Standard Test Method for
Radiant Heat Resistance of Flame Resistant Clothing Materials with Continuous Heating[1]

1. Scope

1.1 This test method rates the non-steady state thermal resistance or insulating characteristics of flame resistant clothing materials subjected to a continuous, standardized radiant heat exposure.

1.1.1 This test method is not applicable to clothing materials that are not flame resistant.

NOTE 1—The determination of a clothing material's flame resistance shall be made prior to testing and done in accordance with the applicable performance standard, specification standard, or both, for the clothing material's end-use.

1.1.2 This test method does not predict skin burn injury from the standardized radiant heat exposure as it does not account for the thermal energy contained in the test specimen after the exposure has ceased.

NOTE 2—See Appendix X4 for additional information regarding this test method and predicted skin burn injury.

1.2 This test method is used to measure and describe the response of materials, products, or assemblies to heat under controlled conditions, but does not by itself incorporate all factors required for fire hazard or fire risk assessment of the materials, products, or assemblies under actual fire conditions.

1.3 The values stated in SI units are to be regarded as standard. The values given in parentheses are mathematical conversions to inch-pound or other units that are commonly used for thermal testing.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D123 Terminology Relating to Textiles

D1776 Practice for Conditioning and Testing Textiles

D1777 Test Method for Thickness of Textile Materials

D3776 Test Methods for Mass Per Unit Area (Weight) of Fabric

E457 Test Method for Measuring Heat-Transfer Rate Using a Thermal Capacitance (Slug) Calorimeter

F1494 Terminology Relating to Protective Clothing

2.2 *ASTM Special Technical Publication:*

ASTM Report, "ASTM Research Program on Electric Arc Test Method Developments to Evaluate Protective Clothing Fabric; ASTM F18.65.01 Testing Group Report on Arc Testing Analysis of the F1959 Standard Test Method-Phase I"

ASTM Manual 12 Manual on the Use of Thermocouples in Temperature Measurement

3. Terminology

3.1 *Definitions:*

3.1.1 *break-open, n—in testing thermal protective materials,* a material response evidenced by the formation of a hole in the test specimen during the thermal exposure that may result in the exposure energy in direct contact with the heat sensor.

3.1.2 *charring, n—*the formation of a carbonaceous residue as the result of pyrolysis or incomplete combustion.

3.1.3 *dripping, n—*a material response evidenced by flowing of the polymer.

3.1.4 *embrittlement, n—*the formation of a brittle residue as a result of pyrolysis or incomplete combustion.

3.1.5 *heat flux, n—*the thermal intensity indicated by the amount of energy transmitted divided by area and time; kW/m^2 (cal/cm^{2}s).

3.1.6 *ignition, n*—the initiation of combustion.

3.1.7 *melting, n*—a material response evidenced by softening of the polymer.

3.1.8 *non-steady state thermal resistance, n*—in testing of *thermal protective materials*, a quantity expressed as the time-dependent difference between the incident and exiting thermal energy values normal to and across two defined parallel surfaces of an exposed thermal insulative material.

3.1.9 *radiant heat resistance (RHR), n*—in testing of *thermal protective materials*, the cumulative amount of thermal exposure energy identified by the intersection of the measured time-dependent heat transfer response through the subject material to a time-dependent, empirical performance curve, expressed as a rating or value; kJ/m^2 (cal/cm^2).

3.1.10 *response to heat exposure, n*—in testing the thermal *resistance of thermal protective materials*, the observable response of the material to the energy exposure as indicated by break-open, melting, dripping, charring, embrittlement, shrinkage, sticking, and ignition.

3.1.11 *shrinkage, n*—a decrease in one or more dimensions of an object or material.

3.1.12 *sticking, n*—a material response evidenced by softening and adherence of the material to the surface of itself or another material.

3.1.13 For the definitions of protective clothing terms used in this method, refer to Terminology F1494, and for other textile terms used in this method, refer to Terminology D123.

4. Summary of Test Method

4.1 A vertically positioned test specimen is exposed to a radiant heat source with an exposure heat flux of either (*a*) 21 kW/m^2 (0.5 cal/cm^{2}s) or (*b*) 84 kW/m^2 (2 cal/cm^{2}s).

NOTE 3—Other exposure heat flux values are allowed. The test facility shall verify the stability of the exposure level over the material's exposure time interval (used to determine the radiant heat resistance value) and include this in the test results report.

4.2 The transfer of heat through the test specimen is measured using a copper slug calorimeter. The change in temperature versus time is used, along with the known thermophysical properties of copper to determine the respective thermal energy delivered.

4.3 A Radiant Heat Resistance rating of the test specimen is determined as the intersection of the time-dependent cumulative radiant heat response as measured by the calorimeter to a time-dependent, empirical performance curve identified in 10.9.

4.4 Subjective observations of the thermal response of tested specimens are optionally noted.

5. Significance and Use

5.1 This test method is intended for the determination of the radiant heat resistance value of a material, a combination of materials, or a comparison of different materials used in flame resistant clothing for workers exposed to radiant thermal hazards.

5.2 This test method evaluates a material's heat transfer properties when exposed to a continuous and constant radiant heat source. Air movement at the face of the specimen and around the calorimeter can affect the measured heat transferred due to forced convective heat losses. Minimizing the air movement around the specimen and test apparatus will aid in the repeatability of the results.

5.3 This test method maintains the specimen in a static, vertical position and does not involve movement, except that resulting from the exposure.

5.4 This test method specifies two standard sets of exposure conditions: 21 kW/m^2 (0.5 cal/cm^{2}s) and 84 kW/m^2 (2.0 cal/cm^{2}s). Either can be used.

5.4.1 If a different set of exposure conditions is used, it is likely that different results will be obtained.

5.4.2 The optional use of other conditions representative of the expected hazard, in addition to the standard set of exposure conditions, is permitted. However, the exposure conditions used must be reported with the results along with a determination of the exposure energy level stability.

5.5 This test method does not predict skin burn injury from the standardized radiant heat exposure.

NOTE 4—See Appendix X4 for additional information regarding this test method and predicted skin burn injury.

6. Apparatus and Materials

6.1 *General Arrangement*—The apparatus consists of a vertically oriented radiant heat source, specimen holder assembly, protective shutter, sensor assembly, and data acquisition/analysis system. The general arrangement of the radiant heat source, specimen holder, and protective shutter of a suitable apparatus is shown in Fig. 1.

6.1.1 *Radiant Heat Source*—A suitable, vertically oriented radiant heat source is shown in Fig. 1. It consists of a bank of five, 500 W infrared, tubular, translucent quartz lamps having a 127-mm (5.0-in.) lighted length and a mean overall length of 222 mm (8¾ in.). The lamps are mounted on 9.5 ± 0.4-mm (3/8 ± 1/64-in.) centers so that the lamp surfaces are approximately 0.4-mm (1/64-in.) apart. The bank or array of lamps are mounted and centered behind a 63.5 by 140-mm (2½ by 5½-in.) cut-out that is positioned in the center of a 12.7-mm (½-in.) thick, 86-mm (3⅜-in. wide, by 292-mm (11½-in.) long high temperature insulating board as shown in Fig. 2. The quartz lamps shall be heated electrically, and the power input controlled by means of a rheostat or variable power supply having a capacity of at least 25A.

6.1.1.1 Setting and monitoring the voltmeter readout on a voltage-controlled variable power supply is one method to calibrate and monitor the exposure level during the testing on a system so equipped. A voltmeter, accurate to ±1 V, is typically installed with the appropriate load circuit to indicate lamp operating power.

6.1.1.2 Any covers or guards installed on the quartz lamp assembly shall be designed such that any convective energy generated is not allowed to impinge on the sample specimen (vertical, umimpeded ventilation is required.)

NOTE 5—Radiant measurement systems designed with closed lamp

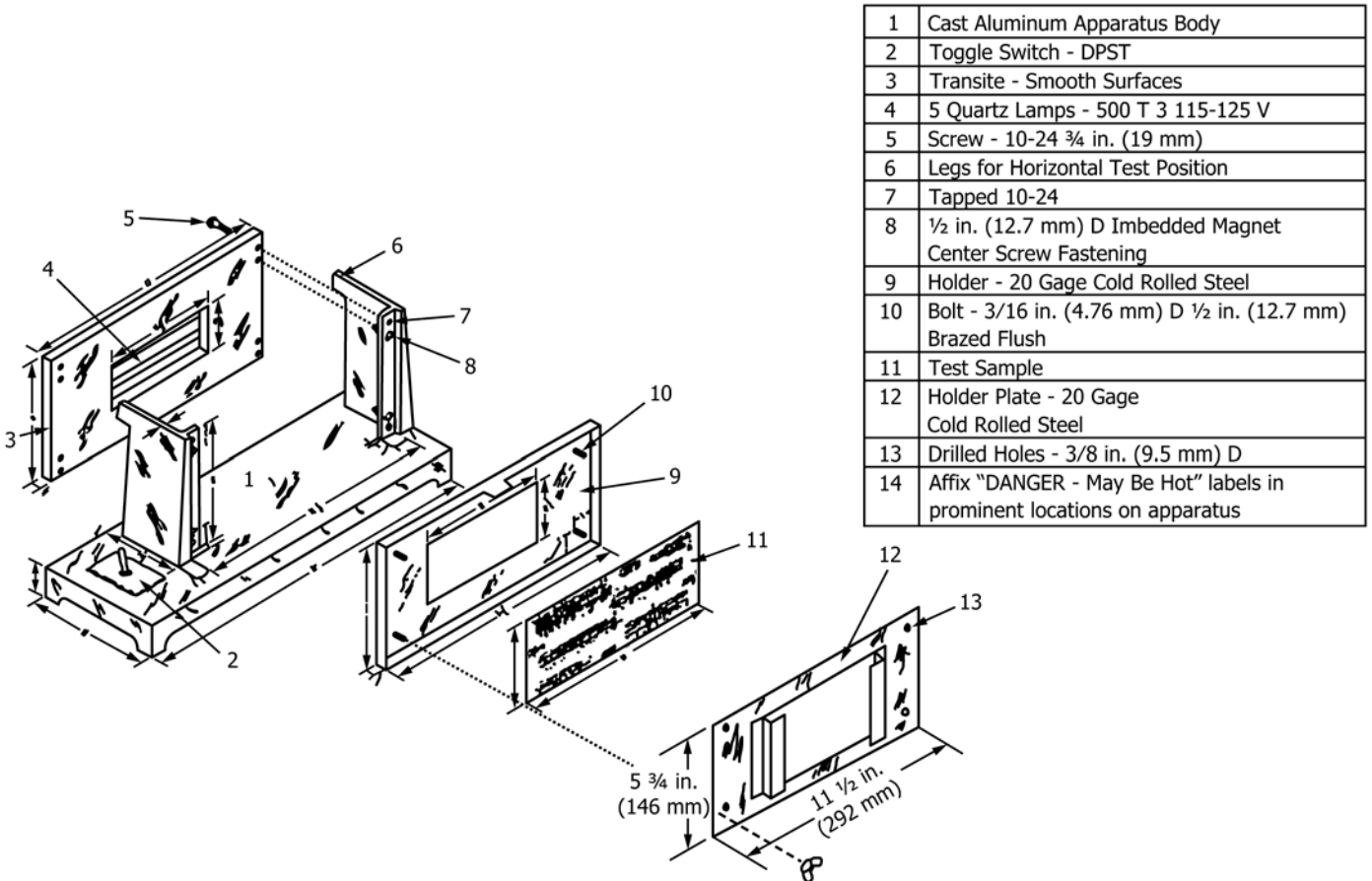| 1	Cast Aluminum Apparatus Body
2	Toggle Switch - DPST
3	Transite - Smooth Surfaces
4	5 Quartz Lamps - 500 T 3 115-125 V
5	Screw - 10-24 ¾ in. (19 mm)
6	Legs for Horizontal Test Position
7	Tapped 10-24
8	½ in. (12.7 mm) D Imbedded Magnet Center Screw Fastening
9	Holder - 20 Gage Cold Rolled Steel
10	Bolt - 3/16 in. (4.76 mm) D ½ in. (12.7 mm) Brazed Flush
11	Test Sample
12	Holder Plate - 20 Gage Cold Rolled Steel
13	Drilled Holes - 3/8 in. (9.5 mm) D
14	Affix "DANGER - May Be Hot" labels in prominent locations on apparatus

FIG. 1 General Expanded View of a Compliant Radiant Resistance Performance Test Apparatus (See Figures 2, 3, and 4 for specific item details.)
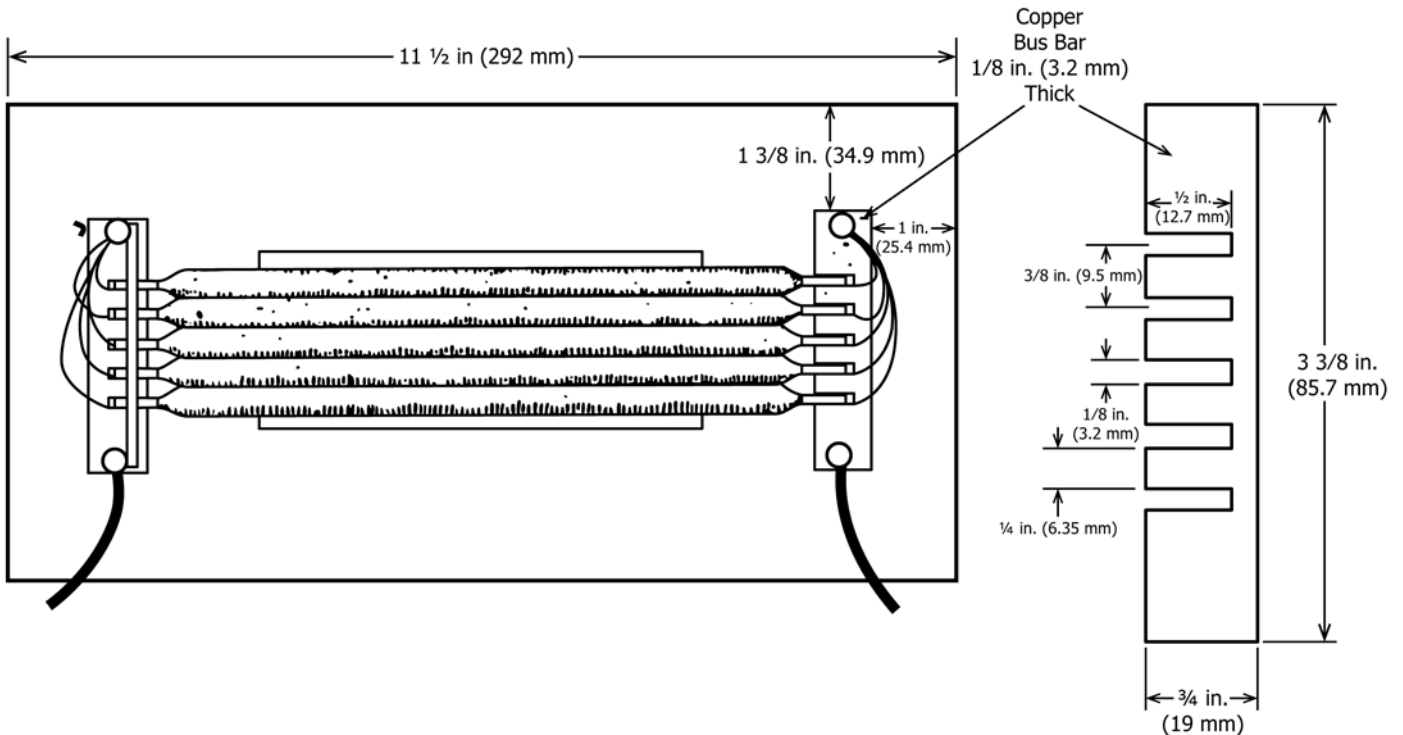

FIG. 2 Detailed View of Position of Quartz Lamps on Thermal Insulating Board
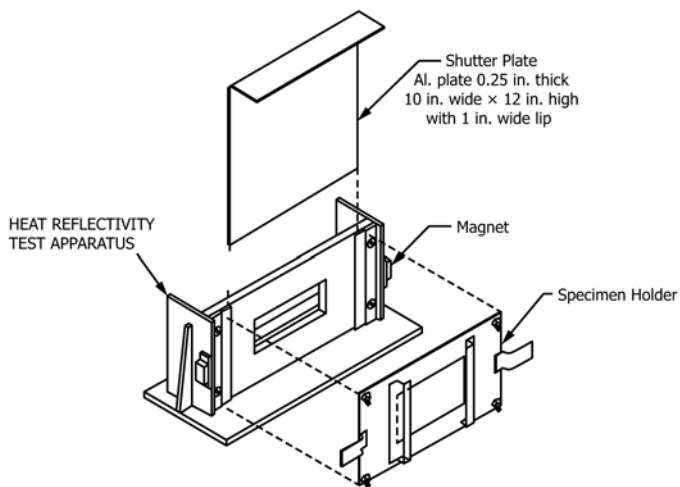
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FIG. 3 Detailed View of a Compliant Radiant Protective Performance Test Apparatus Showing Holder with Window, Manual Shutter Plate, and Specimen Holder with Calorimeter Brackets. (A magnet/tab arrangement is shown as an equipment design option to hold the specimen holder to the assembly.)

assembly covers and covers with minimal ventilation have been found to exhibit large measurement biases in round robin testing.

NOTE 6—Transite monolithic, non-asbestos fiber cement board[3,4] has been found to be effective as a high temperature insulating board.

6.1.2 *Specimen Holder Assembly*—A specimen holder and holder plate with a 64 by 152-mm (2½ by 6-in.) center cut-out is positioned so that the distance from the nearest lamp surface to the test specimen is 25.4 ± 0.4 mm (1.0 ± $\frac{1}{64}$ in.). The rear holder plate thickness is 0.9 ± 0.05 mm (0.036 ± 0.002 in.) and includes a bracket to hold the copper calorimeter sensor

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[3] The sole source of supply of this type of product known to the committee at this time is BNZ Materials, Inc., 6901 South Pierce Street, Suite 260, Littleton, CO 80128, Ph: 800-999-0890.

[4] If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.

assembly. This rear plate holds the specimen in place so that it covers the complete cutout section (see typical designs shown in Figs. 3 and 4). Several specimen holders are recommended to facilitate testing.

NOTE 7—The copper calorimeter sensor assembly holder plate bracket is constructed such that the calorimeter assembly is in a reproducible fixed vertical position when installed and is held flush and rigidly against the rear holder plate.

6.1.3 *Protective Shutter*—A protective shutter, as shown in Fig. 3, is placed between the radiant energy source and the specimen. The protective shutter blocks the radiant energy just prior to the exposure of a specimen. Manual or mechanically operated shutter designs are allowed with and without water-cooling.

6.1.4 *Rheostat or Variable Power Supply*—A standard laboratory rheostat or appropriate power supply with a capacity of at least 25 A, which is capable of controlling the output intensity of the tubes over the range specified in 4.1.

6.1.5 *Sensor*—The radiant heat sensor is a 4 ± 0.05 cm diameter circular copper slug calorimeter constructed from electrical grade copper with a mass of 18 ± 0.05 g (prior to drilling) with a single iron-constantan (ANSI Type J) thermocouple wire bead (0.254 mm wire diameter or finer—equivalent to 30 AWG) installed as identified in 6.1.5.2 and shown in Fig. 5 (see Test Method E457 for information regarding slug calorimeters). The sensor holder shall be constructed from non-conductive heat resistant material with a thermal conductivity value of ≤0.15 W/m·K, high temperature stability, and resistance to thermal shock. The board shall be nominally 1.3 cm (0.5 in.) or greater in thickness and meet the specimen holder assembly requirements of 6.1.2. The sensor is held into the recess of the board using three straight pins, trimmed to a nominal length of 5 mm, by placing them equidistant around the edge of the sensor so that the heads of the pins hold the sensor flush to the surface.

6.1.5.1 Paint the exposed surface of the copper slug calorimeters with a thin coating of a flat black high temperature
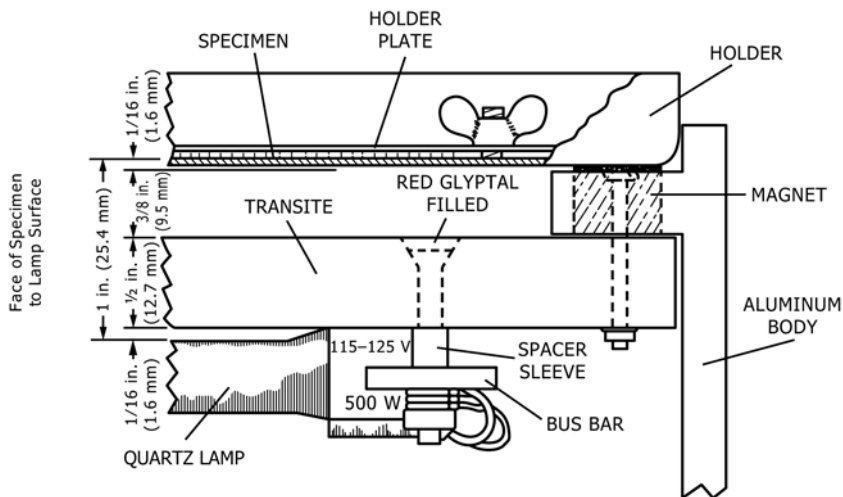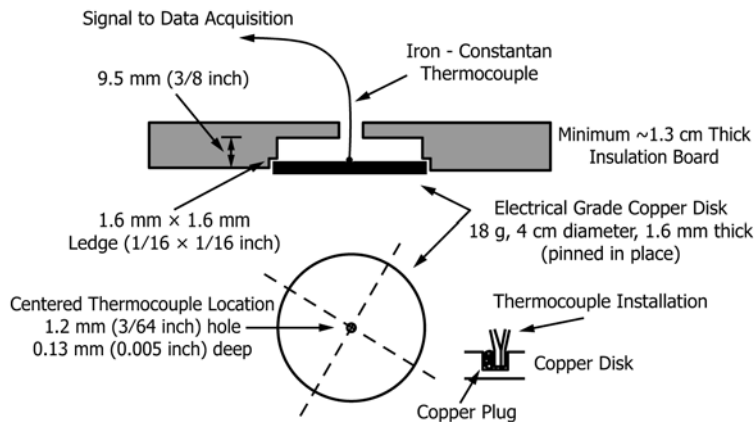

FIG. 4 Sample Position Example—Top View Enlargement

Note 1—Secure the copper disk into the supporting insulation board with 3 or 4 sewing pins cut to 9.5 mm (0.375 in.) in length (positioned around the periphery so that the sewing pin heads hold the disk into the board).

FIG. 5 Radiant Heat Resistance Test Sensor (Copper Calorimeter Mounted in Insulation Block) Showing Mechanical Bonding of Thermocouple to Copper Disk

spray paint with an absorptivity of 0.9 or greater.[4,5] The painted sensor must be dried and cured, in accordance with the manufacturer's instructions, before use and present a uniformly applied coating (no visual thick spots or surface irregularities). In the absence of manufacturer's instructions, an external heat source (for example, an external heat lamp), shall be used to completely drive off any remaining organic carriers in a freshly painted surface before use.

Note 8—Absorptivity of painted calorimeters is discussed in the ASTM Report, "ASTM Research Program on Electric Arc Test Method Development to Evaluate Protective Clothing Fabric; ASTM F18.65.01 Testing Group Report on Arc Testing Analysis of the F1959 Standard Test Method—Phase I."

6.1.5.2 The thermocouple wire is installed in the calorimeter as shown in Fig. 5.

(1) The thermocouple wire shall be bonded to the copper disk either mechanically or by using high melting point (HMP) solder.

6.1.5.3 A mechanical bond shall be produced by mechanically deforming the copper disk material (utilizing a copper filling slug as shown in Fig. 5) around the thermocouple bead.

6.1.5.4 A solder bond shall be produced by using a suitable HMP solder with a melting temperature of >280°C.

Note 9—HMP solders consisting of 5 % Sb-95 %Pb (~307°C melting point) and 5 %Sb-93.5 %Pb-1.5 %Ag (~300°C melting point) have been found to be suitable. The 280°C temperature minimum identified above corresponds to the point where melting of the solder bond would be experienced with an ~17 second exposure of an 84 kW/m^2 heat flux to a prepared copper calorimeter with a surface area of 12.57 cm^2 and a mass of 18.0 grams. A careful soldering technique is required to avoid "cold" solder joints (where the solder has not formed a suitable bond of the thermocouple to the copper disk).

6.1.6 *Data Acquisition/Analysis System*—A data acquisition/analysis system is required that is capable of recording the calorimeter temperature response, calculating the resulting thermal energy, and determining the test endpoint by comparing the time-dependent thermal energy transfer reading to the empirical performance curve.

6.1.6.1 The data acquisition component must have a minimum sampling rate of four samples per second for temperatures to 250°C with a minimum resolution of 0.1°C and an accuracy of ±0.75°C. It must be capable of making cold junction corrections and converting the millivolt thermocouple signals to temperature.[6]

6.1.7 *Solvents,* alcohol or petroleum solvent for cleaning the copper slug calorimeter.

6.1.8 *Paint,* flat-black, spray type with an absorptivity value of >0.90.

7. Hazards

7.1 This test method uses a high radiant energy source to test materials. The apparatus shall be adequately shielded to minimize any radiant exposure to personnel. Avoid viewing the lamps when energized.

7.2 Perform the test in a hood to carry away combustion products, smoke, and fumes. Shield the apparatus or turn off the hood while running the test; turn the hood on to clear the fumes. Maintain an adequate separation between the radiant heat source and combustible materials.

7.3 The specimen holder and sensor assembly become heated during prolonged testing—use protective gloves when handling these hot objects.

7.4 Observe the appropriate precautions when a specimen ignites or releases combustible gases. Use only the appropriate fire suppression materials for electrical systems if it becomes necessary to extinguish a fire at the unit.

7.5 Refer to manufacturer's Material Safety Data Sheets (MSDS) for information on handling, use, storage, and disposal of chemicals used in this test method.

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[5] Zynolyte #635 has been found suitable. The sole source of supply of Zynolyte #635 known to the committee at this time is Aervoe Industries, 1198 Mark Circle Gardnerville, NV 89410, Ph: 800–227–0196.

[6] See NIST Monograph 175 or MNL12 *Manual on the Use of Thermocouples in Temperature Measurement.*

8. Sampling and Specimen Preparation

8.1 *Laboratory Sample*—Select a minimum of a 1.0 m^2 sample size from the material to be tested. Individual test specimens will be produced from this sample.

8.2 *Laundering of Laboratory Sample:*

8.2.1 For specimens submitted without explicit test laundering specifications, launder the laboratory sample for one wash and dry cycle prior to conditioning. Use laundry conditions of AATCC Test Method 135, (1, V, A, i).

8.2.1.1 Stitching the edges of the laboratory sample is allowed to minimize unraveling of the sample material.

8.2.1.2 Restoring test specimens to a flat condition by pressing is allowed.

8.2.1.3 If an alternative laundry procedure is employed, report the procedure used.

8.2.2 For those materials that require cleaning other than laundering, follow the manufacturer's recommended practice using one cleaning cycle followed by drying and note the procedure used in the test report.

8.2.3 Samples submitted with instructions to not launder shall be tested as received.

8.2.4 Record the procedure used in the test report for materials that are submitted with explicit laundering instructions. For samples submitted with instructions not to launder, record in the test report that the samples were tested as received.

8.3 *Test Specimens*—Cut eight (8) test specimens in a diagonal sampling pattern across the prepared laboratory sample. A minimum dimension of 250 mm (10 in.) long and 100 mm (4 in.) wide is required for proper fit of the test specimens in the holder identified in 6.1.2.

8.3.1 If the laboratory sample edges have been stitched to reduce unraveling (see 8.2.1.1), test specimens are cut so they do not incorporate the stitching material.

8.3.2 Cut the long length direction from the machine (for example, warp or wale) direction of the material.

8.3.3 Three of the eight test specimens identified above are required for determining average thickness and surface density (see 8.5 and 8.6).

8.4 *Conditioning*—Condition each test specimen for at least 24 h at 21 ± 2°C (70 ± 5°F) and 65 ± 5 % relative humidity. The specimens shall be tested within 30 min of removal from the conditioning area.

8.4.1 If any specimens removed from conditioning cannot be tested within 30 min, return them to the conditioning area or seal them in polyethylene bags (or other material with low water vapor permeability) until immediately prior to testing.

8.4.2 Bagged specimens have a four (4) hour storage limit and are required to be tested within 20 min after removal from the bag.

8.4.3 Bagged specimens that exceed the four (4) hour storage limit shall be removed from their bag and reconditioned in accordance with 8.4 prior to testing.

8.5 *Determination of Test Specimens Average Thickness*—Determine the three specimens average thickness following Test Method D1777.

8.6 *Determination of Test Specimens Average Surface Density*—Determine the three specimens average surface density (mass divided by surface area) identified in 8.3.3 following Test Method D3776.

9. Preparation, Calibration, and Maintenance of Apparatus

9.1 *Radiant Heat Flux Calibration:*

9.1.1 Calibrating the test apparatus radiant heat flux value is an iterative process. In some cases, several calibration passes will be required to establish the standard value for testing within the specifications described below.

9.1.1.1 A radiant heat flux recalibration is required anytime the quartz bulb assembly is turned off after a calibration value has been established.

9.1.2 Select the standard radiant heat flux level that will be used for testing.

9.1.2.1 The standard values to select from are: (*a*) 21 kW/m^2 (0.5 cal/cm^2s) and (*b*) 84 kW/m^2 (2.0 cal/cm^2s).

NOTE 10—Other values of radiant heat flux can be selected to represent the conditions of an expected hazard. However, this deviation must be reported within the results with a summary of the stability of the level reported consisting of an average and standard deviation from ten calibration passes (with no changes to the power setting to the quartz bulb assembly).

9.1.3 Set the quartz bulb assembly power supply output to the approximate value expected for the selected radiant heat flux level.

9.1.4 Energize the lamps and allow the bulb assembly to warm up before proceeding with the calibration.

9.1.4.1 A minimum of 60 s warm-up is required for radiant heat flux exposure values ≤42 kW/m^2 (≤1 cal/cm^2s).

9.1.4.2 A minimum of 15 s warm-up is required for radiant heat flux exposure values >42 kW/m^2 (>1 cal/cm^2s).

9.1.5 Place the shutter device between the specimen holder location and the lamps to completely block the radiant heat.

9.1.6 Place the copper calorimeter sensor, which is initially at room temperature, into a specimen holder plate (with no specimen) and then place the assembly into the specimen holder testing location in front of the shuttered heat source. Ensure that the sensor that has a clean, black surface without signs of paint blistering, exposed copper, or any accumulation of deposits otherwise recondition the sensor surface as described in 9.3.2.

9.1.7 Start the data acquisition system, remove the shutter, and collect the copper calorimeter sensor information for a minimum period of 10 s of radiant energy exposure.

9.1.8 Replace the shutter and remove the specimen holder/copper calorimeter sensor and allow it to cool to room temperature. Remove the shutter and also allow it to cool to room temperature.

NOTE 11—Use protective gloves when handling the hot shutter and specimen/copper calorimeter assembly.

9.1.9 Calculate the average exposure heat flux value using a sampling interval that starts with the temperature measured at time = 0 (sample taken just before the shutter is removed) and ends with the temperature measured at exposure time = 10 s

using the computational method identified in 11.1 (Sensor Response). This value is the measured radiant heat flux.

9.1.9.1 If this value is not within ± 2.1 kW/m^2 (± 0.05 cal/cm^{2}s) of the standard value selected in 9.1.2, adjust the quartz bulb assembly power supply output appropriately and repeat the calibration sequence outlined in 9.1.5 through 9.1.9.

9.1.9.2 If this value is within ± 2.1 kW/m^2 (± 0.05 cal/cm^{2}s) of the standard value selected in 9.1.2, the unit is considered calibrated and the resulting heat flux value is recorded.

9.2 *Verification of Quartz Bulb Assembly Output Uniformity:*

9.2.1 *Initial Output Verification of New Lamps:*

9.2.1.1 Complete the radiant heat flux calibration in 9.1 for an output of 84 kW/m^2 [2 cal/cm^{2}s], then use an optical pyrometer to obtain at least five (5) measured color temperatures of each lamp through the approximate center of the lamp. The optical pyrometer shall utilize a target reference (for example, internal calibrated lamp or filament) with an emission wavelength between 0.5 and 2.0 µm, a temperature measurement range of at least 1400 to 2200 K [2000 to 3400°F], and an effective target size of ≤ 1.5 mm.

Note 12—Single range disappearing filament-type and classic photoscreen wedge-type optical pyrometers have been found effective.

9.2.1.2 The alternate use of a radiometer in the sample specimen position to measure at least five (5) measure values of radiant energy output at the approximate center of each lamp (collimated so that only one lamp is visible to the radiometer for each measurement of the array) is permitted. The radiometer used shall have a detection wavelength range of at least 0.5 to 4 µm, with a measurement precision of at least ± 5 %, and a viewing angle that subtends the individual lamp viewing collimation slit. For each of the individual lamp measurements, the collimation slit used shall be of uniform dimension that is less than or equal to the bulb diameter in use. During lamp output measurement, the collimation slit centerline shall align with the centerline of the respective lamp.

Note 13—The IR peak intensity of the quartz lamps occurs at ~1.2 µm.

9.2.1.3 Average the five measured values of each lamp and assign this its color temperature or radiant energy output (based on the measurement technology used).

9.2.1.4 Average the values from all five (5) lamps and assign this the array value.

9.2.1.5 *If an Optical Pyrometer is Used*—Compare the average value of each of the lamps in the array from 9.2.1.3 to the array average from 9.2.1.4. If any of the individual lamp averages are greater than ± 15 K of the array average, replace the identified lamp and repeat 9.1 and 9.2.1.

9.2.1.6 *If a Radiometer is Used*—Compare the average radiometer value of each of the lamps in the array from 9.2.1.3 to the array average from 9.2.1.4. If any of the individual lamp averages are greater than ± 15 % of the array average, replace the identified lamp and repeat 9.1 and 9.2.1.

9.2.1.7 *If a Variable Power Transformer Supply is Used to Power the Lamps*—Record the voltage of the new calibrated lamp array to the nearest 0.5 VAC.

9.2.2 *Output Verification of Lamps in Service:*

9.2.2.1 Follow the procedure in 9.2.1 to re-verify the individual lamps and the lamp array outputs at intervals not to exceed 150 h of lamp operating time at a heat flux output of 84 kW/m^2 (2 cal/cm^{2}s), or intervals not to exceed 500 h of lamp operating time at a heat flux output of 21 kW/m^2 (0.5 cal/cm^{2}s), or a voltage change of more than 5 V for an output setting of 84 kW/m^2 (2 cal/cm^{2}s) from that noted in 9.2.1.7 (for systems using a variable power transformer supply to power the lamps).

Note 14—The operating life expectancy of the 500 W quartz infrared lamps specified in 6.1.1 is typically 5000 h at full output per the manufacturer (~130 kW/m^2 (3.1 cal/cm^{2}s)). However, experience has shown that the age and the variation in color temperature of the lamps in the array can affect the incident heat flux delivered to the test specimen.

9.3 *Sensor Care:*

9.3.1 *Initial Temperature*—Cool the sensor prior to and after an exposure with a jet of air or contact with a cold surface so that it is in thermal equilibrium and at room temperature prior to positioning the sensor behind the test specimen. Thermal equilibrium is obtained when the sensor temperature is within $\pm 1°C$ of room temperature for a 60 second period prior to use.

9.3.2 *Surface Reconditioning*—Wipe the sensor face with a nonabrasive material immediately after each exposure, while hot, to remove any decomposition products that condense on the sensor since these could be a source of error. If a deposit collects and appears to be irregular or thicker than a thin layer of paint, the sensor surface requires reconditioning. Carefully clean the cooled sensor with solvent, making certain there is no ignition source nearby. If bare copper is showing, repaint the surface with a thin layer of flat black high temperature spray paint identified in 6.1.5.1. Perform at least one calibration run on the newly painted sensor before using it in a test run.

9.4 *Specimen Holder Care*—Use dry specimen holders at $\pm 1°C$ of ambient temperature for test runs. Alternate with several sets of holders to permit cooling between runs, or force cool with air or water. Clean the holder with a nonaqueous solvent when it becomes coated with tar, soots, or other decomposition products.

10. Procedure

10.1 The results from a minimum of five test specimen exposures are required for determination of a radiant heat resistance rating. If additional specimens are taken from the laboratory sample and exposed, they shall be included in the determination of the radiant heat resistance rating.

10.2 *Procedure for Testing at a Radiant Flux ≤ 42 kW/m^2 (≤ 1 cal/cm^{2}s):*

10.2.1 *Calibrate the Radiant Source*—Calibrate the system as described in 9.1.

10.2.2 Perform specimen testing following 10.4 – 10.14. Do not turn off the radiant heat source.

10.2.3 After the fifth specimen and every fifth that follows (for tests involving large specimen populations), verify and record the radiant source calibration following 9.1.5 to 9.1.9. Recalibrate the system if required as described in 9.1.

10.3 *Procedure for Testing at a Radiant Flux >42 kW/m^2 (>1 cal/cm^{2}s):*

10.3.1 *Calibrate the Radiant Source*—Calibrate the system as described in 9.1.

10.3.2 Execute a single test exposure following 10.4 to 10.13.

10.3.3 Shut down the radiant lamps and let the system cool.

10.3.4 Repeat 10.3.1 to 10.3.3 for the remaining specimens.

NOTE 15—Operating the apparatus at high radiant flux values has been observed to place significant thermal stress on the quartz lamp system and significantly shortens its stable operating lifetime. As a result, the lamps are to be shut down after each measurement unless the system is documented to be stable (radiant heat source does not exceed the ±2.1 kW/m² (±0.05 cal/cm²s) tolerance over a five specimen exposure testing period). If it has been demonstrated that the apparatus is stable, the procedure in 10.2 can be followed.

10.4 *Specimen Mounting*—Center a test specimen in the opening of the holder. For multi-layered specimens, place the surface of the material intended as the outer layer of a protective system toward the radiant heat source. Secure the specimen in the holder (material is fixed between the specimen holder mounting plates).

10.4.1 Note in the testing report any specimen thickness change before exposure as the result of mounting it into the sample holder. Determine the average value of the material thickness values taken at the center of the sample holder and at any edge, after placement of the specimen in the holder assembly.

10.5 Ensure that the sensor has a clean, black surface without any accumulation of deposits or defects; otherwise recondition the sensor surface as described in 9.3.2.

10.5.1 Place the copper calorimeter sensor assembly into the specimen holder plate so that it is facing the back of the specimen and is flush with the back of the sample holder plate.

10.5.2 Note in the report if the sensor is in contact with the specimen surface.

NOTE 16—Single layer, flat material specimens usually exhibit a small air gap, typically ~0.9 mm (see 6.1.2 for plate thickness dimensions) between it and the sensor prior to testing. Multi-layer samples, after being placed and fixed in the holder, can be deformed such that their surface extends past the back of the holder plate and makes contact with the calorimeter.

10.6 *Test Exposure*—Place the manual or mechanically operated shutter device between the specimen holder location and the exposure lamps to completely block the radiant heat.

10.7 Place the copper calorimeter/specimen assembly prepared in 10.4 and 10.5, which is initially at room temperature, into the specimen holder testing location in front of the shuttered heat source.

10.8 Start the data acquisition system, remove the shutter, and collect and record the copper calorimeter sensor information.

10.9 Terminate the sample exposure (replace the shutter and remove the specimen holder/calorimeter assembly) after the total accumulated thermal energy as measured by the calorimeter (see 11.1) meets/exceeds the following empirical performance curve criteria:

$$J/cm^2 = 5.0204 \times t_i^{0.2901} \ (cal/cm^2 = 1.1991 \times t_i^{0.2901}) \qquad (1)$$

where:

t_i = the time value in seconds of the elapsed time since the initiation of the radiant energy exposure (shutter removed).

NOTE 17—The empirical performance criteria identified in Eq 1 has been selected for the historical continuity of data generated previously with earlier revisions of this test method. It is the functional equivalent to the "Stoll"[7] predicted second-degree skin burn injury curve found in other ASTM test methods. See additional discussion in Appendix X4.

10.10 The time value where the measured cumulative radiant heat exposure value of the test specimen intersects the empirical performance curve described in Eq 1, $t_{intersect}$, determines the radiant heat resistance value for that individual test specimen and is given as:

$$radiant\ heat\ resistance\ value,\ J/cm^2 = t_{intersect}\ seconds \qquad (2)$$

$$\times radiant\ exposure\ heat\ flux\ value,\ kW/m^2/10$$

$$(cal/cm^2 = t_{intersect}\ seconds \times radiant\ exposure\ heat\ flux\ value,\ cal/m^2s)$$

10.11 Subjective information observed during testing is optionally recorded with each specimen exposure (see Appendix X1 and Appendix X2 for examples).

10.12 Allow the specimen holder/calorimeter assembly to cool to room temperature before dissembling and removing the exposed specimen. Remove the shutter and also allow it to cool to room temperature.

10.13 Immediately inspect the copper calorimeter after disassembly for paint blistering or exposed bare copper prior to cleaning. If blistering or surface defects are found, the specimen test is invalid and must be repeated, and the sensor shall be reconditioned as described in 9.3.2.

NOTE 18—Use protective gloves when handling the hot shutter and specimen/copper calorimeter assembly.

10.14 Prepare and test the remaining specimens as outlined in 10.4 – 10.13 (following 10.2 or 10.3 as applicable).

11. Calculations of Results

11.1 *Sensor Response*—The sensor response of the calorimeter is determined shortly before and all during the radiant heat exposure to the test specimen.

11.1.1 The temperature value just prior to raising the shutter marks the sampling time initiation point, or t = 0 value.

11.1.2 The heat capacity of each copper slug at the initial temperature is calculated using:

$$C_p = \frac{4.1868 \times (A + B \times t + C \times t^2 + D \times t^3 + E/t^2)}{63.54 g/mol} \qquad (3)$$

where:

t = (measured temperature °C + 273.15)/1000
A = 4.237312
B = 6.715751
C = -7.46962

[7] Derived from: Stoll, A.M. and Chianta, M.A., "Method and Rating System for Evaluations of Thermal Protection," *Aerospace Medicine*, Vol 40, 1969, pp. 1232–1238; and Stoll, A.M. and Chianta, M.A., "Heat Transfer through Fabrics as Related to Thermal Injury," *Transactions—New York Academy of Sciences*, Vol 33 (7), Nov. 1971, pp. 649–670.

D = 3.339491
E = 0.016398

NOTE 19—The heat capacity of copper in J/g°C at any temperature between 289 K and 1358 K is determined by means of Eq 3 (Shomate Equation with coefficients from NIST).

11.1.3 *Calculating Cumulative Heat Values*—The time-dependent cumulative heat values are determined from the temperatures at the beginning and end of the sampling intervals.

11.1.3.1 The copper slug heat capacity is determined at the appropriate time intervals. This is done by calculating an average heat capacity for each sensor from the initial heat capacity, determined in 11.1.2, and the measured temperature at time interval of interest:

$$\bar{C}_p = \frac{C_p @ Temp_{initial} + C_p @ Temp_{final}}{2} \quad (4)$$

11.1.3.2 The measured cumulative radiant heat exposure value at any exposure time duration is determined in J/cm² by using the relationship:

$$Cumulative\ radiant\ heat\ exposure,\ Q$$
$$= \frac{mass \times \bar{C}_p \times \left(Temp_{final} - Temp_{initial}\right)}{area} \quad (5)$$

where:

Q = cumulative thermal energy detected by the calorimeter, J/cm²
$mass$ = mass of copper disk/slug (g)
$\bar{C}_p$ = average heat capacity of copper during the temperature rise (J/g°C)
$Temp_{final}$ = temperature of copper disk/slug at time interval of interest (°C)
$Temp_{initial}$ = initial temperature of the copper disk/slug at time = 0 (°C)
$area$ = area of the exposed copper disk/slug (cm²)

11.1.3.3 For a copper disk/slug that has a mass of 18.0 g and exposed area of 12.57 cm² (4 cm diameter), the determination of cumulative thermal energy delivered at any time interval reduces to:

$$Cumulative\ thermal\ energy,\ Q = 1.432 \times \bar{C}_p \times \left(Temp_{final} - Temp_{initial}\right) \quad (6)$$

NOTE 20—If a copper disk/slug with a different mass, or exposed area, or both, is used, the constant factor in Eq 6 must be adjusted correspondingly. If required, the value in cal/cm² can be determined by multiplying the cumulative thermal energy in Eq 6 by the conversion factor 1/4.1868 cal/J.

11.1.3.4 *Calculating Radiant Heat Flux for Sensor Calibration:*

(1) Incident heat flux to the copper calorimeter can be calculated over any time interval using:

$$Incident\ heat\ flux,\ q = \frac{mass \times \bar{C}_p \times \left(Temp_{final} - Temp_{initial}\right)}{absorptivity \times area \times \left(time_{final} - time_{initial}\right)} \quad (7)$$

where the absorptivity is the value for the black paint used for the calorimeter surface (typically ~0.9).

(2) For a copper disk/slug that has a mass of 18.0 g, an exposed area of 12.57 cm², a paint absorptivity of 0.9, and a 10 second calibration sampling interval the determination of incident heat flux reduces to:

$$Incident\ heat\ flux,\ kW/m^2 = 1.591 \times \bar{C}_p \times \left(Temp_{t=10s} - Temp_{t=0s}\right) \quad (8)$$

NOTE 21—If a copper disk/slug with a different mass, or exposed area, or both, is used, or the calibration time interval is changed from 10s the constant factor in Eq 8 must be adjusted correspondingly. If required, the value in cal/cm² can be determined by multiplying the incident heat flux in kW/m² by the conversion factor 0.02389 cal m²/kW cm²s.

11.2 *Determination of Radiant Heat Resistance Rating:*

11.2.1 *Radiant Resistance Values*—Take the average of at least five sample test radiant heat resistant values determined in Section 10 and report this value as the specimen radiant heat resistance (RHR) rating, J/cm² (cal/cm²). Any additional specimens tested from the laboratory sample shall be included in the averaged value.

12. Report

12.1 State that the test has been performed as directed in Test Method F1939, using Method A, 21 kW/m² (0.5 cal/cm²s) or B, 84 kW/m² (2 cal/cm²s).

12.1.1 If a different exposure level is selected, report this value and document the stability of the exposure level as the average and standard deviation from 10 calibration passes where:

12.1.1.1 For radiant flux values ≤42 kW/m² (≤1 cal/cm²s), report that no changes are made to the power setting to the quartz bulb assembly after each pass.

12.1.1.2 For radiant flux values >42 kW/m² (>1 cal/cm²s), report that the power was cycled off to the quartz bulb assembly for a minimum of 60 seconds after each pass. If it has been established that the exposure conditions are stable (see Note 15), then report that no changes were made to the power setting to the quartz bulb assembly after each pass.

12.2 Describe the material sampled and the method of sampling used. In the material description, include:

12.2.1 Sample identification.

12.2.2 Sample conditioning employed.

12.2.3 Number and ordering of layers in the specimen.

12.2.4 Description of each material used to make up the specimen including type of fiber, construction, average surface density (basis weight), thickness, and color.

12.3 Report the following information:

12.3.1 Conditions of test, including:

12.3.1.1 Initial calibrated exposure energy, and values determined in 10.2.

12.3.1.2 Reason for exposure level for example specification requirement or representative of anticipated end use.

12.3.1.3 *Number of Layers Tested*—Single or multiple with the order of lay-up and any thickness changes prior to exposure as determined in 10.4.1.

12.3.2 The individual radiant heat resistance values from each tested specimen from the laboratory sample.

12.3.3 The radiant heat resistance rating as determined in 11.2.

13. Precision and Bias

13.1 A single operator intra-laboratory test series was performed in April 2007 to determine method precision using the apparatus and procedure described in this test method.

TABLE 1 Single Laboratory Precision of the Test Method

Test	Fabric A 7 oz/yd^2	Fabric B 4.5 oz/yd^2	Fabric C 6 oz/yd^2	Fabric D (Aluminized) 8.5 oz/yd^2	Fabric E (3 Layer) 18.4 oz/yd^2
1	6.7	7.2	6.5	64.1	34.9
2	7.6	7.8	7.5	53.4	35.7
3	7.3	7.4	5.9	55.0	35.8
Average	7.2	7.5	6.6	57.5	35.4
$s_r{}^A$	0.44	0.30	0.80	5.78	0.50
%CV	6.1	4.0	12.2	10.1	1.4
r^B	1.23	0.82	2.23	16.02	1.40

$^A s_r$ = repeatability standard deviation (pooled within-laboratory standard deviation)
$^B r$ = repeatability = 2.80 s_r

13.1.1 Three commercially available single layer fabrics and two multi-layer systems used in radiant energy personal protective equipment were selected for testing at 21 kW/m^2 (0.5 cal/cm^{2}s) and 84 kW/m^2 (2 cal/cm^{2}s), respectively (single layer fabrics identified in Table 1 as fabrics A, B, and C, and multi-layer fabrics as D and E). Three (3) separate tests were conducted on each fabric type using the number of specimens identified in 10.1.

13.1.2 The results of single operator intra-laboratory precision study are shown in Table 1.

13.1.3 *Repeatability*—The repeatability, *r*, of this test method has been established as the value tabulated in Table 1. Two single test results, obtained in the same laboratory under normal test method procedures, that differ by more than this tabulated *r* must be considered as derived from different or non-identical sample populations.

13.1.4 *Reproducibility*—The reproducibility of this test method is being determined and will be available on or before June 2008.

13.2 *Bias*—The value for radiant heat resistance (RHR) rating can only be defined in terms of a test method. Within this limitation, this test method has no known bias.

14. Keywords

14.1 apparel; flame resistance; protective clothing; radiant heat protection; radiant heat resistance

APPENDIXES

(Nonmandatory Information)

X1. SPECIMEN RESPONSE TO RADIANT ENERGY EXPOSURE

X1.1 Subjective effects of the radiant energy exposure on the specimen observed in Section 10 may be included in the report. Observe the effect of the exposure on the test specimen, including each of the layers in a multiple layer specimen. Describe this effect as one or more of the following: break open, charring, dripping, embrittlement, ignition, melting, shrinkage, sticking.

X2. SUBJECTIVE VISUAL EXAMINATION AND EVALUATION OF THE EXPOSED SPECIMEN

X2.1 The subjective observations on the specimen ignition during the exposure may be reported using the rating system below:

X2.1.1 *Ignition:*
X2.1.1.1 1 = no ignition, no smoke.
X2.1.1.2 2 = slight ignition, slight smoke.
X2.1.1.3 3 = moderate ignition, dark smoke.
X2.1.1.4 4 = significant ignition, thick blackish smoke.
X2.1.1.5 5 = heavy ignition, thick blackish smoke or flames, or both.

X2.2 Except for the subjective observation on ignition, the exposed specimen may be evaluated in each of the categories as listed in 10.3 on each side of the specimen.

X2.2.1 The surface of the specimen exposed to the radiant heat source shall be identified as the front side.

X2.2.2 The surface facing the heat sensor shall be identified as the back side.

X2.2.3 For visual examination, lay the exposed specimen parallel on a flat surface with proper illumination.

X2.3 Subjective ratings in the categories (see 10.3) may utilize the 1 to 5 system with 1 = best and 5 = worst behavior. The total value of the assigned ratings for each category will determine the specimen ranking.

X2.4 Rate each specimen after exposure using the following subjective terms:

X2.4.1 *Break open:*
X2.4.1.1 1 = no break open.
X2.4.1.2 2 = slight break open.
X2.4.1.3 3 = moderate, cracks in specimen.
X2.4.1.4 4 = significant, cracks in specimen.
X2.4.1.5 5 = extensive cracks and holes in specimen.

X2.4.2 *Melting:*
X2.4.2.1 1 = no melting.
X2.4.2.2 2 = slight melting.
X2.4.2.3 3 = moderate melting.
X2.4.2.4 4 = significant melting.
X2.4.2.5 5 = extensive melting.

X2.4.3 *Dripping:*

TABLE X2.1 Suggested Visual Response Report Form (see 10.3)

Categories	Front Side Rating 1 2 3 4 5	Back Side Rating 1 2 3 4 5	Total
Break open			
Melting			
Dripping			
Charring			
Embrittlement			
Shrinkage			
Sticking			
Ignition			

X2.4.3.1 1 = no dripping.
X2.4.3.2 2 = slight dripping.
X2.4.3.3 3 = moderate dripping.
X2.4.3.4 4 = significant dripping.
X2.4.3.5 5 = heavy dripping.

X2.4.4 *Charring:*
X2.4.4.1 1 = no charring.
X2.4.4.2 2 = slight specimen scorching.
X2.4.4.3 3 = moderate specimen charring.
X2.4.4.4 4 = significant specimen chars and embrittlement.
X2.4.4.5 5 = severe charring, specimen embrittles and has cracks or holes, or both.

X2.4.5 *Embrittlement:*
X2.4.5.1 1 = no embrittlement.
X2.4.5.2 2 = slight, specimen starts to harden.
X2.4.5.3 3 = moderate, small hardened areas.
X2.4.5.4 4 = significant, specimen completely embrittles.
X2.4.5.5 5 = heavy specimen embrittlement or cracks or holes, or both.

X2.4.6 *Shrinkage:*
X2.4.6.1 1 = no shrinkage.
X2.4.6.2 2 = slight shrinkage.
X2.4.6.3 3 = moderate shrinkage.
X2.4.6.4 4 = significant shrinkage.
X2.4.6.5 5 = extensive shrinkage.

X2.4.7 *Sticking:*
X2.4.7.1 1 = no sticking.
X2.4.7.2 2 = slight sticking.
X2.4.7.3 3 = moderate sticking.
X2.4.7.4 4 = significant sticking.
X2.4.7.5 5 = extensive sticking.

X2.4.8 The visual ratings of the specimen exposed may be reported using the format of Table X2.1.

X3. DETERMINATION OF RADIANT HEAT RESISTANCE VALUE EXAMPLE

X3.1 The following example provides an overview of this test method's technique to determine a radiant heat resistance value using a fictitious sample material.

X3.1.1 The radiant heat exposure of a fictitious specimen (10.8–10.10) yields a sensor response as illustrated in Fig. X3.1 (for this example, assume an 84 kW/m^2 (2 cal/cm^{2}s) heat flux). The cumulative energy from the copper calorimeter sensor is determined (using 11.1) for each sampling interval with each point being plotted to illustrate the sensor response. The exposure termination criteria, or "Stoll" curve (10.9, Eq 1) establishes the endpoint for the test and is plotted for each data acquisition time step.

X3.1.2 The time value at the intersection of the two curves is used to compute the radiant heat resistance value (see 10.10):
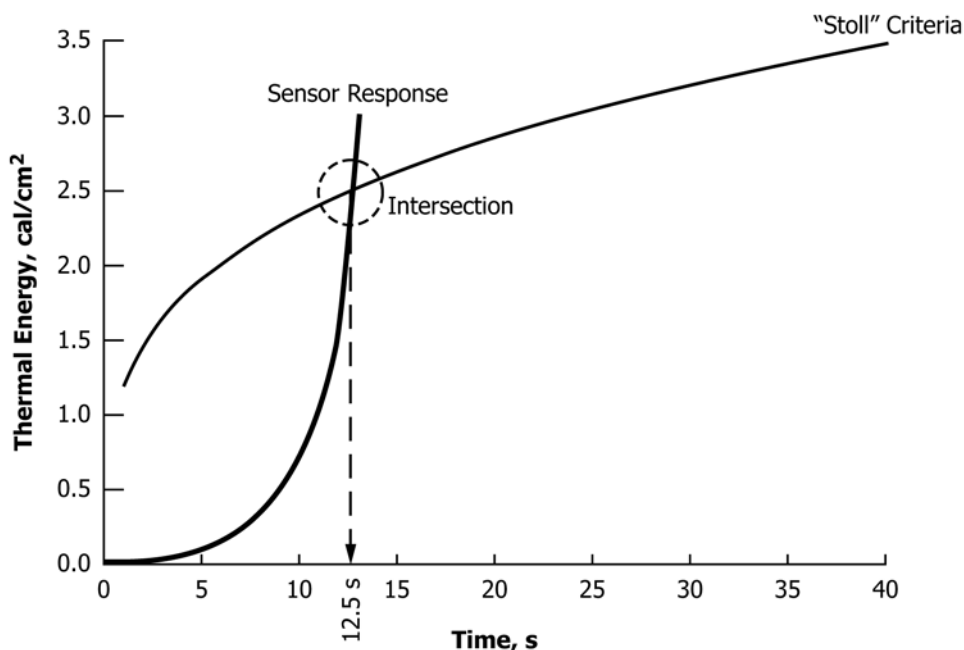

FIG. X3.1 Sensor Response to Radiant Heat Exposure

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$$12.5\ s \times 84\ kW/m^2/10 = 105.0\ J/cm^2$$
$$(12.5\ s \times 2\ cal/cm^2 s = 25\ cal/cm^2)$$

Note that the value determined using this test method does not represent or correlate in any way with a material's thermal protective ability against a predicted second-degree skin injury as the thermal energy remaining in the specimen after the radiant source is removed has not been accounted for.

X4. HISTORICAL AND STANDARD REVISION STRATEGY INFORMATION

X4.1 Prior to the current revision, this test method was referred to as the "Radiant Protective Performance" or RPP test. It was originally designed as a bench top test to attempt to compare radiant energy insulating values of materials used for protective clothing. A natural clothing comparison criteria was developed from the second-degree burn injury model generated from experimental burn injury data by A.M. Stoll and M.A. Chianta of the U.S. Naval Air Development Center. Unfortunately, even though the original intent of this test method was not to predict burn injury, a significant amount of confusion ensued with end-users of this test method. This confusion eventually escalated to the point where end-users believed that a measured RPP value ultimately represented the radiant energy assault protection (to a predicted second-degree burn injury) of the materials comprising their personal protective equipment.

X4.2 Subcommittee F23.80 recognized that the described RPP test method was being misunderstood and further noted that the test method was confusing end-users. Essentially, it was not designed for second-degree burn injury prediction protection as it did not account for the thermal energy contained in the exposed test specimen after the standardized radiant heat exposure has ceased. This thermal energy, still in a specimen after heating, would continue to deliver thermal energy to the wearer long after the radiant source was removed with significant potential for rapidly escalating burn injury without immediate garment removal (within fractions of a second according to the model). This is evident in the graph shown in Fig. X3.1.

X4.3 Due to the large body of RPP data in the marketplace from the previous version of this test method, subcommittee F23.80 has decided to retain this test method, but remove all reference to protection, correct several technical items (specific to slug calorimetry), and provide updates to the data acquisition equipment (moving away from strip-chart recorders). A new test method has been commissioned and is in development that is designed to account for the thermal energy remaining in a specimen after an exposure and accommodate end-user requirements for a bench top burn injury prediction to radiant exposures.

X4.4 Limited testing to date has shown that the radiant heat resistance values determined in this revised test method appear to be within ±5 % of the historical RPP values.