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Interlaboratory Evaluation of Smoke Density Chamber

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TABLE OF CONTENTS

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T. G. Lee

Results are reported of a interlaboratory (round-robin) evaluation of the smoke density chamber method for measuring the smoke generated by solid materials in fire. A statistical analysis of the results from 10 material-condition combinations and 18 laboratories is presented. For the materials tested, the median coefficient of variation of reproducibility was 7.2% under non-flaming exposure conditions and 13% under flaming exposure conditions. A discussion of errors and recommendations for improved procedures based on user experience is given. A tentative test method description is included as an appendix.

Key Words: Building materials; fire tests; interlaboratory tests; round-robin; optical density; smoke; smoke density chamber; statistical analysis.

Interlaboratory Evaluation of
Smoke Density Chamber

1. Introduction

In January 1970, an interlaboratory comparison study on the measurement of the smoke generation characteristics of materials was initiated by the Fire Research Section, Building Research Division 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 specimens of 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][1/]. It was later used to evaluate the smoke properties of over 140 aircraft interior materials [2]. The laboratory method measures the smoke generation characteristic of solid specimens of given thickness under both flaming and non-flaming exposure conditions, which represents two parameters of fire hazard. All specimens are exposed to an irradiance level of 2.5 W/cm^2 (2.2 Btu/sec ft^2) and, in the flaming exposure, also to the flames from a small propane-air pilot burner. 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

[1/] Figures in brackets indicate the literature references at the end of this paper.

Instrument Company (AMINCO)[2/] 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. Two samples each of two materials (pure alpha-cellulose paper and a PVC-PVA copolymer) were distributed for a preliminary screening and general familiarization with the test procedure. The reported results and comments indicated the need to provide better alighment of the burner in the flaming exposure; and to correct for smoke deposits on the windows of the photometer. The results of these initial studies were considered reasonable for tests of this type.

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

The test results from the 22 participating laboratories are summarized in this report. A statistical analysis of the

[2/] Certain commercial equipment, instruments, or materials are identified in this paper in order to adequately specify the experimental procedure. In no case does such identification imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that the material or equipment identified is necessarily the best available for the purpose.

Table 1

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 Radiation 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

data and comments on possible sources of errors are also included.

2. Participants

A total of 22 laboratories, three with home-built and 19 with commercial chambers participated in the study. The list is given in Table 1. The laboratories are identified in the report by code letters only. The cooperation, comments and suggestions from the participating laboratories, are gratefully acknowledged.

3. Test Procedures

Detail test procedures were supplied to the participants in a tentative test method standard. Slight modification in procedures were subsequently (after the test) made, but these are not expected to appreciably change the precision estimate based on the reported results. The latest version of the test method standard is given in Appendix II.

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 non-flaming 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 reasonably small number of tests.

Table 2 Type and Number of Tests Performed by Each Laboratory

Specimen	conditions[a/]	A S	B	C	D	E EE	F	G	H	I	J	K	L LL	M	N	O OO	P	Q	R
B. Linoleum	N	8	2	2	2	2	2	2	2	2	8	2	2	2	2	2	2	2	2
Polypropylene Rug	N	2	8	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Red Oak, 1/4"	N	2	2	8	2	2	2	2	2	2	2	2	8	2	2	2	2	2	2
ABS, 0.022"	N	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	3	3	3	3	3	3	3	3	8	2	2	2	2
	N	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
α- Cellulose Paper	N	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
	N	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

a/ F = Flaming ; N = Non-flaming

Table 3 Test Materials [a/]

Material	Thickness inch	Density lb/ft^3	Density g/cm^3	Color	Description
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	Créam	Rigid 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	1.8	0.03	Blue	Rigid low density insulating foam, fire retardant treated
PVA/PVC	0.047	75	1.2	Brown	Flexible
ABS	0.032	66	1.05	Cream	Rigid Plastic

[a/] All specimens were 3 x 3 inches

The experimental design is shown in Table 2. 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 in those laboratories.

4. Test Material

The materials selected (Table 3) represent common interior finish and construction materials, including simple and composite plastic, cellulosic and inorganic-base materials with thickness ranging from 0.022 to 1.03 in (0.5 to 26 mm). These materials exhibit different forms of physical response to fire exposure: such as slow melting, fast shrinking, rapid decomposition and nearly non-reactive. 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 an 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, density, and thickness will produce the same quantity of smoke under the same conditions.

TABLE 4 SUMMARY OF SELECTED TEST PARAMETERS

Lab	Completion Date (1970)	Conditioning Predry	Conditioning 50%RH	Test Sequence Random	Test Sequence Duplicate Pr.[b]	Chamber Wall Temp. °C	Flowmeter Reading Air mm [c]	Flowmeter Reading Propane mm [d]	Photometer Lamp, Volt	Burner Distance,[e] Vert.	Burner Distance,[e] Horiz.
B	3-31	Y	Y [a]	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

a/ y=yes, n=no, blank=no data.
b/ duplicate pair means 2 specimens of a material measured sequentially.
c/ steel ball.
d/ all use plastic ball except (s), steel ball; * denotes propane of commerical grade.
e/ - denotes 1/4", otherwise given; 6H denotes 6-holes burner in contrast to 6-tubes burner.

5. Results

Table 4 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. A voltage of 4± 0.2 volts ac or dc has since been adopted in the revised test method following completion of this study.

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 modified specimen holder with trough and burner with flamelets pointing in three directions were distributed to test participants for use only in the flaming test on the polystyrene sample. This holder and burner combination retains the melted portion of the specimen under test and exposes it directly to the burner flamelets. The modified burner and holder were subsequently used by 12 laboratories to evaluate the 0.032 in. ABS (acrylonitrile butadiene styrene) specimens. It has since been adopted in the revised test method for all flaming tests.

TABLE 5 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	501.5	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/FL.	PVC/FL.	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	438.0
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 6 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	8.0	8.5	1.0

LAB:	CELLULOSE	PVC	TILE/FL.	PVC/FL.	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 7 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/FL	PVC/FL.	P. STYR./FI
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 8. Mean $T_{.9Dm}$ For Each Material and Laboratory

LAB.	LINOLEUM	POLY. RUG	RED OAK	ABS	POLYSTYRENE
B	9.80	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	11.05	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	16.60	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/FL.	PVC/FL.	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	13.65

TABLE 9 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	a/	169	100	94	371	356	61	67	30	9
	739	a/	620	630	598	a/	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.	16	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 b/					
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					

a/ Data not reported or withdrawn by request

b/ Specimens did not ignite; methane was used as fuel

TABLE 10 -SUMMARY OF VALUES FOR 18 LABORATORIES (AMINCO)

		Non-flaming Exposure							Flaming Exposure				
									Modified Burner		Straight Burner		
		Lino.	Rug	Red Oak	ABS	α-cell	PVC-Gyp	P. Sty	ABS/.032 [f]	P.Sty.	PVA/PVC [e]	PVC-Gyp	Tile
	BETWEEN-LAB												
D_m(corr.)	Mean	725 [d]	621	552	188	162 [d]	109	23	451.4	391	548	62	20
	S. D. [a]	49	52	40	20	4.7	6.6	6.3	17.3	52	39	19	6.9
	Coef. Var.%	6.7	8.4	7.2	11	2.9	6.0	27	3.8	13	7.1	31	34
	WITHIN-LAB												
	S. D. [b]	46	28	18	12	4.2	3.5	6.7	20.4	32	22	10.5	4.6
	Coef. Var.% [c]	6.4	4.5	3.2	6.4	2.6	3.2	29	4.5	8.0	4.0	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

a/ S. D. = Calculated Standard Deviation

b/ Between-lab. Standard deviation were based on mean of each lab. With-in lab. Standard deviation based on individual values.

c/ Coef. Var. = Coefficient of Variation.

d/ Excluding Lab. LL

e/ Pre-round-robin, 17 labs.

f/ Candidate reference material, 12 labs.

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. (See Appendix II-B)

are shown in Tables 5, 6, 7, and 8 respectively.[3/]

Individual values are tabulated in Appendix I. 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 9.

6. Statistical Analysis

6.1 Means and Standard Deviation

Table 10 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

[3/] See Appendix II (Appendix B) for definition of terms.

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 10 with their counterpart in Table 9 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 the 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 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 random 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.

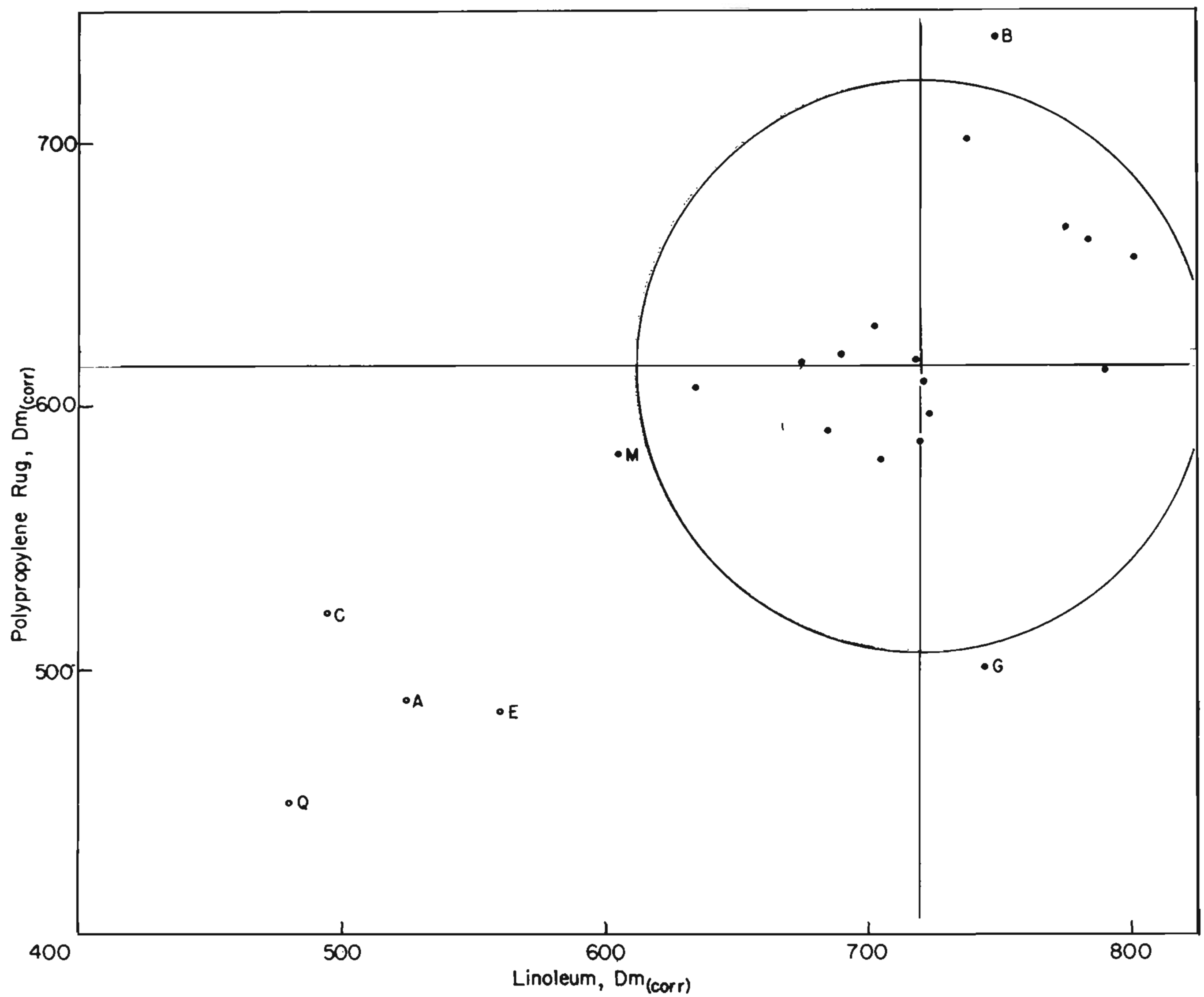


FIG. 1 Youden Plot of Linoleum vs. Polypropyrene Rug

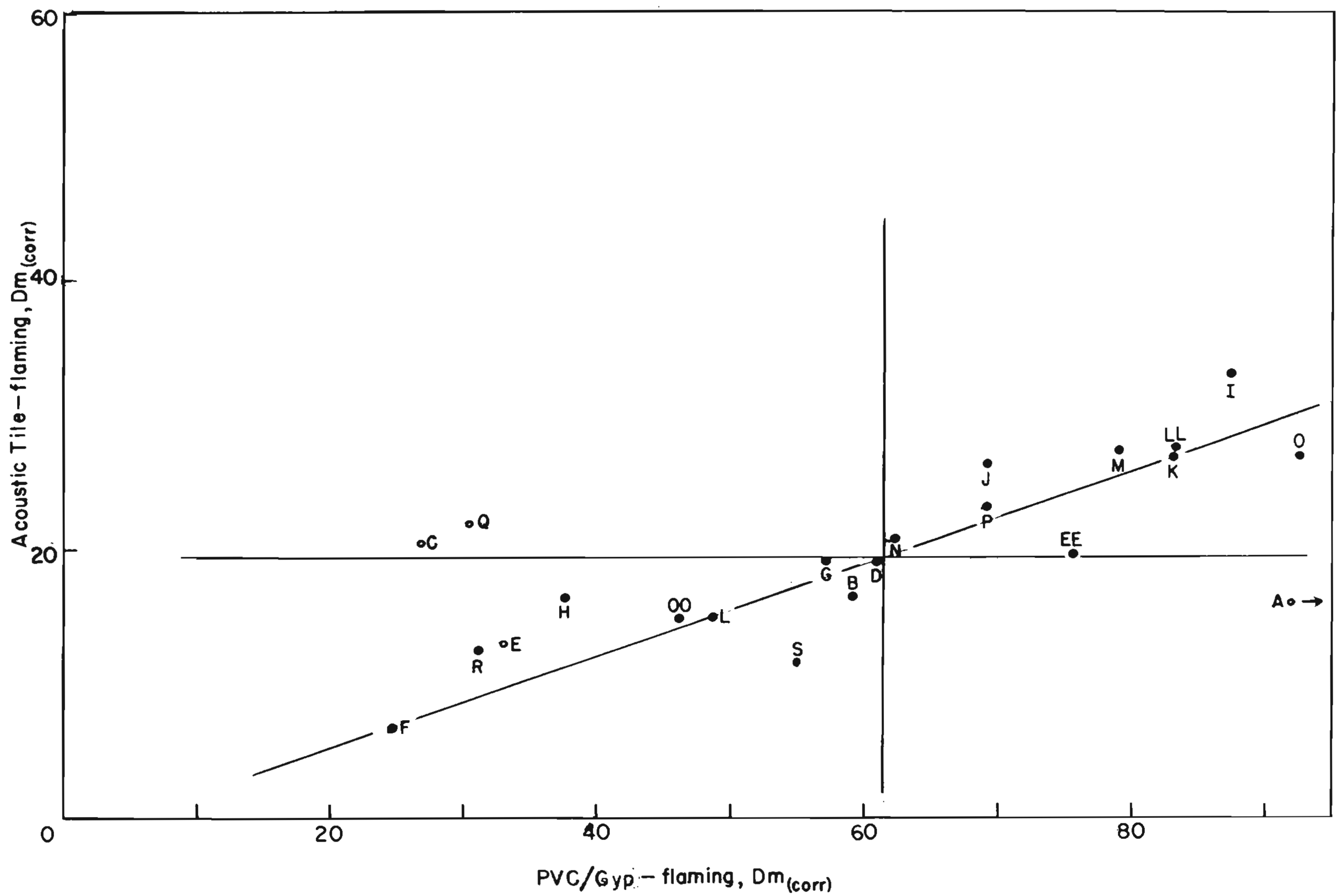


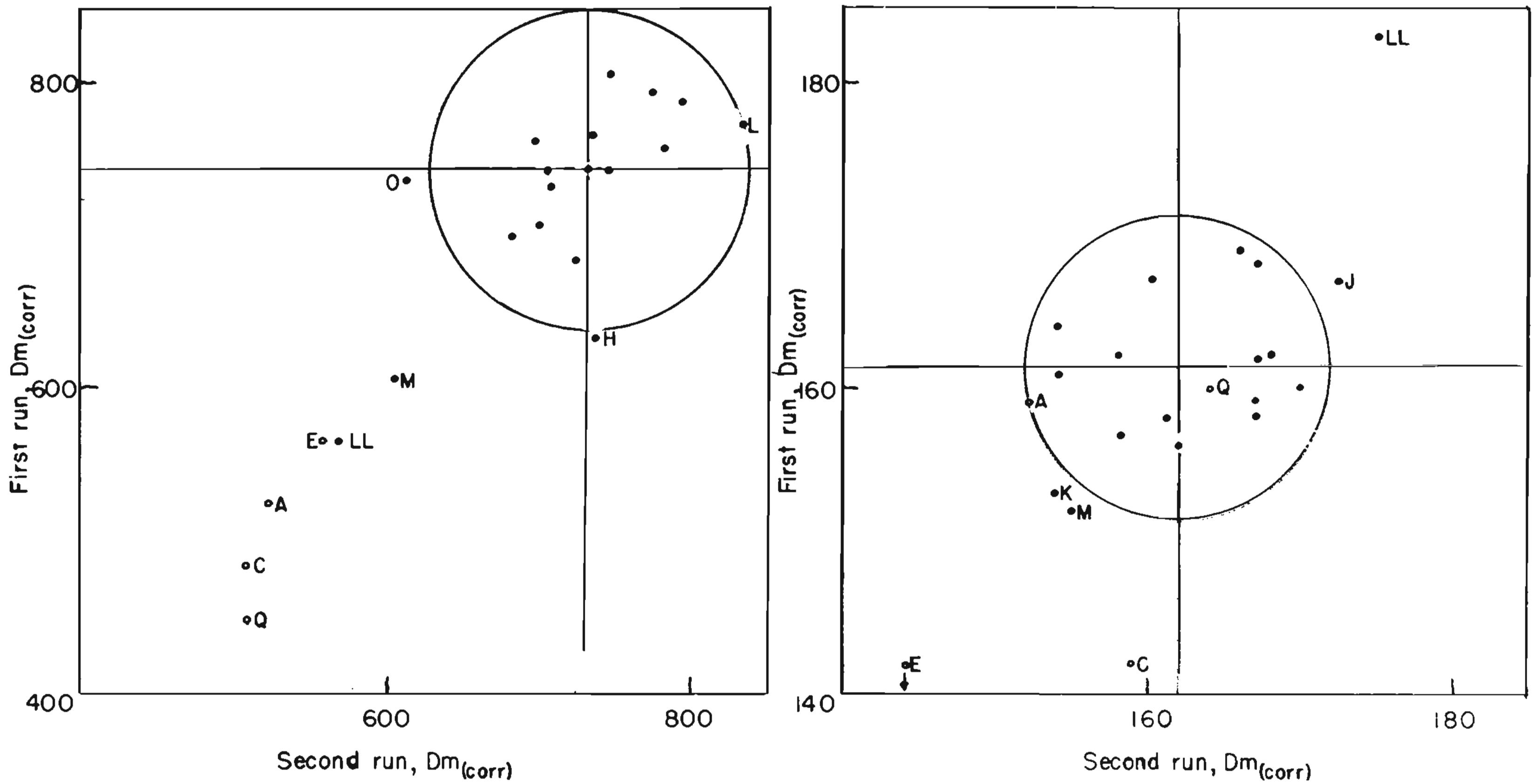
FIG. 2 Youden Plot of PVC/Gypsum vs. Acoustic Tile, Flaming

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 representative 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. The data, particularly 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 systematic biases, about 90% of the points should be within a circle whose radius is 2.15 times the standard deviation.

Analysis of Table I-1 (Appendix I) 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. Deviation from the mean values of D_m (corr.) for each laboratory are plotted against the mean of all laboratories.



Linoleum 725 ± 49

Alpha Cellulose 162 ± 4.7

FIG. 3 Youden Plots of Linoleum and α-cellulose

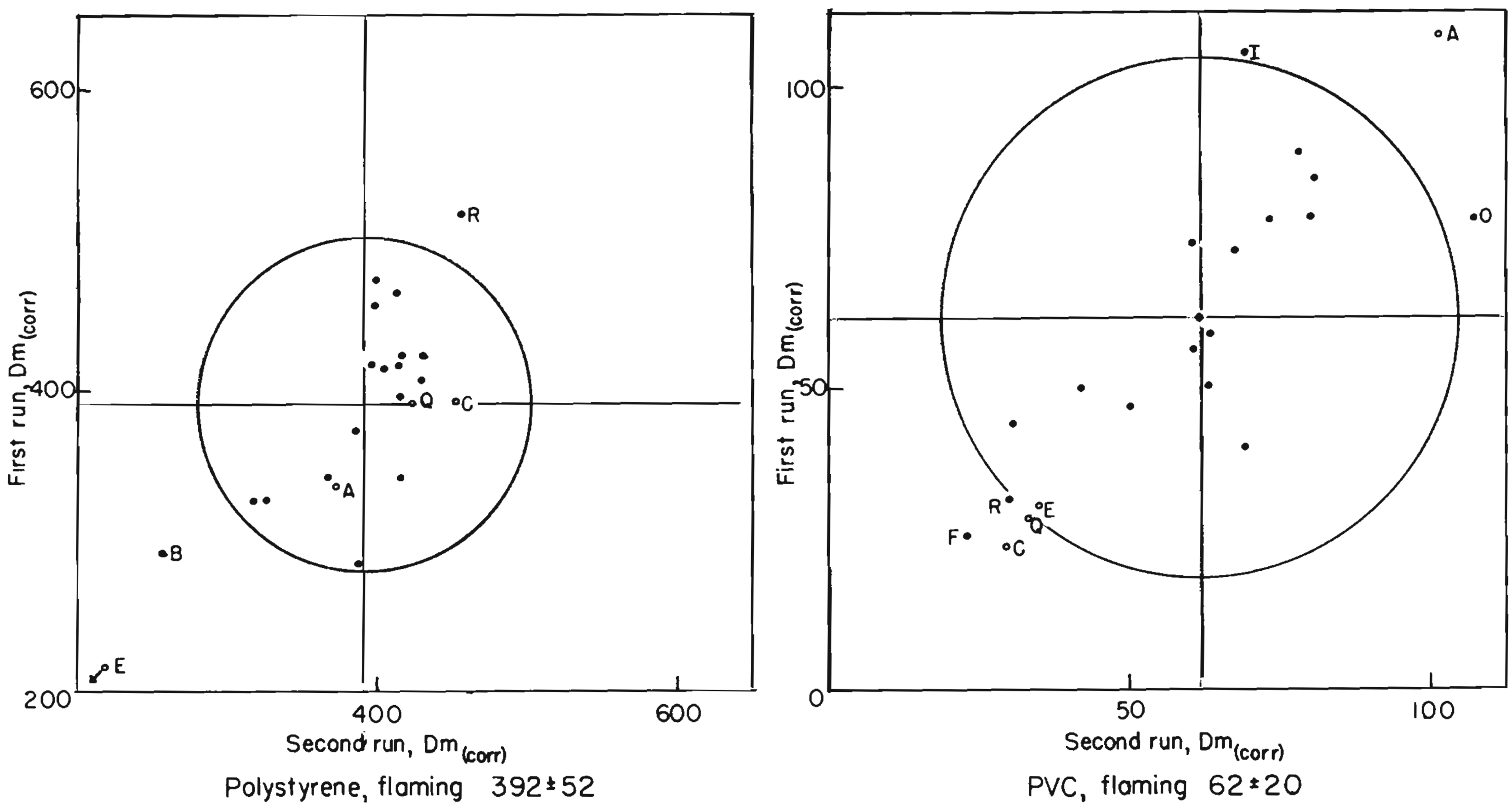


FIG. 4 Youden Plots of Polystyrene Foam and PVC, Flaming Condition

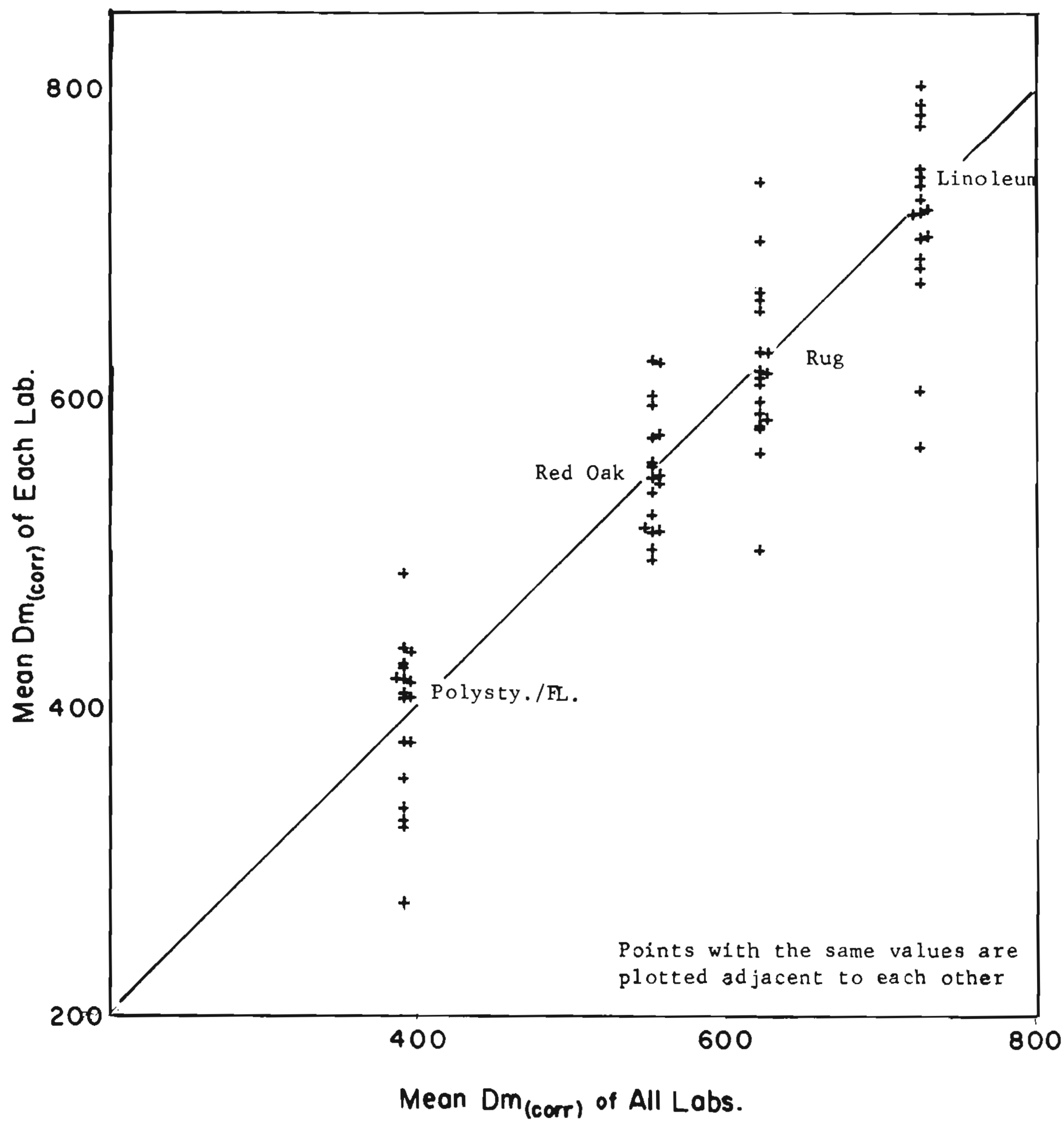


FIG. 5 Mean $D_{m(corr.)}$ of All Labs vs. Each Lab., 4 Materials

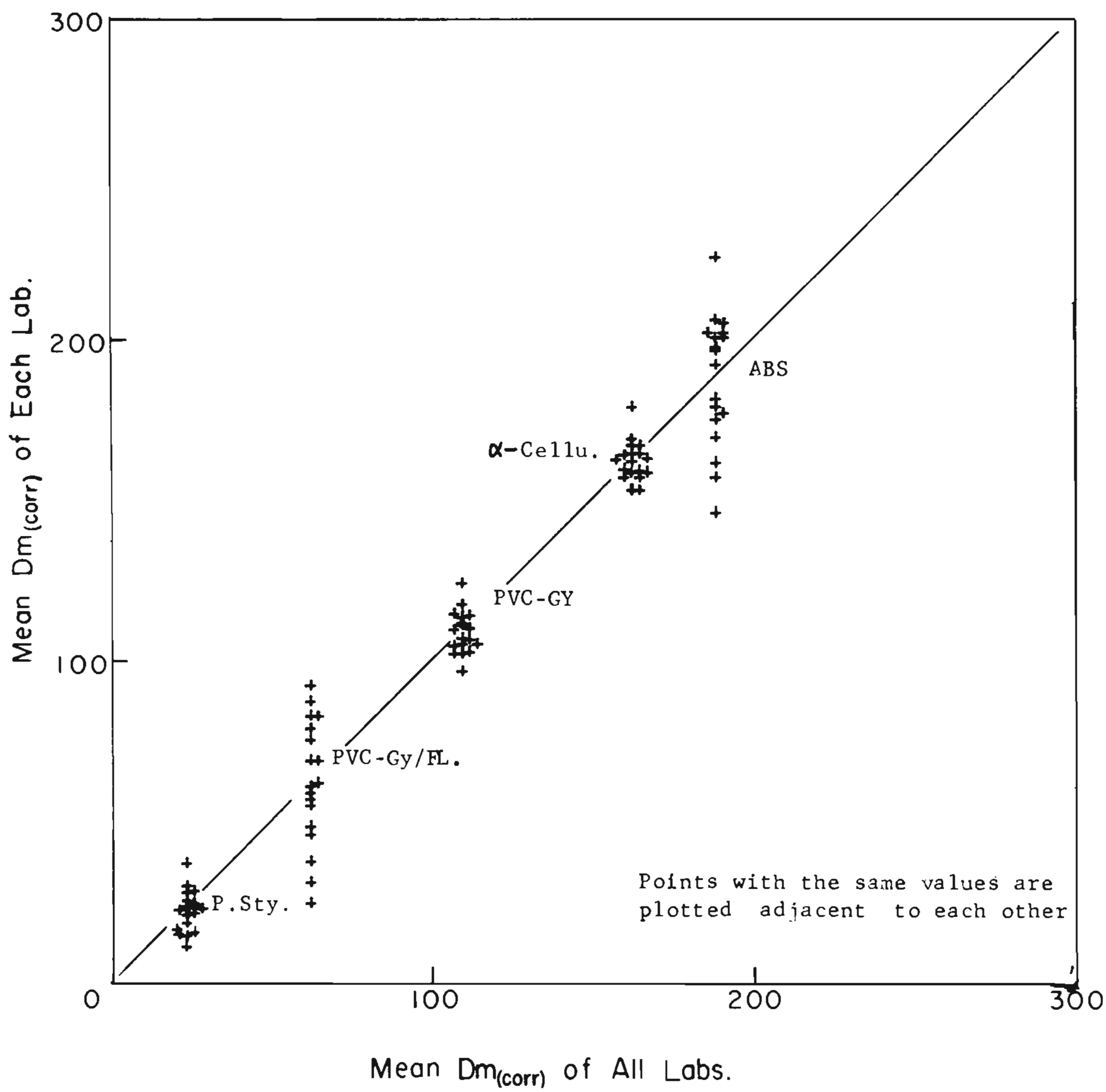


FIG. 6 Mean $D_{m(corr.)}$ of All Labs vs. Each Lab., 5 Materials

Table 11 - Material Rankings by 18 Labs. (AMINCO)
(Flaming or non-flaming exposure)

LAB.	Lino.	Rug	Red Oak	Polysty/Fl.	ABS	α-cellu.	PVC-Gyp	PVC-Gyp/Fl.	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

6.3 Ranking of Materials

Of the 10 material-conditions included in the tests, all 18 laboratories with AMINCO chambers ranked 9 of the material-conditions in the same order in terms of D_m (corr.) with only 3 reversal, see Table 11. 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.

Table 12 shows the ranking order of the laboratories for each material and the ranking sums (score) for each laboratory. A ranking order of 10, for example, 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]. The score rank indicate the ranking of the score.

7. 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

Table 12 D_m(corr.) Ranking and Score of Labs for Each Material (18 AMINCO Labs.)

LAB.	Non-Flaming Exposure									Flame 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

deviations from the average, that they should examine their procedures more carefully to locate sources of such departures.

7.1 Variation Between 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 results of home-built chambers are lower than the AMINCO type with the difference more pronounced at the higher end of the scale.

The mean values of 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 Table 13.

7.2 Materials

The materials selected for the tests covered a wide range of smoke levels as well as physical properties. Table 9 and 10 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.

Table 13 Adjustment of Data

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	Not used; limited only to AMINCO chamber

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

As indicated by the D_m (corr.) values in Table 10 under the non-flaming 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 attributed 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 the result of using

Table 14 Results of Pre-Round-Robin and Candidate Reference Specimens

Lab	α-Cellulose Dm	α-Cellulose Dc	PVC/PVA Flaming Dm	PVC/PVA Flaming Dc	ABS/32 mil Flaming[a] Dm(corr)	ABS/32 mil Flaming[a] Dc
A	163	7	501	6		
	161	7	460	15		
B	171	2	561	5	433	10
	153	8	564		440	25
C	166	5	498	26		
	163	7	513	18		
D	161	5	597	7		
			607	11		
E	160	10	505	15	(EE) 452	22
	161	16	513	14	437	18
F	174	5	553	12	487	24
	175	5	516	17	491	24
G	166	3	505	13		
	176	3	517	13		
H	160	3	560	11		
	165	5	592	12		
I	161	4	581	5	(J)435	23
	157	3	597	9	475	27
K	150		550		488	26
	162		543		453	19
L	163	2	549	8	462	20
	156	3	608	12	457	18
LL	164	9	513	14		
	169	8	523	11		
M	157	6	620	18		
	166	7	629	13		
OO					439	26
					440	17
O	156	4			420	18
	162	5			471	16
P	162	6	545	7	469	25
	176	2	568	6	474	27
Q	175	2	549	14	426	54(32) [b]
	160	2	541	14	455	58(36)
R	162	9	531	20		
	163	10	606	19		
S	166	5	495	7	439	26
	162	4	535	9	417	27
U					415	20
					462	22
Between Lab						
Mean	163.6		548.4		451.4	
S.D.	4.8		38.9		17.3	
Coef.Var%	2.9		7.1		3.8	
Within Lab						
S.D.	6.1		22.0		20.4	
Coef.Var%	3.7		4.0		4.5	

a/ Modified Burner and Trough Holder
b/ Values in parentesis were used to calculate Dm(corr)

improper fuel flow rate and burner distance, (See Table 4). 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 and the 0.032" ABS sheet used in the post-round-robin tests. There, the coefficient of variation was only 7.1% (mean D_m (corr.) = 548) and 4.5% (mean D_m (corr.) = 458) for the two materials respectively.

In order to detect possible gross errors in procedure or equipment, a short series of tests was conducted prior to the round-robin on two materials. The data are shown in Table 14. Also included are results of tests performed after the round-robin on a candidate reference material (ABS). The unusually high D_c values on ABS for Lab. Q were attributed to the additional smoke deposited on the window during an excessive exposure time after a maximum smoke level has been reached. A D_c correction of 22 was arbitrarily subtracted from the reported values. The statistical results from these tests are summarized in Table 10.

Of all the parameters listed in Table 10, the D_c values, photometer window deposit, has a relatively higher between-laboratory variance; which appears to be systematic. This may have been caused by the differences in window temperature among chambers and/or improper procedure (e.g. failure to remove the specimen from the front of the furnaces within one minute after teaching the minimum transmittance).

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. 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 flaming exposure conditions, a reference standard material with a maximum specific optical density in the range of 400 to 500 appears 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 modified 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 selecting from two burners.
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 fluctuation causes excessive variation of irradiance, 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 should minimize temperature and smoke deposit variability among the chamber windows.
10. Remove the specimen and commence smoke exhaust one minute after reading maximum smoke value in order to reduce photometer window deposit.
11. 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.

Recommendations 1 and 4 have since been included in the revised test method. An effective method for changing filters, as per Recommendation 11, is now available from AMINCO.

9. Acknowledgment

I would like to thank all participating laboratories and their representatives for their helpful comments, 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.

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