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NATIONAL BUREAU OF STANDARDS REPORT

10 244

Preliminary Report

INTERLABORATORY EVALUATION OF SMOKE DENSITY CHAMBER

NBS

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

NATIONAL BUREAU OF STANDARDS

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[3] Located at 5285 Port Royal Road, Springfield, Virginia 22151.

NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT		NBS REPORT
4212229	May 26, 1970	10 244

Preliminary Report

INTERLABORATORY EVALUATION OF SMOKE DENSITY CHAMBER

by

T. G. Lee

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Preliminary Report

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.

The 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 standardized conditions, smoldering 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 many 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 an 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 familiarization 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 the clear beam reading caused by the window deposits. The results of this initial study showed a between-laboratory coefficient of variation of 2.6% for smoldering α-cellulose (mean Dm = 162) and 7.1% for flaming

[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)

PVC/PVA plastic (mean Dm = 553) for the first 12 reporting laboratories. The reproducibility was considered reasonable for tests of this type.

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 preliminary tests. The data on the important single value of smoke potential - maximum specific optical density - is summarized in this report for those laboratories who reported their data before May 20, 1970.

2.0 PARTICIPANTS

A total of 17 laboratories, three with home-built and 14 with AMINCO chambers reported their results. These were:

Laboratory	Location	Representative
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 Product Lab (Madison)	Madison, Wisc.	H. W. Eickner J. Brenden
General Electric Co. (Plastic Dept)	Mt. Vernon, Ind.	C. Bialous
General Tire & Rubber Co. (Chem Plastic Dept)	Akron, Ohio	G. Wear
Johns-Manville (Research Center)	Mansville, Ohio	E. Davis
Lawrence Radiation Laboratory	Livermore, Calif.	J. Gaskill
Mobay Chemical	Pittsburgh, Pa.	R. Hagins
National Bureau of Standards	Gaithersburg, Md.	T. Lee
National Research Council (Canada)	Ottawa, Canada	J. McGuire
Owens Corning Fiberglas Corp.	Granville, Ohio	P. Hays
Union Carbide (Plastic 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

Weyerhaeuser Co.	Longview, Wash.	D. Crawford

The laboratories are identified in the report by code letters only.

3.0 TEST PROCEDURES

The detailed test procedures were described in a revised test method standard, (see attachment). 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 eight materials and 10 test conditions (two materials were tested under both flaming and smoldering conditions). The instructions requested that duplicate tests be preformed for each of the test condtions, 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 prior to tests because of the lack of facility or time.

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 non-reactive. The smoke levels from the materials covered the 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.

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 for each of the 17 laboratories the duplicate values of Dm(corr), the maximum specific optical density. Table 4 shows the average values of the duplicate determinations of Dm(corr) for each test condition and laboratory.

Table 5 summarizes for each material the arithmetic mean, the standard deviation between laboratories and within laboratories (based on duplicate tests) and the corresponding coefficients of variations. This data is based on results from the 13 laboratories with the AMINCO model. Fig. 2 shows the correlation of each lab against the mean.

Results of one AMINCO (LL) and all three home-built (A, E, C) models are not included in this analysis for statistical reasons.

Table 6 shows the ranking order of the laboratories for each material and the sum of the ranking (score) for each laboratory. A ranking order of 10, for example, means that the particular laboratory has a Dm 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. If the score departs from an expected limits (with 95% confidence level) which can be accounted for by random error, the presence of systematic error is assumed. Lab S exceed the limiting score; (77 for the number of labs and materials involved) and the data is considered suspect [3].

A convenient way of showing systematic deviations is to plot the value for each laboratory against the mean value for all laboratories for the various materials. This is shown in Fig. 1 for the two consistently high and two consistently low laboratories.

Table 7 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 distribution shows, for example, that one or two laboratories at the extreme ends can effect the calculated mean and standard deviation.

6.0 DISCUSSION

This round robin was designed to examine statistically the range of validity of the test method by including materials with a wide range of properties in terms of composition, thickness, reaction to heat and flame, and production of smoke. It included diverse types of laboratories - research as well as testing oriented; experienced as well as new to the smoke work. The results, therefore should reflect a conservative estimate of the method's precision.

An interlaboratory test of this type indicates to the participating laboratories who have reported systematic deviations from the average, the need for them to examine their procedures more carefully. One or two values for some materials in Table 4 are very close to the limit for discard under statistical procedures. They, nevertheless, were not excluded though it would improve the result on reproducibility. However, the data from Lab LL for two materials justify rerun because of the high within-lab variability; Lab - LL is not included in this analysis. The optical system and thermal properties of the inside walls varies between the home-built and AMINCO models. The data from the former are being analyzed separately and are not included here.

The results of the Dm(corr) values show that deviations between laboratories (reproducibility) may be three times greater than the deviation within a laboratory (repeatability). This implies that variations in procedures

[3] Youden, W. J., Ranking Laboratories by Round-Robin Test. Material Research Standard. 3 1, 9-13 (1963)

among laboratories account for most of the error rather than specimen variation. The deviation in reproducibility was much less for those laboratories who had attended the pre-test briefings; as compared to those who had not attended.

Looking at Table 5, under the smoldering exposure condition the five non-melting materials have a maximum coefficient of variation of 9.3%. The other two materials which melt, ABS and Polystyrene, have coefficients of variation of 12 and 27% respectively. However, the 27% coefficient of variation represents a standard deviation of only 6.3. The ABS melts gradually and flows down away from the center high irradiance region. The Polystyrene foam melts and shrinks into the bottom of the holder rapidly where the bottom edge shields it from further exposure. These changes in shape and position during exposure introduce somewhat higher variability.

Under the flaming exposure, the large coefficient of variation for tile may have been partially caused by specimen non uniformity (irregular hole size). For both the tile and the PVC faced gypsum, the actual value of the S.D. is only 7.6 and 19 respectively, representing low absolute variations for low smoke producing products.

7.0 CONCLUSION

The results of laboratory variability of Dm(corr), maximum specific optical density, for a wide variety of materials from 13 laboratories using AMINCO model Smoke Density Chambers are presented. The results are reasonable relative to other round robin studies involving flaming or fire tests. A more detailed analysis of the complete results taking into account values other than that for Dm(corr) will be made and sent to the participating laboratories after all the round-robin participants have sent in their data.

8.0 ACKNOWLEDGEMENT

We would like to thank each participating laboratory and their representative for their helpful comments, effort and cooperation in making this joint study possible; the participants for attending the pre-test conference; Forest Products Lab for providing the red oak specimens; and Dr. H.Ku (NBS) for advice on the statistical design and analysis.

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TABLE I

Interlaboratory Evaluation of Smoke Density Chamber Test Method
Schedule of Tests

Specimen	Condition	LABS																	
		~~A~~ S	B	C	D	~~EE~~ E	F	G	H	I	J	K	~~LL~~ L	M	N	O	P	Q	R
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
[illegible] - 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
Accustic 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

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

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	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 Dm(corr.) Values for each Laboratory and Material

Material / Test Condition

		Non-flaming Exposure														Flaming Exposure					
	Lab	Linoleum		Rug		Red Oak		ABS		Poly Styrene		α-cell		PVC-Gyp		Acous. Tile		PVC-Gyp		Poly Styrene	
	Run	1	2																		
AMINCO MODEL	B	764	733	741	738	562	534	197	205	17	25	164	154	114	109	15	18	57	61	292	254
	EE	795	772	675•	652•	555	556	195	210	24	32	159	161	113	108	19	20	78	73	326	327
	F	792	787	603	623	606	632	204	209	26	20	160	170	107	113	6	7	26	23	413	414
	G	687	722	580	580	524	524	147	146	24	19	162	168	113	101	21	18	51	63	327	317
	H	632	736	592	588	583	565	153	162	20	25	157	158	104	101	15	19	44	31	408	428
	I	695	762	594	601	505	499	193	192	11	11	162	167	108	102	32	34	99	69	459	397
	K	704	735	579	593	556	596	166	192	30	27	153	154	102	103	27	27	85	81	320+	359+
	L	831	773	656	656	645	600	230	222	24	23	161	154	111	113	16	14	47	50	414	404
	M	608	601	583	581	555	545	199	206	29	17	152	155	120	116	29	26	78	80	441	421
	N	743	744	498	505	491	499	200	211	18	13	158	167	125	124	17	25	65*	55*	451	411
	P	742	702	628	600	508	479	159	165	23	25	167	159	105	106	21	25	70	71	398	473
	R	657	780	596	639	535	555	193	162	33	27	156	162	109	106	11	14	32	30	519	453
	S	806	863	682	655	603	567	194	202	24	50	169	166	117	112	6	17	41	69	422	415
	LL	372	568	341	564	520	557	166	198	18	31	184	175	117	113	27	28	89	77	340	132
HOME BUILT	A	566	532	486	493	473	473	174	195	29	31	158	152	109	120	19	13	108	102	336	374
	E	557	564	488	481	492	490	132	130	21	18	144	132	96	88	15	11	31	35	400	400
	C	483	508	513	531	352	414	63	110	9	13	142	159	93	91	15	26	24	30	391	452

* Assumed values, data not reported

+ Rerun values: 371, 381

• Clear beam value error, assumed 20

TABLE 3 (Cont.) Dm(corr.) Values of 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	S	B	K	L	LL	M	F	H	EE	N	P	G	R	I
	842	664	619	608	559	201	164	97	343	343	73	57	13	24
	746	689	599	635	534	213	159	102	325	282	66	56	9	20
	744	646	597	561	529	215	160	95	345	465	77	54	10	22
AMINCO	789	628	620	591	530	198	171	101	285	478	63	51	9	25
MODEL	779	628	591	590	518	192	157	100	371	356	67	61	9	30
	768	620	630	598	412	176	164	98	287	461	65	53	12	29
Lab	A			C					E					
									*					
	530			338					23					
	513			374					35					
HOME	526			348					32					
BUILT	528			367					28					
	520			373					28					
	528			372					31					

* Burner position error, no flaming

Table 4

Dm(corr.) Results (mean of two determinations) for 17 Laboratories

Lab	Linoleum(S)	Polypropylene(S)	Red Oak (S)	ABS	P.Styrene	α-cellulose	PVC-Gypsum
B	748.5	759.5	548.0	201.0	21.0	159.0	111.5
EE	783.5	663.5	555.5	202.5	28.0	160.0	110.5
F	789.5	613.0	619.0	206.5	23.0	165.0	110.0
G	704.5	560.0	524.0	146.5	21.5	165.0	107.0
H	684.0	590.0	574.0	157.5	22.5	157.5	102.5
I	728.5	597.5	502.0	192.5	11.0	164.5	105.0
K	719.5	585.0	576.0	179.0	28.5	153.5	102.5
L	602.0	656.0	622.5	226.0	23.5	157.5	112.0
M	604.5	582.0	550.0	202.5	23.0	153.5	118.0
N	743.5	501.5	495.0	205.5	15.5	162.5	124.5
P	722.0	614.0	493.5	162.0	24.0	163.0	105.5
R	718.5	617.5	545.0	177.5	30.0	159.0	107.5
S	634.5	668.5	585.0	198.0	37.0	167.5	114.5
LL	470.0	452.5	538.5	182.0	24.5	179.5	115.0
A	549.0	489.5	473.0	184.5	30.0	155.0	114.5
E	560.5	484.5	491.0	131.0	19.5	138.0	92.0
C	495.5	522.0	383.0	86.5	11.0	150.5	92.0

Flaming Exposure

Lab	PVC Gypsum	P. Styrene	Acoustic Tile
B	59.0	273.0	16.5
EE	75.5	326.5	19.5
F	24.5	413.5	6.5
G	57.0	522.0	19.5
H	37.5	419.0	17.0
I	54.0	423.0	33.0
K	83.0	339.5	27.0
L	48.5	409.0	15.0
M	79.0	431.0	27.5
N	60.0	451.0	21.0
P	70.5	435.5	23.0
R	51.0	486.0	12.5
S	55.0	418.5	11.5
LL	63.0	[illegible]	27.5
A	195.0	[illegible]	16.0
E	33.0	[illegible]	13.0
C	27.0	421.[illegible]	20.5

TABLE 5 Results of Dm(corr.) for 13 Lab (AMINCO)

Standard Deviation and Coefficient of Variation

Mean Values, Between-Lab and Within-Lab

	Non-flaming Exposure							Flaming Exposure		
	Lino	Rug	Red Oak	ABS	α-cell	PVC-Gyp	P. Sty	P. Sty	PVC-Gyp	Tile
BETWEEN-LAB										
Mean	737	616	553	189	160	110	24	394	58	19
S. D.	58	57	42	23	4.4	6.3	6.4	60	19	7.6
Coef.Var %	7.9	9.3	7.7	12	2.8	5.7	27	15	33*	37**
WITHIN-LAB										
S. D.	40	13	18	9.5	4.3	3.6	6.5	27	9.2	3.2
Coef.Var %	5.4	2.1	3.2	5.0	2.7	3.3	27	6.9	16	17

* If one outlying value (24.5) is set aside, coef. of var. becomes 28

** If one outlying value (6.5) is set aside, coef. of var. becomes 32

Table 6

Ranking and Score of Labs for Each Material

LAB.	Non-Flaming Exposure							Flaming			Non-Flaming Score	Flaming Score
	Lino	Rug	Red Oak	ABS	Cell	PVC	P.Sty	P.Sty	PVC	Tile		
B	9	13	6	8	5.5	9	3	1	7	5	53.5	13
EE	10	11	8	9.5	7	8	10	3	10	7.5	63.5	20.5
F	11	7	12	12	11.5	7	6.5	6	1	1	67	8
G	3	2	4	1	11.5	5	4	2	6	7.5	30.5	15.5
H	2	5	9	2	3.5	1.5	5	7	3	6	28	16
I	7	6	3	6	10	3	1	9	13	13	36	35
K	5	4	10	5	1.5	1.5	11	4	12	11	38	27
L	12	10	13	13	3.5	10	8	5	4	4	69.5	13
M	1	3	7	9.5	1.5	12	6.5	10.5	11	12	40.5	13.5
N	8	1	2	11	8	13	2	10.5	8	9	45	27.5
P	6	8	1	3	9	4	9	12	9	10	40	31
R	4	9	5	4	5.5	6	12	13	2	3	45.5	18
S	13	12	11	7	13	11	13	8	5	2	80	15

Table 7

Frequency Distribution $\eta = 13$

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

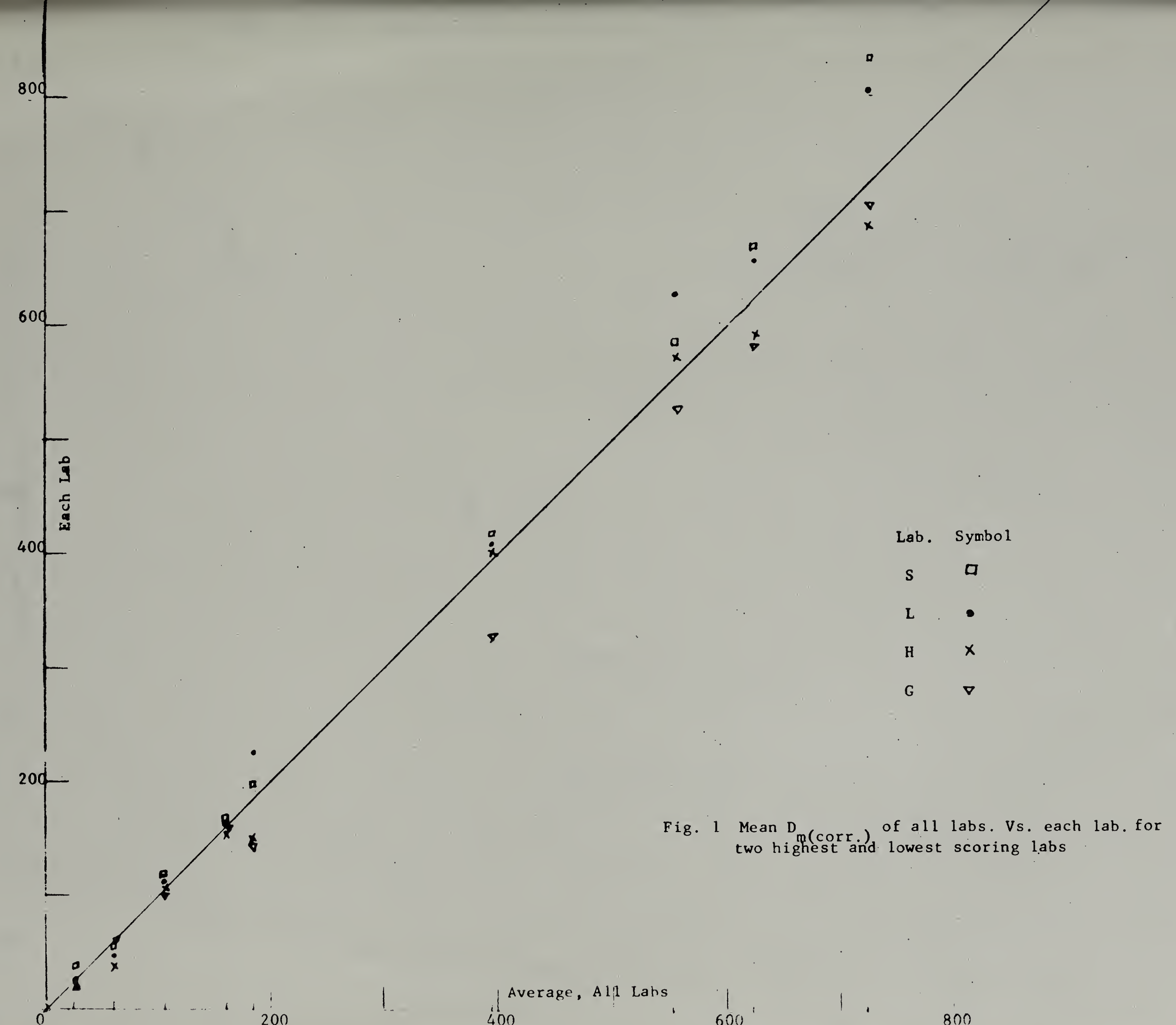

Fig. 1 Mean $D_{m(corr.)}$ of all labs. Vs. each lab. for two highest and lowest scoring labs

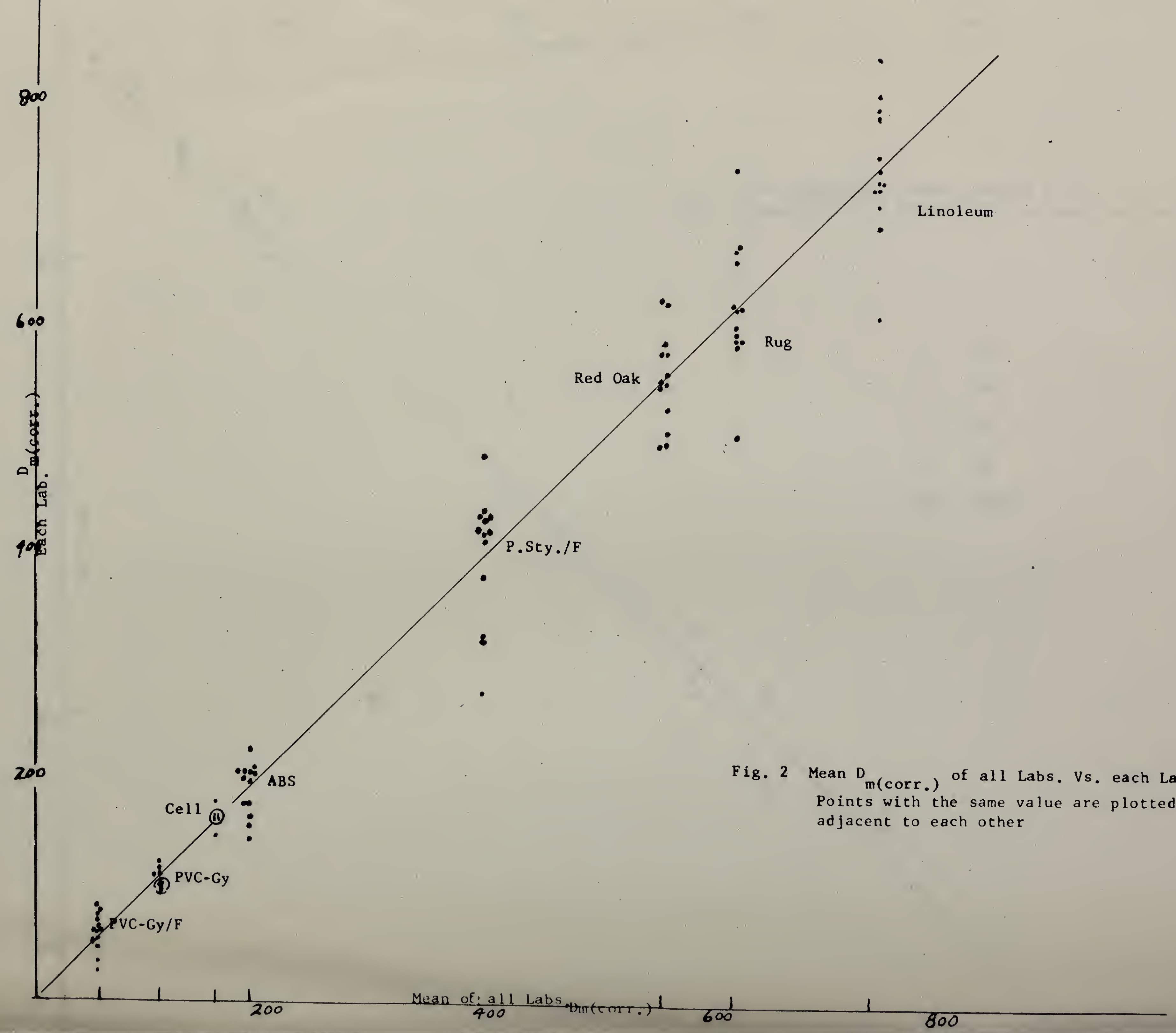

Fig. 2 Mean $D_{m(corr.)}$ of all Labs. Vs. each Lab. Points with the same value are plotted adjacent to each other

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