Designation: F 1959/F 1959M – 99

Standard Test Method for Determining the Arc Thermal Performance Value of Materials for Clothing[1]

This standard is issued under the fixed designation F 1959/F 1959M; 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 is used to measure the arc thermal performance value of materials intended for use as flame resistant clothing for workers exposed to electric arcs that would generate heat flux rates from 2 to 600 $cal/cm^2 s$.

1.2 This test method will measure the arc thermal performance value of materials which meet the following requirements: less than 6 in. char length and less than 2 s afterflame when tested in accordance with Federal Test Method 191A Method 5903.1.

1.2.1 It is not the intent of this procedure to evaluate non flame resistant materials except where used as under layers in multiple layer specimens.

1.3 The materials used in this test method are in the form of flat specimens.

1.4 This test method may be used to generate information for the development of smaller scale test methods.

1.5 This standard shall be used to measure and describe the properties of materials, products, or assemblies in response to convective and radiant energy generated by an electric arc under controlled laboratory conditions.

1.6 The values stated in either SI units or in other units shall be regarded separately as standard. The values stated in each system may not be exact equivalents, therefore each system must be used independently of the other, without combining values in any way.

1.7 *This standard shall not be used to describe or appraise the fire hazard or fire risk of materials, products, or assemblies under actual fire conditions. However, results of this test may be used as elements of a fire assessment which takes into account all of the factors which are pertinent to an assessment of the fire hazard of a particular end use.*

1.8 *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.* For specific precautions, see Section 7.

2. Referenced Documents

2.1 *ASTM Standards:*

D 123 Terminology Relating to Textiles[2]

D 4391 Terminology Relating to the Burning Behavior of Textiles[3]

F 1494 Terminology Relating to Protective Clothing[4]

2.2 *ANSI/IEEE Standard:*[5]

Standard Dictionary of Electrical and Electronics Terms

2.3 *Federal Standard:*[6]

Federal Test Method Standard (FTMS) No. 191A Method 5903.1, Flame Resistance Cloth Vertical

3. Terminology

3.1 *Definitions:*

3.1.1 See also Terminology D 4391.

3.1.2 *arc duration*, *n*—time duration of the arc, s.

3.1.3 *arc energy, vi dt*, *n*—sum of the instantaneous arc voltage values multiplied by the instantaneous arc current values multiplied by the incremental time values during the arc, J.

3.1.4 *arc gap*, *n*—distance between the arc electrodes, in.

3.1.5 *arc thermal performance value (ATPV)*, *n*—*in arc testing*, the incident energy on a fabric or material that results in sufficient heat transfer through the fabric or material to cause the onset of a second-degree burn based on the Stoll curve.

3.1.6 *arc voltage*, *n*—voltage across the gap caused by the current flowing through the resistance created by the arc gap, V.

3.1.7 *asymmetrical arc current*, *n*—the total arc current produced during closure; it includes a direct component and a symmetrical component, A.

[1] This test method is under the jurisdiction of ASTM Committee F-18 on Electrical Protective Equipment for Workers and is the direct responsibility of Subcommittee F18.65 on Wearing Apparel.

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[2] *Annual Book of ASTM Standards*, Vol 07.01.

[3] *Annual Book of ASTM Standards*, Vol 07.02.

[4] *Annual Book of ASTM Standards*, Vol 11.03.

[5] Available from the Institute of Electrical and Electronics Engineers, Inc., 345 E. 47th St., New York, NY 10017.

[6] Available from Standardization Documents Order Desk, Bldg. 4, Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.

3.1.8 *blowout*, *n*—the extinguishing of the arc caused by a magnetic field.

3.1.9 *closure*, *n*—point on supply current wave form where arc is initiated.

3.1.10 *breakopen*, *n—in electric arc testing*, a material response evidenced by the formation of one or more holes in the material which may allow thermal energy to pass through the material.

3.1.10.1 *Discussion*—The specimen is considered to exhibit breakopen when any hole is at least one-half square inch in area or at least one inch in any dimension. Single threads across the opening or hole do not reduce the size of the hole for the purposes of this test method. In multiple layer specimens of flame resistant material, all the layers must breakopen to meet the definition. In multiple layer specimens, if some of the layers are ignitable, breakopen occurs when these layers are exposed.

3.1.11 *breakopen threshold energy* (E_{BT}), *n*—the average of the five highest incident energy exposure values below the Stoll curve where the specimens do not exhibit breakopen.

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

3.1.13 *closure*, *n*—point on supply current wave form where arc is initiated.

3.1.14 *delta peak temperature*, *n*—difference between the maximum temperature and the initial temperature of the sensor during the test, C.

3.1.15 *dripping*, *n—in testing flame-resistant clothing*, a material response evidenced by flowing of the fiber polymer.

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

3.1.17 *heat attenuation factor HAF*, *n*—in electric arc testing, the percent of the incident energy which is blocked by a material at an incident energy level equal to ATPV.

3.1.18 *heatflux*, *n*—the thermal intensity indicated by the amount of energy transmitted per unit area and time (cal/cm^{2}s)(W/cm^2).

3.1.19 i^2t, *n*—sum of the instantaneous arc current values squared multiplied by the incremental time values during the arc, A^2/s.

3.1.20 *ignitability, n (ignitable, adj)—in electric arc exposure*, the property of a material involving ignition accompanied by heat and light, and continued burning resulting in consumption of at least 25 % of the exposed area of the test specimen.

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

3.1.22 *incident energy monitoring sensors*, *n*—sensors mounted on each side of the panel, using the calorimeters described in 6.3, not covered by fabric, used to measure incident energy.

3.1.23 *incident energy* (E_i), *n—in electric arc testing*, the total heat energy received at a surface as a direct result of an electric arc.

3.1.23.1 *Discussion—In an arc test*, incident energy for a specimen is determined from the average temperature rise response of the two monitor sensors adjacent to the test specimen.

3.1.24 *material response*, *n*—material response to an electric arc is indicated by the following terms: breakopen, melting, dripping, charring, embrittlement, shrinkage, and ignition.

3.1.25 *melting*, *n*—in testing flame resistant clothing, a material response evidenced by softening of the fiber polymer.

3.1.26 *peak arc current*, *n*—maximum value of the AC arc current, A.

3.1.27 *RMS arc current*, *n*—root mean square of the AC arc current, A.

3.1.28 *shrinkage*, *n—in testing flame resistant clothing*, a material response evidenced by reduction in specimen size.

3.1.29 *Stoll curve*, *n*—curve produced from data on human tissue tolerance to heat and used to predict the onset of second degree burn injury, (see Table 1).

3.1.30 *time to delta peak temperature*, *n*—the time from beginning of the initiation of the arc to the time the delta peak temperature is reached, s.

3.1.31 *X/R ratio*—The ratio of system inductive reactance to resistance. It is proportional to the L/R ratio of time constant, and is, therefore, indicative of the rate of decay of any DC offset. A large X/R ratio corresponds to a large time constant and a slow rate of decay.

3.2 For definitions of other textile terms used in this method, refer to Terminologies D 123 and F 1494.

4. Summary of Test Method

4.1 This test method determines the incident energy which would predict a second degree burn injury when the material(s) is exposed to heat energy from an electric arc.

4.1.1 During this procedure, the amount of heat energy transferred by the material(s) is measured during and after exposure to an electric arc.

4.1.1.1 The heat flux of the exposure and that transferred by the test specimen(s) are both measured with calorimeters. The

TABLE 1 Human Tissue Tolerance to Heat, Second Degree Burn[A]

Exposure Time	Heat Flux		Total Heat		Calorimeter[B] Equivalent		
s	kW/m^2	cal/cm^{2}s	kWs/m^2	cal/cm^2	Δ*T* °C	Δ*T* °F	ΔmV
1	50	1.2	50	1.20	8.9	16.0	0.46
2	31	0.73	61	1.46	10.8	19.5	0.57
3	23	0.55	69	1.65	12.2	22.0	0.63
4	19	0.45	75	1.80	13.3	24.0	0.69
5	16	0.38	80	1.90	14.1	25.3	0.72
6	14	0.34	85	2.04	15.1	27.2	0.78
7	13	0.30	88	2.10	15.5	28.0	0.80
8	11.5	0.274	92	2.19	16.2	29.2	0.83
9	10.6	0.252	95	2.27	16.8	30.2	0.86
10	9.8	0.233	98	2.33	17.3	31.1	0.89
11	9.2	0.219	101	2.41	17.8	32.1	0.92
12	8.6	0.205	103	2.46	18.2	32.8	0.94
13	8.1	0.194	106	2.52	18.7	33.6	0.97
14	7.7	0.184	108	2.58	19.1	34.3	0.99
15	7.4	0.177	111	2.66	19.7	35.4	1.02
16	7.0	0.168	113	2.69	19.8	35.8	1.03
17	6.7	0.160	114	2.72	20.2	36.3	1.04
18	6.4	0.154	116	2.77	20.6	37.0	1.06
19	6.2	0.148	118	2.81	20.8	37.5	1.08
20	6.0	0.143	120	2.86	21.2	38.1	1.10
25	5.1	0.122	128	3.05	22.6	40.7	1.17
30	4.5	0.107	134	3.21	23.8	42.8	1.23

[A] Stoll, A. M. And Chianta, M. A., "Method and Rating System for Evaluation of Thermal Protection," Aerospace Medicine, Vol 40, 1968, pp. 1232–1238.

[B] Iron/constantan thermocouple.

rate at which the temperature of the calorimeters increases is a direct measure of the heat energy received.

4.2 Material performance for this procedure is determined from the amount of heat transferred by the specimen(s).

4.3 Heat transfer data is used to predict the onset of second degree burn using the Stoll curve.

4.4 This procedure incorporates incident energy monitoring sensors.

4.5 Material response shall be further described by recording the observed effects of the electric arc exposure on the specimens using the terms in 12.4.

5. Significance and Use

5.1 This test method is intended for the determination of the arc thermal performance value of a material, a combination of materials or a comparison of different materials will measure the arc thermal performance value of materials intended for use in flame resistant clothing for workers exposed to electric arcs.

5.1.1 This test method is intended for the determination of the arc thermal performance value of a material, a combination of materials, or a comparison of different materials.

5.1.2 Because of the variability of the arc exposure, different heat transmission values may result for individual sensors. Evaluate the results of each sensor in accordance with Section 12.

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 This test method specifies a standard set of exposure conditions. Different exposure conditions may produce different results. In addition to the standard set of exposure conditions, other conditions representative of the expected hazard may be used.

6. Apparatus

6.1 *General Arrangement For Determining Arc Thermal Performance Using Three Two-Sensor Panels and Monitor Sensors*—The test apparatus shall consist of supply bus, arc controller, recorder, arc electrodes, three two-sensor panels, and monitor sensors.

6.1.1 *Arrangement of the Two-Sensor Panels*—Three two-sensor panels shall be used for each test and spaced as 120 degrees as shown in Fig. 1. Each two-sensor panel shall have two monitoring sensors. One monitoring sensor shall be positioned on each side of the two-sensor panel as shown in Fig. 2.

6.1.2 *Panel Construction*—Each two sensor panel and each monitor sensor holder shall be constructed from non-conductive heat resistant material. Each two-sensor panel shall be 8 by 21.5 in. ± 0.5 in. as shown in Fig. 2. Each two sensor panel and monitoring sensors shall be adjustable from 8 in. (200 mm) to 24 in. [600 mm] from the centerline of the arc electrodes as shown in Figs. 1 and 3. Two sensors shall be mounted in the panel as shown in Fig. 2. Each sensor shall be mounted flush with the surface of the mounting board.

6.2 *Sensor Response*:

6.2.1 Panel sensor response shall be compared with the Stoll Curve.

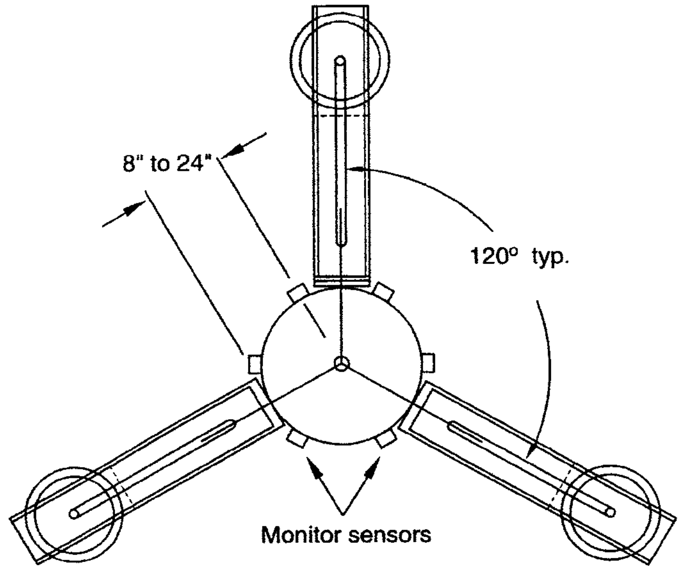


FIG. 1 Arrangement of Three Panel Sensors with Monitor Sensors

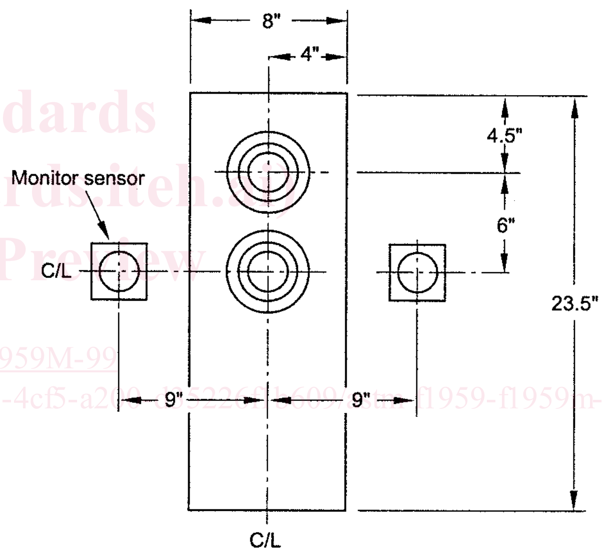


FIG. 2 Two Sensor Panel (Face View) with Monitor Sensors

6.2.2 Monitor sensor response is converted to incident energy in units of cal/cm^2 by multiplying the delta T C (ΔT) by the constant factor 0.135 cal/cm^2 C.

6.3 *Sensor Construction*—The sensor mount used to hold the calorimeter shall be constructed from non-conductive heat resistant material as shown in Fig. 4. The calorimeter shall be constructed from electrical grade copper with four thermocouple wires installed in the arrangement as shown in Fig. 5. The thermocouple wire shall be installed in the calorimeter as shown in Fig. 6. For test exposures above 40 cal/cm^2 only, alternate calorimeters for the monitor sensors may be used provided they are calibrated and have a similar response.

6.4 *Supply Bus and Electrodes*—A typical arrangement of the supply bus and arc electrodes is shown in Fig. 7. The arc shall be in a vertical position as shown.

6.4.1 *Electrodes*—Make the electrodes from stainless steel (Alloy Type 303 or Type 304) rod of a nominal ¾ in. [19 mm]

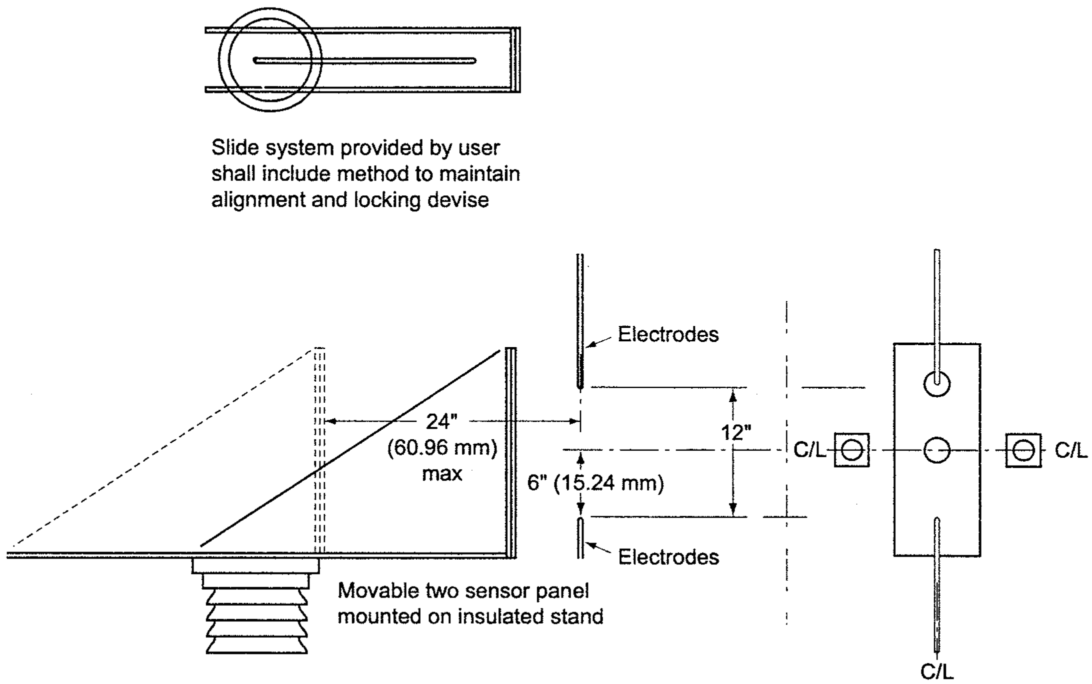


FIG. 3 Sliding Two Sensor Panel

diameter. Lengths of 18 in. [450 mm] long initially have been found to be adequate.

6.4.2 *Fuse Wire*—A fuse wire, connecting the ends of opposing electrodes tips, is used to initiate the arc. This wire is consumed during the test; therefore, its mass shall be very small to reduce the chance of molten metal burns. The fuse wire shall be a copper wire with a diameter not greater than 0.02 in. [0.05 mm].

6.5 *Electric Supply*—The electric supply should be sufficient to allow for the discharge of an electric arc with a gap of up to 12 in. [305 mm] with alternating arc current from 4000 up to 25 000 amperes and with arc duration from 3 cycles [0.05 s] up to 90 cycles [1.5 s] from a 60 Hz supply. The X/R ratio of the test circuit shall be such that the test current contains a DC component resulting in the first peak of the test current having a magnitude of 2.3 times the symmetrical RMS value.

6.6 *Test Circuit Control*—Repeat exposures of the arc currents shall not deviate more than 2 % per test from the selected test level. The make switch shall be capable of point on wave closing within 0.2 cycles from test to test such that the closing angle will produce maximum asymmetrical current with an X/R ratio of the test circuit as stated in 6.5. The arc current, duration, and voltage shall be measured. The arc current, duration, voltage and energy shall be displayed in graph form and stored in digital format.

6.7 *Data Acquisition System*—The system shall be capable of recording voltage, current, and sufficient calorimeter outputs as required by the test. The temperature data shall be acquired at a minimum sampling rate of 50 ms/channel for 30 s. The current and voltage data should be acquired at a minimum rate of 2 kHz. The acquisition system shall be able to record temperatures to 250 C with sufficient sensitivity to read sensor response to 1°C for a single layer system. For multiple layer systems, the system should be able to record temperatures to 400 C. The system should have a resolution of 0.1°C and an accuracy of 1.5°C.

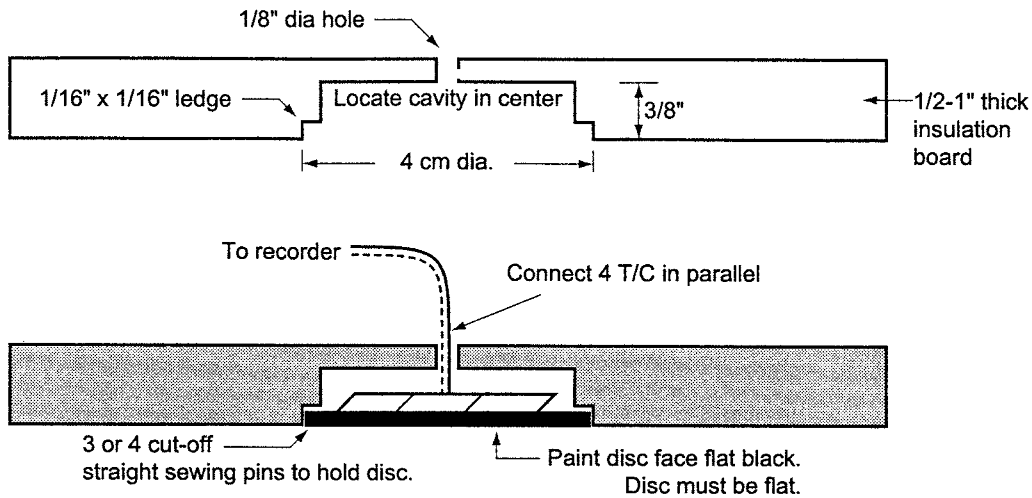
6.8 *Data Acquisition System Protection*—Due to the nature of this type of testing, the use of isolating devices on the calorimeter outputs to protect the acquisition system is recommended.

7. Precautions

7.1 The test apparatus discharges large amounts of energy. In addition, the electric arc produces very intense light. Care should be taken to protect personnel working in the area. Workers should be behind protective barriers or at a safe distance to prevent electrocution and contact with molten metal. Workers wishing to directly view the test should use very heavily tinted glasses such as ANSI/ASC Filter Shade 12 welding glasses. If the test is conducted indoors there shall be a means to ventilate the area to carry away combustion products, smoke, and fumes. Air currents can disturb the arc reducing the heatflux at the surface of any of the calorimeters. The test apparatus should be shielded by non-combustible materials suitable for the test area. Outdoor tests shall be conducted in a manner appropriate to prevent exposure of the test specimen to moisture and wind (the elements). The leads to the test apparatus should be positioned to prevent blowout of the electric arc. The test apparatus should be insulated from the ground for the appropriate test voltage.

7.2 The test apparatus, electrodes and calorimeter assemblies become hot during testing. Use protective gloves when handling these hot objects.

7.3 Use care when the specimen ignites or releases combustible gases. An appropriate fire extinguisher should be readily available. Ensure all materials are fully extinguished.



Heat flux (q):

$$q = \frac{\text{mass} \times \text{heat capacity copper} \times \text{temperature rise}}{\text{area of disc} \times \text{time}}$$

$$= \frac{mC_p\,\Delta T}{A\,\Delta\theta}$$

$$C_p = 0.0942 \text{ cal/g °C}$$
$$= 0.0523 \text{ cal/g °F}$$

If disc weighs 18 g:

$$q = 0.0135\ \Delta T/10 \text{ s °C}$$
$$q = 0.0075\ \Delta T/10 \text{ s °F}$$

Heat Flux (g):

$$g = \frac{\text{mass} \times \text{heat capacity copper} \times \text{temperature rise}}{\text{area of disc} \times \text{time}}$$

$$= \frac{mC_p\Delta T}{A\Delta\theta} \qquad C_p = 0.0942 \text{ cal/g °C}$$
$$= 0.0523 \text{ cal/g °F}$$

If disc weighs 18 g:

$$q = 0.0075\ \Delta T/10 \text{ s °F}$$
$$= 0.0135\ \Delta T/10 \text{ s °C}$$

FIG. 4 Calorimeter and Thermocouple Detail

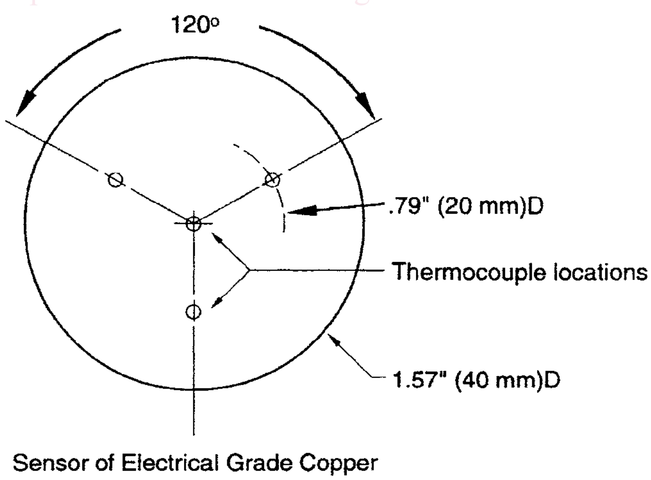


FIG. 5 Calorimeter

7.4 Immediately after each test, the electric supply shall be shut off from the test apparatus and all other lab equipment used to generate the arc. The apparatus and other lab equipment shall be isolated and grounded. After data acquisition has been completed, appropriate methods shall be used to ventilate the test area before it is entered by personnel. No one should enter the test area prior to exhausting all smoke and fumes.

8. Sampling and Specimen Preparation

8.1 *Test Specimens for Two-Sensor Panel Test*—From the material to be tested, make the post-laundered specimen size at least 26 in. [610 mm] long and at least 12 in. [305 mm] wide. Refer to Section 10, to determine number of samples.

8.1.1 The length direction should be cut in the warp or wale direction of the material.

8.2 *Laundry Conditioning of Test Specimens*:

8.2.1 Launder the required amount of material for the test specimens.

8.2.1.1 Launder three times in a washing machine using a commercially available detergent without chlorine bleach and with a warm 120°F [50°C] water setting.

NOTE 1—Drying is not required following the first two launderings.

8.2.1.2 Following the three laundry cycles, tumble dry in a dryer on a setting appropriate for the fabric. Remove specimens when dry.

8.2.1.3 Samples may be restored to a flat condition by pressing.

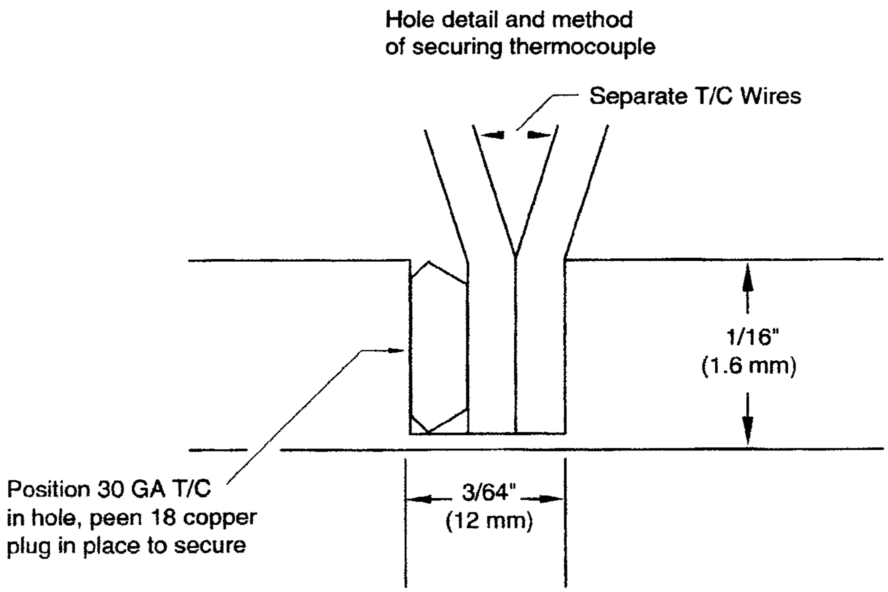


FIG. 6 Thermocouple Wire Installation

8.2.2 For those materials that require cleaning other than laundering, follow the manufacturer's recommended practice and note the procedure used in the test reports.

9. Calibration and Standardization

9.1 *Data Collection System Precalibration*—The data collection system shall be calibrated by using a thermocouple calibrator/simulator. This will allow calibrations to be made at multiple points and at levels above 100°C. The data collection system shall be calibrated. Due to the nature of the tests frequent calibration checks are recommended.

9.2 *Calorimeter Calibration Check*—Calorimeters shall be checked to verify proper operation. Measure and graph the temperature rise of each calorimeter and system response. At 30 seconds no one calorimeter response shall vary by more than 4°C from the average of all calorimeters. Any calorimeter not meeting this requirement shall be suspected of faulty connections and shall be replaced or repaired.

NOTE 2—One acceptable method is to expose each calorimeter to a fixed radiant energy source for thirty seconds. For example, place the front surface of a 500 watt spot light[7] 10.5 in. from the calorimeter. The spot shall be centered on and perpendicular to the calorimeter.

9.3 *Arc Exposure Calibration*—Prior to each calibration, position the electrodes of the test apparatus to produce a 12 in. (305 mm) gap. The face of the monitor sensors shall be parallel and normal to the centerline of the electrodes. The midpoint of the electrode gap shall be at the same elevation as the center point of the monitor sensors (See Fig. 1). Connect the fuse wire to the end of one electrode by making several wraps and twists and then to the end of the other electrode by the same method. The fuse wire shall be pulled tight and the excess trimmed. The test controller should be adjusted to produce the desired arc current and duration.

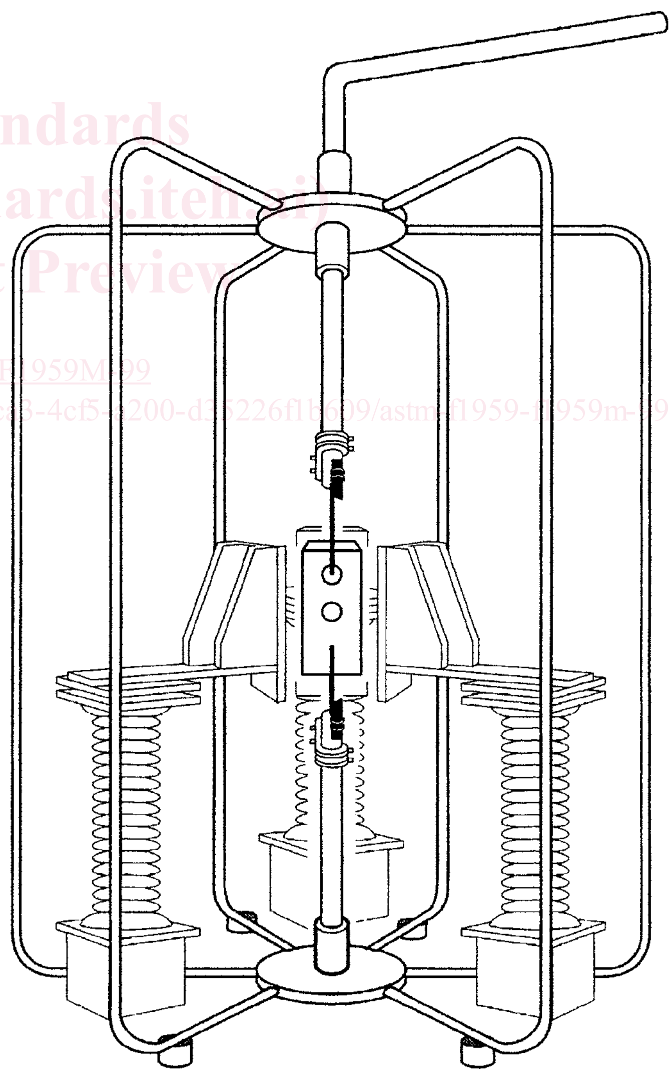


FIG. 7 Supply Bus and Arc Electrodes for Panels

[7] A 500W light source is available from the Strand Electric and Engineering Co. Ltd. as Part No. 83 (500W, 120V light source).