Designation: ~~F2178 – 12~~ F2178 – 17

Standard Test Method for Determining the Arc Rating and Standard Specification for Eye or Face Protective Products[1]

This standard is issued under the fixed designation F2178; 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 and product specification is used to measure the arc rating and specify the requirements for products intended for use as eye or face protection for workers exposed to electric arcs that would generate heat flux values from 84 to 25 120 ~~kW/m~~kW/m^2 [2 to 600 cal/cm^{2}s]. Products are tested as sold.

1.2 This test method determines an arc rating for eye or face protective products. The faceshield, safety spectacle, goggle or or other applicable portions of the complete product must meet ANSI Z87.1. This excludes the textile or non ANSI Z87.1 testable parts of the hood assemblies or other tested products. This standard does not measure optical and impact properties (see ANSI Z87.1) but does specify requirements for optical and impact properties.

1.3 The materials covered by this standard are in the form of faceshields attached to the head by protective helmets (hard hats), headgear, hood assemblies, safety spectacles or goggles. Faceshields, safety spectacles or goggles are tested with or without other face and head protective products, for example, sock hoods, balaclavas, sweat shirt hoods or jacket hoods.

1.3.1 Fabric layers used in hood assemblies or other items tested under this standard shall meet the requirements of Specification F1506.

1.4 This test method shall be used to measure and describe the properties of materials, products, or assemblies in response to convective and radiant energy generated by an electric arc under controlled laboratory conditions and does not purport to predict damage from light other than the thermal aspects measured.

1.5 The values stated in SI units shall be regarded as standard except as noted. Within the text, alternate units are shown in brackets. The values stated in each system may ~~no~~not be exact equivalents; therefore, alternate systems must be used independently of the other. Combining values from the systems described in the text may result in nonconformance with the method.

1.6 This standard does not purport to describe or appraise the effect of the electric arc fragmentation explosion and subsequent molten metal splatter, which involves the pressure wave containing molten metals and possible fragments of other materials except to the extent that heat energy transmission due to these arc explosion phenomena is reduced by test specimens.

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

1.8 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate ~~safety~~ safety, health and ~~health~~environmental practices and determine the applicability of regulatory limitations prior to use.* For specific precautions, see Section 7.

1.9 *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]

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

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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.

C177 Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-Hot-Plate Apparatus
D123 Terminology Relating to Textiles
D3776 Test Methods for Mass Per Unit Area (Weight) of Fabric
D4391 Terminology Relating to The Burning Behavior of Textiles
E457 Test Method for Measuring Heat-Transfer Rate Using a Thermal Capacitance (Slug) Calorimeter
F1494 Terminology Relating to Protective Clothing
F1506 Performance Specification for Flame Resistant and Arc Rated Textile Materials for Wearing Apparel for Use by Electrical Workers Exposed to Momentary Electric Arc and Related Thermal Hazards
F1958/F1958M Test Method for Determining the Ignitability of Non-flame-Resistant Materials for Clothing by Electric Arc Exposure Method Using Mannequins
F1959/F1959M Test Method for Determining the Arc Rating of Materials for Clothing

2.2 *ANSI/IEEE Standards:*
IEEE Standard Dictionary of Electrical and Electronics Terms[3]
ANSI Z87.1-2003 Practice for Occupational and Educational Eye and Face Protection[4]

3. Terminology

3.1 *Definitions*—For definitions of other textile terms used in this method, refer to terminology in Terminology D123, D4391, F1494 and the IEEE Standard Dictionary of Electrical and Electronics Terms.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *afterflame, n*—persistent flaming of a material after the ignition source has been removed.

3.2.2 *afterflame time, n*—the length of time for which a material continues to flame after the ignition source has been removed.

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

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

3.2.5 *arc gap, n*—distance between the arc electrodes, cm [in.].

3.2.6 *arc rating, n*—value attributed to materials that describes their performance to exposure to an electric arc discharge, J/cm^2 (cal/cm^2).

[3] Available from Institute of Electrical and Electronics Engineers, Inc. (IEEE), 445 Hoes Ln., P.O. Box 1331, Piscataway, NJ 08854-1331, http://www.ieee.org.
[4] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

3.2.6.1 *Discussion*—

The arc rating is expressed in J/cm^2 (cal/cm^2) and is derived from the determined value of *ATPV* or E_{BT} (should a material system exhibit a breakopen response below the ATPV value).

3.2.7 *arc thermal performance value (ATPV), n*—the incident energy of a fabric or material that results in 50 % probability that sufficient heat transfer through the specimen is predicted to cause the onset of a second-degree skin burn injury based on the Stoll curve, kW/m^2 [cal/cm^2].[5]

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

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

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

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

[5] 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.

3.2.11.1 *Discussion*—

The specimen is considered to exhibit breakopen when any hole in the material or fabric is at least 1.6 cm^2 [0.5 in.^{2}] in area or at least 2.5 cm [1.0 in.] in any dimension. For textile materials, single threads across the opening or hole do not reduce the size of the hole for the purposes of this test method. In multiple layer specimens, if some of the layers are ignitable, breakopen occurs when these layers are exposed.

3.2.12 *breakopen threshold energy (E_{BT}), n*—the incident energy on a fabric or material that results in a 50 % probability of breakopen.

3.2.12.1 *Discussion*—

This is the value in J/cm^2 [cal/cm^2] determined by use of logistic regression analysis representing the energy at which breakopen of the layer occurred.

3.2.13 *deformation, n—for electric arc testing of eye or face protective products*, the sagging of material greater than 7.6 cm [3 in.] or melting in any manner that the faceshield/window touches any part of the body.

3.2.14 *dripping, n—in electric arc testing*, a material response evidenced by flowing of a specimen's material of composition.

3.2.14.1 *Discussion*—

Dripping is exhibited by either the fabric material or faceshield material, or other parts of eye or face protective products.

3.2.15 *electric arc ignition, n—in electric arc testing of eye or face protective products*, the initiation of combustion as related to electric arc exposure, a response that causes the ignition of textile test specimen material which is accompanied by heat and light, and then subsequent burning for at least 5 s, and consumption of at least 25 % of the test specimen area.

3.2.15.1 *Discussion*—

For multilayer specimens, consumption of the innermost FR layer must be at least 25 %.

3.2.16 *faceshield, n*—a protective device commonly intended to shield the wearer's face, or portions thereof, in addition to the eyes, from certain hazards.

~~3.2.17 *heat attenuation factor, HAF, n—in electric arc testing*, the average of the percent of the incident energy that is blocked by a material.~~

~~3.2.17.1 *Discussion*—~~

~~*In arc testing of eye or face protective products*, *HAF* (face) is based on the highest sensor reading among the four head sensors for each head exposure. HAF (eye) is based on the highest sensor reading among the two eye sensors for each head exposure.~~

3.2.17 *heat flux, n*—the thermal intensity indicated by the amount of energy transmitted per area and time W/m^2 [cal/cm^{2}s].

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

3.2.19 *incident energy monitoring sensors, n*—sensors mounted on each side of each head, using calorimeters, not covered by specimens, used to measure incident energy.

3.2.20 *incident exposure energy (E_i), n—in arc testing*, the total incident energy delivered to monitor calorimeter sensors as a result of the arc exposure, J/cm^2 [cal/cm ^{2}].

3.2.20.1 *Discussion*—

In an arc test exposure, incident exposure energy for a specimen is determined from the average of the measured incident energy from the respective two monitor sensors adjacent to the test specimen.

3.2.21 *material response, n*—material response to an electric arc is indicated by the following terms: breakopen, melting, dripping, deformation, afterflame time, shrinkage, and electric arc ignition.

3.2.22 *melting, n—in arc testing*, a material response evidenced by softening of the material.

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

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

3.2.25 *shrinkage, n—in testing eye or face protective products*, a material response evidenced by reduction in specimen size.

3.2.26 *Stoll curve, n*—an empirical predicted second-degree skin burn injury model, also commonly referred to as the *Stoll Response*.

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

4. Summary of Test Method

4.1 This test method determines the heat transport response across a material, fabric, or fabric system when exposed to the heat energy from an electric arc. This heat transport response is assessed versus the Stoll curve, an approximate human tissue tolerance predictive model that projects the onset of a second-degree burn injury.

4.1.1 Products are mounted on the standard mannequin head containing copper slug calorimeters inserted in the eyes, mouth, and chin positions. During this procedure, the amount of heat energy transferred by the specimen eye or face protective products is measured during and after exposure to an electric arc.

4.1.2 The thermal energy exposure and heat transport response of the test specimen(s) are measured with copper slug calorimeters. The change in temperature versus time is used, along with the known thermo-physical properties of copper to determine the respective thermal energies delivered to and through the specimen(s).

4.2 This procedure incorporates incident energy monitoring sensors.

4.3 Product and material performance for this procedure are determined by comparing the amount of thermal energy generated by the arc flash on monitor sensors with the energy transferred by or through the test specimen(s) and measured by sensors on the mannequin head.

4.4 Product and material responses shall be further described by recording the observed effects of the electric arc exposure on the specimens using the terms in the Report section.

5. Significance and Use

5.1 This test method is intended for the determination of the arc rating of a product/design, intended for use as eye or face protection for workers exposed to electric arcs.

5.1.1 Because of the variability of the arc exposure, different heat transmission values may be observed at individual sensors. The results of each sensor are evaluated in accordance with Section 12.

5.2 This test method maintains the specimen in a static, vertical position and does not involve movement except that resulting from the exposure.

5.3 This test method specifies a standard set of exposure conditions. Different exposure conditions may produce different results.

5.4 This specification covers the minimum performance criteria for arc resistance and other requirements for eye or face protective products used by workers who may be exposed to thermal hazards of momentary electric arcs or flame.

5.5 The purchaser has the option to perform or have performed any of these tests in order to verify the performance of the eye or face protective product. Claims for failure to meet the specification are subject to verification by the manufacturer.

NOTE 1—In addition to the standard set of exposure conditions, other conditions representative of the expected hazard may be used and shall be reported should this data be cited.

6. Apparatus

6.1 *General Arrangement for Determining Rating Using Sensor Heads and Monitor Sensors*—The test apparatus shall consist of supply bus, arc controller, recorder, arc electrodes, two (or optionally three) four-sensor heads, and four (or optionally six) incident energy monitoring sensors. The arc exposure shall be monitored with two incident energy-monitoring sensors for each sensored head.

6.1.1 *Arrangement of the Four-Sensor Heads*—The standard test set up is three four-sensor heads spaced at 120° around the arc (Fig. 1). When one video camera is used to view the testing, it shall be placed so that the front of two of the heads can be viewed. A single head which is viewed from the rear may be removed to facilitate viewing. Each head shall be located vertically to the arc electrodes as shown in Fig. 2. Only calorimetry data from heads that are viewed from the front shall be used (a minimum 50 % view of the facial area is required) to record subjective data during the test. Each four-sensor head shall have two incident energy monitoring sensors. One monitoring sensor shall be positioned on each side of each four-sensor head as shown in Fig. 3.

6.1.2 *Head Construction*—Each four-sensor head and each monitor sensor holder shall be constructed from non-conductive heat resistant material as shown in Fig. 4. Use a mannequin head, size large, made from a non-conductive high temperature resin/fiberglass construction. (A mannequin head, such as Model 7001 D-H, Morgese Soriano or equivalent has been found to be acceptable.) The high-temperature resin used in the construction of the head shall be non-melting and flame resistant. Each four-sensor head and monitoring sensors shall be placed 12 in. (305 mm) from the centerline of the arc electrodes as shown in Fig. 2. Four-sensors shall be mounted in the head as shown in Fig. 4. The mouth sensor shall be forward of the eye sensor plane by 6 mm [¼ in.]. The chin sensor shall be in the horizontal plane (perpendicular to the plane of the eye and mouth) under the chin as shown in Fig. 4. The chin sensor shall protrude below the lowest point of the chin by 3 mm [⅛ in.].

6.1.3 Each four-sensor head may be mounted on the mannequin body specified in Test Method F1958/F1958M and the mannequin to simulate a human body. Any clothing on the mannequin (if used) shall be reported.

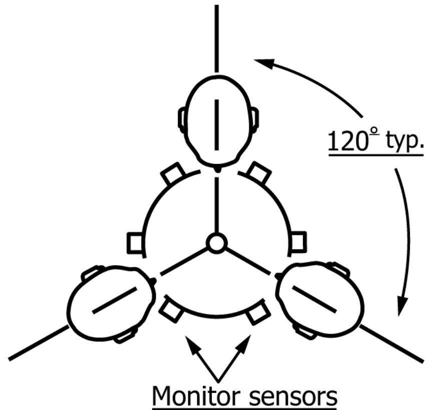

FIG. 1 Location of Mannequin Heads

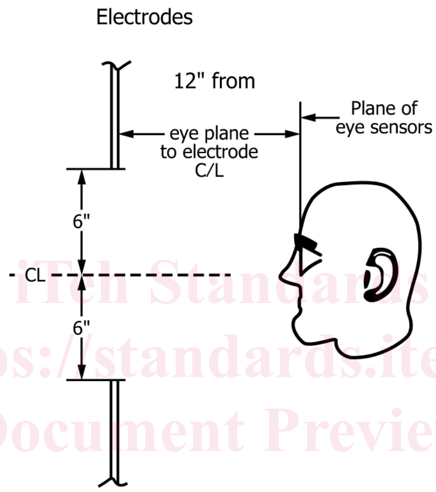

FIG. 2 Vertical Location of Heads to Arc Electrodes

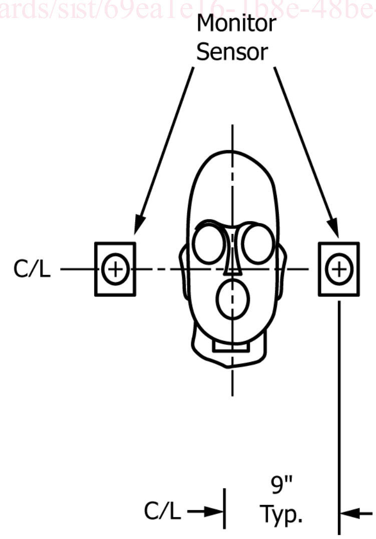

FIG. 3 Mannequin Head with Monitor Sensors

6.2 The four-sensor head and monitor sensors shall be copper slug calorimeters constructed from electrical grade copper with a single thermocouple wire installed as identified in Fig. 5 (see Test Method E457 for information regarding slug calorimeters).

6.2.1 The exposed surface of the copper slug calorimeters shall be painted with a thin coating of a flat black high temperature spray paint with an emissivity of >0.9. The painted sensor shall be dried before use and present a uniformly applied coating (no

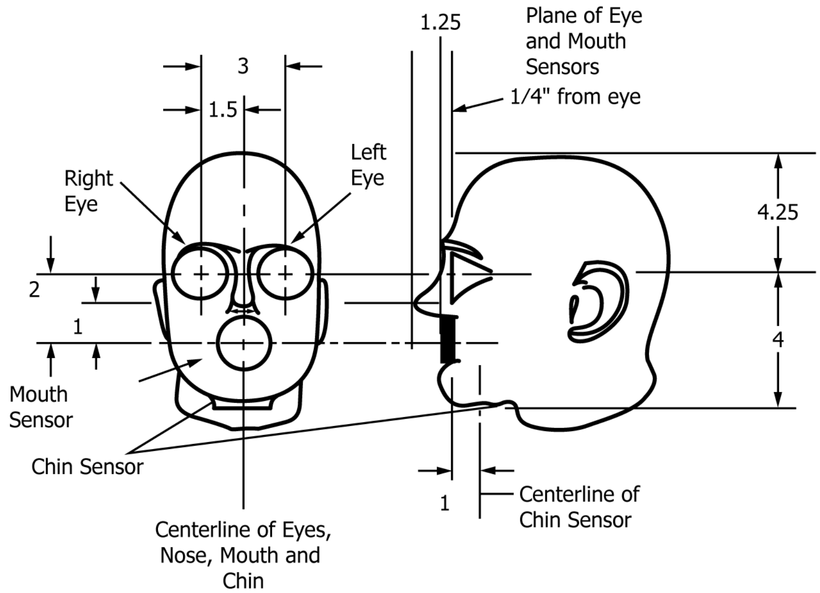

FIG. 4 Mannequin Head and Sensor Locations

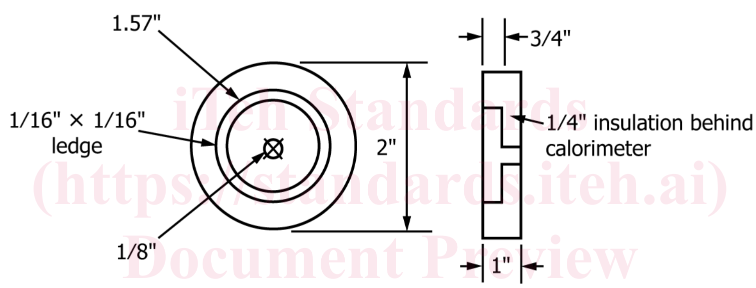

FIG. 5 Sensor Mount

visual thick spots or surface irregularities). Note that an external heat source, for example, an external heat lamp, may be required to completely drive off any remaining organic carriers in a freshly painted surface.

6.2.1.1 *Discussion*—An evaluation of the emissivity of the painted calorimeters used in this test method is available from ASTM; "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/F1959M Standard Test Method—Phase 1."

6.2.2 The thermocouple wire is installed in the calorimeter as shown in Fig. 5.

6.2.3 Alternate calorimeters are permitted for use as monitor sensors provided they are calibrated and have a similar response to those in 6.2. The use of a different thermocouple junction, exposed surface area, slug material, and mass are allowed and their performance shall be documented in the test results.

6.3 *Sensor Construction*—The sensor mount used to hold the calorimeter shall be constructed from a thermally stable heat resistant material with a minimum thermal conductivity value as indicated in Table 3 (such as Fire-Resistant Structural Insulation or equivalent) and shown in Fig. 5 to prevent unwanted heat conduction. For test exposures above 40 cal/cm^2 only, existing monitoring sensors may be moved away from the arc center line, perpendicular to the arc, provided they are not blocked. A multiplier shall be determined to give an equivalent exposure value at 30.5 cm [12 in.] (for example, at 45.7 cm [18 in.], the multiplier is 2.25).

6.3.1 For test exposures which create a sensor temperature in excess of 400°C, alternate calorimeters for the monitor sensors shall be used. The alternate sensors shall be calibrated and shall have a similar response. An alternate approach for test exposures which create a sensor temperature in excess of 400°C is to increase the distance between the arc centerline and the monitor sensors from the standard distance of 30.5 cm to 45.7 cm [12 to 18 in.], and to apply a conversion factor to the incident energy measured at a distance of to 45.7 cm [18 in.] in order to approximate the energy at a distance of 30.5 cm [12 in.] In this procedure, the specimen remains at a distance of 30.5 cm [12 in.] from the arc centerline. Copper calorimeter sensor data above 400°C shall be not be valid.

NOTE 2—At an ambient temperature of 25°C, the calorimeter temperature would reach 300°C (ΔT of 275°C) at approximately 36 cal/cm^2.