*Billy T. Lee*[1]

# Standard Room Fire Test Development at the National Bureau of Standards

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**ABSTRACT:** Research results with the proposed ASTM standard room fire test for interior finish materials are presented. The materials selected for the study were two untreated plywoods, a fire-retarded plywood, polystyrene, polyisocyanurate, and gypsum board. Three 900-s duration test scenarios were considered. Scenario A is a constant nominal 160-kW ignition source exposure. Scenario B achieves the same maximum exposure after three intervals of 30 s each in which the heat release rate is increased in equal steps of 40 kW. Scenario C evaluates a material over a 300-s exposure at a nominal 40 kW, with another 300-s exposure at a nominal 160 kW, followed by 300 s at zero exposure. This zero exposure allows the material to be screened for self-burning properties afterwards. The study demonstrated that all three scenarios could adequately differentiate material fire behavior, in terms of the maximum degree of fire buildup attained and the time to reach the maximum, for the materials selected. However, Scenario C would allow a more comprehensive evaluation of materials.

Thermal radiation incident on the floor and doorway air temperature were found to be the most consistent parameters for determining room fire buildup including room flashover. Surface flame spread and rate of heat release are discussed for the room fires.

**KEY WORDS:** fire growth, flame spread, heat release, interior finish, room fire, fire test method

Evidence shows that room fire testing offers the only means for satisfactorily measuring the fire hazards of some synthetic foam materials [*1,2,3*]. In order for these foamed plastic materials to be accepted by the codes, they either have to be covered with a barrier layer equivalent to 12.7-mm-thick gypsum board or, if they are to be exposed, their fire safety must be demon-

[1]Fire prevention engineer, Center for Fire Research, National Bureau of Standards, Gaithersburg, MD 20899.

strated by a full-scale room fire test. In the model code of the International Conference of Building Officials (ICBO), a particular room fire test was specified for this purpose [*4*]. A task group was then set up to develop a modified version of this ICBO test which would be acceptable as an ASTM standard test method. A proposed method has been published in the grey pages of the 1982 ASTM Annual Book of Standards [5] for information purposes. In addition to requirements regarding the room and ignition exposure, the method specifies a hood outside the doorway to collect all of the exhaust gases in order to provide information on the rates of heat, smoke, and toxic gas production. Before the test method can be accepted as an ASTM standard, a suitable heat release rate scenario for the ignition source has to be agreed upon, and intralaboratory and interlaboratory evaluations of repeatability and reproducibility must be conducted.

Eventually, room fire tests could be replaced with a mathematical model which could predict fire development for other room sizes and configurations and ignition conditions. Prerequisite to this approach is the need for an improved understanding of surface flame spread and its relation to the thermal environment in the room.

The objectives of the present project and of this paper are:

1. To evaluate the effects of three different heat release rate scenarios for the ignition source on the room fire behavior of a variety of interior finish materials having a broad range of fire properties.
2. To evaluate the various methods used for determining room flashover, an event representing a transition from a fire in which the flame spread normally can be confined to the room of fire origin to a fire which could readily involve the active burning of adjoining spaces and, eventually, of the entire structure.
3. To provide surface flame spread data from room fires as a function of the degree of fire development in the room.
4. To help evaluate the practicality of the operational procedure recommended in the proposed standard.

## Experimental

### *Test Room and Exhaust Hood*

The test room is constructed in accordance with the proposed ASTM method [5]. A hood to collect the effluent from the room is located above the door. This hood has horizontal dimensions of 3.7 × 4.9 m and discharges into a 1.2-m square duct. The ducting is comprised of an initial upward section, then a downward portion, and finally another upward section. Measurement of heat release rate and smoke are made in the downward flow portion. The collection system was calibrated for the rate of heat release measurement using a diffusion burner, 0.305 m on each side, installed under the hood. For a rate of about 250 kW, weight loss of propane and volumetric measurement of propane with a rotameter were used to calibrate the hood. The accuracy of the rotameter was verified to within 3% using both wet and dry gas displacement meters. Both weight loss and volumetric readings indicated a calibration factor of about 0.70 for the hood measurement. For rates up to 4 MW, an orifice meter made to the American Gas Association and American Society of Mechanical Engineers (ASME) specifications and the building displacement gas meter were used with natural gas to calibrate the hood. A calibration factor of 0.70 also was found for the higher rates. Accordingly, the heat release rate values reported for the room fires have been adjusted by a factor of 0.70 to match the calibration data. The cause for this systematic behavior is being investigated.

The response time for the rate of heat release measurement is a composite of the transport time for the effluent to reach the gas sampling location, the transport time of the gas sampling system itself, and the response time of the individual analyzers as well as the response time of the electronic filters used on pressure transducers which monitor the Pitot-static tubes. Babrauskas [*6*] gives a discussion of various methods of correcting for the time delays before choosing a delay of 30 s as a reasonable approximation. Data on heat release as a function of time have been adjusted by subtracting 30 s to correct for the system response time.

The heat release rate from the room fire tests was measured using the oxygen consumption technique [*7*] which is based on the measurements of gas concentrations and mass flow in the exhaust duct. The hood also was used to quantify smoke from the room fires in terms of a critical cross section which is based on optical density and mass flow measurements in the hood duct [*8*].

### *Test Materials*

In the assessment of a fire test method, it is desirable to use materials having a diverse range of fire properties. Six materials having significantly different flame spread behavior and heats of combustion were used in this study. These materials are indicated in Table 1. The 5.6-mm plywood was similar to that used in the room fire test at the University of California [*9*] and was used to assess the reproducibility between the two facilities for this material.

### *Test Procedure*

The test specimen fully covered the back wall, the two side walls, and the ceiling. With the specimen in place, the interior dimensions were in conformance with the recommended standard room size of 2.44 ± 25 mm by 3.66 ± 25 mm by 2.44 ± 13 mm high. The specimen was backed with 13-mm gypsum board. For the foam plastics, the specimen was glued to the gypsum

TABLE 1—*Interior finish materials used in standard room fire test.*

| Material | Measured Thickness, mm | Density, kg/m$^3$ |
|---|---|---|
| Polystyrene | 50.8 | 30 |
| Polyisocyanurate | 50.8 | 33 |
| Gypsum board | 13.2 | 757 |
| Plywood 1 | 5.6 | 586 |
| Plywood 2 | 12.8 | 534 |
| Fire-retarded plywood | 13.1 | 545 |

board using 3M-2226 adhesive made by the 3M Corporation.[2] For the 5.6-mm plywood, the room construction replicated that used in the University of California test.

The relative humidity in the fire room was controlled with a humidifier to within 42 and 55% for at least 24 h prior to the test. The temperature of the laboratory was controlled so that the test room was maintained within the proposed test conditions of 21 ± 3°C.

A 305 by 305 by 305-mm high propane gas diffusion flame burner in one back corner served as the ignition source. The flux levels on the back wall over the burner, at the 1.22 and 1.83-m heights above the floor and 0.15 m away from the corner, are given in Table 2 for the burner operating at the nominal 160 kW setting in the room lined with fire-exposed gypsum board. The flux levels in Table 2 can be used as a check on the reproducibility of the ignition source intensity when such tests are repeated at other facilities. The measurement of thermal flux can be affected by condensation of water vapor on the fluxmeter surface. The use of hot water, for example, above 50°C as coolant for the fluxmeter would alleviate this problem. The data in the table showed that flux levels were 5 to 8% higher with the coolant water at 70°C than those levels when 18°C water was used.

TABLE 2—*Average flux levels on back wall of room at 1.22-m and 1.83-m heights over burner.*

| Water Temperature for Cooling Fluxmeter, °C | 1.22-m Height Flux Level, kW/m$^2$ | 1.83-m Height Flux Level, kW/m$^2$ |
|---|---|---|
| 18 | 59 | 52 |
| 70 | 62 | 56 |

NOTES—
1. Wall and ceiling finish were fire-exposed gypsum board.
2. In each run, the burner operated at a constant 160 kW for 300 s. Measurements were taken between 180 and 300 s.
3. Average values were based on four runs with 18°C water and four runs with 70°C water.

[2]The use of trade names does not constitute endorsement by the National Bureau of Standards.

Three ignition exposure scenarios, each producing a maximum nominal value of 160 kW net[3] rate of heat release, were considered. This rate corresponded to a nominal propane flow rate of 1.84 L/s (actual rate of 2.06 L/s) at 20°C and 100 kPa. Scenario A was a constant 160 kW maintained for 900 s and was chosen to evaluate the effect of a severe sudden thermal insult on materials. Scenario B, proposed by Task Group 1 of ASTM E 5.13 in 1982, started at 0.25 of its maximum value, increased to 0.50 of its maximum at 30 s, to 0.75 of its maximum at 60 s, to its maximum in 90 s and was maintained at that level to 900 s. This scenario was chosen to evaluate the effect of having an increasingly severe fire exposure on materials. Scenario C started with 0.25 of its maximum value, maintained for 300 s, increased to the maximum for another 300 s, and the ignition source was then turned off for the final 300-s period. Scenario C was selected to evaluate the effect of a longer low fire exposure on materials, particularly char-forming materials such as wood, and to examine their subsequent behavior under a severe fire exposure. This scenario also allowed an evaluation of the self-sustained fire spread characteristics of materials.

Measurements described in the proposed room fire test method [5] were recorded continuously. Time-lapse photography and continuous video coverage of the burner flame and adjacent walls and ceiling were taken to allow mapping of the surface flame spread as a function of time. Prior to room flashover, the degree of fire buildup was measured by the maximum air temperatures reached near the ceiling and near the top of the doorway and by the thermal flux incident on the floor. For the determination of room flashover, five criteria were used. These criteria were based on the times of occurrence for:

1. Flameover, defined here as the emergence of flames from the doorway ($t_F$).
2. The ignition of crumpled newspaper on the floor ($t_{FO}$),
3. The attainment of a heat flux of 20 kW/m$^2$ on the floor ($t_{\text{Floor}}$),
4. The attainment of 600°C average air temperature near the ceiling ($t_I$).
5. The attainment of 600°C average air temperature near the top of the doorway ($t_D$).

## *Room Fire Tests*

Fifteen tests were performed and are outlined in Tables 3 and 4 along with their ambient test conditions. Except for the untreated plywoods, each material was subjected to all three ignition exposure scenarios. The 5.6-mm plywood was used only to check on the reproducibility between tests conducted at the National Bureau of Standards and at the University of California [*9*] using

[3]Recalibration indicated that all of the ignition exposures were 12% higher than the nominal values.

TABLE 3—*Summary of standard room fire test results.*

| | | | Occurrence Time for Flashover Indicators in Seconds | | | | | |
|---|---|---|---|---|---|---|---|---|
| Test No. | Material | Exposure | Flameover, $t_F$ | Newspaper Ignition[a], $t_{FO}$ | Floor Flux[b], 20 kW/m², $t_{Floor}$ | Interior Air Temperature 600°C, Average[c], $T_I$, $t_I$ | Doorway Air Temperature 600°C, Average[c], $T_{D20}$ and $T_{D2}$: $t_{D20}$ | $t_{D2}$ |
| 1B | gypsum board | A | none | none | (4.5 kW/m², 740 s) | none | none | none |
| 2 | gypsum board | B | none | none | (3.5 kW/m², 870 s) | none | none | none |
| 3B | gypsum board | C | none | none | (3.2 kW/m², 600 s) | none | none | none |
| 15 | fire-retardant treated plywood | A | 861 | [d]B, 861 F | 847 | 163 | 851 | 229 |
| 4 | fire-retardant treated plywood | A | none | [e]B, none F | (13.8 kW/m², 900 s) | 186 | 300 | 218 |
| 6 | fire-retardant treated plywood | B | none | 483 B, 568 F | (18.5 kW/m², 510 s) | 431 | 469 | 509 |
| 5 | fire-retardant treated plywood | C | none | 528 B, [e]F | (16.1 kW/m², 580 s) | 387 | 528 | 424 |
| 7 | Plywood 2 | C | 193 | 206 B, 209 F | 195 | 169 | 200 | 215 |
| 8 | Plywood 1 | B | 134 | 143 B, 165 F | 140 | 101 | 137 | 141 |
| 10 | polystyrene | A | 48 | 39 B, 40 F | [f] | 47 | 50 | 48 |
| 11 | polystyrene | B | 83 | 80 B, 82 F | 71 | 74 | 83 | 84 |
| 12 | polystyrene | C | 110 | 107 B, 109 F | 101 | 105 | 112 | 106 |
| 9 | polyisocyanurate | A | 14 | 15 B, 16 F | 19 | 23 | 28 | 22 |
| 13 | polyisocyanurate | B | 50 | 51 B, 52 F | 42 | 45 | 52 | 46 |
| 14 | polyisocyanurate | C | 312 | 314 B, 315 F | 315 | 312 | 315 | 313 |

[a] Back and front newspaper flashover indicators denoted by B and F, respectively.
[b] Maximum flux and its time of occurrence given in parenthesis.
[c] Average interior temperature $T_I$ based on eight 0.51-mm thermocouples located 0.10 m down from ceiling. $T_{D20}$ based on the average of two 0.51-mm thermocouples located 0.10 m down from top of doorway. $T_{D2}$ based on 0.05-mm thermocouple at same location.
[d] Back indicator ignited prematurely by falling embers.
[e] Newspaper discolored due to heating.
[f] Resolution inadequate.

TABLE 4—*Summary of standard room fire test results.*

| Test No. | Material | Exposure | Rate of Heat Release at $t_{Floor}$, MW | Peak Rate of Heat Release and Time | | Peak $T_I$ and Time | | Peak $T_{D20}$ | | Ambient Conditions: Temperature | | Ambient Conditions: Relative Humidity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | MW | s | °C | s | °C | s | °C | °F | % |
| 1B | gypsum board | A | none | 0.3 | 70 | 400 | 60 | 325 | 780 | 19 | 67 | 45 |
| 2 | gypsum board | B | none | 0.2 | 840 | 395 | 120 | 305 | 880 | 21 | 70 | 42 |
| 3B | gypsum board | C | none | 0.2 | 560 | 405 | 350 | 320 | 360 | 19 | 66 | 52 |
| 15 | fire-retardant treated plywood | A | 2.1 | 6.2 | 860 | 865 | 890 | 810 | 900 | 23 | 73 | 51 |
| 4 | fire-retardant treated plywood | A | none | 0.5 | 260 | 715 | 260 | 600 | 300 | 23 | 73 | 42 |
| 6 | fire-retardant treated plywood | B | none | 0.6 | 480 | 745 | 487 | 640 | 530 | 21 | 70 | 47 |
| 5 | fire-retardant treated plywood | C | none | 0.5 | 480 | 720 | 468 | 610 | 530 | 22 | 71 | 48 |
| 7 | Plywood 2 | C | 1.7 | 6.7 | 260 | 930 | 340 | 895 | 360 | 21 | 70 | 51 |
| 8 | Plywood 1 | B | 1.9 | 8.5 | 260 | 850 | 312 | 860 | 180 | 21 | 70 | 55 |
| 10 | polystyrene | A | [a] | 9.4 | 100 | 1050 | 75 | 930 | 60 | 21 | 70 | 48 |
| 11 | polystyrene | B | 4.2 | 4.2 | 70 | 1015 | 86 | 800 | 90 | 22 | 71 | 50 |
| 12 | polystyrene | C | 3.1 | 3.5 | 110 | 970 | 120 | 940 | 120 | 22 | 71 | 48 |
| 9 | polyisocyanurate | A | 2.2 | 5.2 | 50 | 1200 | 80 | 1245 | 100 | 21 | 70 | 54 |
| 13 | polyisocyanurate | B | 2.9 | 4.3 | 50 | 1065 | 60 | 1040 | 60 | 22 | 72 | 55 |
| 14 | polyisocyanurate | C | 3.2 | 4.1 | 310 | 1095 | 320 | 1020 | 320 | 24 | 75 | 47 |

[a] Resolution inadequate.

ignition Scenario B. For the 12.8-mm plywood, only Scenario C was considered. This exposure was expected to produce the most charring of the three ignition scenarios and thus could best be used to show the subsequent behavior of charred plywood when subjected to the maximum exposure of 160 kW.

## Results and Discussion

### *Effect of Heat Release Rate Scenarios on Fire Development*

One would expect that as the ignition exposure increases in severity from Scenarios C to A, the peak values of heat release rate, air temperatures, and thermal radiation also would increase with decreasing times of occurrence. An examination of Tables 3 and 4 shows that this was generally the case if one were to ignore small variations in the data and even large variations in the data once flashover has occurred. Post flashover conditions become more a function of the burning behavior of the room lining material than of the ignition source.

The different ignition scenarios gave erratic results for the fire-retardant treated plywood. This was partly due to the difficulty in the conditioning of the material over a reasonable period of time and possibly partly due to a difference in composition or a nonuniformity in fire-retardant treatments between different panels of the material.

Test 8 with the 5.6-mm plywood was the same as Test C-213 conducted at the University of California [*9*]. However, Test 8 resulted in a more rapid fire buildup than C-213, mainly because the ignition exposure in Test 8 was found to be 12% higher than that used in Test C-213. Both tests used an AD-type plywood obtained separately from neighborhood lumber yards. A comparison of results from the two tests is given in Table 5. Differences between the two plywoods also may have accounted for some of the difference in fire buildup times between Test C-213 and Test 8. It should be noted that the difference was also within the experimental repeatability expected between similar runs.

TABLE 5—*Comparison of data between National Bureau of Standards (NBS) and University of California (UC) for room fire tests of plywood.*

| Test | Time of Occurrence | | | | Rate of Heat Release at Flashover Based on $t_{Floor}$, $Q$ (MW) |
|---|---|---|---|---|---|
| | Flameover, $t_F$(s) | Ignition of Newspaper, $t_{FO}$(s) | 20 kW/m$^2$ Flux at Floor, $t_{Floor}$(s) | 600°C Avg Interior Air Temperature, $t_I$(s) | |
| C-213 (UC) | 170 | 210 | 205 | 115 | 2.1 |
| 8 (NBS) | 134 | 165 | 140 | 101 | 1.9 |

*Comparison of Various Methods for Determining Flashover*

Flashover is defined here as the event in which the thermal radiation level becomes high enough to ignite light combustible materials, such as newspaper, in the lower part of the room. This corresponds to thermal radiation levels on the floor of about 20 kW/m$^2$. The five criteria discussed in the Test Procedure section for determining the occurrence of room flashover were applied to the room fire tests performed under this study. The results are shown in Table 3 under headings of $t_F$, $t_{FO}$, $t_{\text{Floor}}$, $t_I$, and $t_D$. All five criteria are consistent with each other for severe room fires. For moderately severe fires, one or more criteria might not be satisfied.

The application of each of these criteria has its own problems. Flameover may not always occur for the situation where there is sufficient thermal radiation to ignite combustible items in the lower part of the room. Accidental ignition of the newspaper indicators could occur. Materials separating from the ceiling and falling over the flux meters, thereby either obscuring or transferring additional heat to the fluxmeters, are also possibilities. Local heating and flame contact can occur at some of the thermocouples near the ceiling, resulting in readings that are higher than average with consequent premature times for flashover. For example, in Tests 7, 8 and 15, the times for $t_I$ were much too soon compared with the times for $t_F$, $t_{FO}$, $t_{\text{Floor}}$, and $T_D$. The hot air inside the room usually becomes well mixed by the time it is exhausted through the doorway. Consequently, the peak doorway air temperature may be a more reliable indicator of the fire buildup than is the interior air temperature.

As there are many problems that can arise in determining flashover, it is necessary to have more than one reliable method for monitoring flashover. Analysis of Table 3 indicates that the most reliable flashover indicators are the incident flux on the floor, the newspaper indicator, and the doorway temperature. For determining the degree of fire buildup short of flashover, obviously the newspaper indicator is not useful. Thus, for most applications, the floor flux and the doorway temperature are the most suitable.

*Flame Spread Patterns*

Figure 1 shows the flame spread patterns at selected times for Test 7, but these patterns are typical for all of the room fire tests except for their times of occurrence. Only the flame spread along those portions of the back wall and ceiling, which could be viewed through the doorway, was actually observed. The remaining portions of each profile shown had to be estimated based on past experience with room fire testing of interior finish materials. This is part of an effort to better understand surface flame spread and its relation to the thermal environment in the room and will be discussed further for another publication.

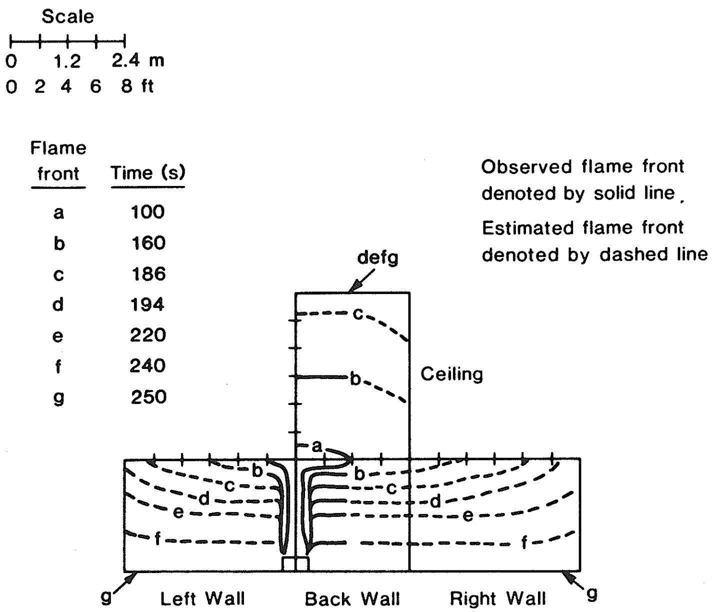


FIG. 1—*Flame spread profiles for Test 7 (Plywood 2, Exposure C).*

## *Heat Release Measurements*

The rate of heat release histories for Tests 7 to 15 are shown in Figs. 2 to 4. For the gypsum board tests, these rates were basically the same as those for the propane burner. With measurement accuracies of ±50 kW, the rate histories for Tests 1B to 3B for gypsum board would not be meaningful and thus were not included. For the fire-retardant treated plywood, the peak rates in Tests 4 to 6 were an order of magnitude lower than that for Test 15. Consequently, the rate of heat release history is given only for Test 15. In every test, the fire was not extinguished until the peak fire development had passed. Peak rates and the rates occurring at the time $t_{\text{Floor}}$, when 20 kW/m$^2$ was measured at the floor, are presented in Table 4. For the plywood materials, the rates at time $t_{\text{Floor}}$ ranged from 1.7 to 1.9 MW. This was consistent with a value of 2.1 MW found for plywood tested at the University of California [*9*].

Integrating the rates of heat release shown in Figs. 2 to 4 over time gave the total heat produced in each fire test. In Table 6, this total heat was compared with that calculated from the weight loss of the test material multiplied by the net heat of combustion and by the combustion efficiency for the material. The net heat is equal to the gross heat minus the heat of vaporization of water.

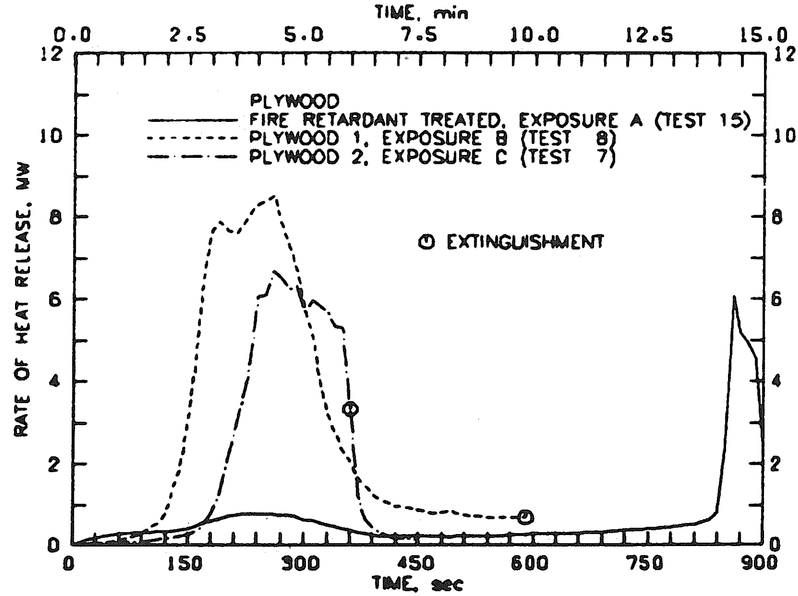


FIG. 2—*Rate of heat release history for plywood.*

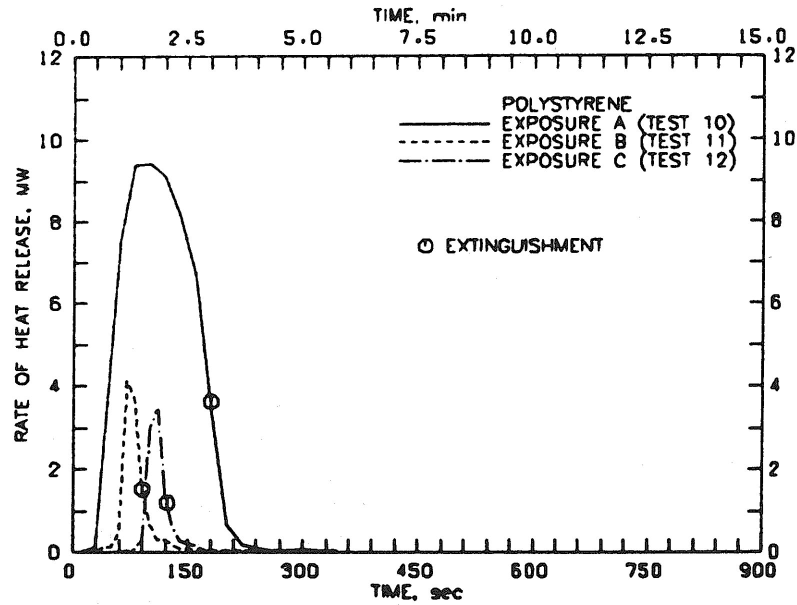


FIG. 3—*Rate of heat release history for polystyrene.*

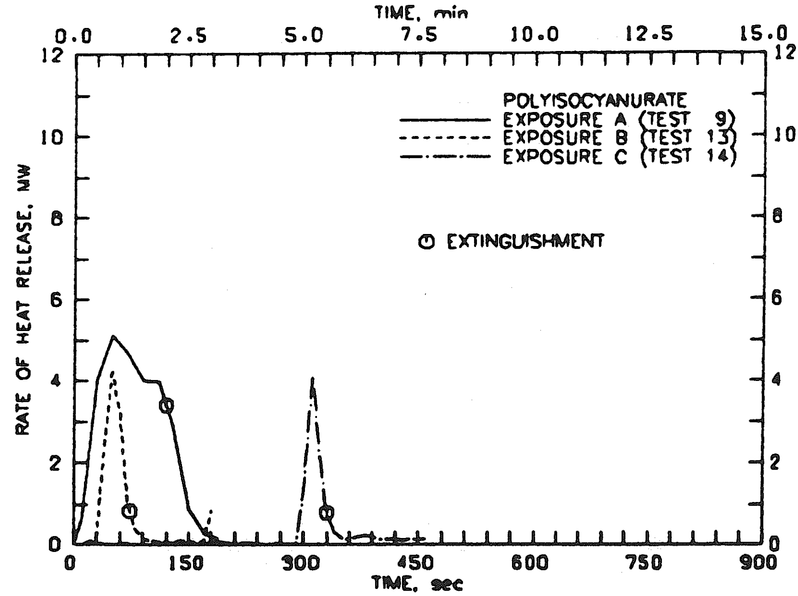


FIG. 4—*Rate of heat release history for polyisocyanurate.*

## *Recommended Changes in Test Procedure*

In the test series, C.P. grade propane was used in lieu of commercial grade to avoid fractionation problems. Any additional cost and inconvenience were minor as one 45-kg bottle would last for about twelve tests, and the increased expense per test was insignificant compared with the material and labor involved. The present proposed standard room fire test method called for thermocouples, mounted on supports, to be located 100 mm down from the center of the ceiling and from the center of each of the four ceiling quadrants and from the ceiling directly over the center of the ignition burner. The method cautioned against attachments to the specimens. However, for the 15 tests conducted in this study, 6.4-mm holes were drilled through the ceiling at these positions for the thermocouples and then resealed with gypsum spackling compound. No adverse effects on the fire development due to these penetrations in the ceiling was observed. The proposed test method suggested either photographic coverage or video taping to record the fire spread in the room. Both methods were used in this study. When time-lapse coverage such as with 35-mm color slides was used, the flame spread and even the ignition of the newspaper flashover indicators could not be determined in some instances due to obscuration from the smoke and glare of the fire. Continuous coverage made such determinations much easier. Consequently, it is recommended that C.P. grade propane, thermocouple penetration of the ceiling, and video

TABLE 6—*Comparison of total heat release from room tests with values calculated from mass loss.*

| Test No. | Material | Original Weight, kg | Weight Loss, kg | Combustion Efficiency | Calculated Net Heat Release, $Q_N$ (MJ) | Measured Net Heat Release, $Q_s$ (MJ) |
|---|---|---|---|---|---|---|
| 15 | fire-retardant treated plywood | 233.1 | 69.2 | <1.0 | <1050 | 620 |
| 7 | Plywood 2 | 222.6 | 65.1 | 1.0 | 980 | 890 |
| 8 | Plywood 1 | 107.1 | 107.1 | 1.0 | 1620 | 1490 |
| 10 | polystyrene | 49.3 | 49.3 | 0.59 | 1110 | 1010 |
| 11 | polystyrene | 49.3 | 11.9 | 0.59 | 270 | 130 |
| 12 | polystyrene | 49.3 | 5.9 | 0.59 | 130 | 100 |
| 9 | polyisocyanurate | 55.4 | 25.3 | 0.53 | 350 | 500 |
| 13 | polyisocyanurate | 55.4 | 8.3 | 0.53 | 110 | 130 |
| 14 | polyisocyanurate | 55.4 | 8.4 | 0.53 | 120 | 110 |

NOTES—

1. Lining material in Tests 1B, 2, 3B, 4, 5, and 6 did not burn well. Consequently, measurements of total heat and mass loss would not be accurate and were not included.
2. Net heat of combustion of 15.1 MJ/kg for treated and untreated plywood.
3. Net heat of combustion of 38 MJ/kg for Polystyrene Foam GM 47 in Ref *10* used for polystyrene.
4. Net heat of combustion of 26 MJ/kg for Polyisocyanurate Foam 29 in Ref *10* used for polyisocyanurate.
5. Combustion efficiencies for polystyrene and polyisocyanurate from Ref *11*.
6. $Q_N$ = weight loss × net heat of combustion × combustion efficiency.
7. $Q_s$ = integrated value of room heat release rate history.

tape or more complete time-lapse photographic coverage be adopted in any new test procedure.

## Concluding Remarks

1. The study demonstrated that all three exposure conditions could adequately differentiate material fire behavior for the materials evaluated when the test material covers the walls and ceiling of the room. Consequently, each condition could be used to indicate the fire safety level for room interior finish materials. However, ignition Scenario C has advantages over Scenarios A and B in that materials can be evaluated and rated over a reasonable length of time of 300 s at a low exposure of about 40 kW/m$^2$, 300 s at a high exposure of about 160 kW/m$^2$, and then over another 300-s period for self-burning without enhancement from the burner source. Scenario A cannot evaluate interior finish materials at low exposures nor self-burning properties of materials. Scenario B included four successive exposure levels, but the period of change from lowest to highest exposures lasted only 90 s. This may not be adequate time to evaluate some materials at the lower exposures. Furthermore, no evaluation of self-burning was included.

2. The three exposure conditions will be evaluated further with tests using the same materials lining only the walls and gypsum board on the ceiling. Ignition Scenario A also will be evaluated for these materials lining just the ceiling, with gypsum board lining the walls.

3. In determining the degree of fire buildup, including room flashover, measurements of the incident flux on the floor and of the air temperature near the top of the doorway are recommended. Flameover time, newspaper indicators, and interior air temperatures either cannot determine the degree of fire buildup or are less reliable.

4. Flame spread in the fire room is difficult to follow with time-lapse photography in intervals of 15 to 30 s. Shorter intervals of 1 or 2 s or continuous video coverage is recommended during the rapid fire growth period.

5. In this study, there was a reasonable agreement between the total heat release measured by oxygen consumption and the heat calculated from the mass loss of the materials in the fire.

6. It is recommended that the proposed standard room fire test method be amended to adopt the use of C.P. grade propane in lieu of commercial grade to avoid fractionation in the burner fuel and to allow thermocouple penetration of the ceiling for measurement of air temperature near the ceiling.

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# DISCUSSION

*R. B. Williamson*[1] *(written discussion)*—An evaluation of Table 5, which compares the results of plywood tests conducted both by the University of California Fire Research Laboratory and by the National Bureau of Standards Center for Fire Research, indicates that the time of occurrence of all parameters is shorter for the experiment conducted at the National Bureau of Standards than at the University of California Fire Research Laboratory. I believe the cause of this may be linked to a higher burner ignition source rate of heat release in the National Bureau of Standards experiments than in our experiments at the University of California Fire Research Laboratory. Our measurements of rate of heat release during burner calibration experiments gave very good correlation between propane gas flow rate to the burner versus net energy release rates measured by oxygen consumption.

This paper indicates that their rate of heat release measurement derived from oxygen consumption required a correction factor of 0.704 to match the predicted rate of heat release from propane gas flow measurements.

It may be quite possible that their error is not in the measurement of heat release by oxygen consumption but in their measurement of propane gas input to the ignition source burner.

*B. T. Lee (closure)*—A recalibration of the flowmeter used for metering the propane to the burner indicated that the heat release rate values for the burner were 12% higher than originally believed. This would have contributed to the differences between the plywood tests conducted at the National

[1]Professor of engineering science, Department of Civil Engineering, University of California, Berkeley, Richmond, CA 94804.

Bureau of Standards (NBS) and the University of California (UC). However, the calibration of the hood at NBS for rate of heat release measurement was accomplished using several different techniques, one of which was the measurement of weight loss of propane in the 250 kW range as was done in the UC calibration. The calibration factor for the NBS hood was about 0.70 in every case. Differences in calibration factors between the NBS and UC hoods are due to differences in the construction of the hood ducting where the measurements of flow and oxygen levels are made. UC has a straight vertical duct. NBS has a complex duct with four short 90 degree bends, complicating flow measurements. A more complete description of our hood system and an elaboration of the various means used to calibrate our hood have been incorporated into the section entitled Test Room and Exhaust Hood.