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SURFACE FLAMMABILITY OF MATERIALS: A SURVEY OF TEST METHODS AND COMPARISON OF RESULTS

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The fire hazard or surface flammability of materials is a matter of major interest to many public and private agencies. Although not a newly discovered phenomenon, most efforts to evaluate this property of materials quantitatively have taken place only in the past 25 years. These efforts have been uncoordinated, a considerable number of methods developed having little relation to one another or to actual fire conditions.

There are many approaches to this yet unsolved problem. The nine test methods discussed represent most of those used. Others are deserving of discussion but have not been included due primarily to a lack of detailed information.

Essential details of each method are included, followed by a comparison of the physical differences between the several methods and their significance. Reproducibility is discussed, and the relation of the classifications by the several methods is shown to fill a growing need for such information. The test methods by themselves are adequate for comparing materials. Since they must also be related to actual fire conditions for real value, accomplishments to date showing this relation are reported. In the conclusion, suggestions are made regarding courses of action to promote activity and unify action in this important field of endeavor.

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Tunnel Test (ASTM Method E 84)[2]

The tunnel test (**7,8**) is probably the best known of the currently used tests for evaluating the fire hazard of building material. The equipment is a 25 ft long horizontal tunnel-like unit with burners at one end and a flue at the other. The interior cross-section is 18 in. wide by 12 in. high, and the walls, cover, and floor are all insulated (Fig. 1). A test specimen 25 ft long by 20 in. wide is mounted on the underside of the cover so that when the cover is placed on the tunnel walls, an 18 in. width of the specimen becomes the ceiling of the tunnel. The fire exposure is provided by two gas-fired burners located symmetrically $7\frac{1}{2}$ in. below the specimen and arranged so that the flame will impinge upon one end of the specimen. Fire exposure, draft conditions, initial tunnel temperature, and preheat conditions are required to be the same within pre-established limits for all tests. In a typical test which lasts 10 min., temperature and smoke density measurements are made at the exit end of the tunnel and flame spread along the underside of the sample is visually observed through glass ports along one side of the wall of the tunnel.

Test results are reported in terms of numerical ratings for flame spread, fuel

[2] Method of Test for Surface Burning Characteristics of Building Materials (E 84 – 59 T), 1959 Supplement to Book of ASTM Standards, Part 5.

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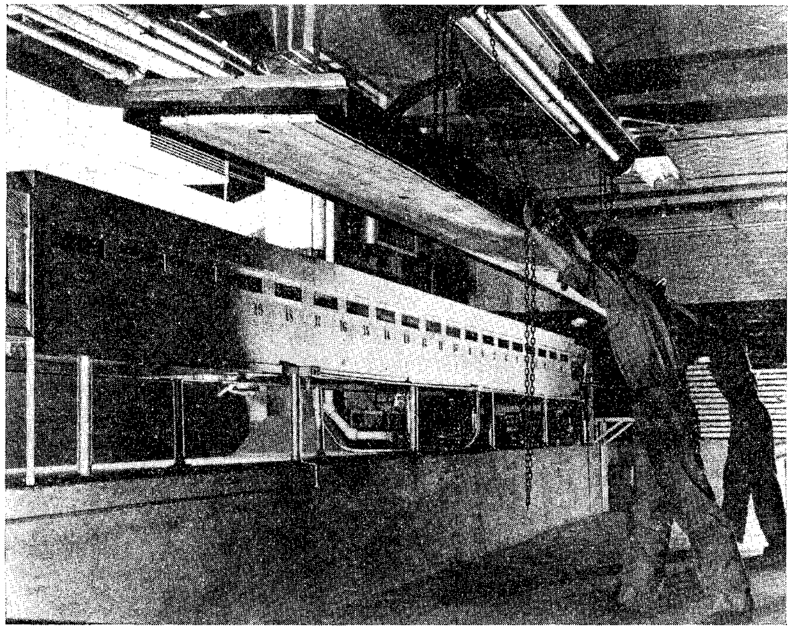


Courtesy Underwriters' Laboratories, Chicago.

FIG. 1.—Apparatus for Tunnel Test (ASTM Method E 84).

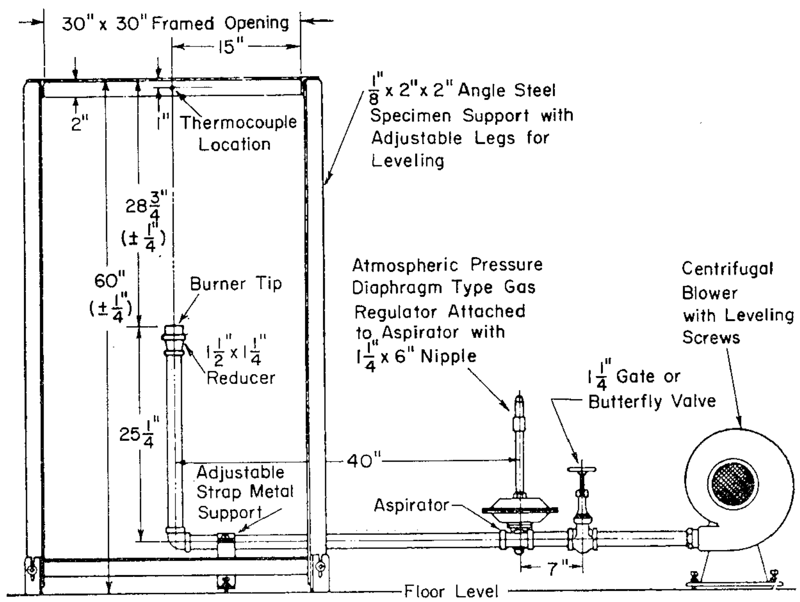
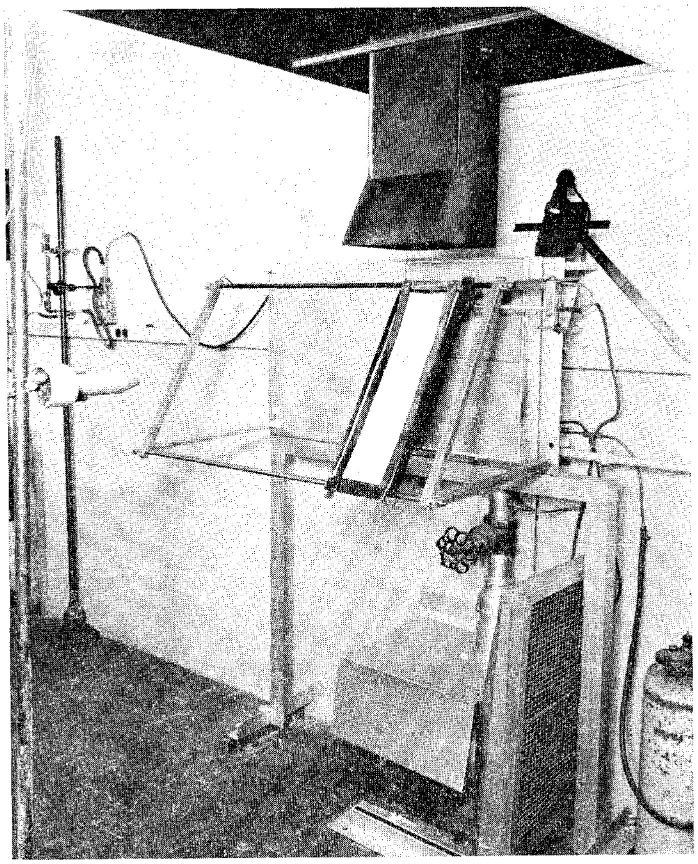


FIG. 2.—Apparatus for Federal Test SS-A-118b.

contributed, and smoke density as compared with select red oak and asbestos-cement board having ratings of 100 and 0, respectively, for each of the reported items.

Despite considerable discussion and objection regarding technical details of the test, the ratings resulting from this method have widespread use. They are used by several national model building codes, many local codes, and other regulatory bodies, primarily as a means of limiting the use of combustible interior finish materials in buildings. At least two major test agencies use the results as the basis of a listing service for building materials. Several manufacturers and building materials trade organizations use the test results for comparison purposes.

This method was originally developed by the Underwriters' Laboratories in 1941 and has been in continuous use since that time. There are presently at least five such tunnel installations and the number of tests conducted can be numbered in the thousands.



Courtesy U. S. Department of Commerce, National Bureau of Standards.

FIG. 3.—Apparatus for Radiant Panel Test.

FEDERAL SPECIFICATION SS-A-118B TEST

One of the first methods used to evaluate fire hazard of materials, was developed in 1934 for use in the Federal Government procurement specification for acoustical material (SS-A-118b) (3,9).

A 36 by 36-in. specimen is supported in a horizontal position on a 2 by 2 by $\frac{1}{8}$-in. angle frame assembled to give a clear opening of 30 by 30 in. The fire exposure is from a gas burner located $28\frac{3}{4}$ in. below the center of the specimen (Fig. 2). This exposure is controlled to follow the ASTM standard time-temperature curve based upon temperature at a point 1 in. below the center of the specimen.

Ratings used with this method are class A (noncombustible), class B (fire retardant), class C (slow burning), and class D (combustible). To be class A, no flame can issue from the specimen nor glow progress beyond the area covered by the exposure flame in a 40-min test. For class B, in a 40-min test sustained flaming from the specimen cannot exceed 10 sec duration, it must occur within a period not exceeding 5 min from the time first observed, and no flaming can reach the angle frame at any point. For class C, in a test lasting 20 min there can be flaming provided it does not reach the angle frame, and all flaming must ceas within 5 min of the removal of the exposure flame. Also for classes A, B, and C, the specimen must remain in place during the flame exposure and progressive glowing to any edge of the specimen is not permissible.

A number of government, commercial, and manufacturing agencies are equipped to conduct tests using this method, and over the years many hundreds of tests have been conducted. The classifications are used in Federal Specification SS-A-118b, and the method is used to some extent in the developmental testing of new materials. It has been passed over for general building code and insurance rating work in favor of other procedures because it is not a good flame spread test. Flame spread observations are difficult due to the limited surface available for flame travel after impingement of the exposure flame on the specimen.

RADIANT PANEL TEST

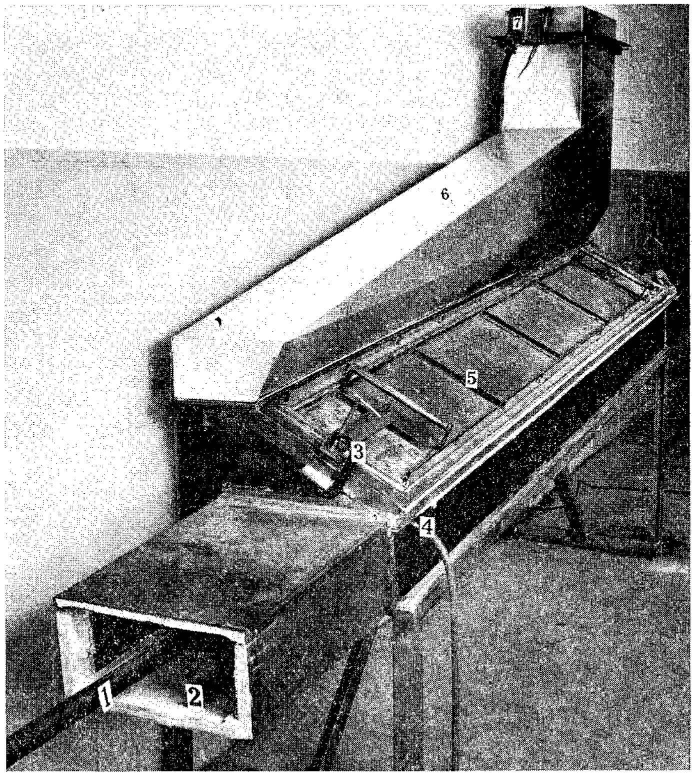
The National Bureau of Standards developed the radiant panel test (2) to fill the need for a relatively simple method of measuring the surface flammability of materials.

The equipment includes a 12 by 18-in. radiant heat panel, a specimen holder, a gas pilot, a stack, and proper instrumentation to assure reproducible test conditions (Fig. 3). The radiant panel is mounted in a vertical position and supplied with a premixed gas-air mixture. Its energy output is maintained constant by a radiation pyrometer. The holder supports a 6 by 18-in. specimen in an inclined position so that the top 6-in. edge of the specimen is $4\frac{1}{2}$ in. and the bottom edge $9\frac{5}{8}$ in. from the radiant panel. The gas pilot is located near the top edge of the specimen. The stack, which is located above the specimen, collects heat and products of combustion from the burning specimen and supports the thermocouples for measuring the gas temperatures and a smoke sampling tube.

During typical tests the specimen is exposed to the radiant panel for 15 min. When sufficiently heated, it is ignited by the gas pilot. The rate of flame movement down the panel is recorded along with stack temperatures. Smoke is drawn constantly through the sampling device, which includes a glass fiber filter disk to collect smoke deposits.

The test results reported are a flame spread index and milligrams of smoke deposit for the volume flow rate during the test period. The flame spread index is calculated from the time intervals the flame front arrived at 3-in. positions along the length of the specimen, the maximum observed stack temperature rise above that observed when testing asbestos-cement board, and a constant arbitrarily chosen to yield a flame spread index of approximately 100 for red oak. The index is computed in this manner to recognize both the ignition and heat evolution characteristics of the material being tested.

This test method was given recognition by ASTM as a tentative in 1960.[3] It has not been used in building code or rating work and includes a statement that it is not intended for this purpose. It is being actively considered for use as the Federal Standard for surface flammability. It is presently in use by at least eight organizations for direct comparison of the surface flammability of material. The number of tests conducted is probably in the hundreds.



Courtesy U. S. Forest Service, Forest Products Laboratory Photograph.
FIG. 4.—Apparatus for Small Tunnel Test.

SMALL TUNNEL TEST

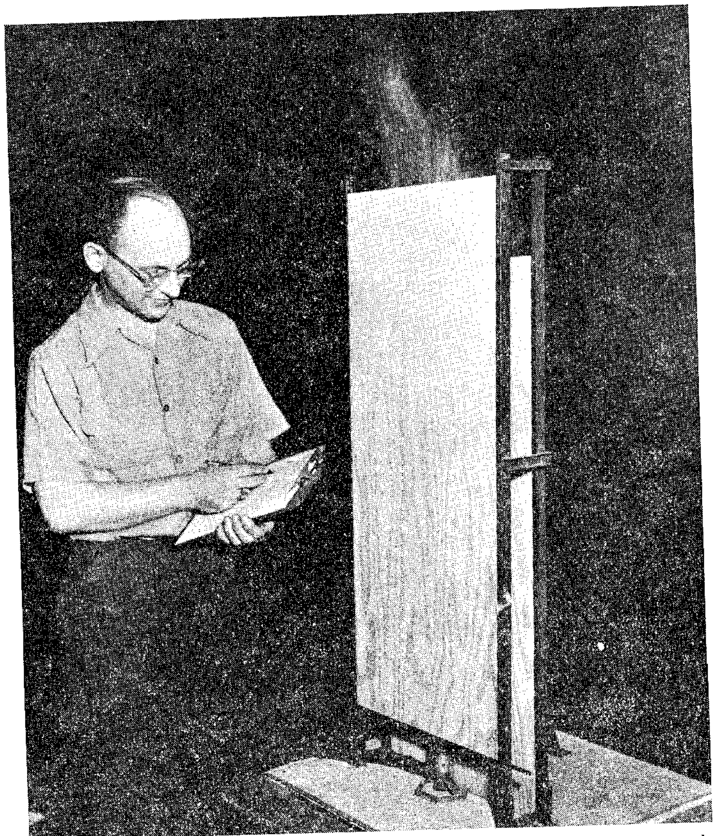
The Forest Products Laboratory (FPL) developed the small tunnel test as a more modest means of evaluating the fire hazard of materials than the ASTM tunnel test, Method E 84 (**15,16**).

The test equipment has three main parts, a fire box, an 8 ft long specimen combustion chamber, and a hood and stack. The fire box contains a T-head gas burner burning gas at the rate of 3400 Btu per min. The specimen com-

[3] Method of Test for Surface Flammability of Materials Using a Radiant Heat Energy Source (E 162 – 60 T). 1960 Supplement to Book of ASTM Standards, Part 5.

bustion chamber has insulated walls, floor, cover, and a horizontal 12-gage metal partitioning hot plate located a few inches above the bottom of the chamber. The hot plate has a number of holes varying from $1\frac{7}{16}$ in. to $\frac{3}{8}$ in. in diameter along the full length of one side. A specimen $13\frac{3}{4}$ in. wide by 8 ft long is secured to the underside of the insulated cover which is placed so that the short dimension of the specimen slopes upward at a 30-deg angle and its lower edge is $1\frac{1}{16}$ in. above the side of the hot plate with the holes. A small pilot burner burning 85 Btu per min is located under the $13\frac{3}{4}$ in. sloping edge of the specimen (Fig. 4).

In a typical test, the main gas burner produces hot gases which heat the underside of the hot plate and flow through the holes along the edge of the plate. The specimen is thus subjected to both radiant heat from the hot plate and the hot gases. When the specimen is sufficiently heated by this exposure, it is ignited by the pilot burner. The rate of flame spread along the specimen is observed through ports in the tunnel, and temperatures and smoke density are recorded in the flue.



Courtesy U. S. Forest Service, Forest Products Laboratory Photograph.

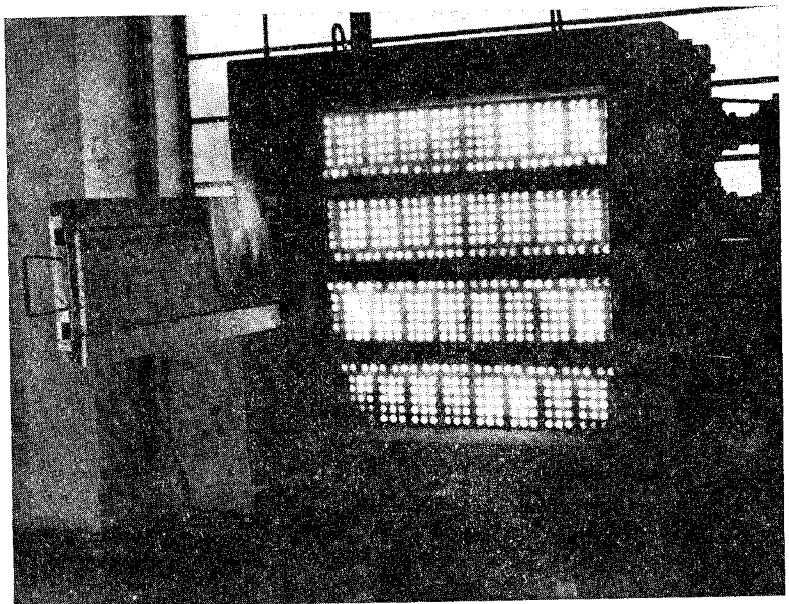
FIG. 5.—Apparatus for Schlyter Test.

tween faces. Any material showing little flame spread in this test with a severe exposure and with the faces close together may be expected to perform well when tested by any of the other described methods.

FM CALORIMETER TEST

The Factory Mutual (FM) calorimeter test was developed to produce data to investigate a different approach to the problem of fire spread (6). In this approach, it is believed that the fire spread capability of a material is dependent upon its heat-producing rate. To support the spread of flame, a material must produce sufficient heat to create combustible gases ahead of the flame front and to overcome all heat losses to the blanket of gases adjoining the burning material or to nearby surfaces.

The equipment consists of a combustion chamber 4 ft wide by $3\frac{3}{4}$ ft high by $17\frac{1}{2}$ ft long with main fire exposure burners and evaluating burners at one end and a flue and stack at the other (Fig. 6). The combustion chamber is lined with insulating fire brick and has a $4\frac{1}{2}$ by 5-ft opening in the top to accommodate either the test specimen or a standard cover made of insulating concrete. The main fire exposure burners burn gasoline at a rate of 27,500 Btu per min. The evaluating burners are arranged to introduce metered gas fuel into the furnace at a point directly under the removable cover. Excess air for combustion is provided at constant rate and temperature. Temperatures are measured in the flue beyond the region of actual flaming. Smoke density is not measured.



Courtesy Joint Fire Reasearch Organization, England.

FIG. 7.—Apparatus for Spread of Flame Test (BS 476).

In a typical test, a $4\frac{1}{2}$ by 5-ft specimen is subjected to fire from the main exposure burners for 30 min. The resulting recorded time-temperature curve represents the fuel contribution from both the exposure and the specimen. The specimen is then replaced with the standard concrete cover and the test is re-run in what is termed an evaluation test. In the evaluation, all conditions are exactly the same except that the evaluating burners provide the heat originally produced by the specimen. With a main exposure the same as when the specimen was tested, metered fuel is introduced through the evaluating burners at the proper rates to follow the curve produced in the first test. With the metered fuel rates recorded in the evaluation test, the total fuel contributed from the specimen and rates of burning for various time periods are computed.

To date, most of the test effort has been devoted to the evaluation of insulated steel deck constructions, glass-fiber-reinforced plastic, and impregnated lumber, all at one exposure rate. Development of data at other exposures and a broadening of the type material tested are still in the future.

No other test device of this nature is in existence. The calorimeter has been related to large-scale tests on which the original Factory Mutual class I classification for insulated steel deck construction was based, and it is now used to test assemblies for this classification.

SPREAD OF FLAME TEST (BS 476)

The British Joint Fire Research Station has used the spread of flame test (BS 476) for a number of years to classify wall and ceiling materials according to the tendency to spread flame over their surfaces (10,11).

The equipment consists of a 3 by 3-ft gas-fired radiant panel mounted in a vertical position, and a frame arranged to hold the 9-in. edge of a 9 by 36-in. specimen in a vertical position and perpendicular to one side of the radiant panel at its midpoint (Fig. 7). A small gas flame is located at the intersection of the specimen and the radiant panel. With this arrangement, the intensity of the exposure on the specimen decreases as its distance from the radiant panel increases.

In a typical test, the specimen is placed in position with the radiant panel functioning, Immediately, a 7 in. long vertical gas flame is applied to the hot end of the specimen for 1 min. Observations are made of the time of spread of the flame front for measured distances along the specimen. These measurements are continued until the flames have died out or for 10 min, whichever is longer. Resulting ratings are as follows based on the rate and extent of the flame spread:

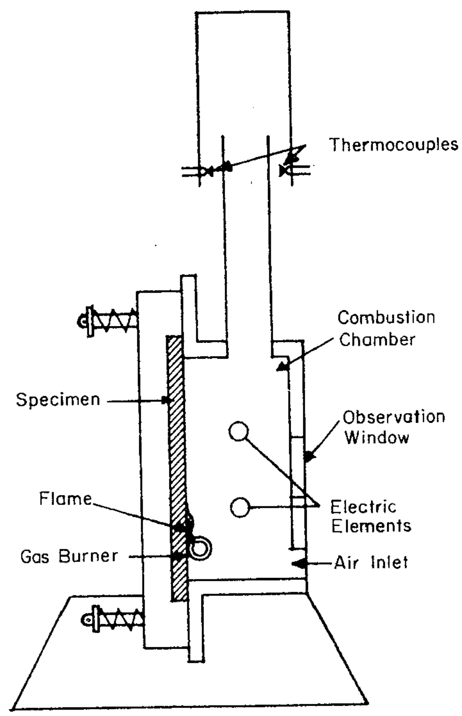


FIG. 8.—Apparatus for New British Building Board Test.

Class I—Surfaces of very low flame spread,
Class II—Surfaces of low flame spread,
Class III—Surfaces of medium flame spread, and
Class IV—Surfaces of rapid flame spread.

In addition to the Joint Fire Research Station, the Fire Safety Institute in Delft, the Netherlands, and the Commonwealth Experimental Building Station in Australia use this procedure, with probably hundreds of tests being conducted by the three organizations. There has been some dissatisfaction because the method is not sufficiently severe, with too many materials receiving the class I classification. This has led to the development of the Australian pilot ignition test and the new British building board test.

NEW BRITISH BUILDING BOARD TEST

The British Joint Fire Research Station was unable to modify the surface spread of flame test (BS 476) so as to increase its selectivity within the class I range. Because of this plus a desire to develop a simpler procedure, the new British building board test was developed (11,12).

The test makes use of an insudlate test cabinet having an interior width of $7\frac{1}{2}$ in., a height of $7\frac{1}{2}$ in., and a depth of $3\frac{1}{2}$ in. (Fig. 8). The cabinet has one open face arranged to accommodate a 9 by 9-in. specimen with a $7\frac{1}{2}$ by $7\frac{1}{2}$-in. area exposed to the heating elements. The cabinet also has a small chimney on the top within which two thermocuples are located to measure flue gas temperature. The exposure is initially from a gas jet at the rate of 30 Btu per min, and after

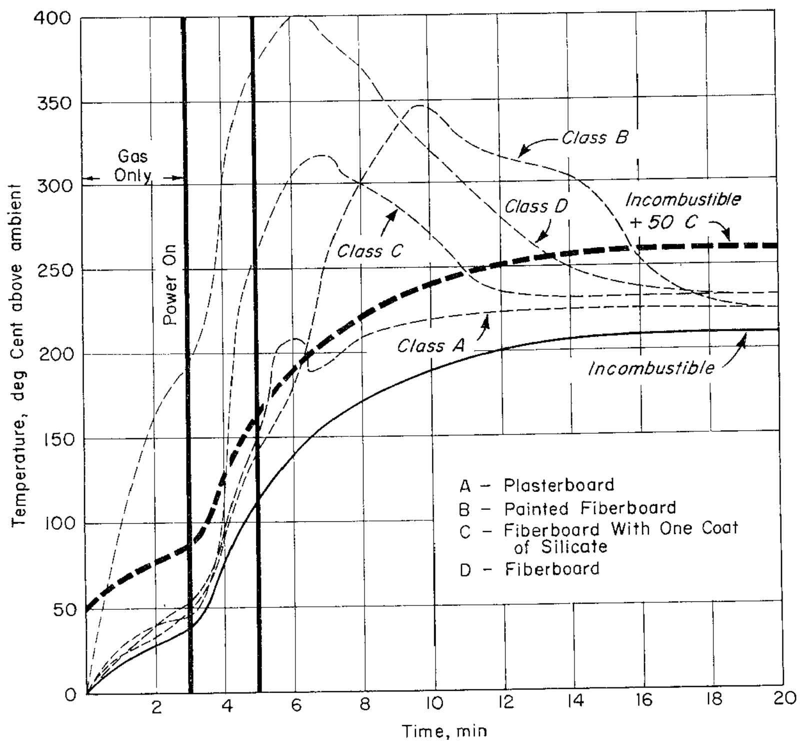


FIG. 9.—Representative Curves for Classes A (Plasterboard), B (Painted Fiberboard), C (Fiberboard with One Coat of Silicate), and D (Fiberboard) Obtained with New British Building Board Test.

3 min radiant heat is added from two electrical heating elements at 85 Btu per min (1500 w).

The test duration is 20 min during which the flue time-temperature data are recorded. In classifying materials, the flue time-temperature curve is compared with a corresponding flue time-temperature plus 50 C curve for a noncombustible specimen. The classification is based upon (1) the length of time the flue temperature of the specimen remained above the reference curve and (2) the time at which the flue temperature reached the reference curve. Figure 9 shows the reference curve and representative curves for each of the classes which are defined as follows:

Class A—Materials for which the flue temperature exceeds the reference curve for less than 3 min and does not reach the reference curve in 3 min,

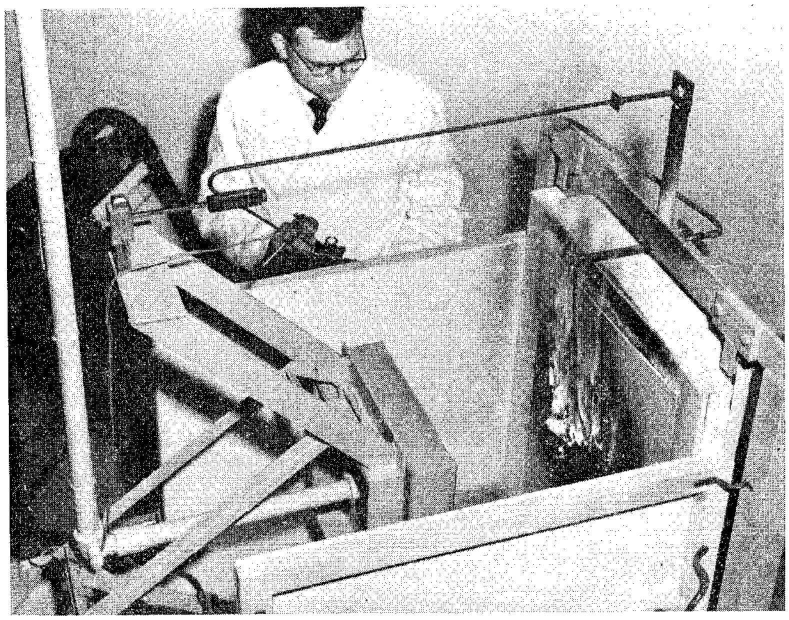
Class B—Materials for which the flue temperature exceeds the reference curve for more than 3 min but does not reach the reference curve until after 5 min,

Class C—Materials for which the flue temperature exceeds the reference curve for more than 3 min and reaches the reference curve between 3 and 5 min, and

Class D—Materials for which the flue temperature exceeds the reference curve in 3 min or less.

Test results indicate this procedure has in effect divided class I materials according to BS 476 into two parts without significantly changing the position of the class II, III, and IV materials.

The method is newly developed and the sponsor is believed to be the only organization to have such equipment. A considerable number of tests have been conducted, and experience to date indicates that the method has promise and is likely to be adopted as a new British Standard.



Courtesy Commonwealth Experimental Building Station, Australia.

FIG. 10.—Apparatus for Pilot Ignition Test.

TABLE I.—COMPARISON OF PHYSICAL DIFFERENCES BETWEEN TEST METHODS.

Test Method	Sample Size and Position	Exposure	Test Duration	Conditioning Requirements
Tunnel, ASTM E 84	25 ft by 20 in., horizontal	5000 Btu per min, gas flame	10 min or less	to constant weight at 70 ± 5 F at RH 35 to 40 per cent
Federal Test, SS-A-118b	36 by 36 in., horizontal	ASTM standard time-temperature curve = 1400–1500 Btu per min, gas flame	40 min or 20 min	to constant weight at 75 ± 5 F at RH 50 ± 5 per cent
Radiant panel (NBS)	6 by 18 in. at 30 deg from vertical	1430 Btu per min, 12 by 18 in. gas-fired radiant panel and pilot flame	15 min or less, continuous pilot	to constant weight at 75 ± 5 F at RH 50 ± 5 per cent
Small tunnel (FPL)	8 ft by 13¾ in., 13¾ in. side at 30 deg, 8 ft side at 6 deg	3400 Btu per min plus 85 Btu per min from pilot flame, gas-fired	18.4 min or less	to constant weight at 80 ± 10 F at RH 30 ± 5 per cent
Schlyter (FPL)	two pieces 12 by 31 in., vertical, 2 in. apart	97 or 291 Btu per min, gas flame	3 min	to moisture content 7 ± 1 per cent
FM calorimeter	4½ by 5 ft, horizontal	27,500 Btu per min, gasoline	30 min	to constant weight at ambient conditions
Spread of flame, BS 476	9 by 36 in., 9 in. edge vertical	3 by 3 ft gas-fired radiant panel and pilot flame	10 min or when flames die out; 1 min for pilot	to constant weight at 50 to 70 F at RH 55 to 65 per cent
New British building board	9 by 9 in., vertical	30 Btu per min for 3 min, then 85 Btu per min more; gas and electricity	20 min	20 C and 56 per cent RH
Pilot ignition	24 by 18 in., 24-in. edge vertical	1000 Btu per min, 12 by 12 in. gas-fired radiant panel and pilot flame	time to ignition of specimen plus 2 min	to moisture content in equilibrium with air at 60 to 80 F at 55 to 65 per cent RH

Pilot Ignition Test

The Commonwealth Experimental Building Station (CEBS), Sydney, Australia, devised the pilot ignition test after considerable exploratory work with the British BS 476 test, model, and full-scale room tests (14). The equipment consists of a 12 by 12-in. gas-fired radiant panel and a wooden frame mounted on a movable carrier (Fig. 10). A 24 by 18-in. specimen is secured to the wooden frame as in trade practice, with the long dimension vertical and facing the radiant panel. A gas pilot flame is located 2 in. above the center of the specimen and $\frac{1}{2}$ in. from its surface.

In the test, the panel is moved toward the radiant panel at a predetermined rate designed to expose the specimen to temperatures equivalent to wall temperatures observed in full-scale tests. Observations are made of time for ignition and of the flame intensity (by radiation pyrometer) for 2 min after ignition of the specimen. Test duration is normally between 6 and 15 min.

Recorded data are converted to ignitability, spread of flame, and heat-evolved index numbers which are then combined for a final numerical rating designated the early fire hazard index for the specimen tested. The spread of flame and heat-evolved index numbers were based on the flame intensity data which had been previously related to full-scale room test results. The Commonwealth Experimental Building Station believes that ignition time, spread of flame, and heat evolved are of little value individually as performance criteria, but when combined represent a truer measure of the fire hazard of a material.

The equipment at CEBS is the only known equipment of this type. By this date, they have probably conducted about 200 to 300 tests. This method became a section of Australian Standard No. A-30 in 1958 as the means for measuring surface flammability of materials in lieu of the BS 476 test.

Physical Differences Between Tests

The specimen size and position, the exposure and its duration, and pretest conditioning requirements have been listed in Table I for each method discussed.

Specimen Size:

Convenience, economy, and possibly the thought that "the larger-the-better," rather than scientific reasons, have apparently been factors governing specimen size. Note that the size ranges from 9 by 9 in. to 25 ft by 20 in.

Specimen Position:

Specimen position has been given more consideration in some cases. In the Schlyter test, the exposure, the burning of the specimens, and the re-radiation between the two surfaces all contribute to the preheating of unburned surfaces above and in advance of the flame, creating especially favorable conditions for flame spread. Products of combustion from the specimen under test actually contribute to some degree to the preheating of unburned portions of the specimen in all except the NBS radiant panel test. In this test, the preheating effect has been minimized by arranging for the flame front to move downward while the products of combustion move upward. In both the ASTM tunnel (E 84) and the FM calorimeter tests, the specimen is flat and there is a forced draft. The FPL small tunnel test slopes the specimen slightly so as to obtain better results using natural draft. The other methods all depend upon natural draft.

Exposure:

Again for most of the tests, both the exposure and its duration have been arbitrarily selected after development tests showing the exposure yielding the most usable results for the equipment used. The exposure for the Australian pilot ignition test is an exception. In this test, exposure temperatures on the specimen being tested are the same as those actually observed on a noncombustible wall lining used in a series of full-scale room tests.

The exposures range from severe to light with both direct flame impingement and radiant sources. For those with direct flame impingement, the portion of the specimen directly exposed to the flame varies from 100 per cent with the FM calorimeter to a small percentage with the FPL and ASTM tunnel tests. In the tests using radiant exposures, a pilot flame is the ignition source, and the radiant panels are arranged to expose either all portions of the specimen to the same temperature conditions or to temperatures decreasing with distance from the source.

Conditioning Requirements:

All test agencies have recognized the fact that fire test results can be affected by varying specimen conditions. This factor can be controlled relatively easily and most agencies have established standards for the conditioning of the specimen. These standards are not all the same but are believed to be sufficiently close so as to not be a major factor when comparing results by different test methods.

REPRODUCIBILITY

There has been little documentation establishing the reproducibility of test results by either the same test apparatus from day to day or similar test apparatus at different locations.

Generally, individual laboratories appear to be aware of their responsibility in this respect and have established practices and procedures designed to produce identical day-to-day test conditions and results as evidenced in the written test specification. This includes standard provisions for the following, all not necessarily applicable to all tests: (1) draft, (2) fire exposure, (3) equipment size and orientation, (4) preheat and furnace wall temperatures, (5) test observations and techniques for obtaining same, and (6) preconditioning of specimen.

When a test method has passed the developmental stage and has gained sufficient stature to be adopted for use by other than the originating agency, there has been an initial effort by the participating agencies to produce consistent test results. The inconsistencies which show up are worked out to a degree at this time. They usually emphasize the importance of the above mentioned standard provisions and lead to an improved test specification. A good example of this is the recent round-robin testing program sponsored by ASTM Committee C 20 on Acoustical Materials (5). These tests examined results by four ASTM tunnels, by the FPL small tunnel, and by the NBS radiant panel methods on the same materials.

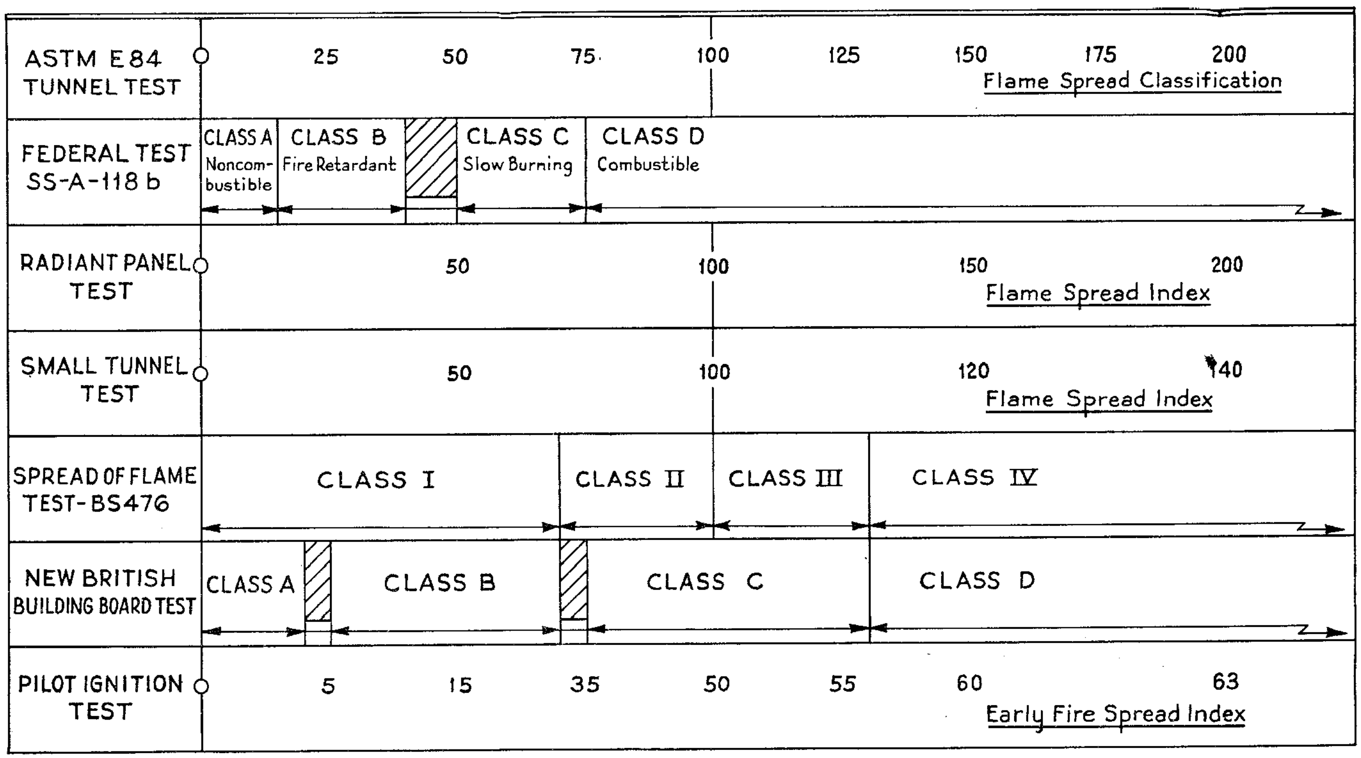
As this stage during which tests are being adopted for use by other agencies has occurred only in recent years, the need or nature of follow-up measures necessary to assure continued consistency of tests results by a given method has not been discussed.

The sponsors of the NBS radiant panel test have anticipated this situation to some extent by making available at nominal cost a standard sample for checking the operation and calibration of radiant panel test equipment.

RELATION OF RESULTS OF VARIOUS TESTS

There is no material which has been tested by all the listed methods in a formal comparison test program. From the

TABLE II.—APPROXIMATE RELATION OF CLASSIFICATIONS BY VARIOUS METHODS.



Spread of Flame (BS 476) and New British Building Board Test:

Both of these methods have been related to full- and one-fifth-scale room tests (11,13). The room was 12 ft wide by 18 ft long by 9 ft high; all walls were lined with the material under test, and the floor was untreated wood. The room contained a table, a cupboard, and several chairs, all of wood. In the models, the furniture was scaled but all parts were of sufficient size so they would not burn through prior to "flash-over." Flash-over is a condition occurring when the accumulation of heat in a room due to fire leads to the sudden involvement of most of the combustibles in the room. A comparison of data from limited full-scale tests and corresponding data from models showed the flash-over times resulting from the burning of both the furniture and the lining to be essentially similar. On this basis, models were used to obtain flash-over data for comparison with results obtained with both the BS 476 and new building board tests. In developing the latter, the several classifications were keyed directly to flash-over data. The classifications by the two methods and their corresponding flash-over time are as follows:

BS476 Test	
Class I	9 to 18 min
Class II–IV	5 to 9 min
New Building Board Test	
Class A	15 to 18 min
Class B	9 to 15 min
Class C	7 to 9 min
Class D	Less than 7 min

Pilot Ignition Test:

The Commonwealth Experimental Building Station in Australia utilized full- and $\frac{1}{4}$-scale room test, and a vertical spread of flame tests in connection with their development of the pilot ignition test (14). The room was 14 ft long by 12 ft wide by 9 ft high, with an adjoining 14 by 4-ft corridor. Exploratory tests for the proper exposure included wood cribs in the corner, different quantities of furniture, and a gas burner. The wood cribs would not produce uniform exposures. When furniture was used, some combinations were insufficient to involve a combustible lining, and others caused such severe exposure conditions that the effect of the linings would be difficult to observe. The final exposure selected was from a gas burner which created reproducible conditions equivalent to a moderate loading of furniture in the test room. The time for ignition of the wallboard, the rate of flame spread up the wall, and the rate and extent of spread across the ceiling were observed in each test. The wall temperatures resulting from this exposure in a room with noncombustible lining are those used in the pilot ignition test.

In the model tests, the same observations were made. Although some data recorded in both the full-scale and model rooms were comparable, it was difficult to observe ceiling flame spread rate. It was concluded that the models were not suitable for precise measurement of all fire phenomena.

The vertical spread of flame tests were made using apparatus similar to the pilot ignition test apparatus except that the specimen was 9 ft high by 21 in. wide and the radiant panel was 6 ft high by 1 ft wide. The specimen was moved toward the radiant panel so that it would be exposed to the same temperatures as those observed on the wall of the noncombustible lined test room. Time to ignition and rate of spread to the top were observed.

There was good correlation of vertical flame spread as measured in the experimental room, and as measured in the vertical spread of flame test, with the time to reach a specified radiation intensity with the pilot ignition apparatus. Ignition time from the two large tests checked well with those measured with the pilot ignition equipment. On the basis of this correlation, the pilot ignition apparatus is used to measure all three factors in the CEBS early flame spread index: namely, ignition time, vertical flame spread, and heat evolved.

The data in Table III show the relation between the early flame spread index derived from the pilot ignition test and actual results from the full-scale room tests.

Factory Mutual Large-Scale Tests:

In 1954 to 1955, large-scale tests were conducted on five composite constructions of graded combustibility which could be used on steel decks (17). The test structure was 100 ft long, 20 ft wide, and 10 ft high. A fire exposure approximating the ASTM standard time-temperature curve was created in the first 20-ft bay. Temperatures and rate and extent of flame spread down the structure were observed in a 30-min test.

In these large-scale tests, the rate of flame spread down the structure varied from the full 100-ft length in approximately 10 min to 60 ft in 30 min depending upon the composite construction tested. Since these large-scale tests, the FM calorimeter was developed and composite constructions identical to those used on the large structure were tested. The tests showed a direct relation between the burning rates from the calorimeter and the flame spread in the large-scale tests.

With (1) FM calorimeter burning rates for each of the large-scale test constructions, (2) the flame spread results from the large-scale tests, and (3) FM calorimeter burning rates for another construction not tested in the large-scale test structure, the extent and nature of flame spread may be predicted. To date, this test work has been limited in scope. It is hoped that the work will be extended to more commonly used interior trim materials in the near future.

TABLE III.—AUSTRALIAN PILOT IGNITION AND FULL-SCALE ROOM TEST RESULTS.

Material	Early Flame Spread Index	Time To Ignition	Time for Flame Spread to Ceiling
Soft fiberboard (with fire-resisting paint)	33	8 min	Did not reach ceiling
Soft fiberboard (with casein paint)	38	4 min	8 ft 6 in. in 2 min
Hardboard (with fire-retarding water paint and overcoat)	40	13½ min	5½ min
Hardboard (plain)	63	6 min	1½ min
Plywood veneer (with varnish)	80	6 min	15 sec

Danish Tests:

Although they cannot be readily related to the data presented in this paper at this time, a series of controlled full-scale and correlation tests sponsored by the Directorate of the Government Ships Inspection Service of Denmark and conducted in 1958 under the supervision of the National Testing Laboratory in Copenhagen is worthy of note (4).

The test structure consisted of a concrete enclosure 5.35 ft wide by 8 ft long by 7½ ft high with a doorway in one end representing a typical ship's cabin. This cabin opened into the side of a ship's corridor 3.3 ft wide by 7½ ft high by 33 ft long centered on the cabin door. The cabin door was of wood and was left ajar 5 in. as permitted by shipping regulations and the cabin was filled with dry spruce representing the normal combustible content of such a cabin. The corridor walls and ceiling were lined with the material under test, linoleum being used for the floor in all tests.

Tests were conducted on 12 lining materials including beech veneer plywood; Navilite, a noncombustible product; a painted wood surface with a 6-mm asbestos covering; and wood with various paint and plastic veneer surface treatments. Tests were conducted under identical conditions insofar as practicable and all were thoroughly documented including time to ignition of the corridor lining and time to flash-over.

TABLE IV.—DANISH SHIPS' CORRIDOR TEST RESULTS.

Material	Ignition Time, min:sec	Flash-Over Time, min:sec
Flat oil paint on wood	7:30 to 7:40	9:45
Untreated beech veneer plywood	7:15 to 8:20	11:20
Normal plast laminate	8:10 to 8:55	12:45
Normal plast laminate with asbestos cover	...	22:00
Froth producing (fire retardant) paint on wood	17:10 to 17:50	18:50

The several materials were also tested by Swedish, Danish, and the original Schlyter test methods so these test results could be compared with the full-scale tests.

In the full-scale tests, flash-over occurred in all except that with the noncombustible lining. As would be expected, the time of ignition and flash-over was dependent upon the combustibility of the materials tested. From the viewpoint of safety to life, one of the primary conclusions from the large-scale tests was that the fire hazard of the material is not as important as the extent to which the material must be heated before it is capable of maintaining a flame

The ignition and flash-over times for several of the tested materials are listed in Table IV as a matter of interest. No details are available on the exact nature of the linings tested.

In relating the results of the several laboratory methods with the large-scale tests, the testing authority made the following statement which is worthy of quoting: ". . . . . it would be premature to assign to any of the present laboratory methods for determining the more or less fire spreading character of materials an independent function as binding criterion for the purpose of approval in a schematic, rigidly defined system. By such a dogmatic overrating of measuring results, the significance and importance of which is not thoroughly known, there is a danger not only of increasing personal fire risk believed to be reduced, but also of side-tracking the development of suitable linings and ceilings."

SUMMARY

The ultimate goal in this field of endeavor is a complete knowledge of the surface flammability property of materials under varied fire conditions and appropriate methods to evaluate this surface flammability. This paper presents the current status of worldwide efforts to reach this goal. It is quite evident that although considerable thought and effort have already been devoted to this project, there is still much to be done. The accomplishments to date represent many uncoordinated approaches. The primary use of any method is for comparison of different materials or coatings and there have been limited efforts to relate test method results to actual fire conditions.

Several suggestions are presented here which it is believed will be helpful in reaching the ultimate goal. First, it is suggested that some form of clearing house be established to keep all interested agencies informed on all surface flammability

accomplishments. At the present time one must individually approach any test group he knows is active in this field to obtain data on its test work.

A steering program representing the best thought of groups and individuals in this field should be developed, kept up-to-date, and made available to guide and assist interested groups in taking steps toward the ultimate goal. Many individual efforts and diverse approaches presently in existence show a definite need for such a program.

Present activity with regard to the refinement of test methods and procedures for reproducible and consistent results by the same method and the correlation of results by different methods should be continued. It should not, however, be permitted to overshadow the collection, dissemination, and evaluation of test data and the development of a steering program.

These suggestions would all seem to be within the scope of ASTM Committee E 5 on Fire Tests of Materials and Construction. The collection of test data, their dissemination, and evaluation could be easily handled by task groups, each responsible for following the test activity of a given country or test agency. The committee is appropriately organized to develop a steering program and has representation from many agencies interested in reaching the ultimate goal. The committee is already active in reviewing correlation efforts on several test methods.

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