



Designation: F2731 – 10

Standard Test Method for Measuring the Transmitted and Stored Energy of Firefighter Protective Clothing Systems¹

This standard is issued under the fixed designation F2731; 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 provides procedures for measuring the combination of transmitted and stored energy that occurs in firefighter protective clothing material systems as the result of exposure to prolonged, relatively low levels of radiant heat.

1.1.1 This test method applies a predetermined compressive load to a preheated specimen to simulate conductive heat transfer.

1.1.2 This test method is not applicable to protective clothing systems that are not flame resistant.

1.1.3 *Discussion*—Flame resistance of the material system shall be determined prior to testing according to the applicable performance and/or specification standard for the material's end-use.

1.2 This test method establishes procedures for moisture preconditioning of firefighter protective clothing material systems.

1.3 The second-degree burn injury used in this standard is based on a limited number of experiments on forearms of human subjects.

1.3.1 *Discussion*—The length of exposures needed to generate a second-degree burn injury in this test method exceeds the exposures times found in the limited number of experiments on human forearms.

1.4 The values stated in SI units are to be regarded as the standard. The values given in parentheses are mathematical conversions to English units or other units commonly used for thermal testing.

1.5 *This standard is used to measure and describe the properties of materials, products, or assemblies in response to radiant heat under controlled laboratory 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 *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 appro-*

priate safety and health practices and determine the applicability of regulatory limitations prior to use. Specific precautionary information is found in Section 7.

2. Referenced Documents

2.1 *ASTM Standards:*²

D123 Terminology Relating to Textiles

D1777 Test Method for Thickness of Textile Materials

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

F1494 Terminology Relating to Protective Clothing

F1930 Test Method for Evaluation of Flame Resistant Clothing for Protection Against Flash Fire Simulations Using an Instrumented Manikin

2.2 *AATCC Test Methods:*³

AATCC 70 Test Method for Water Repellency: Tumble Jar Dynamic Absorption Test

AATCC 135 Dimensional Changes in Automatic Home Laundering of Durable Press Woven or Knit Fabrics

2.3 *NFPA Standard:*⁴

NFPA 1971 Standard on Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting

3. Terminology

3.1 *Definitions:*

3.1.1 *break-open, n*—in testing thermal protective materials, a material response evidence by the formation of a hole in the test specimen.

3.1.1.1 *Discussion*—The specimen is considered to exhibit break-open when a hole is produced as a result of the thermal exposure that is at least 3.2 cm² (0.25 in.²) in area or at least 2.5 cm (1.0 in.) in any dimension. Single threads across the opening or hole do not reduce the size of the hole for purposes of this test method.

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.

³ Available from American Association of Textile Chemists and Colorists (AATCC), P.O. Box 12215, Research Triangle Park, NC 27709, <http://www.aatcc.org>.

⁴ Available from National Fire Protection Association (NFPA), 1 Batterymarch Park, Quincy, MA 02169-7471, <http://www.nfpa.org>.

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

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

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

3.1.5 *heat flux, n*—the thermal intensity indicated by the amount of energy transmitted per unit area and per unit time; kW/m²(cal/cm²-s).

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

3.1.7 *melting, n*—in testing thermal protective materials, a response evidenced by softening of the polymer.

3.1.8 *response to heat exposure, n*—in testing for the transmitted and stored energy 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.

3.1.8.1 *Discussion*—For the purposes of this test method, response to heat exposure also includes any non-textile reinforcement material used as part of the protective clothing material system that is tested.

3.1.9 *second-degree burn injury, n*—reversible burn damage in the epidermis and upper layers of the dermis, resulting in blistering, severe pain, reddening, and swelling.

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

3.1.11 *sticking, n*—a response evidenced by softening and adherence of the material to other material.

3.1.11.1 *Discussion*—For the purpose of this test method, the observation of sticking applies to any material layer in the protective clothing material system.

3.1.12 *stored energy, n*—energy stored in a fabric/composite after the heating source is removed.

3.1.12.1 *Discussion*—The term stored energy referred to in this standard only accounts for the energy released to the sensor after compressing. Stored energy is also lost to the compressor block and the surrounding environment.

3.1.13 *thermal protective clothing system, n*—any combination of materials which when used as a composite can, under certain conditions, permit a measured level of heat transfer to occur.

3.1.13.1 *Discussion*—The rate at which this heat transfer occurs can vary depending on the materials.

3.2 For definitions of other terms used in this test method, refer to Terminology **D123** and Terminology **F1494**.

4. Summary of Test Method

4.1 A vertically positioned test specimen, representative of the lay-up in firefighter protective clothing, is exposed to a relatively low level of radiant heat flux at 8.5 ± 0.5 kW/m²(0.2 ± 0.012 cal/cm²-s) for a fixed period of time.

4.2 During the time of radiant heat exposure, a data collection sensor, positioned 6.4 ± 0.1 mm (0.25 ± 0.004 in.) behind and parallel to the innermost surface of the test specimen, measures the heat energy transmitted through the test specimen.

4.3 In the same test apparatus, the test specimen is compressed against the data collection sensor at a pressure of 13.8 ± 0.7 kPa (2.0 psi \pm 0.1 psi) for a fixed period of time. This

load could possibly simulate a firefighter leaning against a wall, squatting or sitting down. This compression step occurs after the fixed radiant heat exposure time and after the specimen is moved away from the heating source.

4.4 During the time of compression against the data collection sensor, the data collection sensor continues to measure the heat energy transferred from the test specimen for a fixed duration of time.

4.5 The total energy transmitted and stored by the test specimen is used to predict whether a second degree burn injury can be predicted. If a second-degree burn injury is predicted, the time to a second degree burn injury is reported.

4.6 Two different sets of procedures are provided. In Procedure A, an iterative method is used to determine the minimum length of the radiant heat exposure followed by a 60 second compression that will result in the prediction of a second degree burn injury. In Procedure B, testing is conducted at fixed radiant heat exposure and a 60-second compression period. The report for Procedure B includes if a second degree burn injury has been predicted and if predicted, the time for a second degree burn injury.

4.7 If a second degree burn injury is not predicted, the result is indicated as “no predicted burn.”

4.8 **Appendix X1** contains a general description of human burn injury, its calculation and historical notes.

5. Significance and Use

5.1 Firefighters are routinely exposed to radiant heat in the course of their fireground activities. In some cases, firefighters have reported burn injuries under clothing where there is no evidence of damage to the exterior or interior layers of the firefighter protective clothing.⁵ Low levels of transmitted radiant energy alone or a combination of the transmitted radiant energy and stored energy released through compression can be sufficient to cause these types of injuries. This test method was designed to measure both the transmitted and stored energy in firefighter protective clothing material systems under a specific set of laboratory exposure conditions.

5.2 The intensity of radiant heat exposure used in this test method was chosen to be an approximate midpoint representative of ordinary fireground conditions as defined for structural firefighting **(1)**, **(2)**⁶. The specific radiant heat exposure was selected at 8.5 ± 0.5 kW/m²(0.20 ± 0.012 cal/cm²-s) since this level of radiant heat can be maintained by the test equipment and produces little or no damage to most **NFPA 1971** compliant protective clothing systems.

5.2.1 *Discussion*—Utech defined ordinary fireground conditions as having air temperatures ranging from 60 to 300°C and having heat flux values ranging from 2.1 to 21.0 kW/m²(0.05 to 0.5 cal/cm²-s).

5.3 Protective clothing systems include the materials used in the composite structure. These include the outer shell, moisture

⁵ Development of a Test Method for Measuring Transmitted Heat and Stored Thermal Energy in Firefighter Turnouts, final report presented to National Institute for Occupational Safety and Health (NIOSH) National Personal Protective Technology Laboratory (NPPTL) under Contract No. 200-2005-12411, April 29, 2008.

⁶ The boldface numbers in parentheses refer to a list of references at the end of this standard.

barrier, and thermal barrier. It is possible they will also include other materials used on firefighter protective clothing such as reinforcement layers, seams, pockets, flaps, hook and loop, straps, or reflective trim.

5.4 The transmission and storage of heat energy in firefighter protective clothing is affected by several factors. These include the effects of “wear” and “use” conditions of the protective clothing system. In this test method, conditioning procedures are provided for the laundering of composite samples prior to testing, and also composite sample moisture preconditioning. The amount of moisture added during preconditioning typically falls into a worst case amount in terms of predicted heat transfer, as suggested by Barker (3).

5.5 Two different procedures for conducting the test are provided in this test method. Procedure A involves an iterative approach to determine the minimum exposure time followed by a fixed 60-second compression time required to predict a second degree burn injury. In this approach, the length of the radiant exposure is varied systematically using a series of tests to determine the length of the radiant exposure that will result in the prediction of a second degree burn injury. Procedure B involves using a fixed radiant heat exposure time to determine if a second degree burn injury will or will not be predicted. If a second degree burn injury is predicted, the time to a second degree burn injury is reported. If a second degree burn injury is not predicted, the result is indicated as “no predicted burn.” Procedure B involves a fewer number of tests. This procedure includes recommended fixed radiant exposure times.

6. Apparatus and Materials

6.1 *General Arrangement*—The transmitted and stored energy testing apparatus shall consist of a specimen holder, sensor assembly, transfer tray, data collection sensor, compressor assembly, heating source, and a data acquisition/controls/burn damage analysis system. An overhead view of these components, minus the data acquisition/controls/burn damage analysis system, is illustrated in Fig. 1.

6.2 *Specimen Holder*—The specimen holder shall consist of upper and lower mounting plates made of stainless steel. Each plate shall be 170 by 170 ± 1 mm (6.6 by 6.6 ± 0.04 in.) and the thickness shall be 6.4 ± 0.1 mm (0.25 ± 0.004 in.), with a centered 100 by 100 ± 1 mm (3.9 by 3.9 ± 0.04 in.) hole. The lower plate shall have an attached handle that is at least 75

mm (3 in.) in length. The lower specimen mounting plate shall have a minimum of two alignment posts attached perpendicular to the plane of the plate. The upper sample mounting plate shall have corresponding holes on each side so that the upper specimen mounting plate fits over the lower specimen mounting plate. The specimen holder components are shown in Fig. 2.

6.2.1 The handle of the sample holder shall be made of or surrounded by a material with a low thermal conductivity.

6.2.2 The alignment posts shall be positioned such that they do not interfere with the test specimen.

6.3 *Sensor Assembly*—The sensor assembly shall be composed of a water cooled plate and a sensor holder.

6.3.1 The water cooled plate is constructed from a 3.2 ± 1-mm thick copper sheet with 3.2 ± 1-mm outer diameter copper tubing soldered to the back side. The copper plate shall be machined at its centerline to accept the data collection sensor with a tolerance of +0.3 mm. The four corners of the plate shall be drilled to accept a countersunk screw.

6.3.1.1 The copper tubing shall be looped back and forth across the back side of the copper plate to provide a uniform temperature across the surface of the copper plate.

6.3.1.2 Water shall flow through the copper tubing at a rate of no less than 100 mL/min and the water shall have a temperature be 32.5 ± 1°C.

6.3.2 *Discussion*—The 32.5°C temperature was set based on the average surface temperature of the forearms of volunteers as measured by Pennes (4).

6.3.2.1 The exposed surface of water cooled plate shall be painted with a thin coating of flat black high temperature spray paint with an emissivity of 0.9 or greater. The painted water-cooled plate shall be dried before use and shall present a uniformly applied coating (no visual thick spots or surface irregularities).

(1) Information about paints that can meet the emissivity requirement please refer to 6.5.2.

6.3.3 The sensor holder shall be a 166 by 166 ± 2 mm (6.54 by 6.54 ± 0.8 in.) aluminum block. The thickness of the block shall be no less than 25.4 mm (1 in.). The four corners of the block shall be drilled and tapped such that they align with the holes found in the water cooled plate. After the sensor holder and water cooled plate are attached with the flat head countersunk screws the sensor holder shall be machined at its

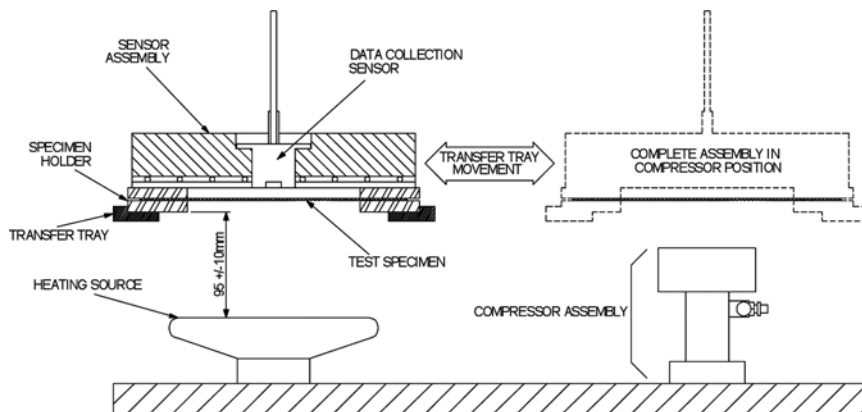


FIG. 1 Overhead View of Major Apparatus Components

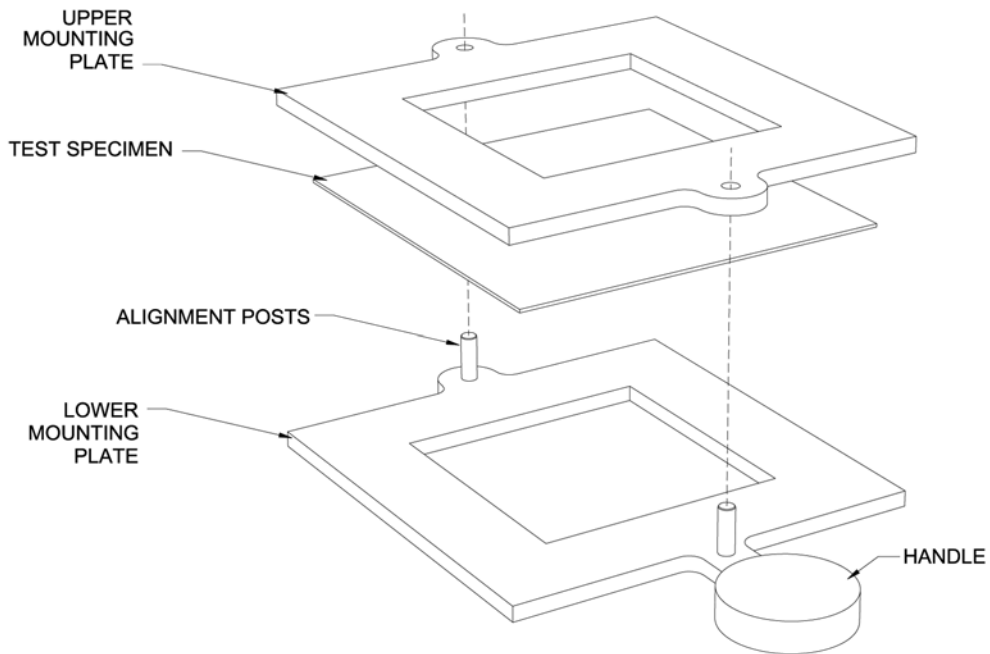


FIG. 2 Specimen Holder

centerline to accept the data collection sensor with a tolerance of +0.3 mm and -0.00 mm such that the sensor face is flush with the bottom face of the water cooled plate. Specifications for the sensor assembly are provided in Fig. 3.

6.3.3.1 When attaching the water cooled plate to the sensor holder, the flat head countersunk screws shall be below the surface of the water cooled plate.

6.4 *Transfer Tray*—The transfer tray shall be designed to transfer the combined specimen holder and sensor assembly between the heating source and the compressor and shall complete this transfer in 5.0 ± 0.5 second. This assembly shall be made to securely hold both the specimen holder and sensor assembly together.

6.4.1 When the specimen holder and the sensor assembly are held together an air gap of 6.4 mm (0.25 in.) is formed between the skin side of the specimen and the data collection sensor.

6.5 *Data Collection Sensor*—The data collection sensor shall be a water cooled Schmidt-Boelter thermopile type sensor

with a diameter of 25.4 mm (1 in.). The heat flux range shall be from 0 to 11.4 kW/m^2 (0 to $0.267 \text{ cal/cm}^2\text{-s}$ or 0 to $1 \text{ Btu/ft}^2\text{/s}$).

6.5.1 Water shall flow through the data collection sensor at a rate of no less than 100 mL/min and the water shall have a temperature be $32.5 \pm 1^\circ\text{C}$.

6.5.2 The exposed surface of the data collection sensor shall be painted with a thin coating of flat black high temperature spray paint with an emissivity of 0.9 or greater. The painted sensor shall have a uniformly-applied coating and must be calibrated against a NIST-traceable sensor or heating source before use.

NOTE 1—Emissivity of painted calorimeters is discussed in the ASTM Report, “ASTM Research Program on Electric Arc Test Method Development to Evaluate Protective Clothing Fabric; ASTM F18.65.01 Testing Group Report on Arc Testing Analysis of the F1959 Standard Test Method—Phase 1.”

6.5.3 The data collection sensor must be held rigidly in the sensor assembly.

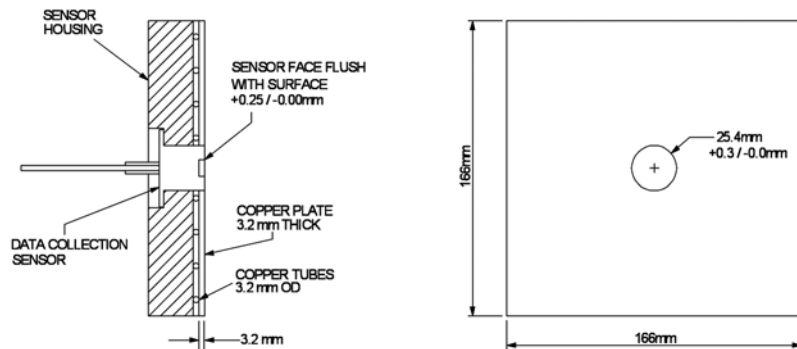


FIG. 3 Specification for Sensor Assembly

6.6 *Compressor Assembly*—The compressor assembly shall consist of a compressor block, air cylinder, air regulator and a framework that rigidly holds the system in place. When activated, the regulated air shall activate the piston and force the circular heat resistant block against the sample and data collection sensor with a pressure of 13.8 ± 0.7 kPa (2.0 ± 0.1 psi) based on the top surface area of the compressor block. Specifications for the compressor assembly are provided in Fig. 4.

6.6.1 The compressor block shall be constructed of Marinite or other material(s) with an equivalent thermal conductivity (0.12 W/m K) and shall have a diameter of 57 ± 0.5 mm (2.25 in.) and a thickness of 25.4 ± 0.5 mm (1 ± 0.02 in.).

6.7 *Heating Source*—The heating source shall consist of a black ceramic thermal flux source.⁷ The heating source shall be 120 by 120 mm \pm 5 mm (4.7 by 4.7 \pm 0.2 in.) and shall be set 95 ± 10 mm (3.75 \pm 0.4 in.) away from the specimen holder.

6.7.1 Equip the heating source with a thermocouple attached to the upper surface. The thermocouple shall be no more than 2-mm thick and shall be well bonded, both mechanically and thermally, to the heating source. Temperature data from the thermocouple are fed to a temperature controller used to maintain a constant heat flux.

6.8 *Data Acquisition/Controls/Burn Damage Analysis System*—This system includes all software and hardware needed for data acquisition and storage, control of the experiment and burn damage calculations.

6.8.1 *Data Acquisition*—The system shall be capable of measuring the maximum output from the sensor with sufficient sensitivity. The system shall also collect data at a rate no less than ten times per second and record the data with an appropriate time stamp.

6.8.2 *Controls*—The system shall be able to send analog or digital signals to the testing apparatus. These signals will be used to move the transfer tray and to activate and deactivate the compressor.

⁷ The sole source of supply of the apparatus known to the committee at this time is Ogden Manufacturing Company, 64 W. Seegers Rd, Arlington Heights, IL 60005, Part number EL-3-650. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,¹ which you may attend.

6.8.3 *Burn Damage Analysis System*—The calculated heat flux history shall be recorded and applied to a skin model using software that calculates the temperature history at the base of epidermis and dermis using the skin model prescribed in Section 11.

NOTE 2—These calculations will predict either no predicted burn or a time to second-degree burn.

6.9 *Analytical Balance*—Capable of measuring weight to a precision of at least 0.01 g.

6.10 *Thickness Gauge*—Meeting requirements of Test Method D 1777.

6.11 *Plastic Bags*—Resealable plastic bags that are sufficiently large to accommodate a single 152 by 152 by 6.4-mm (6.0 by 6.0 by 0.25-in.) specimen.

NOTE 3—A quart size resealable plastic bag has been found to be suitable.

7. Hazards

7.1 Perform all testing and calibration in a hood or ventilated area to carry away byproducts, smoke, or fumes due to the heating process. Procedures for testing and calibration shall be performed using the same hood and ventilation conditions.

7.2 Exercise care in handling the specimen holder and sensor assembly, as specimens become heated during prolonged testing. Use heat-protective gloves when handling these hot objects.

7.3 Caution must be used around the testing device as it has moving parts which can create pinch-points.

8. Specimens

8.1 Test a minimum of five specimens per firefighter protective clothing system to be evaluated.

8.2 Cut specimens to measure 152 by 152 ± 5 mm (6.0 ± 0.2 in.). Specimens shall consist of all layers representative of the clothing system to be tested, including reinforcement layers, reflective trim, or other layers as applicable.

8.3 Measure the weight of each individual layer and of the assembled protective clothing material system in accordance with Test Method D3776. Measure the thickness of each layer and of the assembled protective clothing material system in accordance with Test Method D1777.

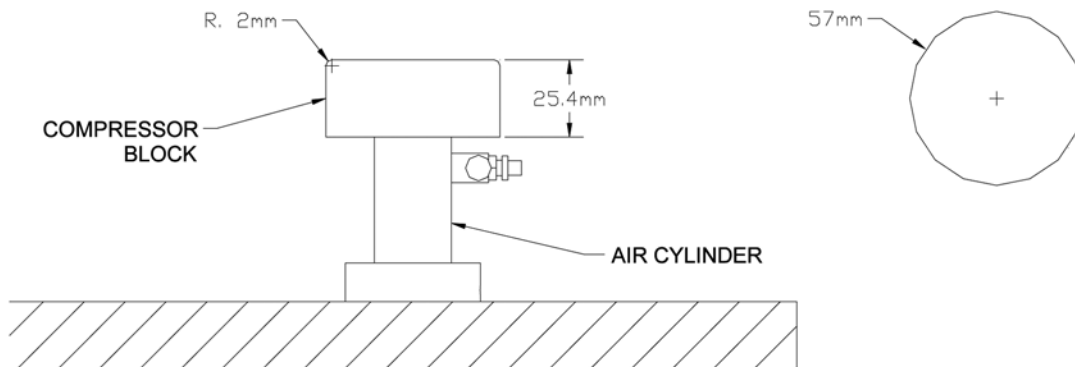


FIG. 4 Compressor Assembly

8.3.1 Specimens shall not be stitched to hold individual layers together during testing.

8.3.2 When tested with reflective trim or outer reinforcement material that has a dimension less than 152 mm (6 in.), the trim or reinforcement specimen shall be sewn to the center of outer shell of the composite so that it will be directly positioned over the thermal sensor of the test apparatus.

8.3.3 Reinforcement materials that are less than 60 mm in one dimension shall not be tested. These materials are likely not to cover the entire surface of the compressor block and would alter the applied pressure.

9. Conditioning

9.1 When specified, launder sample materials representative of the protective clothing material system for five wash and drying cycles in accordance with **AATCC 135**, Machine Cycle 1, Wash Temperature IV, Drying Condition Ai.

9.2 For tests to be conducted under dry conditions, condition specimens at $21 \pm 3^\circ\text{C}$ and $65 \pm 10\%$ relative humidity for a minimum of 24 hours.

9.3 For tests to be conducted under wet conditions, the following preconditioning procedure shall be used for each specimen:

9.3.1 Condition the specimen in a room environment at $21 \pm 3^\circ\text{C}$ and $65 \pm 10\%$ relative humidity for a minimum of 24 hours.

9.3.2 Weigh the specimen using an analytical balance, described in section 6.9, and record the weight.

9.3.3 Immerse two pieces of standard 152 by 152-mm (6 by 6-in.) AATCC blotter paper in distilled water for 10 ± 2 seconds.

9.3.4 Place one blotter paper on top of the other and run them through a wringer, that meets the requirements of 10.2 of **AATCC 70**, Test Method for Water Repellency: Tumble Jar Dynamic Absorption Test, with a 30 lb load on the rolls.

9.3.5 Place the innermost separable layer of the protective clothing material system between the two wrung blotter papers.

NOTE 4—For firefighter protective clothing material systems, the normal innermost separable layer is typically the thermal barrier.

9.3.6 Place the remaining layers of the protective clothing system on the uppermost wrung blotter paper. Place each layer as they would be found in the protective clothing ensemble minus the wrung blotter paper.

9.3.7 Place both the blotter papers and the specimen in a plastic bag, then place a $152 \pm 5\text{-mm}$ (6.0 by 6.0 \pm 0.2-in.) block weighing 275 ± 5 g in the center and on top of the bag, to remove the air, and seal it. Remove the weight and allow the bagged specimen to equilibrate in an environmentally controlled room ($21 \pm 3^\circ\text{C}$ and $65 \pm 10\%$ relative humidity) for a period of at least twelve hours, but not more than 24 hours.

9.3.7.1 Place only one specimen in each plastic bag.

9.3.7.2 Ensure that bagged samples are not stacked.

9.3.8 Remove the specimen from the plastic bag and subject the specimen to testing.

9.3.8.1 Weigh the samples after moisture conditioning and record the moisture add on.

9.3.8.2 Perform testing within three minutes from the time the specimen is removed from the sealed plastic bag.

10. Procedures

10.1 Calibration Procedure:

10.1.1 Allow the heating source to heat up for a minimum of 30 minutes after being turned on.

10.1.2 Prepare water bath to deliver $32.5 \pm 1^\circ\text{C}$ to sensor and sensor assembly at a rate of no less than 100 mL/min.

10.1.3 Reduce or turn off the hood airflow to minimize forced convective air currents from disturbing the heat flux sensor response.

10.1.4 Calibrate the apparatus to deliver an average thermal flux of 8.5 ± 0.5 kW/m² (0.20 ± 0.012 cal/cm²-s) as measured with the data collection sensor and data acquisition system.

10.1.4.1 Use the data collection sensor as the only heat sensor in setting the total 8.5 kW/m² (0.20 cal/cm²-s) exposure condition.

10.1.4.2 Measure the total heat flux directly and only from the voltage output of the data collection sensor.

10.1.4.3 Do not use other heat sensing devices to reference or adjust the total heat flux read by the data collection sensor.

10.1.5 Without a mounted specimen, place the sensor assembly minus the upper mounting plate of the specimen holder on top of the specimen holder with the sensor surface facing towards the heating source, and then expose the sensor assembly directly to the radiant heat source.

10.1.6 Adjust the temperature of the heating source until the total heat flux is 8.5 ± 0.5 kW/m² (0.20 ± 0.012 cal/cm²-s) using the data collection sensor as specified in 6.5.

10.1.7 Once an initial setting of 8.5 ± 0.5 kW/m² (0.20 ± 0.012 cal/cm²-s) has been made, record the operating parameters for test purposes.

10.1.8 Record the response of the data collection sensor for 60 seconds.

10.1.9 Calculate the average of the last 50 seconds and use the calculated average to determine the heat flux level.

10.2 *Test Procedure A*—Radiant Heat Exposure Time to Predict Second Degree Burn Injury.

10.2.1 With the specimen holder in the non-exposure position, mount the specimen in the test apparatus by placing the outside of the garment face down on the lower mounting plate of the specimen holder. The subsequent layers shall be placed on top in the order used in the garment, with the surface worn toward the skin facing up. Then place the upper mounting plate of the specimen holder above the specimen.

10.2.2 Position the sensor assembly on top of the specimen holder and test specimen.

10.2.3 Place the sensor assembly and specimen holder in the transfer tray.

10.2.4 Select an initial time for the period of radiant heat exposure.

NOTE 5—For 3-layer firefighter protective clothing material systems, an initial radiant exposure time of 90 s is recommended.

10.2.5 Move the transfer tray over the heating source and begin collecting data with the data acquisition system as soon as the tray starts to move.

NOTE 6—It is required to automate the process of moving the transfer