INDICATOR TUBES

Basic Data (supplied by Mfr.)				Calibration Data (NBS)						
				Packing Length		Transition Zone		Concentration		
Tube	Concentration Range	Sample Volume	Sampling Rate	Precleaning	Indicating	Length	Error	Actual	Indicated‡	Error
	ppm	cm^3	seconds per stroke	mm	mm	mm	%	ppm	ppm	%
HCℓ	2- 30	1000	11	30	60	4	±7	5		
Type A								25	30	+20
								86	95	+10
	10- 300*	100						200	180	-10
HCℓ	2- 100	500	30	0	65	2	±3			
Type B	20- 500	100						300	570	+90
CO	10- 300	1000	27	40	50	2	±4	50		
	100-3000	100						100	120	+20
								200	220	+10
								500	500	0
								1000	1000	0
HCN	2- 30	500	10	30	50	6	±8	5		
	10- 150	100						30	35	+20
								75		
HF	1- 15	1000	5	0	60	3	±5	16	14	-13
	5- 150*	100								
NO + NO_2	0.5-10	500	9	30	60	5	±8			
	5- 50*	100								
SO_2	5- 150	1000	12	0	65	4	±6			
	50-1500	100								
NH_3	25- 700	1000	9	0	75	3	±4			

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* Concentration range extended by use of individual calibration (not furnished by the manufacturer)

‡ Average readings of three separate tubes

APPENDIX 2

TYPICAL SMOKE ACCUMULATION CURVES FOR SELECTED MATERIALS

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

F Flaming exposure

NF Nonflaming (smoldering) exposure

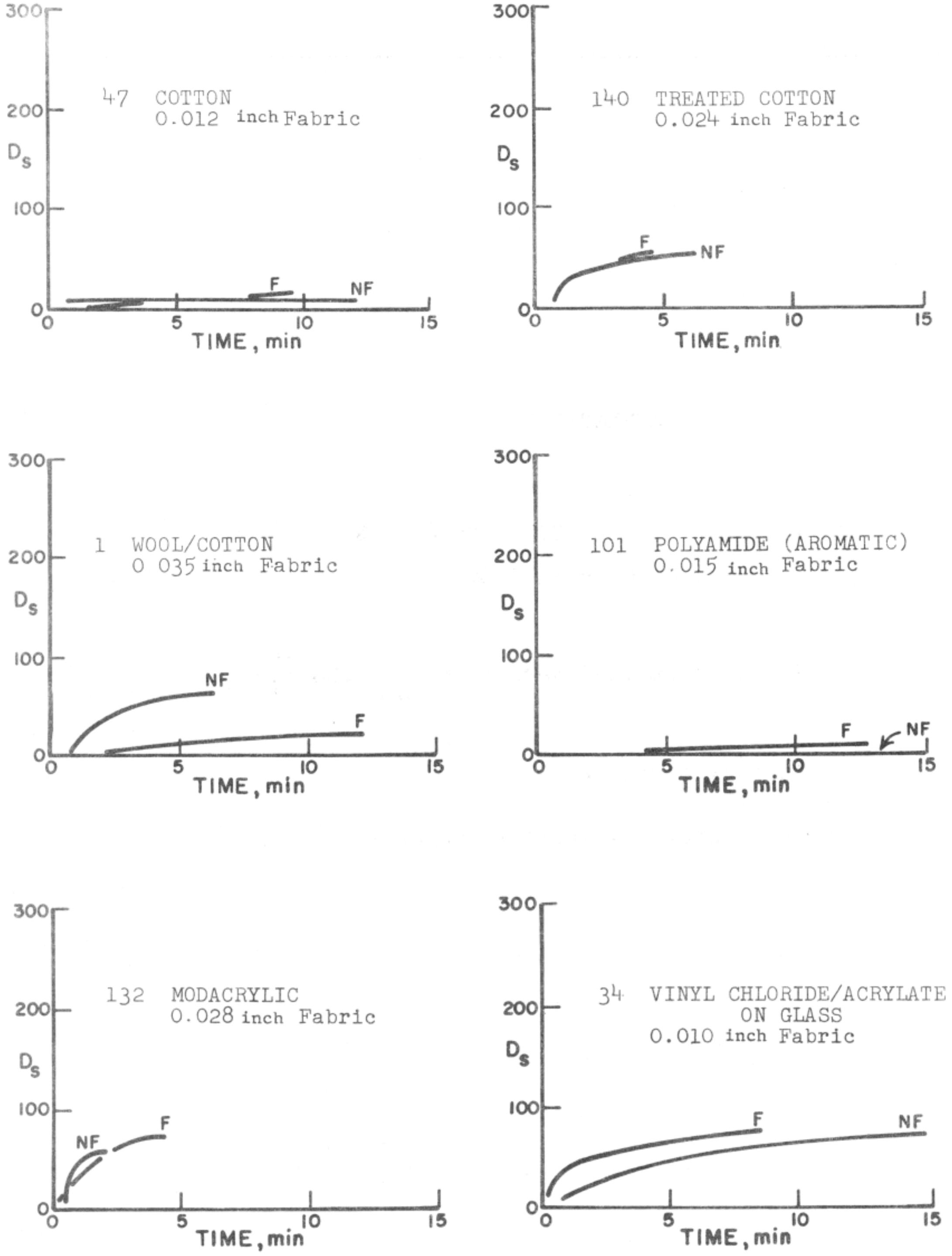

Fig. 2.1 Typical Smoke Curves - Fabrics

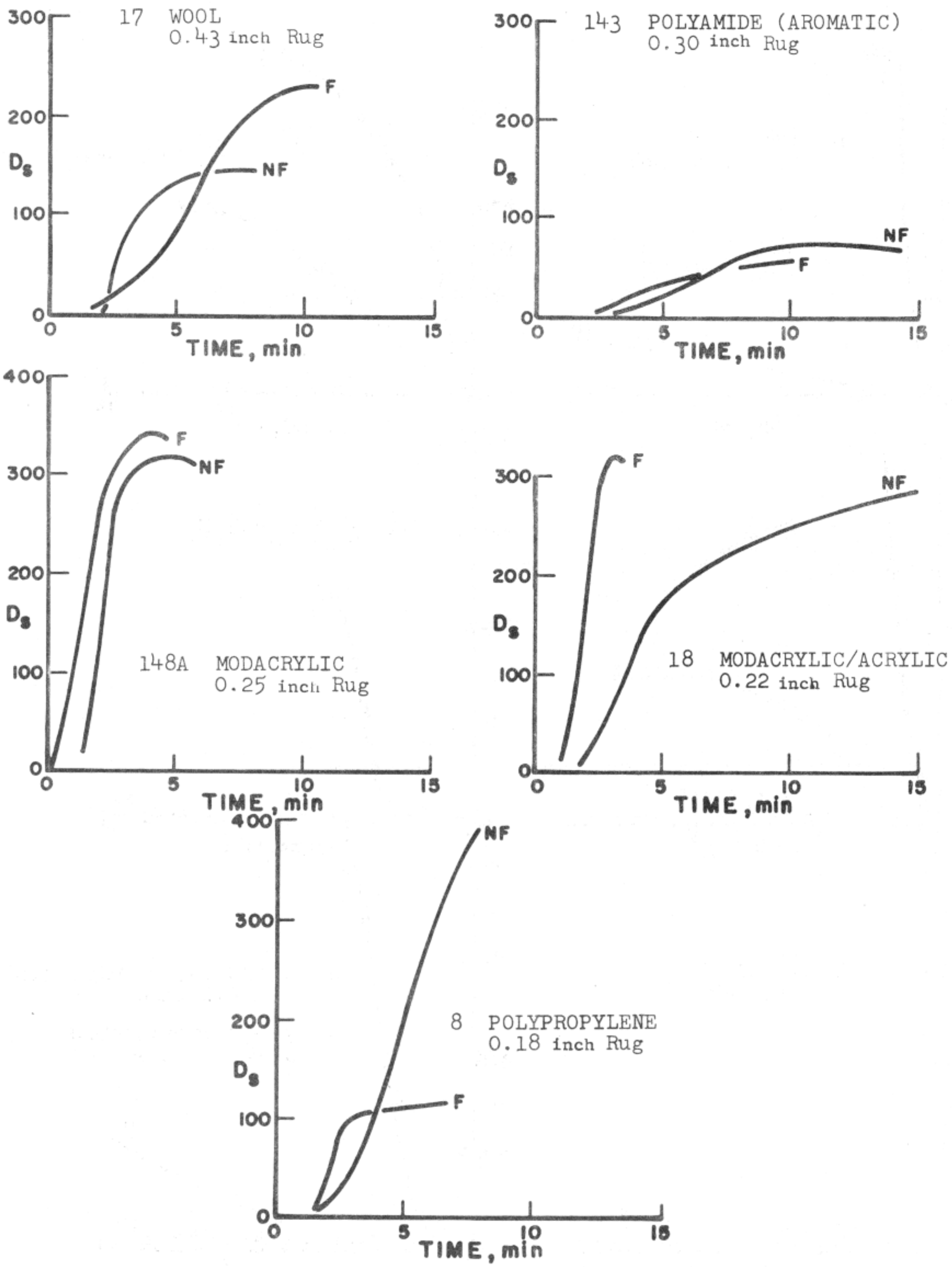

Fig. 2.2 Typical Smoke Curves - Rugs

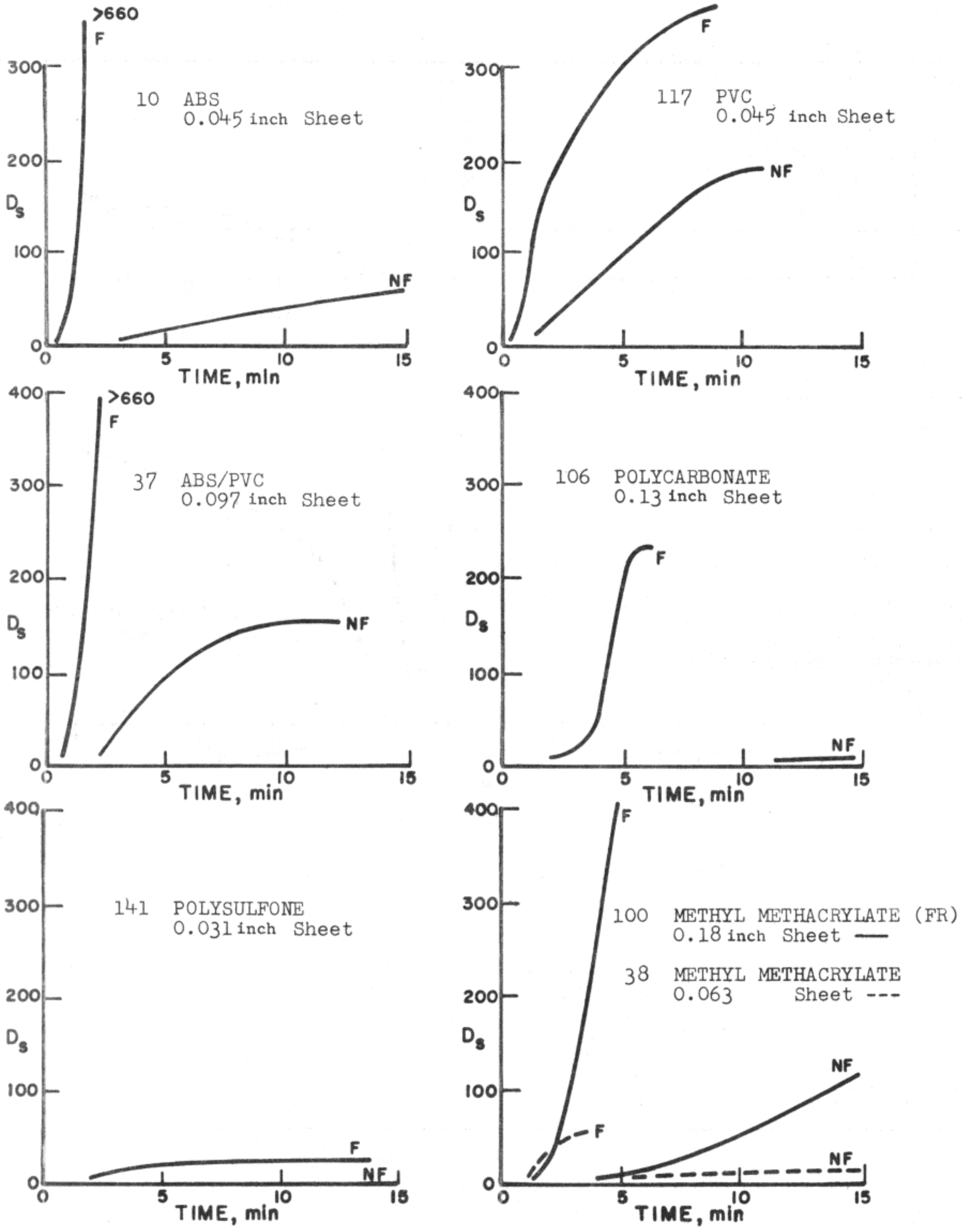

Fig. 2-3 Typical Smoke Curves - Sheets

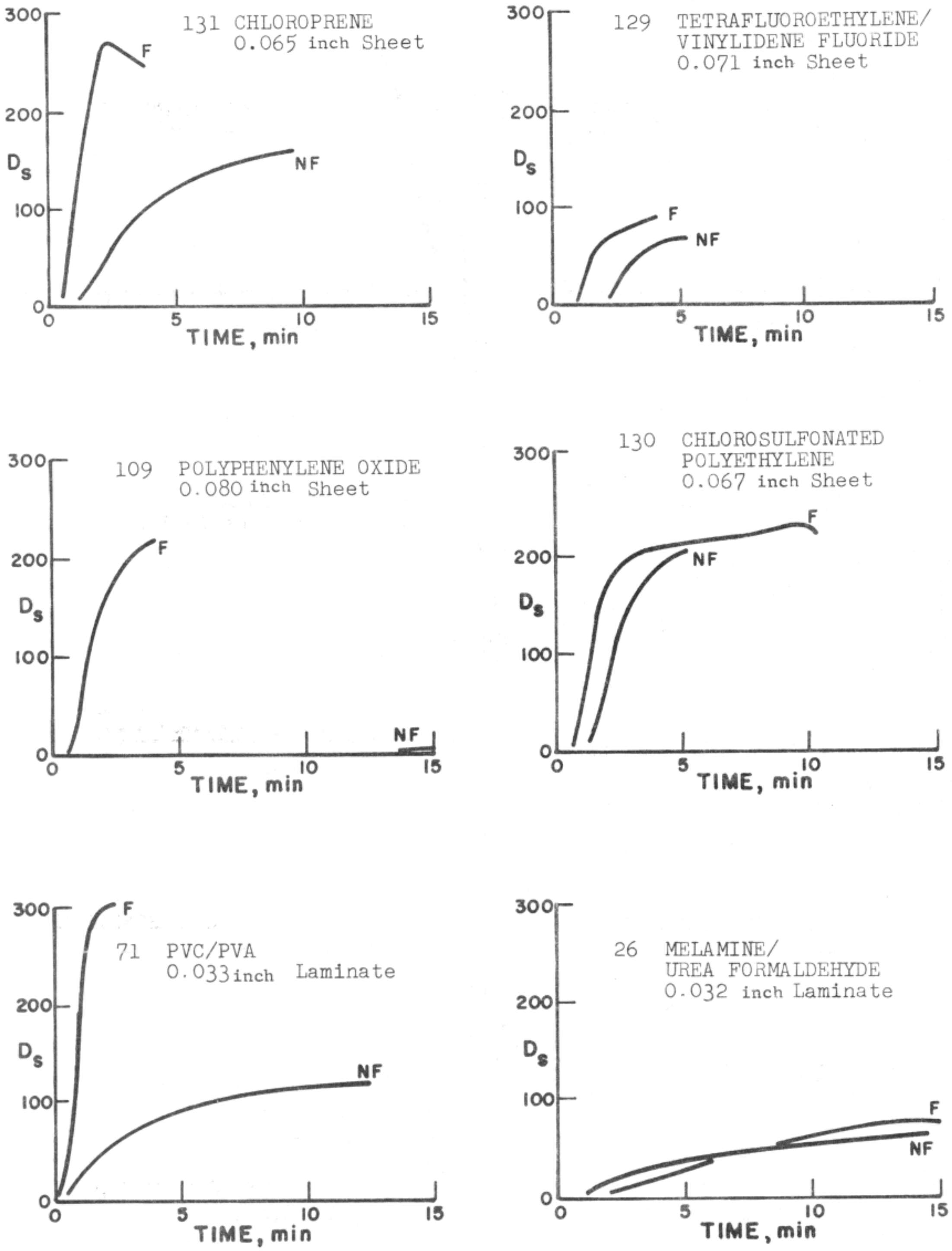

Fig. 2-4 Typical Smoke Curves - Sheets, Laminates

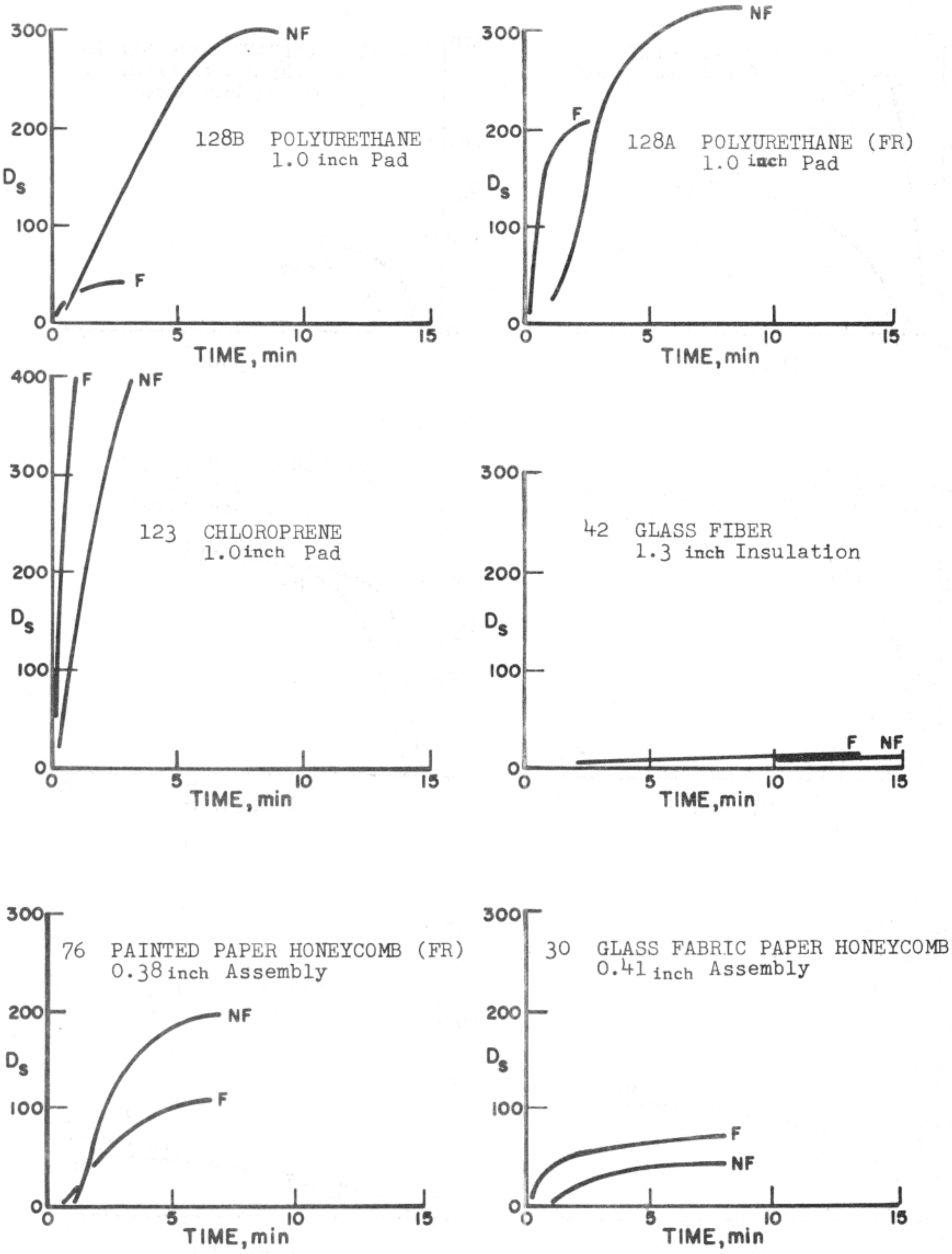

Fig. 2.5 Typical Smoke Curves - Pads, Insulation, Assemblies

APPENDIX 3
MATERIALS DESCRIPTION

TABLE I

No.	Code	Thickness inch	Unit* Weight oz/yd^2	Color and Surface	Designation	Present or Intended Use	Approximate Chemical Composition (Based on IR Spectroscopy)
1	F-1	.035	11	Light-Blue	Fabric (UC)	Drapery	Wool/Cotton (75:25)
2	F-1	.030	9.6	Light-Blue	Fabric (UC)	Drapery	Modacrylic
3	F-1	.055	14	Blue (Multi-Color) pattern	Fabric (UC)	Drapery	Modacrylic/nylon/cotton
4	F-1	.050	13	Tan Corduroy	Fabric (UC)	Upholstery	Polyamide (Nylon type)
5	F-2	.030	12	Blue Matte	Fabric (C)	Upholstery	Polyvinylchloride/Methyl Methacrylate/Ester plasticizer on Cotton
6	F-2	.045	26	Gold Matte	Fabric (C)	Upholstery	Polyester Plasticizer (Phthalate-type), possible PVC, on cotton

ABBREVIATIONS

F1,F2 - Fabric (uncoated, coated)
R1,R2 - Rug (unpadded, padded)
S1,S2,S3 - Sheet (flexible, semi-rigid, rigid)
L1,L2,L3 - Laminate (flexible, semi-rigid, rigid)

* 1 oz/yd^2 = 3.39×10^{-3} g/cm^2

Designation

C	Coated
UC	Uncoated
F	Flexible
SR	Semi-rigid
R	Rigid
P	Padded
UP	Unpadded
FR	Fire-retardant treated

ABS	Acrylonitrile/Butadiene/Styrene
PETP	Polyethylene terephthalate polyester
PMMA	Poly methyl methacrylate
PVA	Poly vinyl acetate
PVC	Poly vinyl chloride

TABLE I MATERIALS DESCRIPTION (continued)

No.	Code	Thickness inch	Unit Weight oz/yd^2	Color and Surface	Designation	Present or Intended Use	Approximate Chemical Composition (Based on IR Spectroscopy)
7	R-2	.33	62	Blue/Gray Loop	Rug (P)	Flooring	Pile: Modacrylic /Acrylic Backing: Polyester fiber Pad: Polyester urethane foam
8	R-1	.18	31	Blue/Green Loop	Rug(UP)	Flooring	Pile: Copolymer Poly(propylene-Butylene) Center: Cellulosic Backing: Polyethylene
9	S-1	.046	46	Tan Matte	Sheet (F)	Panel and Door Covering	PVA/ABS, china clay pigmented possible PVC.
10	S-2	.045	38	Dark Gray Matte	Sheet (SR)	Food Trays, Window frames	ABS (~25%:10%:65%)
11	S-3	.080	67	Green Polished	Sheet (R)	Food Trays, Window frames	ABS (~25:10:65)
12	S-3	.080	81	Tan Matte	Sheet (R)	Ceilings, Seat panels	Copolymer: PVC/Poly methyl methacrylate(~95:5)

See p. 3-1 for list of abbreviations

TABLE I MATERIALS DESCRIPTION Page III

No.	Code	Thickness inch	Unit Weight oz/yd^2	Color and Surface	Designation	Present or Intended Use	Approximate Chemical Composition (Based on IR Spectroscopy)
13	S-2	.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	.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	.22	44	Blue Loop	Rug (UP)	Flooring	Wool
17	R-2	.43	83	Multi-Color Loop	Rug(P)	Flooring	Pile: Wool Back: Polyester Pad: Urethane foam
18	R-1	.22	59	Black/Gray Loop	Rug (UP)	Flooring	Modacrylic/Acrylic
19	S-1	.21	9.2	Green Open cell	Pad (F)	Carpet underlay	Polyester urethane foam

See p. 3-1 for list of abbreviations

TABLE I MATERIALS DESCRIPTION

No.	Code	Thickness inch	Unit Weight oz/yd^2	Color and Surface	Designation	Present or Intended Use	Approximate Chemical Composition (Based on IR Spectroscopy)
20	L-3	.042	68	Gold Embossed	Laminate(R)	Panels - Overhead and sides	Face: Polyvinyl acetate with trace of ABS covered with PETP Polyester Back: Aluminum sheet
21	L-3	.044	79	Tan Dull Brushed	Laminate (R)	Panels - Overhead and sides	Face: Vinyl Chloride/Acrylate copolymer (80:20) on Back: Aluminum sheet
22	L-1	.009	8.1	Aluminum Matte Shiny	Laminate(F)	Window shades	Face: PETP Polyester Back: Vinyl acetate, PVC copolymer
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	.035	39	Gray Glossy	Laminate (R)	Galley area	Face: Melamine formaldehyde Back: Urea formaldehyde
26	L-3	.032	35	Blue Glossy	Laminate (R)	Galley area	Face: Melamine formaldehyde Back: Urea formaldehyde

See p. 3-1 for list of abbreviations

TABLE I

MATERIALS DESCRIPTION

No.	Code	Thickness inch	Unit Weight oz/yd^2	Color and Surface	Designation	Present or Intended Use	Approximate Chemical Composition (Based on IR Spectroscopy)
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	.028	8.0	Tan/Gold Trace	Fabric(UC)	Drapery	Modacrylic
29	F-1	.030	9.3	Turquoise, Gold Trace	Fabric (UC)	Drapery	Modacrylic
30	A	.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	.010	9.6	White Matte	Sheet (F)	Lowered ceilings	Vinyl chloride/Acrylate, possible Polyvinyl acetate
32	L-3	.045	75	Lt. Blue Matte	Laminate (R)	Lowered ceilings	Vinyl Chloride/Acrylate copolymer film on aluminum sheet

See p. 3-1 for list of abbreviations

TABLE I MATERIALS DESCRIPTION

No.	Code	Thickness inch	Unit Weight oz/yd^2	Color and Surface	Designation	Present or Intended Use	Approximate Chemical Composition (Based on IR Spectroscopy)
33	S-3	.093	91	White Matte	Sheet (R)	Hatrack	ABS (40:40:20), possible PVC
34	F-2	.010	10	Tan Smooth	Fabric (C)	Underside hatrack bullnose	Vinyl chloride/ Acrylate copolymer on glass fabric(28%) plus pigment (13%)
35	S-3	.095	90	Gray Dull	Sheet (R)	Toilet floor pans	ABS (40:40:20), possible PVC
36	A	.063		Tan Smooth	Assembly (molded)	Ceiling panel joint	Plasticized PVC Plasticized di - (2 Ethyl-Hexyl) Phthalate
37	S-3	.097	92	White Matte	Sheet (R)	Magazine rack	ABS (40:40:20)/PVC
38	S-3	.063	53	Clear Polished	Sheet (R)	Window pane	Methyl methacrylate/Methyl acrylate copolymer (90:10)
39	S-3	.064	62	Tan Matte	Sheet (R)	Control panel	ABS (40%: 40%: 20%), possible PVC

See p. 3-1 for list of abbreviations

TABLE I MATERIALS DESCRIPTION

No.	Code	Thickness inch	Unit Weight oz/yd^2	Color and Surface	Designation	Present or Intended Use	Approximate Chemical Composition (Based on IR Spectroscopy)
40	S-1	.002	1.3	Clear Smooth	Film (F)	Protective coating	Polyvinyl fluoride
41	A	.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	.046	44	Tan Matte	Sheet(F)	Seat panels	PVA/ABS, china clay pigmented, possible PVC
45	S-3	.063	60	Tan Matte	Sheet (R)	Seat panels	PVC/ABS
46	S-3	.057	55	White Matte	Sheet(R)	Seat panels	PVC/PMMA (90:10)
47	F-1	.012	4.0	White Matte	Fabric (UC)	Lining for seat pads	Cotton
48	A	.57	82	Tan Matte	Assembly	Seat panels	Face: PVC/ABS Back: Polyurethane

See p. 3-1 for list of abbreviations

TABLE I MATERIALS DESCRIPTION

No.	Code	Thickness inch	Unit Weight oz/yd^2	Color and Surface	Designation	Present or Intended Use	Approximate Chemical Composition (Based on IR Spectroscopy)
49	A	.52	120	White Matte	Assembly	Seat panels	Face: PVC/PMMA (90:10) Back: Urethane foam - Polyether type
50	S-3	.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
54	A	1.3	28	Blue Smooth	Assembly	Insulation	Face: Organic-filled nylon fabric Back: Glass fiber batt
55	F-2	.004	4.2	Tan Smooth	Fabric (C)	Cover for insulation batt	Polyethylene film over nylon fabric (filled rubber)
56	F-2	.004	2.9	Lt. Blue Smooth	Fabric (C)	Cover for insulation batt	Organic-filled nylon 6-6 fabric
57	F-2	.006	6.1	Green Smooth	Fabric (C)	Bulkhead assembly Lining	Plasticized PVC on Glass fabric

See p. 3-1 for list of abbreviations

TABLE I

MATERIALS DESCRIPTION

No.	Code	Thickness inch	Unit Weight oz/yd^2	Color and Surface	Designation	Present or Intended Use	Approximate Chemical Composition (Based on IR Spectroscopy)
58	F-1	.054	14	Bluish Multi-colored weave	Fabric (UC)	Drapery	Modacrylic/Nylon/Cotton
59	S-1	.020	16	White/color pattern	Sheet (F)	Partitions	PVC/PVA (89:11)
60	S-3	.060	64	Gold Glossy	Sheet (R)	Side panels	Plasticized PVC/PVA with ABS
61	S-3	.060	62	Blue Glossy	Sheet (R)	Side panel	PVC/PVA (Small amount of ABS)
62	S-3	.069	70	White with pattern	Sheet (R)	Window panel	Polyvinyl Butyral film on PVC/PVA (90:10)
63	F-1	.030	9.5	Yellow/ Gold trace	Fabric (UC)	Drapery	Modacrylic/Polyester
64	R-1	.33	64	Blue/Green Loop	Rug (UP)	Flooring	Modacrylic/acrylic
65	R-1	.23	41	Brown/white/ Black loop	Rug (UP)	Flooring	Modacrylic/acrylic
66	S-1	.032	25	Tan/Yellow Burlap	Sheet (F)	Sidewall	Plasticized PVC

See p.3-1 for list of abbreviations

TABLE I MATERIALS DESCRIPTION

No.	Code	Thickness inch	Unit Weight oz/yd^2	Color and Surface	Designation	Present or Intended Use	Approximate Chemical Composition (Based on IR Spectroscopy)
67	L-2	.022	24	White Burlap	Laminate (SR)	Baggage liner	Polyester plastic filled Glass fiber fabric
68	L-2	.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	.026	24	Blue/White Simulated fabric	Laminate (SR)	Sidewall, partition liner	PVC/PVA
70	L-2	.031	28	Gray Glossy	Laminate (SR)	Sidewall, partition liner	Face: Acrylate Back: PVC/PVA
71	L-2	.033	31	Tan/White Embossed	Laminate (SR)	Sidewall, partition liner	PVC/PVA (93:7)
72	L-3	.075	71	Red Matte	Laminate (R)	Door liners	Face: PVC/PVA Back: ABS/PVC
73	S-3	.11	110	Gray Glossy	Sheet (R)	Cockpit liner	ABS/PVC
74	S-3	.50	440	Clear Glossy	Sheet (R)	Window panes	Methyl Methacrylate
75	F-1	.060	19	Turquoise Corrugated	Fabric (UC)	Upholstery	Cotton/Nylon (Small amount of Polyester)

See p. 3-1 for list of abbreviations

TABLE I MATERIALS DESCRIPTION

No.	Code	Thickness inch	Unit Weight oz/yd^2	Color and Surface	Designation	Present or Intended Use	Approximate Chemical Composition (Based on IR Spectroscopy)
76	A	.38	76	White Smooth	Assembly (Honeycomb)	Ceiling panel	Face: Acrylic/vinyl coating over plywood (paper) Core: Paper with cresolformaldehyde resin adhesive
100	S-3	.18	180	Clear Polished	Sheet (R)	Window panes	Methyl methacrylate
101	F-1	.015	4.4	White	Fabric (UC)	Drapery	Polyamide (Aromatic-type)
102	F-1	.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	.033	26	Aluminum Glossy	Fabric (C)	High temperature liner	Aluminum on asbestos
106	S-3	.13	120	Clear Glossy	Sheet (R)	Window panes Fabricated parts	Poly (diphenylol propane) carbonate
107	F-1	.013	5.8	White	Fabric (UC)	Drapery	Modacrylic (100%)
108	F-1	.013	5.9	Orange	Fabric (UC)	Drapery	Modacrylic (100%)
109	S-3	.080	62	Yellow Glossy	Sheet (R)	Paneling	Poly (phenylene oxide)

See p. 3-1 for list of abbreviations

TABLE I

MATERIALS DESCRIPTION

No.	Code	Thickness inch	Unit Weight oz/yd^2	Color and Surface	Designation	Present or Intended Use	Approximate Chemical Compostion (Based on IR Spectroscopy)
110	S-3	.13	110	Dk. Gray Matte	Sheet (R)	Paneling	PVC/PMMA plus ABS
111	S-3	.060	57	Green Matte	Sheet (R)	Paneling	PVC/PMMA plus ABS
112A	S-2	.060	54	Clear Glossy	Sheet (SR)	Fabricated parts	Polysulfone
B		.020	18				
113	S-1	.30	11	White Fluffy	Pad	Seat padding, Wall insulation	Glass fiber (100%)
114	F-2	.010	7.8	White Matte	Fabric (C)	Headliner	Glass fabric coated with Acrylic (Aromatic plasticizer)
115	S-1	.0015	2.2	Clear Smooth	Film (F)	Protective cover	Poly (difluorochloroethylene)
116	S-2	.020	17	Tan Smooth	Sheet (SR)	Panel sub-strate	Polyamide (Aromatic type)
117	S-3	.045	50	White Gloosy	Sheet (R)	Paneling	PVC/Poly(vinylidene chloride)
118 A	S-1	.002	2.1	Amber	Sheet(F)	High temperature insulation	Polytetrafluoroethylene films over polyimide
B		.005	5.4	Clear			
C		.003	3.5				
D		.005	5.9	Glossy			

See p. 3-1 for list of abbreviations

TABLE I

MATERIALS DESCRIPTION

No.	Code	Thickness inch	Unit Weight oz/yd^2	Color and Surface	Designation	Present or Intended Use	Approximate Chemical Composition (Based on IR Spectroscopy)
119	F-2	.007	5.0	Blue	Fabric (C)	Headliner	Glass fabric (97%) with organic finish
120	S-2	.23	20	Gray Fibrous	Pad	Insulation	Asbestos fiber
121	S-3	.063	64	Tan Smooth	Sheet (R)	Panel Sub-strate	Polyamide (Aromatic type)
122	S-3	.11	130	Gray Glossy	Sheet (R)	Paneling	Polyvinyldichloride
123	S-1	4.0	380	Black Open cell	Foam (F)	Seat padding	Chloroprene
124	F-1	.012	9.2	Maroon Glossy	Fabric (UC)	Wall covering	Plasticized poly(vinylidene chloride)
125	F-2	.005	4.0	Lt. Green Glossy	Fabric (C)	Headliner	Glass fabric (97%) with organic finish
126	F-2	.006	4.2	Lt. Gray Glossy	Fabric (C)	Headliner	Glass fabric (83%) with organic finish
127	S-2	.034	29	Blue Matte	Sheet (SR)	Paneling	Face: Plasticized PVC/PVA (90:10) Back: Polyamide (Aromatic type)
128	S-1	A 4.0	89	White Open cell	Foam (F)	Seat padding	Polyether Urethane (FR)
		B 4.0	67	White Open cell			Polyether Urethane

See p. 3-1 for list of abbreviations

TABLE I

MATERIALS DESCRIPTION

No.	Code	Thickness inch	Unit Weight oz/yd^2	Color and Surface	Designation	Present or Intended Use	Approximate Chemical Composition (Based on IR Spectroscopy)
129	S-1	.071	99	Black Smooth	Sheet (F)	Elastomer, Seals	Copolymer of Tetrafluoroethylene/Vinylidene fluoride
130	S-1	.067	83	Tan Smooth	Sheet (F)	Elastomer, Gaskets	Chlorosulfonated polyethylene
131	S-1	.065	82	Black Smooth	Sheet (F)	Elastomer, Hoses	Chloroprene
132	F-1	.028	8.7	Green	Fabric (UC)	Drapery	Modacrylic and Metallized fiber (94:6)
133	L-1	.040	36	Copper Glossy	Laminate (F)	Dado paneling	Face: Plasticized PVC/PVA Back: Polyamide(aromatic type)paper
134	L-1	.032	27	Lt. Tan Glossy	Laminate (F)	Hatrack	Face: Plasticized PVC/PVA and cotton fiber Back: Polyamide(aromatic type)paper
135	L-2	.029	26	Blue/White pattern Smooth	Laminate (SR)	Paneling Bulkhead Dividers	Face: PVC/PVA (90:10) Back: Polyamide(aromatic type)paper
136	L-3	.099	84	Lt.Gray/Gold pattern Rough	Laminate (R)	Flooring	Plasticized PVC/PVA Top Coating - mostly plasticized
137	L-3	.074	72	Clear/White/Blue Smooth	Laminate (R)	Window reveals Dado, Seat backs	Plasticized PVC/PVA (90:10) over pigmented ABS, asbestos-filled

See p. 3-1 for list of abbreviations

TABLE I

MATERIALS DESCRIPTION

No.	Code	Thickness inch	Unit Weight oz/yd²	Color and Surface	Designation	Present or Intended Use	Approximate Chemical Composition (Based on IR Spectroscopy)
138	F-1	.015	5.8	Green Smooth	Fabric (UC)	Drapery (FR)	Polyamide (Aromatic type) Cotton (50%:50%)
139	F-2	.007	6.6	White Smooth	Fabric (C)	Headliner, Baggage liner	Glass fabric (60%) coated with Polyvinylidene fluoride
140	F-1	.024	12	White/Blue Smooth	Fabric (UC)	Mattress ticking (FR)	Cotton
141	S-2	.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	.30	45	Green Loop	Rug (UP)	Flooring	Polyamide (Aromatic type)
144	F-1	.035	11	Green/ White/ Orange	Fabric (UC)	Upholstery	Polyamide (Aromatic type)
145	F-2	.031	18	Silver Reflective	Fabric (C)	Insulation, Baggage liner	Aluminum/polyester film on Asbestos fabric
146	F-1	.035	9.9	White	Fabric (UC)	Upholstery, Drapery	Polyamide (more Aromatic groups than 143 & 144)
147	S-3	.23	210	Clear Glossy	Sheet (R)	Window panes, Fabricated parts	Poly Methyl Methacrylate

See p. 3-1 for list of abbreviations

TABLE I

MATERIALS DESCRIPTION

No.	Code	Thickness inch	Unit Weight oz/yd^2	Color and Surface	Designation	Present or Intended Use	Approximate Chemical Composition (Based on IR Spectroscopy)
148	R-1	.25	56	(A) Blue (B) Brown (C) Green Loop	Rug (UP)	Flooring	Pile: Modacrylic (100%)
149	F-1	.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	.054	75	Lt. Tan Matte	Laminate (R)	Paneling	Plasticized PVC/PVA on aluminum sheet
152	L-2	.057	52	Lt. Blue Matte	Laminate (SR)	Paneling	Face (blue): PVC/PVA (89:11) Back (tan) : PVC/PMMA (90:10)
153	F-1	.033	6.8	White Open Weave	Fabric (UC)	Casement drapery	Modacrylic/Rayon/ Poly(vinylidene Chloride) 20%
154	S-1	.11	63	Red Closed cell	Sheet (F)	Padding	Silicone Rubber
155	S-3	.060	53	Clear Glossy	Sheet (R)	Window panes Fabricated parts	Polycarbonate
156	F-2	.007	6.3	White Smooth	Fabric (C)	Headliner	Poly(vinylidene fluoride) coating on Polyamide (aromatic type) fabric

See p. 3-1 for list of abbreviations

TABLE I MATERIALS DESCRIPTION

No.	Code	Thickness inch	Unit Weight oz/yd^2	Color and Surface	Designation	Present or Intended Use	Approximate Chemical Composition (Based on IR Spectroscopy)
157	F-1	.035	10	White	Fabric (UC)	Drapery	Modacrylic (100%)
158	S-2	.028	29	Cream Glossy	Sheet (SR)	Panels, Fabricated parts	PVC/ABS (94:6)
159	S-2	.034	34	Olive Glossy	Sheet (SR)	Panels, Fabricated parts	PVC/Acrylic (90:10)
160	S-3	.055	65	White Glossy	Sheet (R)	Panels, Fabricated parts	Styrene/Polyester, fiberglass-reinforced (25%), TiO_2 pigment
161	L-3	.032	57	Wood Grain pattern Smooth	Laminate (R)	Panels, Interior finish	PVC/Acrylic on Aluminum sheet
162	F-1	.020	13	White	Fabric (UC)	High-temperature insulation fabric	Asbestos/ Glass/ Polyamide (aromatic type)
163	L-2	.031	39	Wood Grain pattern Smooth	Laminate (SR)	Panels, Interior finish	PVC/PVA (95:5) on filled asbestos (71%)
164	S-3	.070	60	White Glossy	Sheet (R)	Fabricated parts	ABS

APPENDIX 4

TABLE II

SUMMARY OF TEST RESULTS; SMOKE AND GAS CONCENTRATION

SAMPLE NUMBER	SPECIMEN WEIGHT	TEST EXPOSURE F=Flaming N=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
	g			min^{-1}	min	ppm	ppm	ppm	ppm
1	2.2	F	14	2	NR	50	0	6	
		N	60	19	1.2	30	0	5	
2	1.8	F	72	29	0.5	200	200 S	45	
		N	50	24	0.7	45	150 S	35	
3	2.8	F	60	20	1.0	80	40	15	
		N	89	35	0.9	20	25	10	
4	2.6 [a]	F	16	4	15.0	30	0	0	
		N	6	< 1	NR	70	0	0	
5	4.4	F	193	185	0.3	270	150 S	0	
		N	191	30	1.4	80	150 S	0	
6	5.0	F	204	163	0.3	350	200 S	3	
		N	272	28	1.5	400	300 S	2	
7	12.2	F	439	200	0.8	500	90	20	
		N	375	140	1.2	125	30	30	
8	7.0	F	96	50	1.8	140	0	2	
		N	418	60	2.0	800	0	2	
9	9.1	F	380	178	0.5	500	300 S	20	
		N	276	67	1.2	180	80 S	12	

a. Material not fully exposed because of melting, shrinking, etc.
b. Tested in 5/8-inch thickness
c. Tested in 1-inch thickness
d. Probably acrylonitrile vapor indication

NR Not reached
S Measured with chloride ion electrode

TABLE II

SUMMARY OF TEST RESULTS; SMOKE AND GAS CONCENTRATION

SAMPLE NUMBER	SPECIMEN WEIGHT	TEST EXPOSURE F=Flaming N=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
	g			min^{-1}	min	ppm	ppm	ppm	ppm
10	7.1	F	>660	340	0.6	260	0	10	NO+NO$_2$:30
		N	76	6	4.3	25	0	8	
11	11.8	F	>660	280	0.7	360	0	10	
		N	167	8	3.5	40	0	9	
12	15.1	F	229	61	1.0	550	1200 S	0	
		N	107	17	3.0	600	800 S	0	
13	5.4	F	289	120	0.6	200	300 S	3	
		N	55	4	6.5	60	250 S	2	
14	4.0	F	139	96	0.6	120	300 S	0	
		N	20	4	3.8	60	250 S	0	
15	2.6 b	F	35	6	1.4	50	0	2	
		N	156	9	0.5	50	0	2	
16	9.4	F	123	23	1.6	190	0	15	
		N	87	6	2.1	90	0	20	
17	15.2	F	129	50	2.2	320	0	15	NO+NO$_2$:25
		N	206	40	2.0	300	0	60	
18	11.6	F	350	170	1.2	270	30	8	
		N	312	59	2.1	240	6	50	

TABLE II

SUMMARY OF TEST RESULTS; SMOKE AND GAS CONCENTRATION

SAMPLE NUMBER	SPECIMEN WEIGHT	TEST EXPOSURE F=Flaming N=Nonflaming	S M O K E			GAS CONCENTRATION			
						Maximum Indication, Colorimetric Tube			
			Maximum Specific Optical Density D_m	Maximum Rate R_m	Time to $D_s = 16$ t_c	CO	HCl	HCN	OTHERS
	g			min^{-1}	min	ppm	ppm	ppm	ppm
19	1.7	F	58	10	1.9	150	0	2	
		N	77	13	0.6	45	0	0	
20	13.0	F	76	14	5.2	210	100	2	
		N	22	2	21.6	20	80	0	
21	14.9	F	81	26	2.1	230	200	0	
		N	82	17	5.0	30	100	0	
22	1.3	F	28	4	1.5	90	70	0	
		N	24	4	5.7	10	30	0	
23	50. a	F	162	11	5.6	500	0	65	$NO+NO_2$: 50
		N	105	3	13.6	30	0	2	
24	11.4	F	454	160	0.7	550	1300 S	4	
		N	167	40	1.8	60	1000 S	1	
25	7.2	F	94	9	3.5	320	0	10	
		N	44	6	4.5	80	0	4	
26	6.7	F	50	4	3.7	300	0	8	
		N	43	6	3.6	130	0	7	
27	4.6	F	> 660	260	0.8	700	50	25	
		N	126	5	5.3	50	20	8	

TABLE II

SUMMARY OF TEST RESULTS; SMOKE AND GAS CONCENTRATION

SAMPLE NUMBER	SPECIMEN WEIGHT	TEST EXPOSURE F=Flaming N=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
	g			min^{-1}	min	ppm	ppm	ppm	ppm
28	1.5	F	76	23	0.4	170	150	60	
		N	48	20	0.8	60	150	50	
29	1.6	F	66	23	0.5	200	150	60	
		N	52	17	0.9	40	200	40	
30	12.3	F	63	11	0.6	280	45	7	
		N	45	14	1.9	75	8	1	
31	1.8	F	72	21	0.2	110	110	1	
		N	68	4	3.6	50	90	1	
32	14.7	F	74	15	3.5	150	200	0	
		N	58	6	7.7	50	200	0	
33	17.6	F	458	190	0.7	650	150	20	
		N	207	48	2.4	30	30	5	
34	2.0	F	74	16	0.4	180	80	1	
		N	68	11	1.3	55	60	1	
35	17.4	F	446	200	0.6	750	100	20	
		N	277	74	2.1	35	30	12	
36	17.7 a	F	>660	240	0.5	850	1300 S	0	
		N	390	40	2.6	30	1000 S	0	

TABLE II

SUMMARY OF TEST RESULTS; SMOKE AND GAS CONCENTRATION

SAMPLE NUMBER	SPECIMEN WEIGHT g	TEST EXPOSURE F=Flaming N=Nonflaming	SMOKE: Maximum Specific Optical Density D_m	SMOKE: Maximum Rate R_m min^{-1}	SMOKE: Time to $D_s = 16$ t_c min	GAS CONCENTRATION, Maximum Indication, Colorimetric Tube: CO ppm	HCl ppm	HCN ppm	OTHERS ppm
37	18.2	F	641	220	0.7	700	150	50	
		N	156	37	2.9	40	20	5	
38	10.7	F	50	16	1.6	160	0	0	
		N	12	2	NR	30	0	0	
39	12.2	F	460	190	0.6	500	110	20	
		N	146	26	2.3	60	25	6	
40	0.2	F	4	< 1	NR	60	0	0	HF:7
		N	1	< 1	NR	20	0	0	HF:0
41	15.3	F	448	170	0.4	450	150	20	
		N	181	38	1.5	45	100	5	
42	4.8 c	F	10	2	NR	150	0	13	
		N	8	< 1	NR	130	0	14	
43	21.3 c	F	8	< 1	NR	180	0	18	
		N	4	< 1	NR	160	0	15	
44	10.3	F	466	230	0.4	700	300 S	20	
		N	240	120	1.1	180	80 S	12	
45	12.2	F	>660	260	0.4	1000	300	40	
		N	276	65	1.7	150	40	6	

TABLE II

SUMMARY OF TEST RESULTS; SMOKE AND GAS CONCENTRATION

SAMPLE NUMBER	SPECIMEN WEIGHT	TEST EXPOSURE F=Flaming N=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
	g			min^{-1}	min	ppm	ppm	ppm	ppm
46	12.2	F	303	120	0.8	700	1300 S	1	
		N	172	35	2.0	350	900 S	0	
47	0.7	F	8	1	NR	150	0	1	
		N	8	< 1	NR	80	0	0	
48	16.9	F	>660	180	0.5	1200	300	40	
		N	280	130	1.4	400	250	15	
49	21.2	F	518	220	0.7	1200	1600 S	15	
		N	414	100	1.4	250	1200 S	2	
50	6.2 a	F	229	110	0.2	700	150	30	
		N	164	59	0.4	200	0	3	
51	17.0	F	>660	250	0.2	1100	400	38	
		N	302	50	0.6	400	400	30	
52	4.6 c	F	30	8	2.5	250	0	3	
		N	318	46	0.5	250	0	2	
53	5.9	F	60	23	0.2	230	15	10	
		N	87	34	0.6	90	8	5	
54	4.1	F	24	7	0.8	140	8	6	
		N	56	26	0.4	80	1	7	

TABLE II

SUMMARY OF TEST RESULTS; SMOKE AND GAS CONCENTRATION

SAMPLE NUMBER	SPECIMEN WEIGHT g	TEST EXPOSURE F=Flaming N=Nonflaming	SMOKE Maximum Specific Optical Density D_m	SMOKE Maximum Rate R_m min^{-1}	SMOKE Time to $D_s = 16$ t_c min	GAS CONCENTRATION Maximum Indication, Colorimetric Tube CO ppm	HCl ppm	HCN ppm	OTHERS ppm
55	0.9	F	30	6	2.9	160	50	2	
		N	35	5	3.1	80	35	1	
56	0.6	F	18	3	5.2	120	9	3	
		N	40	3	7.8	50	5	1	
57	1.0	F	27	7	1.3	100	40	1	
		N	40	4	3.9	60	12	1	
58	2.6	F	58	22	1.0	80	40	15	
		N	89	35	1.0	20	25	10	
59	3.0	F	115	64	0.4	250	600	0	
		N	28	8	1.8	100	400	0	
60	12.8	F	609	260	0.5	1100	1500 S	15	
		N	290	47	1.2	150	800 S	4	
61	12.7	F	600	250	0.5	1000	1400 S	25	
		N	267	77	1.4	130	850 S	8	
62	13.2	F	436	180	0.5	800	700 S	20	
		N	216	33	1.6	320	450 S	5	
63	2.0	F	60	20	0.5	280	150	45	
		N	78	22	0.7	80	100	40	

TABLE II

SUMMARY OF TEST RESULTS; SMOKE AND GAS CONCENTRATION

SAMPLE NUMBER	SPECIMEN WEIGHT	TEST EXPOSURE F=Flaming N=Nonflaming	S M O K E			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
	g			min^{-1}	min	ppm	ppm	ppm	ppm
64	12.1	F	295	140	0.6	380	30	25	
		N	254	92	1.3	160	0	55 d	
65	8.3	F	355	310	0.7	300	0	17	
		N	327	86	2.0	170	0	110 d	
66	5.0	F	199	180	0.4	420	450	0	
		N	180	44	1.4	500	450	1	
67	4.7	F	69	28	0.4	230	20	0	
		N	60	6	4.2	30	8	0	
68	6.7	F	311	160	0.6	500	800 S	0	
		N	246	19	2.4	200	200	0	
69	5.3	F	234	200	0.4	500	800 S	0	
		N	178	33	1.2	190	500	0	
70	5.5	F	295	250	0.4	450	700 S	1	
		N	178	26	1.2	150	300	1	
71	6.0	F	300	230	0.4	450	1100 S	1	
		N	104	25	1.0	280	350	1	
72	14.1	F	>660	260	0.6	1200	800 S	17	
		N	286	45	1.6	130	400	7	

TABLE II

SUMMARY OF TEST RESULTS: SMOKE AND GAS CONCENTRATION

SAMPLE NUMBER	SPECIMEN WEIGHT g	TEST EXPOSURE F=Flaming N=Nonflaming	SMOKE: Maximum Specific Optical Density D_m	SMOKE: Maximum Rate R_m min^{-1}	SMOKE: Time to $D_s = 16$ t_c min	GAS CONCENTRATION, Maximum Indication, Colorimetric Tube: CO ppm	HCl ppm	HCN ppm	OTHERS ppm
73	20.8	F	574	180	0.6	1300	400	40	
		N	442	58	2.0	200	200	20	
74	86.9	F							
		N	328	5	9.0	140	0	0	
75	3.9	F	39	13	0.9	180	0	5	
		N	175	29	1.2	120	0	5	
76	16.0	F	151	35	1.2	220	80	7	
		N	200	70	1.4	100	5	3	
100	32.9	F	383	120	1.9	2200	100	0	
		N	203	12	6.0	400	8	0	
101	0.9	F	10	< 1	NR	70	0	1	
		N	0	0	NR	10	0	1	
102	1.0	F	8	1	NR	95	0	2	
		N	5	< 1	NR	10	0	0	

TABLE II

SUMMARY OF TEST RESULTS; SMOKE AND GAS CONCENTRATION

SAMPLE NUMBER	SPECIMEN WEIGHT	TEST EXPOSURE F=Flaming N=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
	g			min^{-1}	min	ppm	ppm	ppm	ppm
103	5.7	F	30	6	1.5	330	1600 S	2	
		N	20	2	6.8	110	1300 S	1	
104	9.4	F	25	4	2.8	130	15	5	
		N	25	5	3.0	70	12	4	
105	5.2	F	11	2	NR	110	35	1	
		N	10	1	NR	75	13	0	
106	18.4	F	210	70	2.8	400	0	0	
		N	12	1	NR	50	0	0	
107	1.2	F	39	15	0.4	160	120	35	
		N	41	10	0.8	90	100	30	
108	1.2	F	39	11	0.6	220	110	30	
		N	41	13	0.6	60	100	30	
109	12.4	F	183	66	0.9	270	0	1	
		N	168	5	18.2	120	0	0	
110	23.2	F	>660	220	0.6	1000	1000 S	20	
		N	498	68	2.3	280	700	10	
111	11.0	F	566	310	0.5	1100	600 S	19	
		N	248	42	1.8	180	600 S	8	

TABLE II SUMMARY OF TEST RESULTS; SMOKE AND GAS CONCENTRATION

SAMPLE NUMBER	SPECIMEN WEIGHT	TEST EXPOSURE F=Flaming N=Nonflaming	S M O K E			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
	g			min^{-1}	min	ppm	ppm	ppm	ppm
112 A	11.2	F	40	12	2.6	220	0	0	SO_2:150
		N	4	< 1	NR	30	0	0	SO_2: 0
113	1.9	F	4	< 1	NR	60	0	0	
		N	4	< 1	NR	5	0	0	
114	1.6	F	9	3	NR	70	25	0	
		N	11	2	NR	20	17	0	
115	0.5	F	0	0	NR	60	0	0	HF:0
		N	0	0	NR	5	0	0	HF:0
116	2.3	F	6	< 1	NR	70	0	0	
		N	3	< 1	NR	15	0	0	
117	9.5	F	321	100	0.6	650	2000 S	5	
		N	173	25	1.6	750	1100 S	2	
118 D	1.1	F	15	< 1	NR	280	0	1	HF:11
		N	0	0	NR	< 5	0	0	HF: 0
119	1.0	F	1	< 1	NR	80	0	0	
		N	2	< 1	NR	10	1	0	
120	3.0	F	1	< 1	NR	90	11	0	
		N	1	< 1	NR	10	10	0	

TABLE II SUMMARY OF TEST RESULTS; SMOKE AND GAS CONCENTRATION

SAMPLE NUMBER	SPECIMEN WEIGHT g	TEST EXPOSURE F=Flaming N=Nonflaming	SMOKE: Maximum Specific Optical Density D_m	SMOKE: Maximum Rate R_m min^{-1}	SMOKE: Time to $D_s = 16$ t_c min	GAS CONCENTRATION, Maximum Indication, Colorimetric Tube: CO ppm	HCl ppm	HCN ppm	OTHERS ppm
121	12.2	F	14	< 1	NR	170	15	5	
		N	7	< 1	NR	100	13	1	
122	23.0	F	125	30	1.1	800	2500 S	1	
		N	66	13	3.2	700	2000 S	1	
123	20.0 c	F	> 660	290	0.2	1000	1100	8	SO_2:45 H_2S: 40
		N	508	120	0.3	500	1500 S	6	SO_2:40
124	1.9	F	26	8	3.9	150	700	0	
		N	34	4	3.9	20	300	0	
125	0.9	F	2	< 1	NR	60	0	0	
		N	1	< 1	NR	10	0	0	
126	0.9	F	1	< 1	NR	60	0	0	
		N	1	< 1	NR	10	0	0	
127	5.5	F	309	250	0.4	380	700 S	2	
		N	162	45	1.0	100	1000 S	1	
128 A	4.2 c	F	262	120	0.2	320	150	25	
		N	286	62	0.7	160	25	2	

TABLE II

SUMMARY OF TEST RESULTS; SMOKE AND GAS CONCENTRATION

SAMPLE NUMBER	SPECIMEN WEIGHT	TEST EXPOSURE F=Flaming N=Nonflaming	SMOKE			GAS CONCENTRATION			
						Maximum Indication, Colorimetric Tube			
			Maximum Specific Optical Density D_m	Maximum Rate R_m	Time to $D_s = 16$ t_c	CO	HCl	HCN	OTHERS
	g			min^{-1}	min	ppm	ppm	ppm	ppm
128 B	3.5 c	F	41	15	0.6	150	2	2	
		N	300	54	0.7	190	2	2	
129	20.1	F	109	40	1.2	480	0	2	HF:80
		N	75	28	2.5	20	0	0	HF:90
130	16.7	F	230	92	0.8	750	400 S	0	SO_2:50
		N	196	70	1.1	60	200 S	0	SO_2:40
131	18.8	F	233	130	0.7	550	200	5	
		N	161	42	1.6	100	200 S	2	
132	1.8	F	67	25	0.4	210	150 S	46	
		N	62	28	0.6	90	100 S	37	
133	7.5	F	503	300	0.4	500	800 S	1	
		N	218	57	1.3	80	900 S	0	
134	5.6	F	368	340	0.4	470	600 S	0	
		N	150	29	1.5	70	350 S	0	
135	5.3	F	170	83	0.4	200	600 S	1	
		N	94	30	1.0	70	400 S	1	
136	18.3	F	342	160	0.6	800	900 S	3	
		N	169	47	1.2	250	500 S	1	

TABLE II

SUMMARY OF TEST RESULTS; SMOKE AND GAS CONCENTRATION

SAMPLE NUMBER	SPECIMEN WEIGHT	TEST EXPOSURE F=Flaming N=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
	g			min^{-1}	min	ppm	ppm	ppm	ppm
137	14.8	F	440	140	0.5	620	1700 S	10	
		N	154	41	1.7	120	800 S	1	
138	1.0	F	10	2	NR	100	0	4	
		N	9	< 1	NR	40	0	2	
139	1.5	F	1	< 1	NR	45	0	0	HF:26
		N	1	< 1	NR	< 5	0	0	HF:10
140	2.4	F	50	16	0.8	270	17	8	$NO+NO_2$: 8
		N	51	14	0.9	210	14	5	
141	5.4	F	28	4	5.9	180	0	0	SO_2:30
		N	1	< 1	NR	< 5	0	0	SO_2: 0
143	8.6	F	51	10	3.2	700	0	48	$NO+NO_2$:10
		N	65	7	4.8	880	0	40	NH_3:60
144	2.4	F	32	8	2.4	130	0	3	$NO+NO_2$: 12
		N	30	8	3.4	20	0	0	
145	3.6	F	11	2	NR	80	25	1	
		N	14	2	NR	20	15	0	
146	2.3	F	8	< 1	NR	140	0	5	$NO+NO_2$:8
		N	6	< 1	NR	10	0	2	

TABLE II

SUMMARY OF TEST RESULTS: SMOKE AND GAS CONCENTRATION

SAMPLE NUMBER	SPECIMEN WEIGHT	TEST EXPOSURE F=Flaming N=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
	g			min^{-1}	min	ppm	ppm	ppm	ppm
147	42.4	F	>660	88	1.4	2000	120	5	
		N	304	15	4.5	200	20	0	
148 A	11.4	F	410	130	0.5	400	1000 S	70	
		N	314	66	1.5	120	300 S	90	
148 C	11.5	F	464	190	0.5	500	1000 S	90	
		N	324	150	1.5	100	250 S	90	
149	2.3	F	50	20	1.2	80	300 S	50	
		N	66	30	1.2	50	200 S	60	
150	4.8 a	F	101	43	0.4	270	40	12	$NO+NO_2$:12
		N	205	42	0.4	40	0	2	
151	15.2	F	202	91	0.9	350	900 S	1	
		N	148	45	2.9	40	500 S	0	
152	10.5	F	223	76	0.6	500	1200 S	1	
		N	88	20	1.7	180	300 S	1	
153	1.5	F	19	6	1.1	80	150	15	
		N	25	10	1.1	80	90	20	
154	12.5	F	151	50	0.9	60	0	0	
		N	44	10	2.8	10	0	0	

TABLE II SUMMARY OF TEST RESULTS; SMOKE AND GAS CONCENTRATION

SAMPLE NUMBER	SPECIMEN WEIGHT	TEST EXPOSURE F=Flaming N=Nonflaming	S M O K E			GAS CONCENTRATION Maximum Indication, Colorimetric Tube			
			Maximum Specific Optical Density D_m	Maximum Rate R_m	Time to $D_s = 16$ t_c	CO	HCl	HCN	OTHERS
	g			min^{-1}	min	ppm	ppm	ppm	ppm
155		F							
		N							
156	1.3	F	3	< 1	NR	100	0	0	HF:35
		N	2	< 1	NR	40	0	0	HF:24
157	2.0 a	F	90	130	0.6	130	200	25	
		N	18	4	4.6	20	80	20	
158	5.1	F	195	170	0.5	300	150 S	5	
		N	59	25	1.2	35	150 S	1	
159	6.7	F	154	74	0.7	240	200 S	0	
		N	63	20	1.5	50	100 S	0	
160	13.1	F	190	70	0.7	500	200	0	
		N	106	18	3.3	125	150	0	
161	11.5	F	43	18	2.0	110	130	0	
		N	24	8	4.4	25	70	0	
161 x	1.5	F	52	20	0.3	120	150	0	
		N	29	11	1.0	25	80	0	
162	2.5	F	1	< 1	NR	30	0	0	
		N	0	0	NR	< 5	0	0	