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EVALUATION OF EXISTING FLAMMABILITY TEST METHODS By comparison of the flammability characteristics of interior materials

Eldon B. Nicholas



MARCH 1980

FINAL REPORT

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Prepared for

U.S. DEPARTMENT OF TRANSPORTATION FEDERAL AVIATION ADMINISTRATION National Aviation Facilities Experimental Center Atlantic City, New Jersey 08405

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PREFACE

The author would like to acknowledge Mr. Constantine Sarkos, NAFEC Program Manager, for his helpful advice in planning this test program as well as guidance throughout the program. Grateful thanks is extended to Mr. Richard Johnson for the operation of all of the test equipment utilized in the program.

The cooperation of the following airplane and seat manufacturers by furnishing test materials made this study possible: Boeing Company, Seattle, Washington; Lockheed-California Company, Burbank, California; Douglas Aircraft Company, Long Beach, California; Universal Oil Products, Banton, Connecticut; Hardman Aerospace, Los Angeles, California; Custom Products, Sun Valley, California; Flight Equipment and Engineering, Miami, Florida; Weber Aircraft, Burbank, California; General Tire and Rubber Co., Newcomerstown, Ohio.

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LIST OF ABREVIATIONS

ABS	Acrylonitrite/Butadiene/Styrene
AIA	Aerospace Industries Association
ASTM	American Society for Testing and Materials
Btu	British thermal units
°C	Degrees centigrade
°C/min	Degrees centigrade per minute
FAR	Federal Aviation Regulations
FR	Flame retardant
Fs	Flame spread factor
Is	Flame spread index
LOI	Limiting oxygen index
PVC	Polyvinyl chloride
PVF	Polyvinyl fluoride
Q	Heat evolution factor
r	Coefficient of correlation
RHR	Rate of heat release
RHRA	Rate of heat release apparatus
TGA	Thermogravimetric analysis
W/cm ²	Watts per square centimeter
Чc	Char yield

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INTRODUCTION

PURPOSE.

The purpose of this project was to evaluate and compare the flammability characteristics of selected aircraft interior materials by five widely used laboratory fire test methods.

BACKGROUND.

Federal Aviation Administration (FAA) regulations governing the selection of air transport cabin interior materials based on flammability criteria have been in existence since 1946. In May 1972 the most recent regulations upgrading the requirements for material flammability were promulgated (reference 1). With this upgrading, the majority of the cabin materials were required to be "self-extinguishing." Because this regulation is based on the vertical Bunsen burner test, it primarily addresses the ease by which a material may be ignited with a small flame.

There is a serious question concerning the effectiveness and meaning of the present self-extinguishing requirements in relation to a postcrash cabin fire. Under these self-sustaining fire conditions, a flammability test method should measure flame spread rate and heat evolution, as well as the ignitability of a material.

Recent tests have revealed other deficiences in the vertical Bunsen burner tests; e.g., some urethane foams are self-extinguishing by virtue of the rapid smoke buildup in the ventilation-limited test chamber, and some fabrics are selfextinguishing because they possess a very low melting temperature, causing the material to melt away from the flame before ignition can occur. In addition to these findings, there has recently been considerable controversy between test laboratories concerning the definition and measurement of burn length. This often results in a material being categorized as acceptable by one laboratory but unacceptable by another. Thus, even a simple test like the vertical test can often possess operational problems and provide data that is not entirely objective.

DISCUSSION

GENERAL APPROACH.

The general approach taken was to burn representative cabin materials, utilizing five of the most popular laboratory test methods for measuring flammability. The following test methods were employed for 'his study: (1) ASTM E-162 Radiant Panel (reference 2), (2) Ohio State Rate of Heat Release Apparatus (RHRA) (reference 3), (3) Vertical Bunsen Burner Test (references 4 anu 5), (4) ASTM D-2863 Limiting Oxygen Index (reference 6), and (5) Thermogravimetric Analyzer (reference 7).

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Twenty materials providing a cross section of physical and chemical characteristics of the more important cabin usage catagories (panels, foams, fabrics, flooring, and thermoplastics) were tested by each of the selected test methods. By comparing such measurements as ease of ignition, flame spread rate, and heat evolution for a series of materials, the intent of the project was to determine if a relationship existed between any of the test methods.

The chosen materials meet the requirements of the May 1972 regulations and are currently used in wide-bodied jet (DC-10, L-1011 and B-747) aircraft. They were received for use on this project through the courtesy of the Aerospace Industries Association (AIA) member airframe manufacturers as well as a number of seat and fabric manufacturers. These materials are described in table 1 which shows the chemical composition, thickness, unit weight, and cabin use. Decriptive information on chemical composition was provided by the supplier.

EQUIPMENT DESCRIPTION.

RADIANT PANEL. A detailed description of the radiant panel can be found in the ASTM Book of Standards (reference 2). An illustration of the panel taken from this source is shown in figure 1.

Basically, this is a method of measuring the surface flammability of materials. It employs a radiant heat source consisting of a 12- by 18-inch panel in front of which is placed an inclined 6- by 18-inch specimen of material. The orientation of the specimen is such that ignition is forced at its upper edge and the flame front progresses downward. A factor derived from the rate of progress of the flame front and another relating to the rate of heat liberation by the material under test are combined to provide a flame spread index (I_S) .

<u>RATE OF HEAT RELEASE</u>. A complete description of this apparatus and its operation can be found in a proposed ASTM standard publication (reference 3). An illustration of the apparatus is shown in figure 2. The RHRA consists of a 8- by 14- by 29-inch chamber with a radiant heat source consisting of four electrically energized heating elements (Glowbars) located at the back of the chamber. A variable transformer connected to the heating elements provides the capability of varying the heat flux at the surface of the test specimen from 0 to 8.3 watts per square centimeter (W/cm^2). Air is metered through the chamber from the bottom and exhausted through a 4- by 6-inch exhaust duct. A thermopile arrangement is located in such a way as to measure the temperature difference of the incoming and exhausted air. This test determines the release rate of heat from a material as a function of time when the material is subjected to radiant heat alone or radiant heat with forced ignition from a pilot flame. Materials can be tested in either a vertical or horizontal orientation.

VERTICAL BUNSEN BURNER. The vertical Bunsen burner test apparatus is described in detail in references 4 and 5. A photograph of the equipment is shown in figure 3. This is the test method referenced for showing compliance with Federal Aviation Regulations for the flammability of cabin interior materials (reference 1). Essentially, this apparatus consists of a draft-free cabinet 12 by 12 by 24 inches high, a specimen holder, a Bunsen burner with the necessary equipment to meter and regulate gas flow, and a timer for recording the flame time.

TABLE 1. DESCRIPTION OF MATERIALS

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No.	Chemical Composition	Thickness (in.)	Unit Weight (oz/yd ²)	Cabin Use
Fabrics				
204 209 210 211 212 218	Wool (90%)/Nylon (10%) FR Treated Nylon PVC/Cotton (Naugaform⊉) Wool (95%)/PVC (5%) Wool (100%) Cotton	0.052 0.052 0.044 0.036 0.040 0.012	16.6 16.2 36.2 12.3 14.8 3.6	Seat Cover and Drapery Seat Cover Seat Backrest Seat Cover Seat Cover Ticking
Foams				
213 215	FR Urethane FR Urethane	0.500 0.500	15.2 15.0	Seat Cushion Seat Cushion
Thermo- Plastics				
220 235	Polysulfone Polycarbonate	0.069 0.083	62.5 78.6	Thermoformed Parts Thermoformed parts
Panels				
223	PVF/rigid PVC/PVF/fiberglass-phenolic/ Nomex®-phenolic honeycomb/fiberglass- controlled epoxy	0.600	84.5	Sidewall
224	PVF/fiberglass-phenolic/Nomex paper- phenolic honeycomb-fiberglass batt/ fiberglass-phenolic	0.503	78.9	Ceiling
225	PVF/fiberglass-phenolic/Nomex paper- phenolic honeycomb/fiberglass-phenolic	0.505	89.8	Stowage Compartment
227	PVF/fiberglass-phenolic/Nomex-phenolic/ fiberglass-phenolic	0.087	46.8	Sidewall, Window Panel
228	PVF/Kevlar [®] -epoxy resin/Nomex-phenolic honeycomb/Kevlar-epoxy resin/PVF	0.395	43.6	Ceiling
229	PVF/polyester-chopped glass/Nomex- phenolic honeycomb/polyester-chopped glass	0.525	100.0	Stowage Compartment
233	PVF/fiberglass-epoxy/Nomex-honeycomb/ fiberglass-epoxy	0.380	56.5	Sidewall
234	Polyester-fiberglass molding compound	0.080	101.0	Ceiling
Flooring				
226 230	Wool carpet PVC over ABS laminate	0.250 0.080	74.0 95.4	Passenger Compartment Service and Lavatory

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FIGURE 1. RADIANT PANEL (E-162) (SHEET 1 of 2)

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FIGURE 1. RADIANT PANEL (E-162) (SHEET 1 OF 2)

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FIGURE 1. RADIANT PANEL (E-162) (SHEET 2 OF 2)

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LIMITING OXYGEN INDEX. This method is described in detail in ASTM Standard Method D-2863 (reference 6). A photograph of the equipment is shown in figure 4. Briefly, the apparatus consists of a test column of heat-resistant glass tube (3 inches inside diameter and 17.75 inches high). At the base of the column is a bed of glass beads approximately 3 inches deep to mix and distribute the metered mixture of oxygen and nitrogen evenly. The limiting oxygen index (LOI) is the minimum concentration of oxygen, expressed as percent by volume, in a mixture of oxygen and nitrogen which will just support combustion of a material.

<u>THERMOGRAVIMETRIC ANALYSIS</u>. Thermogravimetric analysis (TGA) is a method which provides a record of weight changes in a material sample as a function of temperature while it is being heated in a low-mass furnace. A Perkin Elmer TGS-1 Thermobalance (reference 7) was used in this study. A photograph of the TGA equipment is shown in figure 5.

The TGS-1 Thermobalance consists of an electrobalance mounted in a vacuum chamber permitting control of the atmosphere around the sample which is suspended inside the furnace from the balance beam. The furnace temperature is controlled through a Perkin Elmer temperature program control unit and the weight loss of the decomposing sample is recorded on a calibrated millivolt recorder.

TEST METHOD MEASUREMENTS.

RADIANT PANEL. Radiant panel test results are contained in table 2 and include the following:

1. Flame spread factor (F_S) where:

$F_{s}=1+1/t_{3}+1/(t_{6}-t_{3})+1/(t_{9}-t_{6})+1/(t_{12}-t_{9})+1/(t_{15}-t_{12})$

 $(t_3 \dots t_{15})$ are elapsed times in minutes from the start of specimen exposure until arrival of the flame front at distances from the top of the specimen indicated in inches by the numerical subscripts. The times associated with the furthest flame front advance are used in computing F_s .

2. The heat evolution factor (Q) is calculated according to the relation, Q=0.1 T/ β in which 0.1 is a constant, T is the observed maximum stack temperature rise at any stage of combustion over that observed from an asbestos cement board specimen, and β is the maximum stack thermocouple temperature rise for unit heat input rate from the calibration burner.

3. Flame spread index (I_S) is the product of the flame-spread factor (F_S) and the heat evolution factor (Q); $I_S = F_S Q$.

4. In addition to the above standardized information required to calculate I_s , other data collected and reported in the table includes ignition time (the time observed for the materials to start to burn), time for the flame front to reach the 3-inch flame front line, and the time to reach maximum recorded temperature rise.





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RADIANT PANEL RESULTS (ASTM TEST METHOD E-162) TABLE 2.

								Time to	Time to
	Material					T Net stack	Ignition Time	Reach 3 in line	Max. Temp.
	Category	Material No.	Fe	প	Is	Temp. Rise (°C)	(sec)	(sec)	(sec)
	Fabrics	204	12.3	6.24	78	35	80	33	50
		209	3.3	0.36	2.3	2	9	24	46
		210	17.4	12.1	211	67	2	24	96
		211	20.9	9.54	202	53	10	27	57
		212	15.3	5.04	77	28	6	35	60
		218	1.0	0	0	0	I	DNR(1)	I
	Foams	213	39.2	3.48	137	19	4	13	32
12		215	56.1	3.90	218	22	4	9	28
2	Thermoplastics	220	4.1	5.58	23	31	Q	93	222
	·	235	7.2	3.42	25	19	œ	66	100
	Panels	223	1.4	4.86	6.5	27	20	185	216
		224	8.6	2.04	18	п	14	41	92
		225	2.9	1.80	5.1	10	10	63	156
		227	7.4	1.08	80	ę	Ś	27	I
		228	17.1	4.68	80	26	٢	17	72
		229	9.2	3.42	32	19	12	38	96
		233	5.9	6° 0	5.2	5	'n	41	72
		234	4.2	6.93	29	39	11	148	234
	Flooring	226	5.4	9.78	53	54	7	136	244
		230	3.5	8.01	28	45	S	288	204

(1) Flame front did not reach 3-inch line.Data not available. NOTES:

<u>RATE OF HEAT RELEASE</u>. Rate of heat release tests were conducted in both the vertical and horizontal configuration. In the vertical configuration the test specimens were exposed to a radiant heat flux at the surface of the specimen of 2.5, 5, and 7.5 W/cm². The specimens exposed at 5 and 7.5 W/cm² were tested with and without piloted ignition; however, at 2.5 W/cm² the specimen would not ignite without the aid of a pilot flame. Horizontal tests were conducted at 2.5 and 5 W/cm² with piloted ignition. Self-ignition of the horizontal test specimens at 2.5 W/cm² could not be obtained, and at 5 W/cm² ignition was difficult to determine. Because the nonpiloted specimens burned relatively little, only forced ignition results are reported.

Results of the rate of heat release test are contained in tables 3 through 8. The rate of heat release (RHR) is calculated from the recorder millivolt (mV) reading of the thermopile output, the exposed surface area of the test specimen and the constant, K_h , obtained from calibration runs, where:

K_h = <u>RHR (Btu/min)</u> Recorder Reading (mV)

RHR(Btu/min-ft²) = <u>K_h(mV output</u>) A

A = exposed surface area of specimen (ft^2).

Total heat release in Btu/ft^2 is determined by integrating the millivolt output over the time interval of interest.

Total heat release is reported at 3-, 5-, and 10-minute intervals. The time required to reach maximum RHR is also reported in the tables.

VERTICAL BUNSEN BURNER. Vertical Bunsen burner test results are presented in table 9. These tests were conducted in accordance with Federal Aviation Regulations (FAR) 25.853a and 25.853b. Fabrics, foams, and carpets were exposed to the Bunsen burner flame for 12 seconds; thermoplastics and panels were exposed for 60 seconds.

The flaming time is the time in seconds that the test specimen continued to burn after removal of the burner flame.

Burn length is the distance from the exposed edge of the test specimen to the furthest evidence of irreparable damage, not including damage from soot or smoke.

All of the materials used in this test program satisfied the applicable FAR requirements.

LIMITING OXYGEN INDEX. The LOI test results are contained in table 10. The LOI is calculated by using the formula:

 $LOI(\%) = \frac{100 \times 02}{02 + N2}$

RATE OF HEAT RELEASE RESULTS, VERTICAL TEST SPECIMEN, 2.5 W/cm², WITH PILOT TABLE 3.

Material Category	Material No.	Peak Rate of Heat Release (Btu/min-ft ²)	Time to Reach Peak RHR (sec)	Total 3 min	Heat Rele (Btu/ft ²) 5 min	ase 10 min
Fabrics	204	254	48	511	713	1048
	209(T) 210	77	1 v	1 00		
	211	233	93	335 335	396 396	493 493
	212	216	37	343	467	652
	218(2)	ı	1	J	I	۱
Foams	213(1)	I	ı	I	I	١
	215(1)	I	1	I	ı	١
Thermo-	220(1)	I	I	I	ı	١
plastics	235(1)	I	ł	ī	ı	۱
Panels	223	334	127	969	1189	1893
	224	195	62	423	687	1338
	225	463	194	748	1294	2104
	227	68	28	141	194	343
	228	267	56	608	960	1470
	229	178	113	361	643	933
	233	8	33	132	194	282
	234	351	222	299	677	1629
Flooring	226	729	173	1242	2316	3161
	230	484	229	678	1576	3152

(1) Fabric 209 foams, and plastics fell from specimen holder and could not be tested in vertical configuration. (2) Fabric 218 chars but does not produce enough heat to raise thermopile temperature. NOTES:

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RATE OF HEAT RELEASE RESULTS, VERTICAL TEST SPECIMEN, 5 $W/\,\mathrm{cm}^2$, WITH PILOT TABLE 4.

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Material Category	Material No.	Peak Rate of Heat Release (Btu/min-ft ²)	Time to Reach Peak RHR (sec)	Total 3 min	Heat Releas (Btu/ft ²) 5 min ⁽³⁾	e 10 mín ⁽³⁾
Fabrics	204	455	36	1074	I	1
	209(1) 210	- 723	- 76	- 1541	11	11
	211 212 218 (2)	347 355 -	18 24 -	643 819		
Foams	213(1) 215(1)	11	11	i i	11	
Thermo- plastics	220(1) 235(1)	11	и Н Т	11	11	11
Panels	223 224 225 228 228 233 233	451 282 467 474 412 312 565	95 134 110 59 86 74 107	916 599 405 405 916 1030	1321 977 1488 669 1532 1391 854 1506	
Flooring	226 230	824 544	92 103	1937 1153	2633 1761	11
NOTEC (1)	1 Eshelo 200 fo	ame and alcetic	. foll from the on	od nomboo	ldow and oon	14 204 60

Fabric 209 foams, and plastics fell from the specimen holder and could not be tested in the vertical configuration. Fabric 218 chars but does not produce enough heat to raise thermopile E NUTES

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Material was consumed before time was reached. Data not available.

RATE OF HEAT RELEASE RESULTS, VERTICAL TEST SPECIMEN, 5W/cm², WITHOUT PILOT TABLE 5.

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Material Category	Material No.	Peak Rate of Heat Release (Btu/min-ft ²)	Time to Reach Peak RHR (sec)	Tota 3 min	al Heat Rele (Btu/ft ²) 5 min(4)	ase 10 min ⁽⁴⁾
Fabric	204 209(1) 210 211 212 218(2)	254 - 591 193 -	37 - 102 28 -	45 - 1250 449 396		
Foams	213(1) 215(1)	11	11	11	i I	
Thermo- plastics	220(1) 235(1)	1 1	1.1	11	i 1	11
Panels	223 224 225 227 228 233(3) 234(3)	362 455 401 	69 31 73 80 108 108	634 229 889 396 801 801	801 361 1356 555 1638 1162 -	
Flooring	226 230	787 607	115 115	1558 1294	2360 -	11

(1) Fabric 209 foams and plastics fell from the speciman holder and could not be tested in the vertical configuration. NOTES:

Fabric 218 chars but does not produce enough heat to raise the thermopile temperature. 6

Not tested because of material shortage. ı £ 3

Material consumed before time was reached. Data not available.

RATE OF HEAT RELEASE RESULTS, VERTICAL TEST SPECIMEN, 7.5 W/cm², WITH AND WITHOUT PILOT TABLE 6.

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			MITH PILOT		1	WITHOUT PILOT	
		Peak Rate of		Total Heat Release	Peak Rate of		Total Heat Release
Material Category	Material No.	Heat Release (BTU/min-ft ²)	Time to Reach Peak RHP (sec)	at 3 minutes (BTU/ft ²)	Heat Release (BTU/min-ft ²)	Time to Reach Peak RHR (sec)	at 3 minutes (BTU/ft ²)
Fabric	210	924	92	1867	618	106	1303
Panel	224	262	124	528	270	128	519
	225	439	76	977	524	110	1083
	228	478	75	1083	463	110	977
Flooring	226	866	103	1823	908	91	1858

NOTES: (1) To prevent damage to the test apparatus, a limited number of materials were tested at this high flux level.

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RATE OF HEAT RELEASE RESULTS, HORIZONTAL TEST SPECIMEN, 2.5 $W/cm^2,\ WITH$ PILOT TABLE 7.

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Material Category	Material No.	Peak Rate of Heat Release (Btu/min-ft ²)	Time to Reach Peak RHR (sec)	Tota. 3 min	l Heat Rele (Btu/ft ²) 5 min	ease 10 min(2)
Fabrics	204 209 210	239 352 334	57 111 90 25	414 652 713 306	581 1013 995 528	
	212 218(1)	175	<u>5</u>	317	423	i i j
Foams	213 215	467 479	55 76	898 960	1215 1312	
Thermo- plastics	220 235	215 511	408 242	238 317	634 1242	1664 2509
Panels	223 224 225 228 228 233 233	337 191 388 324 325 308	128 181 184 184 153 168 292 292	564 370 537 537 564 669 97 97	1039 678 1153 203 704 1180 590	1655 1400 1911 484 1743 1735 1013 1233
Flooring	226 230	686 414	163 98	1083 652	2122 1435	2958 2597

(1) Fabric 218 chars but does not produce enough heat to raise the thermopile temperature.
(2) Material was completely consumed before the time was reached.
- Data not available. NOTES:

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RATE OF HEAT RELEASE RESULTS, HORIZONTAL TEST SPECIMEN, 5 W/cm^2 , with PILOT TABLE 8.

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Material Category	Material No.	Peak Rate of Heat Release (Btu/min-ft ²)	Time to Reach Peak RHR (sec)	Total He (Btu/ 3 min	at Release ft2)(2) 5 min
Fabrics	204	332 540	57	475 1003	696 1338
	202 210 211	370 201	58 29	502 458	1013 687
	212 218(1)	239 -	о ^с 1	-	-
Foams	213 1 215	459 539	62 54	942 1074	1303 1462
Thermo- plastics	220 235	498 554	189 131	872 925	1779 1541
Panels	223 224 225 228 229 233 234	355 321 439 437 416 416	96 152 104 86 73 73	784 696 942 467 810 493 766	1215 1277 1479 766 1224 1426 1426 1189
Flooring	226 230	829 451	121 122	1814 1004	2694 [.] 1726

(1) Fabric 218 chars but does not produce enough heat to raise the thermopile temperature. NOTES:

(2) All materials were consumed before 10 minutes.Data not available.

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TABLE 9. VERTICAL TEST RESULTS PER FAR 25.853 (ASTM TEST METHOD F501-77)

Material		Flaming Time	Burn Length	
Category	Material No.	<u>(sec)</u>	(in.)	Passes FAR
Fabrics	204	14.0	1.9	ves
	209	0.5	2.7	ves
	210	4.3	2.8	ves
	211	4.4	3.2	ves
	212	2.1	2.1	ves
	218	0.5	4.6	yes
Foams	213	1.0	4.5	yes
	215	0.5	3.3	yes
Thermoplastics	220	0.5	3.2	yes
	235	0.8	1.1	yes
Panels	223	5.5	5.6	yes
	224	0.5	3.6	yes
	225	11.8	5.5	yes
	227	0.5	5.5	yes
	228	4.0	5.6	yes
	229	0.5	3.1	yes
	233	1.7	3.8	yes
	234	2.4	2.8	yes
Flooring	226	0,5	1.5	yes
5	230	0.5	1.5	yes

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Limited Oxygen Index <u>
100x02</u> 02+N2 35.4 27.4 26.2 34.8 34.8 43.2 28**.**8 34**.**1 24.7 24.7 36.7 34.5 31.4 46.9 46.9 26.7 32.1 32.2 37.3 27.3 27.9 Nitrogen Flow (cm³/sec) 164 204 1183 116 109 83 131 220 220 86 86 86 209 161 156 106 171 188 122 202 163 Oxygen Flow (cm³/sec) 8 1 2 3 3 3 3 55 49 76 63 76 63 Material No. 204 209 210 211 212 218 218 223 224 225 227 228 228 223 233 213 215 220 235 226 230 Thermoplastics Material Category Flooring Fabrics **Panels** Foams

TABLE 10. LIMITING OXYGEN INDEX TEST RESULTS

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where 0_2 is the volumetric flow of oxygen in cubic centimeters per second (cm^3/sec) at the limiting concentration to just support the combustion of the specimen, and N₂ is the corresponding volumetric flow of nitrogen in cm^3/sec .

THERMOGRAVIMETRIC ANALYSIS. Results of the TGA tests are summarized in tables 11, 12, and 13. The results reported in these tables include: (1) temperature at first decomposition, or the temperature at which the material began to lose weight because of exposure to heat; (2) the temperature at 50 percent weight loss, or the temperature where 50 percent of the initial weight of the test specimen was decomposed; and (3) the char yield (Y_c), or the percent weight of the specimen remaining as char or unburned material after exposure to a temperature of 700 degrees centigrade (°C).

TGA tests were conducted at three conditions: (1) in air at a heating rate of 20° centigrade per minute (°C/min), (2) in air at 160° C/min, and (3) in nitrogen at 20° C/min.

TEST RESULTS AND ANALYSIS

RADIANT PANEL ASTM E-162.

The test data contained in table 2 show the following characteristics for the materials tested by this method.

The fabrics exhibited the greatest range in behavior. Those fabrics containing polyvinyl chloride (PVC) had the higher flame spread index (I_S) ; both PVC-containing materials exceeded 200. Wool and a wool/nylon blend had the next higher flame spread indices at 77 and 78, respectively. It is noteworthy that the wool blended fabrics, although containing 90 percent or more wool, had significantly different ratings, apparently depending on the use of PVC or nylon. The F_S values of the flame retardant (FR) nylon and cotton materials were both very low, indicating that these materials are superior in terms of the radiant panel test. However, the reasons for these low F_S values are qualified below.

The low melting temperature of the nylon resulted in rapid melting, and the material flowed away from the hottest heating zone before significant flaming occurred. Because of the light weight and apparent heavy FR nature of the cotton fabric, this material charred without producing heat or flame when exposed to the radiant panel.

The urethane foams experienced rapid surface flame propagation rates and consequently had the highest F_s value of all of the materials tested. However, the foams also produced less heat than about 50 percent of the materials tested, primarily because the foams are significantly lighter in weight.

The thermoplastics, panels, and flooring materials all have a relatively low I_s . Only two of the 12 materials tested in these catagories had a I_s value

THERMOGRAVIMETRIC ANALYSIS RESULTS IN AIR AT 20° C/min HEATING RATE TABLE 11.

Material Category	<u>Material No.</u>	Temp. at First Decomposition (°C)	Temp, at 50 Percent Weight Loss (°C)	Char Yield at 700° C (%)
Fabrics	204 209 211	263 218 277 277	398 470 DNR(1) 449	4.5 0 0.8 0.8
Foams	216 218 213 215	273 273 301	454 345 DNR DNR	0.5 8,4 88,2 88,2
Thermoplastics	220 235	484 502	DNR 545	71.1 1.4
Panels	223 224 225 228 228 233 233	279 254 286 319 312 343	DNR 481 565 DNR DNR	50°7 35°3 67°9 67°9 57°2 57°2
Flooring	226 230	271 273 293	449 400	1,1 6,0

NOTE: (1) DNR = Did not reach 50% weight loss.

THERMOGRAVIMETRIC ANALYSIS RESULTS IN AIR AT 160° C/min HEATING RATE TABLE 12.

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Material Category	Material No.	Temp. at First Decomposition (°C)	Temp. at 50 Percent Weight Loss (°C)	Char Yield at 700° C (%)
Fabrics	204 209	334 508	424 529	13.3 2.5
	210 211 212	363 330 353	430 433 200	21.3 18.7 26.8
Foams	213 213 215	387	coc DNR (1) NNG	90.2 90.7 86.0
Thermoplastics	220 235	588 574	648 612	39.8 26.9
Panels	223 224 225 229 229	338 347 354 354 354 354 354 355 355 355 355 355	465 657 DNR DNR 555 DNR	27.8 47.9 59.3 25.8 25.2
Flooring	233 234 226 230	375 358 360 360	600 423 440	5.5 17.2

NOTE: (1) Did not reach 50% weight loss.

THERMOGRAVIMETRIC ANALYSIS RESULTS IN NITROGEN AT 20° C/min HEATING RATE TABLE 13.

Material Category	<u>Material No.</u>	Temp. at First Decomposition (°C)	Temp. at 50 Percent Weight Loss (°C)	Char Yield at 700°C (%)
Fabrics	204 209	283 458	432 566	5.9 9.6
	210	300	396	11.0
	211	287	374	2.9
	212	292	398	9.5
	218	240	342	10.5
Foams	213	256	355	0
	215	270	385	6*0
Thermoplastics	220	526	581	38.4
	235	506	555	23.5
Panels	223	210	DNR(1)	59.4
	224	254	505	43.8
	225	268	DNR	57.8
	227	270	DNR	72.9
	228	275	, 095	27.8
	229	303	DNR	55.6
	233	301	DNR	60.0
	234	254	430	40.0
Flooring	226	274	358	17.5
	230	282	387	18.0

NOTE: (1) Did not reach 50% weight loss.

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of more than 50. One of these was a ceiling panel that had a rapid rate of flame travel (high F_8) and the other was a wool carpet that produced relatively large amounts of heat (high Q).

RATE OF HEAT RELEASE.

The Rate of Heat Release Apparatus is a test method that is still under development. As demonstrated in the following discussion, it can provide detailed temporal heat release rate data at various exposure conditions. The test data for this series of tests are contained in tables 3 through 8.

Table 3 shows the test results for materials tested in the vertical configuration while exposed to a surface heat flux of 2.5 W/cm^2 and piloted ignition. It should be noted that ignition of any of the specimens was not possible at this low heat flux level without application of the pilot flame.

Foams, thermoplastics, and some fabrics, such as nylon, that melt and fall from the specimen holder, cannot be tested in the vertical configuration. The light-weight cotton fabric was also excluded from this test group because it only chars and does not produce enough heat to raise the thermopile temperature.

The maximum or peak rate of heat release in British Thermal Units per minute square foot $(Btu/min-ft^2)$ appears to be the most useful test data for ranking materials by this test method. The PVC coated cotton produced a higher heat release than the wool or wool/nylon blends in the fabric category. This finding is consistant with the radiant panel results for heat release.

Panels have a wide range of heat release rate values from a low of 70 $Btu/min-ft^2$ for a light-weight sidewall panel to a high of 463 $Btu/min-ft^2$ for a thicker and heavier storage compartment panel. Panel thickness, unit weight, or composition do not appear to have an outward effect on heat release.

The rate of heat release was greater at 2.5 W/cm^2 for the flooring materials than any other materials tested; 729 Btu/min-ft² for the wool carpet and 484 Btu/min-ft² for the vinyl acrylónitrite/butadiene/styrene (ABS) laminate. The maximum heat release rate from the carpet was reached on a second peak following the burning off of the nap.

Tables 4 and 5 are the results of the rate of heat release tests at 5 W/cm^2 , in the vertical test configuration, with and without piloted ignition. In all but two cases the rate of heat release was higher when piloted ignition was used. In all piloted ignition tests, heat release was higher at 5 W/cm^2 than at 2.5 W/cm². However, at 5 W/cm^2 the specimens were consumed much more rapidly than at 2.5 W/cm². For example, at 5 W/cm^2 fabrics were completely consumed in less than 5 minutes, and panels and flooring materials were consumed in less than 10 minutes.

Table 6 contains the results for a limited number of materials tested in the vertical configuration at a surface heat flux of 7.5 W/cm^2 , with and without piloted ignition. Maximum heat release rates were surprisingly close at 5 W/cm^2 and 7.5 W/cm^2 , with and without a pilot flame.

All twenty of the selected materials were tested in a horizontal configuration. The test specimens were exposed to surface heat flux levels of 2.5 W/cm² and 5 W/cm². The reflective metal surface used to transmit heat to a horizontal specimen precluded heat flux levels above 5 W/cm².

The advantage of testing materials in the horizontal configuration was that all materials including those that melt or fall from the vertical specimen holder could be tested. The pan-like horizontal holder contained the melted material and allowed it to burn in the liquid state. Because positive ignition could not always be accomplished without the aid of a pilot flame, all horizontal tests utilized the pilot flame.

For the 2.5 W/cm^2 tests (table 7), all flaming of the fabric and foam specimens stopped before 10 minutes; thermoplastics, panels, and flooring continued to flame past the 10-minute test period. For the 5 W/cm^2 tests (table 8), all materials were completely consumed before 10 minutes; therefore, total heat release was reported at 3 and 5 minutes only. As with the piloted vertical tests, heat release was higher at 5 W/cm^2 than at 2.5 W/cm^2 . (A urethane foam was the only exception.)

VERTICAL BUNSEN BURNER FLAME TEST.

Test results for the vertical flame test method are contained in table 9.

As required by FAR 25.853, fabrics, foams, and the one carpet (No. 226) were exposed to the 12-second Bunsen burner flame. Panels, thermoplastics, and the laminated flooring material (No. 230) were exposed to the Bunsen burner flame for a 60-second duration.

All of the materials selected for this program comply with the FAR requirements. One of the FAR requirements, flaming time of melted drippings, was not evident with any of the materials and, therefore, was not reported.

The wool/nylon blend fabric (No. 204) and a panel (No. 225) used for storage compartments were the only specimens that continued to flame for long periods after removal of the Bunsen burner flame. However, for both of these materials, the flaming times were less than the 15-second allowable limit prescribed in the FAR. For most materials, the burn lengths and flaming times were well within the FAR allowable limits.

LIMITING OXYGEN INDEX (LOI).

Test results obtained by this test method are contained in table 10.

The National Aeronautics and Space Administration (NASA) Ames Research Center (reference 8) has specified an LOI of 35 or greater in their endeavors to select and develop advanced interior materials for aircraft.

The two urethane foams had the poorest LOI values (both 24.7 percent) of any of the materials tested. The flooring materials also had low LOI values: 27.3 percent for the wool carpet and 27.9 percent for the PVC/ABS laminate.

Four of the six fabrics recorded an LOI comparable or greater than 35; however, the PVC coated fabric (No. 210) and the nylon fabric (No. 209) had low LOI values of 26.2 and 27.4 percent, respectively. The panels ranged from a low of 26.7 percent for the ceiling panel (No. 228) to a high of 46.9 percent for a sidewall/window panel (No. 227).

Although panel No. 227 exhibited an LOI approximately 10 units or more higher than the remaining panels, it is noteworthy that the gross chemical composition of this panel was no different than that of any of the other panels.

THERMOGRAVIMETRIC ANALYSIS (TGA).

TGA results are contained in tables 11 through 13. Analysis was conducted under three different test conditions: (1) at a heating rate of 20° C/min in an air environment, (2) at a heating rate of 160° C/min (maximum rate attainable) in an air environment, and (3) at a heating rate of 20° C/min in a nitrogen environment.

A possible useful method for rating materials is in terms of the temperature reached when the material first starts to decompose. Higher temperatures at first decomposition were obtained with the higher heating rates (except for panel No. 227) because the environmental temperature was greater than the sample temperature at 160° C/min, as compared to 20° C/min, because of the finite time required for the absorption of heat by the sample as the result of heat sink effects. Therefore, the slower heating rate is a more accurate test for determining the sample temperature at initial decomposition.

Char yield was found to be dependent on both heating rate and environmental composition. In air, char yield varied significantly with heating rate (e.g., thermoplastics, fabrics, etc.) with no consistent trends. In most cases the char yield (at 20° C/min) was greater in nitrogen than in air. However, there were seven materials that were exceptions to this rule, with the urethane foams the most extreme example. Although the temperature at first decomposition for the foams was fairly comparable in both environments, the Y_C value at 700° C was considerably less in nitrogen (0 and 0.9 percent) as compared to air (94 and 98 percent).

COMPARISON OF TEST METHODS

The five different test methods were compared in terms of the measurements of ignitability, flame spread, heat release, or general performance. This was done primarily by plotting and comparing the measurements of interest by each test method. Because there were more fabrics and panels tested than other materials, the results from these two materials catagories were used for comparison purposes. In addition to the plotted data, the coefficient of correlation (r) was calculated for each set of plotted results. This calculation was done separately for fabrics and panels and is recorded along with the related plot. The coefficient of correlation is a simple way of indicating the degree of relationship between each pair of variables, and was calculated

from the formula:

$$r = \frac{N\Sigma XY - (\Sigma X) (\Sigma Y)}{\sqrt{\left[N\Sigma X^2 - (\Sigma X)^2\right] \left[N\Sigma Y^2 - (\Sigma Y)^2\right]}}$$

where:

N is the number of materials

- X is the value from the X axis of the plot
- Y is the value from the Y axis of the plot

The value of r ranges from -1.00 to 0.00 to +1.00, with -1.00 and +1.00 indicating perfect relationship between the two variables and 0.00 indicating no relationship.

Figures 6A through 6F show the plotted data for the results considered to be related to ignitability. The plotted data and the coefficient of correlation for the six pairs of ignitability data indicates that there is no apparent relationship between the various test measurements. The highest correlation was between decomposition temperature at 160° C/min heating rate and LOI for fabrics (figure 6D). This pair of variables has an r value of -0.704. Because the variables here are inversely related, which is contrary to the expected behavior, it is believed that this relatively high r value is more fortuitous than indicative of a physical relationship.





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FIGURE 6. COMPARISON OF MATERIALS FOR IGNITABILITY (SHEET 2 of 2)

Figures 7A through 7C show the plotted data for the three pairs of test results related to flame spread. Again, the panels did not show a very good correlation. However, there appears to be a relationship for fabrics between the time-to-peak rate of heat release at both 2>5 W/cm² and 5 W/cm² and the radiant panel F_s (figures 7B and 7C).

Figures 8A through 8H show the plotted data for the results of the heat release category. Some correlation for panels is evident from the RHR results of the rate of heat release apparatus operating at 2.5 W/cm² and 5 W/cm² in the horizontal specimen configuration and the radiant panel E-162 heat evolution factor Q (figures 8B and 8D).

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Figures 8E and 8F show a good correlation of panels for the radiant panel E-162 heat evolution factor Q versus RHR in the vertical test configuration at heat flux exposures of 2.5 and 5 W/cm². If panel No. 225 is omitted for these calculations, the r value in both cases would be over 0.9. Char yield, Y_c , times unit weight of material in oz/yd² versus radiant panel E-162 heat evolution factor Q (figure 8G) also shows good correlation for panels.

Figures 9A through 9J contain the plotted data based on the performance of a material in terms of the indices or measurements recommended for the individual test. As shown in figure 9C, the two measurements/indices which exhibited the greatest relationship to one another were the horizontal rate of heat release at 2.5 W/cm² and the LOI (r=0.832 for fabrics, 0.621 for panels, and 0.669 for fabrics and panels together). The remaining nine pairs of variables show very little correlation.

Figures 10A and 10B are plots of RHR versus time for three specimen surface heat flux levels in the vertical test configuration. In figure 10A, a wool carpet shows two heat release peaks when tested at 2.5 W/cm². The first peak corresponds to the burning off of the pile surface; the second peak is reached following ignition of the heavier base material. There is no discernible lag time between the ignition of the pile and base material at 5 and 7.5 W/cm². The heat release rate profiles are practically identical at 5 and 7.5 W/cm². At 2.5 W/cm² the peak value is lower and occurs later than at 5 or 7.5 W/cm².

The panel (figure 10B) also showed nearly identical heat release profiles at 5 and 7.5 W/cm^2 . At 2.5 W/cm^2 the heat release profile is significantly lower than at 5 or 7.5 W/cm^2 .



COMPARISON OF MATERIALS FOR F! AME SPREAD

FIGURE 7.



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FIGURE 8. COMPARISON OF MATERIALS FOR HEAT RELEASE (SHEET 1 of 2)





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FIGURE 9. TEST METHOD PERFORMANCE (SHEET 1 of 3)





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FIGURE 9. TEST METHOD PERFORMANCE (SHEET 3 of 3)

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Figures 11A through 11D compare the rate of heat release histories for vertical and horizontal configurations at 2.5 and 5 W/cm^2 . In the case of the wool carpet (figures 11A and 11B), the curves are very close for both configurations, with the peak reaching a slightly higher value when tested vertically. The first peak in figure 11A is a result of the burning pile fabrics, has the same value, and occurs at the same time for both the vertical and horizontal tests. Figures 11C and 11D are the vertical and horizontal heat release profiles for a panel. At 2.5 W/cm² the burning characteristics are different at the two sample orientations. However, at 5 W/cm² (figure 11C) the burning characteristics are similar to the carpet material; e.g., a comparable slopeto-peak value for both sample orientations with the vertical peak slightly higher than the horizontal peak.

Ranking of the 20 materials by each test method is presented in tables 14 and 15. The materials are ranked numerically by material number under each of the test methods utilized. The material which obtained the best results is ranked in the first position, with the other test materials following accordingly. Table 14 ranks the material by the usage category they represent; e.g., fabrics, foams, plastics, panels, and floor coverings.

Table 14 illustrates how materials may be ranked differently according to different test methods. The urethane foams and thermoplastics are a good case in point. Each of these categories contained two materials. In terms of the seven test measurements or indices, foam No. 213 was ranked first by four tests while foam No. 215 was ranked first by the remaining three tests. A similar situation existed for the thermoplastics. Strictly in terms of ranking, it would be difficult to select the "best" material from either the two foams or the two thermoplastics. Another example of this anomoly is found with the fabrics. The cotton ticking material (No. 218) was ranked first by four test measurements/indices but was also last twice and next to last once.

Some materials within a usage category are consistently ranked higher than others. This was most prominent in the case of the flooring materials. However, for the panels the selection process was slightly more difficult. Panel No. 227 was ranked first by four test methods. In all four cases it was rated significantly higher than the panel which was ranked second. Although ranked fourth in terms of flame spread index (I_8) , its actual rating $(I_8=8)$ is considered good by most standards and comparable to the first-ranked material $(I_8=5.1)$. Similarly, a ranking of fourth in terms of thermal decomposition at 160° C/min was only 21° C below the material ranked first. Thus, materials should not be compared on a ranking basis without consideration of the magnitude of test measurements or indices. When this type of analysis is performed for the panels, No. 227 appears to be the "best" of the panels.

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In table 15 all materials were ranked irrespective of usage category. This table positively illustrates the futility of selecting materials based on a simple ranking system. The ranking will almost always change for a different test method or measurement. However, if the actual data is analyzed as tabulated above for the panels, it may be possible, in some cases, to select materials which are consistently rated better than others on the basis of multiple tests.



RATE OF HEAT RELEASE, VERTICAL/HORIZONTAL CONFIGURATION COMPARISON (SHEET 1 of 2) FIGURE 11.



TABLE 14. RANKING OF MATERIALS BY USAGE CATEGORY

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					Peak RHR at 2.5 W/cm ² ,	Peak RHR at 5 W/cm ² ,	TGA-lst Decomposition	TGA-lst Decomposition
Usage Category	Rank Order No.	Radiant Panel (I _S)	Vertical Burn Length (in)	<u>101 (%)</u>	Piloted Ignition (BTU/min-ft ²)	Piloted Ignition (BTU/min-ft ²)	at 20°C in Air (°C)	at 160°C <u>in Air (°C)</u>
Fabrics	1	218	204	218	218	218	210	209
	2	209	212	212	212	211	212	210
		212	209	204	211	212	211	212
	4	204	210	211	204	204	204	204
	2	211	211	209	210	210	218	211
	6	210	218	210	209	209	209	218
Urethane								
Foams	1	213	215	213	213	213	215	215
	2	215	213	215	215	215	213	213
The rmo-								
plastics	1	220	235	235	220	220	235	220
	2	235	220	220	235	235	220	235
Panels	1	225	234	227	227	227	227	233
	2	233	229	234	233	233	233	234
	e	223	233	223	224	224	228	229
	4	227	225	224	234	223	229	227
	ŝ	224	227	233	228	. 228	225	224
	9	234	223	229	223	234	223	228
	7	229	224	225	229	229	234	223
	80	228	228	228	225	225	224	225
Floorine	1	230	230	230	230	230	230	230
	5	226	226	226	226	226	226	226

TABLE 15. RANKING OF MATERIALS FOR FIVE TEST METHODS

Rank	Radiant	Vertical Rum		Peak RHR at 2.5 W/cm ² Horizontal With Pilot	Peak RHR at 5 W/cm ² Horizontal	TGA-lst Decomposition	TGA-1st Decomposition
Order No.	Panel (Is)	Length (in)	<u>[2] [2] [2] [2] [2] [2] [2] [2] [2] [2] </u>	(BTU/min-ft ²)	(BTU/min-ft ²)	in Air (°C)	in Air (°C)
1	218F	235T	227P	218F	218F	235T	220T
2	209F	230C	218F	227P	227P	220T	235T
e	225P	226C	234P	233P	211F	227P	209F
4	233P	204F	223P	212F	233F	233P	223P
Ś	223P	212F	212F	211F	212F	228P	215U
9	227P	209F	204F	224P	224P	229P	233P
7	224P	234P	211F	220T	204F	215U	210F
8	220T	210F	224P	204F	223P	230C	230C
6	235T	229P	235T	234P	228P	210F	213U
10	230C	220T	233P	228P	210F	225P	234P
11	234P	211F	229P	210F	234P	212F	229P
12	229P	215U	225P	223P	229P	223P	227P
13	226C	233P	220T	209F	225P	211F	212F
14	212F	213U	230C	229P	230C	213U	224P
15	204F	218F	209F	225P	213U	234P	22 8 P
16	228P	225P	226C	230C	220T	226C	225P
17	213U	227P	228P	213U	215U	204F	204F
18	211F	223P	210F	2150	209F	224P	211F
19	210F	224P	213U	235T	235T	218F	226C
20	2150	228P	2150	226C	226C	209F	21 8 F

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C = Carpets F = Fabric P = Panels T = Thermoplastics U = Urethane

NOTES:

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CONCLUSIONS

Based upon the evaluation of 20 aircraft materials in terms of five widely used flammability test methods, it is concluded that:

1. There were practically no test methods that correlated either ignitability, flame spread, or heat release for both fabrics and panels. The only exception was the Rate of Heat Release Apparatus, for rate of heat release at 2.5 W/cm^2 for a horizontal test configuration versus the limiting oxygen index (figure 9C).

2. Panels show good correlation for heat release between the Rate of Heat Release Apparatus and the Radiant Panel E-162 heat evolution factor.

3. The Rate of Heat Release Apparatus shows no significant difference in test results at heat flux levels of 5 and 7.5 W/cm^2 .

4. The capability of testing a material in a horizontal orientation in the Rate of Heat Release Apparatus permits the evaluation of materials which would normally be precluded because of their melting behavior.

5. In the Rate of Heat Release Apparatus the heat release profiles for materials that do not melt were similar in both the vertical and horizontal test configurations.

6. Ordering of materials in terms of performance is dependent on the test method utilized.

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7. It may be possible, in some cases, to select materials based on multiple test evaluation if consideration is given to the magnitude of the test measurements or indices and not simply to the numerical ranking of the materials.

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