56

NBSIR 73-125

Interlaboratory Evaluation of the Tunnel Test (ASTM E 84) Applied to Floor Coverings

T. G. Lee and Clayton Huggett

Institute for Applied Technology
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U. S. DEPARTMENT OF COMMERCE, Frederick B. Dent, Secretary
NATIONAL BUREAU OF STANDARDS, Richard W. Roberts, Director

Table of Contents

List of Illustrations

List of Tables

Interlaboratory Evaluation of the Tunnel Test (ASTM E 84) Applied to Floor Coverings

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Results of an interlaboratory evaluation of the ASTM E 84 tunnel test method involving eleven laboratories and nine materials, including four carpets, are reported. Data on flame spread, smoke, and fuel contribution are analyzed statistically. Selected physical characteristics of each tunnel are tabulated and compared relative to specifications in the test method. The between-laboratory coefficient of variation (reproducibility) in flame spread classification (FSC) was found to range from 7 to 29% for the four carpets and from 18 to 43% for the other materials tested. The between-laboratory coefficients of variation for smoke developed and fuel contribution ranged from 34 to 85% and from 22 to 117% respectively for all materials tested. The causes of higher variability in smoke and fuel contribution measurement between laboratories is not definitely known but may reasonably be attributed to variations in tunnel construction, maintenance, and operation, in the location of photometers, and in the mounting of thermocouples in different laboratories. Some variability of results may possibly be due to variation in test specimens. Variation in construction and measurement techniques among tunnels may be minimized by updating the test method standard.

Key words: ASTM E84; building materials; carpets; fire tests; flame spread tests; interlaboratory evaluation; round-robin; statistical analysis; test method standard.

1. Introduction

Practically all building code requirements in the United States for control of the flamability of interior surface finish materials are based on the ASTM E 84-70 [1]* twenty-five foot tunnel test method, also used in UL 723, NFPA No. 255-1972 and ANSI A2.5-1970. The reproducibility and appropriateness of the method have not been seriously questioned in the past because the tests were conducted by only two or three laboratories and limited to traditional construction materials. With the recent increase in the number of laboratories with facilities for this type of testing, the widespread use of new types of materials (i.e. thermoplastic and other synthetics), and recent application to carpets, certain inconsistencies in test results have been reported. This has raised serious questions by some safety experts and by certain segments of industry as to the use of the E 84 test for floor covering and other interior finish materials.

Some of the questions which have been raised in regard to the tunnel flame spread test merit technical consideration and are being studied at the National Bureau of Standards (NBS) in cooperation with the Department of Health, Education and Welfare (HEW). The following aspects of the test are of primary concern:

1. the variability of results among different laboratories,

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*Figures in brackets indicate the literature reference at the end of the paper.

2. the merit of the test method for evaluating flooring materials since the test requires mounting a flooring specimen in a ceiling position in the test furnace, and

3. the use of four different formulas to derive the flame spread classification.

The question of variability of the test results is the principal subject of this report, which deals with the reproducibility (among laboratories) and repeatability (within laboratories) of the test method based on round-robin tests of selected materials. The report also gives survey results on physical features of each tunnel and some of the deviations from the published standard method.

2. The ASTM E 84-70 Test Method

The purpose of the test is to determine the comparative surface burning characteristics of material under test by evaluating (1) flame spread; (2) fuel contributed; and (3) smoke developed. The test establishes a basis on which surface burning characteristics of different materials may be compared.

A specimen 20 inches wide x 25 feet long, usually in three sections, is mounted and supported on the top ledge of a long test chamber. The chamber consists of a masonry (fire brick) insulated horizontal tunnel having an inside width of 17.5 inches, a height of 12 inches, and a length of 25 feet. The tunnel is open at both ends, the "fire" and "vent" ends. The specimen in a ceiling position, with the side to be tested facing down, is subjected to diffusion flames from two gas burners pointing upward at the fire end. Forced draft induced by a blower and damper system at the "vent" end of the tunnel pulls air through a small air inlet upstream from the burners into the fire end. A prescribed average velocity measured at the vent end prior to ignition is required. After ignition, a constant negative pressure (draft) is maintained and controlled by the damper system. The flame and draft serve to ignite the specimen and to induce flame spread along the ceiling of the tunnel. Windows located on the side of the tunnel allow an observer to record the extent of flame spread as a function of time. The flame spread classification (FCS) is based on a scale which has 0 for asbestos-cement board and 100 for select grade of red oak flooring. It takes into consideration the distance or time of flame spread by using one of four formulas.

The smoke developed is measured by a photometer system located some distance downstream from the "vent" end. The 10 minute integration of the time versus percent light obscuration curve from the photometer reading forms the basis for reporting smoke developed, again relative to the scale of asbestos-cement board as 0 and red oak as 100.

The fuel contribution is determined by the increase in the flue gas temperature at the "vent" end. It is based on the 10 minute integration of time versus temperature curve of the flue thermocouple output during the test relative to the scale of asbestos-cement board as 0 and red oak as 100.

The test conditions in the tunnel, air supply, and specimen conditioning are controlled and/or recorded by various instruments. However, certain details relating to materials of construction, instrumentation and control are not included in the standard. No mention is made of the expected precision of the method or of the number of tests required, for example. As a result, there is considerable variation in tunnel design and procedures among laboratories using the E 84 method. These problems have been referred to Committee E 5.04 of ASTM for resolution in the past. At present there are six task groups studying various aspects of the problem (see appendix C).

3. Interlaboratory Evaluation of Test Method

To obtain a realistic estimate of the variability of the test method as it is performed by the individual laboratories, a collaborative study sponsored jointly by HEW and NBS was initiated. Eleven (11) laboratories known to have a tunnel facility in this country and Canada agreed to participate. Available data on previous round-robins, though limited to only a few laboratories [2], and the effects of the test method variables [3 , 4] were reviewed prior to this study.

A meeting, attended by representatives from nine of the participating laboratories, was held in October 1971 to discuss the detailed procedures. At this meeting a suggestion was made to specify additional calibration and measurement techniques not mentioned in the test method. This was countered by others who held that the purpose of the round-robin was to evaluate existing test practices in the various laboratories and not to develop a new version of the test.

The procedure finally adopted was for all laboratories to follow the E-84-70 test procedure to the extent practicable. Where deviations were necessary or where detailed procedures were lacking, each laboratory was to follow its own normal test procedures and provide notes on the deviations and individual interpretations. The furnace leakage test of paragraph 4.2 of the method was required and smoke bombs were made available to each laboratory for pinpointing the leakage area if any.

Since the mounting of carpet specimens was a probable source of laboratory variability and is not specified by the method, all mounting on a backing board was performed by NBS before the materials were distributed. A prescribed randomized test sequence and detailed instructions were supplied to the participating laboratories. A uniform data sheet was also provided. A 2-minute sample presoak (specimen loading time) before starting the test was required to help standardize the test procedure. A representative from NBS also visited each laboratory to make air velocity measurements using a single calibrated anemometer, to survey physical characteristics of the facilities, and to witness selected tests.

The procedures agreed upon were designed to give results based essentially on the current practices of each laboratory and also to provide a basis for comparing the effects of deviations for possible future modification of the method. A supplemental questionnaire, prepared by Underwriters' Laboratories, Inc. (UL) was sent to each laboratory to help pinpoint the differences in construction and methodology among the facilities.

3.1 Participants

A total of 11 laboratories collaborated in this joint study. The list of participants and laboratory abbreviations are given in Table 1. The degree of experience in using the test method among laboratories varies from less than a year to over 20 years. Some laboratories (UL, UL/SAN, UL/CAN, NRC, SwRI, AMB, FM) test primarily for the public

Table 1. Participants of Interlaboratory Evaluation of the ASTM E-84 Test Method

Participant	Abbreviation
Mr. Tom Castino Underwriters' Laboratories, Inc. Northbrook, Illinois 60062	UL
Mr. Alex Briber Underwriters' Laboratories, Inc. Santa Clara, California 95050	UL/SAN
Mr. Norman Pearce Underwriters' Laboratories of Canada Scarborough, Ontario, Canada	UL/CAN
Mr. Calvin H. Yuill Southwest Research Institute San Antonio, Texas 78228	SwRI
Mr. A. Rose National Research Council Ottawa 7, Ontario, Canada	NRC
Mr. D. R. Crawford Weyerhauser Company Longview, Washington, 98632	WEY
Mr. W. A. Ranzenberger Technical Center Owens Corning Fiberglas Granville, Ohio 43023	OCF
Mr. Robert Friedheim National Gypsum Research Laboratories Buffalo, New York 14217	NG
Mr. P. G. Gott Factory Mutual Research Corporation Norwood, Massachusetts 02062	FM
Mr. Lewis G. Bricker Ambric Testing and Engineering Association Philadelphia, Pennsylvania	AMB
Mr. Robert Robins Hardwood Plywood Manufacturing Association Arlington, Virginia	HPMA

TABLE 2. TEST MATERIALS, BACKING, AND ADHESIVE[a/]

Specimen Number	Material	Nominal Thickness in	Density lb/ft²	Density oz/yd²	Description
0	Red Oak Flooring	25/32	2.8		NOFMA certified, Ozark brand, clear plain top grade Bismarck mill, 2 1/4" wide tongue and groove.
1	Glass Fiber Batts	1	0.11		Exposed surface, Neoprene coated.
2	Sheet vinyl	3/32	0.64		filled vinyl surfaces, inorganic felt backed.
3	Lauan Plywood Unfinished	3/16	0.45		Sanded, 4.4 mm, 3 ply panel.
4	Carpet A	5/16		81	Woven, level loop, Jute backing, pile 38 oz/yd², Acrylic, brown.
5	Carpet B	1/2		64	Tufted shag, 1 1/8" length tuft, pile 24 oz/yd², jute backing, Nylon
6	Carpet A + Underlayment	5/16 1/2		81 56	Same as #4 Rubberized hair felt pad.
7	Carpet C	3/8		86	Tufted, level loop, pile 20 oz/yd², Nylon, 1/8" foam rubber attached pad.
8	Paperboard (corrugated)	0.14	0.17		125 # Test, B flute, Brown (corrugated) paper.
	Asbestos-Cement Board	1/4	2.5		Flexboard, Type F.
	Adhesive for carpets	0.13 lb/ft² applied			A.P. Green Insulation (silicate) adhesive for mounting carpet to ACB board.

a/ All specimen sections were 20.5 x 96 inches, except #1.

whereas others limit their activities to research and development work for their own company (WEY, OCF, HPMA, and NG)*. The laboratories are identified in the report by code letters only, the usual practice in round-robin studies.

3.2 Test Materials

In order to obtain meaningful results and yet not to burden the participating laboratories with an excessive amount of testing, the selection of materials was made by consultation with the participants. Table 2 gives the relevant data on the materials and the adhesive selected for the program. The materials selected represent common construction and flooring materials, which included simple and composite plastic, cellulosic and inorganic-base materials, varying in thickness from 0.09 to 1 inch. The four carpet systems selected included two types of synthetic fiber, woven and tufted level loop as well as tufted shag construction, separate underlayment as well as integral foam backing, and an identical carpet both with and without underlayment. The materials exhibited various forms of physical response to fire exposure such as slow melting, fast shrinking, char formation, and delamination.

The expected flame spread classifications (FSC) for the materials span a wide range, from about 25 to 1000. The test included materials with relatively similar flammability in order to determine the sensitivity of the method. All materials were obtained from commercial sources without special controls on uniformity except the plywood. All specimens were cut, randomized, and mounted when necessary, before

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* HPMA and NG would also accept testings from the public.

distribution. The carpets were cut parallel to the roll direction while wood specimens were supplied with grain parallel to their length.

All materials were cut into three 8 foot sections except the glass fiber batts which come in 25 foot rolls. Carpets were cemented to a standard 1/4 inch thick asbestos cement board (ACB) using an adhesive (silicate) applied to the rough side of the board. For the carpet tested with underlayment the latter was first cemented to the ACB board and the carpet then stapled on top of the underlayment using 1 1/8" length staples spaced 10 inches apart in both directions (staple penetrates the underlayment only). Wire mesh screen (1-inch hexagonal chicken netting) laced with tie-wire in the back of ACB board covered the front of the specimen. The procedure of using either staples or wire mesh screen to prevent fallout is typical of practicing laboratories. The combination of staples and screening for these tests was intended to minimize separation between the carpet and underlayment, and thus to reduce a source of variability in test results.

Normally, sheet vinyl floor covering is adhered to the ACB board with an adhesive that would keep the flooring from delaminating from the substrate during the test, but for this work the material was treated as a thin laminate and procedure A1.8 in the test standard was followed. The procedure used consisted of placing 1/4" diameter steel rods, spanning the width of the tunnel at 2-ft intervals to support the specimen. A similar method was used on the glass fiber batt except that the rods were inserted through the center of the material.

The densities of the plywood panel specimens are given in weight per 4 x 8 ft sheet. The density distribution is considered better than normal for commercial material of this type since about 20% of the panels from the high and low density ends of the lot were removed before distribution. The mean and calculated standard deviation for the material used are 14.5 ± 1.3 lb/panel for all the panels and 15.0 ± 1.4 lb/panel for those used at the first section of the furnace. With some exceptions, the panel with the highest density among a set of three randomized specimens was placed at the fire end of the furnace.

Red oak flooring was purchased in a single lot from a mill in Bismarck, Missouri, randomized and distributed as reference material.

Though specimen selection and mounting were performed by NBS, specimen conditioning in accordance with the E-84 specification of 70 ± 5°F and 35 - 40% RH was performed by each laboratory. The moisture contents of the red oak specimens after conditioning were also reported.

3.3 Experimental Design

Each laboratory began the test program with 3 specimens of red oak, a reference material supplied by NBS. If the calibration test results were within the expected range in flame spread based on past experience (100 ± 5), the laboratory was to proceed to test other materials following the test sequence table assigned by NBS. The table was based on randomization of 21 tests (3 replicates and 7 materials) for each of the 11 laboratories. Individual laboratories were allowed to choose, prior to the testing program, an option of 2 or 3 replicate runs per material. Most performed 3 replicate runs, giving a total of 210 out of a possible 231 tests, excluding red oak.

TABLE 3. SELECTED CHARACTERISTICS OF E 84 TUNNELS.

CHARACTERISTIC	LABORATORY A	B	C	D	E	F	G	I	J	K	L	E-84
FLAME SPREAD												
Air inlet Slit Height, in.	3 1/8	3	3 1/4	3	3 1/4	2 7/8	3	3 1/8	3 1/8	2 7/8	3	3
Slit to Burner, distance, in	54	56	57	49	54	52	13	66	54	55	54	—
Window Type 1/	D	D	D	S fl.	D	S re.	S. re.	S fl.	D	D	S re.	S re.
Bricks for turbulence	6	6	5	6	6	0	0	0	6	6	0	[illegible]
Window Size, outside, in.	10 X 4	12 X 4	11 X 4	7.5 X 2.5	10 X 1.5	11.5 X 3.5	11.5 X 2.5	12 X 3	11 X 3.5	11 X 4	12 X 2.5	11.7 X 2.7
Draft												
Manometer Location, ft. 2/	23	8	22	9.9	10	3.0	4.5	13	21	34	13	—
" Position 3/	C	P	P	P		P	C	C	P	P	C	—
Regulation, Auto/Man.	M	M	M	M	A	M	M	M	A	M	M	A/M
Typical Value, in. H_2O	.078 ± .002	.07 ± .01	.075 ± .002	.070	.075 ± .003	0.055 ±.005	0.075	0.070	0.075 ± .002	0.075 ± .01	0.075	.075
FURNACE AIR VELOCITY 4/												
Lab. Anemometer, type 5/	HW	HW	DV	HW	HW	DV	3"RV	DV	3"RV	DV	DV	HW
Velocity Lab. Anem. ft/min.	240	270	234	218	235	240	264	240	230	240	250	240
Velocity Ref. Anem. ft/min	220	300	245	195	250	230	240	220	230	232	240	—
Air Temp. °F		83	75	75	90	65	73	70	86	70	74	70
SMOKE												
Photometer Location, ft. 2/	31	40	30	14.5	36	3.5	6	12.5	29	38	32	—
Elevation, ft. 6/	-3	0	4	0	8.8	-0.2	0.3	0.2	-2.5	0	7	—
Path Length, in.	34	36	36	38	16	24	24	34	16	36	49	—
Type/ 7/	B	W	A	A	B	IP39	IR B-3M	W	B	W	[illegible]	—
Open/Seal	0	S	0	S	0	0	0	0	0	0	[illegible]	—
FUEL CONTRIBUTION												
Gas, type 8/ 9/	City	City	B M	City	B M	City	Propane	City	City/BM	BM	City	—
Heating Rate BTU/min 10/	4770	5010	5300	4410	4860	5000	4870	4860	5250	4830	4950	5000
Thermocouple, Post OD, in.	1/2	1/4	1/2	1/2	1/4	1 1/16	1/4	1/2	5/16	3/4		—
Unshield length, in.	1 3/4	1/4	1/2	1 1/2	1 1/2	3/16	1	1	3/8	1 1/2	1	—
Junction, S/T 11/	S	S	T	S	S I/C	S Pt/R	S I/C	S I/C	S	T	S	—
[illegible] 12/												
Afterburner	N	N	Y	N	N	N	Y	Y	Y	Y	N	—
Conditioning, RH,%	35-40	37-43	40-54	Specimen 40	Specimen 40	40-45	N	35-40	35-40	40-50	Specimen 40	35-40
Preheat: Gas (G) or Wood(W)	G	G	G	G	W	G	G	G	G	W	G	G
Duct Insulation	Y	Y	Y	Y	Partial	Y	N	Y	Y	Y	N	—
Leakage Test: E-84/Bomb	Y/Y	Y/Y	Y/Y	Y/Y	Y/Y	Y/N	N/N	Y/Y	Y/Y	Y/Y	Y/N	Y/N

Notes

1. Double, single flush (fl.) or single recessed (re.) relative to inside wall.
2. Linear distance between "vent" end and location in duct.
3. At center (C) or periphery of duct.
4. Measured at center of tunnel, 24 ft. from fire end using the reference 4" rotating-vane anemometer and aneometer from each lab. at stated Temp.
5. HW = Hot wire anemometer, DV = deflecting-vane volometer, R. V. = rotating-vane.
6. Between mid-height of furnace and duct.
7. A = Weston - 594BB B = Weston-856/BB W=Weston.
8. BM = bottle methane.
9. Average used on all runs of specimen #3.
10. Diameter of tubing protruding into furnace
11. S = straight, T = Twisted. All thermocouples are Cr/Al except as noted.
12. Y = Yes N = No

A total of 8 materials including 4 carpet systems were used in the test program. Two carpet systems and 4 other materials were tested by all 11 laboratories, one carpet system by 5 laboratories and the other carpet by the remaining 6 laboratories. A comprehensive data sheet, based on suggestions from participants, was required for each test. A sample is shown in Appendix A.

4. Survey Results

4.1 Physical Characteristics of Furnaces

Selected tunnel characteristics of each laboratory are listed in Table 3. These were obtained by direct measurement during the authors' visits to the laboratories and by data furnished by the tunnel operator.

It is not the purpose of this study to show correlation, if any, between any of the characteristics and test reproducibility. But these data should form a useful basis for comparing each tunnel with the present E 84 requirements and for possible use in future revision of the test method standard.

4.1.1 Furnace Windows

According to Table 3, only 3 laboratories conformed to the specified description of windows, namely of the single, recessed type. (See Appendix B for a sketch of the furnace required by the Standard). Others used double or single flush (inside) windows. The purpose of adopting double windows was to reduce air leakage and possibly smoke deposits on windows to improve observation. To compensate for the loss of flow turbulence in the tunnel where the recessed part of the window is covered in the double type window, a common practice is to introduce 5 or 6 bricks (position not standardized) at intervals on the wall and floor edges along the tunnel. Experiments have shown that these bricks are necessary to meet the burning time requirement for the red oak standard reference material. Figure 5 shows the double-type window with brick (top) and the recessed-type window (bottom).

4.1.2 Location of Manometer and Photometer

The locations of the draft manometer to control flow and the photometer to measure smoke are not specified in the method. The drawing (Figure 1 in the Standard), shows that the photometer is further downstream from the "vent" end than the draft manometer. These distances from the "vent" end in the 11 tunnels listed in Table 3 varied from about 3 to about 34 feet for the manometers and from 3.5 to 40 feet for the photometers.

All photometers were oriented the same way, on a vertical axis, with the detector located at the bottom as indicated by the drawing in the standard.

4.1.3 Draft Control

The regulation of draft pressure in the tunnel may either be manual or automatic according to the method. A few laboratories used the automatic method. The response time of the regulator is not specified in the method. Automatic regulation is generally more consistent if not faster than manual regulation.

Data indicate that, depending on the type of material tested, variation in draft pressure within a single run is typically $\pm$ .01 inch for a negative pressure of 0.075 inch of water.

4.1.4 Furnace Air Velocity and Temperature

The method requires a linear air velocity of 240 $\pm$ 5 ft/min average, measured at seven positions near the "vent" end. Most laboratories used a thermal anemometer or a deflecting vane type velometer for such measurements. Because of the continuous fluctuation of the pointer in these instruments caused by turbulent flow, the uncertainty in each reading is believed to be at least $\pm$ 15 ft/min.

To measure air velocity variations among laboratories in this survey, a single 4 inch rotating vane-actuated anemometer (Bendix-Friez) was used. It was placed at the center, midheight and about one foot before the "vent" end of the tunnel. To observe dial readings through a tunnel window from the outside, a light source aimed at a small mirror mounted below the dial was also used.

The rotating vane type anemometer measures the total flow passing through its rotor while displaying the cumulative results on its dial, similar to gas meter. The calculated velocity is in itself an average over the time period of measurement and the cross sectional area within the 4 inch diameter. This type of anemometer, if calibrated, is believed to be more suitable in terms of precision and accuracy for the purpose.

The velocity data in Table 3 are only a comparison, at the time of measurement, of air flow values determined by the reference anemometer and anemometer of each laboratory. For the fire tests, the required 240 $\pm$ 5 ft/min average velocity based on the regular measurement method of each laboratory was used.

Furnace air temperature during velocity measurements by the reference and laboratory anemometers is also given in Table 3. The test method is not explicit on the temperature at which velocity calibration is to be made. Experimental data by Robins [6] showed that velocity decreased about 12 ft/min (from 252 to 240) when air temperature increased 20°F (from 72°F to 92°F) under a constant static pressure of -0.075" water. The effect of temperature on velocity measurements at this range, though small, can be a source of error if not specified in the method. However, as pointed out by Armstrong [7] the practical effect would be insignificant in view of the extreme variation in temperature and hence velocity that exists after ignition and during the tests from one run to the next.

4.1.5 Thermocouple Type and Mounting

Aside from the diameter of the thermocouple wire the method does not specify type of junction, exposure length, mounting technique and size of the thermocouple post for flue gas measurement. A comparison of those parameters is also included in Table 3.

4.1.6 Relative Humidity of Intake Air

Temperature and relative humidity for the intake air to the tunnel furnace as well as for specimen conditioning are very specific in the standard. Many laboratories used a very elaborate system to maintain these conditions. However, some laboratories do not strictly adhere to the 35 - 40% relative humidity requirement at all times because of heavy testing schedules and/or adverse weather conditions. Data in Table 3 gives RH values based on typical reported values in the data sheets. Some laboratories only condition the specimens.

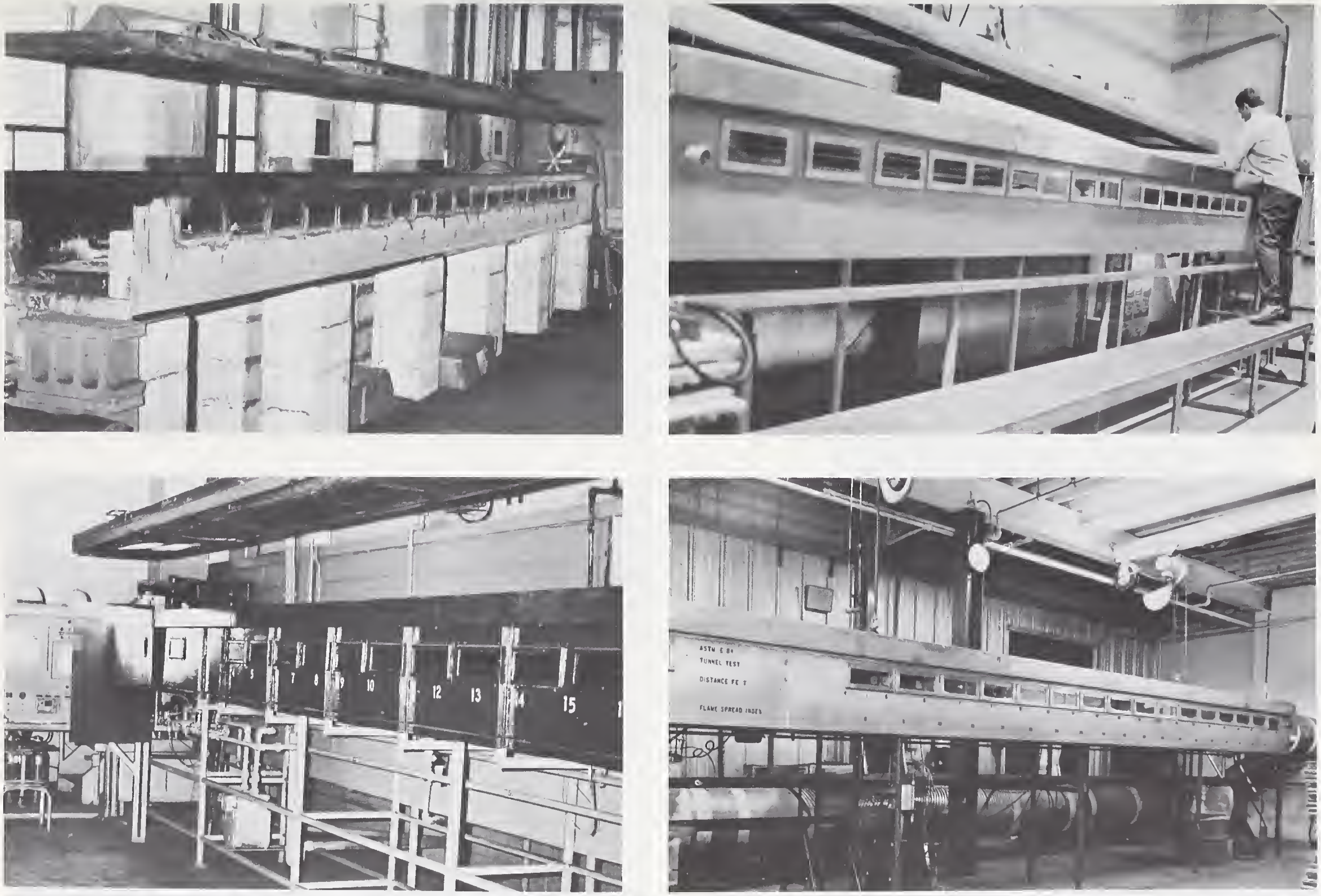

Figure 1. Representative E 84 tunnels.

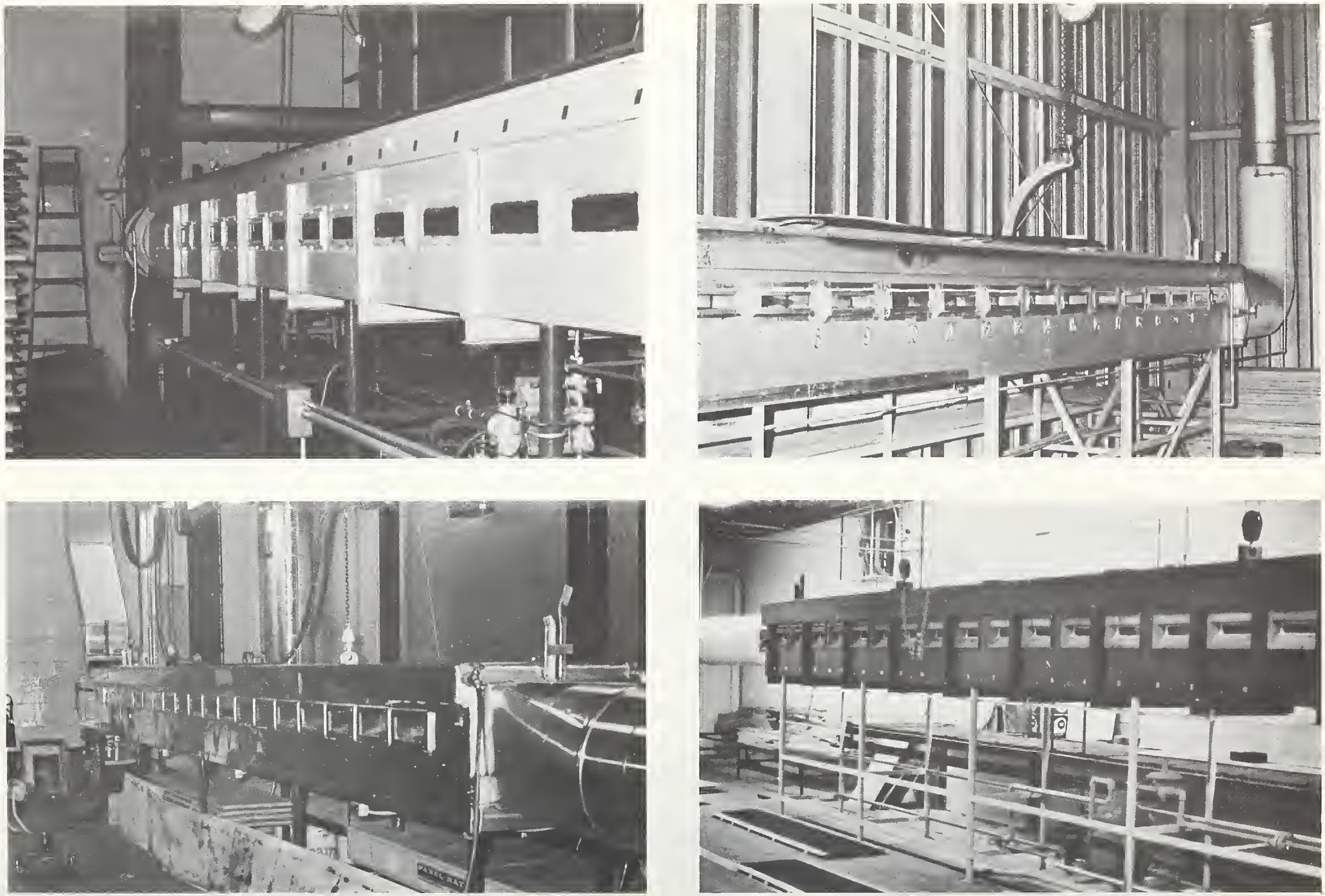

Figure 2. Representative E 84 tunnels.

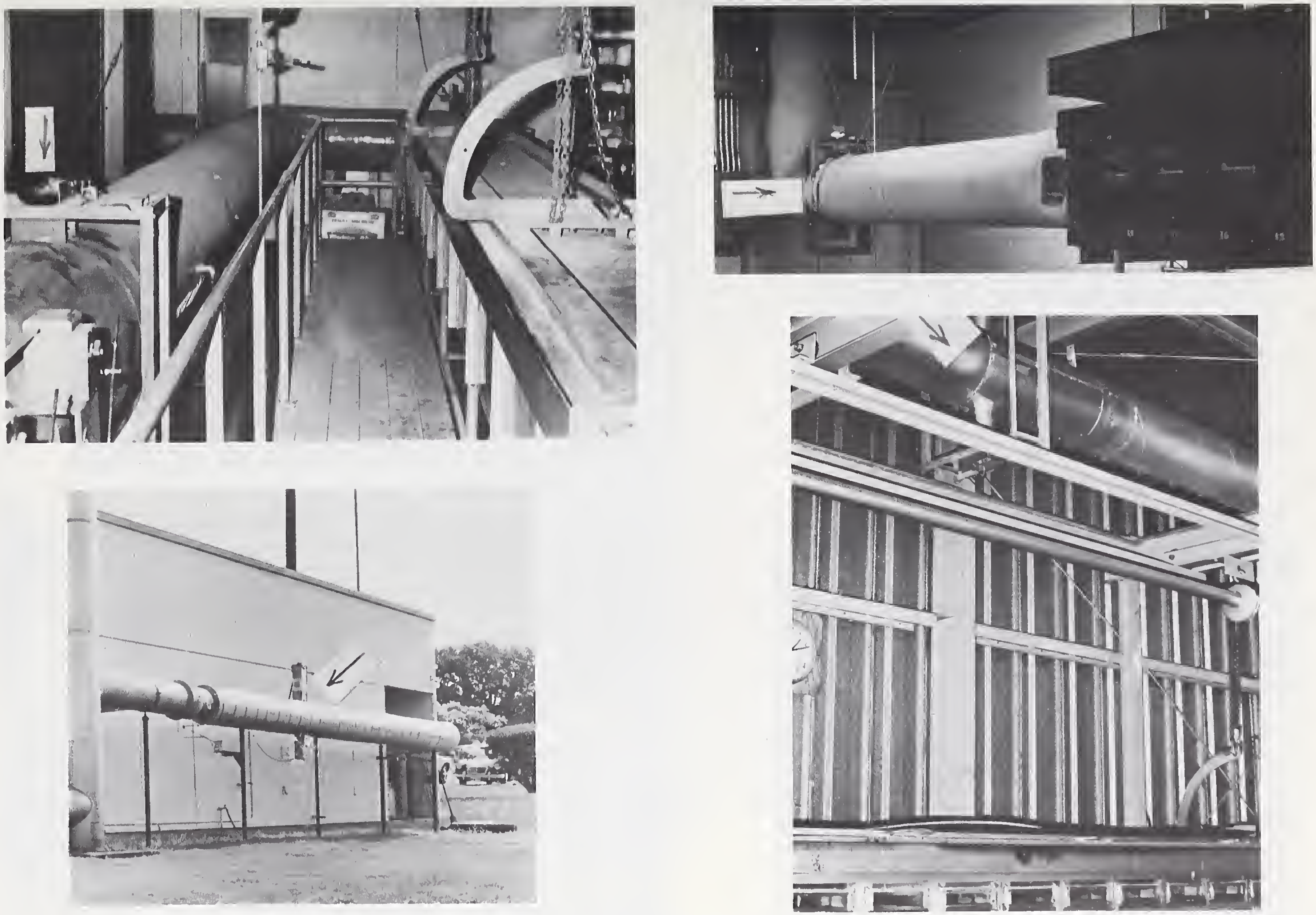

Figure 3. Examles of smoke meter locations.

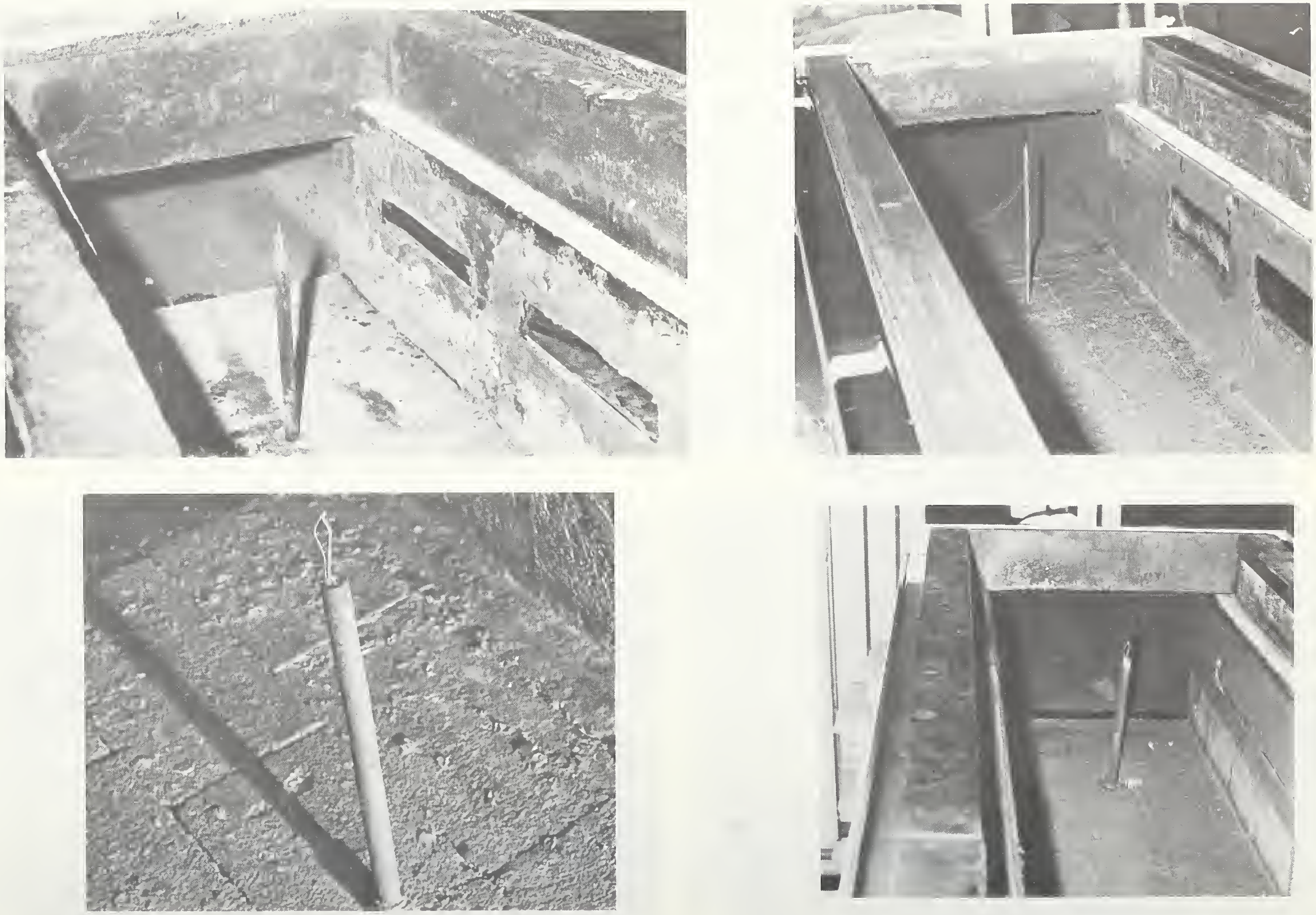

Figure 4. Examples of thermocouple mountings

Figure 5. Examples of windows and bricks

Figure 6. Examples of burners

4.2 Illustration of Furnace Characteristics

Figures 1 and 2 are photographs showing overall views of the tunnels in eight (8) of the laboratories that participated in this study. Note the contrast between tunnels shown in the photographs. The variations of photometer locations (distance from "vent" end) and the elevation of the exhaust duct relative to the tunnel are illustrated in Figure 3. Figures 4 and 6 illustrate the variation in thermocouple and burners construction respectively among tunnels. The difference between single-recessed windows and double type windows as well as the location of bricks for turbulence are shown in Figure 5.

5. Results of Tests

Data for flame spread classification, smoke developed, and fuel contribution from each laboratory are tabulated in Tables 4, 5, and 6 respectively. These were based on results calculated by the operator at each laboratory relative to his own red oak reference of 100. Figure 7 shows a plot based on the mean of all laboratories versus the means of each laboratory for flame spread of all materials.

Table 7 shows the moisture content, burning time, FSC, smoke, and fuel contribution of red oak reference material supplied by NBS. Except for one laboratory the FSC results are in general agreement with those obtained by each laboratory in their own calibration. The excepted laboratory (D) based its own calibration on red oak grown in a different region of the country relative to that used by others. The method of moisture measurement and moisture content limit for Red Oak reference are not specified in the standard.

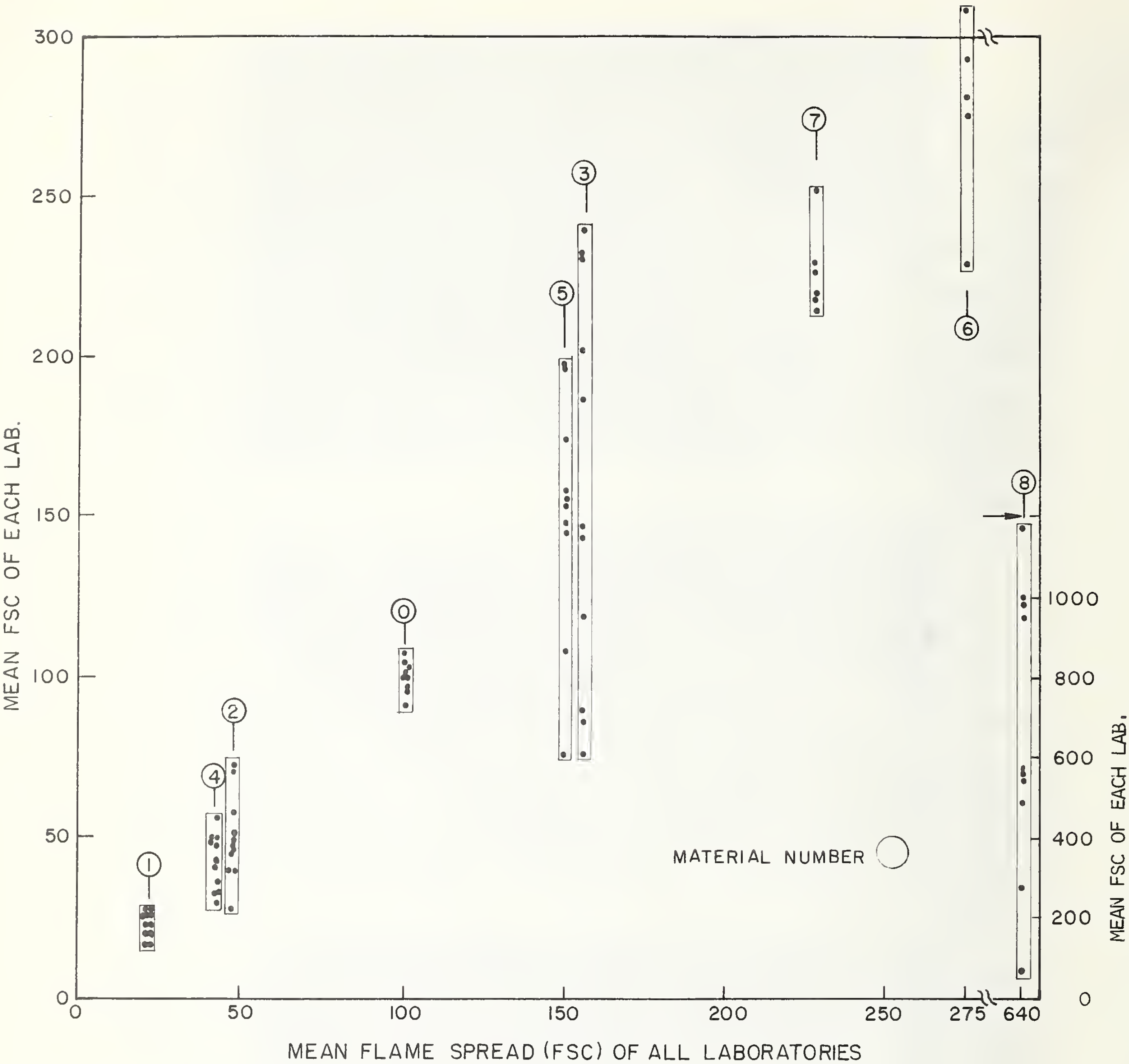

FIGURE 7. MEAN FSC OF EACH LAB. VERSUS MEAN FSC OF ALL LABORATORIES.

Table 4. TEST DATA ON FLAME SPREAD (FSC).[a/]

Labs	MATERIALS 1	2	3	4	5	6	7	8	0
A	23	44	262	36	176		254	1100	99
	26	49	231	28	135		264	1320	93
	23	44	220	33	145		236	1100	95
B	15	38	69	49	157	275		74	100
	15	38	170	46	157	275		76	98
	18	41	116						98
C	26	72	189	33	152		208	580	95
	26	69	185	77	147		208	500	98
	28	69	185	33	163		226		98
D	23	51	122	36	145		208	1100	86
	23	46	71	36	143		222	920	89
	23	43	75	36	(367)		220	920	94
E	30	80	100	30	155		220	510	97
	25	70	75	35	140		215	610	98
	25	65	80						98
F	18	38	165	33	169		232	72	108
	21	38	74	54	179		236	825	104
	21	41	200	33	173		220	550	98
G	18	46	220	51	110	244		440	105
	18	46	183	46	100	200		550	98
	13	51	200	48	110	244		733	100
I	(13)	25	271	61	207	331		1000	104
	21	31	211	41	183	301		1000	100
	25	25	214	46	200	301		1000	98
J	26	39	77	41	197	289		688	106
	26	37	154	41	192	308		56	102
	27	40	196	44	199	284		69	97
K	23	54	77	23	73		228		100
	23	59	73	33	73		228		100
	23	57	75						
L	21	51	200	71	(367)	275		1000	90
	21	51	190	41	(412)	285			96
	21	51							

[a/] Units based on red oak = 100.

TABLE 5. TEST DATA ON SMOKE DEVELOPED [a]

	MATERIALS							
Labs	1	2	3	4	5	6	7	8
A	15	225	95	75	135		145	25
	20	240	70	75	135		175	15
	15	195	85	130	135		225	80
B	44	241	23	102	125	510		18
	19	231	64	201	114	447		18
	28	260	87					
C	15	205	71	18	103		177	10
	17	235	70	(148)	147		180	8
	14	254	65	44	113		204	
D	36	252	53	55	86		140	17
	18	208	64	65	80		206	26
	18	205	76	77	(88)		156	23
E	50	435	85	50	285		576	50
	35	315	85	70	360		565	55
	25	300	80					
F	98	540	70	162	280			5
	56	585	100	195	370		550	25
	55	590	67	69	290		1000	31
	58	154	46	117	88	188		46
G	58	162	78	170	65	218		60
	60	165	72	150	72	170		67
I		242	63	279	132	447		32
	11	247	179	253	168	395		11
	16		132	237	132	374		11
J	24	224	91	169	111	365		18
	36	229	71	211	97	374		7
	23	215	66	224	100	382		16
K	12	189	48	75	72		155	
	17	225	60	74	69		155	
	14	210	92					
L	12	305	140	210	150	560		110
	14	285	135	25	130	525		
	23	275						

[a] Units based on red oak = 100.

TABLE 6. TEST DATA ON FUEL CONTRIBUTION[a]

Labs	MATERIALS 1	2	3	4	5	6	7	8
A	15	0	85	20	35		60	15
	10	0	85	20	40		70	35
	10			30	40		70	25
B	12	0	24	10	34	98		6
	20	0	41	32	31	84		13
	13	0	56					
C	11	11	82	28	48		61	29
	10	6	51	14	57		63	29
	9	9	72	19	64		66	
D	0	0	60	19	45		50	29
	18	0	40	20	70		72	13
	18	0	55	20	(26)		52	28
E	0	5	55	15	55		80	15
	0	10	40	15	55		80	40
	1	10	40					
F	1		46	3	43			4
	3		34	3	46		54	11
			48	5	38		58	16
G	12	2	30	45	45	96		63
	3	14	55	25	81	97		46
	12	9	80	45	73	92		56
I	33	11	133	48	81	187		56
	37		171	62	97	148		3
	38		154	57	94	156		19
J	0	0	44	8	25	76		15
	0	0	34	9	20	80		2
	0	0	53	10	31	71		6
K		5	50	6	16		27	
		2	40	14	6		71	
			52					
L	11	21	121	16	62	107		41
	13	19	125	10	77	98		
	12	22						

[a] Units based on red oak =100.

Table 7. Results of Specimen Moisture, Flame Spread, Fuel Contribution, and Smoke on Red Oak Supplied by NBS

Lab.	Moisture[a]		Flame Spread[b]		Smoke[c]	Fuel[c]
	Method/	percent	Time, min.	FSC		
A	-	-	5.6	99	85	98
			6.4	93	100	90
			6.1	95	70	90
B	W	4.3	5.5	100	112	101
		4.3	5.7	98	95	103
		4.5	5.7	98	90	89
C	P	6.5	6.1	95	74	99
		6.5	5.7	98	64	92
		6.6	5.7	98	38	91
D	W	5.9	7.7	86	120	86
		5.8	7.1	89	109	87
		6.0	6.3	94	95	101
E	P	6.5	5.9	97	89	99
		6.5	5.7	98	110	98
			5.8	98	102	102
F	P	5.8	5.1	108	54	100
		6.3	5.3	104	92	94
		6.4	5.7	98	92	91
G	P	6.5	5.2	105	99	100
		6.7	5.8	98	102	99
		6.7	5.5	100	102	100
I	W	6	5.5	100		
		7	5.3	104	135	140
		6	5.7	98		
J	W	6.7	5.2	106	94	100
		7.5	5.4	102	99	100
		6.4	5.9	97	107	90
K	P	6.7	5.5	100	113	97
		6.6	5.5	100	108	98
L	P	7.3	6.8	90	56	80
		6.8	6.0	96	85	95

a/ P = Conductivity moisture probe. W = Weigh loss after heating.
b/ Based on E 84, time to end of tunnel.
c/ Based on calibration standard of each laboratory using red oak = 100.

5.1 Statistical Results

One of the purposes of the interlaboratory evaluation of the test method was to determine the degree of uncertainty of the resultant data. Table 8 summarizes the results on flame spread, smoke, and fuel contribution in terms of the means, ranges, and the within-laboratory (repeatability) and between laboratory (reproducibility) coefficients of variations for each material. The repeatability and reproducibility data are given in terms of the expected precision of a single determination within a single laboratory and a single determination among the laboratories respectively. The values were derived from a "between-within" analysis of variance made separately for each material [5,8]. A weighting factor was used to normalize results between two and three replicate runs. The analysis is based on all the data from the 11 laboratories except the 4 values in parentheses in Table 4 which resulted from errors in test procedure (the incorrect surface of Material #1 was exposed in one case and asbestoes papers were used on the furnace floor in the other cases). Because of the wide scatter in numerical values on FSC for material #8, data less than 77 were excluded from the calculation for coefficient of variation.

It is meaningless to express an overall reproducibility and repeatability for all materials tested because the results appear to be material dependent. For most materials, reproducibility would improve only slightly if it were based on the averages of 2 or 3 replicate runs. For a method of converting the statistical result to that based on more than single tests, see Appendix E.

Table 8. Statistical results of tests.[a]

	MATERIALS 1	2	3	4	5	6[b]	7[b]	8
FLAME SPREAD (FSC)								
Mean	22	48	155	42	150	278	226	638
Range	(13-30)	(25-80)	(69-271)	(23-77)	(73-207)	(200-331)	(208-264)	(56-1320)
Coef. Var.%								
Within-Lab.	8	7	23	27	7	6	4	14[c]
Between-Lab.	18	29	43	29	26	12	7	31[c]
SMOKE DEVELOPED								
Mean	29	269	81	132	148	398	337	36
Range	(11-98)	(189-590)	(23-179)	(18-279)	(69-370)	(365-560)	(140-1000)	(5-110)
Coef. Var.%								
Within-Lab.	35	11	29	31	17	7	32	41
Between-Labs.	70	42	38	55	59	34	82	85
FUEL CONTRIBUTION								
Mean	11	6	68	21	50	106	62	25
Range	(0-38)	(0-22)	(24-171)	(3-62)	(6-97)	(71-187)	(27-80)	(2-63)
Coef. of Var.%								
Within-Lab.	39	44	20	33	19	11	20	52
Between-Lab.	101	117	57	76	48	33	22	71

a/ Analysis based on data from 11 labs. with 2 to 3 replicate runs per material.

Within-lab coefficient of variation (repeatability) is between single measurements in the same lab.
Between-labs. coefficient of variation (reproducibility) is between single measurements in different labs.
Units for the range and mean are based on red oak = 100.

b/ Analysis based on data from 5 labs. for material #6 and 6 labs. for material #7.

c/ Data less than 77 were excluded in the analysis.

5.2 The Use of Other Formulas for FSC Calculation

Because of anomalies in some test results caused by the application of four sets of formulas in the calculation of FSC, many methods have been proposed to avoid the problem. The method in the present standard calls for the use of four completely different methods of calculation depending on the time and on whether or not the flame spread reaches the far end. As a result some normal measurement errors are exaggerated by the discontinuity in going from one formula to another. See Appendix D.

One of the earlier proposed methods, for example, is based on "rate", $FSC = 28.2\frac{d}{t}$, where d is maximum distance burned (ft.) and t is the corresponding time (min.) to reach the maximum distance regardless of whether or not the flame reaches the end of the tunnel.

A more recent (Dec. 1972) proposed method made by the task group on the E-84 calculation method under ASTM Committee E5.04 is based on the following "area" formulas:

$$FSC = 0.564\,A \qquad \text{for } A \leq 97.5 \text{ ft min.}$$

$$FSC = 5362/(195-A) \qquad \text{for } A > 97.5 \text{ ft min.}$$

where A is the integrated area under the curve based on the flame or burned front distance as a function of time on the last 19 1/2 ft of the specimen during the 10 minute test period. Of several alternate calculation methods, this method has the advantage of minimizing differences in results obtained from the present standard and the proposed method.

If this method is adopted, it is essential to define flame or burned front in the standard more explicitly, since its correct interpretation is much more critical in determining the result than that in the present standard. The flame front or flame spread is not defined in the present

TABLE 9. DATA AND RESULTS BASED ON THE PRESENT AND PROPOSED FORMULAS FOR FSC CALCULATIONS ON SPECIMEN #3.

Lab.	Density, lb/sheet (4' X 8') Location a/ 1st.	2nd.	3rd.	Flame Spread b/ Distance Ft.	Time Min.	Standard FSC	Proposed "area" FSC	Proposed "rate" FSC	Start. Temp. c/ °F	Max. Temp. d/ °F	Fuel Btu/Min
A	16.9	15.5	13.7	25	2.1	262	193	262	102	1220	4750
	16.5	14.2	13.7	25	2.4-	231	170	231	110	1180	
	14.0	14.0	13.8	25	2.5	220	179	220	101	1160	4800
B	12.6	14.0	14.2	19(18)	3.0	69	62	127	114	745	5020
	15.2	15.0	12.6	25	3.25	170	153	170	110	953	5000
	17.2	16.2	12.9	25	4.75	116	118	116	110	1063	5025
C	16.5	14.2	13.7	25	2.9	189	136	189	110	1235	5300
	14.9	14.2	13.2	25	2.9+	185	136	185	110	1005	5270
	16.9	12.8	14.2	25	2.9+	185	135	185	105	1175	5320
D	14.0	14.5	16.9	25	4.8	122	130	122	105	1235	4400
	12.7	16.2	12.6	20.5	3.3	71	75	129	104	815	4390
	14.5	14.6	14.2	23.5	2.85	75	119	178	106	940	4425
E	12.8	16.9	16.9	25(18)	5.6(2.7)	100	136	(130)	107	1042	4860
	15.0	14.1	14.7	20	2.6	75	75	157	110	866	4855
	15.2	13.6	13.5	21	2.6	80+	85	167	109	795	4865
F	14.1	14.7	15.7	25	3.3	165	146	165	105	980	5000
	15.0	14.4	14.0	22.5	3.2	74	100	150	105	790	5000
	17.2	13.3	12.7	25	2.7	200	150	200	100	990	5000
G	15.7	14.8	13.9	25	2.5	220		220	100	950	4870
	15.0	14.0	13.7	25	3.0	183		183	105	1000	4870
	14.8	12.9	12.9	25	2.75	200		200			
I	15.8	14.7	13.5	25	2.0	271	196	271	110	1100	4820
	14.7	14.3	13.5	25	2.6	211	174	211	110	1330	4800
	17.2	13.2	13.1	25	2.5	214	161	214	110	1300	5000
J	13.9	14.7	15.6	24.5	3.5	77	134	152	105	920	5260
	15.3	14.3	13.8	25	3.5	154	156	154	104	940	5250
	17.5	13.2	13.1	25	2.8	196	161	196	102	1060	5260
	13.8	13.7	13.7	22	3.9	73	98	120	101	810	5220
K	13.1	13.5	13.6	24.5	2.8	77	162	190	105	900	4870
	13.1	13.9	15.1	22	3.0	73	100	155	102	870	4750
	15.1	15.3	17.5	23.5	3.5	75	121	145	102	940	4860

a/ Furnace locations of each section, first section at fire end.
b/ 25 ft and 19 1/2 ft are equivalent in physical and formula terms respectively.
c/ Buried thermocouple at 14 ft.
d/ Exposed thermocouple at 24 ft.

standard. Various operators have different techniques for judging the front. Their judgements are often complicated by the difficulties in viewing through heavy smoke deposits on windows from certain specimens. These sources of interpretation and reading errors require study.

The anomaly from using the standard calculation is particularly noticeable in the results on material #3, plywood. Flame spread data for this specimen are used as an example to compare the results of applying each method of calculation. Table 9 presents data on material #3, giving specimen density, furnace position of each specimen, time and distance of maximum travel, and results of FSC by the standard and two proposed methods of calculations. Input fuel rate and starting temperature were included to show the normal test variations, also typical in tests of other materials.

6. Discussion

6.1 Tunnel Construction Variables

The differences of detail in construction and measurement techniques among laboratories, as shown by Table 3, are obvious. The relative effect of any of the variables (i.e. smoke meter location, windows, velocity control etc.) on the results is difficult to assess by looking at these data alone. However, gross effects not easily masked by other variables can sometimes be detected. For example, the consistently high or low smoke results from Laboratories D, E, F and G on several materials may have been caused by differences in their smoke measuring system relative to that of the other laboratories as shown in table 3. Leakage may also contribute to the low values for laboratory G since it did not follow the leak-test procedures.

The smoke value in the standard is determined by the ratio of the area under the smoke obscuration curve for the specimen and for the red oak reference. Since both specimen and reference are subjected to the same exhaust duct and photometer measurement system, the effect of any existing bias should in principle, be compensated. This is not valid for two reasons. One is due to the fact that smoke concentration (mass or optical) is not proportional to obscuration but to the log of reciprocal transmission. Because of the compression at the higher end of the log scale, the concentration ratio of two smokes will vary depending on the actual magnitude of the smoke value for the reference material. Since the level of obscuration from the reference material is determined by the concentration of smoke reaching the photometer and by its path length, unequal losses in ducts resulting from differences in design become important.

A second factor which may explain the inadequacy of using red oak for a smoke reference is the mechanism of smoke loss. For example, the coagulation and decay of wood smoke which consists mainly of condensed liquids is extremely temperature dependent whereas the decay of synthetic carpet smoke (mostly carbon particulates) is much less temperature sensitive but coagulation-time dependent. Therefore, a tunnel with a cold and short duct, say, will result in a low reference value for red oak and thus give a higher ratio for carpet smoke. On the other hand, a hot and long duct will tend to increase the time for coagulation losses but not condensation losses. This will result in a lower value for carpet smoke.

Specimen #3, plywood, has the lowest variability (between-laboratories) in smoke among the materials tested. Based on the reasons mentioned above this is not unexpected. The normalizing factor of using a reference material is more effective when the specimen and reference smokes are similar in nature. This also indicates the need to study the problem of selecting reference materials.

There is general agreement among the laboratory operators on attributing part of the large variability of smoke results to the lack of a specification on the smoke photometer and its location. However, we believe that to attain reasonable reproducibility in test results, the smoke measurement system including exhaust duct length, insulation, photometer path length, instrument range, etc. should be standardized in all tunnels.

The causes of variability in fuel contribution is not clear. For example, laboratories that rank first or second in terms of high value in fuel contribution for all materials are Laboratories G, I and L. These are 3 of the 4 tunnels using the single-type windows and without turbulence bricks. The bricks are not required by the present standard.

Certainly the lack of uniformity in thermocouple type, location, and mounting method among tunnels is a factor contributing to the variability. Perhaps in future modifications several thermocouples should be used in each tunnel to minimize the effect of high temperature gradients which make the location of a single thermocouple very critical. A means to minimize soot deposit on the junction of the thermocouple is also needed. This should improve the reproducibility of the test method.

In addition to the factors mentioned, some operators attribute the variability of smoke and fuel developed to the physical condition of

Table 10. Mean FSC for Each Material and Laboratory

Lab	Materials							
	1	2	3	4	5	6	7	8
A	24	46	238	32	152		251	1170
B	16	39	118	47	157	275		75
C	26	70	186	33	154		214	540
D	23	47	89	36	144		217	980
E	27	72	85	32	147		218	560
F	20	39	146	40	173		229	482
G	16	48	201	48	107	228		574
I	23	27	232	49	197	311		950
J	26	39	142	42	196	293		271
K	23	57	75	28	73		228	
L	21	51	195	56	390	281		1000

Table 11. FSC Ranking of Materials by Each Laboratory[a/]

Lab	Materials							
	1	2	3	4	5	6	7	8
A	1	3	5	2	4		6	7
B	1	2	5	3	6	7		4
C	1	3	5	2	4		6	7
D	1	3	4	2	5		6	7
E	1	3	4	2	5		6	7
F	1	2	4	3	5		6	7
G	1	2	5	3	4	6		7
I	1	2	5	3	4	6		7
J	1	2	4	3	5	6		7
K	1	3	5	2	4		6	
L	1	2	4	3	6	5		7

a/ Based on mean of 3 or 2 runs.

ledges and covers of the tunnel as well as to the size of the flame as a result of burner variation.

6.2 Results of Flame Spread Measurement (FSC)

Tables 10 and 11 give the average value of FSC for each material and the rank ordering of the materials by each laboratory respectively. It is unrealistic to expect good agreement in ranking between materials #2 and #4 and between materials #3 and #5 because of the close proximity of FSC values. Otherwise most laboratories agreed on the relative ranking of the materials tested.

In terms of code classification based on NFPA Code 101, (1970) there is good agreement among laboratories on five of the materials (Materials 2, 4, 5, 6 and 7) in Table 12. But the discrepancy on the other three materials, though explainable, may be of the type that has caused concern in the past to material producers who must meet code requirements which use specific ranges of values for material classification.

The variability of the FSC for the carpets tested does not appear excessive relative to other types of materials. The poorest in terms of reproducibility is material #5, a shag nylon, where the average for the lowest laboratory (except laboratory K) was 107 and for the highest laboratory was 197. There were two individual runs in which the values were slightly over 200, which would have disqualified it as a Class C material. Data on material #5 from laboratory L is excluded because of the use of asbestos paper on the furnace floor. The value of Lab. K would become 111 and closer to the mean, if the new method of calculation based on "rate" were adopted.

TABLE 12. Code Classification of Materials[a/]

Lab	Materials							
	1	2	3	4	5	6	7	8
A	A	B	D	B	C			E
B	A	B	C	B	C	D		B
C	B	B	C	B	C		D	E
D	A	B	C	B	C		D	E
E	B	B	C	B	C		D	E
F	A	B	C	B	C		D	D
G	A	B	D	B	C	D		E
I	A	B	D	B	C	D		E
J	B	B	C	B	C	D		D
K	A	B	B	B	B		D	
L	A	B	C	B	D	D		E

a/ Based on average flame spread (FSC) of 3 runs
NFPA Code 101, Life Safety Code Classification (1970)

A = 0-25 FSC
B = 26-75 FSC
C = 76-200 FSC
D = 201-500 FSC
E = over 500

The carpet results also indicate the effect of including the underlayment in the test. Identical carpet specimens (#4 and #6) gave an average flame spread classification of only 42 without and 278 with underlayment. This points out the need for knowing whether underlayment was used in the reported test results, and whether it will be used in the proposed application.

The variability of FSC for material #1 (fiber glass batt) is numerically small. A level of 25 is used as a cut off point between Class A and B by most code authorities. Six laboratories rate the material in Class A. Two rated it in Class B, and three rated it in A or B depending on the particular run.

6.3 Effect of Using a Single Formula for FSC Calculation

The between-laboratory variability of FSC results for material #3, plywood panel, was of the order of 43%. The variability is exaggerated by using the two formulas required in the method for calculating the FSC, depending on whether or not the flames traveled the full length of the specimen. Undoubtedly some of the variability was a result of variation in specimen density, (Range 0.40 to 0.53 lb/ft^2) a normal range for a commercial product of this type. For example, the 1st and 2nd runs of Laboratory J in Table 9 were similar in rate, but because the flame front stopped within a half foot of the end for the first run, the FSC value was 77, compared with 154 for the second run where the flame reached the end of the specimen. In spite of the difference, however, both would be Class C (76-200) under the NFPA Code 101 Life Safety Code Classification. Table 9 also shows that in some cases (i.e. Laboratories D, F, J) the same material could be classified as Class B

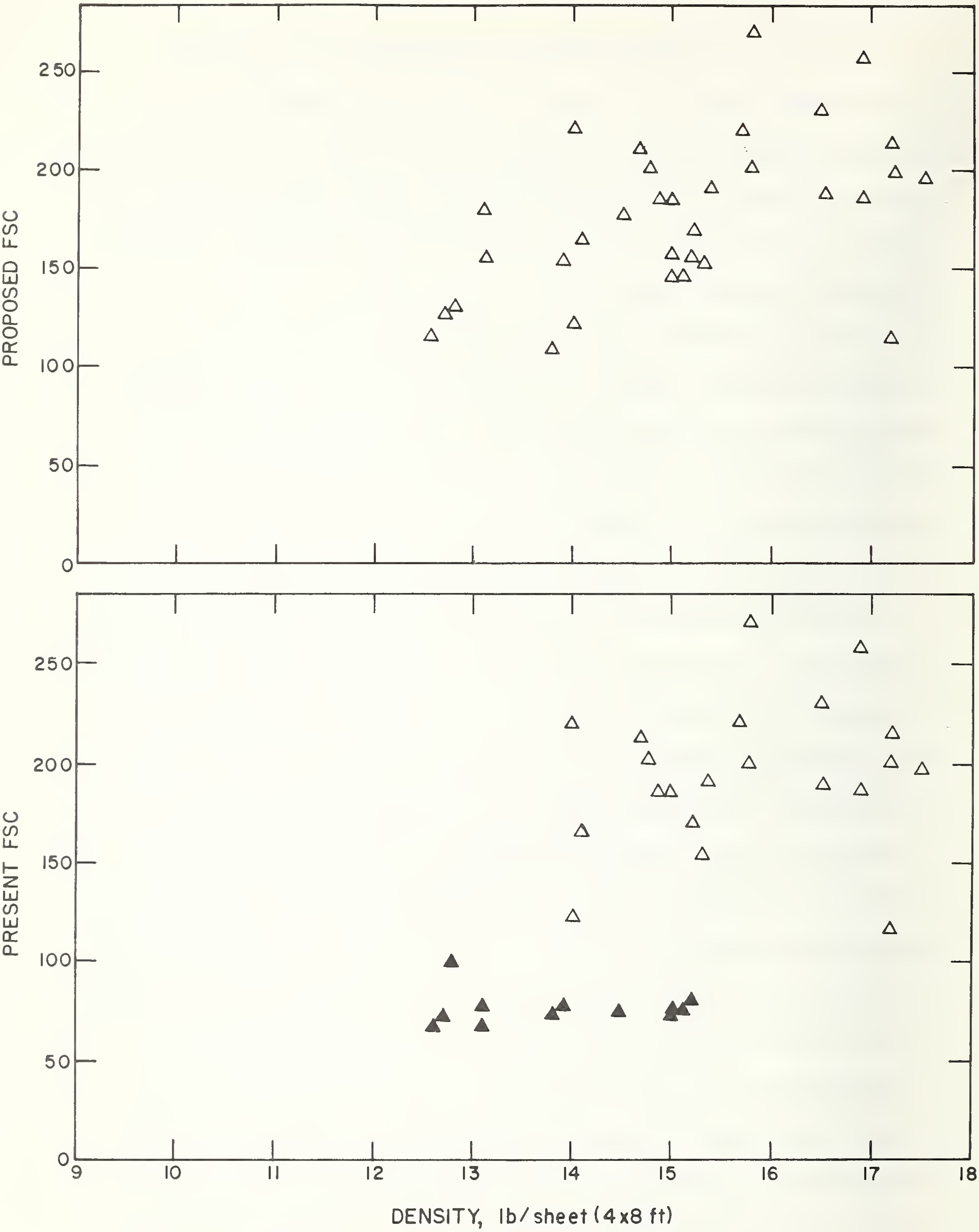

FIGURE 8. FSC AS FUNCTION OF DENSITY OF SPECIMEN #3 BASED ON THE PRESENT (BOTTOM) AND "RATE" (TOP) FORMULAS. ▲ DATA AFFECTED BY CHANGE OF FORMULA.

(26-75) or Class C (76-200) even within a single laboratory under normal testing variability caused by the use of 2 sets of formulas. For this reason material producers have in the past frequently questioned the precision of the test.

If the "rate" or "area" method was used in the calculation, as shown in Table 9, the exaggerated scatter in results would be minimized. This is further illustrated in Figure 8 where the FSC results for the plywood panels are plotted as a function of density of specimen at the burner section of the tunnel using the present and the single "rate" methods for FSC calculation. Observations by others [6] show that the panel section at the fire end has proportionately more effect on the result.

Figure 8 shows the limited dependence of flame spread on density of the panel. Specimens less than about 13 lb/panel did not produce sufficient fuel for a complete burn to the end (FSC<100). The data spread of FSC for the 14-15 lb/panel group is wider than that of the 15-17 lb/panel group based on the present two-formula method. An artificial barrier near FSC of 70. is evident in Figure 8 (bottom). Results based on a single formula as shown in Figure 8 (top) appear to be more credible. Either of the two proposed methods of calculations will improve on the consistency of test results compared to the present formulas.

The complexity of the problem in using the tunnel data for the evaluation of flame spread hazard is further shown in Figure 9. It shows the flame spread distance as a function of time for each of the materials tested based on typical runs. FSC values based on the Standard

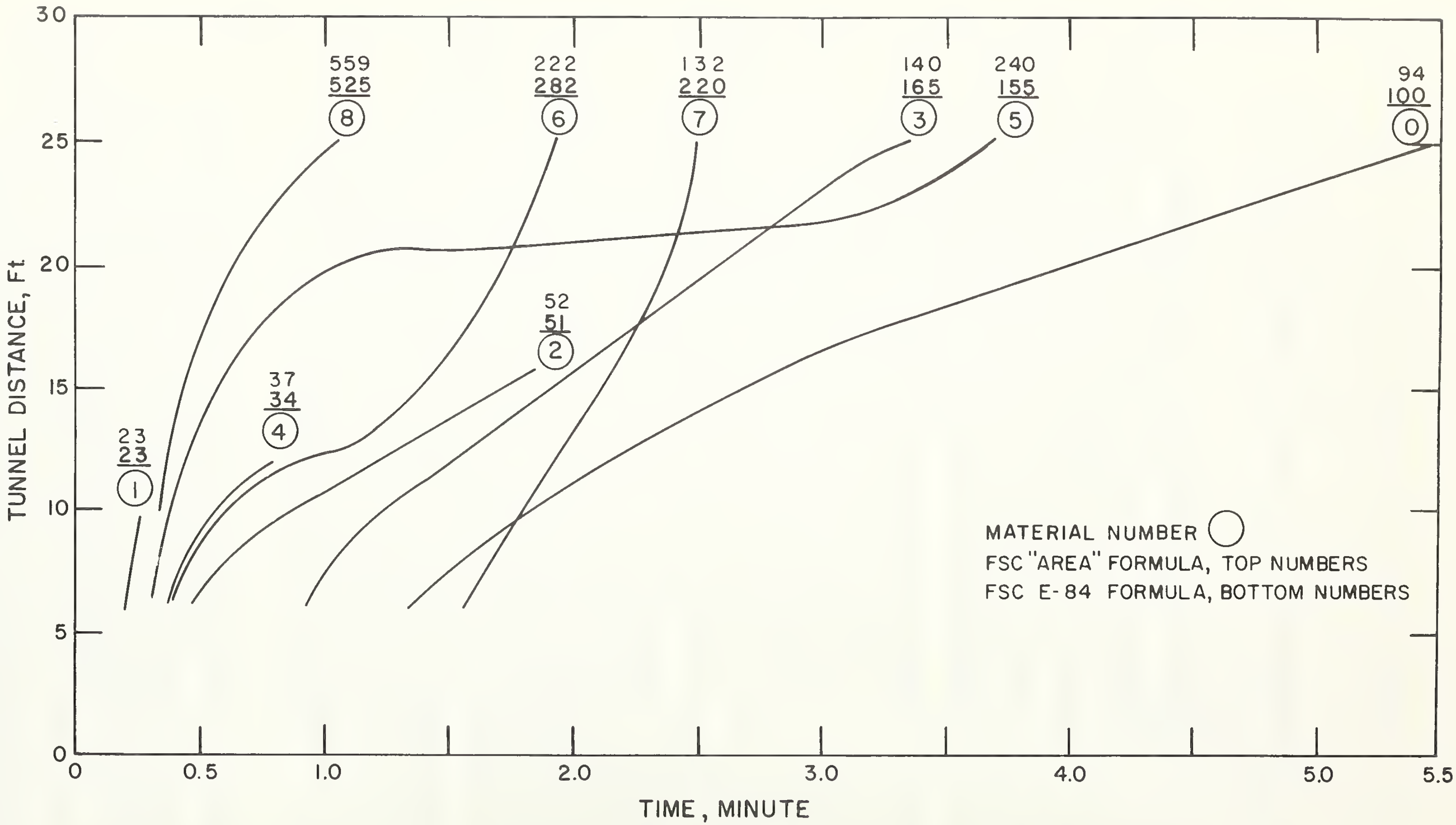

FIGURE 9. FLAME SPREAD OF TEST MATERIALS BASED ON TYPICAL SINGLE RUNS.

and one proposed method (area under the curve) of calculations are also given. Materials have different induction periods, and varying flame front velocities as well as different times of arrivals at the end of the tunnel. The factors used to formulate a rating method such as FSC may necessarily be arbitrary - but good repeatability of test results should be an important criterion.

7. Conclusions

Based on the test results from eleven (11) laboratories using the ASTM E 84 (tunnel) method involving 240 tests on 9 (8+ reference) materials, observations and measurements of tunnel facilities, and discussion with operators, the following conclusions are presented.

1. For a randomized sample of red oak, the standard reference material, 10 out of 11 laboratories obtained results in fair agreement with their previous calibration defined as 100 for flame spread classification (FSC) and fuel contribution. Individual values, from the 10 laboratories ranged from 90 to 108 for FSC and from 80 to 140 for fuel contribution. For smoke developed the agreement is not as good; it ranged from 38 to 135.
2. The median test reproducibilities in terms of the between-laboratory coefficient of variation for the eight (8) materials tested are as follows:

   Flame spread classification, 27% (ranged from 7 to 43%)

   Smoke developed 57% (ranged from 34 to 85%)

   Fuel contribution 64% (ranged from 22 to 117%)

3. The test reproducibility of the 4 carpet systems tested in terms of coefficient of variation for flame spread (FSC) ranged from 7 to 29% calculated on the basis of single tests in different laboratories.

4. Use of different calculation methods for FSC improved the reproducibility of results for the plywood. Similar improvement is expected on other borderline materials.

5. There are significant variations in construction and in measurement techniques among tunnels because of the lack of detailed specification in the test method standard. It is reasonable to assume that these variations affect the reproducibility of the test results.

6. The rating of material using the NFPA code 101 (1970) classification method (i.e. A, B, C, D and E) shows good agreement among laboratories on five of the materials and poor agreement on the other three materials.

8. Recommendations

1. More detailed specifications, improved design, and standardization in the construction and operation of tunnel furnaces are needed in order to improve reproducibility in the measurement of flame spread, smoke and fuel contribution. This would serve all concerned including code

officials, consumers, producers and the testing laboratories.

2. Tunnel operators should meet, discuss and implement solutions to the interlaboratory variability problem. Task groups in ASTM E 5.04 have been formed to examine various facets of the problems. Since recommendations for improvement are urgently needed, concurrent study by others should be encouraged and supported.

3. Organizations who use the test results from the ASTM E 84 test method for regulatory purposes should be consulted. Their views and legal authority are needed in order to support, supplement, expedite and enforce recommendations from the task groups studying the problem.

4. The reproducibility of measurement of smoke and fuel contribution reported in this round robin is not acceptable. Alternative methods for smoke and potential heat measurement are available.

9. Acknowledgement

The participating laboratories performed all tests without compensation. The valuable contributions in terms of advice and generous cooperation from the staff of each laboratory are gratefully acknowledged. The Carpet and Rug Institute donated all the carpet specimens. Owens-Corning Fiberglas, Hardwood Plywood Manufacturers Association, and Armstrong Cork Company provided the necessary fiber glass batt, plywood panel, and sheet vinyl flooring specimens, respectively. Consultation on statistical problems was provided by Dr. J. Mandel, Statistical Consultant, Institute of Material Research, National Bureau of Standards.

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Health Services and Mental Health Administration-HEW

Public Building Service-General Services Administration

Naval Facilities and Engineering Command

Veterans Administration

The draft of this report was made available to the participating laboratories for comment and data verification. Most comments were useful and were accepted. Others, especially those on the influence of tunnel variables on results, though valuable, are not considered within the scope of this paper, but would be available to the task groups.

Appendix A. Example of Data Sheet

INTERLABORATORY EVALUATION OF 25 - ft. TUNNEL TEST, ASTM E-84

Lab Code ____________ Operator ____________ Date ____________ Time ____________

Test No. ____________ Specimen No. ____________ Material ____________ Density oz/yd^2 ________ lb/ft^2 ________

Moisture, % ________

Specimen Conditioning:
Temp. ________
R. Humi. ________
Duration ________ days

Date of Last Calibration ____________ Number of Test After Preheat ____________ Air Temp. (room) ____________ Humidity, % ________

Sample Insertion Temp. (14') ________ (24') ________

Starting Temp. (14') ________ " " (24') ________

Final Temp. (14') @ 10 min. ________ (24') ________

Max. Temp. ________ Time ________

Gas Meter Reading Used (ft_3) before ________ after ________ ________

Fuel Flow Rate ________ ft^3/min ________ BTU/min

Draft Pressure in. H_2O ____________

Max. variation in run, in. H_2O ____________

Air velocity (24') ________

Gas Pressure (after orifice) ________

Gas Temp. ________

Flame Spread
Temp. (24') 3.0 min. ________ ^oF
Time to 980°F ________ min.
Distance Max. Spread ________
Time Max. Spread ________

FSC = ________

Flame Spread, Ft.	Ignition	4	6	8	10	12	14	16	18	20	22	24	25 over (19.5)
Time, min.													

Fuel Contribution
Area Specimen ________
" Blank ________
" Red Oak ________

FC = ________

Exposed Surface

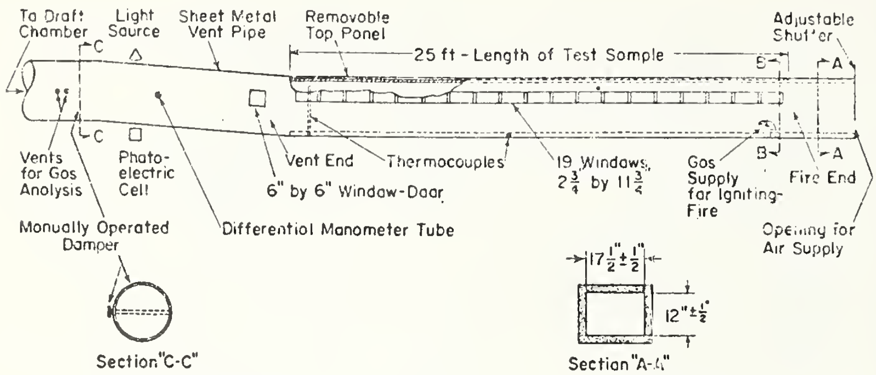
2 4 6 8 10 12 14 16 18 20 22 24

Smoke Developed
Area Specimen ________
" Blank ________
" Red Oak ________

SD = ________

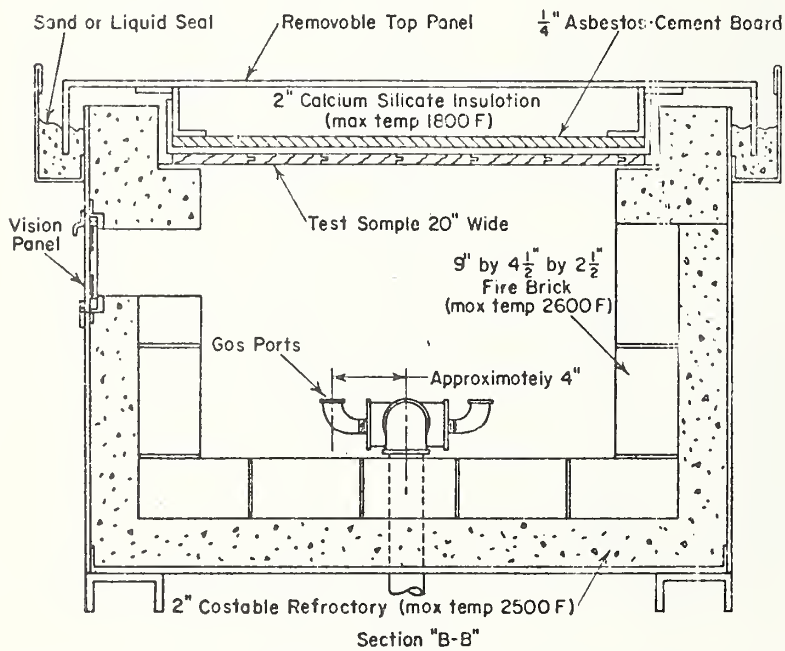
Notes:

Appendix B. Dimension of ASTM E-84 Furnace



U.S. Customary Units	Metric Equivalents
2¾ by 11¾ in.	7.0 by 29.8 cm
6 by 6 in.	15 by 15 cm
12 ± ½ in.	30.5 ± 1.3 cm
17½ ± ½ in.	44.4 ± 1.3 cm
25 ft.	7.62 m

FIG. 1—Test Furnace Showing Critical Dimensions.



U.S. Customary Units	Metric Equivalents	U.S. Customary Units	Metric Equivalents
¼ in.	6.3 mm	9 by 4½ by 2½ in.	23 by 11.5 by 6.5 cm
2 in.	5.1 cm	1800 F	982 C
4 in.	10.2 cm	2500 F	1371 C
20 in.	50.8 cm	2600 F	1427 C

FIG. 2—Test Furnace Showing Critical Dimensions (Section "B-B").

40-3

Appendix C. Task Groups Under ASTM E 5.04 to Study Revision of E 84 Test Method Standard (organized between 1967 and Oct. 1972):

1. Specimen Mounting Methods for E 84.
2. Flame Spread Calculation Methods for E 84.
3. Revision of the Scope in E 84. (To or Not to include carpets).
4. Evaluation of Procedures on Smoke Measurement in E 84.
5. E 84 Tunnel Operator's Group.
6. Criteria for Evaluation of Laboratories Conducting E 84 Tests.

Appendix D. Method of Flame Spread Classification (FSC) Under the Current E 84-70 Standard

6. Classification

6.1 The flame spread classification (FSC) shall be determined as follows:

6.1.1 For materials on which the flame spreads 19-1/2 ft (5.94 m):

6.1.1.1 In 5-1/2 min or less, the classification shall be 100 times 5-1/2 min divided by the time in min (t) in which the flame
1. spreads 19-1/2 ft (5.94 m), (FCS = 550/t).

6.1.1.2 In more than 5-1/2 min but not more than 10 min, the classification shall be 100 times 5-1/2 min divided by the time in min (t) that the flame spreads 19-1/2 ft (5.94 m), plus 1/2 the
2. difference of 100 minus this result, (FSC = 50 + 275/t).

6.1.2 For materials on which the flame spreads less than 19-1/2 ft (5.94 m), and then ceases to continue or recedes in a 10 min test period.

6.1.2.1 When the extreme flame spread distance (d) is more than 13-1/2 ft (4.11 m) and less than 19-1/2 ft (5.94 m), the classification shall be 100 times 5-1/2 min times the distance (d) divided by 19-1/2 ft (5.94 m) times 10 min, plus 1/2 the difference
3. of 100 minus this result, (FSC = 50 + 1.41d) FSC(metric) = 50 + 4.62d).

6.1.2.2 When the extreme flame spread distance (d) is 13-1/2 ft (4.11 m) or less, the classification shall be 100 times the distance
4. (d) divided by 19-1/2 ft (5.94m), (FSC = 5.128d) (FSC(metric) = 16.84d).

Appendix E. Calculation of Reproducibility Based on the Averages of Replicate Tests

$$Bm = \sqrt{B_s^2 - Ws^2 + \frac{Ws^2}{m}}$$

$$Wm = \frac{Ws}{\sqrt{m}}$$

where Bm = Between-labs coefficient of variation, (c.v.), between averages of m replicates in different labs.

Bs = Between-lab. C.V., between single tests in different labs.

Wm = Within-lab. C.V., based on the averages of m tests in a single lab.

Ws = Within-lab C.V. based on single tests in single lab.

m = Number of replicate runs.

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16. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)

Results of an interlaboratory evaluation of the ASTM E 84 tunnel test method involving eleven laboratories and nine materials, including four carpets, are reported. Data on flame spread, smoke, and fuel contribution are analyzed statistically. Selected physical characteristics of each tunnel are tabulated and compared relative to specifications in the test method. The between-laboratory coefficient of variation (reproducibility) in flame spread classification (FSC) was found to range from 7 to 29% for the four carpets and from 18 to 43% for the other materials tested. The between-laboratory coefficients of variation for smoke developed and fuel contribution ranged from 34 to 85% and from 22 to 117% respectively for all materials tested. The causes of higher variability in smoke and fuel contribution measurement between laboratories is not definitely known but may reasonably be attributed to variations in tunnel construction, maintenance, and operation, in the location of photometers, and in the mounting of thermocouples in different laboratories. Some variability of results may possibly be due to variation in test specimens. Variation in construction and measurement techniques among tunnels may be minimized by updating the test method standard.

17. KEY WORDS (Alphabetical order, separated by semicolons)
ASTM E 84; building materials; carpets; fire tests; flame spread tests; interlaboratory evaluation; round robin; statistical analysis; test method standard.

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