Designation: F1060 – 16

Standard Test Method for Evaluation of Conductive and Compressive Heat Resistance (CCHR)[1]

This standard is issued under the fixed designation F1060; 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 thermal insulation of materials used in protective clothing when exposed for a short period of time to a hot surface with a temperature up to 600°F (316°C).

1.2 This test method is applicable to materials used in the construction of protective clothing, including, but not limited to: woven fabrics, knit fabrics, battings, sheet structures, and material composites, intended for use as clothing for protection against exposure to hot surfaces.

1.3 This test method should be used to measure and describe the properties of materials, products, or assemblies in response to heat under controlled laboratory conditions and should not be used to describe or appraise the thermal hazard or fire risk of materials, products, or assemblies under actual exposure conditions.

1.4 The values as stated in SI units are to be regarded as the standard. The values in parentheses are given for information only.

1.5 *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/D1776M Practice for Conditioning and Testing Textiles

D4391 Terminology Relating to The Burning Behavior of Textiles

F1494 Terminology Relating to Protective Clothing

3. Terminology

3.1 *Definitions*—In testing thermal protection clothing material, the response to hot surface contact is indicated by the following descriptive terms:

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

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

3.1.3 *heat flux*—the thermal intensity indicated by the amount of energy transmitted divided by area and time, W/m^2 ($cal/cm^2 \cdot s$).

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

3.1.5 *ignition*—the initiation of combustion.

3.1.6 *melting*—a material response evidenced by softening of the polymer.

3.1.7 *shrinkage*—a decrease in one or more dimensions of an object or material.

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

3.1.9 *thermal end point*—in the testing of thermal protective materials, the point where the copper slug calorimeter sensor response (heat energy measured) intersects with a predicted skin burn injury model.

3.2 For all terminology related to protective clothing, see Terminology F1494.

3.3 For definitions of other textile terms used in this test method, refer to Terminology D123.

4. Summary of Test Method

4.1 This test method measures the performance of insulative materials. A material is placed in contact with a standard hot surface. The amount of heat transmitted by the material is compared with the human tissue tolerance and the obvious effects of the heat on the material are noted.

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[1] This test method is under the jurisdiction of ASTM Committee F23 on Personal Protective Clothing and Equipment and is the direct responsibility of Subcommittee F23.80 on Flame and Thermal.

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[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.

4.2 The temperature of the hot surface is measured/controlled with a thermocouple and the heat transmitted by the test specimen is measured with a copper calorimeter. The calorimeter temperature increase is a direct measure of the heat energy received.

4.3 A contact pressure of 3 kPa (0.5 psi) is used to compare material performance under controlled conditions. If a different pressure is chosen to represent a specific use condition, where it is used should be noted under test conditions (13.1.2.3).

4.4 The material performance is determined from the amount of heat transferred by the specimen and the observed effect of the heat exposure on the specimen. The thermal protection is the exposure time required to cause the accumulated heat received by the sensor to equal the heat that will result in a pain sensation (see Table 1) or cause a second degree burn in human tissue (see Table 2), as predicted from comparison of heat transfer data with human tissue heat tolerance curves (see Table 1 and Table 2).

5. Significance and Use

5.1 This test method rates materials intended for use as protective clothing against exposure to hot surfaces, for their thermal insulating properties and their reaction to the test conditions.

5.2 The thermal protection time as determined by this test method relates to the actual end-use performance only to the degree that the end-use exposure is identical to the exposure used in this test method; that is, the hot surface test temperature is the same as the actual end-use temperature and the test pressure is the same as the end-use pressure.

5.2.1 Higher pressures, beyond the 3 kPa (0.5 psi) pressure provided by the calorimeter assembly in this test method shall be permitted to be used in this test method to simulate the conditions of protective clothing use.

5.3 The procedure maintains the specimen in a static, horizontal position under a standard pressure and does not involve movement.

5.4 One of the intended applications for this test method is comparing the relative performance of different materials.

5.5 This test method is limited to short exposure because the model used to predict burn injury is limited to predictions of time-to-burn for up to 30 seconds, and predictions of time-to-pain for up to 50 seconds. The use of this test method for longer hot surface exposures requires a different model for determining burn injury or a different basis for reporting test results.

6. Apparatus

6.1 *General Arrangement*—The arrangement of the individual components of the test apparatus is shown in Fig. 1.

6.1.1 Alternatively, transmit temperature output readings to a data acquisition unit, then computer process to obtain the test result.

6.2 *Hot Plate*—Shall have a flat heated surface with the smallest dimension, a minimum of at least 200 mm (8 in.) and have the ability to achieve a temperature of at least 371°C (700°F) and to permit temperature control within 2.8°C (±5°F).

6.3 *Surface plate*— The flat plate shall be 6.4 mm (¼ in.) thick, 140 by 140 mm (5.5 by 5.5 in.) wide, with a 2.4 mm (3⁄32 in.) hole drilled from the edge to the center of the plate (Fig. 2). Use either electrolytic copper or T-1100 aluminum surface plates. The surface plate must be flat, smooth, and free from pits and cavities. (Flatness is indicated by negligible light passing between a straight edge and the plate surface.) Loss of the original mill finish (as judged with the naked eye) or warping, or both, may result in failure to achieve calibration with the reference standard.

6.4 *Sensor*—A copper calorimeter mounted in an insulating block with added weight and constructed as shown in Figs. 3 and 4 with the standard characteristics listed below. The following equations permit the determination of the total incident heat energy from the copper calorimeter:

$$q = \frac{mass \times C_p \times (Temp_{final} - Temp_{initial})}{area \times (time_{final} - time_{initial})} \quad (1)$$

where:

q	=	heat flux (cal/cm²s),
mass	=	mass of the copper disk/slug (g),
C_p	=	heat capacity of copper (0.09426 cal/g°C at 100°C),
$temp_{final}$	=	final temperature of copper disk/slug at $time_{final}$ (°C),
$temp_{initial}$	=	initial temperature of copper disk/slug at $time_{initial}$ (°C),
area	=	area of the exposed copper disk/slug (cm²),
$time_{final}$	=	ending time (s), and
$time_{initial}$	=	starting time (s).

TABLE 1 Human Tissue Tolerance to Pain Sensation

Exposure Time	Heat Flux		Total Heat		Calorimeter Equivalent		
	cal/cm²·sec	W/cm²	cal/cm²·s	W sec/cm²	ΔT°, F	ΔT°, C	ΔmV
1.0	0.640	2.70	0.640	2.70	8.53	4.74	0.250
1.5	0.475	2.00	0.713	3.00	9.51	5.28	0.275
2.0	0.385	1.61	0.770	3.22	10.27	5.71	0.293
3.0	0.280	1.17	0.840	3.51	11.20	6.22	0.322
5.0	0.195	0.82	0.975	4.08	13.00	7.22	0.375
7.0	0.155	0.65	1.085	4.54	14.47	8.04	0.420
10.0	0.118	0.49	1.180	4.94	15.73	8.74	0.458
20.0	0.076	0.32	1.520	6.36	20.27	11.26	0.582
30.0	0.060	0.25	1.800	7.53	24.00	13.33	0.690
50.0	0.060	0.25	3.000	12.55	40.00	22.22	1.150

TABLE 2 Human Tissue[A] Tolerance to Second Degree Burn

Exposure Time, s	Heat Flux		Total Heat		Calorimeter[B]		Equivalent, ΔmV
	cal/cm²·s	W/cm²	cal/cm²·s	W/cm²	ΔT,° F	ΔT, °C	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1	1.2	5.0	1.20	5.0	16.0	8.9	0.46
2	0.73	3.1	1.46	6.1	19.5	10.8	0.57
3	0.55	2.3	1.65	6.9	22.0	12.2	0.63
4	0.45	1.9	1.80	7.5	24.0	13.3	0.69
5	0.38	1.6	1.90	8.0	25.3	14.1	0.72
6	0.34	1.4	2.04	8.5	27.2	15.1	0.78
7	0.30	1.3	2.10	8.8	28.0	15.5	0.80
8	0.274	1.15	2.19	9.2	29.2	16.2	0.83
9	0.252	1.06	2.27	9.5	30.2	16.8	0.86
10	0.233	0.98	2.33	9.8	31.1	17.3	0.89
11	0.219	0.92	2.41	10.1	32.1	17.8	0.92
12	0.205	0.86	2.46	10.3	32.8	18.2	0.94
13	0.194	0.81	2.52	10.6	33.6	18.7	0.97
14	0.184	0.77	2.58	10.8	34.3	19.1	0.99
15	0.177	0.74	2.66	11.1	35.4	19.7	1.02
16	0.168	0.70	2.69	11.3	35.8	19.8	1.03
17	0.160	0.67	2.72	11.4	36.3	20.2	1.04
18	0.154	0.64	2.77	11.6	37.0	20.6	1.06
19	0.148	0.62	2.81	11.8	37.5	20.8	1.08
20	0.143	0.60	2.86	12.0	38.1	21.1	1.10
25	0.122	0.51	3.05	12.8	40.7	22.6	1.17
30	0.107	0.45	3.21	13.4	42.8	23.8	1.23

[A] 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, "Transaction-New York Academy of Sciences," Vol 33 (7), Nov. 1971, pp 649–670.
[B] A calorimeter with an iron/constantan thermocouple.

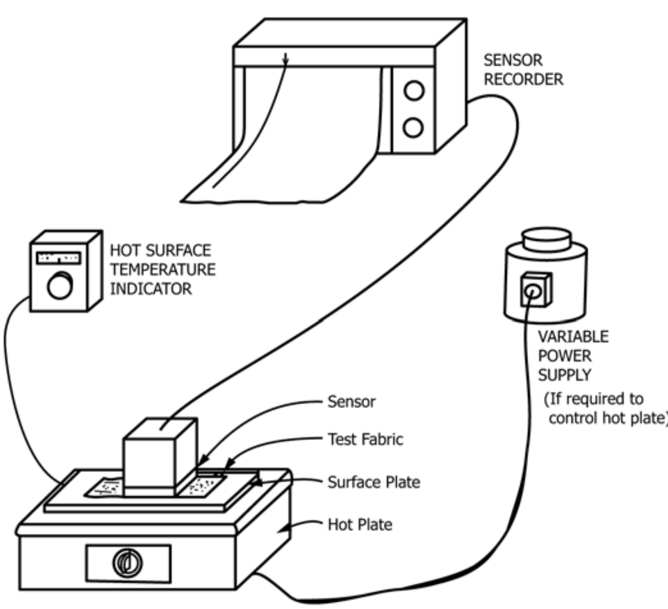
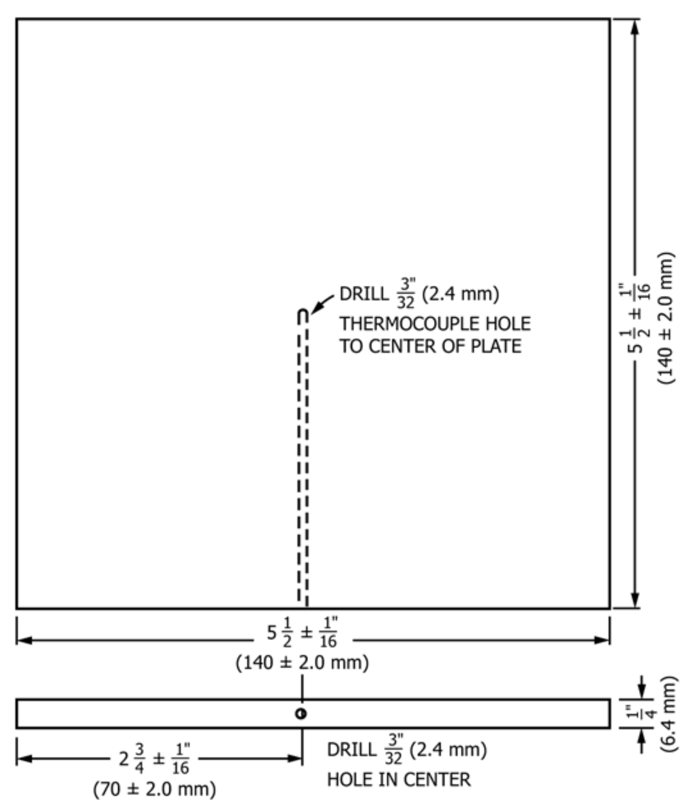


FIG. 1 Thermal Protective Performance Apparatus, Hot Surface Contact



Material: Electrolytic Copper or T-1100 aluminum

FIG. 2 Surface Plate

For a copper disk/slug that has a mass of 18.0 g and exposed area of 12.57 cm², the determination of heat flux reduces to:

$$q = \frac{0.135 \times (Temp_{final} - Temp_{initial})}{(time_{final} - time_{initial})} \quad (2)$$

If you use a copper disk/slug with a different mass, or exposed area, or both, the constant factor should be adjusted correspondingly. Also note that a different mass/surface area sensor will give different rates of temperature change to incident heat energy so the calculations made later will need to note this and make appropriate changes to correct (for example, see 10.3, 12.1.2, 13.1.3.1). The calorimeter must fit securely in the insulating block and its surface must be flush with the face of the insulating block. (**Warning—**Surface variations may result in failure to achieve calibration with the reference standard.)

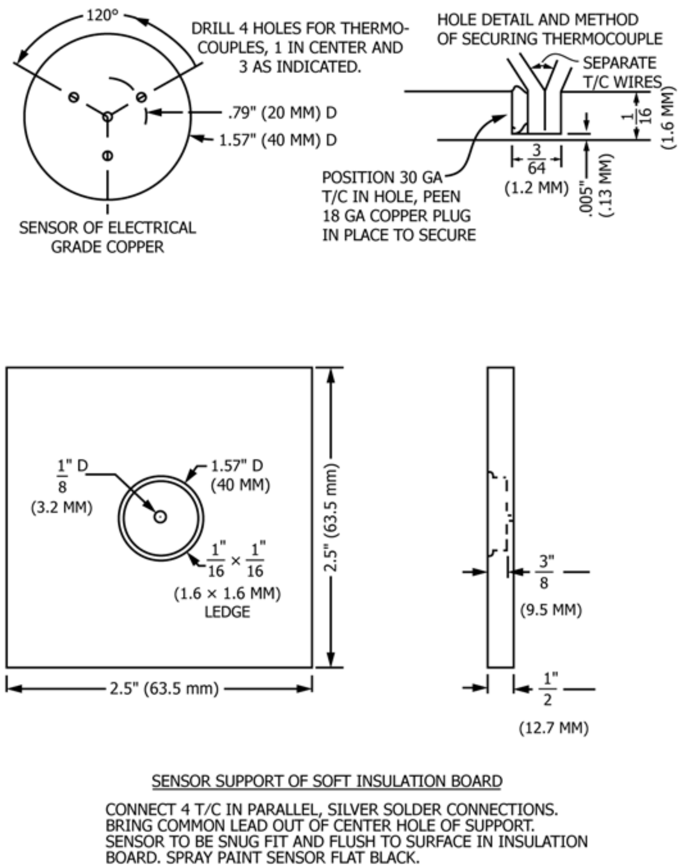


FIG. 3 Details of Calorimeter Construction

6.5 *Calibration Specimen*—Six new, not previously tested sheets of ordinary newspaper with total thickness of 0.53 ± 0.05 mm (0.021 ± 0.002 in.).

6.6 *Recorder*—Any strip chart recorder with full-scale deflection of at least 150°C (300°F) or 10 mV and sufficient sensitivity and scale divisions to read sensor response to 1°C (±2°F) or ±0.05 mV. A chart speed to read exposure time to ±0.1 s is required, 13 mm/s (0.5 in./s) is satisfactory.

7. Hazards

7.1 Perform the test in a hood or a ventilated area to carry away degradation products, smoke, and fumes. Exercise care to prevent contact with hot surfaces. Use protective gloves when handling hot objects. Have an appropriate portable fire extinguisher nearby.

8. Sampling

8.1 *Lot Size*—For acceptance sampling purposes, a lot is defined as a single shipment of a single style of fabric. A lot constitutes all or part of a single customer order.

8.2 *Lot Sample*—As a lot sample for acceptance testing, take at random the number of rolls of fabric directed in an applicable material specification or other agreement between the purchaser and the supplier.

8.3 *Laboratory Sample*—As a laboratory sample, take from the outside of each roll in the lot sample a full width swatch of fabric 1 m (1 yd) long after discarding a full width length of at least 1 m (1 yd) from the very outside of each roll.

9. Specimen Preparation

9.1 Cut and identify five test specimens from each swatch in the laboratory sample. Make each test specimen 100 by 150 ± 2 mm (4 by 6 ± 1⁄16 in.) with two of the sides of the specimen parallel with the warp yarns in woven fabric samples, with the wales in knit fabric samples, or with the length of the fabric in batts or sheet structure. Do not cut samples closer than 2 % of the fabric width from the selvage. Cut specimens from a diagonal zone across the sample swatch so as to get as representative a sample of all yarns present as practical.

9.2 Alternatively cut test specimens from a finished garment. Cut specimens using the orientation indicated in 9.1. Test specimen shall not include any seam.

9.3 Bring the specimens to a controlled moisture content by preconditioning in a 48.9°C (120°F) oven for 4 h and then exposing to a standard atmosphere for testing textiles, that is, in air maintained at a relative humidity of 65 ± 2 % and at a temperature of 21 ± 1°C (70 ± 2°F) for at least 4 h. See the portion of the Definitions Section of Practice D1776/D1776M containing the definitions for "standard atmosphere for preconditioning textiles" and for "standard atmosphere for testing textiles."

10. Calibration and Standardization

10.1 *Apparatus*—Center the surface plate on the hot plate and place a thermocouple in the thermocouple (T/C) well of the surface plate to measure exposure temperature.

10.2 *Test Exposure*— Adjust control to the hot plate to obtain desired temperature. Allow temperature to stabilize to within 2.8°C (±5°F) of the desired test temperature as indicated by three successive readings taken at least 5 min apart.

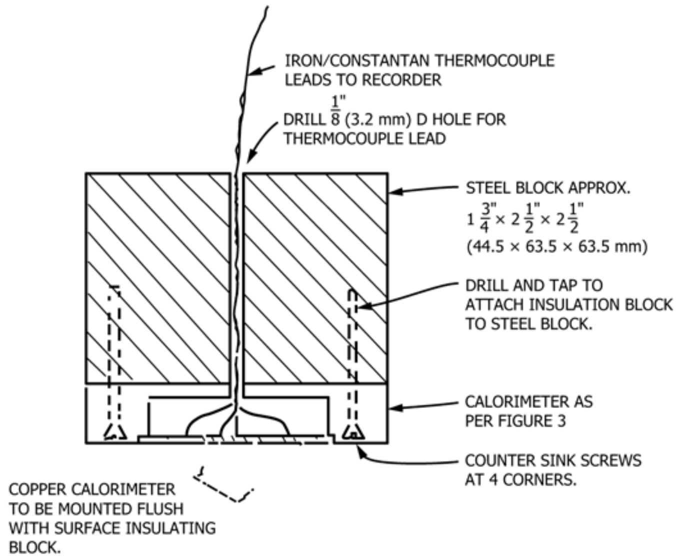
10.3 *Reference Standard*—Six new sheets of ordinary newspaper[3] conditioned as specified in 9.3 are the calibration specimen used as a reference standard. When the reference standard is used with a plate temperature of 200 ± 3°C (392 ± 5°F), correct operation of the apparatus and data analysis are indicated with the results of Time to Pain = 1.0 ± 0.2 s and Time to Burn = 3.0 ± 0.3 s.

10.4 *Sensor Care:*

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

10.4.2 *Surface Reconditioning*—Inspect the sensor face immediately after each run. If it has collected any degradation products, or polymer has stuck to it, the surface requires reconditioning. Carefully clean the cooled sensor with acetone or petroleum solvent, making certain there is no ignition source nearby. If bare copper is showing, repaint the surface with a

[3] The type of newsprint used by the *Wall Street Journal* has been found satisfactory for this purpose.



NOTE 1—Grind steel block to give total assembly weight of 3.125 ± .025 lb. (1417.5 ± 11 gr).

FIG. 4 Details of Calorimeter and Weight Assembly

thin layer of flat black spray paint (emissivity > 0.95). After repainted surface has air dried, heat sensor on hot surface plate to at least 65°C (150°F) to "cure" paint prior to using the reconditioned sensor in a test run.

10.5 *Preparation of Human Tissue Heat Tolerance Overlays*—The thermal end point is determined with a plot of energy versus time to cause a pain sensation or second degree burn in human tissue. Plot, on the recorder chart paper, the calorimeter equivalent for second degree burn from Table 2, which corresponds to the recorder scale ΔT°F, ΔT°C, or ΔmV (column 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 to give a graph which compares directly with the recorder sensor trace. If pen deflection is from left to right, and paper movement down, plot from right to left—origin at lower right. If recorder trace differs, adjust the graph accordingly. Make an exact transparent duplicate for the overlay. Compare the overlay with the original to ensure that duplication did not change the overlay size. In like manner, plot the pain tolerance curve using data from Table 1.

11. Procedure

11.1 *Specimen Mounting*—Place the cut specimens on the table, and if multiple layers, in the order they are worn, with the surface worn next to the skin facing up. Center the sensor on the specimens and draw the long ends up either side of the sensor and hold in place by grasping the blocks weighting the sensor.

11.2 *Specimen Exposure*—Start the recorder chart movement and position the sensor on the hot surface plate. Continue the exposure until the sensor response exceeds the values of the calorimeter equivalent temperature rise for second degree burn (temperature rise of 35 to 40°F, 20 to 25°C, or 1.0 to 1.2 mV for long exposures). Assemblies that have superior insulation may not permit heat transfer that will exceed the heat criteria. In this case, stop the test after 1 min, or a period of time representing the desired use condition. Remove the sensor and specimen from the hot surface, separate specimen layers and start cooling the sensor. Expose three specimens or combinations of layers of materials.

12. Interpretation of Results

12.1 The information obtained from this test is an observation of the physical damage produced by the exposure, and the time predicted to cause a pain sensation or a second degree burn from the heat transferred through the test specimen. Refer to Terminology D4391.

12.1.1 *Response to Hot Surface Contact*—After the exposed specimen has cooled, observe the effect of the exposure. The observed conditions may be described by one or more of the terms defined in Section 3.

12.1.2 *Exposure Time*— The time to the thermal end point is determined graphically from the recorder chart of the sensor response and the criterion overlay prepared in 10.5. Position the overlay on the recorder chart, matching the zero of the overlay with the point on the recorder chart corresponding to the time at which the sensor and the specimen were placed in direct contact with the hot plate. Place the horizontal (time) axis in line with the initial trace of the pen. Keep the overlay square with the recorder chart. Exposure time is read to the nearest 0.1 s from the overlay chart at the point where the sensor response curve and the tissue tolerance curve cross. If the sensor response curve and the tissue tolerance curves do not cross, record "no pain" or "no burn" as the test result.

NOTE 1—The first indication of pen deviation may be determined as the intersection of the continuation of the time baseline of the tracer in the *x* direction, and the extension of the first straight line portion of the sensor response back toward the base line.

13. Report

13.1 State that the test has been performed in accordance with this ASTM designation F1060, and report the following information:

13.1.1 *Material:*

13.1.1.1 A detailed sample description including fabric weight and thickness, type treatments if any, source, and any other relevant information. Include data for all materials involved in this test;

13.1.1.2 Number of rolls in lot sample, and

13.1.1.3 Number of specimens tested.

13.1.2 *Conditions of Test if Other Than Standard,* such as:

13.1.2.1 Hot surface temperature;

13.1.2.2 Number of layers tested—single, multiple and order of layers, and

13.1.2.3 Contact pressure.

13.1.3 *Test Results:*

13.1.3.1 Human tissue criteria—pain, second degree burn, or both;

13.1.3.2 Exposure time for each specimen for each criterion used;

13.1.3.3 Average exposure time for all specimens tested for each criterion used, and

13.1.3.4 Description of the effect of the exposure energy as listed in 12.1.1.

14. Precision and Bias

14.1 *Precision*—A temporary precision statement is included, pending completion of an interlaboratory study that will allow stating both within-laboratory and between-laboratory precision.

14.1.1 *Single Laboratory Study*—Five multilayer material composites were tested in one laboratory, using one operator to measure time-to-pain and time-to-burn parameters, as required by the procedure. Five specimens were measured for each material. The data set was analyzed and precision reported for each material separately in the form of standard errors and critical differences.

14.1.2 Within-Laboratory Precision, based upon determination in one laboratory, is given in Table 3 for time-to-pain and time-to-burn (second degree), with each material shown separately.

14.1.3 Until the interlaboratory study is completed, users of the test method are advised to exercise conventional statistical caution in making any comparisons of test results.

14.2 *Bias:*

14.2.1 The values of time-to-pain and time-to-burn can be defined only in terms of a test method.

14.2.2 This test method has no known bias.

14.2.3 There is no independent referee test method for determining whether or not this test method has any bias.

15. Keywords

15.1 hot surface contact; protective clothing; textiles; thermal; thermal resistance

TABLE 3 Within-Laboratory Precision Table – 95 % Probability Level Showing Values for Standard Error (SE) and Critical Difference (CD) (Single Laboratory/Single Operator Determination)

	Time To Pain			Time to Burn		
Material	Sp in Av	SE	CD	Sp in Av	SE	CD
A	1	1.071	3.00	1	1.307	3.66
	3	0.618	1.73	3	0.755	2.11
test std	5	0.479	1.34	5	0.584	1.64
	7	0.405	1.13	7	0.494	1.38
B	1	0.152	0.42	1	0.583	1.63
	3	0.088	0.25	3	0.337	0.94
test std	5	0.068	0.19	5	0.261	0.73
	7	0.057	0.16	7	0.220	0.62
C	1	0.415	1.16	1	0.428	1.20
	3	0.239	0.67	3	0.247	0.69
test std	5	0.185	0.52	5	0.191	0.54
	7	0.157	0.44	7	0.162	0.45
D	1	0.228	0.64	1	0.336	0.94
	3	0.132	0.37	3	0.194	0.54
test std	5	0.102	0.29	5	0.150	0.42
	7	0.086	0.24	7	0.127	0.36
E	1	0.705	1.97	1	1.377	3.85
	3	0.407	1.14	3	0.795	2.23
test std	5	0.315	0.88	5	0.616	1.72
	7	0.266	0.75	7	0.520	1.46