



# Standard Test Method for Evaluating Heat Transfer through Materials for Protective Clothing Upon Contact with a Hot Liquid Splash<sup>1</sup>

This standard is issued under the fixed designation F2701; 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 ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

## INTRODUCTION

This test method is for materials used to protect workers in the event of a hot liquid splash incident. The intent of this test method is to test materials or assemblies of materials that will prevent hot liquid from penetrating through the materials to avoid direct contact of the hot liquid with the heat sensors used to simulate human tissue response. The test method determines whether there is sufficient heat transmitted through the material or assemblies of materials to cause a second degree burn injury during a controlled splash of hot liquid at a specified temperature. The test method utilizes similar equipment and a similar test set-up to that of Test Method F955 for Molten Substances, but the temperatures of the hot liquid hazards are limited to a much lower level than the molten substances tested in accordance with Test Method F955. The specimens of this test method are expected to remain impermeable to the hot liquids during the test exposure.

## 1. Scope

1.1 This test method is used to measure the heat energy transmission through materials used in protective clothing and gloves that are exposed to a Hot Liquid Splash. This test method is applicable to woven fabrics, knit fabrics, battings, and sheet structures with permeable or impermeable coatings or laminations intended for use as clothing or gloves for protection against brief exposures to hot liquid splash hazards.

1.2 This test method is used to measure and describe the properties of materials or assemblies of materials in response to hot liquids under controlled laboratory conditions.

1.3 This test method is applicable to materials from which finished protective apparel articles are made.

1.4 This test method is limited to the hot liquid temperatures that are 40°C (72°F) below the flash point of the specific hot liquid used for testing.

NOTE 1—Specific thermally stable silicone liquids are available with flash points in the range of 315°C (599°F). When these thermally stable silicone liquids are used, a maximum hot liquid temperature of 260°C (500°F) is achievable. The intent of specifying the maximum temperature at 40°C (72°F) below the liquid flash point is to reduce the hot liquid fire hazard which increases significantly at temperatures equal to or above the flash point of the liquid.

1.5 This test method does not measure the flammability of materials, nor is it intended for use in evaluating materials exposed to any other thermal exposure other than hot liquid exposures.

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

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.* Specific hazard statements are given in Section 8.

## 2. Referenced Documents

2.1 *ASTM Standards*:<sup>2</sup>

D93 Test Methods for Flash Point by Pensky-Martens Closed Cup Tester

D123 Terminology Relating to Textiles

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

F955 Test Method for Evaluating Heat Transfer through Materials for Protective Clothing Upon Contact with Molten Substances

<sup>1</sup> 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.

Current edition approved April 15, 2008. Published May 2008. DOI: 10.1520/F2701-08.

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

## F1494 Terminology Relating to Protective Clothing

### 3. Terminology

#### 3.1 Definitions of Terms Specific to This Standard:

3.1.1 *break-open*—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.

3.1.1.1 *Discussion*—In hot liquid testing of thermal protective materials, a hole in one or more layers of the material allows hot liquid to pass through the material and consequently allows thermal energy to pass through the material.

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

3.1.3 *dripping*—a material response evidenced by flowing of a specimen's material of composition.

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

3.1.5 *flash point*—for hot liquid testing, the lowest temperature at which a liquid can form an ignitable mixture in air near the surface of the liquid.

3.1.5.1 *Discussion*—An ignition source is required to ignite the vapor and air mixture as the flash point, and the flame may extinguish when the ignition source is removed.

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

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

3.1.8 *liquid breakthrough*—in hot liquid testing, observation of the presence of the liquid used in testing on the test specimen surface adjacent to the sensor board surface.

3.1.9 *melting*—in testing thermal protective materials, a material response evidenced by softening of the material.

3.1.10 *response to hot liquid pour*—in testing thermal protective materials, the observed effect of hot liquid contact on textile properties or deterioration of the material.

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

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

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

3.3 for definitions of other protective clothing terms used in this test method, refer to Terminology **F1494**.

### 4. Summary of Test Method

4.1 A material specimen is mounted on an incline and is exposed to a hot liquid pour of prescribed temperature, volume, pour rate, and height above the specimen.

4.2 The amount of heat energy that is transmitted through the test specimen during and after the hot liquid exposure is measured using two copper slug calorimeters. The heat trans-

ferred is assessed versus the Stoll burn injury curve, an approximate human tissue tolerance predictive model that projects the onset of a second-degree skin burn injury as manifested by a blister (See **12.2**).

4.3 A specific set of subjective evaluations is performed on the test specimen response to the hot liquid exposure using a standardized rating scale for appraisal (found in **Fig. X1.1**).

### 5. Significance and Use

5.1 Workers in some industries are exposed to hot liquid splash hazards. The protective clothing used needs to provide a degree of protection. Whether personal injury results from such hazards depends on the resistance of the material from which the protective clothing is made to hot liquids and the amount of heat transferred through the material to the wearer.

5.2 This test method rates materials that are intended for protective clothing used against potential exposures to a hot liquid splash, for their impermeability to the hot liquid, for their thermal insulating properties, and for their reaction to the hot liquid test exposure.

5.3 The protective performance, as determined by this test method, will relate to the actual end-use performance only to the degree that the end-use exposure is identical to the exposure used in the test method.

5.4 Visual inspection of the specimen subjectively notes the material's response to hot liquid exposure.

### 6. Apparatus

6.1 The test apparatus consists of the following components:

6.1.1 An inclined specimen mounting and exposure board with two copper slug calorimeters and supports,

6.1.2 A funnel held in a fixed position above the specimen mounting and exposure board which controls the flow rate of the hot liquid and the location at which the hot liquid flow contacts the surface of the specimen on the mounting and exposure board,

6.1.3 A catch pan which collects the hot liquid as it flows off the bottom of the specimen surface while the specimen is on the mounting and exposure board,

6.1.4 A container in which the hot liquid is heated and from which the hot liquid is poured into the funnel,

6.1.5 The mounting and exposure board, funnel, catch pan, and heating and pouring container shall be suitable for the hot liquid being poured and for exposure to temperatures up to at least  $28^{\circ}C$  ( $50^{\circ}F$ ) above the pouring temperature.

6.1.6 A hot plate for heating the liquid to the desired exposure temperature,

6.1.7 A ventilated hood in which to heat and pour the hot liquid, and

6.1.8 Instruments and data collection devices for measuring test exposure conditions and the temperature rise of the copper calorimeters.

#### 6.2 Sensor Construction

6.2.1 The two sensors each consist of a  $40 \pm 0.5$  mm diameter circular copper slug calorimeter constructed from electrical grade copper with a mass of  $18 \pm 0.05$  grams (prior

to drilling) with a single Iron-Constantan (ANSI type J) or a single Nickel-Chromium-Nickel-Aluminum (ANSI type K) thermocouple wire bead (0.254 mm wire diameter or finer – equivalent to 30 AWG) installed as identified in 6.2.4 and shown in Fig. 1 (see Test Method E457 for information regarding slug calorimeters).

6.2.2 The sensors are affixed into the respective recess of the holding board specified in 6.3 below.

NOTE 2—Inserting three straight pins, trimmed to a nominal length of 5 mm, equidistant around the edge of the sensor so that the heads of the pins hold the sensor flush to the surface has been found suitable to affix the sensors to the board.

6.2.3 Paint the exposed surface of the copper slug calorimeters with a thin coating of a flat black high temperature spray paint with an absorptivity of 0.9 or greater. The painted sensor must be dried and cured, according to the manufacturers instructions, before use and present a uniformly applied coating (no visual thick spots or surface irregularities). In the absence of manufacturers 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.

6.2.4 The thermocouple wire is installed in the calorimeter as shown in Fig. 1.

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

(1) 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.

(2) A solder bond shall be produced by using a suitable HMP solder with a melting temperature > 280°C.

NOTE 3—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<sup>2</sup> heat flux to a prepared copper calorimeter with a surface area of 12.57 cm<sup>2</sup> and a mass of 18.0 g. 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).

### 6.3 Specimen/Sensor Board

6.3.1 The specimen/sensor board shall be 254 by 406 mm (10 by 16 in.) and fabricated of a non-conductive, liquid and 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 13 mm (0.5 in.) or greater in thickness.

NOTE 4—Liquids that permeate into the specimen/sensor board can affect the performance of the copper calorimeters and the measurement of a specimen’s protective qualities. Consider the use of different board materials for different test liquids.

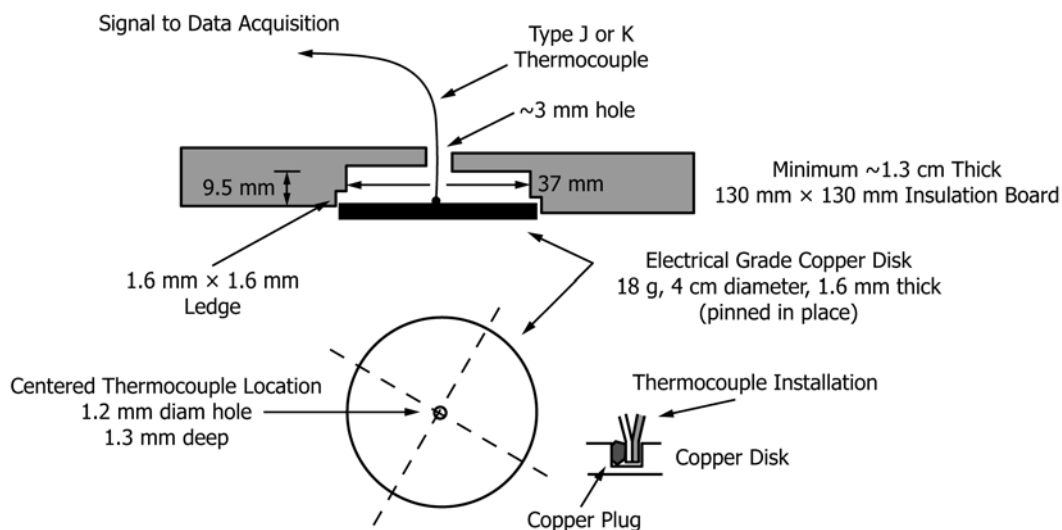
6.3.2 The copper slug calorimeters shall be located in the centerline of the sensor board and mounted as shown in Fig. 1. The calorimeters shall be located 102 mm and 204 mm (4 in. and 8 in.) respectively, from the top of the board to the calorimeter centers as indicated in Fig. 2.

6.3.3 An attachment method shall be provided that affixes the test specimen to the board such that it covers both sensors and extends at least 50 mm (2 in.) beyond all edges.

6.3.4 The sensor board shall be inclined at an angle of 45° from horizontal.

6.3.5 The sensor board shall be located so that it meets the pour geometry illustrated in Fig. 2, where the hot liquid is introduced at the centerline of the board directly onto the area of the specimen corresponding to the center of the upper sensor.

6.4 Funnel—The funnel cone top opening shall have a diameter of at least 203 mm (8 in.), the funnel cone shall have



NOTE 1—Sensor Construction (using mechanical connection of thermocouple wire)—Place a straight, bare tip thermocouple wire into the hole located in the center of the copper disk. Place a short “copper plug” into the center hole with the thermocouple junction by clipping a section of bare copper wire of appropriate diameter that, when combined with the thermocouple wire, will just fit into the center hole. Use a center punch to mechanically wedge the wire bundle into place. Peen around the hole to further secure the thermocouple into the copper disk. Take care not to cut the thermocouple wire during this assembly process. Check the electrical continuity and thermal response prior to using the completed copper slug calorimeter.

FIG. 1 Sensor Calorimeter Construction

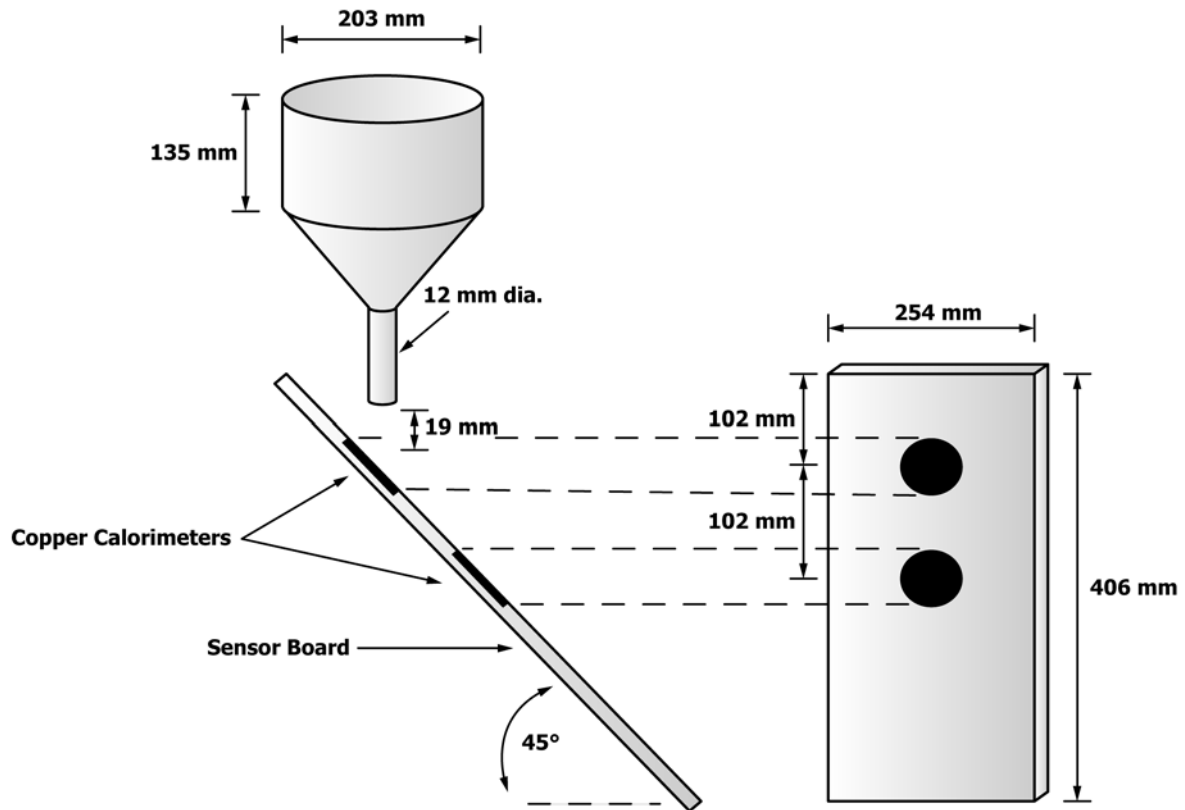


FIG. 2 Schematic of Test Apparatus

a height of at least 135 mm and the funnel cone shall be of a sufficient size to hold 1 liter of hot liquid, the funnel bottom cone or spout opening shall be  $12 \pm 1$  mm ( $0.49 \pm 0.04$  in.), and the funnel shall include a means to control the hot liquid flow rate such as a designated size orifice through which the hot liquid flows as it passes through the funnel. The funnel shall be supported in the test apparatus so that the funnel bottom cone opening or funnel spout is positioned directly above the center of the upper sensor in the sensor board with a distance of  $19 \pm 1$  mm ( $0.75 \pm 0.04$  in.) above the center of the upper sensor in the sensor board.

6.4.1 The funnel shall be equipped with a temperature recording device that measures the maximum temperature of the liquid in the funnel during the 10 seconds that the liquid is flowing through the funnel.

6.5 *Heating and Pouring Container*—The heating and pouring container shall hold at least 1.5 litres of hot liquid and shall be of a design that permits 1.0 litres of hot liquid to be accurately poured into the funnel top opening in a time period of 5 to 7 seconds so as to create a total hot liquid flow time of  $10 \pm 1$  seconds.

6.6 *Hot Plate*—A hot plate with sufficient heating capacity for heating the test liquid to  $28^\circ\text{C}$  ( $50^\circ\text{F}$ ) above the desired hot liquid exposure temperature shall be used.

6.7 Pouring height shall be approximately at the height of the funnel cone top opening.

6.8 *Data Acquisition System*—The system shall be capable of recording the calorimeter outputs as required by the test.

6.8.1 The temperature data (calorimeter outputs) shall be acquired at a minimum sampling rate of one sample per second for each calorimeter. The acquisition system shall be able to record temperatures to  $150^\circ\text{C}$  ( $302^\circ\text{F}$ ), have at least a resolution of  $0.1^\circ\text{C}$  ( $0.2^\circ\text{F}$ ), and measuring precision of  $\pm 0.75^\circ\text{C}$  ( $\pm 1.4^\circ\text{F}$ ).

## 7. Materials

7.1 Descriptions of liquids available for hot liquid testing are included in [Table 1](#).

## 8. Hazards

8.1 Perform the test in a ventilated hood to carry away hot liquid fumes and decomposition gases. During testing there shall be no ignition sources within the ventilated hood. A fire extinguisher of the carbon dioxide type, shall be readily available in the testing hood area.

8.2 Care shall be exercised in handling hot liquids. The sensor board, calorimeter assembly and catch pan become heated during testing. Use normal safety practices for the handling of the hot liquids, hot objects and potentially flammable materials including thermally protective, impermeable gloves, safety goggles, a faceshield, a hard hat and impermeable flame resistant protective clothing when handling these hot objects, during the hot liquid pour and for collection of the hot liquid after testing.

8.3 Extreme care shall be taken to prevent contact between the hot liquids and water because splatter of the hot liquid and hot water can result.



**TABLE 1 Hot Liquid Information**

NOTE 1—When this test method is used for a hot liquid other than below, use a pour temperature equal to or less than 40°C (72°F) below the Flash Point (open cup) temperature of the liquid.

Substance	Smoke Point <sup>A</sup>	Approximate Flash Point <sup>B</sup>	Pour Temperature (maximum)
Canola Oil	204°C (400°F)	246°C (475°F)	206°C (403°F)
Safflower Oil	232°C (450°F)	260°C (500°F)	220°C (428°F)
Peanut Oil	232°C (450°F)	271°C (520°F)	231°C (448°F)
Corn Oil	232°C (450°F)	277°C (531°F)	237°C (459°F)
Silicone Dynalene 600	>260°C (>500°F)	315°C (599°F)	260°C (500°F)

<sup>A</sup>Smoke point indicates the temperature at which the oil is thermally degrading. Do not reuse oils that have been used above the smoke point temperature since degradation changes the oil composition and flash point. The silicone oil listed is more costly than vegetable oil, but due to its thermal stability, the silicone oil is expected to be more reusable than vegetable oils. Sources of smoke point information are, *Journal of Chemical Education*, Vol. 80, No. 5, May 2003, Corn Refiners Association, "Corn Oil", 5th Edition, 2006, www.corn.org., Dyanlene Inc., Whitehall, PA

<sup>B</sup>Flash point is defined in Section 3. Sources for flash point information are available at various internet sites and from Dyanlene Inc. in Whitehall, PA. It is highly recommended that the flash point of each liquid used for this test method be tested in accordance with Test Method D93.

8.4 Consult MSDS hazard information for each liquid used in testing to determine potential toxicity of each liquid and the associated vapors generated during heating.

## 9. Sampling and Test Specs

9.1 *Sample Size*—Sample size shall be of at least 2 m (2.2 yd) of a full-width piece of the test material.

9.2 *Sample Conditioning*—Samples shall be conditioned for at least 8 hours at 25 ± 3°C (77 ± 5°F) and 50 ± 10 % RH prior to testing. Testing shall be performed within 30 minutes of removal of sample from conditioning.

9.2.1 Laundering or dry cleaning of samples is optional, but if samples are laundered or dry cleaned, the laundering, or dry cleaning conditions, or both, shall be included in the report.

9.3 *Test Specimens*—Cut and identify three test specimens from each sample. Make each test specimen 355 by 560 mm (14 by 22 in.). Do not cut samples closer than 10 % of the material width from the edge of the material and arrange the specimens across the sample width so as to obtain a representative sampling. Cut the specimens so that the longer dimension is in the warp direction of the sample.

### 9.4 *Sensor Care:*

9.4.1 *Initial Temperature*—Cool the sensor after a hot liquid exposure to approximately 30°C (86°F) immediately prior to positioning the test specimen.

9.4.2 *Surface Reconditioning*—Wipe the sensor face with a nonabrasive material immediately after each run, while it is hot, to remove any decomposition products which condense on the sensor surface, since these could be a source of error. If there is a deposit on the surface of the sensor that appears to be thicker than a thin layer of paint, or is irregular in thickness, the sensor surface requires reconditioning. Carefully clean the cooled sensor with acetone or petroleum solvent, making certain there is no ignition source nearby. Repaint the surface, if bare copper is showing, with a thin layer of flat black spray paint as identified in 6.2.3 above.

## 10. Procedure

10.1 *Specimen Mounting*—A piece of the test material, prepared in accordance with 9.2 and 9.3, is placed flush against the sensor board with the sample material extending over the sensor board edges, centered horizontally over the calorimeters with the top of the specimen extending about 50 mm (2

in.) above the top of the sensor board and the bottom of the specimen extending about 100 mm (4 in.) below the bottom of the sensor board. Attach the test material to the sensor board by an appropriate means—using six metal binder clips with a width of 32 mm (1.25 in.) has proven to be effective.

10.1.1 *Multiple Layer Samples*—For the standard tests to measure the protective property of multiple layer samples, place the surface of the material to be used as the outside of the garment facing out. Place the subsequent layer(s) underneath in the order used in wearing with the surface to be worn toward the skin facing the calorimeters.

10.2 *Liquid Heating and Pour Method*—Maintain the initial temperature of the liquid to be used for the hot liquid exposure at 25 ± 2°C (77 ± 4°F). Add one liter of the liquid to the heating and pouring container. Heat the container on the hot plate until test liquid temperature is approximately 5°C (9°F) above the desired hot liquid exposure temperature. Remove the container from the hot plate, position the container above the funnel at the level of the top of the funnel and pour the one liter of hot liquid into the funnel so that all liquid is in the funnel reservoir within 3 to 5 seconds. (Take extreme care to avoid being splashed by the hot liquid.) The cooling that takes place when the hot liquid container is removed from the hot plate and the liquid is poured into the funnel will reduce the hot liquid temperature by approximately 5°C (9°F) but this will vary depending on the liquid being used, the hot liquid exposure temperature and the time required to pour the hot liquid into the funnel. A few pours will be necessary to determine the degree to which the hot liquid will cool during the testing process.

10.2.1 The calorimeter data acquisition system and the funnel reservoir temperature data acquisition are started approximately 10 seconds before the hot liquid pour is initiated. This establishes the pre-exposure copper slug calorimeter temperatures for the heat energy determination. The pre-exposure copper slug calorimeter shall be 30 ± 2°C (86 ± 4°F).

10.2.2 The flow rate of the hot liquid through from the funnel reservoir onto the specimen is adjusted so that the one liter of hot liquid flows onto the test specimen in 10 ± 1 seconds when the one liter of hot liquid is poured into the funnel in 3 to 5 seconds. The flow rate is adjusted by positioning the appropriate size orifice in the flow path within the base of the funnel reservoir. Conduct trial pours with

different orifice sizes to establish the hot liquid flow rate of one liter in  $10 \pm 1$  seconds.

10.2.3 Continue calorimeter data acquisition for 40 seconds after the 10 seconds of hot liquid exposure. The total data acquisition time is approximately 60 seconds from the time the data acquisition system is started until data acquisition is ended.

10.2.4 Visually observe the specimen during and immediately after the pour for any unusual material response characteristics. Remove the specimen from the specimen sensor board and record the material response characteristics listed in 12.6 using the report form provided in Fig. X1.1.

10.2.5 Expose two specimens for each sample tested.

10.2.6 If the total temperature rise values of the two tests differ by more than 10 %, test a third specimen and average the results for the three tests specimens. Note any explainable reason for the variation.

10.2.7 Collect the used liquid in the collection pan and reuse liquid if not contaminated or degraded by the testing process.

## 11. Calculation

11.1 *Sensor Response*—Determined the response of each calorimeter for 10 seconds before the hot liquid pour has been initiated, during the 10 seconds of the hot liquid exposure, and for 40 seconds after a hot liquid exposure has been completed. The total data acquisition period is approximately 60 seconds.

11.1.1 Once a pour initiation point is determined, the temperature data collected from the calorimeters before and up to the initiation point are averaged to obtain a starting calorimeter temperature,  $T_{\text{initial}}$  (°C) for each respective sensor.

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

$$C_p = \frac{4.1868 \times (A + B \times t^2 + C \times t^3) + E/t^2}{63.546 \text{ g/mol}} \quad (1)$$

$t$  = (measured temperature °C + 273.15) / 1000

$A$  = 4.237312

$B$  = 6.715751

$C$  = -7.46962

$D$  = 3.339491

$E$  = 0.016398

NOTE 5—The heat capacity of copper in  $\text{J/g}^\circ\text{C}$  at any temperature between 289 K and 1358 K is determined by means of Eq 1 (Shomate Equation with coefficients from NIST).

11.1.3 The total incident energy versus time is determined and plotted for the upper and lower heat energy sensors.

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

$$\bar{C}_p = \frac{C_p @ \text{Temp}_{\text{initial}} + C_p @ \text{Temp}_{\text{final}}}{2} \quad (2)$$

11.1.3.2 The total incident energy at each time step is determined in  $\text{J/cm}^2$  by using the relationship,

$$\text{Cumulative heat exposure, } Q = \frac{\text{mass} \times \bar{C}_p \times (\text{Temp}_{\text{final}} - \text{Temp}_{\text{initial}})}{\text{area}} \quad (3)$$

$Q$  = heat energy in  $\text{J/cm}^2$ ,

$\text{mass}$  = mass of the copper disk/slug (g),

$\bar{C}_p$  = average heat capacity of copper during the temperature rise ( $\text{J/g}^\circ\text{C}$ ),

$\text{Temp}_{\text{final}}$  = final temperature of copper disk/slug at time<sub>final</sub> (°C),

$\text{Temp}_{\text{initial}}$  = initial temperature of copper disk/slug at time<sub>initial</sub> (°C), and

$\text{area}$  = area of the exposed copper disk/slug ( $\text{cm}^2$ )

11.1.3.3 For a copper disk/slug that has a mass of 18.0 g and exposed area of  $12.57 \text{ cm}^2$ , the determination of heat energy reduces to:

$$\text{Cumulative heat energy, } Q = 1.432 \times \bar{C}_p \times (\text{Temp}_{\text{final}} - \text{Temp}_{\text{initial}}) \quad (4)$$

NOTE 6—If a copper disk/slug with a different mass, or exposed area, or both, is used, the constant factor in Eq 4 must be adjusted correspondingly. If required, the value in  $\text{cal/cm}^2$  can be determined by multiplying the total heat energy in Eq 4 by the conversion factor 1/4.1868  $\text{cal/J}$ .

11.2 *Predicted Second-Degree Skin Burn Injury Determination (Stoll Curve Comparison)*—The time dependent measured heat energy for each copper slug calorimeter monitor sensor, determined in 11.1.3.3 above, is compared to an empirical human predicted second-degree skin burn injury model<sup>3</sup>, commonly referred to as the “Stoll Curve” or “Stoll Response”.

$$\text{J/cm}^2 = 5.0204 \times t_i^{0.2901} \quad (5)$$

NOTE 7—The “Stoll Response” can also be expressed in  $\text{cal/cm}^2$  by means of:

$$\text{cal/cm}^2 = 1.1991 \times t_i^{0.2901} \quad (6)$$

11.3 The thermal endpoint in seconds for each sensor is the point at which the sensor response intersects the Stoll curve. This indicates the predicted time at which human tissue would receive a second degree burn injury under the test exposure conditions. In some tests, the thermal endpoint is not reached indicating that a second degree burn injury is not predicted to occur under the test exposure conditions.

## 12. Report

12.1 Report the description of the specimen including but is not limited to the number of material layers in the specimen, the sequence of the layers as they would be worn starting from the outer-most layer, the type of material in each layer, the areal density in  $\text{g/m}^2$  ( $\text{oz/yd}^2$ ) of each layer of material, the color of each layer of material, the preconditioning in terms of laundering, dry cleaning and/or ambient conditioning for each specimen prior to testing.

12.2 Report the time in seconds to produce a second-degree burn in accordance with the Stoll curve from the heat transferred through the test specimen (from 11.2) for both the upper and lower sensors on the specimen sensor board. (No second degree burn is one possible value.) All values from the calorimeters during the entire 60 second data acquisition period shall be used.

<sup>3</sup> 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.

**TABLE 2 Precision Information**

Upper Sensor Time to Burn	Lower Sensor Time to Burn	Upper Sensor Temp. Rise °C (°F)	Lower Sensor Temp. Rise °C (°F)
Average = 7.1 s	Average = 7.9 s	Average = 28.4°C (51.1°F)	Average = 33.4°C (60.2°F)
Standard Deviation = 1.5 s	Standard Deviation = 1.1 s	Standard Deviation = 3.6°C (6.5°F)	Standard Deviation = 2.3°C (4.1°F)
95% Confidence Interval = ±2.3 s	95% Confidence Interval = ±1.8	95% Confidence Interval = ±5.8°C (51.1°F)	95% Confidence Interval = ±3.6 °C (6.5°F)
Repeatability = 4.2 s (2.8 x standard deviation)	Repeatability = 3.1 s (2.8 x standard deviation)	Repeatability = 10.1°C (18.2°F) (2.8 x standard deviation)	Repeatability = 6.4 °C (11.5°F) (2.8 x standard deviation)

12.3 Report the total temperature rise in degrees °C (°F) during the hot liquid exposure for both the upper and lower sensors on the specimen sensor board.

12.4 Report any physical damage to test material.

12.5 Report any observations regarding hot liquid absorption, liquid to solid phase change or specimen response during test.

12.6 *Visual Material Response Characteristics*—After the exposed specimen has cooled, carefully remove it from the sensor board and visually observe the effect of the hot liquid exposure on the specimen. The material response is described by one or more of the following terms which are defined in 3.1.1–3.1.5 and 3.1.7–3.1.10: break open, charring, dripping, embrittlement, liquid breakthrough, melting, shrinkage, liquid absorption by test material, and location of the material responses in relation to the upper and lower sensor discs on the specimen sensor board. Use the Material Response Report

Form, (see Fig. X1.1) or a comparable format to report the Material Response Characteristics.

**13. Precision and Bias**

13.1 *Precision*—The repeatability standard deviation and confidence interval are provided in Table 2 for a polychloroprene coated aramid material with an nominal areal density of 400 g/m<sup>2</sup> (12 oz/yd<sup>2</sup>) and a thickness of 0.38 mm (0.15 in.) exposed to a hot liquid splash of canola oil at temperature of 150°C (302°F). for a nylon sample. The 95 % confidence limit for the polyester sample is 240 ± 2°C and for the 6,6 nylon sample is 238 ± 3°C. A detailed summary will be placed on file with ASTM headquarters. The reproducibility of this test method will be available on or before June 30, 2008.

13.2 *Bias*—No justifiable statement can be made on the bias of this test method for evaluating heat transfer through materials, since the true values of heat transfer cannot be established by an acceptable referee method.

**APPENDIX**

**(Nonmandatory Information)**

**X1. MATERIAL RESPONSE REPORT FORM**

X1.1 See Fig. X1.1.

Sample Identification:			
Date of Test:			
Hot Liquids Used:			Tempera- ture of Hot Liq- uid:
Property	Yes	No	Comment
Ignition			
Charring			
Embrittlement			
Breakopen			
Liquid Break-through			
Melting			
Dripping			
Shrinkage			
Adhesions			

**FIG. X1.1 Material Response Report Form**

*ASTM International takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.*

*This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, at the address shown below.*

*This standard is copyrighted by ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States. Individual reprints (single or multiple copies) of this standard may be obtained by contacting ASTM at the above address or at 610-832-9585 (phone), 610-832-9555 (fax), or [service@astm.org](mailto:service@astm.org) (e-mail); or through the ASTM website ([www.astm.org](http://www.astm.org)). Permission rights to photocopy the standard may also be secured from the Copyright Clearance Center, 222 Rosewood Drive, Danvers, MA 01923, Tel: (978) 646-2600; <http://www.copyright.com/>*