



Designation: **F2178/F2178M – 20 F2178/F2178M – 22**

Standard Specification for Arc Rated Eye or Face Protective Products¹

This standard is issued under the fixed designation F2178/F2178M; 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 product specification is used to determine the arc rating and specify the requirements for products intended for use as eye or face protection for workers exposed to electric arcs. The arc rating is determined in the test with an arc which has a heat flux value of 2100 kW/m² [50 cal/cm²/s]. Products are tested as sold.

1.2 The products 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.

1.2.1 Fabric layers used in the design of face protection products such as in hood, neck guards, balaclava, meet the requirements of Specification **F1506**. When fabrics are designed into the protection provided for eye or face protective products, the arc rating of fabric system is first determined by Test Method **F1959/F1959M**.

1.2.2 The arc rating of the eye or face protective product which requires fabric to provide protection to the face or head will not be higher than the lower arc rating of either the fabric system or the shield/visor assembly.

1.3 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 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.

1.4 This standard does not purport to describe or appraise the effect of the electric arc fragmentation or propulsion of parts of equipment or molten metal splatter, deposited from 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.

1.5 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.

1.6 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use. For specific hazards see Section 11.*

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.*

¹ This specification 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. Referenced Documents

2.1 ASTM Standards²

- [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](#)
- [D4391 Terminology Relating to The Burning Behavior of Textiles](#)
- [F1494 Terminology Relating to Protective Clothing](#)
- [F1506 Performance Specification for Flame Resistant and Electric Arc Rated Protective Clothing Worn by Workers Exposed to Flames and Electric Arcs](#)
- [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 Terms³](#)
- [ANSI/ISEA Z87.1, American National Standard for Occupational and Educational Personal Eye and Face Protection Devices⁴](#)

3. Terminology

3.1 For definitions of other textile terms used in this specification, refer to Terminologies [D123](#), [D4391](#), [F1494](#) and the IEEE Standard Dictionary of Electrical and Electronics Terms.

3.2 Definitions:

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*, *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/cm² [cal/cm²].

3.2.6.1 Discussion—

The arc rating is expressed in J/cm² [cal/cm²] and is derived from the determined value of *ATPV* or *EBT* (should a material system exhibit a broken response below the *ATPV* value) or the Arc Rating Limit. It can be expressed in short form as either AR_{ATPV} , AR_{EBT} or AR_{Lim} .

3.2.7 *arc thermal performance value (ATPV)*, *n*—in arc testing, 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.⁵

3.2.8 *arc rating limit (AR_{Lim})*, *n*—the maximum arc thermal energy protection that has been assigned to the product based on the manufacturer's specifications after verification with testing or limits of detection of the test method.

3.2.8.1 Discussion—

For hoods, the AR_{Lim} could be a limit made by the test laboratory based on the equipment limits of the energy exposure (418.4 J/cm² [100 cal/cm²] in many laboratories) or the producer may deliberately specify an incident energy value, which may be lower than the arc rating (*ATPV* or *EBT*) of the material or material assembly for the evaluation of the finished product. In this case,

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 Institute of Electrical and Electronics Engineers, Inc. (IEEE), 445 Hoes Ln., Piscataway, NJ 08854-4141, <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>.

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.

testing may deliberately be carried out only at incident energy exposures lower than the projected arc rating of the material or material assembly provided the system meets the visual assessment and all performance criteria.

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

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

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

3.2.12 *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.

3.2.12.1 *Discussion*—

The specimen is considered to exhibit breakopen when any hole in the material or fabric is at least 1.6 cm² [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.

3.2.12.2 *Discussion*—

A system having multi-layer fabric or multi-layer shields may exhibit formation of holes (ablation) of the outermost layers. Breakopen is not considered attained until the formation of one or more holes has occurred in the innermost layer.

3.2.13 *breakopen threshold energy (EBT), n*—the incident energy on a fabric or material that results in a 50 % probability of breakopen.

3.2.13.1 *Discussion*—

This is the value in J/cm² [cal/cm²] determined by use of logistic regression analysis representing the energy at which breakopen of the layer occurred.

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 *heat flux, n*—the thermal intensity indicated by the amount of energy transmitted per area and time W/m²[cal/cm²s].

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

3.2.17 *incident exposure energy (E_i), n*—in *arc testing*, the total incident energy delivered to monitor calorimeter sensors from the arc exposure, J/cm² [cal/cm²].

3.2.17.1 *Discussion*—

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

3.2.18 *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.

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

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

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

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

3.2.23 *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. Ordering Information

4.1 The following items should be considered by the purchaser when buying eye or face protective products under this specification and included, as necessary, in purchasing documents:

- 4.1.1 Arc Rating of the eye or face protective products, J/cm² [cal/cm²],
- 4.1.2 Type of material in the window of the eye or face protective product,
- 4.1.3 Thickness of the eye or face protective product, mm [in.],
- 4.1.4 Type and weight, g/m² [oz/yd²] of hood fabric material in the eye or face protective product for hoods,
- 4.1.5 Type and material of fasteners (buttons, snaps, zippers or hook and loop fasteners),
- 4.1.6 Style and design or catalog number,
- 4.1.7 Special identification markings (optional), and
- 4.1.8 Notation of conformance to this specification.

5. Physical Requirements

5.1 The faceshield window, safety spectacle or goggle in the eye or face protective product shall meet the requirements of ANSI/ISEA Z87.1. Requirements include: Flammability, Corrosion Resistance, Optical, Cleanability, Markings, Penetration, Minimum Thickness, Drop ball, High Mass, and High Velocity.

5.2 *Scratch Resistance*—Manufacturer shall certify if scratch resistant coating is applied to window of eye or face protective product. standards.iteh.ai/catalog/standards/sist/684a062c-39ee-481a-babf-64c5040fe6b9/astm-f2178-f2178m-22

5.3 *Fogging Resistance*—Manufacturer shall certify if anti-fog coating is applied to window of eye or face protective product.

5.4 *For Hoods, Fabric Material Physical Requirements*—Fabric Material in the hood shall meet the requirements of Specification **F1506**.

6. Performance Requirements

6.1 The stitching, thread, findings, fasteners, or other components used to manufacture the eye or face protective product shall not degrade the flame resistance or thermal performance of the eye or face protective products.

6.2 Eye or face protective products shall conform to the requirements of Section 7 for thermal resistance to an electric arc exposure.

6.3 The results for all performance requirements and subjective material evaluations shall be provided. Subjective material evaluations for at least two arc exposures at or above the arc rating shall be reported. This report shall be made available to the purchaser of eye or face protective product meeting this specification by the eye or face protective product manufacturer.

NOTE 1—Example tables for reporting the test results and subjective material evaluation are shown in **Table 1** and **Table 2**.

6.4 Products tested for full face protection shall have an interface that is designed to prevent burns to parts of the face not represented by sensors on the test mannequin head.



TABLE 1 Eye or Face Protective Product Performance Requirements Test Report

| Company Issuing Report _____ | | |
|---|--|--|
| Date of Report _____ | | |
| Sample description for the eye or face protective product | | |
| Eye or face protective product type, hood, faceshield or other _____ | | |
| Composition of window material _____ | | |
| Coatings on window (if applicable) _____ | | |
| Thickness of window, mm [in.] _____ | | |
| Nominal weight of hood fabric (all layers) (if applicable), oz/yd ² [g/m ²] _____ | | |
| Actual weight of hood fabric as tested (if applicable), oz/yd ² [g/m ²] _____ | | |
| Color of hood fabric if applicable _____ | | |
| | ASTM F2178 Requirement | Material Performance |
| The window in the eye or face protective products shall meet the requirements of ANSI Z87.1 | Requirements Include: Ignition assessment, Optical, Markings, Penetration, Minimum thickness, Drop ball, High mass and High velocity | Certification by manufacturer that window in the eye or face protective product meets the requirements of ANSI/ISEA Z87.1 |
| Scratch resistance | Report Only no minimum value | Certification by manufacturer that scratch resistant coating is applied to window of eye or face protective product |
| Fogging resistance | Report Only no minimum value | Certification by manufacturer that anti-fog coating is applied to window of eye or face protective product |
| For Hoods, Fabric Material | Hood fabric material shall meet the requirements of Specification F1506 | Certification by Eye or Face Protective Product Manufacturer that fabric material in hood meets the requirements of Specification F1506 |
| Stitchings, thread, findings, fasteners or other components shall not degrade the flame resistance or thermal performance of the eye or face protective product | | Certification by Eye or Face Protective Product Manufacturer that stitchings, thread, findings, fasteners or other components do not degrade flame resistance or thermal performance of the eye or face protective product |
| Arc Rating of eye or face protective product | Report Arc Rating ≥ 4.0 cal/cm ² [16.74 J/cm ²] | _____ J/cm ² _____ cal/cm ² Arc Rating (AR_{ATPV}) or Arc Rating (AR_{EBT}) or Arc Rating Limit (AR_{Lim}) |
| For hood systems, Arc Rating of fabric material | Report Arc Rating ≥ 4.0 cal/cm ² [16.74 J/cm ²] | _____ J/cm ² _____ cal/cm ² Arc Rating (AR_{ATPV}) or Arc Rating (AR_{EBT}) or Arc Rating Limit (AR_{Lim}) |

TABLE 2 Subjective Material Evaluation of Eye or Face Protective Products

| | Subjective Material Evaluations at or above Arc Rating | |
|---|--|------------------|
| | Arc Exposure # 1 | Arc Exposure # 2 |
| Incident Energy, cal/cm ² | | |
| After flame time, s | | |
| Breakopen (yes/no) and size in cm [in.] | | |
| Melting (yes/no) | | |
| Dripping (yes/no) | | |
| Deformation of window (yes/no) | | |
| Fabric Shrinkage, % | | |
| Electric Arc Ignition (yes/no) | | |

NOTE 2—If goggles as part of a full face protective system are tested for full face protection, the system shall not have gaps in areas which are not sensed, such as the nose, around the eyes, etc. The interface shall include the full face and be designed to provide the same performance over the whole face area from the chin area all over the head.

6.5 Products tested for full face protection which have removable parts shall be labeled or designed to make removal or use without proper assembly clear to the end user. Removable faceshields, faceplates, goggles or other systems and the properly matched hood or other protective parts of the system shall be designed and marked in such a way that the proper replacement parts are evident to the end user.

7. Thermal Performance Requirements

7.1 The eye or face protective product shall be tested for thermal resistance to an electric arc exposure by the use of this test method. Test parameters shall be 8 ± 1 kA arc current, 30 cm [12 in.] electrode gap, stainless steel electrodes, 30 cm [12 in.] distance between the arc center line and the mouth sensor surface. Modified test parameters may also be used and the results reported on an optional basis.

NOTE 3—This test method is a design test.

7.2 For hoods, the arc rating of the fabric material shall be determined according to Test Method **F1959/F1959M** and reported.

7.3 The arc rating of the eye or face protective product shall be equal to or greater than 4.0 cal/cm^2 [16.74 J/cm^2].

7.4 Systems having an arc rating below 20 cal/cm^2 [83.7 J/cm^2] shall not exhibit ignition or melting and dripping below 20 cal/cm^2 [83.7 J/cm^2].

7.5 *For Procedure A*—System having an arc rating equal or higher than 20 cal/cm^2 [83.7 J/cm^2] shall not exhibit ignition or melting and dripping within the mix zone of the iterative procedure.

7.6 *For Procedure B*—System having an arc rating equal or higher than 20 cal/cm^2 [83.7 J/cm^2] shall not exhibit ignition or melting and dripping in any of the exposures in the verification testing.

8. Summary of Test Method

8.1 This test method determines the heat transmitted or transported across a material when exposed to the heat energy from an electric arc. This heat transport response is compared to the Stoll curve.

8.1.1 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.

8.1.2 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).

8.2 This procedure incorporates incident energy monitoring sensors.

8.3 Product and material performance for this procedure are determined by using the incident energy generated by the arc flash measured by monitor sensors to compare the energy transferred by or through the test specimen(s) and measured by calorimeters on the mannequin head and compared to the Stoll Curve Criteria to predict a protective value called an Arc Rating.

8.4 Alternatively, if the Stoll Curve Criteria is not met, the standard uses the *EBT* or AR_{Lim} to set the Arc Rating.

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

8.6 Accessories for eyes and face protective products such as air supply or cooling devices, lamps, hearing protection or any other accessory attached to the protective product are evaluated for ignition, melt and drip in evaluating the protection level of the product.

9. Significance and Use

9.1 This specification's test method is used to determine an arc rating for eye or face protective products, including face shields, safety spectacles, goggles, or other applicable portions of the complete product that are required to meet the current version of ANSI/ISEA Z87.1. This excludes the textile or parts of the hood assemblies or other rated products that are not testable by

ANSI/ISEA Z87.1. This standard does not measure optical and impact properties (see ANSI/ISEA Z87.1) but does specify requirements for optical and impact properties in accordance with that standard.

9.2 The test method is 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.

9.3 The specification's 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. For whole body protection, additional personal protective equipment (PPE) will be required for parts not covered by this standard.

9.3.1 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 16.

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

9.5 Different exposure conditions produce different incident energies and different heat fluxes. This standard exposure is used for comparison of products and hazard assessment methods may use multiplication factors or other means for determining protection.

9.6 The purchaser has the option to perform or have performed any of these tests 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.

9.7 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.

10. Apparatus

10.1 *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 sensed head.

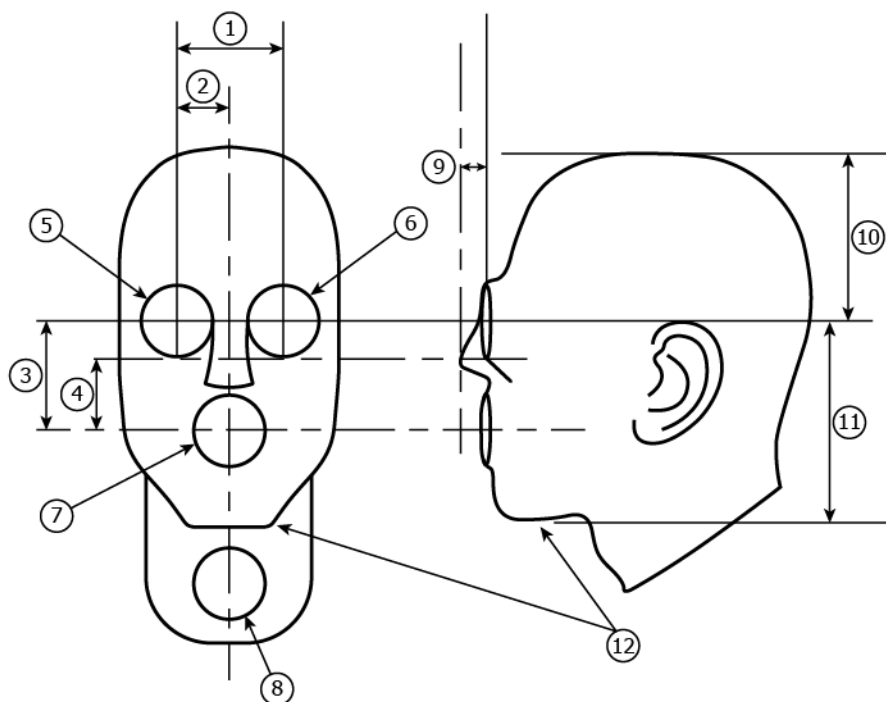
10.2 *Head Construction*—Each four-sensor head and each monitor sensor holder shall be constructed from electrically insulating and flame- and heat-resistant material. The head form shall have four sensors mounted as shown in Fig. 1. The chin sensor shall be in the horizontal plane (perpendicular to the plane of the eye and mouth) under the chin as shown in Fig. 1. The chin sensor shall protrude below the lowest point of the chin by 3 mm [1/8 in.].

10.3 *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 to prevent unwanted heat conduction (such as Fire-Resistant Structural Insulation or equivalent). The dimensions of the sensor mount are shown in Fig. 2.

10.3.1 The calorimeter shall be constructed from electrical grade copper with purity greater than 99.9 %, UNS C11000. The copper disc shall have a thickness of 1.6 mm \pm 0.1 mm, a diameter of 40 mm \pm 0.1 mm and a mass of 18 g \pm 0.5 g. The thickness, diameter and mass of each copper disc shall be measured to determine the actual response coefficient for each calorimeter that is used in heat capacity calculations. In the case of a group of copper discs having an average mass/area ratio within \pm 0.008 g/cm², the average value for the group of calorimeters may be used.

10.3.2 A type K (NiCr-NiAl) thermocouple having a cross sectional area of 0.05 mm² (No. 30 AWG) or equivalent shall be used to construct the calorimeter. The thermocouple shall be installed inside the hole of the copper disc as shown in Fig. 6. The tip of the thermocouple shall be bare for the full length inside the copper disc. Copper filler material may be used to mechanically secure the thermocouple tip in place. The thermocouple wires shall be separated immediately upon exiting the copper disc.

10.3.3 The calorimeter shall be inserted into the cavity of the sensor mount. The copper disc shall be flush with the surface of the sensor material. The copper disc can be secured in place with stainless steel pins (3 or 4) spaced around the circumference of the disc.



| | | | |
|---|------------------|----|------------------------|
| 1 | 7.6 cm [3 in.] | 7 | Mouth Sensor |
| 2 | 3.8 cm [1.5 in.] | 8 | Neck Sensor (Optional) |
| 3 | 5.1 cm [2 in.] | 9 | 3.2 cm [1.25 in.] |
| 4 | 2.5 cm [1 in.] | 10 | 10.8 cm [4.25 in.] |
| 5 | Right Eye | 11 | 10.2 cm [4 in.] |
| 6 | Left Eye | 12 | Chin Sensor |

FIG. 1 Mannequin Head and Head Sensor Locations

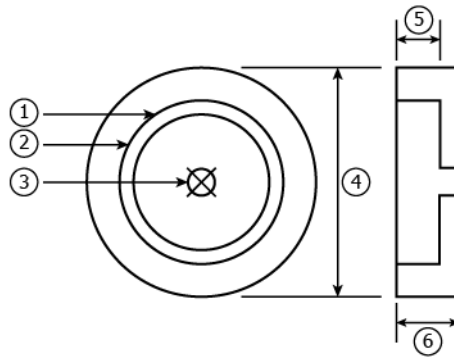
TABLE 3 Thermal Conductivity in accordance with Test Method C177 at Various Mean Temperatures

| Temperature | Thermal Conductivity Btu-in./ft ² ·h, °F [W/m °K] |
|----------------|---|
| 75°F [24°C] | 1.15 [0.17] |
| 400°F [205°C] | 1.13 [0.16] |
| 600°F [316°C] | 1.15 [0.17] |
| 800°F [425°C] | 1.16 [0.17] |
| 1000°F [538°C] | 1.17 [0.17] |

NOTE 4—Stainless steel sewing pins cut to a few millimeters have been used successfully.

10.3.4 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 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.

10.3.4.1 An evaluation of the emissivity of the painted calorimeters used in this test method was conducted by Committee F18; “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.”



| | | | |
|---|---|---|--|
| 1 | 4 cm [1.57 in.] | 4 | 51 mm [2 in.] |
| 2 | 1.6 mm [1/16 in.] × 1.6 mm [1/16 in.] Ledge | 5 | 19 mm [¾ in.] [6.4 mm [1/4 in.] insulation behind Calorimeter] |
| 3 | 3.2 mm [1/8 in.] | 6 | 2.5 cm [1 in.] |

FIG. 2 Sensor Mount

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

10.4 *Arrangement of the Four-Sensor Heads and Monitor Sensors*—The standard test set up is three four-sensor heads spaced at 120° around the arc (Fig. 3). Each head shall be located vertically to the arc electrodes as shown in Fig. 4 at a horizontal distance of 300 mm ± 5 mm [12 in.] from the mouth calorimeter to the center of the electrodes. Each four-sensor head shall have two incident energy monitoring sensors. One monitoring sensor shall be located on each side of each four-sensor head as shown in Fig. 5 at a position and angle indicated in Table 4. The face of the monitor sensors shall be perpendicular to a radius line from the center of the electrode to the center of the monitor sensor.

10.4.1 The actual distance of the monitor sensors and four-sensor head shall be measured and the value used to determine the multiplier for the incident energy calculation. The multiplier factor shall be the square of the ratio of the actual distance of the monitor sensor divided by the actual distance of the four-sensor head to which the monitor is positioned. Example: When having the four-sensor head at 305 mm and the incident energy monitors at 340 mm, the incident correction factor is $(340/305)^2 = 1.24$.

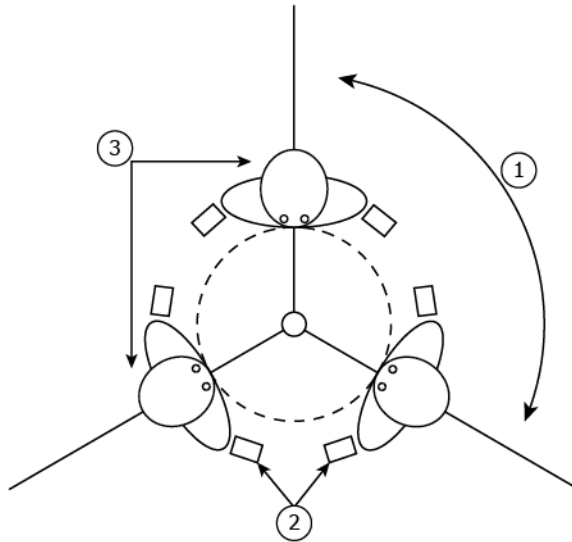
10.4.2 Only calorimetry data from heads that are viewed from the front shall be used (a minimum 50 % view of the facial area is required) to record subjective data during the test. When one video camera is used to view the testing, it shall be placed so that the front of two of the heads can be viewed. A single head which is viewed from the rear may be removed to facilitate viewing.

10.4.3 Each four-sensor head may be mounted on the mannequin body to simulate a human body. Any clothing on the mannequin (if used) shall be reported.

10.5 *Supply Bus and Electrodes*—A typical arrangement of the supply bus and arc electrodes is shown in Fig. 4. The arc shall be in a vertical position as shown.

10.5.1 *Electrodes*—Make the electrodes from stainless steel (Alloy Type 303 or Type 304) rod of a nominal 19 mm [0.75 in.] diameter. Lengths of 45.0 cm [18 in.] long initially have been found to be adequate.

10.5.2 *Fuse Wire*—A fuse wire, connecting the ends of opposing electrodes tips, is used to initiate the arc. This wire is consumed during the test; therefore, its mass shall be very small to reduce any effects on the testing. The fuse wire shall be a copper wire with a diameter not greater than 0.5 mm [0.02 in.].



| | |
|---|--|
| 1 | 120° typical |
| 2 | Monitor Sensors (monitor sensors move back for higher energy levels) |
| 3 | Four-Sensor Head |

FIG. 3 Location of Mannequin Heads

10.5.3 *Structural Cage Arrangement*—The structural cage arrangement shall be made of conductive tubes (for example, metallic tubes such as aluminum or steel). The diameter of the cage shall be between 2.0 and 2.5 m. The height of the cage shall be at least 3 m.

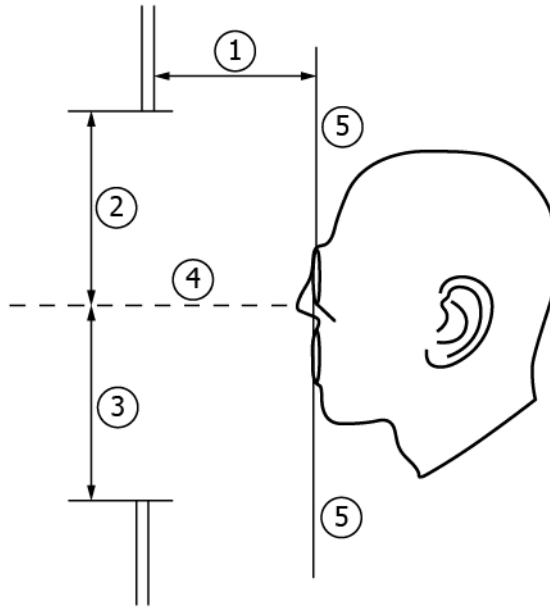
10.6 *Electric Supply*—The electric supply should be sufficient to allow for the discharge of an electric arc with a gap of up to 305 mm [12 in.] with alternating arc current of 8000 A and with arc duration from 3 cycles (0.05 s) up to at least 90 cycles (1.5 s) (from a 60 Hz supply). The X/R ratio of the test circuit shall be such that the test current contains a DC component resulting in the first peak of the test current having a magnitude of 2.3 ± 0.1 times the symmetrical RMS value.

10.7 *Test Circuit Control*—The make switch shall be capable of point on wave closing within ± 0.5 ms from test to test such that the closing angle will produce maximum asymmetrical current with an X/R ratio of the test circuit as stated in 10.5. The arc current, duration, and voltage shall be measured. The arc current, duration, voltage, and energy shall be displayed in graph form and stored in digital format.

10.8 *Data Acquisition System*—The system shall be capable of recording voltage, current, and sufficient calorimeter outputs as required by the test.

10.8.1 The temperature waveform data (calorimeter outputs) shall be acquired at a minimum sampling rate of 100 samples per second per calorimeter. The acquisition system including noise filtering shall have a frequency response of at least 20 Hz (-3db). The acquisition system shall be able to record temperatures to 500 °C. The temperature shall be reported with 3 significant digits and have an accuracy of at least ± 1 °C. (This does not include the accuracy of the calorimeter).

NOTE 5—A minimum acquisition rate and frequency response of the calorimeters is necessary to avoid introducing signal distortion and time shift into the waveform. synchronize the temperature curves with time zero (t_0). A sampling rate of 100 Hz provides a data point at 10 ms intervals and a minimum 20 Hz bandwidth (corresponds to a 10 % - 90 % rise time of 17.5 ms) has been determined to be sufficient. The response of the entire acquisition system can be checked by placing a sinusoidal signal at the thermocouple input and analyzing the system response.



| | |
|------|--|
| 1 | Mouth Plane to Electrode Center Line 30.8 cm [12 in.] |
| 2, 3 | Center Line to Electrode |
| 4 | Center Line |
| 5 | Plane of Mouth Sensor and Eye Sensors |

FIG. 4 Vertical Location of Heads to Arc Electrodes

NOTE 6—The response of the sensors during a calibration test can be checked by examining the curve of each calorimeter and locating the beginning of the rising temperature region. The first data points of temperature rise on the sensor calorimeters should occur within 30 ms of the arc current initiation.

10.8.2 The waveform recorders for current and voltage data shall be acquired at a minimum rate of 2000 samples per second and a frequency response of 200 Hz. The current and voltage acquisition system shall have an accuracy of at least 3 %.

10.8.3 All the waveform recorders for measuring the arc current, voltage and calorimeter signals shall be synchronized to ensure the real time relationship between the waveforms is maintained and no time shift is introduced in the recorded signals.

10.8.4 The arc initiation time (t_0) corresponds to the start of the arc, and shall be reliably determined from the electrical signal of the arc current.

10.9 *Data Acquisition System Protection*—Due to the nature of this type of testing, the use of isolating devices on the calorimeter outputs to protect the acquisition system is recommended.

11. Hazards

11.1 The test apparatus discharges large amounts of energy. In addition, the electric arc produces very intense light. Care shall be taken to protect personnel working in the area. Workers shall be behind protective barriers or at a safe distance to prevent electrocution and contact with molten metal. Workers wishing to directly view the test shall don the appropriate eye protection. If the test is conducted indoors, there shall be a method to ventilate the area to carry away combustion products, smoke, and fumes. Air currents can disturb the arc reducing the heat flux at the surface of any of the calorimeters. The test apparatus shall be shielded by non-combustible materials suitable for the test area. Outdoor tests shall be conducted in a manner appropriate to prevent exposure of the test specimen to moisture and wind (the elements). The leads to the test apparatus shall be positioned to prevent blowout of the electric arc. The test apparatus shall be insulated from ground for the appropriate test voltage.