Designation: F 1939 – 99a

Standard Test Method for Radiant Protective Performance of Flame Resistant Clothing Materials[1]

This standard is issued under the fixed designation F 1939; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers a means of measuring the effect of radiant heat exposure at the standard levels of (*a*) 0.5 or (*b*) 2.0 cal/cm^2 ·s (21 or 84 kW/m^2) on a fabric specimen or a fabric assembly specimen.

1.2 The radiant protective performance (RPP) rating is calculated.

1.2.1 This value is not intended to be used as a performance specification.

1.2.2 The effects of the radiant energy exposure on the specimen may be observed and reported.

1.3 This test method is recommended for use with fabrics that are flame resistant and that are used in the manufacture of protective clothing.

1.4 This test method is not recommended for use with fabrics or with other textile materials that are not flame resistant, and that may or may not ignite and continue to burn from exposure to the radiant heat flux.

1.5 This test method measures and describes the response of materials, products, or assemblies to heat and flame 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.

1.6 The values stated in customary units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units.

1.7 *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.*

[1] This test method is under the jurisdiction of ASTM Committee F-23 on Protective Clothing and is the direct responsibility of Subcommittee F23.80 on Radiant Energy Exposure Test.

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2. Referenced Documents

2.1 *ASTM Standards:* [2]

D 123 Terminology Relating to Textiles
D 1776 Practice for Conditioning Textiles for Testing
E 457 Test Method for Measuring Heat-Transfer Rate Using a Thermal Capacitance (Slug) Calorimeter
F 1494 Terminology Relating to Protective Clothing

3. Terminology

3.1 *Definitions:*

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

3.1.2 *burn injury*, *n*—burn damage that occurs at various levels of depth within human tissue.

3.1.2.1 *Discussion*—Burn injury in human tissue occurs when the tissue is heated and kept at an elevated temperature for a critical period of time. The amount of burn injury, first-, second-, or third-degree depends upon both the level of the elevated temperature and the duration of time. Material performance in this test method is related to the second-degree burn injury and is determined by the amount of thermal energy transmitted through the specimen that is sufficient to cause a second-degree burn. A second-degree burn involves irreversible damage of the epidermis/dermis interface.

3.1.3 *burn time intersection*, *n— in testing of thermal protective materials*, the point where the energy transferred through the specimen and the energy required to predict a second-degree burn are equal, as indicated by the point where the sensor response curve on the recorder chart crosses the curve of the human tissue burn tolerance criteria overlay; or if

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

the data are processed with a computer software program, a similar result achieved by comparison of the heat transferred through the specimen and the human tissue tolerance to heat.

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

3.1.5 *dripping*, *n*—a material response evidenced by flowing and formation of falling droplets.

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

3.1.7 *flame-retardant-treated*, *adj*—having been processed with a flame retardant.

3.1.8 *heat flux*, *n*—the thermal intensity indicated by the amount of energy transmitted per unit area and per unit time; cal/cm^2·s (kW/m^2).

3.1.9 *human tissue burn tolerance*, *n—in the testing of thermal protective materials*, the amount of thermal energy predicted to cause a second-degree burn injury in human tissue.

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

3.1.11 *inherent flame-resistance*, *n—as applied to textiles*, flame resistance that derives from an essential characteristic of the fiber from which the textile is made.

3.1.12 *melting*, *n*—the liquefaction of material under the influence of heat.

3.1.12.1 *Discussion*—Liquid in this context indicates evidence of material flow and dripping, or both. These observations may be made after conclusion of the test exposure.

3.1.13 *radiant protective performance (RPP)*, *n—in testing of thermal protective materials*, the heat transfer characteristics of the material during the test exposure.

3.1.14 *radiant protective performance (RPP) rating*, *n—in testing of thermal protective materials*, the amount of the exposure energy resulting in heat transfer through the test material that predicts a second-degree burn injury in human tissue; cal/cm^2 (kJ/m^2).

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

3.1.16 *second-degree burn injury*, *n*—irreversible burn damage at the epidermis/dermis interface in human tissue (Synonym–second-degree burn).

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

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

3.1.19 *thermal duration*, *n— in the testing of thermal protective clothing*, the total time that a material is exposed to heat energy.

3.1.20 *thermal transfer threshold*, *n—in the testing of thermal protective clothing*, the point at which the heat transferred through the specimen from the thermal exposure has accumulated to the level that a burn injury is imminent.

3.1.21 *thermal transfer threshold time*, *n—in the testing of thermal protective clothing*, the duration of time from the start of the exposure to the thermal transfer threshold.

3.1.22 For the definitions of protective clothing terms used in this method, refer to Terminology F 1494, and for other textile terms used in this method, refer to Terminology D 123.

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*) 0.5 or (*b*) 2.0 cal/cm^2·s (21 or 84 kW/m^2).

4.2 The transfer of heat from the heat source through the test specimen is measured using a heat sensor. The RPP rating of the fabric is calculated from the exposure energy and the thermal transfer threshold time.

4.3 The observations of the thermal response of the specimen resulting from the exposure may be noted.

5. Significance and Use

5.1 Heat transfer is a phenomenon that is contingent upon several critical variables.

5.1.1 Distance, size, and intensity of the heat source are significant in determining the exposure level and the required thermal protection. This test method specifies exposure levels of (*a*) 0.5 or (*b*) 2.0 cal/cm^2·s (21 or 84 kW/m^2) to cover two potential hazards.

5.1.2 Air movement at the face of the specimen can affect the intensity of the exposure. Minimizing the convective air currents between the radiant source and the test specimen will aid in the repeatability of the results.

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

5.3 A higher radiant protective performance rating indicates a longer time to reach the thermal transfer threshold and, therefore, greater protection.

5.4 This test method may be used to measure the relative performance of different materials for garments intended to provide protection from radiant energy, such as proximity fire entry suits, Method A and molten metal protective clothing, Method B.

5.5 This test method is not recommended for acceptance testing of commercial shipments because its between laboratory precision has not been determined.

6. Apparatus and Materials

6.1 *General Arrangement*—The apparatus shall consist of a vertically oriented radiant heat source, specimen holder assembly, protective shutter, sensor assembly, and recorder. The arrangement of the radiant heat source, specimen holder, and protective shutter is shown in Fig. 1.

6.1.1 *Radiant Heat Source*—The vertically oriented radiant heat source shall be in accordance with Fig. 1 and shall consist of a bank of five, 500 W infrared, tubular, translucent quartz lamps having a 5.0-in. (127-mm) lighted length and a mean overall length of 8 $\frac{3}{4}$ in. (222 mm). The lamps shall be mounted on $\frac{3}{8} \pm \frac{1}{64}$-in. (9.5 ± 0.4-mm) centers so that the lamp surfaces are approximately $\frac{1}{64}$-in. (0.4-mm) apart. The bank or array of lamps shall be mounted and centered behind a 2 $\frac{1}{4}$ × 5 $\frac{1}{2}$-in. (63.5 × 140-mm) cut-out that is positioned in the center of a $\frac{1}{2}$-in. (12.7-mm) thick, 3 $\frac{3}{8}$-in. (86-mm) wide,

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

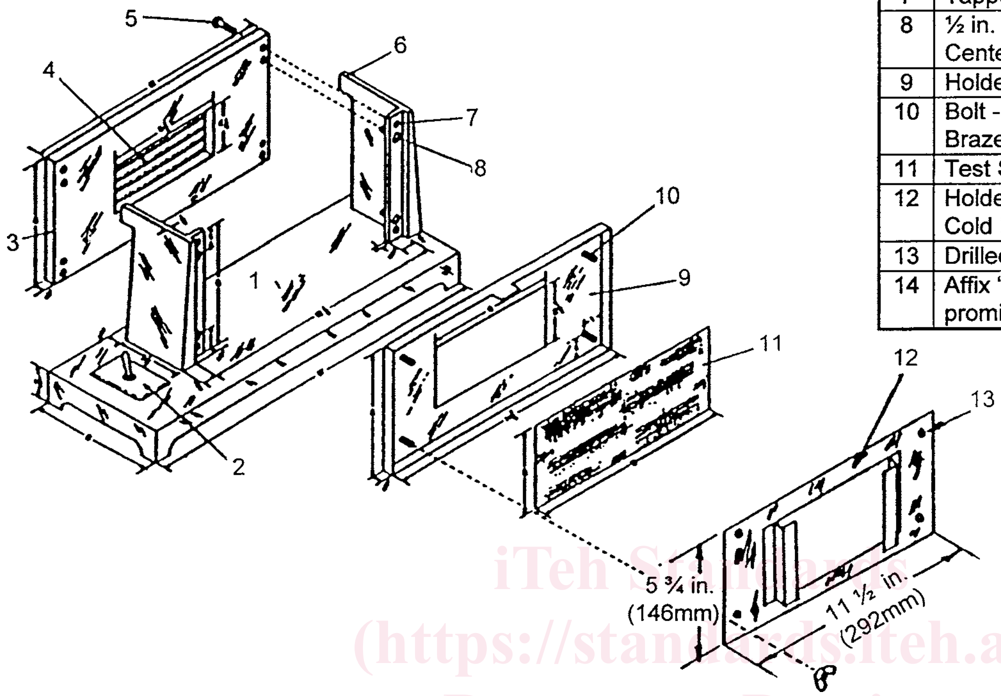


FIG. 1 Expanded View of Radiant Protective Performance Test Apparatus

by 11-½ in. (292-mm.) long transite board as shown in Fig. 2. The quartz lamps shall be heated electrically, and the power

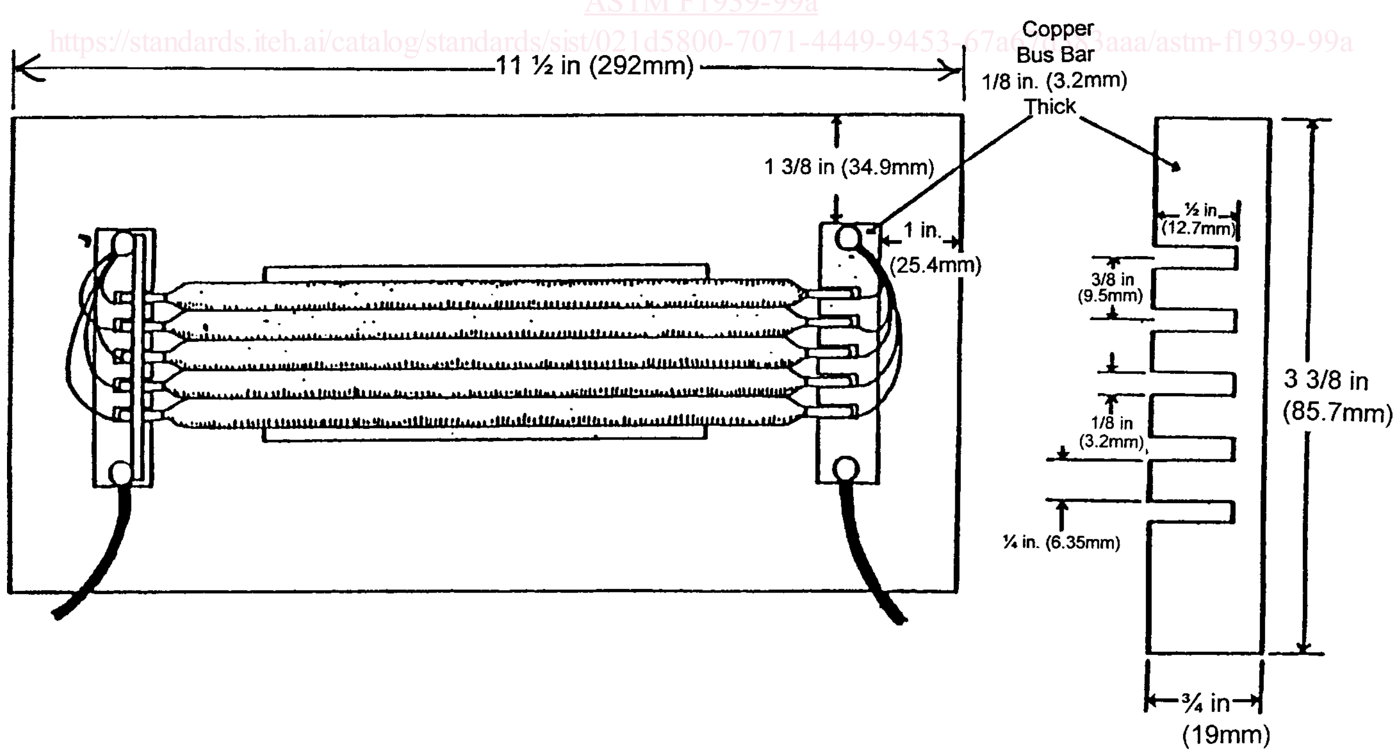


FIG. 2 Position of Quartz Lamps on Transite

input controlled by means of a rheostat having a capacity of at least 25A. A voltmeter, accurate to ± 1 V, shall be installed on the load circuit to indicate operating or load voltage to the lamps.

NOTE 1—The voltage used to achieve a given level of radiant heat energy may be used to set the exposure level for calibration and monitored during the testing to ensure consistent exposure levels.

6.1.2 *Specimen Holder Assembly*—A specimen holder and holder plate with a 2 ½ × 6-in. (64 × 152-mm) center cut-out shall be positioned so that the distance from the nearest lamp surface to the test specimen is 1.0 ± 1⁄64 in. (25.4 ± 0.4 mm). The holder plate, as shown in Fig. 3, shall include a bracket to hold the copper calorimeter sensor assembly and shall cover the complete cut-out section (see Figs. 3 and 4). Several specimen holders are recommended.

6.1.3 *Protective Shutter*—A protective shutter, as shown in Fig. 3, shall be placed between the radiant energy source and the specimen. The protective shutter shall be capable of blocking the radiant load during the period before exposure of the specimen. The shutter may be manually or mechanically operated.

6.1.4 *Rheostat*, a standard laboratory rheostat with a capacity of at least 25A to control the power input to the radiant tubes for use at standard current levels.

6.1.5 *Sensor*—A sensor shall consist of a copper calorimeter that has the surface painted with a thin layer of flat black paint and mounted in an insulating block (see Fig. 5). The calorimeter shall consist of a 1.57-in. (40-mm) diameter, 1⁄16-in. (1.6-mm) thick electrical grade copper disc, weighing 18 ± 0.1 g before thermocouples are attached, with four 30 gage iron/constantan thermocouples connected and mechanically secured, as indicated in Fig. 5, in the center and on three equally spaced radii at 0.79-in. (20-mm) diameter. The insulating block shall consist of a soft heat resistant material 5 ¼ × 5 ¼ × ½ in. (133 × 133 × 12.7 mm) with a recess cut in the middle of one surface to receive the calorimeter as shown in Fig. 5. The sensor assembly should fit without binding into the bracket on the rear plate of the specimen holder. For additional information on calorimeters, refer to Test Method E 457.

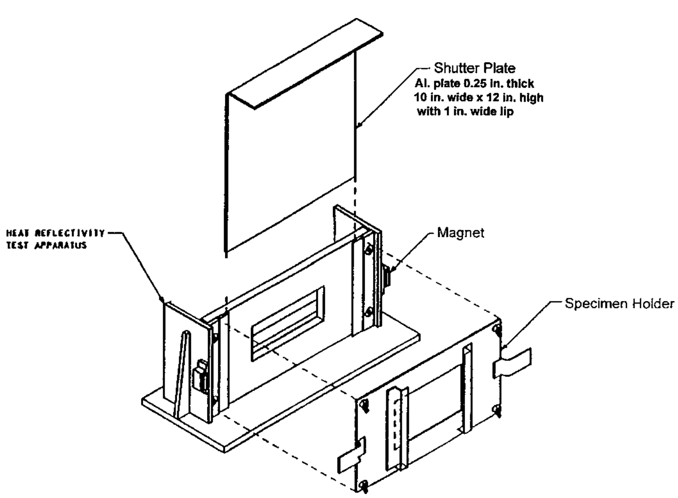


FIG. 3 Modification to Heat Reflective Portion of Radiant Protective Performance Test Apparatus

6.1.6 *Recorder*—Any strip chart recorder with full scale deflection of at least 300°F (150°C) or 10 mV and sufficient sensitivity and scale divisions to read the sensor response to 2°F (1°C) or 0.05 mV. A chart speed to read exposure time to ± 0.1 s is required; ½ in./s (13 mm/s) is satisfactory. As an option, the signal from the sensor may be connected to a data acquisition unit, and the data processed with computer software to produce the results as required in 11.2.2.

6.1.7 *Solvents*, alcohol or petroleum solvent.

6.1.8 *Paint*, flat-black, spray type with an coefficient of absorption > 0.95.

7. Hazards

7.1 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 adequate separation between heat source and combustible materials.

7.2 Because the specimen holder and sensor assembly become heated during prolonged testing, use protective gloves when handling these hot objects.

7.3 Use care when the specimen ignites or releases combustible gases.

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

8. Sampling and Specimen Preparation

8.1 *Laboratory Sample*—Take a full-width 1 yd (1 m) swatch from each fabric roll after first removing the outside layer from the roll.

8.2 *Test Specimens*— Cut and identify five test specimens from each laboratory sampling unit. Make each test specimen 4 × 10 in. ± 1⁄16 in. (75 × 250 mm ± 2 mm) with the long dimension of the specimen parallel with the machine direction of the sampling unit. Stagger specimens diagonally on the sampling unit to obtain a representative sample.

8.3 *Test Result*— A test result is the average of the five specimens from the laboratory sampling unit.

8.4 *Conditioning*— Bring the specimens to a controlled moisture content by preconditioning in a 120± 2°F (48.9 ± 1°C) oven for 4 h and then conditioning the fabric specimens in accordance with Practice D 1776.

9. Preparation, Calibration, and Maintenance of Apparatus

9.1 *Radiant Heat Flux Calibration*:

9.1.1 Expose specimens to a standard radiant heat flux of (*a*) 0.5 or (*b*) 2.0 cal/cm ^{2}.s (21 or 84 kW/m^2). Use the copper calorimeter in setting the exposure heat flux condition. Do not use any other heat sensing device to reference or adjust the heat flux read by the copper calorimeter. Determine the exposure energy directly and only from the temperatures read from the thermocouples. Determine the exposure heat flux prior to each test series and at the end of the testing day to confirm that the level is within the required limits (see 9.1.3).

9.1.2 Select a sensor that has a clean, black surface without any accumulation of deposit. If necessary, recondition a sensor,

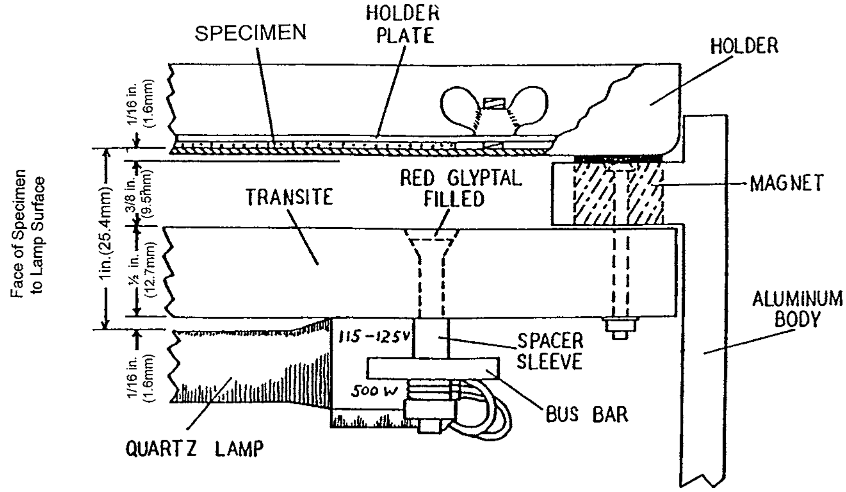


FIG. 4 Sample Position - Top View Enlargement

and cure the paint by exposing it to the radiant energy source. Place the copper calorimeter sensor in the specimen holder in place of a specimen and place the holder plate in front of the heat source. Place a manually or mechanically operated shutter device between the specimen holder containing the copper calorimeter sensor and the lamps to completely block the heat from reaching the sensor when the lamps are turned on. Turn on the lamps for a 60 s warm-up period and then start the recorder and remove the shutter from the front of the specimen holder. Record the response of the sensor for at least 10 s, and identify the initial portion of the curve with linear (straight line) response. Extend this straight line portion of the curve for at least 10 s of response, and take the sensor temperature from the start of the straight line for the initial (0) time, and another temperature 10 s along the straight line for the 10 s time. Subtract the 0 reading from the 10 s reading to obtain the increase.

9.1.3 Calculate the exposure heat flux using the measured temperature rise of the copper calorimeter over a known time duration, the area and mass of the calorimeter, and the heat capacity of copper. Heat flux shall be within ± 0.05 cal/cm^2×s (± 2.1 kW/m ^{2}) of the specified level.

NOTE 2—The exposure heat flux can be determined by multiplying the temperature rise (ΔT) of the calorimeter sensor over a known time duration (Δt) with a conversion factor (K) that combines the characteristics of the copper calorimeter into one term. Exposure heat flux $(q) = m\ C_p\ \Delta T/ A\ \Delta t = K\ \Delta T/ \Delta t$. With the 18 g mass ($m$) of the disc, the 0.0942 cal/g °C heat capacity (C_p) of the copper and 12.566 cm^2 area (A) of the disc, the conversion factor $K = 18 \times 0.0942 / 12.566 = 0.135$ cal/cm ^{2}°C. (If the temperature sensor response is measured in °F, the conversion factor K = 0.075 cal/cm^2°F.) Using a copper calorimeter with the conversion factor calculated above, the temperature rise of the sensor for a time duration of 10 s shall be 67 ± 6.7°F (37 ± 3.7°C) for an exposure heat flux of 0.5 ± 0.05 cal/cm^2·s (21 ± 2.1 kW/m^2) and 267 ± 6.7°F (148 ± 3.7°C) for an exposure heat flux of 2.0 ± 0.05 cal/cm^2·s (84± 2.1 kW/m^2).

9.2 *Sensor Care*:

9.2.1 *Initial Temperature*—Cool the sensor after an exposure with a jet of air or contact with a cold surface. Reheat the sensor to approximate body temperature by contact with the palm of the hand just prior to positioning behind the test specimen. Do not adjust the zero setting of the recorder.

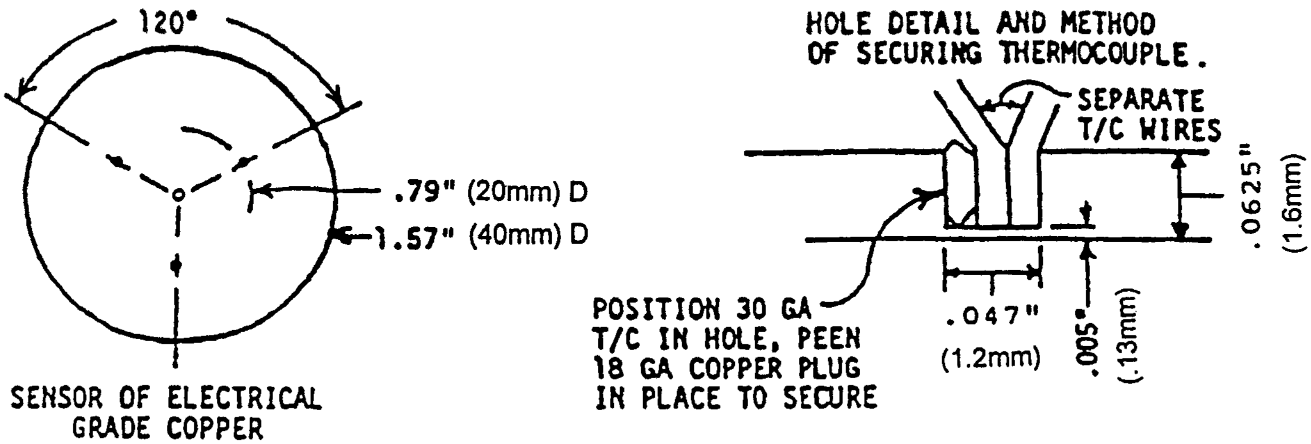
9.2.2 *Surface Reconditioning*—Wipe the sensor face immediately after each run, while hot, to remove any decomposition products that condense on the sensor and could be a source of error. If a deposit collects and appears to be irregular or thicker than a thin layer of paint, the sensor surface requires 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 paint. Perform at least one calibration run to cure the paint on the sensor before using it in a test run. Inspect and recondition the sensor at least after every sample run of five specimens.

9.3 *Specimen Holder Care*—Use dry specimen holders at ambient temperature for test runs. Alternate with several sets of holders to permit cooling between runs, or force cool with air or water. If the holder becomes coated with condensed tar, decomposition products, or soot, clean with a nonaqueous solvent.

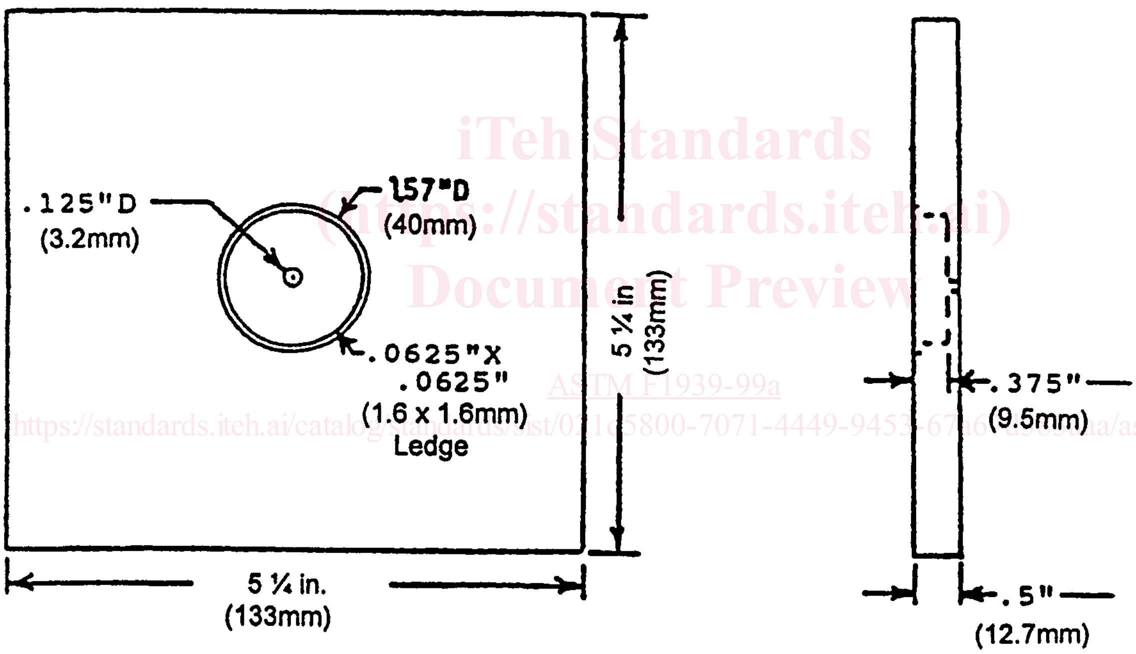
9.4 *Human Tissue Tolerance to Heat Curve*—Plot on the recorder chart paper the sensor equivalent from Table 1 that corresponds to the recorder scale; plot temperature (°F or °C) or thermocouple mV output (columns 6, 7, or 8) on the vertical axis and the corresponding time (column 1) on the horizontal axis. Use chart units based on the recorder full-scale deflection and the chart speed for a graph directly comparable to the recorder sensor trace. If pen deflection is from left to right and paper movement down, plot from right to left with the origin at the lower right. If recorder trace differs, adjust graph accordingly. Make an exact transparent duplicate for the overlay. Compare the overlay with the original to ensure that there has been no change in the overlay size as a result of the copying process.

10. Procedure

10.1 *Specimen Mounting*—Center the specimen in the opening of the holder. When testing a multilayered specimen, place the surface of the material to be used as the outside layer of the garment toward the radiant heat source. Place the sensor assembly in contact with the back of the specimen holder, and then place both in front of the heat source with the distance from the specimen to the nearest lamp surface 1.0 ± 1⁄64 in.



Details of Calorimeter Construction



Sensor support of soft insulation board
(asbestos free "transite" board is satisfactory)

NOTE 1—Connect four 30 ga. Iron/constantan thermocouples in parallel, silver solder connections. Bring common lead out of center hole of support.
NOTE 2—Secure sensor into support with 3 or 4 sewing pins cut to 9.5 mm (0.375 in) in length.
NOTE 3—Paint calorimeter face with flat black paint having a coefficient of absorption of not less than 0.95

FIG. 5 Radiant Protective Performance Test Sensor (Copper Calorimeter Mounted in Insulation Block)

(25.4± 0.4 mm). Place the shutter between the specimen holder and the lamps to completely block the heat from reaching the specimen when the lamps are first turned on.

10.2 *Test Exposure*— Turn on the lamps for a 60 s warm-up period. With the lamps still turned on, remove the shutter from the front of the test specimen, and simultaneously start the recorder. Indicate the start time on the recorder by a pencil mark or other device or, if used, an input to the computer, and continue the exposure for 40 ± –2 s. During the exposure, ignition of the specimen may be noted (see Appendix X1 and Appendix X2).

10.3 *Thermal Response to Radiant Heat Exposure*—After the exposed specimen has cooled, carefully remove it from the holder. The thermal response of the specimen to the radiant