INTERNATIONAL

Designation: ~~F2731 – 11~~ F2731 – 18

Standard Test Method for Measuring the Transmitted and Stored Energy of Firefighter Protective Clothing Systems[1]

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~~ uses one of two procedures to measure: (*1*~~the combination of~~) heat energy, which can be directly transmitted through the multilayer structure without compressive force, that can result in predicted burn injury, or (*2*~~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.~~) heat energy directly transmitted through the multilayer structure, followed by applying a compressive force, which rapidly releases stored heat energy in the multilayer structure that can result in a predicted burn injury.

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

1.1.1 This test method is ~~not~~ applicable only to protective clothing systems that are ~~not flame resistant.~~suitable for exposure to heat and flames.

1.1.2 ~~Discussion—~~Flame resistance of the material system shall be determined prior to testing according to the applicable performance ~~and/or specification standard~~ or specification standard, or both, for the material's ~~end-use.~~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 prediction 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~~exposure 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~~ 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 appropriate ~~safety~~ safety, health, and ~~health~~environmental practices and determine the applicability of regulatory limitations prior to use.* Specific precautionary information is found in Section 7.

1.7 This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D123 Terminology Relating to Textiles
D1777 Test Method for Thickness of Textile Materials
~~D3776~~D3776/D3776M Test Methods for Mass Per Unit Area (Weight) of Fabric
E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a 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.

F1494 Terminology Relating to Protective Clothing
~~F1930~~F1930–17 Test Method for Evaluation of Flame-Resistant Clothing for Protection Against 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~~evidenced 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 cm^2 (0.25 $in.^2$) in area or at least ~~2.5 cm~~ 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.

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/m^2 (cal/cm^2-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—in testing thermal protective materials*, thermal energy that remains in a fabric/composite after the heating source is removed.

3.1.12.1 *Discussion*—

The stored energy measured by 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] 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.

3.1.13 *thermal protective clothing system, n*—any combination of materials which, when used as a composite, can limit the rate of heat transfer to or from the wearer of the clothing.

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~~Terminologies 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/m^2 (0.2 ± 0.012 cal/cm^2-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~~Using the same test apparatus, the test specimen is permitted to be compressed against the data collection sensor at a pressure of 13.8 ± 0.7 kPa (2.0 psi ± 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.~~

4.3.1 This compressive force is intended to simulate a firefighter leaning against a wall, squatting, or sitting down in a manner that expels the insulating air layers from the composite while drawing the clothing materials taut against the skin, and then causes the transfer of the heat energy from the garment layers to the skin.

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~~ second-degree burn injury can be predicted. If a second-degree burn injury is predicted, the time to a ~~second degree~~ 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.~~

4.6 ~~If a second degree burn injury is not predicted, the result is indicated as "no predicted burn."~~This method uses two distinct procedures.

4.6.1 Procedure A uses a low-level radiant heat exposure, without compression, to predict the time to second-degree burn.

4.6.2 Procedure B uses a low-level radiant heat exposure and a 60-s compression period to predict the time to second-degree burn.

4.6.3 The report indicates the predicted time to second-degree burn.

4.6.3.1 If a second-degree burn injury is not predicted, the result is indicated as "no predicted burn."

4.7 ~~Appendix X1~~Test Method F1930–17 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/m^2 (0.20 ± 0.012 cal/cm^2~~-s)~~-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~~ NFPA 1971-compliant protective clothing systems.

[5] ~~Development~~"Development of a Test Method for Measuring Transmitted Heat and Stored Thermal Energy in Firefighter ~~Turnouts,~~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.

5.2.1 Utech ~~**Discussion—**~~(**2**)~~Utech~~ defined ordinary fireground conditions as having air temperatures ranging from 60 to ~~300°C~~300 °C and having heat flux values ranging from 2.1 to 21.0 kW/m^2 (0.05 to ~~0.5~~ 0.5 cal ~~cal/cm~~/cm^2-s).

5.3 Protective clothing systems include the materials used in the composite structure. These include the outer shell, moisture barrier, and thermal barrier. It is possible that 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"~~wear and ~~"use"~~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~~ 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.~~ measures only the transmitted energy that passes through the composite, without compression, during the exposure time. 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~~ likely to be sufficient in the prediction of a ~~second degree~~ second-degree burn injury. Procedure B involves using a fixed radiant heat exposure time to determine if a ~~second degree~~ second-degree burn injury will or will not be predicted. If a ~~second degree~~ second-degree burn injury is predicted, the time to a ~~second degree~~ second-degree burn injury is reported. If a ~~second degree~~ 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. ~~A~~An overhead view of these components, minus the data ~~acquisition/controls/ burn~~ 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~~ 1-mm (3.9 by 3.9 ± ~~0.04 in.)~~ 0.04-in.) hole. The lower plate shall have an attached handle that is at least ~~75 mm~~ 75 mm (3 in.) in length. The lower specimen mounting plate shall have a minimum of two alignment posts attached ~~perpendicular~~perpendicularly 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~~ water-cooled plate and a sensor holder.

6.3.1 ~~The water cooled plate is constructed from a 3.2 ± 1-mm thick~~ Construct the water-cooled plate from a copper sheet with ~~3.2 ± 1-mm outer diameter copper tubing soldered~~ a thickness of no less than 3.1 mm and no more than 6.6 mm, with a water cooling system applied to the back side. The copper plate shall be machined at its ~~centerline~~ center line 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.

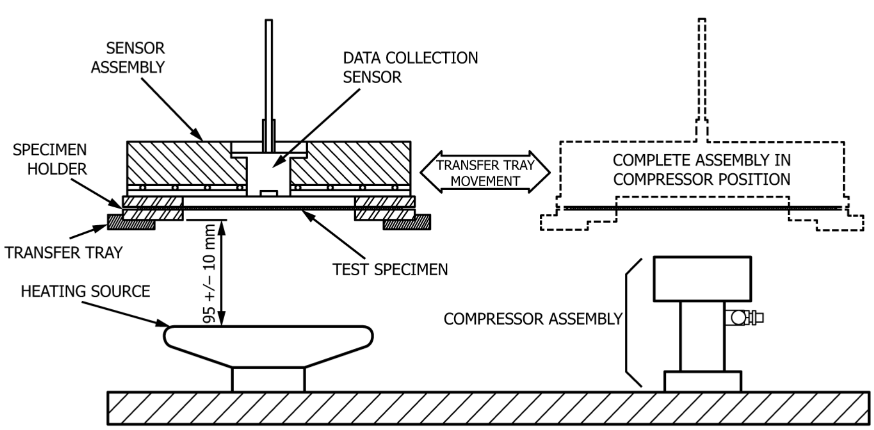

FIG. 1 Overhead View of Major Apparatus Components

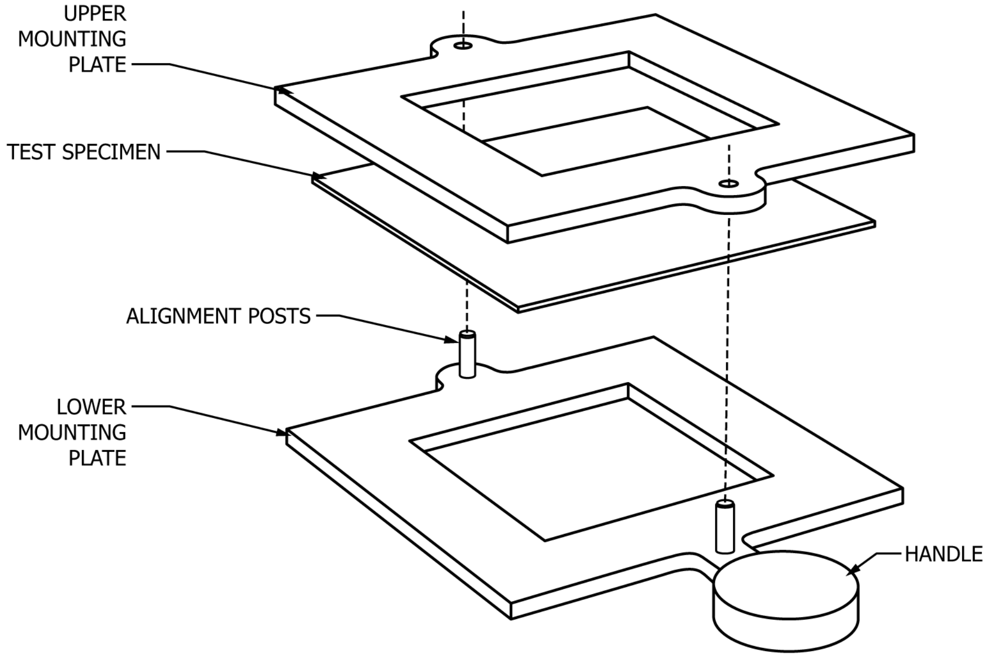

FIG. 2 Specimen Holder

6.3.1.1 ~~The copper tubing shall be looped back and forth across the back side of the copper plate to provide~~ Construct the water-cooled plate assembly such that water flows through it and provides 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~~mL/min, and the water shall have a temperature ~~be 32.5 ± 1°C.~~of 32.5 ± 1 °C.

NOTE 1—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 ~~Discussion—~~The ~~32.5°C temperature was set based on the average surface temperature of the forearms of volunteers as measured by Pennes~~exposed surface of the water-cooled plate shall be painted with a thin coating of flat, black, high-temperature spray paint ~~(~~with~~4).~~ 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).

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.~~For information about paints that can meet the emissivity requirement, please refer to 6.5.2~~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~~ 2-mm (6.54 by 6.54 ± ~~0.8 in.)~~ 0.8-in.) aluminum block. The thickness of the block shall be no less that 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~~ water-cooled plate. After the sensor holder and ~~water cooled~~ water-cooled plate are attached with the ~~flat head~~ flathead countersunk screws, the sensor holder shall be machined at its centerline to accept the data collection sensor with a tolerance of +0.3 mm and ~~-0.00~~ –0.00 mm such that the sensor face is flush with the bottom face of the ~~water cooled~~ water-cooled plate. Specifications for the sensor assembly are provided in Fig. 3.

6.3.3.1 When attaching the ~~water cooled~~ water-cooled plate to the sensor holder, the ~~flat head~~ flathead countersunk screws shall be below the surface of the ~~water cooled~~ 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.~~s. 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~~ 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 cal/cm^2-s or 0 to ~~1~~ 1 Btu ~~Btu/ft~~/ft^2/s).

6.5.1 Water shall flow through the data collection sensor at a rate of no less than 100 ~~mL/min~~mL/min, and the water shall have a temperature ~~be 32.5 ± 1°C.~~of 32.5 ± 1 °C.

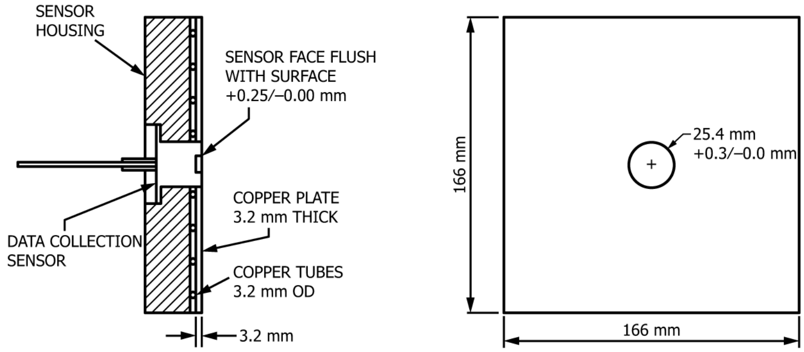

FIG. 3 Specification for Sensor Assembly

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

NOTE 2—Emissivity of painted calorimeters is discussed in the ASTM ~~Report,~~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.

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~~ heat-resistant block against the sample and data collection sensor with a pressure of 13.8 ± 0.7 kPa (2.0 ± ~~0.1 psi)~~ 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.)~~ (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 ± 5 mm (4.7 by 4.7 ± 0.2 in.) and shall be set 95 ± 10 mm (3.75 ± 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~~ 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.

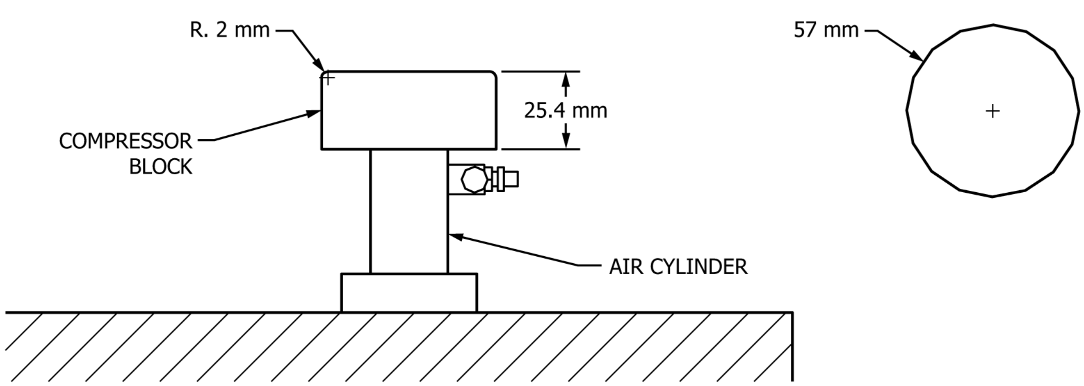

FIG. 4 Compressor Assembly

[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.