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EVALUATION OF EXISTING FLAMMABILITY TEST METHODS BY COMPARISON OF THE FLAMMABILITY CHARACTERISTICS OF INTERIOR MATERIALS

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FINAL REPORT

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16. Abstract

Twenty aircraft materials representing a cross section of the interior of a wide-bodied passenger compartment were tested by five laboratory test methods for comparability. The five test methods utilized were: (1) Radiant Panel, (2) Rate of Heat Release, (3) Vertical Bunsen Burner, (4) Limited Oxygen Index, and (5) Thermogravimetric Analysis. Correlation of the results obtained from the five test methods were made for ignitability, flame spread, heat release, performance, heat flux exposure, and ranking of materials by performance.

Heat release data obtained from the Rate of Heat Release Apparatus and the E-162 radiant panel indicate the best correlation for panels.

17. Key Words

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METRIC CONVERSION FACTORS

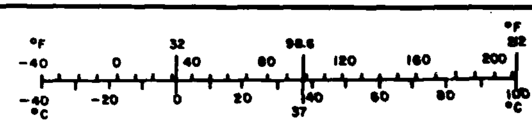
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10 286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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
F_s	Flame spread factor
I_s	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
Y_c	Char yield

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 self-extinguishing 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 this 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 and 5), (4) ASTM D-2863 Limiting Oxygen Index (reference 6), and (5) Thermogravimetric Analyzer (reference 7).

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).

RATE OF HEAT RELEASE. 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

No.	Chemical Composition	Thickness (in.)	Unit Weight (oz/yd^2)	Cabin Use
Fabrics				
204	Wool (90%)/Nylon (10%)	0.052	16.6	Seat Cover and Drapery
209	FR Treated Nylon	0.052	16.2	Seat Cover
210	PVC/Cotton (Naugaform®)	0.044	36.2	Seat Backrest
211	Wool (95%)/PVC (5%)	0.036	12.3	Seat Cover
212	Wool (100%)	0.040	14.8	Seat Cover
218	Cotton	0.012	3.6	Ticking
Foams				
213	FR Urethane	0.500	15.2	Seat Cushion
215	FR Urethane	0.500	15.0	Seat Cushion
Thermo-Plastics				
220	Polysulfone	0.069	62.5	Thermoformed Parts
235	Polycarbonate	0.083	78.6	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	Wool carpet	0.250	74.0	Passenger Compartment
230	PVC over ABS laminate	0.080	95.4	Service and Lavatory

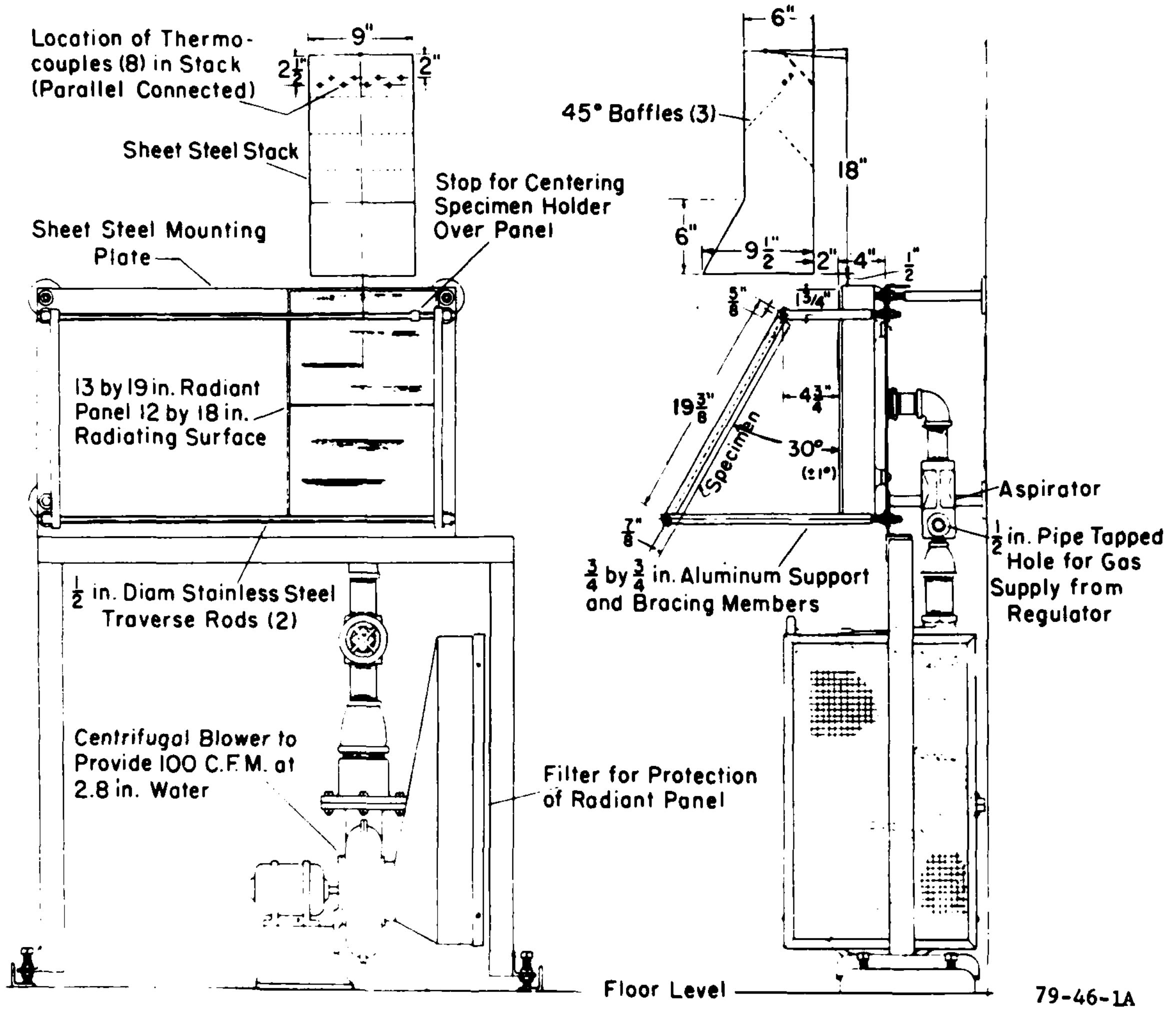

FIGURE 1. RADIANT PANEL (E-162) (SHEET 1 of 2)

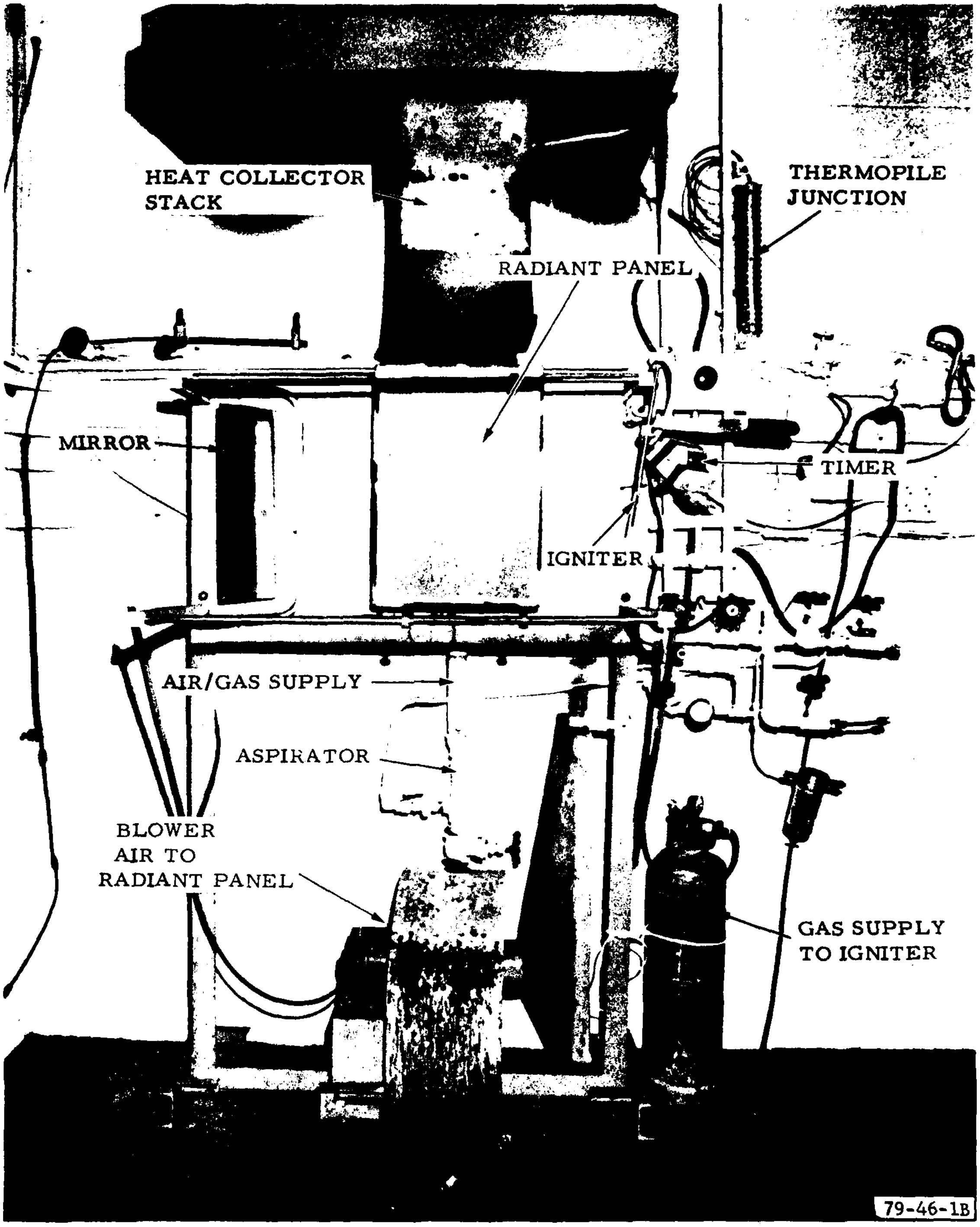

FIGURE 1. RADIANT PANEL (E-162) (SHEET 1 OF 2)

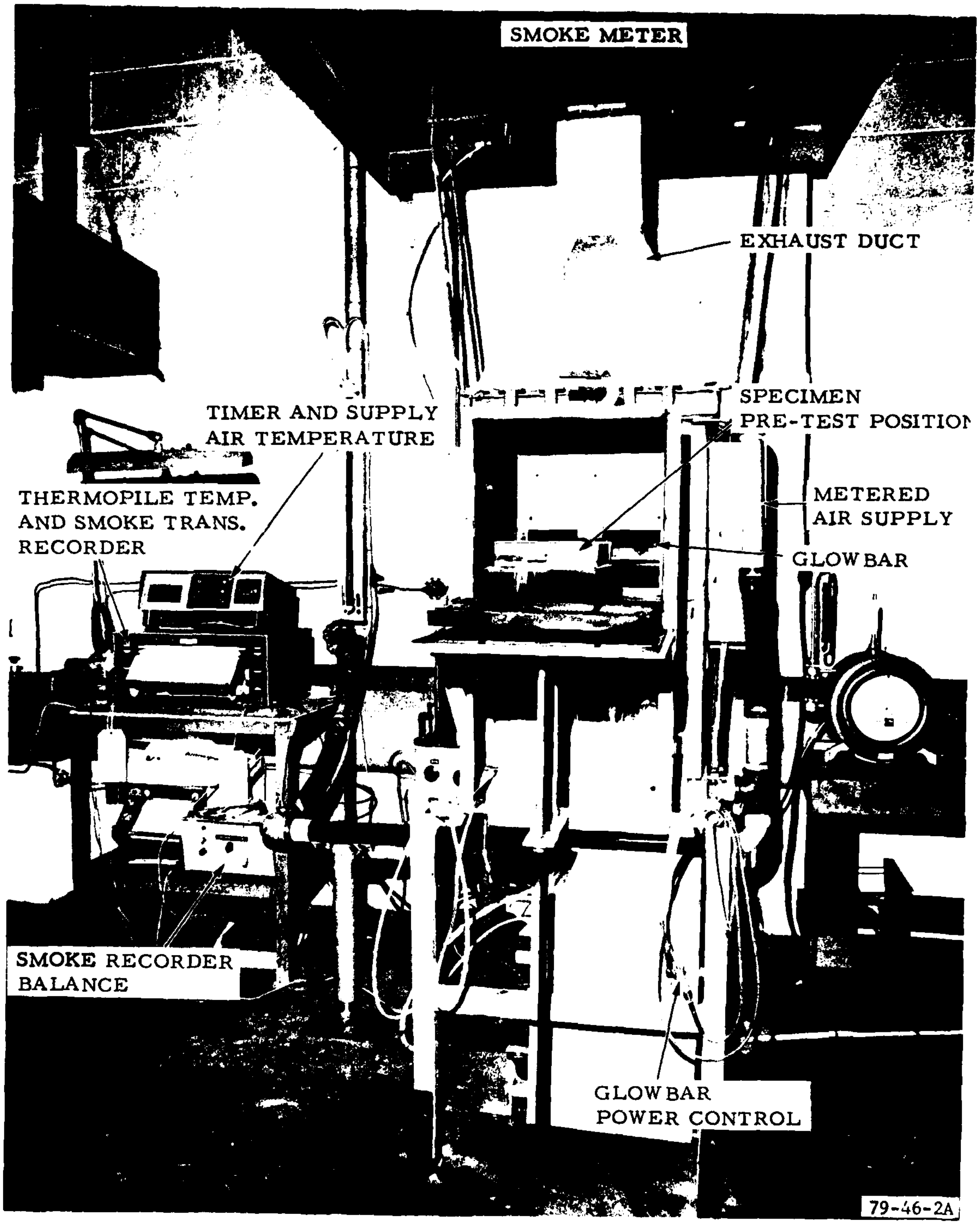

FIGURE 1. RADIANT PANEL (E-162) (SHEET 2 OF 2)

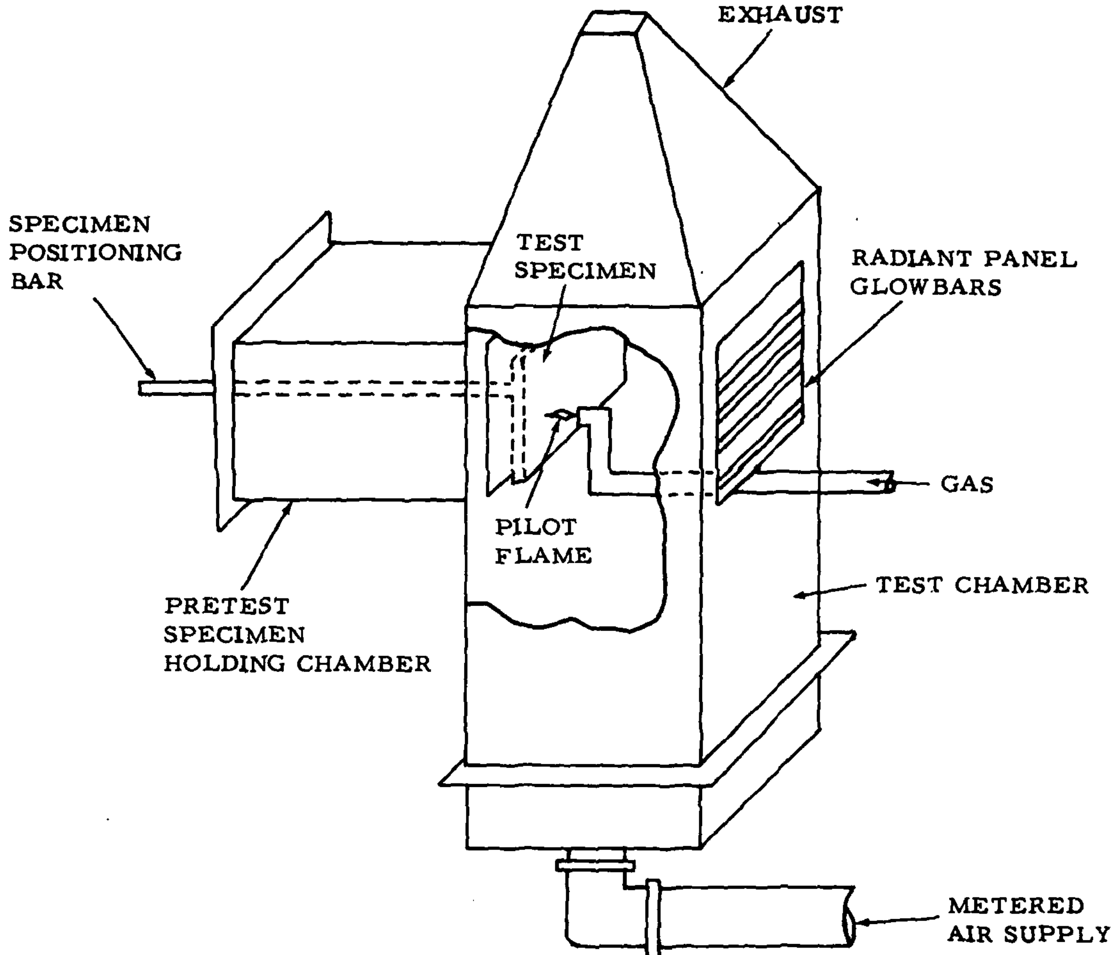

FIGURE 2. RATE OF HEAT RELEASE APPARATUS (SHEET 2 of 2)

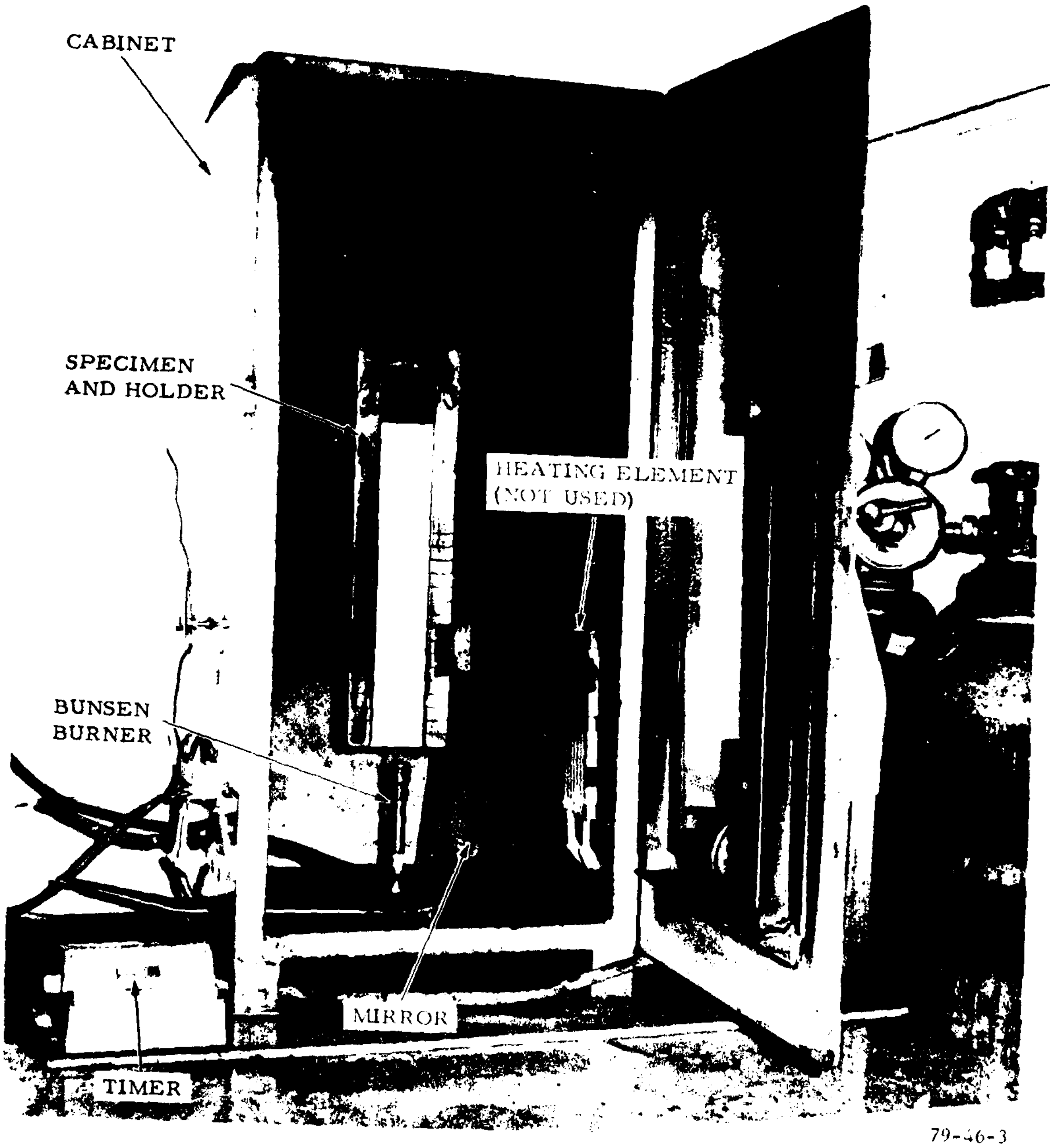

FIGURE 3. VERTICAL, FAR 254.853, ASTM F501

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.

THERMOGRAVIMETRIC ANALYSIS. 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 . . . 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, $Q=0.1\ T/\beta$ 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); $I_s=F_sQ$.

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.

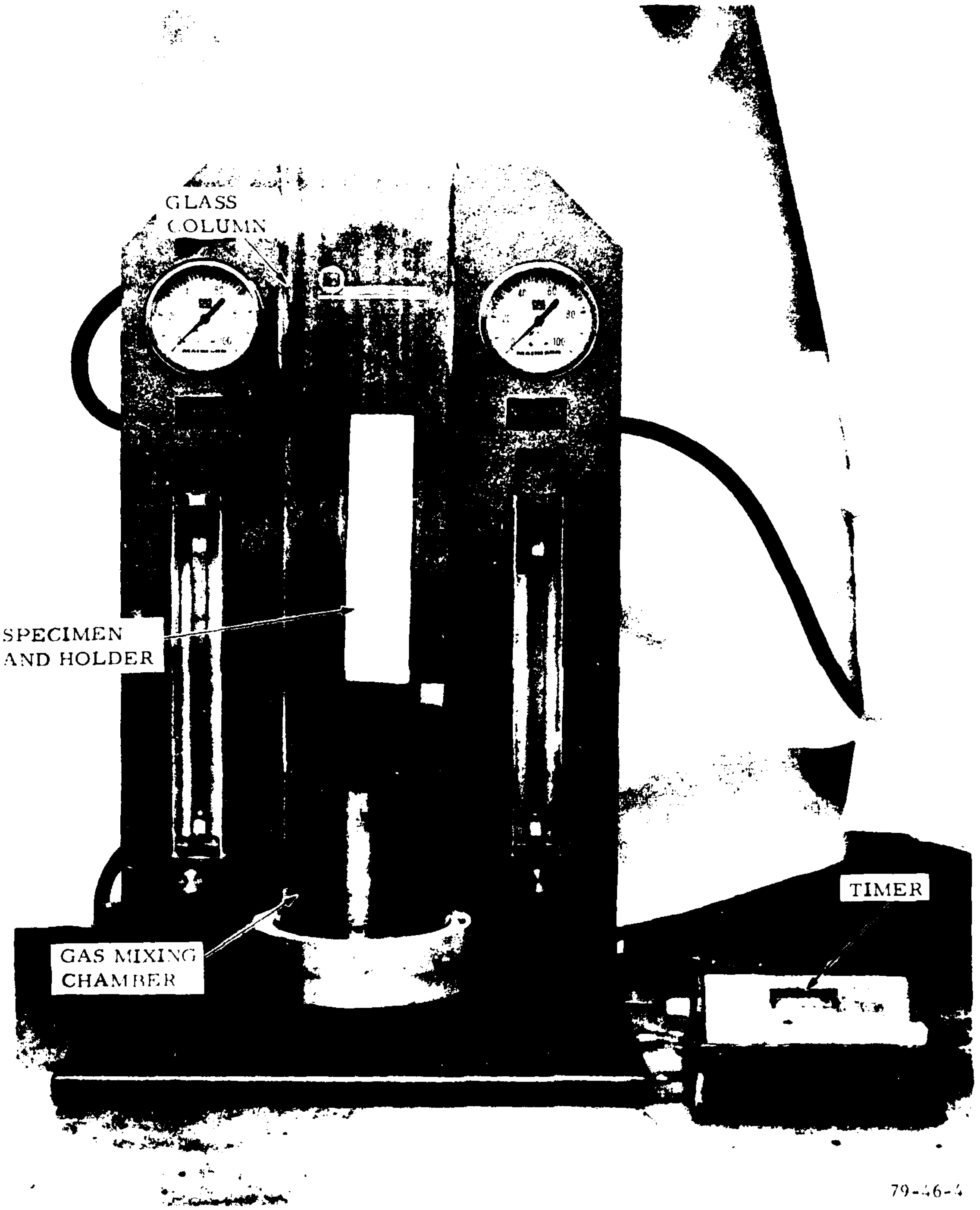

FIGURE 4. LIMITING OXYGEN INDEX

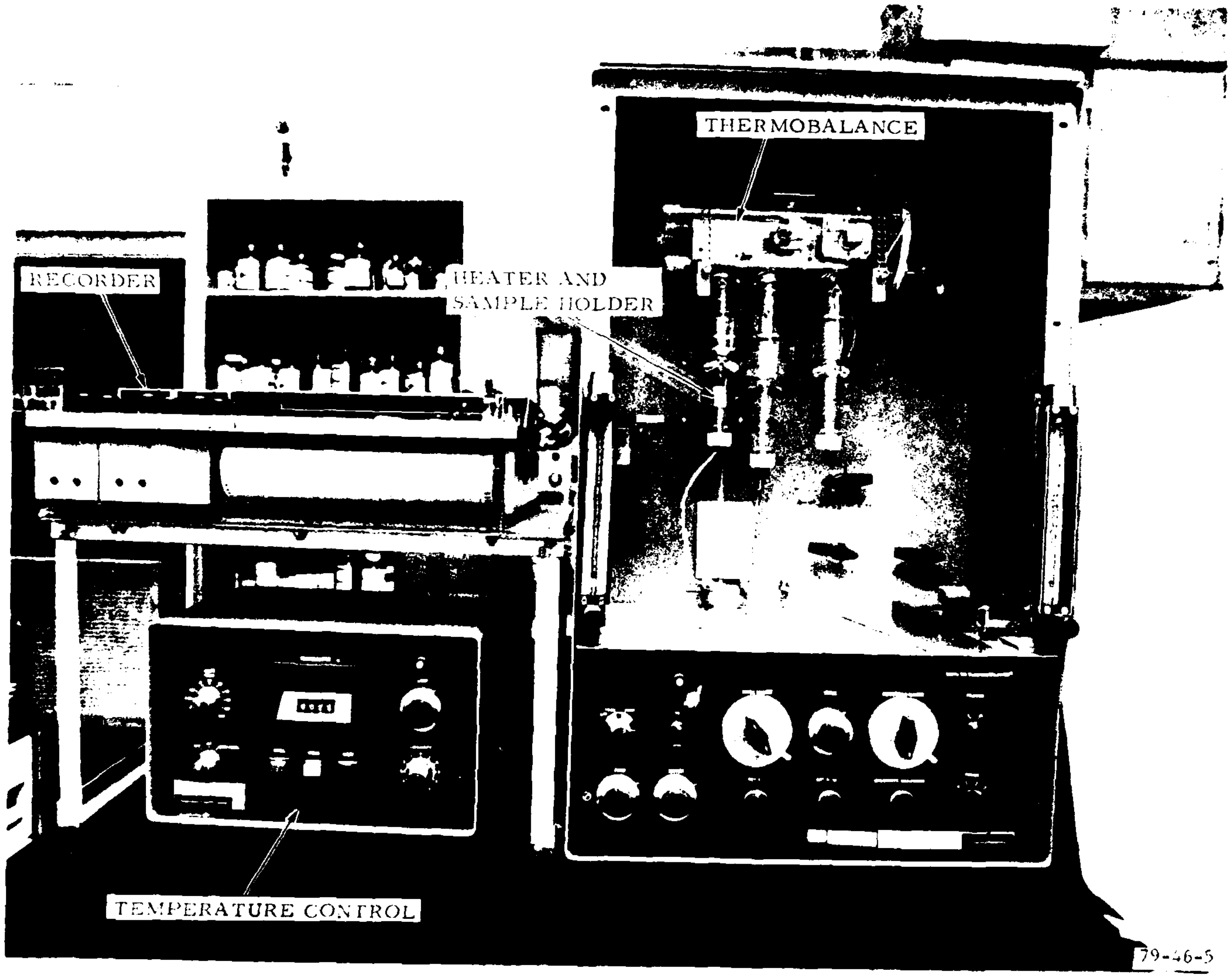

FIGURE 5. THERMOGRAVIMETRIC ANALYSIS

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

Material Category	Material No.	F_s	Q	I_s	T Net stack Temp. Rise (°C)	Ignition Time (sec)	Time to Reach 3 in line (sec)	Time to Max. Temp. (sec)
Fabrics	204	12.3	6.24	78	35	8	33	50
	209	3.3	0.36	2.3	2	6	24	46
	210	17.4	12.1	211	67	5	24	96
	211	20.9	9.54	202	53	10	27	57
	212	15.3	5.04	77	28	9	35	60
	218	1.0	0	0	0	-	DNR(1)	-
Foams	213	39.2	3.48	137	19	4	13	32
	215	56.1	3.90	218	22	4	6	28
Thermoplastics	220	4.1	5.58	23	31	6	93	222
	235	7.2	3.42	25	19	8	66	100
Panels	223	1.4	4.86	6.5	27	20	185	216
	224	8.6	2.04	18	11	14	41	92
	225	2.9	1.80	5.1	10	10	63	156
	227	7.4	1.08	8	6	5	27	-
	228	17.1	4.68	80	26	7	17	72
	229	9.2	3.42	32	19	12	38	96
	233	5.9	0.9	5.2	5	3	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	5	288	204

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

RATE OF HEAT RELEASE. 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/cm^2. The specimens exposed at 5 and 7.5 W/cm^2 were tested with and without piloted ignition; however, at 2.5 W/cm^2 the specimen would not ignite without the aid of a pilot flame. Horizontal tests were conducted at 2.5 and 5 W/cm^2 with piloted ignition. Self-ignition of the horizontal test specimens at 2.5 W/cm^2 could not be obtained, and at 5 W/cm^2 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:

$$K_h = \frac{\text{RHR (Btu/min)}}{\text{Recorder Reading (mV)}}$$

$$\text{RHR(Btu/min-ft}^2) \doteq \frac{K_h(\text{mV output})}{A}$$

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:

$$\text{LOI}(\%) = \frac{100 \times O_2}{O_2 + N_2}$$

TABLE 3. RATE OF HEAT RELEASE RESULTS, VERTICAL TEST SPECIMEN, 2.5 W/cm^2, WITH PILOT

Material Category	Material No.	Peak Rate of Heat Release (Btu/min-ft^2)	Time to Reach Peak RHR (sec)	Total Heat Release (Btu/ft^2) 3 min	5 min	10 min
Fabrics	204	254	48	511	713	1048
	209(1)	-	-	-	-	-
	210	407	85	898	1418	1884
	211	233	40	335	396	493
	212	216	37	343	467	652
	218(2)	-	-	-	-	-
Foams	213(1)	-	-	-	-	-
	215(1)	-	-	-	-	-
Thermo-plastics	220(1)	-	-	-	-	-
	235(1)	-	-	-	-	-
Panels	223	334	127	696	1189	1893
	224	195	62	423	687	1338
	225	463	194	748	1294	2104
	227	89	28	141	194	343
	228	267	56	608	960	1470
	229	178	113	361	643	933
	233	70	33	132	194	282
	234	351	222	299	977	1629
Flooring	226	729	173	1242	2316	3161
	230	484	229	678	1576	3152

NOTES: (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.

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

Material Category	Material No.	Peak Rate of Heat Release ($Btu/min\text{-}ft^2$)	Time to Reach Peak RHR (sec)	Total Heat Release (Btu/ft^2) 3 min	5 min(3)	10 min(3)
Fabrics	204	455	36	1074	-	-
	209(1)	-	-	-	-	-
	210	723	76	1541	-	-
	211	347	18	643	-	-
	212	355	24	819	-	-
	218(2)	-	-	-	-	-
Foams	213(1)	-	-	-	-	-
	215(1)	-	-	-	-	-
Thermo-plastics	220(1)	-	-	-	-	-
	235(1)	-	-	-	-	-
Panels	223	451	95	916	1321	-
	224	282	134	599	977	-
	225	467	110	995	1488	-
	227	218	59	405	669	-
	228	474	75	1083	1532	-
	229	409	86	916	1391	-
	233	312	74	555	854	-
	234	565	107	1030	1506	-
Flooring	226	824	92	1937	2633	-
	230	544	103	1153	1761	-

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

(2) Fabric 218 chars but does not produce enough heat to raise thermopile temperature.

(3) Material was consumed before time was reached.

\- Data not available.

TABLE 5. RATE OF HEAT RELEASE RESULTS, VERTICAL TEST SPECIMEN, $5 W/cm^2$, WITHOUT PILOT

Material Category	Material No.	Peak Rate of Heat Release ($Btu/min-ft^2$)	Time to Reach Peak RHR (sec)	Total Heat Release (Btu/ft^2) 3 min	5 min (4)	10 min (4)
Fabric	204	254	37	45	-	-
	209 (1)	-	-	-	-	-
	210	591	102	1250	-	-
	211	270	100	449	-	-
	212	193	28	396	-	-
	218 (2)	-	-	-	-	-
Foams	213 (1)	-	-	-	-	-
	215 (1)	-	-	-	-	-
Thermo-plastics	220 (1)	-	-	-	-	-
	235 (1)	-	-	-	-	-
Panels	223	362	69	634	801	-
	224	131	31	229	361	-
	225	455	123	889	1356	-
	227	193	73	396	555	-
	228	509	80	1109	1638	-
	229	401	108	801	1162	-
	233 (3)	-	-	-	-	-
	234 (3)	-	-	-	-	-
Flooring	226	787	115	1558	2360	-
	230	607	115	1294	-	-

NOTES: (1) Fabric 209 foams and plastics fell from the speciman holder and could not be tested in the vertical configuration.
(2) Fabric 218 chars but does not produce enough heat to raise the thermopile temperature.
(3) Not tested because of material shortage.
(4) Material consumed before time was reached.
\- Data not available.

TABLE 6. RATE OF HEAT RELEASE RESULTS, VERTICAL TEST SPECIMEN, 7.5 W/cm^2, WITH AND WITHOUT PILOT

		WITH PILOT			WITHOUT PILOT		
Material Category	Material No.	Peak Rate of Heat Release (BTU/min-ft^2)	Time to Reach Peak RHP (sec)	Total Heat Release at 3 minutes (BTU/ft^2)	Peak Rate of Heat Release (BTU/min-ft^2)	Time to Reach Peak RHR (sec)	Total Heat Release 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.

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

Material Category	Material No.	Peak Rate of Heat Release (Btu/min-ft^2)	Time to Reach Peak RHR (sec)	Total Heat Release (Btu/ft^2) 3 min	5 min	10 min(2)
Fabrics	204	239	57	414	581	-
	209	352	111	652	1013	-
	210	334	90	713	995	-
	211	190	45	396	528	-
	212	175	47	317	423	-
	218(1)	—	—	—	—	—
Foams	213	467	55	898	1215	-
	215	479	76	960	1312	-
Thermo-plastics	220	215	408	238	634	1664
	235	511	242	317	1242	2509
Panels	223	337	128	564	1039	1655
	224	191	181	370	678	1400
	225	388	184	537	1153	1911
	227	80	38	132	203	484
	228	324	153	669	704	1743
	229	355	168	643	1180	1735
	233	155	98	361	590	1013
	234	308	292	97	467	1233
Flooring	226	686	163	1083	2122	2958
	230	414	98	652	1435	2597

NOTES: (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.

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

Material Category	Material No.	Peak Rate of Heat Release ($Btu/min-ft^2$)	Time to Reach Peak RHR (sec)	Total Heat Release (Btu/ft^2)(2) 3 min	5 min
Fabrics	204	332	57	475	696
	209	549	74	1003	1338
	210	370	58	502	1013
	211	201	29	458	687
	212	239	30	467	590
	218(1)	-	-	-	-
Foams	213	459	62	942	1303
	215	539	54	1074	1462
Thermo-plastics	220	498	189	872	1779
	235	554	131	925	1541
Panels	223	355	96	784	1215
	224	321	152	696	1277
	225	439	104	942	1479
	227	196	62	467	766
	228	365	86	810	1224
	229	437	118	933	1426
	233	231	73	493	757
	234	416	131	766	1189
Flooring	226	829	121	1814	2694
	230	451	122	1004	1726

NOTES: (1) Fabric 218 chars but does not produce enough heat to raise the thermopile temperature.
(2) All materials were consumed before 10 minutes.
\- Data not available.

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

Material Category	Material No.	Flaming Time (sec)	Burn Length (in.)	Passes FAR
Fabrics	204	14.0	1.9	yes
	209	0.5	2.7	yes
	210	4.3	2.8	yes
	211	4.4	3.2	yes
	212	2.1	2.1	yes
	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
	230	0.5	1.5	yes

TABLE 10. LIMITING OXYGEN INDEX TEST RESULTS

Material Category	Material No.	Oxygen Flow (cm^3/sec)	Nitrogen Flow (cm^3/sec)	Limited Oxygen Index $\frac{100 \times O_2}{O_2+N_2}$
Fabrics	204	90	164	35.4
	209	77	204	27.4
	210	65	183	26.2
	211	62	116	34.8
	212	63	109	36.6
	218	63	83	43.2
Foams	213	56	171	24.7
	215	49	149	24.7
Thermoplastics	220	76	188	28.8
	235	63	122	34.1
Panels	223	76	131	36.7
	224	76	220	34.5
	225	76	166	31.4
	227	76	86	46.9
	228	76	209	26.7
	229	76	161	32.1
	233	74	156	32.2
	234	63	106	37.3
Flooring	226	76	202	27.3
	230	63	163	27.9

where O_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 N_2 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

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

Material Category	Material No.	Temp. at First Decomposition (°C)	Temp. at 50 Percent Weight Loss (°C)	Char Yield at 700° C (%)
Fabrics	204	263	398	4.5
	209	218	470	0
	210	293	DNR(1)	59.5
	211	277	449	0.8
	212	279	454	6.3
	218	238	345	8.4
Foams	213	273	DNR	93.7
	215	301	DNR	88.2
Thermoplastics	220	484	DNR	71.1
	235	502	545	1.4
Panels	223	279	DNR	50.7
	224	254	481	35.3
	225	286	618	47.4
	227	404	565	67.9
	228	319	DNR	36.3
	229	312	DNR	76.3
	233	343	DNR	57.2
	234	274	DNR	69.0
Flooring	226	271	449	1.1
	230	293	400	6.0

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

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

Material Category	Material No.	Temp. at First Decomposition (°C)	Temp. at 50 Percent Weight Loss (°C)	Char Yield at 700° C (%)
Fabrics	204	334	424	13.3
	209	508	529	2.5
	210	363	430	21.3
	211	330	433	18.7
	212	353	435	26.8
	218	303	383	23.6
Foams	213	359	DNR(1)	90.7
	215	387	DNR	86.0
Thermoplastics	220	588	648	39.8
	235	574	612	26.9
Panels	223	338	465	27.8
	224	347	657	47.9
	225	335	DNR	59.3
	227	354	DNR	74.7
	228	344	555	25.8
	229	355	DNR	55.2
	233	375	DNR	59.4
	234	358	600	46.6
Flooring	226	323	423	5.5
	230	360	440	17.2

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

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

Material Category	Material No.	Temp. at First Decomposition (°C)	Temp. at 50 Percent Weight Loss (°C)	Char Yield at 700° C (%)
Fabrics	204	283	432	5.9
	209	458	566	3.9
	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	0.9
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	460	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.

of more than 50. One of these was a ceiling panel that had a rapid rate of flame travel (high F_s) 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 ($Btu/min\text{-}ft^2$) 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 $Btu/min\text{-}ft^2$ for a light-weight sidewall panel to a high of 463 $Btu/min\text{-}ft^2$ 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 $Btu/min\text{-}ft^2$ for the wool carpet and 484 $Btu/min\text{-}ft^2$ 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/cm^2. However, at 5 W/cm^2 the specimens were consumed much more rapidly than at 2.5 W/cm^2. 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/cm^2 and 5 W/cm^2. The reflective metal surface used to transmit heat to a horizontal specimen precluded heat flux levels above 5 W/cm^2.

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 coeficient 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.

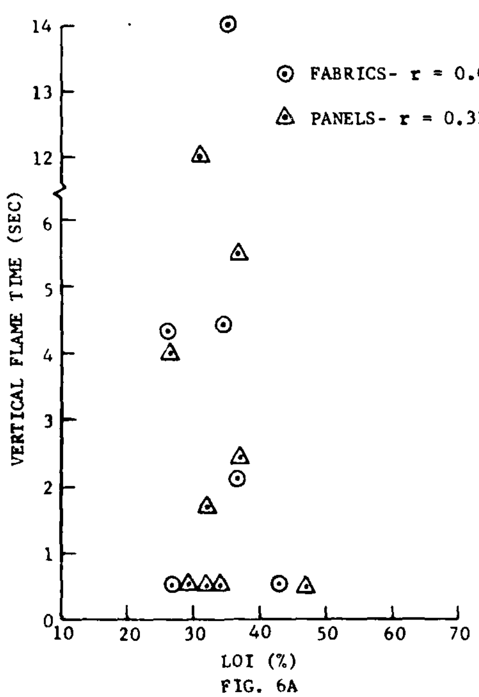

FIG. 6A

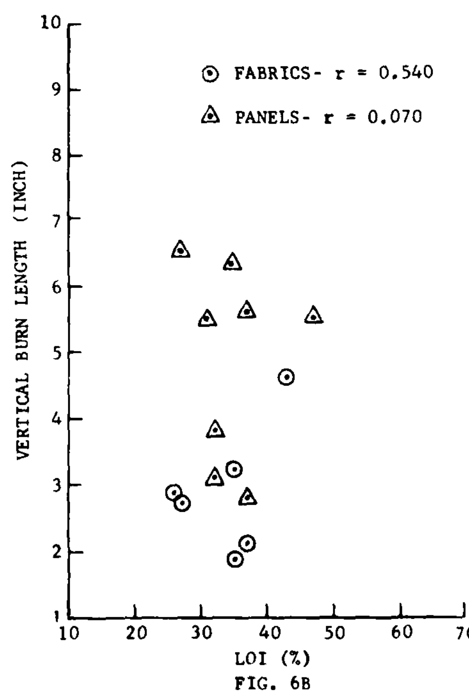

FIG. 6B

FIGURE 6. COMPARISON OF MATERIALS FOR IGNITABILITY (SHEET 1 of 2)

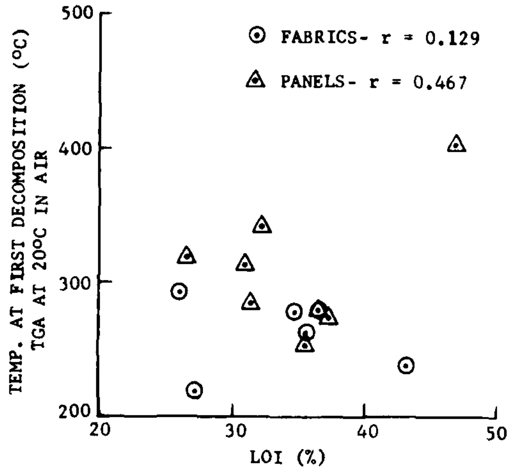

FIG. 6C

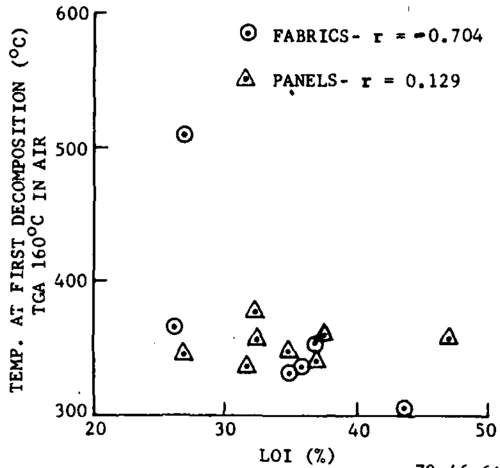

FIG. 6D

79-46-6A

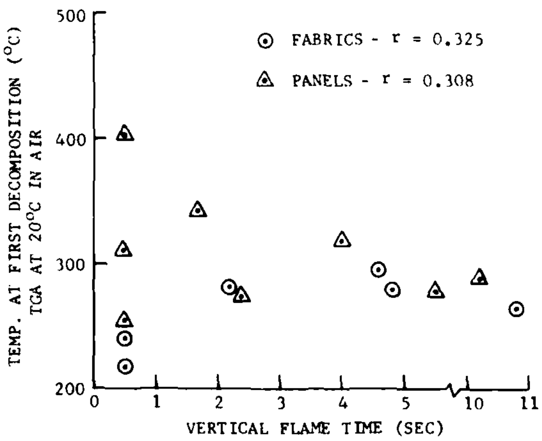

FIG. 6E

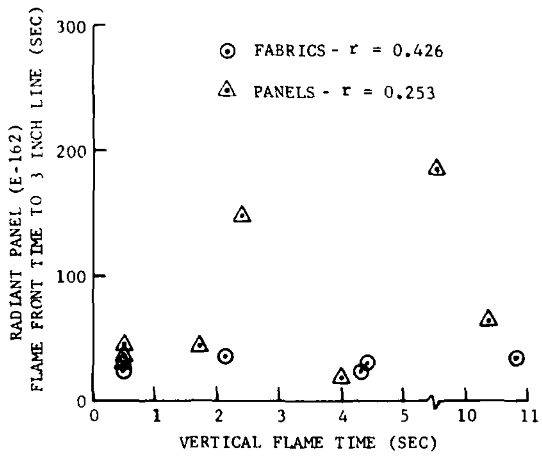

FIG. 6F

79-46-6B

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/cm^2 and 5 W/cm^2 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/cm^2 and 5 W/cm^2 in the horizontal specimen configuration and the radiant panel E-162 heat evolution factor Q (figures 8B and 8D).

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/cm^2. 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/yd^2 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/cm^2 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/cm^2. 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/cm^2. The heat release rate profiles are practically identical at 5 and 7.5 W/cm^2. At 2.5 W/cm^2 the peak value is lower and occurs later than at 5 or 7.5 W/cm^2.

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.

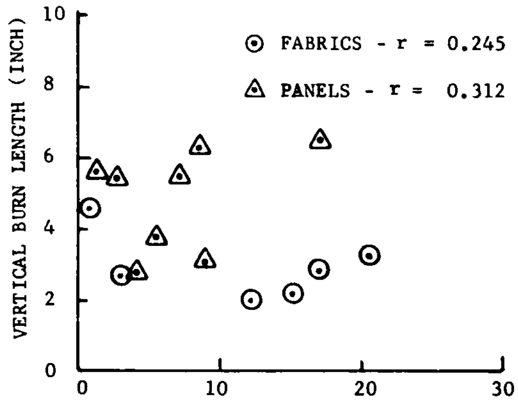

FIG. 7A

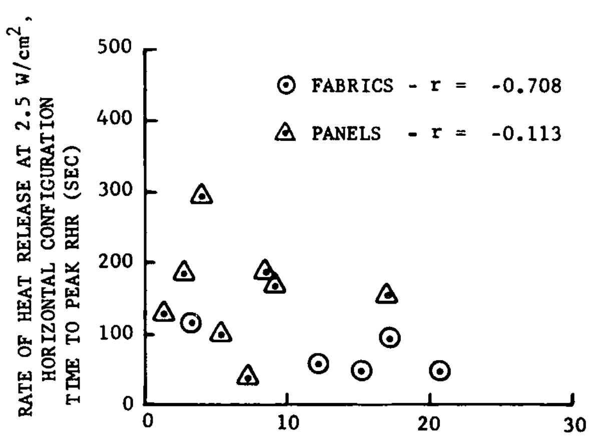

FIG. 7B

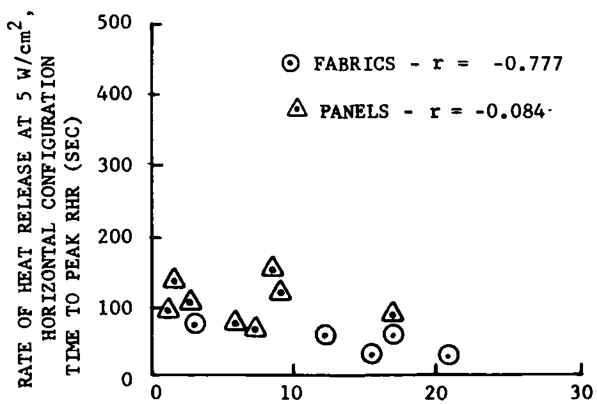

FIG. 7C

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FIGURE 7. COMPARISON OF MATERIALS FOR FLAME SPREAD

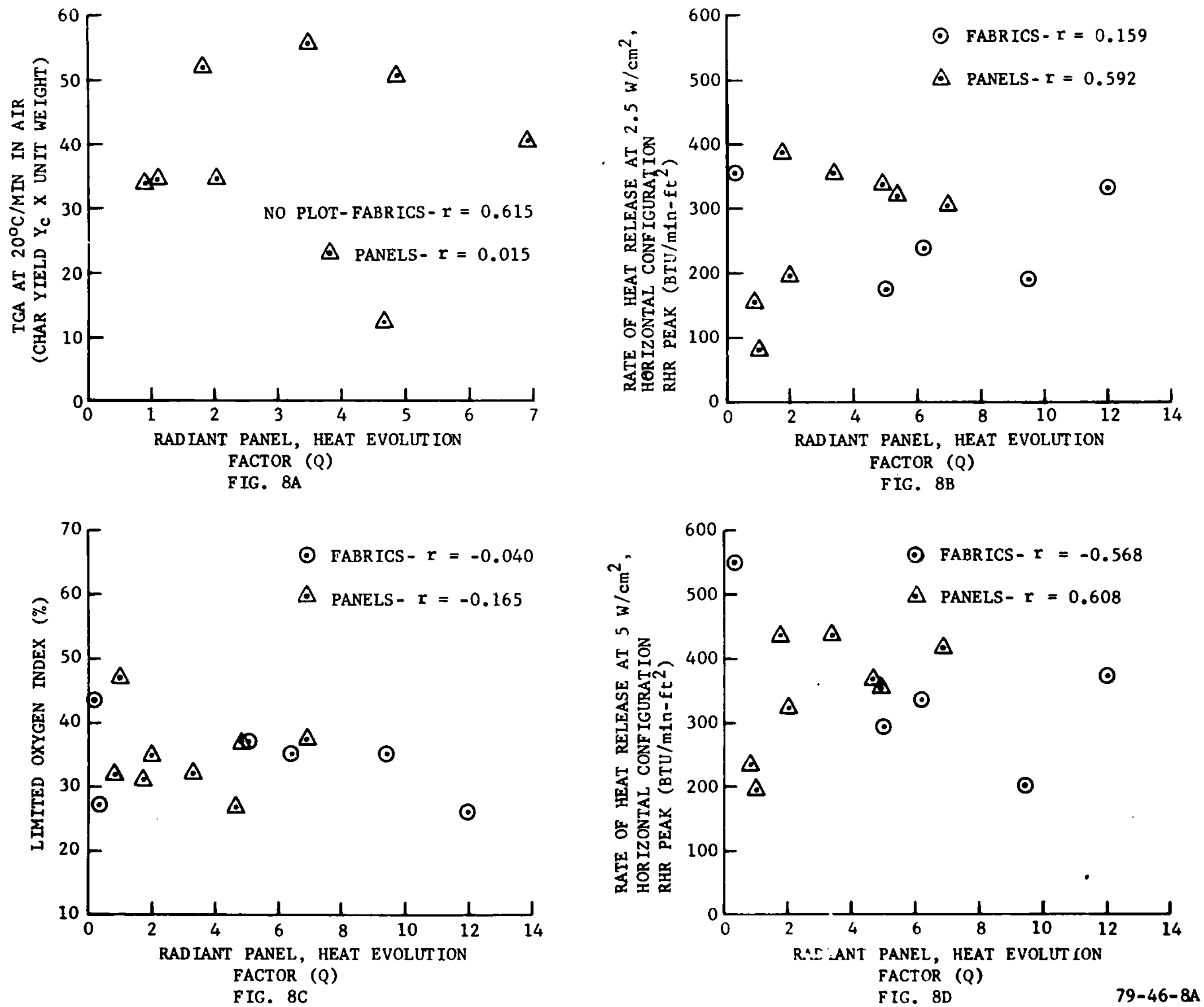


FIGURE 8. COMPARISON OF MATERIALS FOR HEAT RELEASE (SHEET 1 of 2)

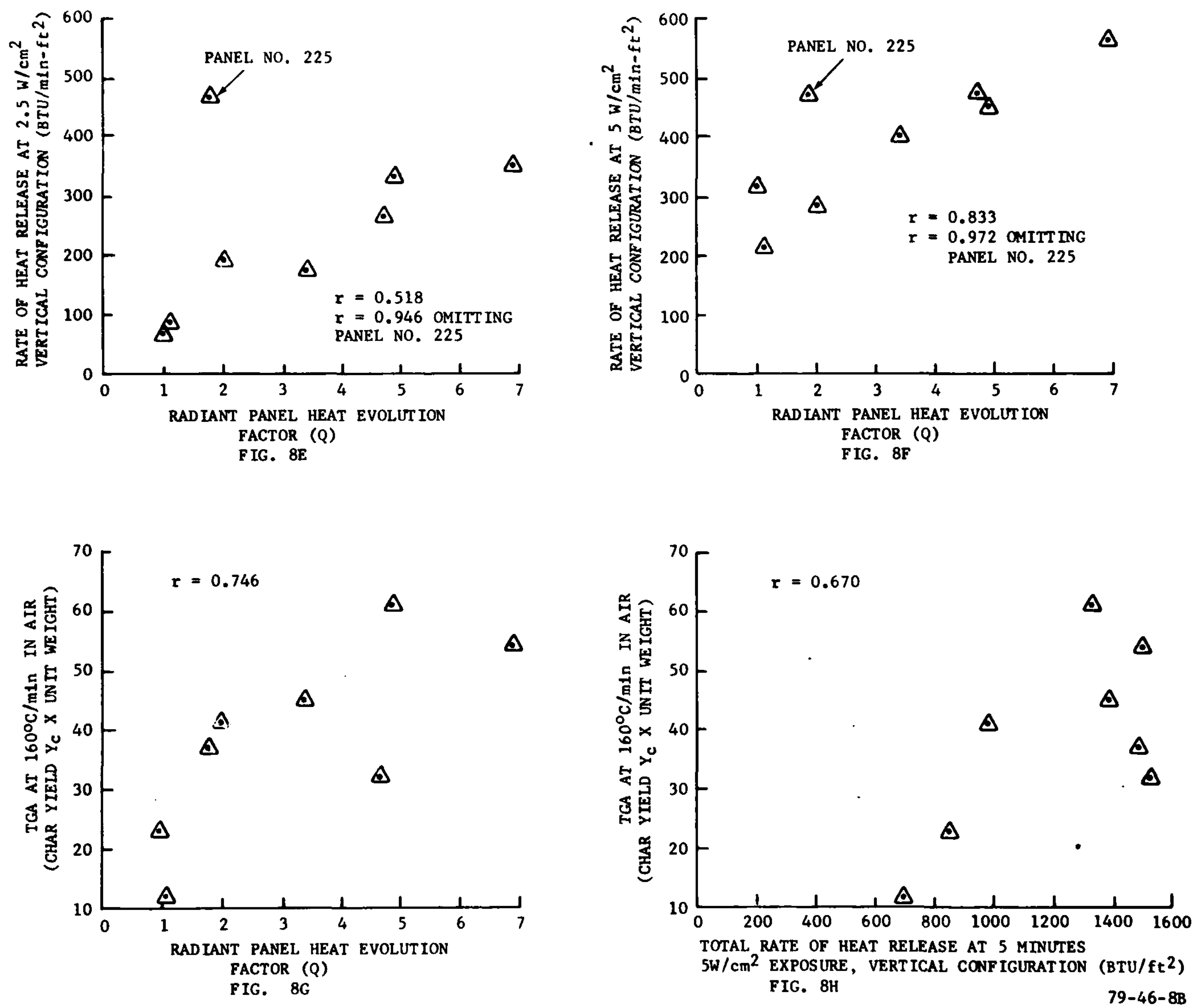


FIGURE 8. COMPARISON OF MATERIALS FOR HEAT RELEASE (SHEET 2 of 2)

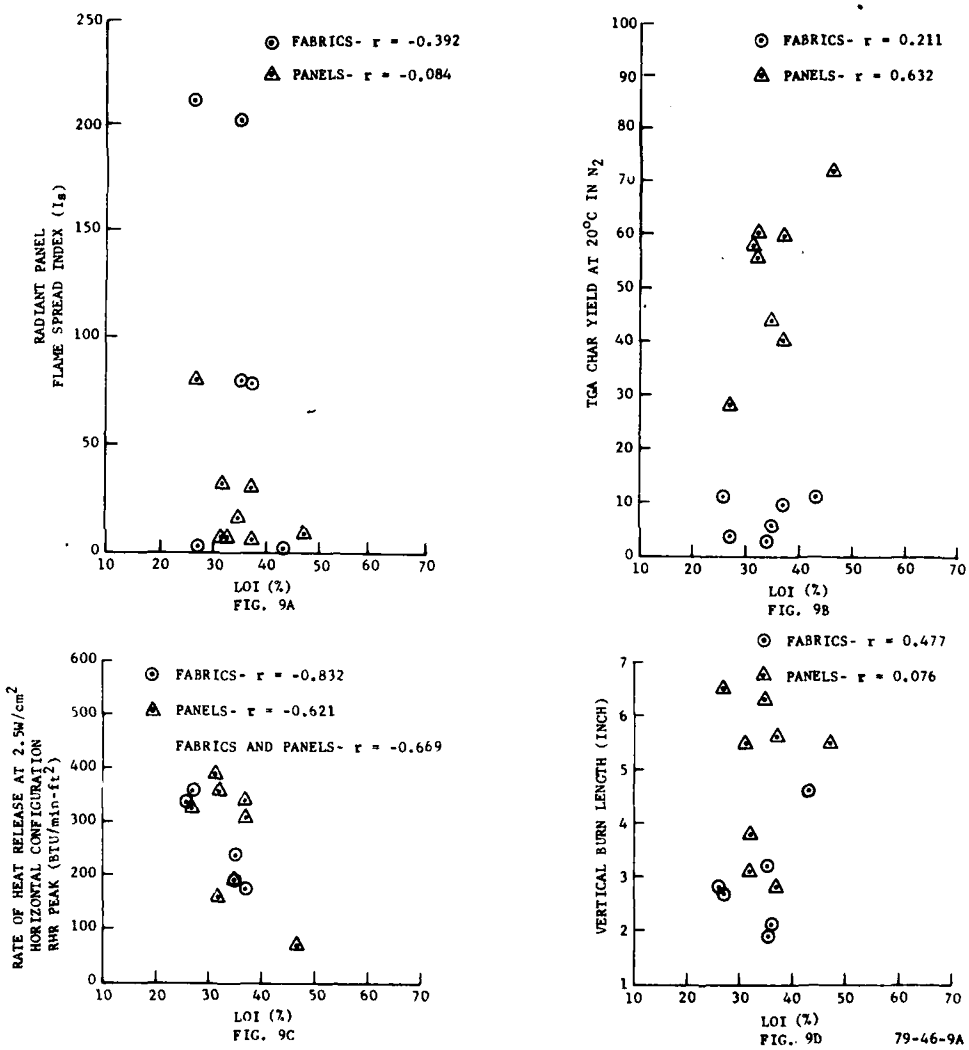


FIGURE 9. TEST METHOD PERFORMANCE (SHEET 1 of 3)

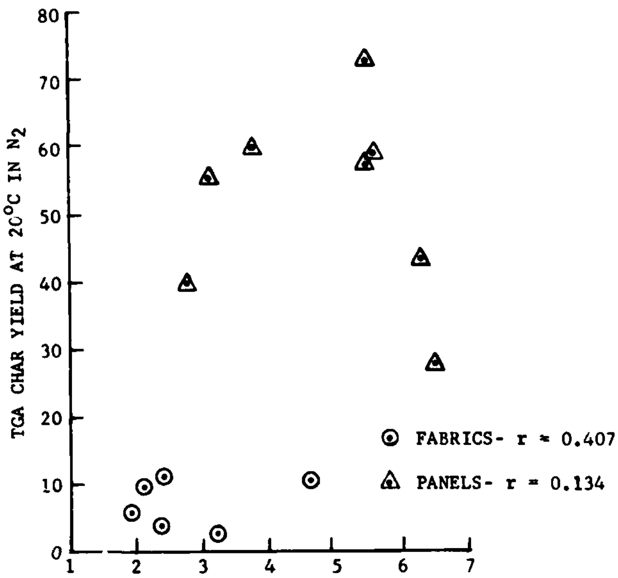


FIG. 9E

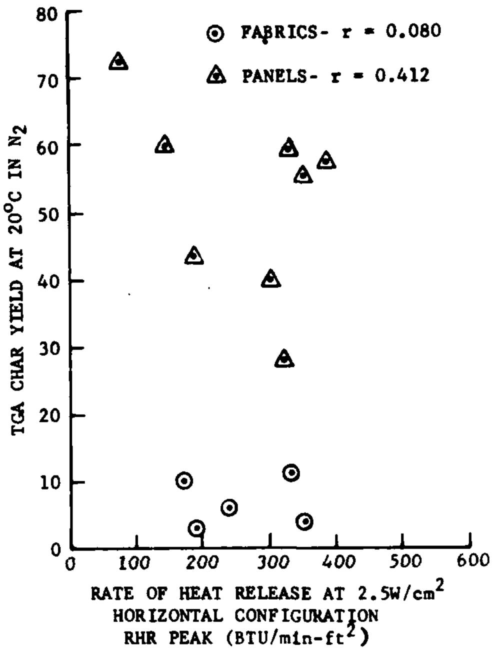


FIG. 9F

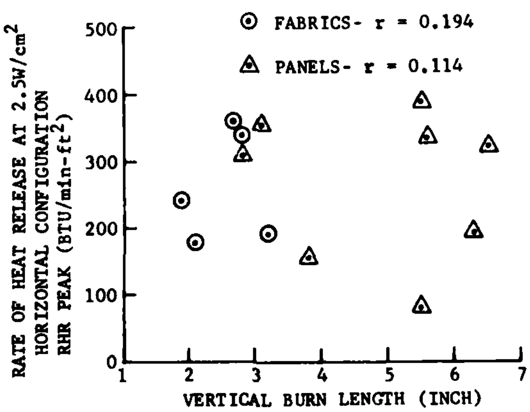


FIG. 9G

79-46-9B

FIGURE 9. TEST METHOD PERFORMANCE (SHEET 2 of 3)

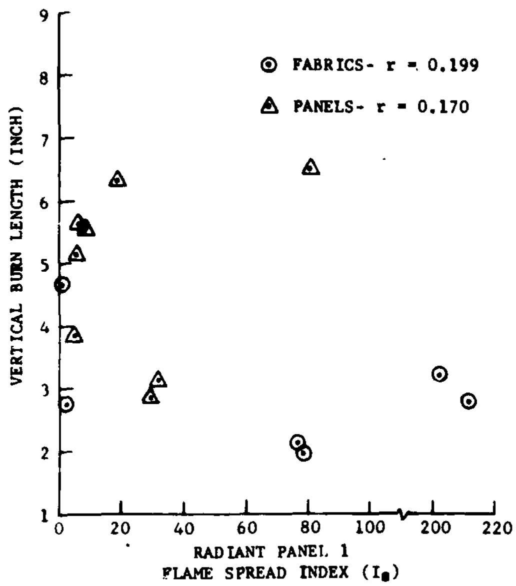


FIG. 9H

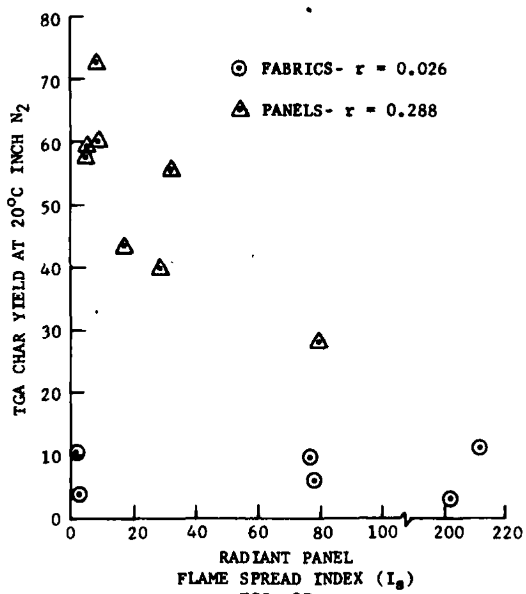


FIG. 9I

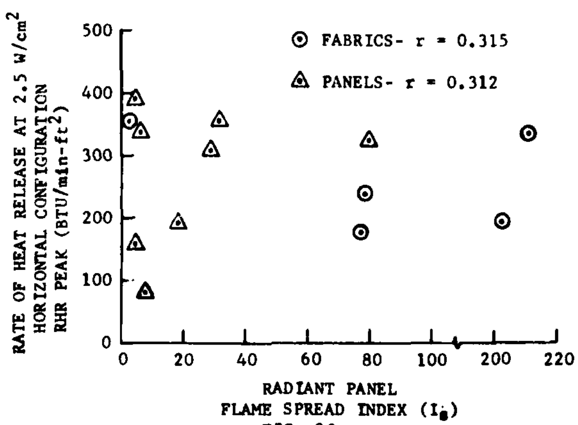
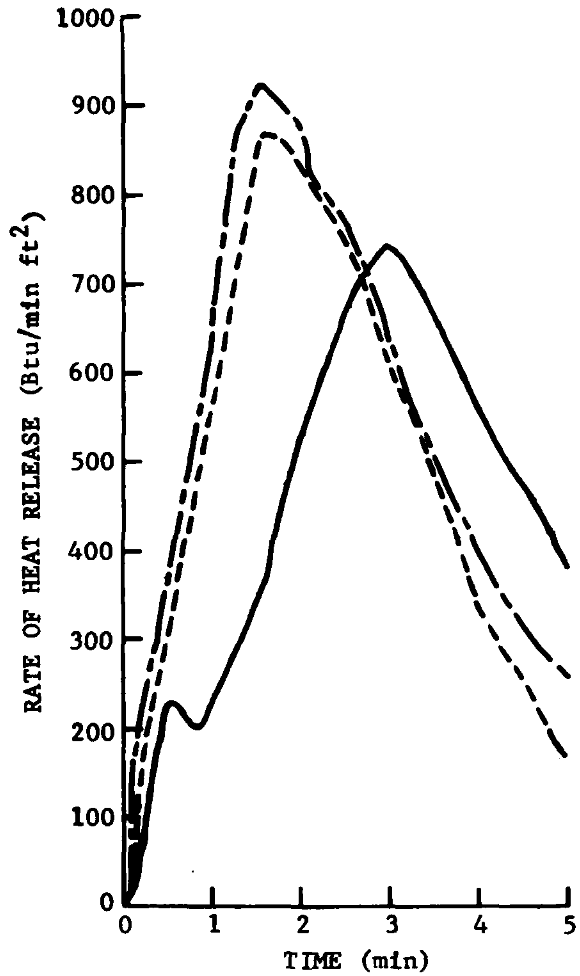


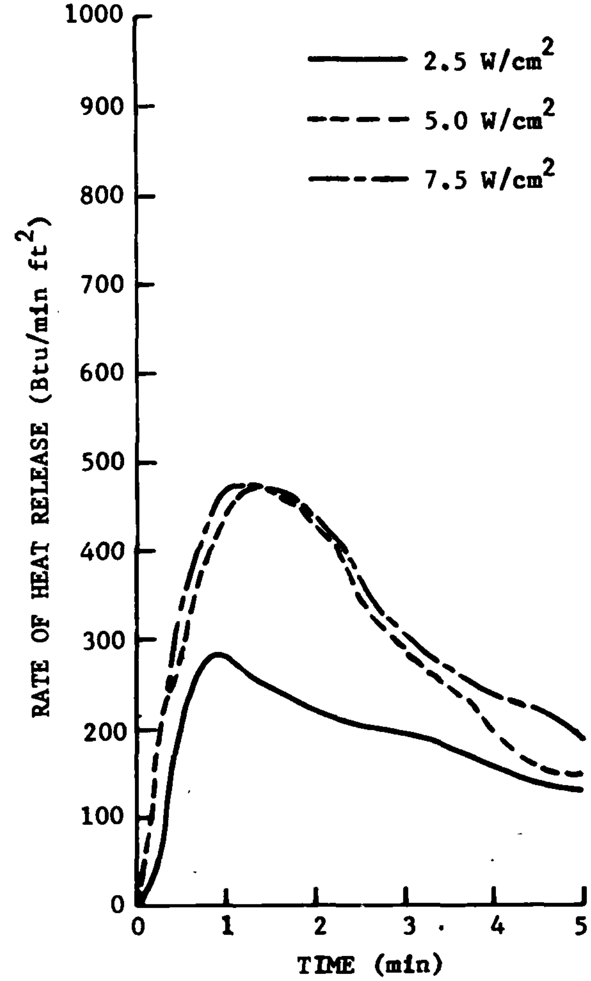
FIG. 9J

79-46-9C

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



A. WOOL CARPET (NO. 226)



B. PANEL---PVF/KEVLAR/NOMEX HONEYCOMB/KEVLAR/PVF (NO. 228)

79-46-10

FIGURE 10. RATE OF HEAT RELEASE COMPARISON, VERTICAL SPECIMEN CONFIGURATION, WITH PILOTED IGNITION

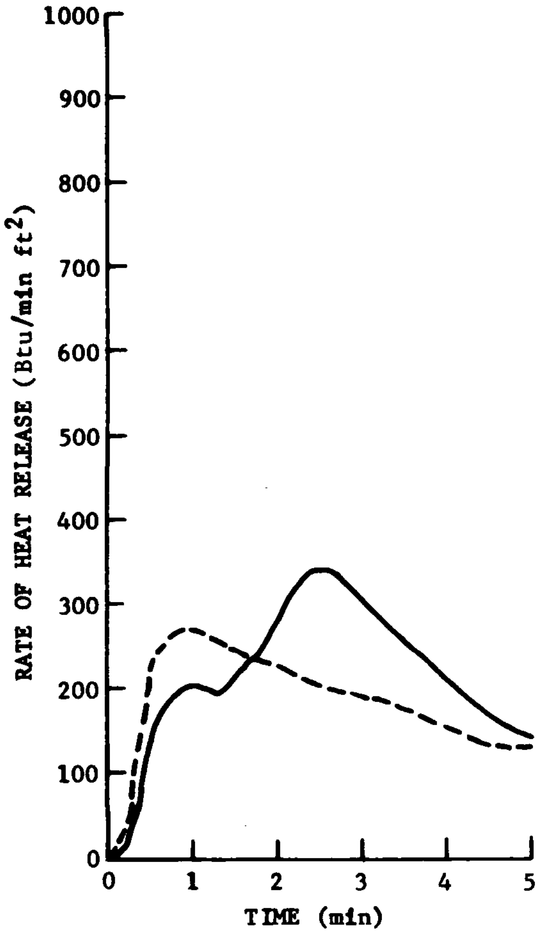
Figures 11A through 11D compare the rate of heat release histories for vertical and horizontal configurations at 2.5 and 5 W/cm^2. In the case of the wool carpet (figures 11A and 11B), the curves are very close for both configurations, with the peak reaching a slightly higher value when tested vertically. 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/cm^2 the burning characteristics are different at the two sample orientations. However, at 5 W/cm^2 (figure 11C) the burning characteristics are similar to the carpet material; e.g., a comparable slope-to-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.

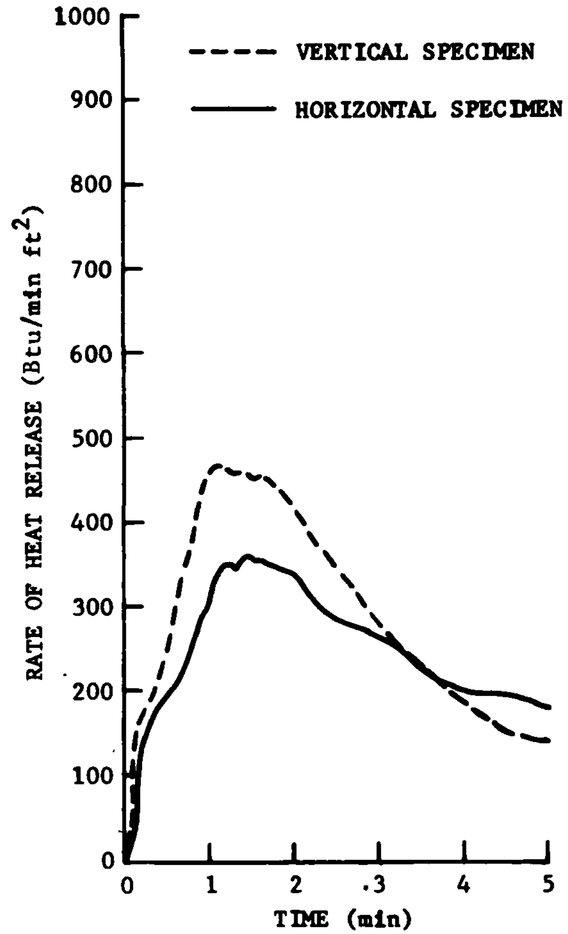
Table 14 illustrates how materials may be ranked differently according to different test methods. The urethane foams and thermoplastics are a good case in point. Each of these categories contained two materials. In terms of the seven test measurements or indices, foam No. 213 was ranked first by four 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_s), its actual rating (I_s=8) is considered good by most standards and comparable to the first-ranked material (I_s=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.

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.



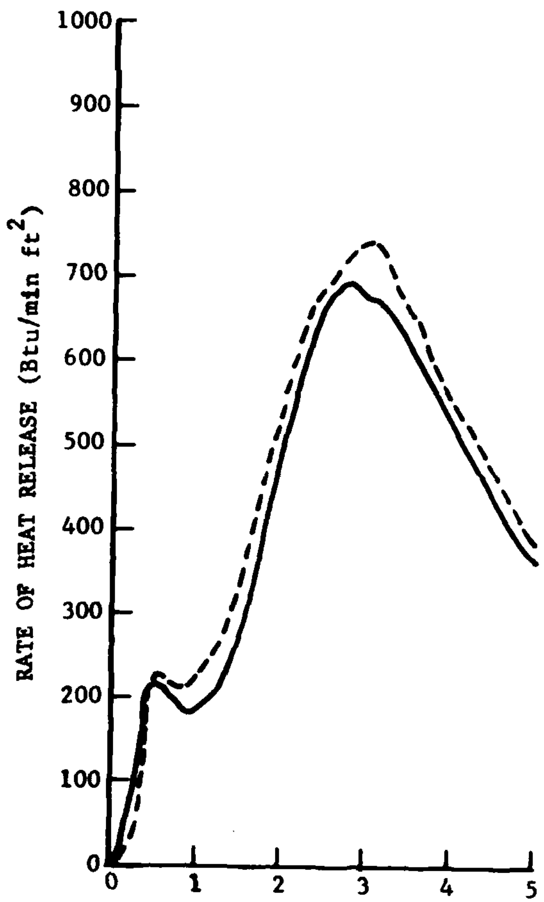
C. PANEL---PVF/KEVLAR/NOMEX HONEYCOMB/KEVLAR/PVF (NO. 228) 2.5 W/cm^2



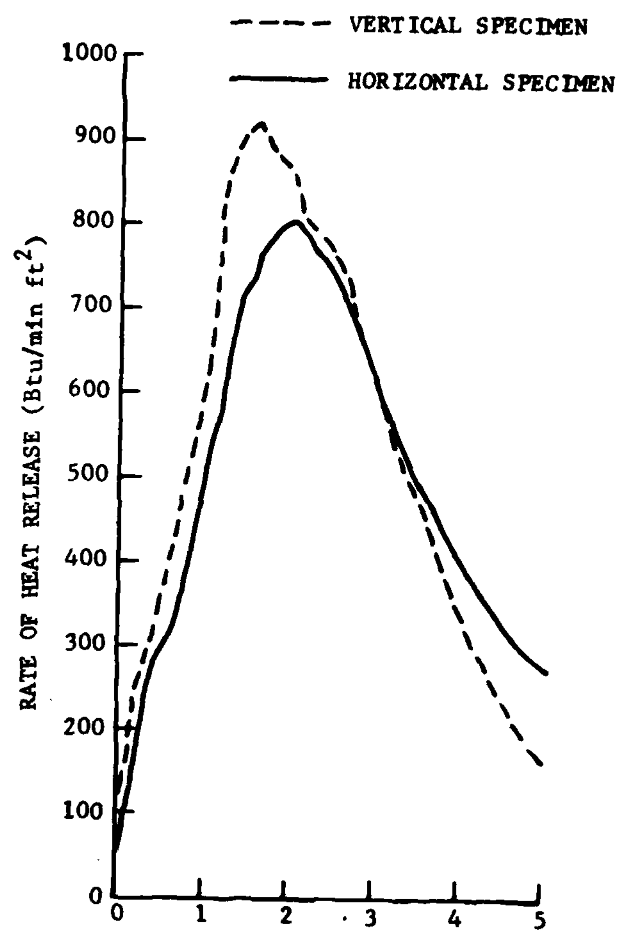
D. PANEL---PVF/KEVLAR/NOMEX HONEYCOMB/KEVLAR/PVF (NO. 228) 5.0 W/cm^2

79-46-11A

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



A. WOOL CARPET (NO. 226)
2.5 W/cm^2



B. WOOL CARPET (NO. 226)
5.0 W/cm^2

79-46-11B

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

TABLE 14. RANKING OF MATERIALS BY USAGE CATEGORY

Usage Category	Rank Order No.	Radiant Panel (I_s)	Vertical Burn Length (in)	LOI (%)	Peak RHR at 2.5 W/cm^2, Piloted Ignition (BTU/min-ft^2)	Peak RHR at 5 W/cm^2, Piloted Ignition (BTU/min-ft^2)	TGA-1st Decomposition at 20° C in Air (°C)	TGA-1st Decomposition at 160° C in Air (°C)
Fabrics	1	218	204	218	218	218	210	209
	2	209	212	212	212	211	212	210
	3	212	209	204	211	212	211	212
	4	204	210	211	204	204	204	204
	5	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
Thermo-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
	3	223	233	223	224	224	228	229
	4	227	225	224	234	223	229	227
	5	224	227	233	228	228	225	224
	6	234	223	229	223	234	223	228
	7	229	224	225	229	229	234	223
	8	228	228	228	225	225	224	225
Flooring	1	230	230	230	230	230	230	230
	2	226	226	226	226	226	226	226

TABLE 15. RANKING OF MATERIALS FOR FIVE TEST METHODS

Rank Order No.	Radiant Panel (I_s)	Vertical Burn Length (in)	LOI (%)	Peak RHR at 2.5 W/cm^2 Horizontal With Pilot (BTU/min-ft^2)	Peak RHR at 5 W/cm^2 Horizontal With Pilot (BTU/min-ft^2)	TGA-1st Decomposition at 20° C in Air (°C)	TGA-1st Decomposition at 160° C in Air (°C)
1	218F	235T	227P	218F	218F	235T	220T
2	209F	230C	218F	227P	227P	220T	235T
3	225P	226C	234P	233P	211F	227P	209F
4	233P	204F	223P	212F	233F	233P	223P
5	223P	212F	212F	211F	212F	228P	215U
6	227P	209F	204F	224P	224P	229P	233P
7	224P	234P	211F	220T	204F	215U	210F
8	220T	210F	224P	204F	223P	230C	230C
9	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	228P
16	228P	225P	226C	230C	220T	226C	225P
17	213U	227P	228P	213U	215U	204F	204F
18	211F	223P	210F	215U	209F	224P	211F
19	210F	224P	213U	235T	235T	218F	226C
20	215U	228P	215U	226C	226C	209F	218F

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

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.

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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