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INTERLABORATORY EVALUATION OF SMOKE DENSITY CHAMBER

NBS

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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INTERLABORATORY EVALUATION OF SMOKE DENSITY CHAMBER

by

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NBS

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

Interlaboratory Evaluation of

Smoke Density Chamber

1.0 INTRODUCTION

In January 1970, an interlaboratory comparison study on the measurement of Smoke Generation Characteristics of Materials was initiated by the Fire Research Section of the National Bureau of Standards (NBS). ASTM Committee E-5 on Fire Tests of Materials and Constructions acted as an advisor to the study. The goal of the study was to evaluate the suitability of the test method for measuring and classifying materials according to their smoke generation potential.

A test method had been developed at NBS and reported in 1967 by Gross, Loftus and Robertson [1]. It was later (1969) used to evaluate the smoke properties of over 140 aircraft interior materials [2]. The laboratory method measures the smoke generation characteristic of materials under two prescribed and standarized conditions, smoldering (non-flaming) and flaming, which reflect two parameters of fire hazard. In the test, smoke from a burning specimen in an enclosed chamber is monitored continuously by a photometer which measures the attenuation of light caused by the smoke.

Because of the general interest in the problem of smoke and the need for standardization of equipment, the American Instrument Co. (AMINCO) decided to build a commercial model of the smoke chamber. These production models became available in the latter part of 1969; while some home-built units were made earlier.

In late 1969, NBS circulated a proposed test method to all known users of the Smoke Density Chamber for comments. Many constructive suggestions were received and were incorporated in a revised draft of the test method. All laboratories having a Smoke Density Chamber were then invited to participate in a interlaboratory evaluation of the method and over three-quarter replied favorably. Two samples each of two materials (pure α-cellulose paper and a PVC-PVA copolymer) were distributed for a preliminary screening and general familarization with the test procedure. The reported results and comments indicated the need to provide better alignment of the burner in the flaming exposure; and to correct for smoke deposits on the windows of the photometer. The results of this initial study were considered reasonable for tests of this type.

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[1] D. Gross, J.J. Loftus and A.F. Robertson, "Method for Measuring Smoke from Burning Materials", ASTM Special Technical Publication No. 422 (1967).

[2] D. Gross, et al, Smoke and Gas Produced by Burning Aircraft Interior Materials, Building Science Series 18, U.S. Government Printing Office (1969).

A meeting, attended by representatives from some of the participating laboratories in the round-robin was held on February 16, 1970 to discuss the preliminary test results and test procedures. A more comprehensive interlaboratory evaluation of the test method followed.

The test results from all the participating laboratories (including those who joined after May 1970) are summarized in this report. Some interpretative statements based on statistical analysis of the data and comments on possible sources of errors are also included.

2.0 PARTICIPANTS

A total of 22 laboratories, three with home-built and 19 with AMINCO chambers participated in the study. The list of these is given in Appendix B. The laboratories are identified in the report by code letters only. The cooperation, comments and suggestions from the participating laboratories, are gratefully acknowledged.

3.0 TEST PROCEDURES

The detailed test procedures were described in a revised test method standard, (see Appendix F). Supplementary notes, instructions, data sheets, and a total of 26 specimens were distributed to the participants after they reported their preliminary test results.

There were a total of 8 materials and 10 test conditions (two materials were tested under both flaming and smoldering conditions). The instructions requested that duplicate tests be performed for each of the test conditions, and an additional six replicates for one designated test condition. This arrangement was selected to permit good statistical estimates to be made of (within-laboratory) repeatability and (between-laboratory) reproducibility with a reasonable small number of tests.

The experiment design is shown in Table 1. It was suggested that tests be made in random order, but some laboratories tested duplicates in sequence. A few did not condition the specimens to moisture equilibrium prior to tests because of the lack of facility or time.

Some laboratories used the previously suggested flowmeter settings based on an air to fuel ratio of 3 to 1, for their pilot burners; whereas the procedure had been modified to require a ratio of 10 to 1 (500 cm^3/min air and 50 cm^3/min propane). This discrepancy introduced a relatively large systematic error in the flaming results for those laboratories.

4.0 TEST MATERIALS

The materials selected (see Table 2) represent common interior finish and construction materials, including simple and composite plastic, cellulosic and inorganic-base materials covering a wide range of thickness. These materials exhibit different forms of physical response to fire exposure: such as slow melting, fast shrinking, rapid decomposition and nearly nonreactive. The smoke levels from the materials span the full range of the test instrument as well as a very narrow region to show the degree of resolution. Most materials were obtained from commercial sources without special controls on uniformity. All the specimens were cut and randomized before distribution. Because of the unanticipated addition of laboratories to the study, a second batch of some materials were prepared.

Since small quantities of fillers, pigments and additives, and other chemical and physical properties affect the smoke potential of materials, it should not be assumed that all materials of the same generic type would produce the same quantity of smoke under the same conditions.

5.0 RESULTS

Table 3 lists the relevant test conditions under which each laboratory performed the tests. The data on lamp voltage were based on the mid-range sensitivity setting of 25 and were recorded by AMINCO during the check-out tests.

Flowmeter settings and burner-to-specimen distances were that reported by the individual laboratory. Laboratories with flowmeter settings much above 30 mm (steel ball) or 75 mm (plastic ball) inadvertently used propane at a higher than required rate.

Because of its shorter service life, the 6-hole Tee burner was replaced with a heavier 6-tube burner of similar flaming characteristics on chambers originally shipped in the spring of 1970. As a result, both types of burners were used in the flaming tests. In addition to this, a special specimen holder and burner was distributed to test participants for use only in the flaming test on the polystyrene sample. This holder-burner combination retains the melted portion of the specimen under test and exposes it directly to the burner flamelets.

Tables 4, 5, 6, and 7 summarize the mean values based on duplicate determinations of:

D_m (corr.) - the maximum specific optical density of smoke, corrected for window deposit.

$T_{.9D_m}$ - the time to reach 90% of D_m.

D_c - the specific optical density of photometer window smoke deposit.

$SON_{(5)}$ - a smoke obscuration number based on the smoke buildup during the first 5 minutes.

Individual values are tabulated in Appendix A. On materials in which a laboratory performed 8 replicate tests, only the first 2 test results are included in these summary tables. The remaining 6 test results, including the mean and standard deviation are tabulated in Table 8.

6.0 STATISTICAL ANALYSIS

6.1 Means and Standard Deviation

Table 9 summarizes, for each material, the arithmetic mean, standard deviation, and coefficient of variation of data from 18 laboratories using the AMINCO-built chamber. The within-laboratory standard deviations are computed from the formula:

$$S^2 = \frac{1}{2k} \sum_{i=1}^{k} (X_{1i} - X_{2i})^2$$

where S is the pooled standard deviation, X_{1i} and X_{2i} are the replicate test results from laboratory i, and k = 18 is the number of laboratories. The between-laboratory standard deviations are computed from the means of the duplicates of these 18 laboratories. The mean and between-laboratory standard deviation of $T_{.9D_m}$, D_c and $SON_{(5)}$ are also included. Results of one AMINCO (Q) and all three home-built (A,C,E) chambers are not included in the analysis. (There were basic differences between individual home-built chambers, and between these chambers and the AMINCO-built chambers, e.g. chamber wall construction, photometer, etc.) A comparison of the within-laboratory standard deviation in Table 9 with their counterpart in Table 8 for the various materials substantiate the assumption that laboratories using AMINCO chambers have approximately equal precision.

6.2 Variability

A simple graphical procedure, known as a Youden Plot, was used for comparing interlaboratory results [3]. A graph is prepared by plotting the value of D_m(corr.) for one material on the X-axis and that for another material of

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[3] Youden, W.J., "Precision Measurement and Calibration, Statistical Concept and Procedures" edited by H. H. Ku, NBS Special Publication 300, Vol. 1, Feb. 1969, U. S. Government Printing Office, Wash., D.C., 20402 or Youden, W. J., Industrial Quality Control, Vol. XV, No. 11, 1959.

about the same value on the Y-axis. Each point represents one laboratory and there will be as many points as there are reporting laboratories. A line parallel to the X-axis is drawn through the median of these points in the Y direction; a line parallel to the Y-axis is drawn through the median of these points in the X direction. The two lines divide the graph into four quadrants.

If only randon errors are present, the points can be expected to be equally distributed in all quadrants. Points tend to be concentrated in the upper right and lower left quadrants when systematic bias by individual laboratory exists.

Figure 1 is a Youden Plot based on non-flaming test data for Linoleum and Polypropylene rug, and Figure 2 for the flaming test data on PVC/gypsum board and Acoustic Tile. In both figures, Labs A, C, E and Q are identified but are not included in determining the medians. Figure 1 is typical of the other Youden plots for materials tested under the non-flaming condition, and Figure 2 for the flaming condition. There is a general tendency for points to concentrate in the upper right and lower left quadrants, which is typical for most interlaboratory data. However, data in Figure 2 show that laboratories have a much greater tendency to have similar results (high or low) on both materials thus indicating a systematic deviation which requires explanation.

Figures 3 and 4 are another form of Youden plot in which the first and second (duplicate) test results for a single material are plotted. If there were no biases, about 90% of the points should be within a circle whose radius is 2.15 times the standard deviation.

Analysis of Table A-1 shows that for all materials with D_m (corr.) values >100, 80% of all the individual values were within ±10% of the mean values for all laboratories; also over 95 percent of all the individual values were within ±20% of the mean values for all laboratories.

An overall distribution of results (18 AMINCO chambers) is shown in Figure 5 and 6. Mean values of D_m (corr.) for each laboratory are plotted against the mean of all laboratories. It indicates in some cases how a few outlying values inflated the computed standard deviations.

6.3 Ranking of Materials

Of the 10 material-conditions included in the tests, all 18 laboratories with AMINCO chambers (with 3 material exceptions) ranked 9 of the material-conditions in the same order in terms of D_m(corr.), see Table 10. Because of the proximity of results between the 10th material, Acoustic tile, D_m(corr.)= 20; and the 9th material, Polystyrene Foam, non-flaming D_m (corr.) =23, some reversal in ranking order occurred. This was not unexpected because of the closeness of the D_m values.

For additional statistical results on the range of duplicates, rankings, and frequency distribution, see Appendix C.

7.0 DISCUSSION

This round robin was designed to examine the level of variability of the test method for materials with a wide range of properties in terms of composition, thickness, reaction to heat and flame, and production of smoke. It also included diverse types of laboratories - research as well as testing oriented; experienced as well as new to smoke measurement work. The result should reflect therefore, a conservative estimate of the precision of the test method.

An interlaboratory test of this type indicates clearly to the participating laboratories who have reported systematic deviations from the average, that they should examine their procedures more carefully to locate sources of such departures.

7.1 Laboratories

The optical system and the thermal properties of the inside walls differ between the home-built (Labs. A, C, and E) and AMINCO chambers. As a group, the home-built chamber results are lower than the AMINCO ones with the difference more pronounced at the higher end of the scale.

The mean values on 5 of the 10 material-conditions supplied by Lab. Q were the lowest of all 22 laboratories. In many cases, Lab. Q deviations from the median exceeded 3 times the standard deviation, and their results have been excluded. Justifiable reruns, and withdrawal of some data by request, based on acknowledged error, were few and are listed in Appendix E.

7.2 Materials

The materials selected for the tests covered a wide range of smoke levels as well as physical properties. Table 8 and 9 reflect the fact that the uncertainty of the test results (in terms of computed standard deviation and coefficient of variation) is considerably greater for materials which change in shape and position during test exposure. For example ABS melted gradually and flowed down away from the high irradiance center region. The Polystyrene foam melted and shrank into the bottom of the holder rapidly where the bottom edge shields it from further exposure.

The results of the D_m (corr.) values show that the ratio of between-laboratory standard deviation (reproducibility), to the within-laboratory standard deviation, range between 0.9 and 2.2. This implies that variations in procedures among laboratories account for most of the error rather than specimen variations. Hence, the averaging of three replicate determinations as specified in the proposed test method standard will not improve the between-laboratory variability, unless some of the major systematic sources of error are removed. However, the required three determinations may help in getting a more representative cross-section of the material.

In terms of ranking materials based on smoke level, these tests show (a) almost total agreement among the laboratories, and (b) the ability to rank order consistently two materials whose smoke density values were within 12% of each other (Polypropylene rug = 621 versus Red oak = 552).

7.3 Results

Looking at the D_m (corr.) values in Table 9 under the smoldering exposure condition the five non-melting materials have a maximum coefficient of variation of 8.4%. The other two materials which melt, ABS and Polystyrene, have coefficients of variation of 11 and 27% respectively. However, the 27% coefficient of variation represents a standard deviation of only 6.3.

Under flaming exposure, the large coefficient of variation for tile and PVC-Gypsum veneer may be due to systematic error. In Figure 2, the high values of Lab. I and LL and the low values of F, R, and H may be due to the use of improper fuel flow rate and burner distance, see Table 3. If these data were excluded, the coefficient of variation for the two materials would be reduced by about one-third. However; for the tile and the PVC/gypsum materials, the actual values of the standard deviation are 6.9 and 19 respectively, representing low absolute variations for low smoke producing materials. The result for Polystyrene under flaming exposure is less affected by variations in burner location and fuel, since once ignited, it becomes strongly exothermic and burns without requiring external energy. This is also true with the thicker PVC/PVA sheet under flaming exposure used in the preliminary tests. There, the coefficient of variation was only 7.1% (mean D_m= 553). (See Appendix D for detailed data).

Of all the parameters listed in Table 9, the D_c values, photometer window deposit, has a relatively higher between-lab, variance; which appears to be systematic. This may be due to deficiency in the window-heater design, which did not minimize the difference in window temperature among chambers.

7.4 Possible Sources of Error

For the materials tested in this study, there was greater variability in the flaming exposure test results compared to the non-flaming tests. There are several possible sources for systematic errors in the flaming test, these include:

1. Type of pilot burner.
2. Position of the pilot burner relative to the specimen surface (horizontal and vertical spacings).
3. Flow rates of propane and air to the pilot burner.

8.0 CONCLUSIONS AND RECOMMENDATIONS

This interlaboratory study of the smoke density chamber test method showed that reproducible test results were attainable for a wide variety of materials tested under flaming and non-flaming exposure conditions.

To improve reproducibility and repeatability even further, and to reduce systematic errors, certain features of the test method description, apparatus and/or experimental procedures may be noted:

1. For improved reproducibility under flaming exposure conditions, a reference standard material with a maximum specific optical density in the range of 400 to 500, would appear useful.

2. Care should be taken in the proper location and use of the standard pilot burner to ensure its identical re-positioning from test to test.

3. Propane and air flowmeters of the proper range and calibration should be used and maintained.

4. The special six-tube burner and holder (used on melting specimens) should be adopted for all flaming specimens. This would simplify procedures and avoid the need of choosing a proper burner.

5. A properly calibrated radiometer should be used and carefully maintained.

6. Checks should be made of the proper furnace voltage prior to each test. In case where line voltage is not stable, a constant voltage transformer may be necessary.

7. The specified temperature limits of the wall surface should be observed.

8. Proper conditioning of all specimens is necessary.

9. Improved specification and/or design of the photometer window heater is needed so as to minimize temperature variability among the chamber windows.

10. Care should be exercised when changing optical filters, to avoid measurement errors. A system where filter changes can be made without removal of the optical drawer is recommended.

9.0 ACKNOWLEDGMENT

We would like to thank all participating laboratories and their representatives for their helpful comments, effort and cooperation in making this joint study possible; the participants for attending the pre-test conference; Mr. John Brendan of the U. S. Forest Products Laboratory for providing the red oak specimens; and Dr. H. H. Ku (NBS) for advice on the statistical design and analysis.

TABLE 1

Interlaboratory Evaluation of Smoke Density Chamber Test Method
Schedule of Tests

Specimen	Condition	LABS																	
		~~A~~				~~EE~~							~~LL~~			~~OO~~			
		S	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
B. Linoleum	S	8	2	2	2	2	2	2	2	2	8	2	2	2	2	2	2	2	2
Polypropylene Rug	S	2	8	2	2	2	2	2	2	2	2	8	2	2	2	2	2	2	2
Red Oak, 1/4"	S	2	2	8	2	2	2	2	2	2	2	2	8	2	2	2	2	2	2
ABS	S	2	2	2	8	2	2	2	2	2	2	2	2	8	2	2	2	2	2
Polystyrene Foam, 1"	F	2	2	2	2	8	2	2	2	2	2	2	2	2	8	2	2	2	2
	S	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
α - Cellulose Paper	S	2	2	2	2	2	8	2	2	2	2	2	2	2	2	8	2	2	2
PVC - Veneer Gypsum Board	F	2	2	2	2	2	2	8	2	2	2	2	2	2	2	2	8	2	2
	S	2	2	2	2	2	2	2	8	2	2	2	2	2	2	2	2	8	2
Acoustic Tile, Mineral Type	F	2	2	2	2	2	2	2	2	8	2	2	2	2	2	2	2	2	8

F = Flaming
S = Smoldering or nonflaming

Table 2 Test Materials (all specimens are 3" x 3")

Material	Thickness	Density		Color	Description
	inch	lb/ft^3	g/cm^3		
Linoleum	0.125	87	1.4	Green	"battleship" linoleum with burlap backing
Polypropylene Rug	0.22	17	0.28	Light Brown	Twist, loop weave, burlap backing
Red Oak	0.25	43	0.69	Natural	Uniform grain, wood, smooth finish
ABS	0.022	66	1.05	Cream	Flexible plastic opaque
α-cellulose	0.030	41	0.66	White	Pure cotton linter matting,(blotter paper)
PVC-Gypsum					
PVC veneer	0.010	51	0.82	Dark Brown	PVC Veneer, simulating wood grain over gypsum board
Paper (S)	0.015				
Gypsum	0.5				
Acoustic ceiling tile	0.75	20	0.32	Painted White	Mineral type, random and irregular shaped holes
Polystyrene Foam	1.03	6.0	0.096	Blue	Rigid low density insulating foam, fire retardant treated

TABLE 3 SUMMARY OF SELECTED TEST PARAMETERS

Lab	Completion Date	Conditioning		Test Sequence		Chamber Wall Temp. °C	Flowmeter Reading		Photometer Lamp, Volt	Burner ** Distance, in.	
		Predry	50%RH	Random or	Duplicate Pr.		Air mm (s)	Propane mm (p)		Vert.	Horiz.
B	3-31	Y	Y	Y		33-36	150	75	2.5	-	-
D	6-10	Y	Y		Y	36	131	75	2.4	-	-
EE	5-08	Y	Y	Y		33-37	140	60*	2.7	-	-
F	5-14	Y	Y		Y	34-37	(150)	68 (s)		3/8	-
G	3-19	Y	Y	Y		33	150	75		-	-6H
H	5-14	Y	Y	Y		33-36	150	75 (s)*		-	-6H
I	5-08	N	Y		Y	34-35	150	70 *	4.2	1/2	-
J	6-25	Y	Y	Y		31-34	150	75	2.4	-	-6H
K	4-16	Y	Y		Y	35-37	140	52	3.5	-	-
L	3-06	Y	Y	Y		34-36	135	45 (s)	3.5	-	-6H
LL	5-06			Y		38-39	140	30 (s)*		5/16	-
M	3-06				Y	36			2.7	-	-6H
N	4-17	Y	Y		Y	35-36	150	75	3.1	-	-
O	6-15	Y	Y		Y	34	150	75	2.7	-	-6H
OO	6-02	Y	Y	Y		34-36	142	75	2.4	-	-
P	4-29	Y	Y	Y		33-37	150	75	4.7	-	-
Q	6-22	Y	Y		Y	35	132	70 (s)*		-	-6H
R	4-16	N	Y	Y		34-36	120	80 (s)	4.2	-	-6H
S	3-17	Y	Y	Y		34-35	150	75		-	-
A	3-26	Y	Y		Y	33-36	not applicable		>90	-	-
C	3-10	Y	Y	Y		33-37	not applicable		>90	-	- 6H
E	3-23	N	Y	Y		33-35	methane		>90	15/64	- 6H

Note: y=yes, n=no, blank=no data
* commercial grade propane
**(-) = 1/4", otherwise given
( )=AMINCO Calibration
(s)=steel ball (p)= plastic ball
duplicate pair = 2 specimens of a material measured sequentially
6H= 6-holes burner

TABLE 4 Mean Dm (corr.) For Each Material and Laboratory

LAB.	LINOLEUM	POLY. RUG	RED OAK	ABS	POLYSTYRENE
B	748.5	739.5	548.0	201.0	21.0
D	703.0	629.5	513.0	201.0	25.5
EE	783.5	663.5	555.5	202.5	28.0
F	790.0	613.0	624.0	206.5	23.0
G	704.5	580.0	524.0	146.5	21.5
H	684.0	590.0	574.0	157.5	22.5
I	728.5	597.5	502.0	192.5	11.0
J	737.5	701.5	595.0	175.5	14.5
K	719.5	586.0	576.0	179.0	28.5
L	802.0	656.0	622.5	226.0	23.5
M	604.5	582.0	550.0	202.5	23.0
N	743.5	561.5	495.0	205.5	15.5
O	674.5	616.0	601.5	197.0	18.5
OO	690.5	629.0	514.0	170.0	15.0
P	722.0	608.5	516.0	162.0	24.0
R	718.5	617.5	544.5	177.5	30.0
S	776.0	668.5	558.5	198.0	37.0
LL	568.0	564.0	538.5	182.0	24.5
Q	480.0	449.5	381.5	197.0	10.0
A	524.0	489.5	473.0	184.5	30.0
C	495.5	522.0	383.0	86.5	11.0
E	560.5	484.5	491.0	131.0	19.5

LAB.	CELLULOSE	PVC	TILE FLAM.	PVC FLAMING	P.STYR. FL.
B	159.0	111.5	16.5	59.0	273.0
D	167.5	105.5	19.0	61.0	353.5
EE	159.5	110.5	19.5	75.5	326.5
F	165.0	110.0	6.5	24.5	405.5
G	165.0	107.0	19.5	57.0	322.0
H	157.5	102.5	16.5	37.5	418.0
I	164.5	105.0	33.0	87.5	428.0
J	169.5	103.0	26.5	69.0	334.5
K	153.5	102.5	27.0	83.0	377.0
L	157.5	112.0	15.0	48.5	409.0
M	153.5	118.0	27.5	79.0	406.0
N	162.5	124.5	21.0	62.0	433.0
O	163.5	114.0	27.0	92.5	425.5
OO	160.0	97.0	15.0	46.0	416.0
P	163.0	105.5	23.0	69.0	435.5
R	159.0	107.5	12.5	31.0	486.0
S	167.5	114.5	11.5	55.0	418.5
LL	179.5	115.0	27.5	83.0	376.5
Q	162.0	86.0	22.0	30.5	406.5
A	155.0	114.5	16.0	105.0	355.0
C	150.5	92.0	20.5	27.0	421.5
E	138.0	92.0	13.0	33.0	22.5

TABLE 5 Mean $T_{.9Dm}$ For Each Material and Laboratory

LAB.	LINOLEUM	POLY. RUG	RED OAK	ABS	POLYSTYRENE
B	9.30	6.00	9.95	12.85	14.00
D	3.15	4.30	10.65	13.80	11.65
EE	9.60	5.40	10.70	14.80	14.75
F	11.15	5.50	10.05	13.50	17.00
G	13.65	6.30	13.80	16.30	12.50
H	9.00	5.50	11.65	14.50	14.75
I	11.00	5.65	11.95	14.25	14.50
J	9.70	5.40	9.20	13.25	15.70
K	10.55	5.75	11.55	13.95	16.85
L	7.70	5.65	9.25	12.90	15.85
LL	8.80	4.95	10.75	14.00	14.25
M	6.65	4.30	10.45	11.70	16.50
N	7.50	4.50	10.75	13.50	15.35
O	9.90	6.75	9.15	14.65	12.15
OO	13.40	5.65	12.10	14.10	13.45
P	10.20	5.65	11.10	14.25	16.15
R	7.95	5.15	11.40	14.45	16.80
S	8.75	5.85	11.35	14.65	17.35
Q	7.65	4.35	13.25	13.55	5.55
A	6.60	3.40	8.75	11.70	22.50
C	12.00	5.15	15.20	11.60	11.95
E	10.00	5.10	12.00	16.00	23.00

LAB.	CELLULOSE	PVC	TILE FLAM.	PVC FLAMING	P.STYR. FL.
B	5.55	5.30	8.50	4.20	5.55
D	5.05	5.90	7.75	4.15	5.50
EE	4.60	5.30	7.00	3.90	6.60
F	4.80	5.35	8.75	3.50	4.25
G	5.80	7.55	9.00	4.30	6.05
H	5.15	5.25	8.75	4.55	5.25
I	5.25	6.30	8.50	4.00	5.70
J	4.35	5.00	6.45	3.90	5.65
K	5.20	5.80	9.05	4.10	6.90
L	4.35	4.90	8.20	4.15	4.85
LL	5.00	5.95	6.70	4.25	11.00
M	4.50	5.45	8.25	3.75	6.75
N	5.15	5.15	12.65	4.00	5.65
O	4.70	5.05	10.25	7.10	6.75
OO	6.65	6.10	8.85	4.50	7.30
P	5.75	5.35	9.05	4.40	6.95
R	6.10	5.65	7.35	3.55	4.50
S	4.95	5.90	7.05	3.90	4.85
Q	5.90	5.55	4.00	3.90	4.25
A	4.40	4.65	5.50	3.45	6.55
C	5.90	6.60	8.80	3.70	4.15
E	5.60	6.50	14.50	4.10	15.65

TABLE 6 Mean SON$_{(5)}$, Smoke Obscuration Number (5 min) For Each Material and Laboratory

LAB.	LINO	RUG	RED OAK	ABS	P STYR
B	706.0	1220.0	208.5	240.0	36.5
D	801.0	1427.0	123.5	208.0	46.5
EE	706.0	1536.5	151.0	184.5	37.0
F	687.5	1320.0	173.5	238.0	36.0
G	428.5	1065.5	65.5	106.0	33.0
H	674.0	1301.0	134.5	141.5	35.5
I	593.5	1268.5	103.0	240.0	21.5
J	741.0	1636.5	200.5	166.5	25.0
K	550.5	1212.0	105.0	187.0	43.0
L	847.5	1419.5	221.0	279.0	42.0
LL	529.0	1361.0	116.5	195.5	35.0
M	780.0	1616.0	155.0	302.5	41.0
N	947.5	1344.0	186.5	251.5	30.5
O	540.5	1107.5	259.5	194.0	39.0
OO	345.5	1343.0	109.5	208.0	31.0
P	494.5	1173.5	103.5	167.0	37.0
R	713.0	1454.0	125.5	174.0	41.0
S	687.0	1299.5	103.5	171.0	39.0
Q	650.5	997.5	70.0	230.5	35.0
A	787.5	1612.5	280.5	297.0	45.0
C	350.0	1128.0	66.0	120.0	27.0
E	377.5	1111.0	90.0	127.5	20.5

LAB.	A CELL	PVC	TILE FLAM.	PVC FL	PSTYR FL.
B	335.5	301.5	34.5	194.5	599.0
D	405.5	266.5	50.5	211.0	567.0
EE	456.5	307.0	56.0	251.5	350.5
F	415.0	287.0	8.0	114.0	1273.0
G	306.0	175.5	46.5	186.5	490.0
H	378.0	259.5	35.5	134.5	731.0
I	395.5	253.5	73.5	297.0	501.5
J	511.5	301.0	90.5	265.5	1000.0
K	329.5	213.5	61.0	270.5	324.0
L	459.5	319.0	30.0	170.0	887.0
LL	455.5	264.0	70.0	260.0	95.0
M	431.0	327.0	56.0	292.5	233.0
N	417.0	291.5	25.0	130.0	657.0
O	452.0	309.0	43.5	139.0	374.5
OO	326.0	216.5	32.0	146.5	225.5
P	306.5	270.5	59.5	226.0	166.0
R	404.5	280.0	26.0	127.0	1348.0
S	388.0	258.5	28.5	197.0	871.0
Q	315.5	216.5	86.5	112.0	948.5
A	445.0	369.0	58.0	393.0	413.5
C	234.0	188.0	26.0	116.0	1101.5
E	300.0	194.0	23.5	115.5	44.5

TABLE 7 Mean Dc, Clear Beam Value, For Each Material and Laboratory

LAB.	LINOLEUM	POLY. RUG	RED OAK	ABS	POLYSTYRENE
B	3.5	22.5	.5	6.5	1.0
D	17.0	22.0	8.0	9.5	1.0
EE	3.5	20.0	5.0	16.5	3.0
F	12.5	18.5	5.5	10.5	5.5
G	14.0	68.0	14.0	7.0	2.0
H	16.5	31.0	12.0	4.0	.5
I	10.5	21.5	8.5	7.0	.0
J	22.0	34.0	10.5	7.5	1.5
K	8.5	24.0	4.5	7.0	2.5
L	13.5	22.5	5.5	10.5	.5
M	13.5	13.0	10.5	12.0	3.0
N	7.0	20.5	6.0	6.0	1.5
O	4.5	27.5	7.5	6.5	1.5
OO	.5	22.5	.0	3.5	.5
P	5.5	21.0	.5	2.0	2.5
R	6.0	15.0	6.5	5.0	2.0
S	1.5	18.0	6.0	3.5	1.0
LL	.5	54.5	4.5	1.5	4.5
Q	8.0	46.0	2.0	6.5	1.0
A	9.0	23.0	4.0	17.0	3.0
C	1.5	27.5	4.5	1.0	.0
E	3.0	68.0	6.0	8.5	1.0

LAB.	CELLULOSE	PVC	TILE FLAM.	PVC FLAMING	P.STYR. FL.
B	4.5	1.5	.5	.5	23.0
D	4.0	2.5	1.0	1.0	25.0
EE	20.5	5.5	1.0	.5	36.0
F	6.0	2.0	1.0	3.5	32.5
G	8.0	2.5	1.0	1.0	30.0
H	4.5	2.5	.5	1.0	29.5
I	6.5	4.0	1.0	4.5	28.5
J	4.5	1.5	.5	.5	22.0
K	3.5	.5	.0	1.0	21.0
L	3.0	1.0	1.0	.5	20.0
M	5.0	2.0	1.0	1.5	25.0
N	5.5	1.5	1.0	.0	23.0
O	4.5	.0	2.0	3.0	21.5
OO	4.0	.5	.0	.0	23.0
P	5.0	.5	.5	.0	33.0
R	6.0	1.0	1.0	1.5	33.0
S	3.5	.5	.5	1.0	25.5
LL	3.5	.0	.0	.0	35.5
Q	8.5	1.0	.0	1.0	30.0
A	6.0	2.0	1.0	1.0	24.5
C	3.5	1.0	.0	1.5	18.5
E	9.5	1.5	.0	.0	1.0

TABLE 8 Dm(corr.)Values for 6 Additional Replicates by Each Lab

	Non-flaming													Flaming					
	Linoleum		Rug		Red Oak		ABS		α-cell			PVC-Gyp		P.Styrene		PVC-Gyp		Acoustic Tile	
Lab	J	S	B	K	L	LL	D	M	F	O	OO	H	Q	EE	N	G	P	I	R
AMINCO MODEL	752	744	664	619	608	559	205	201	164	156	166	97	96	343	343	57	70	24	13
	740	789	689	599	635	534	212	213	159	162	158	102	94	325	282	56	66	20	9
	713	779	646	597	561	529	195	215	160	160	157	95	97	345	451	54	77	22	10
	745	768	628	620	591	530	210	198	171	153	161	101	94	285	478	51	63	25	9
	745	*	628	591	590	518	211	192	157	*	169	100	94	371	356	61	67	30	9
	739		620	630	598	*	211	176	164		166	98	101	287	461	53	77	29	12
Avg.	739	770	649	609	597	534	207	199	162	158	163	99	96	326	395	55	70	25	10
S.D.	14	19	26	16	24	15	6.5	14	5.0	4.0	4.9	2.6	2.8	34	79	3.5	5.9	3.9	1.8
Lab	A				C									E#					
HOME BUILT	530				338									23					
	513				374									35					
	526				348									32					
	528				367									28					
	566				373									28					
	532				372									31					
Avg.	533				362									28					
S.D.	17.7				15.2									3.4					

* Data not reported or withdrawn by request

\# Specimens did not ignite; methane was used as fuel

TABLE 9 - SUMMARY OF VALUES FOR 18 LABORATORIES (AMINCO)

		Non-flaming Exposure							Flaming Exposure		
		Lino.	Rug	Red Oak	ABS	α-cell	PVC-Gyp	P. Sty	P. Sty	PVC-Gyp	Tile
	BETWEEN-LAB										
D_m(corr.)	Mean	725*	621	552	188	162*	109	23	391	62	20
	S. D.$^{+}$	49	52	40	20	4.7	6.6	6.3	52	19	6.9
	Coef. Var%	6.7	8.4	7.2	11	2.9	6.0	27	13	31	34
	WITHIN-LAB										
	S. D.$^{+}$	46	28	18	12	4.2	3.5	6.7	32	10.5	4.6
	Coef. Var%	6.4	4.5	3.2	6.4	2.6	3.2	29	8.0	17	23
	BETWEEN-LAB										
$T_{.9D_m}$	Mean	9.6	5.5	10.8	14.0	5.2	5.6	15.0	6.2	4.2	8.4
	S. D.$^{+}$	1.8	.64	1.1	.98	.62	.63	1.7	1.6	.77	1.4
	Coef. Var%	19.4	11.8	10.4	7.0	11.9	11.1	11.5	26	18.2	17.0
	BETWEEN-LAB										
$SON_{(5)}$	Mean	661	1337	149	203	395	272	36	623	197	45
	Coef. Var%	23.2	12.2	34.9	24.6	14.9	15.1	17.7	56.8	30.9	44.4
	BETWEEN-LAB										
D_C	Mean	8.9	26.4	6.4	7.0	5.6	1.6	1.8	27.0	1.1	.75
	S. D.$^{+}$	6.3	13.8	3.8	3.7	3.9	1.4	1.4	5.2	1.2	.49

S. D. = Calculated Standard Deviation   Coef. Var. = Coefficient of Variation

\+ Between-lab. standard deviation based on laboratory means. With-in lab. standard deviation based on individual values.

* Excluding Lab. LL

Table 10 - Material Rankings by 18 Labs. (AMINCO)

LAB.	Lino.	Rug	Red Oak	Polysty/F	ABS	α-cellu.	PVC-Gyp	PVC-Gyp/F	Polysty.	Tile/F
B	1	2	3	4	5	6	7	8	9	10
D	1	2	3	4	5	6	7	8	9	10
EE	1	2	3	4	5	6	7	8	9	10
F	1	3	2	4	5	6	7	8	9	10
G	1	2	3	4	6	5	7	8	9	10
H	1	2	3	4	5	6	7	8	9	10
I	1	2	3	4	5	6	7	8	10	9
J	1	2	3	4	5	6	7	8	10	9
K	1	2	3	4	5	6	7	8	9	10
L	1	2	3	4	5	6	7	8	9	10
LL	1	2	3	4	5	6	7	8	10	9
M	1	2	3	4	5	6	7	8	10	9
N	1	2	3	4	5	6	7	8	10	9
O	1	2	3	4	5	6	7	8	10	9
OO	1	2	3	4	5	6	7	8	9	10
P	1	2	3	4	6	5	7	8	9	10
R	1	2	3	4	5	6	7	8	9	10
S	1	2	3	4	5	6	7	8	9	10
Mean D_m (corr.)	725	621	552	391	188	162	109	62	23	20

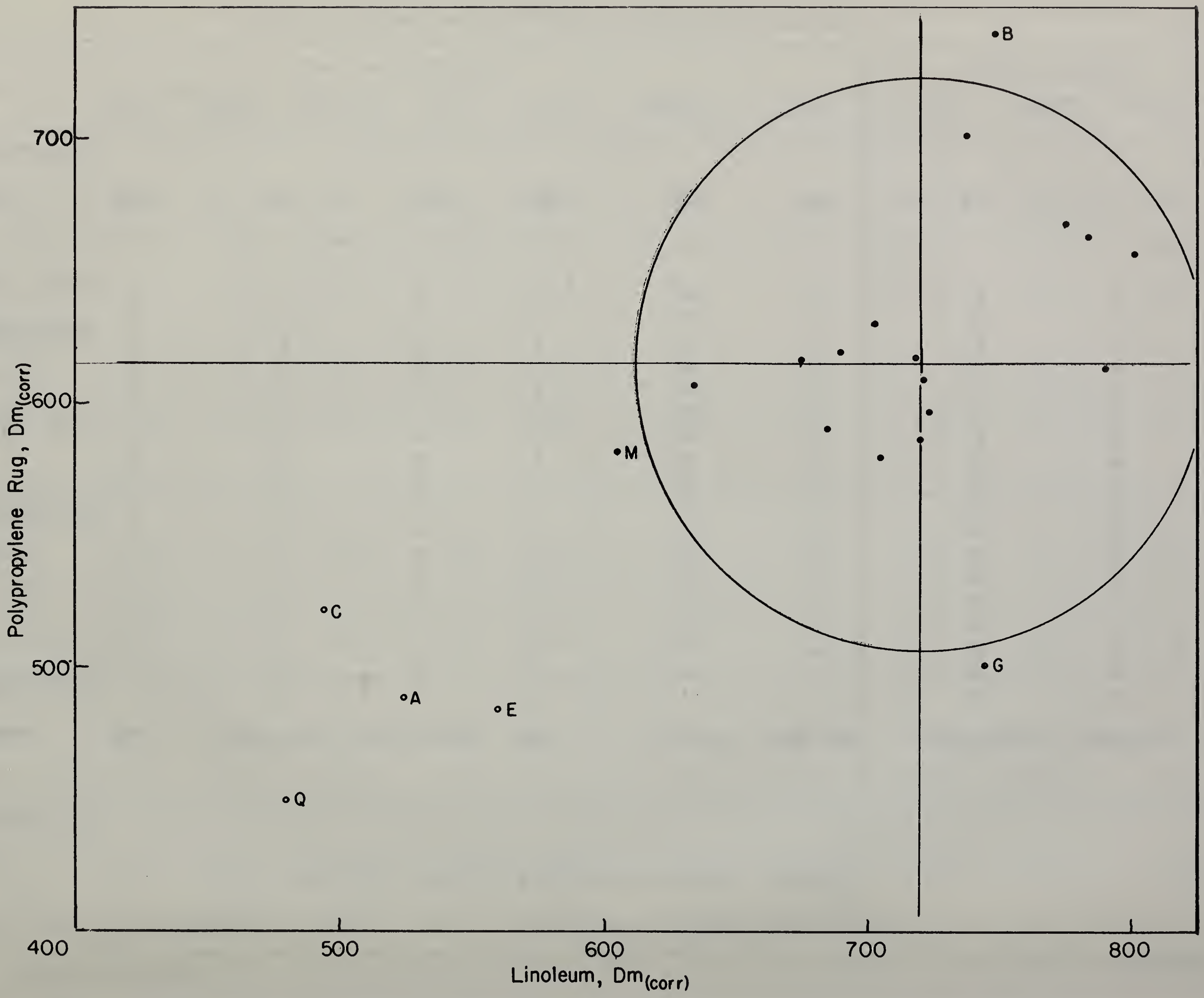


FIG. 1 Youden Plot of Linoleum vs. Polypropyrene Rug

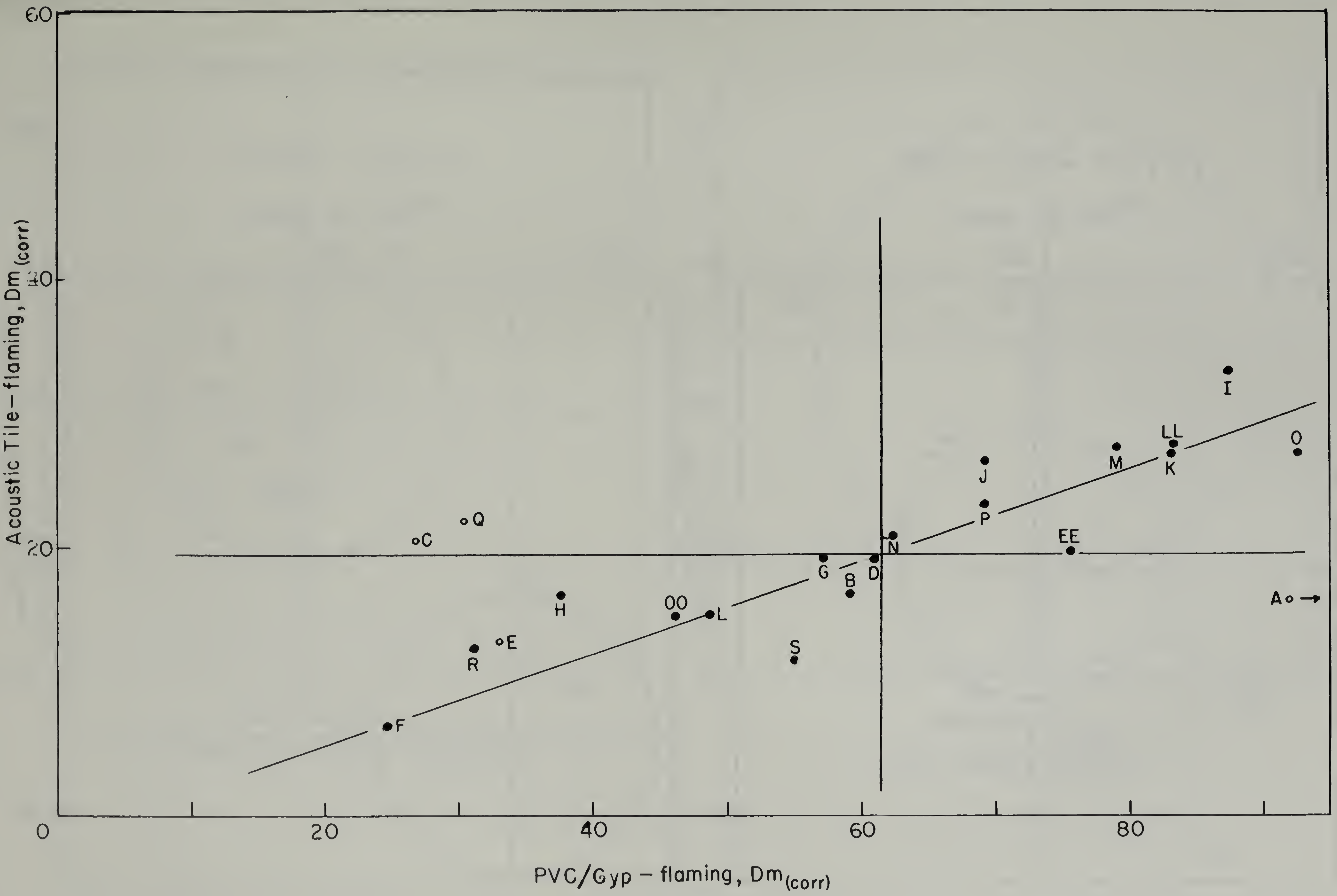
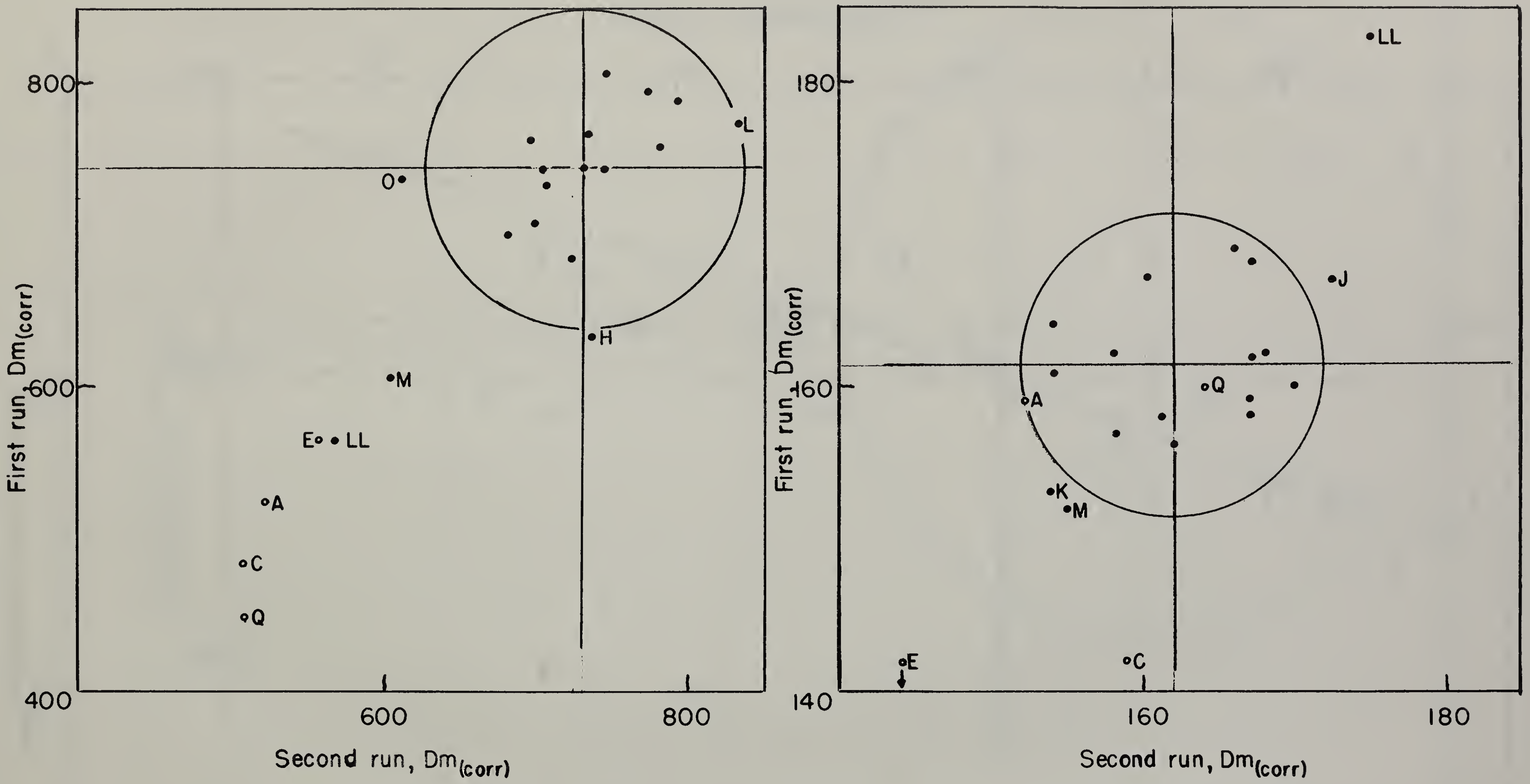


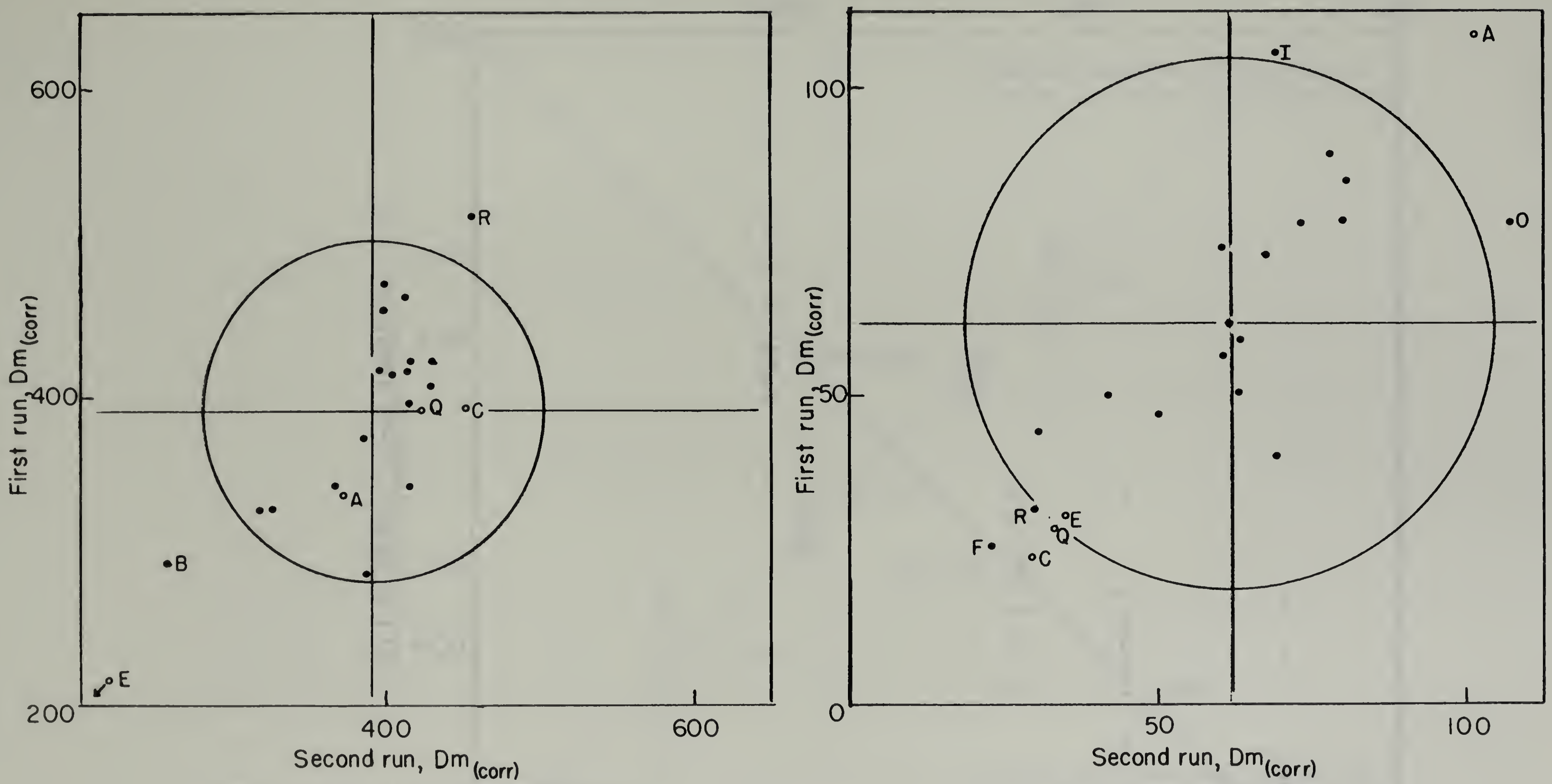
FIG. 2 Youden Plot of PVC/Gypsum vs. Acoustic Tile, Flaming



Linoleum 725 ± 49

Alpha Cellulose 162 ± 4.7

FIG. 3 Youden Plots of Linoleum and α-cellulose



Polystyrene, flaming 392 ± 52

PVC, flaming 62 ± 20

FIG. 4 Youden Plots of Polystyrene Foam and PVC, Flaming Condition

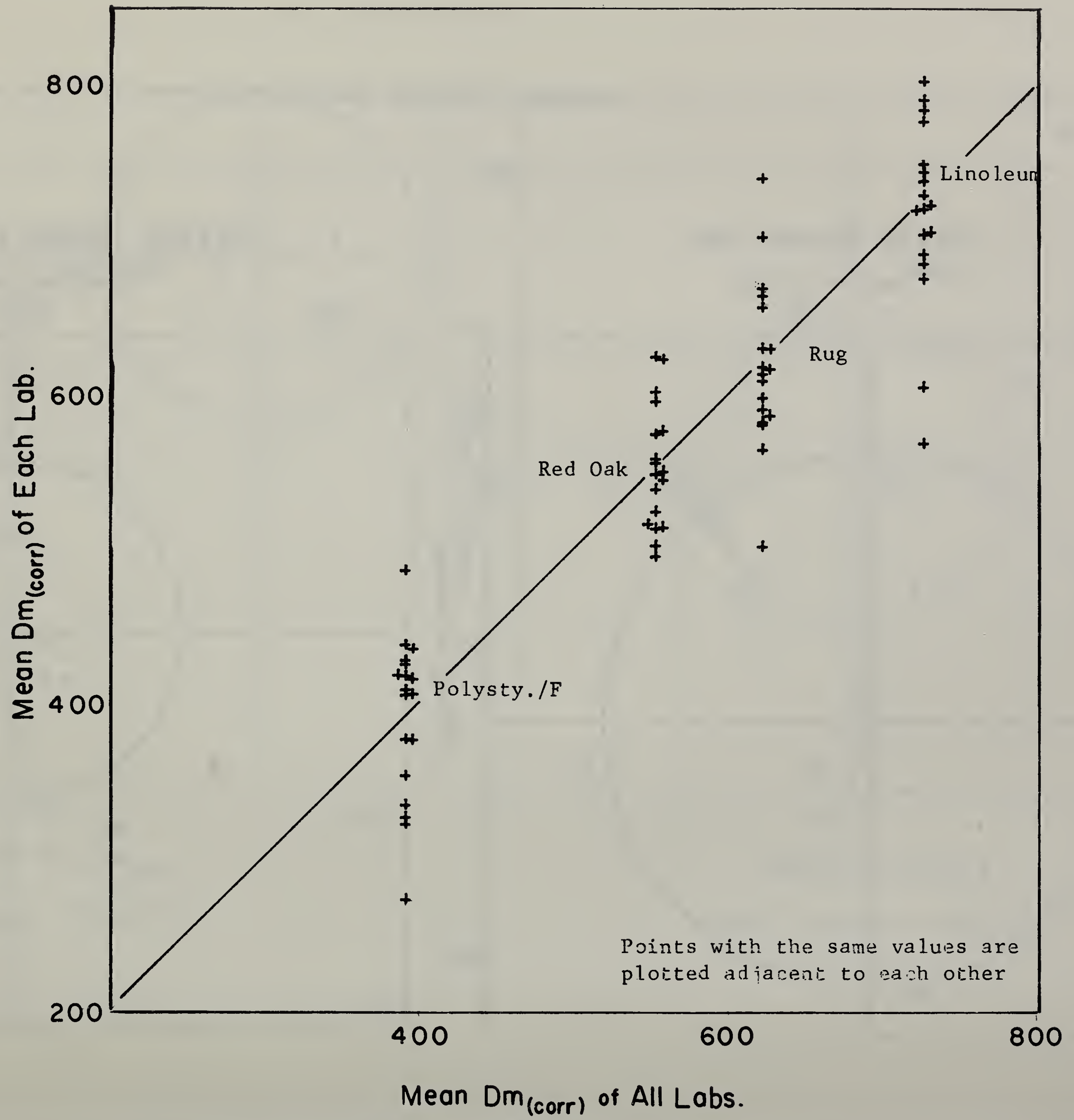


FIG. 5 Mean $D_{m(corr.)}$ of All Labs vs. Each Lab., 4 Materials

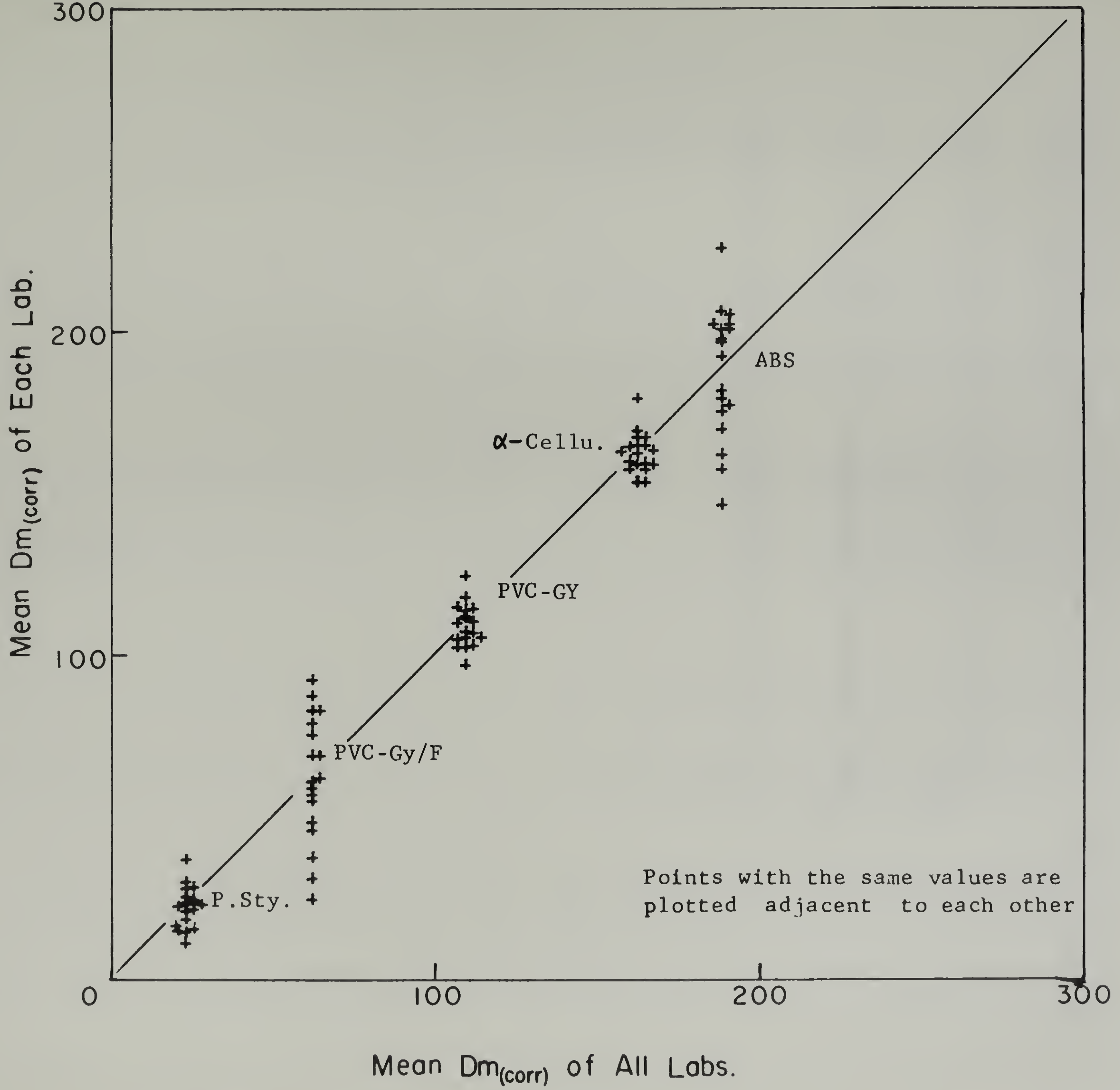


FIG. 6 Mean $D_{m(corr.)}$ of All Labs vs. Each Lab., 5 Materials

APPENDIX A

Table A-1 lists the duplicate values of D_m(corr.) for all materials and all laboratories.

Table A-2 lists the corresponding values of $T_{.9D_m}$.

Table A-3 lists the corresponding values of $SON_{(5)}$

Table A-4 lists the corresponding values of D_c.

TABLE A-1 Duplicate Values of Dm (corr), Maximum Specific Optical Density, Corrected

LAB.	LINOLEUM		POLY. RUG		RED OAK		ABS		POLYSTYRENE	
B	764.	733.	741.	738.	562.	534.	197.	205.	17.	25.
D	707.	699.	633.	626.	525.	501.	197.	205.	22.	29.
EE	795.	772.	675.	652.	555.	556.	195.	210.	24.	32.
F	786.	792.	603.	623.	616.	632.	204.	209.	26.	20.
G	687.	722.	580.	580.	524.	524.	147.	146.	24.	19.
H	632.	736.	592.	588.	583.	565.	153.	162.	20.	25.
I	762.	695.	594.	601.	505.	499.	193.	192.	11.	11.
J	744.	731.	739.	664.	597.	593.	192.	159.	18.	11.
K	704.	735.	579.	593.	556.	596.	166.	192.	30.	27.
L	831.	773.	656.	656.	645.	600.	230.	222.	24.	23.
M	608.	601.	583.	581.	555.	545.	199.	206.	29.	17.
N	744.	743.	498.	505.	491.	499.	200.	211.	18.	13.
O	738.	611.	656.	576.	586.	617.	183.	211.	11.	26.
OO	699.	682.	659.	599.	539.	489.	169.	171.	15.	15.
P	742.	702.	628.	589.	508.	524.	165.	159.	23.	25.
R	657.	780.	596.	639.	534.	555.	193.	162.	33.	27.
S	806.	746.	682.	655.	550.	567.	194.	202.	24.	50.
LL	568.	.	564.	.	520.	557.	166.	198.	18.	31.
Q	450.	510.	446.	453.	385.	378.	184.	210.	10.	10.
A	528.	520.	486.	493.	473.	473.	174.	195.	29.	31.
C	483.	508.	513.	531.	352.	414.	63.	110.	9.	13.
E	564.	557.	481.	488.	490.	492.	130.	132.	18.	21.

LAB.	A CELLULOSE		PVC		TILE FLAM.		PVC FLAMING		P.STYR. FL	
B	164.	154.	114.	109.	15.	18.	57.	61.	292.	254.
D	168.	167.	102.	109.	20.	18.	59.	63.	341.	366.
EE	158.	161.	113.	108.	19.	20.	76.	73.	326.	327.
F	160.	170.	107.	113.	6.	7.	26.	23.	397.	414.
G	162.	168.	113.	101.	21.	18.	51.	63.	327.	317.
H	157.	158.	104.	101.	15.	18.	44.	31.	408.	428.
I	162.	167.	108.	102.	32.	34.	106.	69.	459.	397.
J	167.	172.	100.	106.	29.	24.	77.	61.	283.	386.
K	153.	154.	102.	103.	27.	27.	85.	81.	372.	382.
L	161.	154.	111.	113.	16.	14.	47.	50.	414.	404.
M	152.	155.	120.	116.	29.	26.	78.	80.	416.	396.
N	158.	167.	124.	125.	25.	17.	62.	62.	465.	411.
O	167.	160.	115.	113.	16.	38.	78.	107.	421.	430.
OO	162.	158.	95.	99.	15.	15.	50.	42.	419.	413.
P	159.	167.	106.	105.	21.	25.	73.	65.	398.	473.
R	156.	162.	109.	106.	11.	14.	32.	30.	519.	453.
S	169.	166.	117.	112.	6.	17.	41.	69.	422.	415.
LL	184.	175.	117.	113.	27.	28.	89.	77.	340.	413.
Q	160.	164.	91.	81.	22.	22.	28.	33.	390.	423.
A	158.	152.	109.	120.	19.	13.	108.	102.	336.	374.
C	142.	159.	93.	91.	15.	26.	24.	30.	391.	452.
E	132.	144.	88.	96.	15.	11.	31.	35.	21.	24.

TABLE A-2 Duplicate Values of $T_{.9Dm}$,
Time (min.) at 90% of Maximum Smoke

LAB.	LINOLEUM		POLY. RUG		RED OAK		ABS		POLYSTYRENE	
B	8.5	11.1	5.9	6.1	10.0	9.9	12.7	13.0	10.0	18.0
D	7.8	8.5	4.3	4.3	9.8	11.5	13.3	14.3	9.3	14.0
EE	5.2	11.0	5.4	5.4	9.8	11.6	15.6	14.0	14.0	15.5
F	11.5	10.8	5.5	5.5	10.3	9.8	13.0	14.0	17.0	17.0
G	15.3	12.0	6.3	6.3	14.3	13.3	16.3	16.3	14.0	11.0
H	8.0	10.0	5.5	5.5	11.8	11.5	15.5	13.5	13.0	16.5
I	10.7	11.3	5.3	6.0	10.0	12.1	15.5	13.0	16.0	13.0
J	9.4	10.0	5.5	5.3	9.0	9.4	12.5	14.0	17.6	13.8
K	9.5	11.6	5.9	5.6	11.6	11.5	14.0	13.9	16.7	17.0
L	6.8	8.6	5.6	5.7	9.1	9.4	12.5	13.3	15.7	16.0
LL	7.8	10.0	4.4	5.5	11.5	10.0	14.5	13.5	11.0	17.5
M	6.6	6.7	4.3	4.3	9.7	11.2	12.0	11.4	16.2	15.8
N	7.5	7.5	4.5	4.5	11.0	10.5	14.0	13.0	16.0	14.7
O	10.8	9.0	6.5	7.0	9.5	8.8	16.5	12.8	4.3	20.0
OO	14.0	12.[illegible]	5.8	5.5	12.0	12.2	14.2	14.0	10.7	16.2
P	10.4	10.0	6.0	5.3	11.6	10.6	13.8	14.7	15.5	17.0
R	8.5	7.6	5.3	5.0	11.8	11.0	13.9	15.0	17.0	16.6
S	5.5	9.0	6.6	5.1	11.5	11.2	15.2	14.1	16.5	18.2
Q	6.8	8.5	4.0	4.7	14.0	12.5	13.3	13.8	5.5	5.8
A	7.5	5.9	3.8	3.0	7.8	9.7	11.0	12.4	22.0	23.0
C	12.0	12.0	5.4	4.9	14.5	15.9	7.2	16.0	3.1	20.5
E	9.0	11.0	5.0	5.2	12.0	12.0	17.0	15.0	20.0	26.0

LAB.	A CELLULOSE		PVC		TILE FLAM.		PVC FLAMING		P.STYR. FL	
B	5.7	5.4	5.4	5.2	9.0	8.0	4.0	4.4	5.5	5.6
D	4.8	5.3	5.8	6.0	8.5	7.0	4.3	4.0	5.5	5.5
EE	4.8	4.4	5.2	5.4	6.8	7.2	3.8	4.0	7.6	5.6
F	5.0	4.6	5.4	5.3	8.5	9.0	3.5	3.5	4.0	4.5
G	5.8	5.8	8.3	6.8	9.0	9.0	4.3	4.3	6.3	5.8
H	5.5	4.3	5.0	5.5	8.5	9.0	4.6	4.5	6.0	4.5
I	6.0	4.5	6.1	6.5	8.0	9.0	4.5	3.7	6.2	5.2
J	4.6	4.1	4.9	5.1	6.5	6.4	2.6	5.0	5.9	5.4
K	5.0	5.4	5.8	5.8	9.8	8.3	3.9	4.5	7.0	6.8
L	4.5	4.2	4.8	5.0	7.0	9.4	4.0	4.3	4.8	4.9
LL	5.5	4.5	5.7	6.2	6.7	6.7	4.5	4.2	9.0	13.0
M	4.6	4.4	5.7	5.2	8.0	8.5	3.6	3.7	7.0	6.5
N	4.8	5.5	6.0	4.3	10.3	15.0	4.0	4.0	4.8	6.5
O	4.6	4.8	4.3	5.8	10.0	10.5	4.9	9.3	8.3	5.2
OO	7.0	6.3	6.0	6.2	9.2	8.5	4.5	4.5	7.8	6.8
P	6.0	5.5	5.1	5.6	8.1	10.0	4.5	4.3	10.0	7.9
R	7.6	4.4	5.6	5.7	6.9	7.8	3.9	3.2	5.7	5.3
S	5.0	4.9	5.8	6.0	7.9	6.2	3.6	4.0	4.9	4.8
Q	5.5	6.3	5.8	5.3	2.5	5.5	3.0	4.8	4.5	4.0
A	4.7	4.1	4.6	4.7	6.0	5.0	3.5	3.4	7.4	5.7
C	6.3	5.5	6.4	6.8	8.0	9.6	3.5	3.9	4.6	3.7
E	6.0	5.2	6.0	7.0	17.0	12.0	4.5	3.7	15.3	12.0

TABLE A-3 Duplicate Values of SON$_{(5)}$

Smoke Obscuration Number (5 min)

LAB.	LINOLEUM		POLY. RUG		RED OAK		ABS		POLYSTYRENE	
B	960.	452.	1338.	1102.	259.	158.	214.	266.	10.	33.
D	725.	877.	1437.	1417.	135.	112.	242.	174.	41.	52.
EE	854.	558.	1579.	1494.	167.	135.	112.	257.	38.	36.
F	636.	739.	1309.	1331.	170.	177.	242.	234.	49.	23.
G	325.	532.	1020.	1111.	61.	70.	112.	100.	35.	31.
H	717.	631.	1323.	1279.	137.	132.	123.	160.	38.	33.
I	726.	461.	1276.	1261.	119.	87.	207.	273.	21.	22.
J	819.	663.	1743.	1530.	200.	201.	207.	126.	24.	26.
K	628.	473.	1156.	1268.	100.	110.	173.	201.	45.	41.
L	999.	696.	1389.	1450.	234.	208.	291.	267.	51.	33.
LL	529.	529.	1361.	1361.	89.	144.	184.	207.	45.	25.
M	748.	812.	1603.	1629.	163.	147.	294.	311.	51.	31.
N	958.	937.	1383.	1305.	196.	177.	281.	222.	29.	32.
O	589.	492.	1246.	969.	260.	259.	134.	254.	42.	36.
OO	327.	364.	1260.	1426.	124.	95.	206.	210.	37.	25.
P	527.	462.	1101.	1246.	82.	125.	200.	134.	40.	34.
R	613.	813.	1353.	1555.	123.	128.	209.	139.	49.	33.
S	734.	640.	1182.	1417.	111.	96.	141.	201.	44.	34.
Q	751.	550.	887.	1108.	78.	62.	257.	204.	35.	35.
A	665.	910.	1492.	1733.	341.	220.	327.	267.	49.	41.
C	283.	417.	1053.	1203.	82.	50.	112.	128.	35.	19.
E	413.	342.	1120.	1102.	94.	86.	122.	133.	19.	22.

LAB.	CELLULOSE		PVC		TILE FLAM.		PVC FLAMING		P.STYR. FL	
B	326.	345.	308.	295.	31.	38.	197.	192.	563.	635.
D	445.	366.	253.	280.	54.	47.	201.	221.	490.	644.
EE	431.	482.	318.	296.	59.	53.	257.	246.	108.	593.
F	388.	442.	283.	291.	8.	8.	110.	118.	1112.	1434.
G	315.	297.	152.	199.	46.	47.	172.	201.	501.	479.
H	341.	415.	261.	258.	32.	39.	154.	115.	498.	964.
I	346.	445.	268.	239.	82.	65.	355.	239.	378.	625.
J	469.	554.	285.	317.	122.	59.	296.	235.	852.	1148.
K	339.	320.	233.	194.	56.	66.	285.	256.	325.	323.
L	450.	469.	326.	312.	35.	25.	168.	172.	943.	831.
LL	428.	483.	271.	257.	69.	71.	275.	245.	58.	132.
M	421.	441.	337.	317.	66.	46.	282.	303.	345.	121.
N	435.	399.	287.	296.	23.	27.	130.	130.	762.	552.
O	472.	432.	316.	302.	29.	58.	230.	48.	148.	601.
OO	312.	340.	218.	215.	32.	32.	154.	139.	157.	294.
P	253.	360.	284.	257.	61.	58.	240.	212.	80.	252.
R	357.	452.	281.	279.	26.	26.	131.	123.	1862.	834.
S	386.	390.	263.	254.	12.	45.	160.	234.	862.	880.
Q	329.	302.	220.	213.	91.	82.	110.	114.	1026.	871.
A	436.	454.	355.	383.	66.	50.	401.	385.	382.	445.
C	185.	283.	192.	184.	21.	31.	105.	127.	841.	1362.
E	249.	351.	217.	171.	27.	20.	108.	123.	31.	58.

TABLE A-4 Duplicate Values of Dc

Photometer Window Deposit

LAB.	LINOLEUM		POLY. RUG		RED OAK		ABS		POLYSTYRENE	
B	1.	6.	21.	24.	1.	0.	2.	11.	0.	2.
D	13.	21.	21.	23.	9.	7.	12.	7.	1.	1.
EE	0.	1.	20.	20.	8.	2.	13.	20.	3.	3.
F	17.	8.	21.	16.	6.	5.	9.	12.	6.	5.
G	14.	14.	70.	66.	15.	13.	6.	8.	2.	2.
H	19.	14.	35.	27.	11.	13.	3.	5.	1.	0.
I	8.	13.	21.	22.	8.	9.	3.	11.	0.	0.
J	23.	21.	29.	39.	11.	10.	8.	7.	2.	1.
K	5.	12.	26.	22.	4.	5.	4.	10.	2.	3.
L	14.	13.	20.	25.	5.	6.	11.	10.	1.	0.
M	12.	15.	13.	13.	12.	9.	12.	12.	3.	3.
N	5.	9.	18.	23.	10.	2.	7.	5.	1.	2.
O	6.	3.	25.	30.	9.	6.	5.	8.	0.	3.
OO	1.	0.	20.	25.	0.	0.	2.	5.	0.	1.
P	9.	2.	15.	27.	0.	1.	1.	3.	3.	2.
R	7.	5.	16.	14.	6.	7.	6.	4.	3.	1.
S	2.	1.	20.	16.	10.	2.	5.	2.	2.	0.
LL	1.	0.	50.	59.	8.	1.	2.	1.	9.	0.
Q	9.	7.	48.	44.	1.	3.	7.	6.	1.	1.
A	13.	5.	22.	24.	1.	7.	14.	20.	3.	3.
C	2.	1.	36.	19.	8.	1.	1.	1.	0.	0.
E	2.	4.	87.	89.	11.	5.	8.	9.	0.	2.

LAB.	A CELLULOSE		PVC		TILE FLAM.		PVC FLAMING		P.STYR. FL	
B	4.	5.	1.	2.	1.	0.	1.	0.	26.	20.
D	5.	3.	3.	2.	1.	1.	1.	1.	25.	25.
EE	20.	21.	6.	5.	2.	0.	0.	1.	26.	46.
F	6.	6.	2.	2.	1.	1.	2.	5.	32.	33.
G	8.	8.	2.	3.	1.	1.	1.	1.	30.	30.
H	3.	6.	3.	2.	0.	1.	1.	1.	33.	26.
I	7.	6.	5.	3.	1.	1.	7.	2.	32.	25.
J	4.	5.	2.	1.	1.	0.	1.	0.	20.	24.
K	3.	4.	0.	1.	0.	0.	1.	1.	21.	21.
L	3.	3.	0.	2.	1.	1.	1.	0.	17.	23.
M	5.	5.	2.	2.	1.	1.	1.	2.	25.	25.
N	4.	7.	2.	1.	1.	1.	0.	0.	22.	24.
O	5.	4.	0.	0.	2.	2.	0.	6.	17.	26.
OO	5.	3.	0.	1.	0.	0.	0.	0.	23.	23.
P	5.	5.	1.	0.	1.	0.	0.	0.	34.	32.
R	5.	7.	1.	1.	1.	1.	2.	1.	33.	33.
S	3.	4.	0.	1.	1.	0.	2.	0.	26.	25.
LL	7.	0.	0.	0.	0.	0.	0.	0.	37.	34.
Q	9.	8.	1.	1.	0.	0.	1.	1.	58.	62.
A	7.	5.	2.	2.	1.	1.	1.	1.	26.	23.
C	6.	1.	1.	1.	0.	0.	2.	1.	15.	22.
E	5.	14.	1.	2.	0.	0.	0.	0.	0.	2.

APPENDIX B

Participants of Interlaboratory Evaluation of Smoke Density Chamber.

Laboratory	Location	Representative
Allied Chemical (Plastics Div.)	Morristown, N.J.	K. G. Smack
Armstrong Cork (R & D Center)	Lancaster, Pa.	Z. Zabawsky
DuPont (Engineering Test Center)	Newark, Del.	F. Thompson
DuPont (Plastics Dept.)	Wilmington, Del.	J. Blair
Federal Aviation Adm. (NAFEC)	Atlantic City, N.J.	J. F. Marcy E. Nicholas
Forest Products Lab.	Madison, Wisc.	H. W. Eickner J. Brenden
General Electric Co. (Plastics Dept.)	Mt. Vernon, Ind.	C. Bialous
General Tire & Rubber Co. (Chemical Plastic Dept.)	Akron, Ohio	G. Wear
Johns-Manville Research Center	Manville, N.J.	E. Davis
Koppers Co., Inc.	Monroeville, Pa.	C. Dzik
Lawrence Rediation Laboratory	Livermore, Calif.	J. Gaskill
Mobay Chemical Co.	Pittsburgh, Pa.	R. Hagins
National Bureau of Standards	Gaithersburg, Md.	T. Lee
National Research Council (Canada)	Ottawa, Canada	J. McGuire
Olin (Research Center)	New Haven, Conn.	A. Cianciola
Owens Corning Fiberglas Corp.	Granville, Ohio	P. Hays
Union Carbide (Plastics Dept.)	S.Charlestown, W.Va.	C. Hilado
Uniroyal Inc. (Research Center)	Wayne, N.J.	M. Jacobs
Uniroyal Inc.	Mishawaka, Ind.	G. Jablonski
Rohm & Haas Co. (Redstone Res.Lab.)	Huntsville, Ala.	T. Pratt
Underwriters Laboratory, Inc.	Northbrook, Ill.	J. Thiel
Weyerhaeuser Co.	Longview, Wash.	D. Crawford

APPENDIX C

The range of duplicates for each laboratory and each material is shown in Table C-1. The average range of duplicates for each material (averaged over all laboratories) and for each laboratory (averaged over all materials) also is shown. Table C-2 shows the ranking order of the laboratories for each material and the ranking sums (score) for each laboratory. A ranking order of 10, for examples, means that the particular laboratory has a D_m(corr.) value higher than nine other laboratories for that material. The score for a laboratory is based on the sum of the rankings for all materials [4]. Table C-3 shows the frequency distribution of each material. The full range of the reported values is divided into 10 equal intervals and the number of laboratories whose values fit within each interval is stated. This (non-Gaussian) distribution means that one or two laboratories with extreme values can have a large affect on the calculated means and standard deviation.

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[4] Youden, W. J., Ranking Laboratories by Round-Robin Test. Material Research Standard 3, No. 1, 9-13 (1963).

Table C-1 D_m(corr.) Range of Duplicates

LAB.	Non-flaming Exposure							Flaming Exposure			
	Lino	Rug	Red Oak	ABS	α-cell	PVC	P.Sty	P.Sty	PVC	Tile	Avg. Range
B	31	3	28	8	10	5	8	38	4	3	13.8
D	8	7	24	23	1	7	7	25	4	2	10.8
EE	23	23	1	15	3	5	8	1	5	1	8.5
F	4	20	16	5	10	6	6	17	3	1	8.8
G	35	0	0	1	6	12	5	10	12	3	8.4
H	104	4	18	9	1	3	5	20	13	3	18.0
I	67	7	6	1	5	6	0	62	37	2	19.3
J	13	75	4	33	5	6	7	103	16	5	26.7
K	31	14	40	26	1	1	3	10	4	0	13.0
L	58	0	45	8	7	2	1	10	3	2	13.6
LL	+	+	37	32	9	4	13	73	12	1	22.6
M	7	2	10	7	3	4	12	20	2	3	7.0
N	1	7	8	11	9	1	5	54	0	8	10.4
0	127	80	31	28	7	2	15	9	29	22	35.0
00	17	60	50	2	4	4	0	6	8	0	15.1
P	40	39	16	6	8	1	2	75	8	4	19.9
R	123	43	21	31	6	3	6	66	2	3	30.4
S	60	27	17	8	3	5	26	7	28	11	19.2
Q	60	7	7	26	4	10	0	33	5	0	15.2
A	8	7	0	21	6	11	2	38	6	6	10.5
C	25	18	62	47	17	2	4	61	6	11	25.3
E	7	7	2	2	12	8	3	3*	4	4	5.2
Avg. Range 18 AMINCO Labs.	44.1	22.8	20.7	14.1	5.4	4.3	7.2	33.7	10.6	4.1	

*= low values resulting from no ignition

+= Not included in the averaging, single run

Table C-2 D_m(corr.) Ranking and Score of Labs for Each Material (18 AMINCO Labs.)

LAB.	Non-Flaming Exposure									Flaming Exposure				
	Lino.	Rug	Red Oak	ABS	Cell	PVC	P.Sty	Score	Score Rank	P.Sty	PVC	Tile	Score	Score Rank
B	14	18	9	12.5	5.5	12	6	77	14	1	8	6.5	15.5	2
D	6	13	3	12.5	15.5	6.5	14	70.5	11	5	9	8	22	8
EE	16	15	11	14.5	7	11	15	89.5	15	3	13	9.5	25.5	10
F	17	9	18	17	13.5	10	9.5	94	16	8	1	1	10	1
G	7	2	16	1	13.5	8	7	44.5	3	2	7	9.5	18.5	3
H	4	5	13	2	3.5	2.5	8	38	2	12	3	6.5	21.5	7
I	11	6	2	9	12	5	1	46	4	15	17	18	40	17
J	12	17	15	5	17	4	2	72	13	4	11.5	13	28.5	11
K	9	4	14	7	1.5	2.5	16	54	5	7	15.5	14.5	37	12
L	18	14	17	18	3.5	13	11	94.5	17	10	5	4.5	19.5	4.5
LL	2	7	7	8	18	16	13	71	12	6	15.5	16.5	38	13.5
M	1	3	10	14.5	1.5	17	9.5	56.5	7	9	14	16.5	39.5	15.5
N	13	1	1	16	9	18	4	62	8	17	10	11	38	13.5
O	3	10	16	10	11	14	5	69	10	14	18	14.5	46.5	18
OO	5	12	4	4	8	1	3	37	1	11	4	4.5	19.5	4.5
P	10	8	5	3	10	6.5	12	54.5	6	16	11.5	12	39.5	15.5
R	8	11	8	6	5.5	9	17	64.5	9	18	2	3	23	9
S	15	16	12	11	15.5	15	18	102.5	18	13	6	2	21	6

Table C-3 Frequency Distribution $n = 18$

Linoleum	1	1	0	1	3	4	2	2	1	3
Rug	1	0	0	4	6	2	2	1	1	1
Red Oak	2	3	1	2	4	0	2	1	1	2
ABS	1	2	1	2	2	1	4	4	0	1
α-cellulose	2	2	4	3	3	2	1	0	0	1
PVC-Gypsum	1	0	4	4	2	2	3	1	0	1
P. Styrene	1	3	1	1	5	3	2	1	0	1
P. Styrene/F	1	0	3	1	2	0	6	4	0	1
PVC / F	2	1	0	2	2	3	2	1	3	2
Tile / F	1	1	1	4	3	1	1	5	0	1

APPENDIX D

Dm VALUES OF THE TWO PRELIMINARY SPECIMENS

(First 12 reporting labs.)

Labs	α-cellulose			PVA-PVC (flaming)		
	D_m	Range	D_c	D_m	Range	D_c
H	160 165	5	3 5	560 592	32	11 12
R	162 163	1	9 10	531 606	75	20 19
K	150 162	12		550* 543	7	
O	156 162	6	4 5	Unreported		
S	166 162	4	5 4	495 535	40	7 9
E	160 161	1		505 513	8	
L	163 156	7	2 3	549 608	59	8 12
G	166 176	10	3 3	505 517	12	13 13
C	166 163	3	5 7	498 513	15	26 18
M	157 166	9	6 7	620 629	9	18 13
I	161 157	4	4 3	581 597	16	5 9
P	162 176	14	6 2	545 568	23	7 6
BETWEEN_LABS+						
Mean	162.4			552.7		
Std. Dev.	4.2			39		
Coef. of Var. %	2.6			7.1		

* Assumed value-incomplete run

\+ Based on mean of duplicate for each lab.

APPENDIX E

The following data adjustments were made:

Lab	Material/Condition	No. of Tests	Remarks
H	Polystrene/flaming	2	Rerun, error.
K	Ploystrene/flaming	2	Rerun requested by lab.
S	Linoleum/non-flaming	1	Replaced 2nd by 4th run.
N	PVC/flaming	2	Not reported; assumed 62.
00	Tile/flaming	1	Excluded, error.
LL	Linoleum/non-flaming	1	Withdrew Requested by Lab. (error).
	Rug/non-flaming	1	
	Red Oak/non-flaming	1	
Q	All	All	Not used in statistical calculation (excessive variability)
A,C,E	All	All	Statistical calculation limited to AMINCO chambers

APPENDIX F

TEST METHOD FOR MEASURING THE SMOKE GENERATION CHARACTERISTICS OF SOLID MATERIALS

1. Scope

1.1 This method measures the smoke generation characteristics of solid materials of given thickness when mounted and tested in the manner and with the apparatus described. Measurement is made of the attenuation of a light beam by smoke (suspended solid or liquid particles) accumulating within a closed chamber due to pyrolytic decomposition (smoldering) and flaming combustion. Results are expressed in terms of specific optical density. Optical density (absorbance) is the single measurement most characteristic of the "concentration of smoke."

1.2 This method measures smoke produced under specified thermal exposure conditions comparable to those experienced in accidental fire situations. Materials are tested in simple, composite or assembly form as intended for use. The normally exposed surface of the material faces the radiant source, and materials which are "orientation sensitive" (as in the warp and fill directions of some fabrics) are tested in the worst case condition. The method and apparatus is also suitable for the collection and analysis of the products of combustion and measurement of the effects of ventilation, higher irradiance, and other parameters.

1.3 The photometric scale used to measure smoke by this test method is similar to the optical density scale for human vision.

2. Summary of Method[1]

2.1 This method for measuring the smoke generation characteristics of materials employs as a radiant heat source, a glowing electrical heating element mounted within an insulated ceramic tube and positioned so as to produce an irradiance level of 2.2 Btu/sec ft^2 (2.5 W/cm^2) averaged over the central 1.5 in. (38.1 cm) dia. area of a vertically mounted specimen facing the radiant heater. The nominal 3 by 3 in. (76.2 by 76.2 mm) specimen is mounted within a holder which exposes an area measuring 2 9/16 by 2 9/16 in. (65.1 by 65.1 mm). The holder

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[1] D. Gross, J. J. Loftus and A. F. Robertson, "Method for Measuring Smoke from Burning Materials," ASTM Special Technical Publication No. 422 (1967), describes factors in the development of this method and provides comparative test data on the measurement of the smoke generating characteristics of materials.

can accommodate specimens up to 1 in. (2.5 cm) thick. This exposure provides the nonflaming (smoldering) condition of the test.

2.2 For the flaming condition, a six-hole burner is used to apply a horizontal row of equidistant premixed (air-propane) flamelets across the lower edge of the exposed specimen area. This application of flame in addition to the specified irradiance level from the heating element constitutes the flaming combustion exposure.

2.3 The test materials are exposed to the flaming and nonflaming conditions within a closed 18 ft^3 (0.51 m^3) chamber. A photometric system with a 36 in. (91.4 cm) vertical light path measures the continuous decrease in light transmission as smoke accumulates.

2.4 Calibration procedures for the test equipment are described in Appendix A. The light transmittance measurements are used to express the smoke generation characteristics of the test materials in terms of the specific optical density during the time period to reach the maximum value.[2]

3. Apparatus

3.1 The apparatus shall be essentially as shown in Figs. 1 and 2. A more detailed description of suggested details (using the same paragraph numbers) is given in Appendix C. The apparatus shall include the following:

3.1.1 Test Chamber - As shown in Fig. 2, the test chamber shall be fabricated from continuously welded or soldered sheet metal or laminated panels[3] to provide inside dimensions of 36 by 24 by 36 in. (91.4 by 61.0 by 91.4 cm) for width, depth and height, respectively. The interior surfaces shall consist of porcelain-enameled metal, or equivalent coated metal resistant to chemical attack and corrosion, and suitable for periodic cleaning. Openings shall be provided to accommodate a vertical photometer, power and signal connectors, air and gas supply tubes, an exhaust blower, inlet and exhaust vents, pressure and gas sampling taps, a pressure relief valve, an

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[2] Additional parameters, such as the maximum rate of smoke accumulation, time to a fixed optical density level, or a smoke obscuration index may be more appropriate in particular situations. See Appendix B

[3] Porcelain-enameled steel (interior surface) permanently laminated to asbestos-cement board and backed with galvanized steel (exterior surface), total thickness 3/16 in., by Alliance Wall Corporation has been found suitable.

aluminum foil (0.0010 in. approx. 0.025 mm or less) safety blowout panel, at least 125 in.^{2} (806 cm^2) in area, and a hinged front mounted door with an observation port or window. All openings except the gas sampling taps and inlet vent shall be located on the floor of the chamber. When all openings are closed the chamber shalll be capable of developing and maintaining positive pressure during test periods, in accordance with paragraph 7.10 of Section 7.

3.1.2 Radiant Heat Furnace - As shown in Fig. 3, an electric furnace with a 3 in. (76.2 mm) diameter opening shall be used to provide a constant irradiance on the specimen surface. The furnace is to be located centrally along the long axis of the chamber with the opening facing toward and about 12 in. (30.5 cm) from the right wall. The centerline of the furnace shall be about 7 3/4 in. (19.5 cm) above the chamber floor.

The furnace control system shall consist of a thermocouple-actuated temperature controller with two autotransformers. One autotransformer ("low") shall be adjusted to provide the required irradiance level under steady-state conditions with the chamber door closed, and the second autotransformer ("high") adjusted to a slightly higher level.

3.1.3 Specimen Holder - The specimen holder shall conform in shape and dimension to Fig. 4. and be fabricated to expose a 2 9/16 by 2 9/16 in. (65.1 by 65.1 mm) specimen area. Also shown in Fig. 4 are sketches of a special holder and a special burner for specimens that melt during the test, and a modified retaining rod for use with specimens from 5/8 to 1 in. (1.6 to 2.5 cm) thick.

3.1.4 Framework for Support of the Furnace and Specimen Holder - The furnace and specimen supporting framework shall be constructed essentially in accordance with Fig. 5.

3.1.5 Photometric System - The photometric system shall consist of a light source and photodetector, oriented vertically to reduce variations in measurement brought about by stratification of the smoke generated by the materials under test. The system shall be as shown in Fig. 6, and includes the following:

3.1.5.1 The light source shall be an incandescent prefocused (15 W or greater) lamp powered by a voltage regulating transformer. Two variable resistors in series shall provide coarse and fine intensity adjustment. The light source shall be mounted in a sealed and light-tight box extending from the top or bottom of the chamber. This box shall contain the necessary optics for collimating the light beam.

3.1.5.2 The photodetector shall be a 1P39 single-stage vacuum tube, or a photomultiplier tube, with an S-4 spectral sensitivity response and a dark current less than 10^{-9} A. A sealed box located directly opposite the light source shall be provided to house the photodetector and the focusing optics. A 3/16 in. (4.8 mm) dia. circular stop at the focal plane of the lens, serves to collimate the beam and to minimize the entry of scattered light from off-axis illumination. A glass window shall be used to isolate the photodetecter and its optics from the interior of the chamber.

3.1.6 Radiometer - The radiometer for standardizing the output of the radiant heat furnace shall be of the circular foil type, the operation of which was described by Gardon[4]. The construction of the radiometer shall be as shown in Fig. 7. It shall have a stainless steel reflective heat shield with a 1 1/2 in. (38.1 mm) aperture on the front and a finned cooler supplied with compressed air mounted on the rear to maintain a constant cold junction temperature.

The body (cold-junction) temperature of the radiometer shall be monitored with a thermometer.

3.1.7 Thermocouples for Determining Chamber Wall Temperature and Controlling Furnace Output - Thermocouples shall be provided for determining the chamber wall temperature prior to testing and to provide temperature control of the furnace.

3.1.8 Portable Recorder or Read-Out Meter - The outputs of the radiometer and the thermocouples shall be monitored by a suitable recorder or read-out meter. The photodetector output shall be recorded or monitored with a potentiometer or high-impedance instrument capable of measurement over a range of 5 decades, or more. See Appendix C, paragraph C.3.1.5.

3.1.9 Manometer for Chamber Pressure Measurements - A simple water manometer with a range up to 6 in. (15.2 cm) of water shall be provided to monitor chamber pressure and leakage (see Appendix A). The pressure measurement point shall be through a gas sampling hole at the top of the chamber. A simple water column or relief valve shall be provided to permit control of chamber pressure.

3.1.10 Multiple Flamelet Burner with Premixed Air-Propane Fuel - For a flaming exposure test, either a six-hole "Tee" burner or a six-tube burner, with construction details as shown in Fig. 4, shall be used.

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[4] R. Gardon, "An Instrument for the Direct Measurement of Intense Thermal Radiation, "Review of Scientific Instruments, Vol. 24, pp. 366-370, (1953).

The burner shall be centered in front of and parallel to the specimen holder. The holes or tip of the nozzles shall be centered 1/4 in. (6.4 mm) above the holder edge and 1/4 in. (6.4 mm) away from the specimen surface. Provision shall be made to rotate or move the burner out of position during non-flaming (smoldering) exposures. A premixed air and propane (95% purity or better) test gas shall be used. The air and propane shall be metered by calibrated rotameters and needle valves at 500 cm^3/min. for the air and 50 cm^3/min. for the propane.

3.1.11 Special Burner For Melting Specimens - If, under a normal flaming exposure, the specimen melts or shrinks away from the pilot burner or drips from the holder and thus fails to ignite, a special specimen holder and burner shall be used. The construction details are shown in Fig. 4. Using the outer two tubes as guides, the burner shall be aligned relative to the specimen holder as described in 3.1.10 for the standard burner and holder. In cases where there is question as to the appropriate burner to use, comparison tests shall be made using each burner.

4. Test Specimens

4.1 Size - The test specimens shall be 3 by 3 in. (76.2 by 76.2 mm) by the intended installation thickness up to and including 1 in. (25.4 mm) thick. Specimens provided in thicknesses in excess of 1 in. (25.4 mm), shall be sliced to 1 in. (25.4 mm) thickness and the original surface tested.

4.2 Specimen Orientation - If visual inspection of the specimen indicates a pronounced grain pattern, process-induced surface orientation, or other nonisotropic property, the specimen shall be tested in two or more orientations. The highest smoke density value and the test orientation shall be stated.

4.3 Specimen Assembly

4.3.1 The specimen shall be representative of the materials or composite as intended for use and shall be prepared in accordance with recommended application procedures. However, flat sections of the same thickness and composition may be supplied and tested in place of curved, molded or specialty parts. Substrate or core materials for the test specimens shall be the same as those for the intended application. Where a material or assembly may be exposed to a potential fire on either side, both sides shall be tested.

4.3.1.1 Finish materials, including sheet laminates, tiles, fabrics and others secured to a substrate material with adhesive, and composite materials not attached to a substrate, may be subject to delamination, cracking, peeling, or other separations affecting its smoke generating characteristics. To evaluate these effects, supplementary tests performed on a scored (slit) exposed surface, or on interior layers or surfaces, may be necessary. When supplementary tests are conducted for this purpose, the manner of performing such supplementary tests, and the test results, shall be included in the report with the conventional test.

4.3.2 For comparative tests of finish materials without a normal substrate or core, and for screening purposes only, the following procedures shall be employed:

4.3.2.1 All sheet or film materials shall be tested by the standard procedure regardless of thickness.

4.3.2.2 Liquid film (paints, adhesives, etc.) intended for application to combustible base materials, shall be applied to the smooth face of 1/4 in. (6.4 mm) thick tempered hardboard, nominal density 50 to 60 lb/ft^3 (0.8 to 0.97 g/cm^3), using recommended (or practical) application techniques and coverage rates. Tests shall also be conducted on the hardboard substrate alone and these values shall be recorded as supplemental to the measured values for the composite specimen.

4.3.1.3 Liquid films, (paints, adhesives, etc.) intended for application to noncombustible substrate materials, shall be applied to the smooth face of 1/4 in. (6.4 mm) thick asbestos-cement board, nominally 120 lb/ft^3 (1.9 g/cm^3) in density, using recommended (or practical) application techniques and coverage rates.

4.3.3 It is the intent of this test method to maintain the prescribed exposure conditions on the specimen for the test duration. If, during any test, the specimen tends to melt or drip and fall away from the specimen holder, it shall be tested using a specimen holder which has been modified to retain the fallen residue so that it remains exposed to the radiant heat source throughout the test period. For flaming condition, a special pilot burner (see Fig. 4) should also be used with the modified holder.

4.3.4 Specimen Mounting

4.3.4.1 All specimens, shall be covered across the back, along the edges, and over the unexposed front surface periphery with a single sheet of aluminum foil (0.0015 ± 0.0005 in. or approximately 0.04 mm). The less reflective surface of the foil is to be placed against the specimen back surface. Care shall be taken not to puncture the foil or to introduce unnecessary wrinkles during the wrapping operation. Fold in such a way so as to minimize losses of melted material at the bottom of the holder. Excessive foil along the front edges may be trimmed off, after mounting. In using the special holder with the trough, a flap of foil should be bent forward at the spout to permit flow.

4.3.4.2 All specimens shall be backed with a sheet of asbestos millboard (see paragraph 3.1.3.). The specimen and its backing shall be secured with the spring and retaining rod. A modified "C" shape retaining rod shall be used with specimens from 5/8 to 1 in. (1.6 to 2.5 cm) thick. Do not compress flexible specimens below their normal thickness.

5. Specimen Conditioning

5.1 Specimens shall be predried for 24 hr. at 140°F (60°C) and then conditioned to equilibrium (constant weight) with an ambient temperature of 73 ± 5°F (23 ± 3°C) and a relative humidity of 50 ± 5 percent.

6. Number of Test Specimens

6.1 At least three tests under flaming exposure and three tests under nonflaming (smoldering) exposure shall be conducted on each material (total of six specimens) in accordance with the conditions described herein.

7. Test Procedure

7.1 All tests shall be conducted in a room or enclosed space having a ambient temperature of 73 ± 5°F (23 ± 3°C) and relative humidity of 50 ± 20 percent at the time of test.

7.2 Clean the chamber walls whenever periodic visual inspection indicates the need[5]. Clean the exposed surfaces of the glass windows separating the photodetector and light source housings from the interior of the chamber, before each test (ethyl alcohol is generally effective). Charred residues on the specimen holder and horizontal rods should be removed to avoid contamination.

7.3 During the warm-up period all electric systems (furnace, light source, photometer readout etc.) should be on; the exhaust vent and chamber door closed; and the inlet vent open. When the temperature on the center surface of the back wall reaches 95 ± 4°F (35 ± 2°C), the chamber is

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[5] An ammoniated spray detergent (e.g. "Whistle") and soft scouring pads (e.g. "3M") have been found effective.

considered to be at a steady-state condition and ready for furnace calibration or testing. Calibrate the furnace output irradiance at least twice per test day.

A "blank" specimen holder, with the asbestos millboard backing exposed should always be directly in front of the furnace except when displaced to the side by (1) the specimen holder during a test or (2) the radiometer during calibration. It should be returned immediately to this position when testing or calibration is completed.

7.4 During calibration, the radiometer is placed on the horizontal rods of the furnace support framework and accurately positioned in front of the furnace opening, by sliding and displacing the "blank" specimen holder against the prepositioned stop. With the chamber door closed and inlet vent-opened, the compressed air supply to the radiometer cooler is adjusted to maintain its body (cold-junction) temperature at 200°F (93°C) ± 5 °F. The "low" autotransformer setting is adjusted to produce the calibrated millivolt output of the radiometer corresponding to a steady-state irradiance of 2.2 Btu/sec ft^2 (2.5 W/cm^2) ± 2% averaged over the central 1.5 in. (38.1 cm) dia. area. The "high" autotransformer setting should be about 2 to 5 volts above the "low" setting. The temperature setting of the controller should be approximately 10°C below that corresponding to steady-state conditions, so that a temperature decrease of 10°C is required to switch to the "high" autotransformer. Under normal operation, the on-off cyclic control is required only occasionally.

The recorder or meter described in paragraph 3.1.8 is used to monitor the radiometer output. After the prescribed irradiance level has reached steady-state, the radiometer is removed from the chamber and replaced with the "blank" specimen holder.

7.5 After the system has reached steady-state conditions, adjust meter and/or recorder zero. Adjust the amplifier sensitivity and/or lamp intensity to obtain a full-scale reading of the photodetector (100 percent transmittance) on a convenient range of the recorder or read-out meter. Determine the "dark current" reading (zero percent transmittance) on the maximum sensitivity range of the recorder or read-out meter by blocking the light; alternately, for photometer systems with provision for "dark current" cancellation, adjust the reading to zero.

7.6 For nonflaming (smoldering) exposures, the multiple flamelet burner is removed. For flaming exposures, the burner is positioned across the lower edge of the specimen as described in paragraph 3.1.10. Check the burner distances relative to the "blank" specimen before fuel adjustment and ignition.

7.7 Before positioning the test specimen, verify the starting temperature of the chamber, using the procedure described in paragraph 7.3. Flush the chamber with the door and exhaust and inlet vents open for about 2 minutes.

7.8 Close the exhaust vent and blower. Place the loaded specimen holder on the bar supports and push it into position in front of the furnace (with burner in position for flaming exposure) by displacing the "blank" holder. Quickly close the chamber door and simultaneously start the timer, and/or recorder chart drive. Close the inlet vent completely when the photometer indicates smoke.

7.9 Record light transmittance and the corresponding time either as a continuous plot with a multi-range recorder or at sufficient time intervals with a multi-range meter read-out. Make and note the necessary full-scale range changes in decade steps.

7.10 Observe the increase in chamber pressure with the manometer described in paragraph 3.1.9. A regulator shall maintain the pressure in the range of 4 ± 2 in. (10 ± 5 cm) of water. As a result of pressure rise, the fuel and air valves must be adjusted during the flaming test to maintain constant flow rate.

7.11 Record any observations pertinent to the burning and smoke generating properties of the material under test, in accordance with paragraphs 9.1.6 and 9.1.7.

7.12 Continue the test until a minimum light transmittance value is reached or after an exposure of 20 minutes; whichever occurs first. If desired, the test may be conducted for periods in excess of 20 minutes, when minimum transmittance levels have not been reached during the 20 minute exposure. The term "Extended Exposure" is to be used to identify data developed in tests longer than 20 minutes in duration.

7.13 If transmittance falls below 0.01%, the chamber window should be covered with an opaque screen to avoid possible light scattering effects from room light. Also any supplementary optical filter in the photometer (photomultiplier) system should be removed or displaced in order to extend the measuring range. Prior to removing the filter, turn the high voltage off or adjust the scale to minimize sensitivity. Replace the filter before exhausting smoke from the chamber.

7.14 Extinguish the burner on flaming exposures and start exhausting the chamber within one minute after reaching minimum transmittance or after a 20 minute exposure. Displace the specimen from the front of the furnace by pushing the "blank" specimen holder with a rod inserted from a small hole at the back of the chamber. Continue to exhaust with the inlet vent open until maximum transmittance is reached. Record this transmittance value as the T_c, "clear beam" reading which is to be used to correct for deposits on the photometer windows.

8. Calculations

8.1 Calculate specific optical density, D_s, from the reduction in light transmittance, T, caused by the smoke generated from an exposed specimen area, A, in the closed chamber of volume, V, and over a light path, L, as follows:

$$D_s = \frac{V}{LA} [\log_{10} (\frac{100}{T})] = G [\log_{10} (\frac{100}{T})]$$

where G represents the geometrical factor associated with the dimensions of the chamber and specimen.

8.2 Calculate the maximum specific optical density, D_m, using the formula in paragraph 8.1 with a light transmittance corresponding to the minimum level reached during the test. Correct all maximum specific optical density values by substracting the specific optical density equivalent for soot and other deposits on the photometer windows. As described in paragraph 7.14, the "clear beam" transmittance reading T_c is used to calculate a specific optical density equivalent D_c, using the same formula but with different subscript. A corrected maximum specific optical density calculation is expressed as follows:

$$D_m \text{ (corr.)} = D_m - D_c$$

8.3 For systems without "dark current" cancellation, a correction must be made for any light transmittance reading T, approaching the dark current value T_d. The corrected light transmittance T', is obtained from:

$$T' = 1 - \frac{1-T}{1-T_d}$$

and is used for the specific optical density calculations described in paragraphs 8.1 and 8.2

8.4 Determine $t.9D_m$, the time for the smoke to accumulate to 90 percent of the uncrected maximum specific optical density value from a plot of specific optical density versus time or from the tabulated data.

8.5 When the test is continued beyond the standard 20 minute exposure, all calculations are to be made in accordance with paragraphs 8.1 through 8.4 and the results identified as "Extended Exposure."

9. Report

9.1 The report (see Appendix E) shall include the following:

9.1.1 Complete description of the material tested including: type, manufacturer, shape, thickness and/or other appropriate dimensions, weight or density, coloring, etc.

9.1.2 Complete description of the test specimens, including: substrate or core, special preparation, mounting, etc.

9.1.3 Test specimen conditioning procedure.

9.1.4 Number of specimens tested.

9.1.5 Test conditions: type of exposures, type of burners and holders used, exposure period.

9.1.6 Observations of the burning or smoldering characteristics of the specimens during test exposure, such as delamination, sagging, shrinkage, melting, collapse, etc.

9.1.7 Observations of the smoke generating properties of the specimens during exposure, such as, color of the smoke, nature of the settled particulate matter, etc.

9.1.8 A record of the geometrical factor, G, as calculated from measured values of chamber volume, V, photometer light path length, L, and exposed specimen area, A (see Section 8 on calculations).

9.1.9 Test results calculated as described in Section 8, including the average and range on each set of specimens for D_m (corr.), $t_{.9D_m}$, D_c and others (see Appendix B.) if required.

APPENDIX A
Calibration of Test Equipment

A1.1 Photometric System

A1.1.1 Linearity of the photometer is checked by interrupting the light beam with wire screens of known open area and/or calibrated neutral density filters. The screens or filters should cover the full range of the instrument. Plot the known transmittances versus the recorded transmittance readings of the photometer. Observation of the plot or tabulated readings will establish the linearity of the system.

A1.1.2 Effective light beam cross-section measurements are made at the top and bottom of the chamber, by inserting an opaque sheet of material into the beam path at the front, back and sides of the beam, and noting the point at which the light transmittance reading decreases. Using these measurements, the average diameter of the sensing area to the phototube may be determined.

A1.1.3 Shifts in dark current levels between tests, excessive zero shifts during test or lack of linearity should prompt inspection of the photometer system and replacement of the phototube or battery, as necessary.

A1.2 Radiometer

Calibration of the radiometer is accomplished by placing it at suitable distances from a radiant energy source, while maintaining its body (cold-junction) temperature at 200°F (93°C) with controlled air flow through the rear-mounted cooler, and measuring its electrical output as a function of the irradiance level. The irradiance level is determined calorimetrically by measuring the rate of temperature rise of a blackened thin copper disk of known weight, area (1 1/2 in., 38.1 mm dia), specific heat and absorptivity in place of the radiometer.

The measured millivolt output of the radiometer, at a body temperature of 200°F (93°C), corresponding to an irradiance level of 2.2 Btu/sec. ft^2 (2.5 W/cm^2) is used to establish the furnace control settings discussed in paragraphs 3.1.2 and 7.3.

A1.3 Chamber Pressure Manometer - Leakage Rate Test

For purposes of standardization, periodically conduct a leakage rate test using the manometer and tubing described in paragraph 3.1.9. Pressurize the chamber to 3 in. (approximately 76 mm) of water by introducing compressed air through a gas sampling hole in the top. Time the decrease in pressure from 3 to 2 in. (approximately 76 to 50 mm) of water with a stop watch. This time should not be less than 5.0 minutes.

A1.4 Standard Smoke Generating Material

For checking operational and procedural details of the equipment and method described herein, a single layer of nominal 0.030 in. (approximately 0.76 mm) thick alpha-cellulose (cotton linters) paper[6] should provide repeatable maximum specific optical density values of 165 + 10 when tested under non-flaming conditions. Use of this standard material does not obviate the need for following the calibration and standardization procedure outlined in this Standard.

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[6] Grade 448 alpha-cellulose (cotton linter) paper, nominally 0.030 in. (approximately 0.76 mm) thick, by Hercules, Inc., has been used.

APPENDIX B
Presentation of Test Results

The smoke chamber test results in a curve of specific optical density versus time. The maximum specific optical density, D_m, represents total smoke accumulation. Since the time to reach this point is often indistinct, the time to reach 90% of D_m, $t_{.9D_m}$, generally represents a more easily defined and repeatable point. Additional parameters which may be of particular value include:

R_m: Maximum rate of increase in specific optical density per minute, measured over a 2-min. period.

$t_{D_s=16}$: Time to reach $D_s=16$ (T = 75%), or other smoke level.

This is a simple measure of smoke generation rate, particularly where time is important.

$$SOI = \frac{D_m^2}{2000\, t_{D_s=16}} \left(\frac{1}{t_{.3}-t_{.1}} + \frac{1}{t_{.5}-t_{.3}} + \frac{1}{t_{.7}-t_{.5}} + \frac{1}{t_{.9}-t_{.7}}\right)$$

where $t_{.1}$, $t_{.3}$, etc., indicate the time in minutes at which the smoke accumulation reaches 10, 30, etc., per cent of the maximum density D_m. The smoke obscuration index incorporates the effects of total smoke, generation rate and time to reach $D_s = 16$. (See footnote 1 of main text)

$SON_4 = D_1 + D_2 + D_3 + D_4$

Smoke obscuration number based on the simple addition of the 1, 2, 3 and 4 minute values of specific optical density. This index represents a weighted rate of smoke generation over a 4 minute interval only.

The preceding parameters are obtained for the flaming and nonflaming exposures separately, and the highest value could presumably be used. There may be some merit in combining values from the flaming and nonflaming tests to yield a single composite index, e.g.[7]

$$SOI_c = [\,(SOI)_f \cdot (SOI)_n]^{1/6}$$

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[7] G. Williams-Leir, Private Communication.

A more comprehensive approach to smoke hazard evaluation of a material might include the effects of smoke obscuration under a bracketing set of fire conditions[8], e.g.

$$\mathrm{MSCU} = \sum_{i=1}^{8} (\mathrm{SOI})_i$$

for $i = 1$, nonflaming test (std)
$i = 2$, flaming test (std)
$i = 3$, nonflaming test with forced ventilation
$i = 4$, flaming test with forced ventilation
$i = 5$, nonflaming test at high irradiance level
$i = 6$, flaming test at high irradiance level
$i = 7$, nonflaming test at high irradiance level and forced ventilation
$i = 8$, flaming test at high irradiance level and forced ventilation.

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[8] J. R. Gaskill, Fire Technology, August 1968.

APPENDIX C
Construction Details

(Paragraph numbers correspond to applicable paragraphs in Section 3. Apparatus of main text).

C3.1.2 Radiant Heat Furnace

The furnace shall consist of a coiled wire heating element[9] (525 W or greater) mounted vertically in a horizontal ceramic tube 3 in. (76.2 mm) i.d. by 3 3/8 in. (85.7 mm) o.d. by 1 5/8 in. (41.3 mm) long. The tube is bored out at one end to 3 1/32 in. (77.0 mm) i.d. and to a depth of 5/8 in. (15.9 mm) to accommodate the heating element. A 1/16 in. (1.6 mm) asbestos paper gasket, three stainless steel spacing washers, and two 1/32 in. (0.8 mm) stainless steel reflectors are mounted behind the heating element. A 3/8 in. (9.5 mm) asbestos millboard disc, provided with ventilation and lead wire holes, shall be positioned behind the heating element and used to center the assembly with respect to the front 3/8 in. (9.5 mm) asbestos millboard ring by means of a 6-32 stainless steel screw. The adjustment nuts on the end of the centering screw shall provide proper spacing of the furnace components. The cavities adjacent to the heating element assembly shall be packed with glass wool. The furnace assembly shall be housed in a 4 in. (10.2 cm) o.d. by 0.083 in. (2.1 mm) wall by 4 1/8 in. (10.5 cm) long stainless steel tube. Two additional 3/8 in (9.5 mm) asbestos board spacing rings and a rear cover of 3/8 in. (9.5 mm) asbestos board shall complete the furnace. The furnace is to be located centrally along the long axis of the chamber with the opening facing toward and about 12 in. (30.5 cm) from the right wall. The centerline of the furnace shall be about 7 3/4 in. (19.5 cm) above the chamber floor.

C3.1.3 Specimen Holder

The specimen holder shall conform in shape and dimension to Fig. 4 and be fabricated by bending and brazing (or spot welding) 0.025 in. (0.6 mm) thick stainless steel to provide a 1 1/2 in. (38.1 mm) depth, and to expose a 2 9/16 by 2 9/16 in. (65.1 by 65.1 mm) specimen area. As described in paragraph 3.1.4, the holder shall have top and bottom guides to permit accurate centering of the exposed specimen area in relation to the

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[9] A Silex Percolator Element (e.g., Silex-Bloomfield Type EK6, or Eagle Electric, Cat. No. 385) has been found satisfactory for this purpose when the ceramic shoulder projection and the steel connector prongs are removed so that no obstructions extend beyond the base diameter.

furnace opening. A 3 by 3 in. (76.2 by 76.2 mm) sheet of 1/2 in. (12.7 mm) asbestos millboard, having a nominal density of 50 ± 10 lb/ft^3 (0.85 ± 0.17 g/cm^3), shall be used to back the specimen. A spring bent from 0.010 in. (approximately 0.25 mm) thick phosphor bronze sheet shall be used with a steel retaining rod to securely hold the specimen and millboard backing in position during testing.

C3.1.4 Support of Furnace and Specimen Holder

The framework as shown in Fig. 5 shall have welded to it a 5 in. (12.7 cm) o.d., 1/4 in. (6.4 mm) wall, 2 in. (50.8 mm) long horizontally oriented steel tube to support the radiant heat furnace described in paragraph 3.1.2. This support tube shall have provision to accurately align the furnace opening so that it is: (1) 1 1/2 in. (38.1 mm) away from, (2) parallel to and (3) centered with respect to the exposed specimen area. Three tapped holes with screws equidistantly positioned around the furnace support tube, or one screw at the top of the support in conjunction with two adjustable (vertically along the support tube) metal guide strips mounted horizontally inside to the tube, shall provide adequate alignment.

The framework shall have two 3/8 in. (9.5 mm) diameter transverse rods of stainless steel to accept the guides of the specimen holder described in paragraph C3.1.3. The rods shall support the holder so that the exposed specimen area is parallel to the furnace opening. Spacing stops shall be mounted at both ends of each rod to permit quick and accurate lateral positioning of the specimen holder.

C3.1.5 Photometric System

The photometric system shall consist of a light source and photodetector, oriented vertically to reduce variations in measurement brought about by stratification of the smoke generated by the materials under test. The system shall be as shown in Fig. 6. The collimated beam inside the chamber shall have a path length of 36 in. (91.4 cm) and a sensing cross-section of 1 1/2 ± 1/8 in. (38.1 ± 3.2 mm) diameter (see Appendix A, paragraph A1.1.2). The approximately circular light "spot" shall be centered entirely within the sensing area of the detector. A battery or D.C. power supply, a load resistor (which may be the fixed input impedance of the indicator or recorder) and an electrically shielded cable complete the photometer circuit for a single-stage vacuum tube photometer system. If the input impedance of the indicator or recorder changes when a range change is made, an external resistor shall be provided to maintain a constant impedance load. (A typical photomultiplier photometer system will require a high-voltage D.C. power supply and a neutral density filter of sufficient optical density to produce a convenient signal level for the indicator or recorder.) The photometer system used shall be capable of permitting the recording of reliable optical densities up to 5.0, corresponding to transmittance values of 0.001 percent of the incident light. (See Appendix A, paragraph A1.1.1).

The two optical platforms and their housings shall be kept in alignment with three metal rods, 1/2 in. (12.7 mm) in diameter, fastened securely into 5/16 in. (7.9 mm) thick externally mounted top and bottom plates and symmetrically arranged about the collimated light beam.

C3.1.6 Radiometer

The body (cold-junction) temperature of the radiometer shall be monitored with a 100-220°F (38-100°C) thermometer in a 1/2 by 1/2 by 1 1/2 in. long (12.7 by 12.7 by 38.1 mm) brass well drilled to accept the thermometer with a close fit. Silicone grease may be used to provide good thermal contact.

The circular receiving surface of the radiometer shall be spray-coated with an infrared-absorbing black paint containing a silicone vehicle[10]. The radiometer shall be calibrated calorimetrically in accordance with the procedure summarized in paragraph A1.2 of Appendix A.

C3.1.7 Chamber Wall and Furnace Thermocouples

The wall thermocouple junction shall protrude into the chamber about 0.06 in. (1.5 mm) through a small hole drilled at the geometric center of the chamber back wall. The protruded section shall be bent to contact the inside surface of the chamber wall. A 3/8 in (9.5 mm) diameter, 1/4 in. (6.4 mm) thick polystyrene foam disc and epoxy cement shall cover and seal the thermocouple to the wall.

The furnace thermocouple shall be positioned within the radiant heat furnace about 1/16 in. (1.6 mm) from the surface of the ceramic tube and 1/4 in. (6.4 mm) from the heating coils to provide a temperature sensing input to a controller (see paragraph 3.1.2.). This thermocouple shall be enclosed in a thin stainless steel shielding tube.

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[10] Type 8X906 Flat Black Paint, Midland Industrial Finishes Co., Inc. has been found suitable for this purpose. A thin coating (one mil) of this paint provides an absorptivity of approximately 0.93.

C3.1.10 Burner

The Multiple flamelet burner shall be either a six-hole "Tee" burner or a six-tube burner, with construction details as shown in Fig. 4. The vertical tubes of the six-tube burner shall be made from 1/8 in. (3.2 mm) o.d. by 0.031 in. (0.8 mm) thick-wall stainless steel tubing. All tubes should be crimped at the tip to reduce the opening diameter to 0.055 in. (1.4 mm). The horizontal manifold section of the burner shall consist of 1/4 in. (6.4 mm) o.d. by 0.035 in. (0.9 mm) wall stainless steel tubing. The other end is attached to a fitting in the chamber floor.

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APPENDIX D
Analysis of Products of Combustion

Although not specifically required as a part of the method, products of combustion may be drawn from the chamber at various times during the progress of the test for analysis. The physical properties of the smoke may be investigated by electrostatic or impact collection and various methods of particle analysis. The presence and concentrations of various toxic and irritating gaseous products may be determined using colorimetric gas detector tubes, gas chromatography methods, ion-selective electrodes, or other techniques.

APPENDIX E

SUGGESTED REPORT FORM

SMOKE DENSITY CHAMBER

Sample Code ______________________ Test No. ____________ Date________________

Lab Code ___________________ Operator______________________ Time____________

Recorded Data or Curve

Time, min.	% Trans.	D_s
0	100	0

Operating Conditions

Radiometer Reading ______mV; Irradiance_____W/cm^2

Furnace Voltage __________V

Burner Fuel_____cc/min air; ________cc/min propane

Thermal Exposure: flaming smoldering

Chamber Pressure ____________inch H_2O

Chamber Wall Temp. ________°C

Chamber Surface Condition ______________________

____

Burner & Holder: standard special

Sample

Description - ________________________________

Manufacturer - _______________________________

Preconditioning: Temp. _____°C; Duration ______hr.

Conditioning: Temp.____°C; RH___%; Duration______

Thickness -_____in.; Density______g/cm^3 or lb/ft^3

Initial Wt.________; Final Wt.______; % Loss_____

Special Conditions - __________________________

____

Results

Min. Trans. ____________% at __________ min

Max. Specific Optical Density, D_m = _____________

Time to Reach 90% D_m = ________________ min.

Clear Beam Reading =________%; Equiv. D_c ________

D_m (corr.) = $D_m - D_c$ = _______________

Optional Presentation of Results

Time to Develop $D_s = 16$ = ____________________

Max. Rate, $R = \frac{dD_s}{dt}$ = _________________________

$SON_{(4\ min)} = D_1 + D_2 + D_3 + D_4$ ____________

Remarks

Fig. 1 SMOKE DENSITY CHAMBER

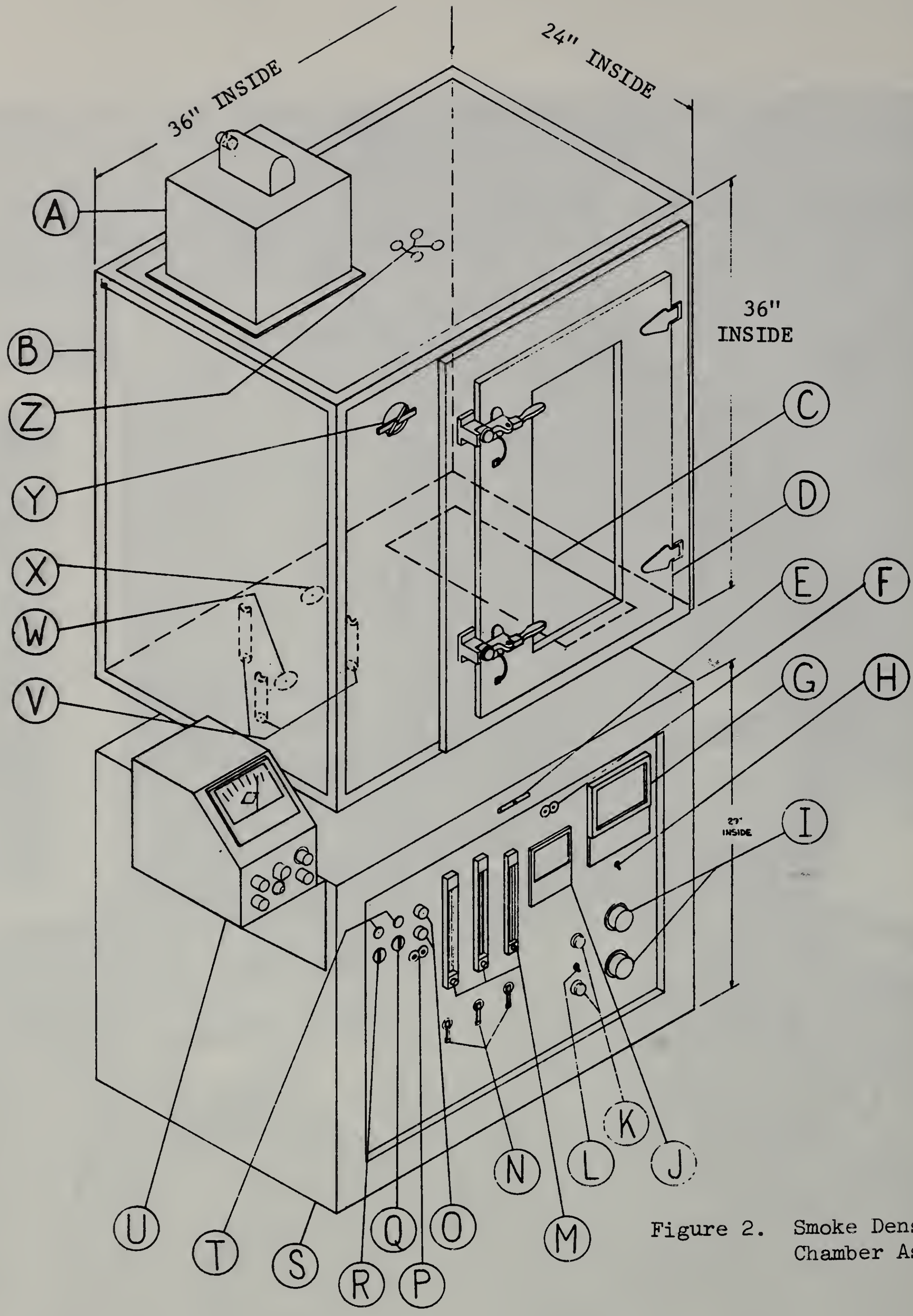
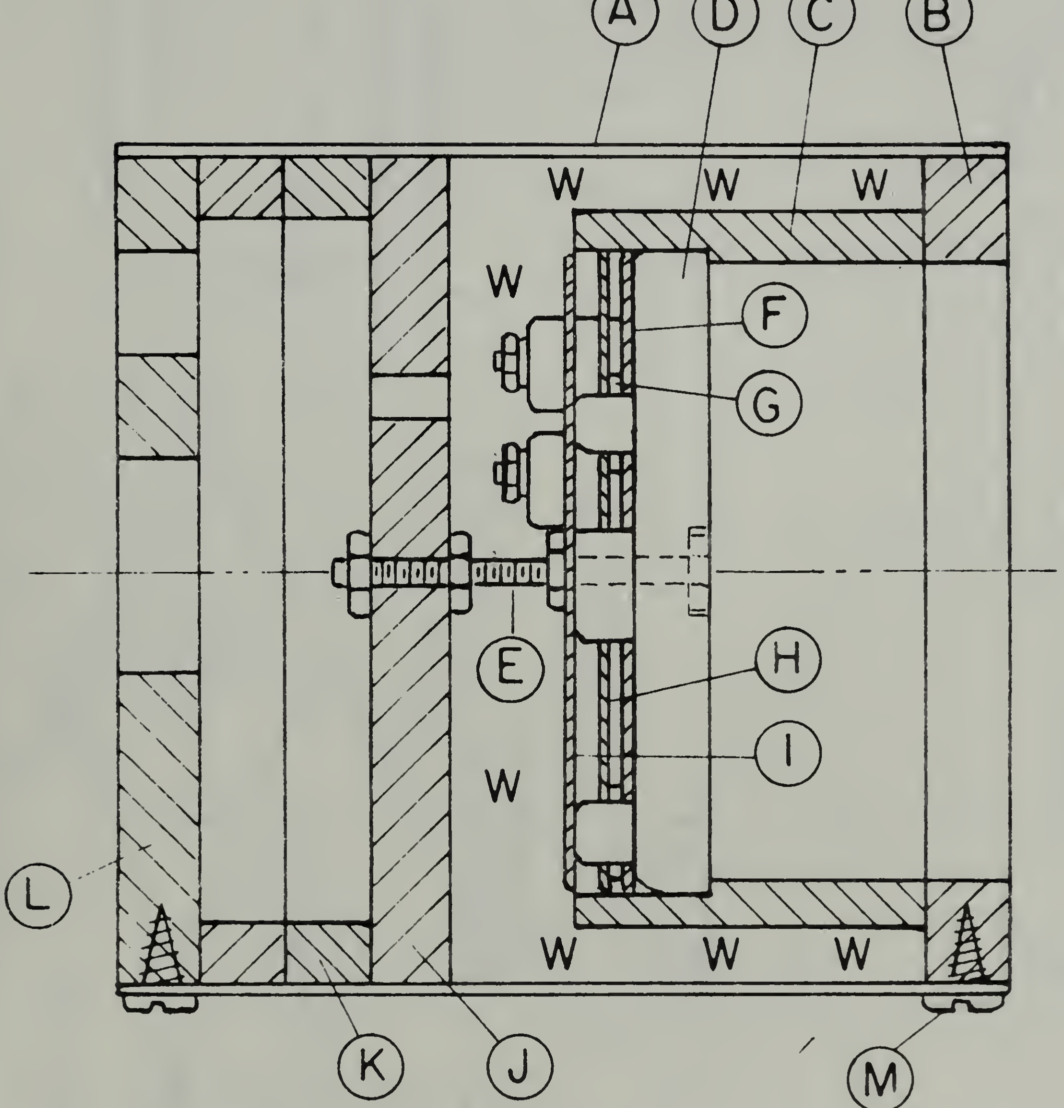


Figure 2. Smoke Density Chamber Assembly

A - Phototube Enclosure
B - Chamber
C - Blowout Panel
D - Hinged Door with Window
E - Exhaust Vent Control
F - Radiometer Output Jack
G - Temperature Controller
H - Temperature Controller Switch
I - Autotransformers

J - Voltmeter (furnace)
K - Fuse Holders
L - Furnace Heater Switch
M - Gas & Air Flowmeters
N - Gas & Air Shutoff Valves
O - Light Intensity Controls
P - Light Voltage Measuring Jack
Q - Light Source Switch
R - Line Switch

S - Support Frame
T - Indicating Lamps
U - Photometer Readout
V - Rods
W - Glass Window
X - Exhaust Vent
Y - Inlet Vent
Z - Access Ports



A - STAINLESS STEEL TUBE
B - ASBESTOS BOARD
C - CERAMIC TUBE
D - HEATING ELEMENT, 525 W
E - STAINLESS STEEL SCREW

F - ASBESTOS PAPER GASKET
G - STAINLESS STEEL SPACING WASHERS (3)
H - STAINLESS STEEL REFLECTOR
I - STAINLESS STEEL REFLECTOR

J - ASBESTOS BOARD
K-ASBESTOS BOARD RINGS
L-ASBESTOS BOARD COVER
M-SHEET METAL SCREWS
W-PYREX GLASS WOOL

FIG. **3** -FURNACE SECTION

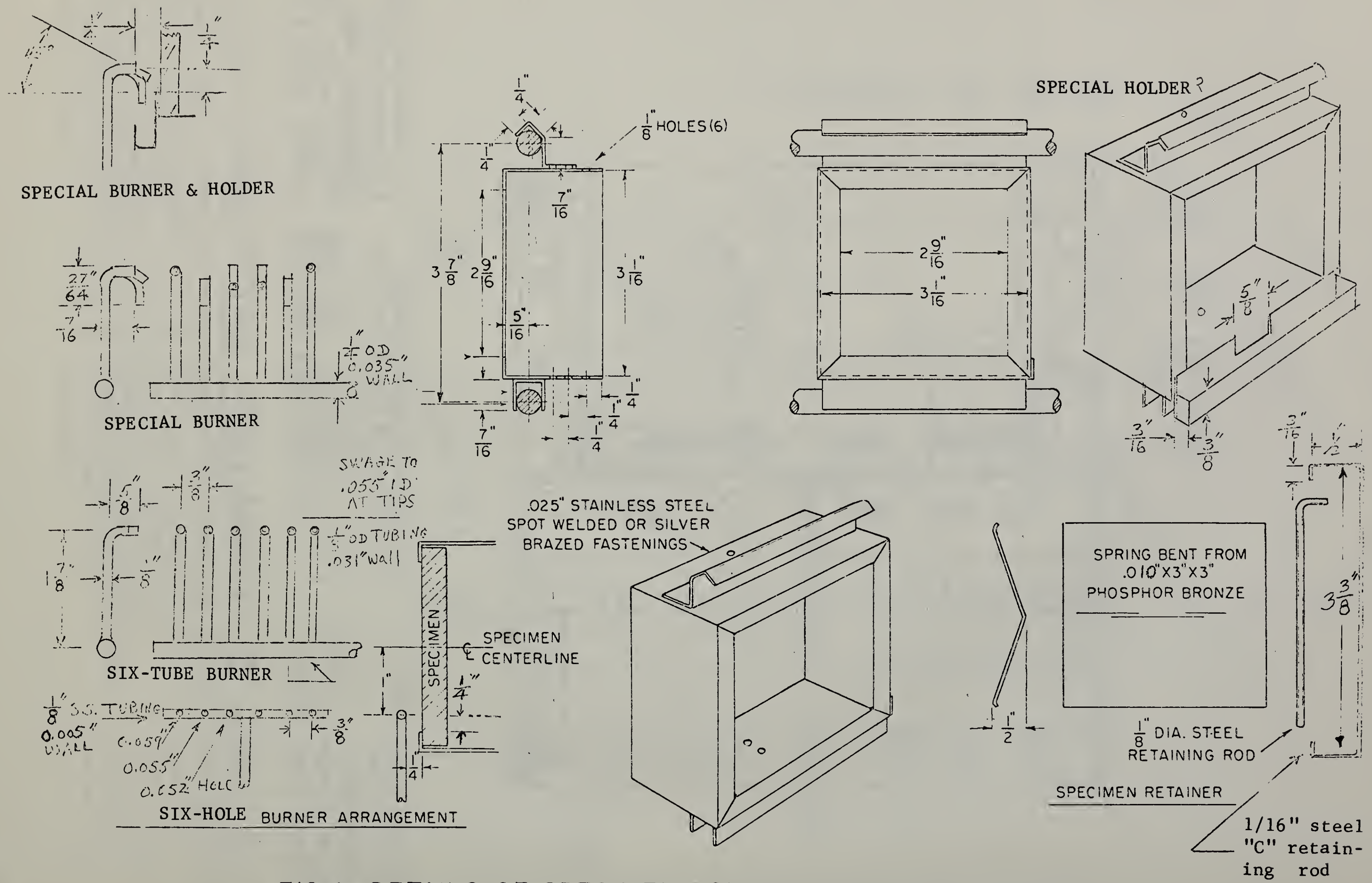


FIG. 4 - DETAILS OF SPECIMEN HOLDER AND PILOT BURNER

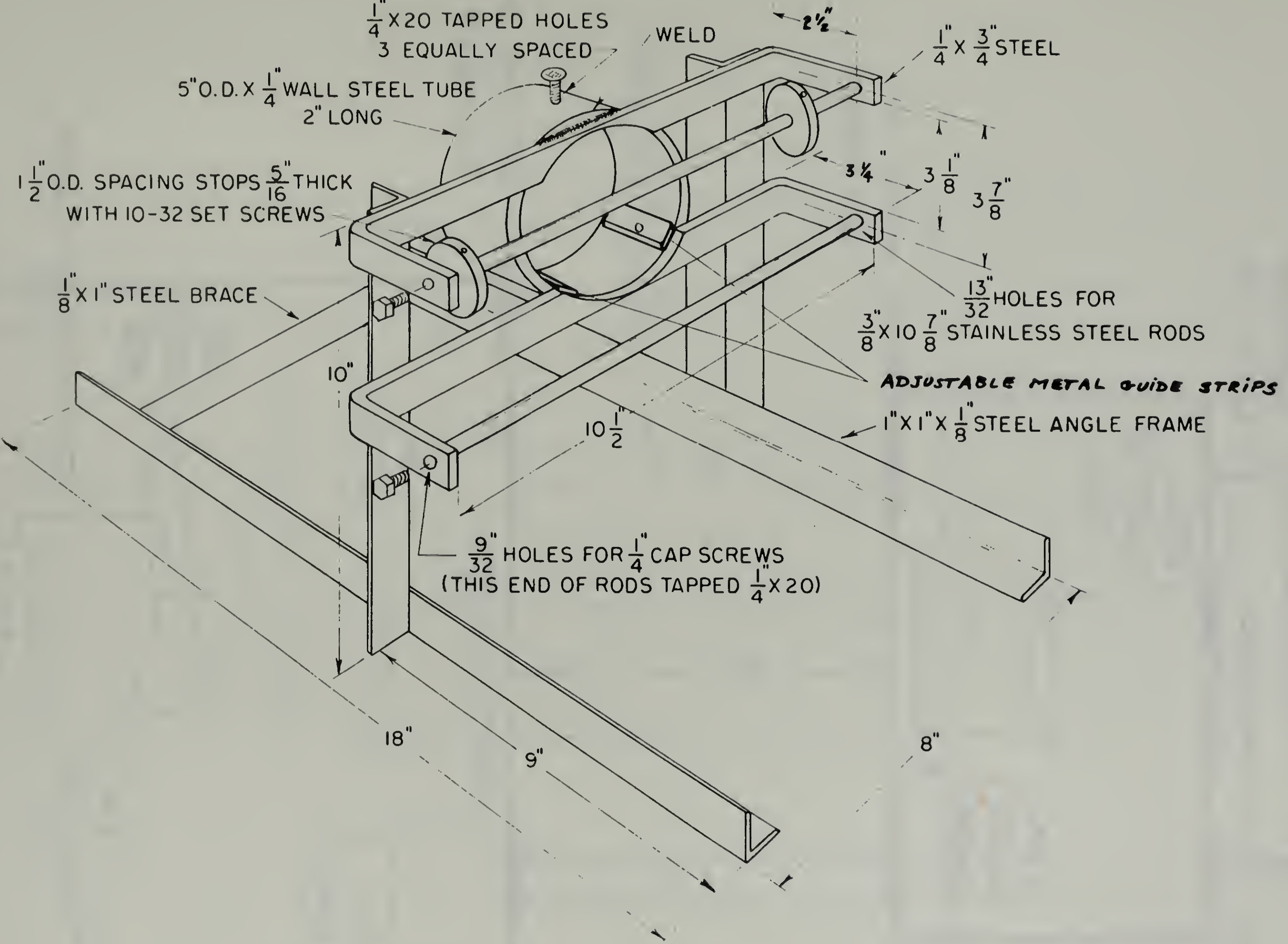


FIG. 5 - FURNACE SUPPORT

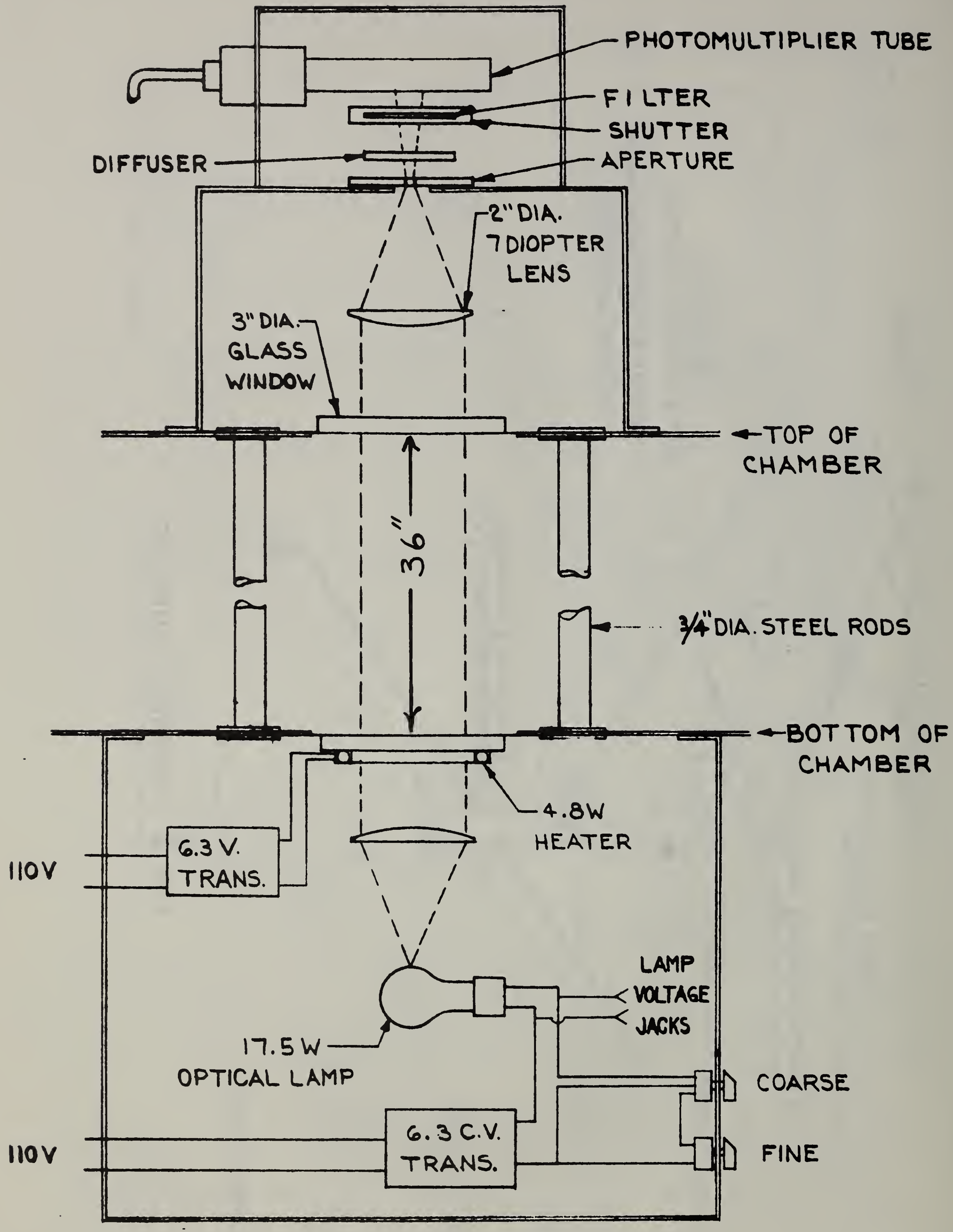


Fig. 6A Photometer Details

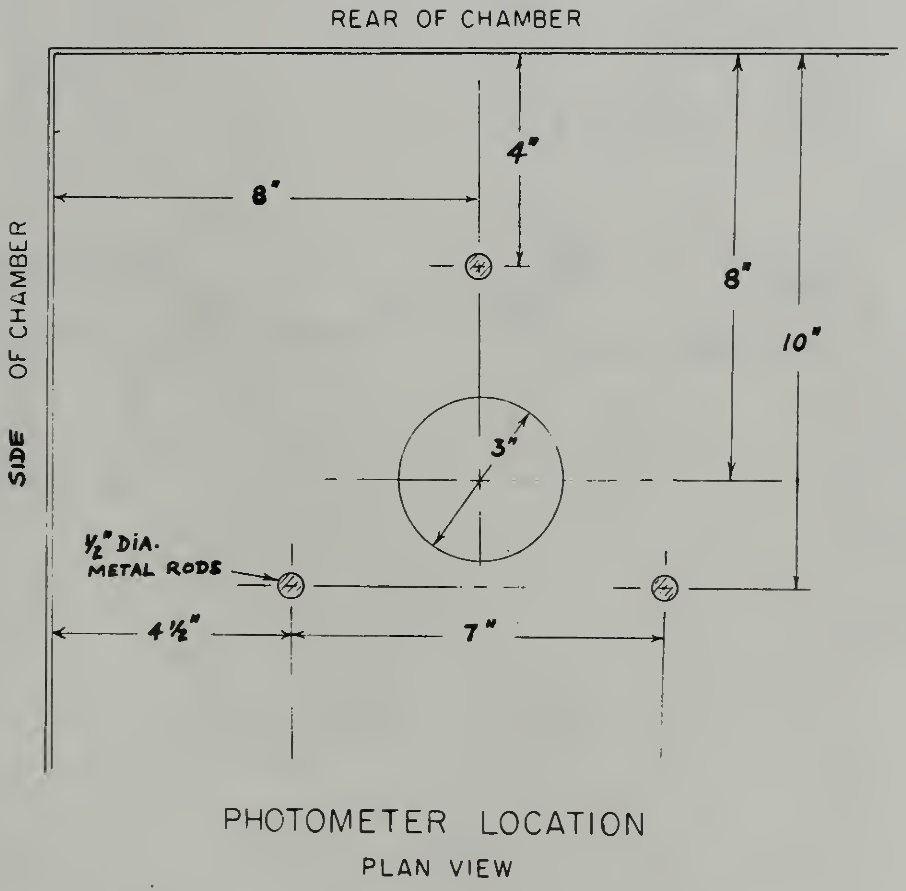


Fig. 6B Photometer Location

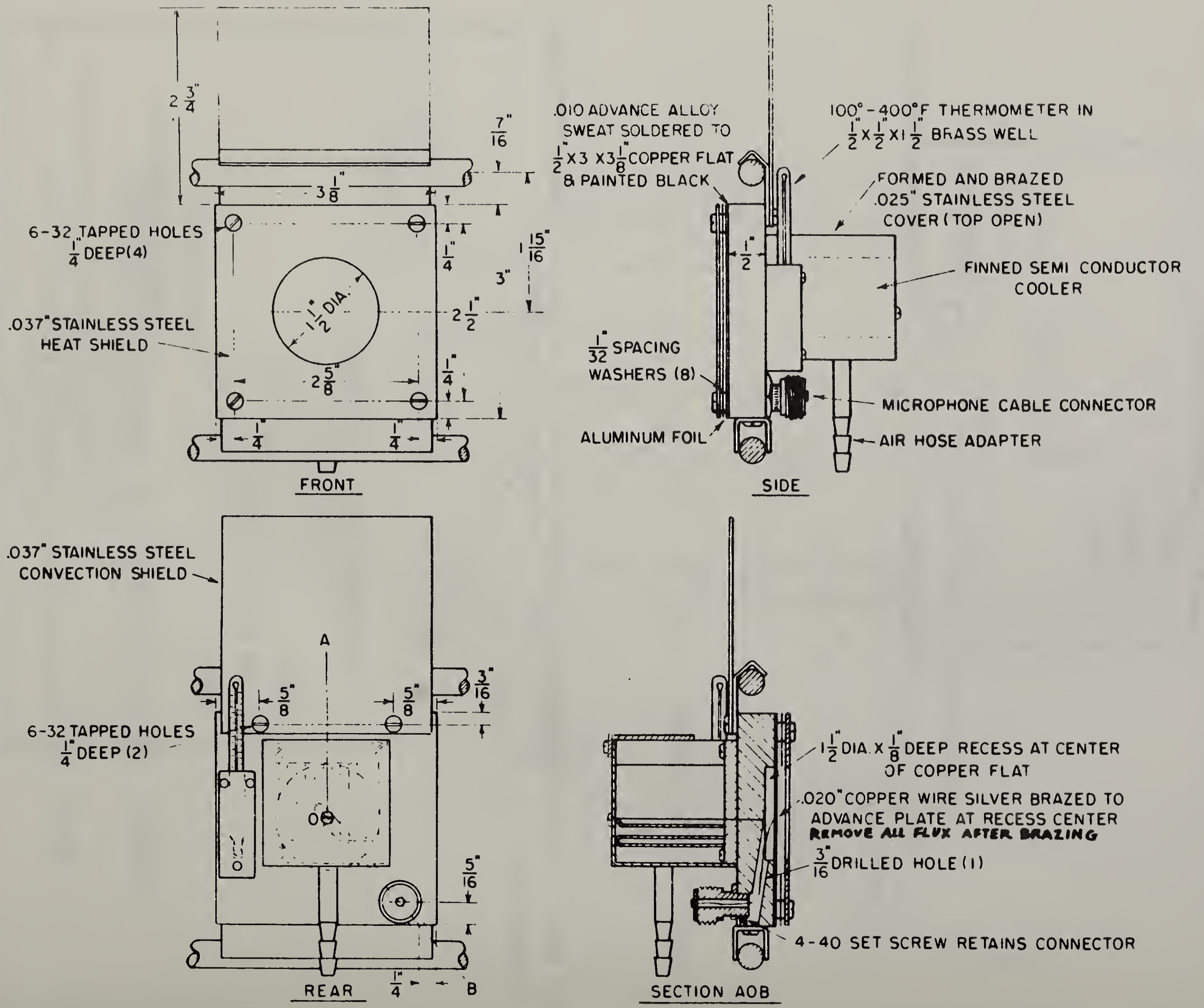


FIG. 7 - RADIOMETER DETAILS

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