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Standard Practice for ~~Determining~~Evaluating Response Characteristics ~~and Design Integrity of Arc Rated Finished Products and Evaluating other Products~~ of Safety Products in an Electric Arc Exposure[1]

This standard is issued under the fixed designation F2621/F2621M; 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 practice identifies protocols for use in conducting arc testing on finished products intended for use as thermal protection by workers who may be exposed to electric arc hazards.

1.1.1 The practice is also used for other components which can be exposed to electric arc, but which do not require an arc rating.

1.1.1.1 If items are tested and they do not meet the appropriate standard, it is the responsibility of the specimen submitter to provide this information for indication in the test report.

1.2 Arc Rated protective items are typically tested using this practice to evaluate the performance of the interface area between the product and the other arc flash PPE or to evaluate zippers and other findings.

1.3 ~~When evaluating arc rated PPE with non-arc rated PPE for due diligence (such as respirators, etc.), this~~ This practice does not ~~result in~~ establish an arc rating for ~~non-arc rated components or products shall be clearly indicated as having~~any product. Other ASTM test methods are to be used when applicable such as ASTM F1959/F1959M~~no~~, F2178~~arc rating.~~, and F2675.

1.4 This practice is not intended to produce an arc rating and does not replicate in all types of arc exposures.

1.5 This practice is used with the following standards:

1.5.1 Protective fabric materials receive arc ratings from Test Method F1959/F1959M.

1.5.2 Face protective products receive arc ratings from Test Method F2178.

1.5.3 Gloves receive arc ratings from Test Method F2675.

1.5.4 Rainwear materials, findings and closures are specified by Specification F1891.

1.5.5 Garments are specified by Specification F1506.

[1] This practice 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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1.6 The test specimens used in this practice are typically in the form of arc-rated finished products. These arc-rated finished products may include, but are not limited to, single layer garments, multi-layer garments or ensembles, cooling vests, gloves, sleeves, chaps, rainwear, balaclavas, faceshields, and hood assemblies with hood shield windows. Non-arc rated finished products may be included when part of a flame-resistant system, or for evaluating heat transmission through the finished product for incident reenactment, or for evaluation of products needed but not available as arc rated (such as respirators, etc.)

1.7 The arc rated finished product specimens are new products as sold or products which have been used for the intended purpose for a designated time.

1.8 This practice is used to determine the response characteristics or design integrity of arc-rated materials, products, or assemblies in the form of finished products when exposed to radiant and convective energy generated by an electric arc under controlled laboratory conditions.

1.9 This practice can be used to determine the integrity of closures and seams in arc exposures, the protective performance of arc-rated products in areas where garment overlap occurs or where heraldry reflective trim or other items are used, and response characteristics such as afterflame time, melting, dripping, deformation, shrinkage, ignition, or other damage, or combination thereof, of fabrics, systems of fabrics, flammable undergarments when included as part of a system, sewing thread, findings, and closures.

1.10 This practice can be used for incident reenactment, training demonstrations, and material/design comparisons.

1.11 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system are not necessarily exact equivalents; therefore, to ensure conformance with the standard, each system shall be used independently of the other, and values from the two systems shall not be combined.

1.12 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.

1.13 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 evidence of projectile damage is assessed and reported.

1.14 *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 precautions, see Section 7.

1.15 *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
D4391 Terminology Relating to The Burning Behavior of Textiles
D6413 Test Method for Flame Resistance of Textiles (Vertical Test)
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
F1891 Specification for Arc and Flame Resistant Rainwear
F1959/F1959M Test Method for Determining the Arc Rating of Materials for Clothing
F2178 Specification for Arc Rated Eye or Face Protective Products

[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.

F2675 Test Method for Determining Arc Ratings of Hand Protective Products Developed and Used for Electrical Arc Flash Protection

2.2 *IEC Standards:*[3]

IEC 61482-1-2 Live working--Protective clothing against the thermal hazards of an electric arc, Part 2 Requirements

3. Terminology

3.1 *Definitions:*

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

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

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

3.1.4 *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.

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

3.1.6 *arc rated finished product, n*—a commercial product used for arc flash protection in the form as it is sold and used.

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

3.1.7.1 *Discussion*—

The arc rating is expressed in 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).

3.1.8 *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.

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

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

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

3.1.12 *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.

3.1.12.1 *Discussion*—

The specimen is considered to exhibit breakopen when any hole 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. Single threads across the opening or hole do not reduce the size of the hole for the purpose of this practice. In multiple layer finished product specimens of flame resistant materials, all the layers must exhibit breakopen in order to meet the definition.

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

3.1.13.1 *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.

3.1.14 *calorimeter, n*—a device used in which the heat measured causes a change in state.

[3] Available from International Electrotechnical Commission (IEC), 3, rue de Varembé, 1st floor, P.O. Box 131, CH-1211, Geneva 20, Switzerland, https://www.iec.ch.

3.1.14.1 *Discussion—*
The determination of heat energy, as a consequence of an electrical arc exposure, is made in this procedure by measuring the change in temperature of an exposed copper slug of specific geometry and mass during finite time intervals.

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

3.1.16 *closure, n*—the point on supply current wave from where arc is initiated.

3.1.17 *deformation, n—for electric arc testing of finished products*, the sagging of material greater than 3 in. or melting in any manner that the faceshield, hood window, or other melted material touches any part of the body.

3.1.18 *dripping, n—in electric arc testing*, a material response evidenced by flowing of a polymer and droplets separating from the material.
3.1.18.1 *Discussion—*
For finished product protective clothing and equipment, dripping can involve the fiber polymer, coatings, findings, the faceshield window material, or any other component of the finished product.

3.1.19 *garment closure, n—in a finished product or garment*, the area in which two parts are joined with a mechanical device.
3.1.19.1 *Discussion—*
Examples of closures are zippers, snaps, buttons or hook & loop fasteners on the front of a coat, a shirt or a pair of pants.

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

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

3.1.22 *heraldry, n—relating to finished products*, an informational symbol or logo on a finished product.
3.1.22.1 *Discussion—*
The logo or symbol is embroidered onto the finished product, or the logo or symbol is on a label which is affixed to the finished product.

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

3.1.24 *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, cal/cm^2.
3.1.24.1 *Discussion—*
In an arc test exposure, incident exposure energy for a specimen is determined from the average of the measured incident energy from all the respective monitor sensors adjacent to the test specimen.

3.1.25 *indicator undergarment, n—in finished product arc exposure*, a light-weight undergarment used to subjectively detect heat transfer through a finished product and heat leakage through closures or interface areas of a finished product garment.

3.1.26 *interface area, n—in arc testing*, the areas of the body at which finished product specimens overlap but are discontinuous.
3.1.26.1 *Discussion—*
The waist and mid-torso area of the body at which a coat overlaps a bib overall is an example of an interface area, and the neck and upper torso area of the body is an example of an interface area.

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

3.1.28 *melting, n—in testing finished products*, a material response evidenced by softening of the fiber polymer, findings, closures, the faceshield window polymer, or any other component of the finished product.

3.1.29 *peak arc current, n*—maximum value of the ac arc current, A.

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

3.1.31 *shrinkage, n—in testing finished products*, a material response evidenced by reduction in specimen size of the fabric, finding, closure, or the faceshield window.

3.1.32 *Stoll curve, n*—curve produced from data on human tissue tolerance to heat and used to predict the onset of second-degree burn injury.

3.1.33 *X/R ratio, n*—the ratio of system inductive reactance to resistance.

3.1.33.1 *Discussion—*

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.

3.2 For definitions of other textile terms used in this practice, refer to Terminology standards D123, D4391, and F1494.

4. Summary of Practice

4.1 This practice identifies procedures for determining the response characteristics and design integrity of materials, products, or assemblies in the form of finished garments or other finished products when exposed to convective and radiant energy generated by an electric arc under controlled laboratory conditions.

4.1.1 When evaluating the design integrity or protective performance of arc rated finished products, the electric arc heat exposure level should be set to be at least equivalent to the arc rating of the finished product being evaluated in cal/cm^2.

4.1.2 When using this practice for incident reenactment, expose the test specimen to an electric arc heat exposure level similar to that determined from the incident criteria. Additional parameters may be used for evaluation such as a box constrained arc such as in IEC 61482-1-2 or other types of exposures which represent the incident being investigated. These would be considered non-standard and require documentation of parameters. This may include different currents and clearing times and different exposure distances and angles.

4.1.2.1 Garments used in an incident reenactment should be chosen to represent the approximate cleaning and wear levels of the incident garment.

4.2 Finished product specimens are mounted on the standard mannequin illustrated in this practice or from Test Method F2178 (used for head protective products). Mannequin legs can be added if exposures to the lower torso and legs are of interest. The mannequin is typically in a standing position with arms down to the sides of the torso. The mannequin may be equipped with copper slug calorimeters in the neck and head positions as specified in Test Method F2178. During this procedure, the amount of heat energy transmitted through the finished product specimens can be measured during and after exposure to an electric arc with the sensors specified in the Test Method or can be evaluated using an indicator garment.

4.2.1 The mannequin can be positioned in other positions, for example, in incident reenactment the mannequin can be in a sitting position or with the arms extending horizontally toward the arc exposure to simulate the conditions of the incident. Indicate modifications to the mannequin position in the test report.

4.2.2 The mannequin can also be equipped with additional calorimeter sensors in other parts of the body, for example, the legs, groin, and arms. Any additional sensors used will be indicated in the test report.

4.2.2.1 When additional sensors are used, the sensor responses relative to the monitor sensor responses will not provide a valid determination of burn injury unless the additional sensors are positioned at the same distance and orientation as the monitor sensors.

4.2.3 ~~A light-weight "indicator undergarment" has~~Lightweight "indicator garments" have been shown to be useful in evaluating energy transfer. The standard indicator ~~garment is~~garments are a white jersey-knit cotton ~~briefs (t-shirt or briefs)~~ brief 170 g/m^2 [5.0 oz/yd^2] ± ~~5 %, and 140 g/m~~10 %, or a white~~2~~ ~~[4.1~~ jersey knit, cotton crew-neck T-shirt 155 [4.6 oz/yd^2] ± ~~5 % white jersey knit, cotton crew-neck T-shirt.~~10 %, or both.

4.2.3.1 If another indicator is chosen, report what is used and document the material response.

4.2.3.2 If other heat indicator approaches are used such as selective placement of panels of 100 % untreated cotton fabric or PVC sheets, these will be described in detail and included in the test report.

4.3 The thermal energy exposure is 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 heat energies delivered to and through the specimen(s).

4.3.1 The heat transfer response and heat leakage of the finished product specimen(s) may be estimated by evidence of thermal changes to the "indicator" undergarment fabric.

4.4 This practice incorporates incident energy monitoring sensors used to determine the heat exposure on the finished product specimen.

4.5 Finished product specimen response characteristics shall be further described by recording the observed effects of the electric arc exposure on the specimens using the terms in the Report.

5. Significance and Use

5.1 This practice can be used for a range of purposes including incident replication, development of improved arc rated protective products, and the determination of the response characteristics and design integrity of new or used arc rated finished products intended for use as protection for workers exposed to electric arcs.

5.1.1 In-service garments can have very different wash and wear histories. Caution must be used when applying test results from a particular used garment. Factors to consider include the garments' wear histories, work environments, and tasks for which the garments were worn; the methods and facilities for garment maintenance; the number of launderings or processings the garments have been subjected to; and other factors that could impact the protective performance of different garments. Test results from specific used garments should be considered only an approximation of results that might be obtained from other used garments of the same type.

5.1.2 When using the practice for evaluating flame resistance, great care should be taken since ignition by electric arc is a statistical phenomenon. An exposure of 20 cal/cm^2 has been consistently shown to evaluate most ignitable materials but some may require higher energy to reach the breakopen point of the fabric depending on coatings or specific fiber types. Consider using a vertical flame test such as Test Method D6413 to evaluate for ignition and use this practice for illustration.

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

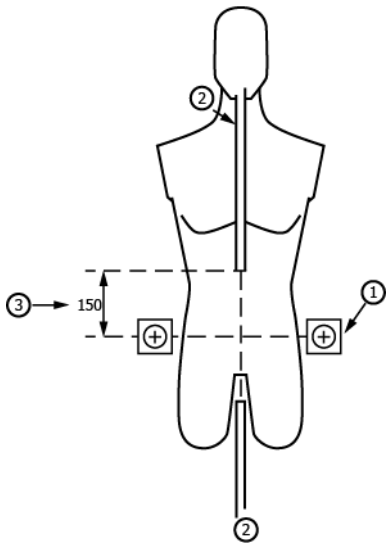
6. Apparatus

6.1 *General Arrangement for Using Mannequins and Monitor Sensors*—The test apparatus shall consist of supply bus, arc controller, recorder, arc electrodes, mannequins, and incident energy monitoring sensors. The arc exposure shall be monitored with two incident energy monitoring sensors for each mannequin.

6.1.1 *Arrangement of the Mannequin(s)*—Mannequins with two monitoring sensors each shall be used for each test. Position monitor sensors on each side of the mannequins as shown in Fig. 1.

6.1.1.1 Additional mannequins with monitoring sensors may be placed around the arc as shown in Fig. 2 to evaluate multiple samples of the same materials at the same distance from the arc. Each mannequin shall be visually observed for ignition.

6.1.2 *Mannequin*—Use a male mannequin torso, size large, made from non-conductive fiberglass construction. The mannequin may be constructed in an erect posture. The mannequin head may be removable. The mannequins typically have detachable arms that are straight and mount in a vertical position to allow the test specimen at the chest to be the closest point to the centerline



1	Monitor Sensors
2	Electrodes
3	Distance to centerline, mm

FIG. 1 Mannequin with Monitor Sensors

of the arc. The arms of the mannequins may be shortened to 10 cm [4 in.] to permit ease of specimen mounting. The position of the mannequins from the centerline of the arc electrodes should be adjustable from 20 cm [8 in.] to 60 cm [24 in.] as shown in Fig. 2 and Fig. 3.

6.1.2.1 A lower torso with legs can be added to the mannequin on an optional basis.

6.1.3 Modify the vertical position of the electrodes and the electrode gap on an optional basis in order to create an arc exposure on any area of the mannequin of particular interest.

6.1.3.1 For finished products that provide protection to the torso, arms, and legs but not the head, an area of interest is the closure area on the mannequin torso.

6.1.3.2 For finished products that provide face protection and protection to the torso, arms and legs, areas of interest are the interface area between the face protection and upper torso protection, the torso closure areas, and the interface area between the coat and pant finished products.

NOTE 1—If additional sensors are used, specify the locations and types of these additional sensors in the report. If a lower torso with legs is added to the mannequin, specify this in the report. If the position of the monitor sensors, the electrodes or the electrode gap is modified relative to Test Methods F1959/F1959M or F2178, specify this in the report.

6.1.4 *Video Cameras*—One or more video cameras shall be used to view the tests. One video camera shall be placed so that the exposed part of mannequin can be viewed.

6.1.5 *Mannequin Construction*—The mannequin torso and head shall be constructed as specified.

6.1.5.1 Alternatively the mannequin may be used from Test Method F2178 especially when head area is being evaluated. If a lower torso and legs are added to the mannequin, the standard mannequin is constructed from a non-conductive, heat-resistant material.

6.2 *Supply Bus and Electrodes*—A typical arrangement of the supply bus and arc electrodes is shown in Fig. 2 and Fig. 3. The arc shall be in a vertical position as shown. See Test Method F2178 for requirements.

6.2.1 For the following specifications, see Test Method F2178: electrodes, fuse wire, electric supply, test circuit control, data acquisition system, data acquisition system protection, calorimeter construction and monitor sensor construction.