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NATIONAL BUREAU OF STANDARDS REPORT

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ROUND ROBIN FLAME SPREAD TESTS
BY THE RADIANT PANEL TEST METHOD

by
D. Gross

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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ROUND ROBIN FLAME SPREAD TESTS BY THE RADIANT PANEL TEST METHOD

by
D. Gross

for
Tri-Service Building Materials Investigation Committee

NBS

U. S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

ROUND ROBIN FLAME SPREAD TESTS BY THE RADIANT PANEL TEST METHOD

ABSTRACT

A report is presented of the first interlaboratory comparison of flame spread measurements as determined by the radiant panel test method. A total of eight laboratories including National Bureau of Standards made measurements on four acoustical tile materials provided by ASTM Committee C-20. Analysis of the results indicate that the precision of the measurements within laboratories was similar but that considerable systematic bias was observed between different laboratories. These biases were such that the participating laboratories yielded flame spread indices which were generally lower than those measured by NBS. Subsequent checks on radiation pyrometers and radiation measuring techniques used by five of the seven participating laboratories indicate that the radiant panel energy output level used by these laboratories was lower than that intended. Although other differences were observed between the test methods used and the results obtained at the various laboratories the primary cause of the biases observed appears to have resulted from the use of uncalibrated radiation pyrometers.

INTRODUCTION

A program to evaluate the degree of correlation between results of flame spread test methods was undertaken by Subcommittee II of ASTM Committee C-20 on Acoustical Materials. The Task Group authorized a series of round robin tests to be conducted by laboratories employing the radiant panel flame spread test method[1] to supplement similar round robin tests by laboratories employing the tunnel method for flame spread rating (E 84-50T) and the eight-foot tunnel test method of Forest Products Laboratory.

The Task Group made available to the National Bureau of Standards approximately 40 tiles of each of the four acoustical materials tested in the tunnel round robin study. The four materials for the radiant panel round robin series were received at NBS on September 9, 1958 and sent out to seven participating laboratories on October 3, 1958. The materials were identified only by the code letters "W", "X", "Y" and "Z" with no reference to appearance, characteristics or manufacturer.

PARTICIPANTS

All private and commercial laboratories which were known to have installed the radiant panel flame spread test equipment at the time, were contacted and all agreed to participate in the round robin study. In addition to NBS, the following laboratories participated:

Benjamin Foster Company
4635 W. Girard Avenue
Philadelphia 31, Pa.

Curtiss-Wright Corporation
Research Division
Quehanna, Pa.

E. I. duPont de Nemours & Co.
Engineering Test Center
Wilmington 98, Del.

Johns-Manville Products Corp.
Research Center
Manville, N. J.

The Lubrizol Corporation
Cleveland 17, Ohio

National Gypsum Company
1650 Military Road
Buffalo 17, N. Y.

United States Testing Co., Inc.
1415 Park Avenue
Hoboken, N. J.

TEST PROCEDURE

The study reported was purposely carried out prior to any cross checks between laboratories. In many instances the equipment had been assembled, installed and adjusted without detailed discussions or visits to NBS in connection with this equipment. In a few instances visits had been made to NBS for the purpose of clarifying some test procedure details. In only one instance had one of the participating laboratories been furnished two specimens each of three materials together with the flame spread index as determined at NBS.

Details of the test procedure used in the radiant panel round robin were specified in a preliminary draft of a proposed Federal Standard for surface flammability entitled "Suggested Method for Flame-Spread Classification of Materials" copies of which were distributed to the participants. The outlined procedures were considered to be sufficiently detailed to permit testing under controlled and reproducible conditions. However, a certain amount of reasonable discretion on the part of individual operators and laboratories was inevitable in the manual test procedures.

The prescribed procedure for the conditioning of specimens prior to test consisted of pre-drying for 24 hours at 160F followed by conditioning to equilibrium at 73 ± 5F and 50 ± 5% relative humidity. This procedure, which reduces differences in moisture content resulting from approaching the equilibrium condition from a high or from a low moisture level, was suggested by Mr. R. H. Neisel of Johns-Manville Corp.

RESULTS

The results of the tests are summarized in the following tables. To maintain the confidential nature of each laboratory's results, code letter identification has been given to all participating laboratories other than NBS. Individual and average flame spread index values are given in Table IA and the corresponding flame spread and heat evolution factors in Table IB. Moisture content and smoke data are listed in Table II. Some characteristics of the individual test apparatus are indicated in Table III from which may be noted the wide variety of gas types, BTU content, hours of operation, etc.

ANALYSIS OF RESULTS

A. Statistical

Analysis of previous data at NBS has shown that, in general, for low values of the flame spread index (below 10-15), the indicated variability expressed as a coefficient of variation is not a representative measure of the precision of the experiment. It was considered that the inclusion of material "X" in a statistical analysis of the interlaboratory results would not add any useful information and the analysis is therefore based upon eight laboratories and materials "W", "Y" and "Z" only.

Assuming that the standard deviation is proportional to the mean[2], the logarithms of the flame spread index values are used in the analysis. Figure 1 is a graph showing the flame spread index for each laboratory plotted against the average flame spread index for all laboratories on logarithmic coordinates. It is evident that laboratories tend to be consistently lower or consistently higher than the average values for all laboratories. Numerical analysis further confirms the existence of systematic bias which could result from shortcomings in specification of the test procedure, from individual modifications in the test procedure, or from different operating conditions. The latter effect will be discussed in detail in the next section. Excepting for material "X", the intralaboratory precisions of the laboratories as measured by the standard deviations of the replicated tests, are of similar magnitude and equivalent to an average coefficient of variation of approximately 20%. These results are in line with statistical experience which shows that laboratories usually vary considerably in their biases and vary relatively little in their individual precisions.

B. Experimental Bias

None of the remarks received from the individuals performing the tests at the various laboratories indicated that the contents of the test specification were either overly vague or unduly restrictive. Although the test specification was closely followed in most particulars, some deviations were noted. A large portion of the experimental bias appears to have been introduced by differences in the calibrations of radiation pyrometers used for monitoring the energy output of the radiant panel. Five laboratories procured identical model radiation pyrometers from the same manufacturer with the implied understanding that they were calibrated instruments. A comparison of 4 of these pyrometers subsequent to the test program showed that this was not the case. Since NBS and laboratory F are the only laboratories known to have performed their own pyrometer calibrations, the other laboratories were actually operating with uncalibrated instruments. It should be noted, however, that laboratory F performed its calibration at a temperature considerably above 670°C and without use of a blackbody source. Table IV lists the measured millivolt readings corresponding to a blackbody temperature of 670°C for those pyrometers subsequently calibrated at NBS; the millivolt readings used by laboratories C, D, E, and F also given for comparison. In each case use of the assumed millivolt reading resulted in operation of the radiant panel at an energy output level corresponding directly to the bias in the results. It was further determined that laboratory A, in employing a narrow angle pyrometer and sighting on the hotter portion of the lower half of the panel was also operating its panel at a considerably lower energy output than that specified.

DISCUSSION

A more detailed investigation of the method for standardization of the radiant panel energy output leads to several necessary considerations. These involve the spectral transmittance characteristics of the radiation pyrometer lens or window and the emittance characteristics of the radiant panel itself.

In order to evaluate the effect of the radiation pyrometer optics, a series of measurements were made using a radiation pyrometer with a calcium fluoride lens as well as this instrument with assorted windows placed in front of it. The results are shown in Table V. The differences observed between the readings obtained while sighting at a blackbody source and those obtained while sighting at the radiant panel source were small. Although this is an indication that the overall emittance of this radiant panel is fairly high, no information was available on the spectral distribution of emittance or on the variability to be expected between different radiant panels. For this reason, several computations were performed based on the assumption that the radiant panel emits energy as a grey body, i.e., one whose emittance is less than one and is independent of wave length. Taking the average wave length cut-offs for fused silica and calcium fluoride as 3.8 and 9.5 microns, respectively, Figure 2 shows the percent energy emitted as a function of emittance for two lens-type radiation pyrometers. If the emittance of the panel were lower in the near infrared region (below 4 microns), as some information indicates it may be, these differences would be further magnified.

It should be noted that the thermal detector of a radiation pyrometer with a calcium fluoride lens "sees" 89% of the energy emitted by a blackbody at 670°C whereas one with a fused silica lens or window "sees" only 40% of this energy. In addition, the droop of the calcium fluoride curve with respect to emittance is much less pronounced than the fused silica curve. Thus, a radiation pyrometer with high transmission in the infrared appears to have significant advantages for standardization of the radiant panel output.

SUMMARY

A series of round robin tests were performed by eight laboratories equipped with the radiant panel flame spread test equipment as authorized by Subcommittee II of ASTM Committee C-20 on Acoustical Materials. The test equipment was installed in the other seven laboratories from the published descriptions of the apparatus and with little or no prior checking or material testing. There was considerable variation among the laboratories in the type and heating value of the gas supplied to the radiant panel, in the type of instrumentation used, in the hours of operating experience prior to this series of tests, etc. Some deviations from the test specifications distributed to the participating laboratories were observed.

The test results are given in Table I. Analysis of the results indicates the existence of systematic experimental bias as shown by consistently low or consistently high flame spread index values by individual laboratories relative to the overall averages. Subsequent investigation revealed that differences in the calibrations of the radiation pyrometers used to monitor the energy output of the radiant panel accounted for a large portion of this systematic bias. The extent to which a laboratory's results were low bore a direct relationship to the low energy output at which its radiant panel operated and necessarily to the difference between the calibrated and assumed readings of its radiation pyrometer. The intralaboratory precisions were found to be of similar magnitude and were equivalent to an average coefficient of variation of approximately 20%.

Analysis shows that a radiation pyrometer with high transmission in the infrared has advantages for standardization of the radiant panel output. The necessity for calibration of the radiation pyrometer has been demonstrated. Under energy output conditions established by means of a calibrated radiation pyrometer and by close following of the test specifications, improved interlaboratory agreement may be expected.

ACKNOWLEDGEMENT

The participation of the National Bureau of Standards in this study was supported by funds furnished by the Department of Defense in connection with the establishment of a Federal Standard for surface flammability. The study was made possible through the splendid cooperation of the many individuals who performed and directed the testing at the participating laboratories. The aid of Mr. H. H. Ku in the statistical interpretation of the test results is gratefully acknowledged.

REFERENCES

1. "A Method For Measuring Surface Flammability of Materials Using a Radiant Energy Source", by A. F. Robertson, D. Gross and J. Loftus, Proc. ASTM, 56, 1437-1453, 1956.

2. "Flame Spread Properties of Building Finish Materials", by D. Gross and J. Loftus, Bull. ASTM 230, 56-60, 1958.

TABLE I. Radiant Panel Round Robin Test Results

A. Flame Spread Index

Specimen	Laboratory								Average All Laboratories
	NBS	A	B	C	D	E	F	G	
W	447 414 402 398	179 192 167 180	185 194 191 220	171 167 149 185 166	384 372 357 331	329 330 335 329	346 274 365 519	185 248 180 213 206	
W Average	415	180	198	168	361	331	376	206	279
X	1.2 4.0 1.1 12.0	4.8 4.2 7.2 9.0	6.15 1.92 5.84 4.25	0 1.5 0 0.52 0	19.0 12.8 7.3 6.3	10.6 2.8 13.0 8.4	N* N* N* N*	10.4 9.0 41. 24	
X Average	4.6	6.3	4.54	0.4	11.3	8.7	N*	21.1	7.1
Y	106 83 99 86	45 40 33 33	63 51 49 62	28 28 30 30 28	114 91 114 77	74 69 65 70	93 101 147 170	43 48 58 55 57	
Y Average	94	38	56	29	99	70-	128	52	71
	34 33 50 29	26 22.5 17 18.2	26 19 27 29	16 18 18 20 21	49 44 50 35	49 45 40 30	21 50 36 36	93 37 44 52 31	
Z Average	36	20.9	25	19	45	41	36	51	34

*N Negative value. Taken as zero in computing averages

TABLE I. (Cont'd)

B. Flame Spread Factor Fs and Heat Evolution Factor Q

Specimen	LABORATORY																Average all Laboratories	
	NBS		A		B		C		D		E		F		G			
	Fs	Q	Fs	Q	Fs	Q	Fs	Q	Fs	Q	Fs	Q	Fs	Q	Fs	Q	Fs	Q
W							13.5	12.7							19.3	9.6		
	26.3	17.0	16.2	11.8	18.5	10.0	14.1	11.9	23.4	16.4	23.5	14.0	27.8	12.4	27.3	9.1		
	25.5	16.2	16.0	11.2	20.1	9.7	12.5	11.9	23.8	15.7	22.8	14.5	28.2	9.7	19.3	9.3		
	25.2	16.0	15.3	10.9	21.0	9.12	14.3	12.9	24.3	14.7	23.1	14.5	29.6	12.4	23.4	9.1		
	25.9	15.4	15.8	11.4	20.2	10.9	12.8	12.9	22.5	14.7	23.6	13.9	40.3	12.9	21.5	9.6		
Fs Average	25.7		15.8		19.9		13.4		23.5		23.3		31.5		22.2		21.9	
Q Average		16.2		11.3		9.9		12.4		15.4		14.2		11.8		9.3		12.6
X							1.0	0										
	6.26	0.2	2.39	2.0	5.05	1.22	1.0	1.5	4.92	3.86	11.67	0.91	3.72	N	5.5	1.9		
	3.38	1.2	2.09	2.0	2.47	0.78	1.0	0	6.89	1.86	2.69	1.04	14.52	N	2.9	3.0		
	2.85	0.4	3.96	1.8	4.78	1.22	1.0	0.5	5.64	1.29	5.26	2.47	3.40	N	8.7	4.7		
	6.73	1.8	3.68	2.45	5.46	0.78	1.0	0	6.34	1.0	5.40	1.55	3.60	N	5.0	4.7		
Fs Average	4.50		3.03		4.44		1.0		5.95		6.25		6.31		5.5		4.66	
Q Average		0.9		2.07		1.00		0.4		2.00		1.49		N		3.6		1.43
Y							3.99	6.7							6.20	7.0		
	10.0	10.6	5.46	8.2	10.46	6.00	3.89	7.22	9.49	12.0	8.76	8.44	11.2	8.25	7.21	6.6		
	10.1	8.2	5.32	7.6	7.88	6.45	3.96	7.73	9.14	10.0	7.84	8.83	11.0	8.76	6.61	8.7		
	10.1	9.8	4.84	6.8	6.98	7.00	4.12	7.2	9.74	11.7	7.90	8.18	14.3	10.3	6.30	8.8		
	9.8	8.8	4.46	7.3	8.16	7.55	3.82	7.2	8.59	9.0	7.95	8.96	19.4	8.76	6.62	8.6		
Fs Average	10.0		5.02		8.37		3.96		9.24		8.07		14.1		6.59		8.17	
Q Average		9.4		7.5		6.75		7.2		10.7		8.60		9.02		7.94		8.39
Z							2.62	6.19							10.[illegible]	8.6		
	5.57	6.2	3.47	7.6	4.47	5.78	2.75	6.7	4.93	10.0	7.61	6.49	8.30	2.58	5.1	7.2		
	5.34	6.2	3.27	6.9	4.44	4.34	2.74	6.7	5.06	8.7	6.60	6.88	8.05	6.19	5.5	8.0		
	5.65	8.8	2.93	5.9	3.65	7.33	2.97	6.7	4.81	10.3	5.34	7.40	8.73	4.12	5.99	8.6		
	5.54	5.2	3.15	5.8	4.42	6.77	2.89	7.2	4.77	7.44	4.22	7.01	8.69	4.12	3.9	8.0		
Fs Average	5.52		3.20		4.24		2.79		4.89		5.94		8.44		6.2[illegible]		5.15	
Q Average		6.6		6.5		6.06		6.7		9.11		6.94		4.25		8.1		6.50

TABLE II. Moisture Content and Smoke Evolution Data

	Laboratory							
	NBS	A	B*	C	D	E**	F	G
"W" Moisture content, %	8.0	7.8	4.95	8.0	5.2	6.6	....	....
Smoke, mg	0.0	0.4	1.9	0.1	....	0.1	0.23	0.3
"X" Moisture content, %	2.2	2.6	1.36	2.0	1.4	1.53	....	....
Smoke, mg	0.0	0.1	....	0.2	....	0.1	....	0.0
"Y" Moisture content, %	7.2	6.9	4.53	6.7	5.0	4.49	....	....
Smoke, mg	0.4	0.3	0.6	0.5	....	0.3	0.2	0.9
"Z" Moisture content, %	7.2	7.3	3.60	5.4	4.2	4.25	....	....
Smoke, mg	0.1	0.2	0.7	0.6	....	0.5	0.1	0.3

Note: Moisture content is expressed as a percentage of the oven-dry weight.
* Conditioned at 40% relative humidity.
** Conditioned at room temperature and humidity.

All others conditioned at 50 ± 5% relative humidity.

TABLE III. Operating Characteristics of Test Apparatus

	Laboratory							
	NBS	A	B	C	D	E	F	G
Date placed in operation	1955	Feb. 1957	May 1957	Jan. 1958	Aug. 1958	Sept. 1957	Jan. 1957	Oct. 1958
Total hours of operation, approx.	2000	80	200	100	100	500	--	8
Type of gas supplied to radiant panel	Natural	Mfgd plus natural	Propane	Propane	Propane	City	Illuminating	Natural plus artificial
Heating value of gas BTU/ft^3	1050	604	2400	2336	2550	750	604	900
Stack calibration constant β, deg F-min/BTU	0.92	1.1	0.90	0.97	0.7	0.77	0.97	0.9
Radiation pyrometer	a	b	c	a	a	a	a	a
Method of calibration of pyrometer	NBS	MFR	MFR	*	*	*	*	*
Hood above apparatus?	Yes	No	...	Yes	Yes	Yes	Yes	Yes

a. Calcium fluoride lens
b. Fused silica lens
c. Fused silica window
* Procured on the basis of pre-calibration but found as a result of this study to be uncalibrated.

TABLE IV. Comparison Between Readings of Identical Model Radiation Pyrometers

Laboratory	Reading of Radiation Pyrometer-Blackbody at 670°C	
	Measured at NBS	Assumed
NBS	2.83 mv *	2.83 mv *
C	5.25	3.05
D	3.20	3.03
E	3.43	3.03
F	2.09	2.4 **

* Actual reading with special extension tube was 1.95 mv.

** Based on (non-blackbody)calibration at 730°C with special extension tube.

TABLE V. Effect of Lens and Window Materials on Readings of Radiation Pyrometer

Radiation Receiver	Nominal Wave Length Cut-off	Radiation Pyrometer Readings		Energy Received from Blackbody at 670C	
		Blackbody at 670C	Radiant Panel Normal Operation *		
	Microns	mv	mv	Watt/ cm^2	Per-cent
Total(Theoretical)	00	--	--	4.49	100
Calcium Fluoride Lens	9.5	1.952	1.952	3.99	89
Calcium Fluoride Lens Plus Vycor (96% Fused Silica) Window	3.8	0.793	0.784	1.80	40
Calcium Fluoride Lens Plus Crystalline Quartz Window		0.734	0.724		
Calcium Fluoride Lens Plus Pyrex Window	2.7	0.338	0.352		

* Adjusted to temperature such that radiant output as measured by radiation pyrometer corresponds to that of a blackbody at 670°C.

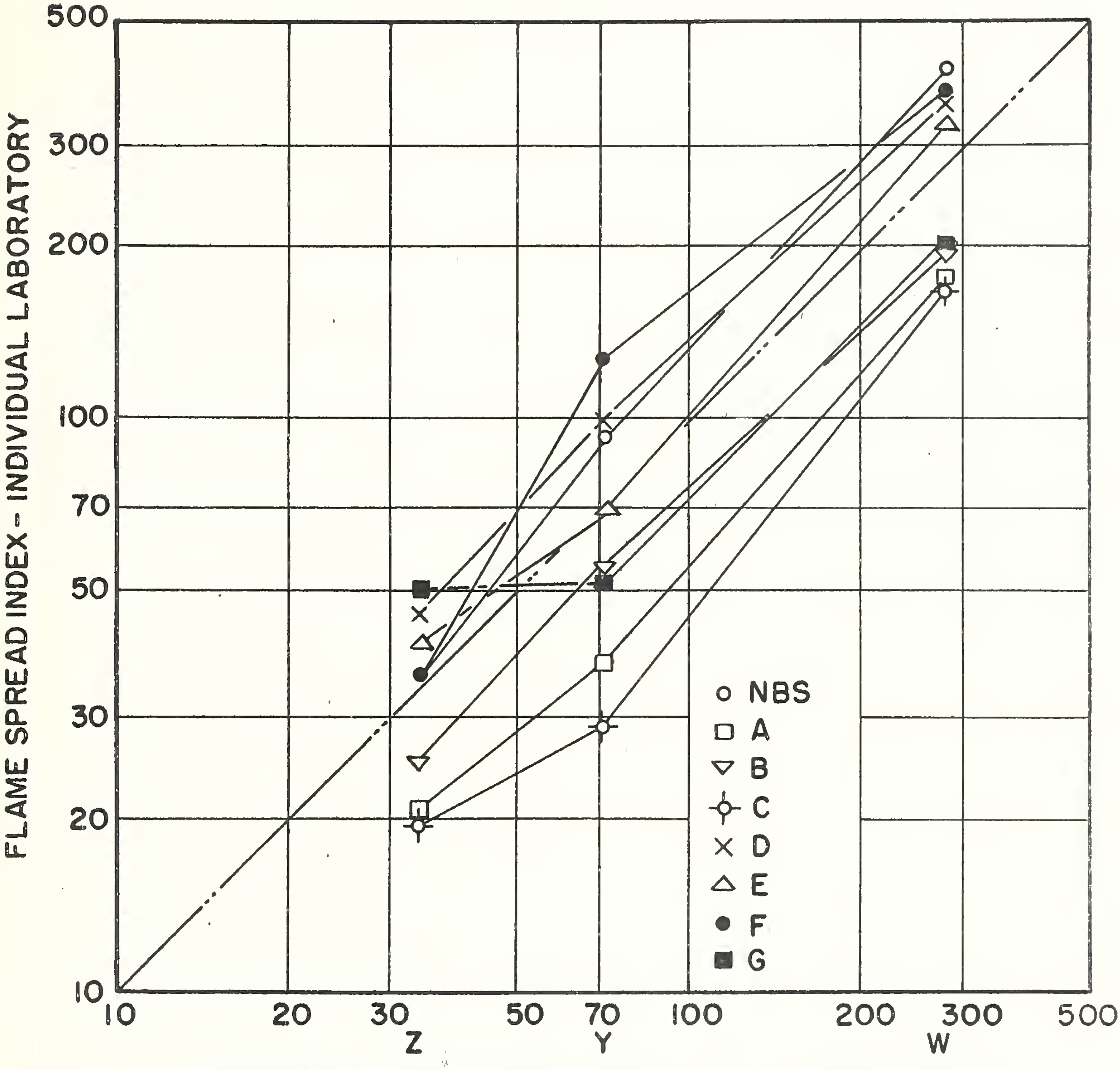

FIG. 1 – FLAME SPREAD INDEX OF INDIVIDUAL LABORATORY VS AVERAGE FLAME SPREAD INDEX FOR ALL LABORATORIES

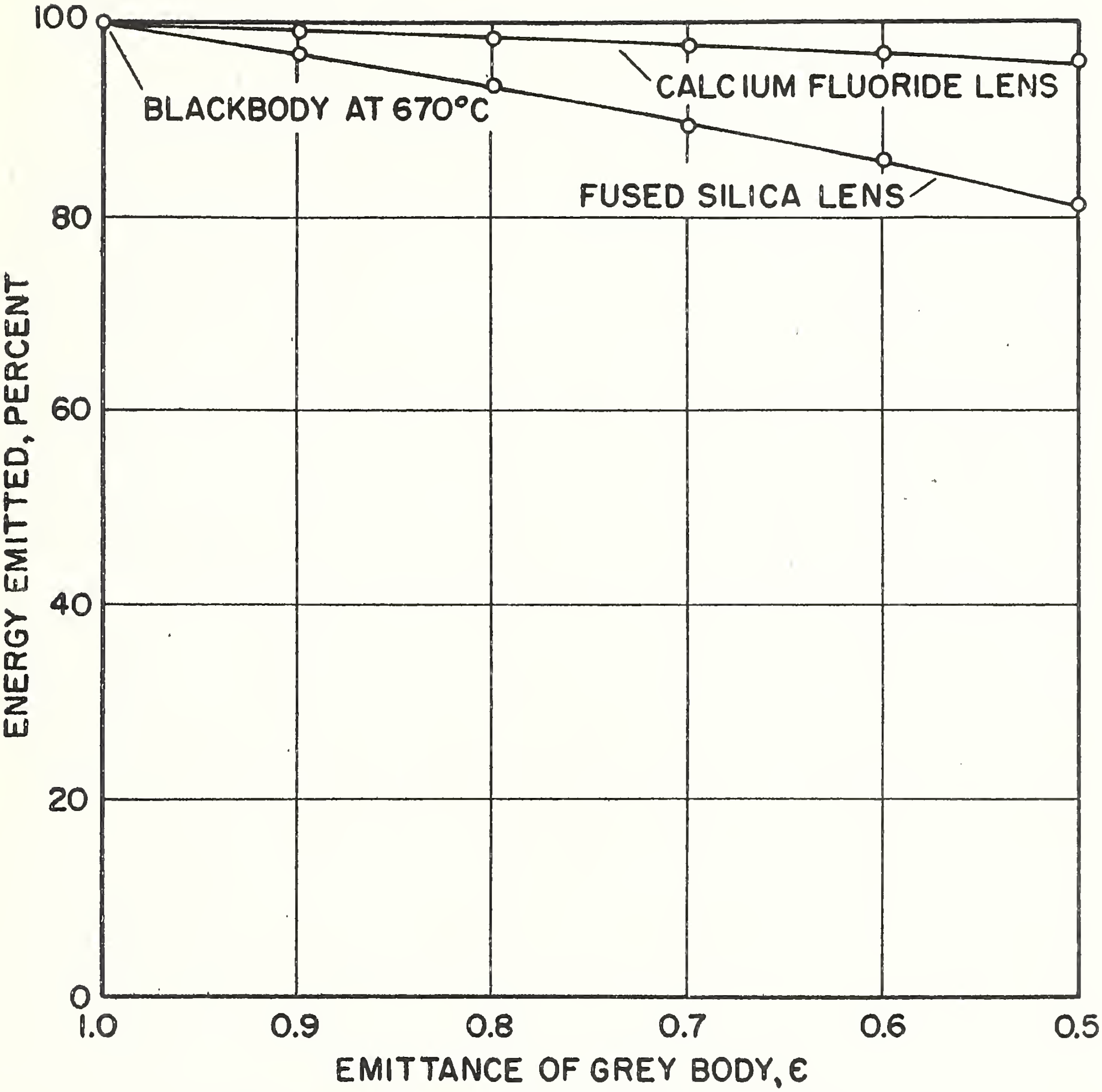

FIG. 2—ENERGY EMITTED BY A GREY BODY
BASED ON CALIBRATIONS BY TWO LENS-TYPE RADIATION PYROMETERS MAINTAINING SAME OUTPUT INDICATIONS AS FROM BLACKBODY AT 670°C

U. S. DEPARTMENT OF COMMERCE
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NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

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