Designation: F2675/F2675M – 13

Standard Test Method for Determining Arc Ratings of Hand Protective Products Developed and Used for Electrical Arc Flash Protection[1]

This standard is issued under the fixed designation F2675/F2675M; 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 is used to determine the arc rating of hand protective products in the form of gloves, glove materials, glove material systems, or other protective products designed to fit on the hand and specifically intended for electric arc flash protection use as protective accessories for workers exposed to electric arc heat flux values from 84 to 25,120 kW/m^2 [2 to 600 cal/cm^{2}s].

1.2 This test method will determine the arc rating of hand protective products made of materials which meet the following requirements for flame resistance: less than 150 mm [6 in.] char length, less than 2 s afterflame and no melt and drip when tested in accordance with Test Method D6413 or receive a reported 50 % probability of ignition of a material or flammable underlayer (see definition of ignition$_{50}$) by this method.

1.2.1 It is the intent of this test method to be used for hand protective products which are flame resistant or which have an adequate flame resistance for the required hazard (see 1.2). Non flame resistant hand protective products may be used as under layers in multiple-layer systems or tested for ignition probability.

1.2.2 It is not the intent of this test method to be used for glove materials, which have been tested by Test Method F1959/F1959M as flat panels of material then sewn into hand protective products. Materials for hand protective products, which are not normally produced in flat panels or which display shrinkage making the material unacceptable to test on panels, shall be tested using this standard.

1.2.3 Rubber insulating gloves meeting Specification D120 and leather protectors meeting Specification F696 are not covered by this test method and are specifically excluded from its Scope.

1.2.4 Hand protective products tested by this method are new and ratings received by this method may be reduced or eliminated by hydrocarbon loading (gasoline, diesel fuel, transformer oil, etc.), sweat, dirt, grease, or other contaminants. The end user takes responsibility for use of hand protective products tested by this method when contaminated in such a manner which could reduce or eliminate the arc rating of the hand protective products.

1.2.5 Gloves tested by this method provide no protection from electric shock. Insulated gloves for protection from electric shock are addressed under other standards including ASTM D120. This test method is designed to provide information for gloves used for electric arc protection only. This test method is not suitable for determining electrical protective properties of hand protective products.

1.3 This test method is used to measure and describe the properties of hand protective products in response to convective and radiant energy generated by an electric arc under controlled laboratory conditions.

1.4 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.5 This test method does not apply to electrical contact or electrical shock hazards.

1.6 *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 that takes into account*

[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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all of the factors, which are pertinent to an assessment of the fire hazard of a particular end use.

1.7 *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 and health practices and determine the applicability of regulatory limitations prior to use. For specific precautions, see Section 7.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D120 Specification for Rubber Insulating Gloves
D123 Terminology Relating to Textiles
D4391 Terminology Relating to The Burning Behavior of Textiles
D6413 Test Method for Flame Resistance of Textiles (Vertical Test)
E457 Test Method for Measuring Heat-Transfer Rate Using a Thermal Capacitance (Slug) Calorimeter
F696 Specification for Leather Protectors for Rubber Insulating Gloves and Mittens
F819 Terminology Relating to Electrical Protective Equipment for Workers
F1494 Terminology Relating to Protective Clothing
F1959/F1959M Test Method for Determining the Arc Rating of Materials for Clothing

2.2 *ANSI/IEEE Standard:*[3]

Standard Dictionary of Electrical and Electronics Terms

3. Terminology

3.1 *Definitions:*

3.1.1 *arc rating, n*—value attributed to materials that describes their performance to exposure to an electrical arc discharge.

3.1.2 *arc thermal performance value (ATPV), n—in arc testing*, the incident energy on a material or a multilayer system of materials that results in a 50 % probability that sufficient heat transfer through the tested specimen is predicted to cause the onset of a second-degree skin burn injury based on the Stoll[4] curve, cal/cm^2.

3.1.3 *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 the material.

3.1.3.1 *Discussion*—The specimen is considered to exhibit breakopen when any hole is at least 3.2 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 purposes of this test method. In multiple layer specimens of flame resistant material, all the layers must breakopen to meet the definition. In multiple layer specimens, if some of the layers are ignitable, breakopen occurs when these layers are exposed.

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

3.1.4.1 *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.

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

3.1.6 *dripping, n—in testing flame-resistant clothing*, a material response evidenced by flowing of a specimen's material of composition.

3.1.7 *ignitability, n (ignitable, adj)—in electric arc exposure*, the property of a material involving ignition accompanied by heat and light, and continued burning resulting in consumption of at least 25 % of the exposed area of the test specimen.

3.1.8 *ignition$_{50}$, n—in arc testing*, the incident energy on a material or flammable underlayer that results in a 50 % probability of ignition of a material or flammable underlayer.

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

3.1.10 *melting, n—in testing flame resistant clothing*, a material response evidenced by softening of the material.

3.1.11 *mix zone, n—in arc testing*, the range of incident energies, which can result in either a positive or negative outcome for predicted second-degree burn injury, breakopen or underlayer ignition. The low value of the range begins with the lowest incident energy indicating a positive result, and the high value or the range is the highest incident energy indicating a negative result.

3.1.11.1 *Discussion*—A mix zone is established when the highest incident energy with a negative result is greater than the lowest incident energy with a positive result.

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

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

3.1.14 *shrinkage, n—in testing flame resistant clothing*, a material response evidenced by reduction in specimen size.

3.1.15 *Stoll*[4] curve, *n*—an empirical predicted second-degree skin burn injury model, also commonly referred to as the *Stoll Response*.

3.2 For other definitions see, D123 Terminology Relating to Textiles, D4391 Terminology Relating to the Burning Behavior of Textiles, F819 Terminology Relating to Electrical Protective Equipment for Workers, F1494 Terminology Relating to Protective Clothing, or IEEE Standard Dictionary of Electrical and Electronics Terms.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from Institute of Electrical and Electronics Engineers, Inc. (IEEE), 445 Hoes Ln., Piscataway, NJ 08854, http://www.ieee.org.

[4] 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.

4. Summary of Test Method

4.1 This test method determines the heat transport response through a hand protective product material or hand protective product material 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 During this procedure, the amount of heat energy transferred by the tested hand protective products is measured during and after exposure to an electric arc.

4.1.1.1 The thermal energy exposure and heat transport response of test specimens 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 heat energy delivered to and through the specimens.

4.2 Hand protective product material performance for this procedure is determined from the amount of heat transferred by and through the tested material.

4.3 Heat transfer data determined by this test method is the basis of the arc rating for the material.

4.3.1 The arc rating determined by this test method is the amount of energy that predicts a 50 % probability of second-degree burn as determined by the Stoll Curve[4] or breakopen (should the specimens exhibit breakopen before the skin burn injury prediction is reached).

4.4 Hand protective product material response is further described by recording the observed effects of the electric arc exposure on the specimens using the terms in 12.6.

5. Significance and Use

5.1 This test method is intended for the determination of the arc rating of a hand protective product material, or a combination of hand protective product materials.

5.1.1 Because of the variability of the arc exposure, different heat transmission values are observed at individual sensors. Evaluate the results of each sensor 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 have the potential to produce different results. In addition to the standard set of exposure conditions, other conditions are allowed and shall be documented in the reporting of the testing results.

6. Apparatus

6.1 *General Arrangement For Determining Arc Rating Using Hand Protective Product Holders and Monitor Sensor*—The test apparatus shall consist of supply bus, arc controller, recorder, arc electrodes, hand protective product holder(s) (one sensor per hand protective product holder), and monitor sensors as shown on Figs. 1 and 2. Fig. 1 below shows two of four hand protective product holders.

6.1.1 *Arrangement of the Hand Protective Product Holder Panels*—Hand protective product holder(s) (one sensor per hand protective product) and monitor sensors (two for each hand protective product holder) shall be used for each test and be spaced equally as shown in Fig. 2. Fewer or more hand protective product holders may be used if the positioning and distance requirements of Section 6 are met. The monitoring sensors shall be positioned between hand protective products.

6.1.2 *Hand Protective Product Holder Construction*—Hand protective product holders and each monitor sensor holder shall be constructed from non-conductive heat resistant material with a thermal conductivity value of < 0.15 W/mK, high temperature stability, and resistance to thermal shock.

NOTE 1—Wood and aluminum covered with calcium silicate with inert fillers and reinforcing agents has been used successfully.

6.1.3 Each hand protective product holder monitor sensor shall be constructed of an instrumented vertical standoff mounted on a horizontal plate. Each standoff shall be 31.8 cm [12.5 in] tall, 7.6 cm [3 in] wide and 1.3 cm [0.5 in] thick. Hand protective product holder dimensions are selected to accommodate a hand protective product with hand-width of 254 to 279 mm (US size 10 hand protective product). Different dimensions are allowed for monitor sensor standoff as long as the position and orientation of the monitor meets.

6.1.4 Each hand protective product holder may be adjustable from 20.0 cm [8 in.] to 60.0 cm [12 in.] from the centerline of the arc electrodes and monitor sensor position may be adjustable from 20.0 cm [8 in.] to 60.0 cm [16 in.] from the centerline of the arc electrodes to allow for greater energy levels in testing. A factor shall be used to calculate incident energy based on the distance of the monitor sensor to the arc. The hand width distance shall be maintained in such a manner to allow hand protective products to fit on the stand in the sensor area as they would fit on a hand. Fig. 2 is an example of one test set up. Monitor sensors and hand protective product holders may be at different distances as long as calculations take distance into account.

NOTE 2—It has been found that some hand protective products require more pressure to maintain contact of the hand protective product material with the sensor. Springs or other means may be used to assure that the glove material maintains contact with the sensor.

6.1.5 One sensor shall be mounted on each standoff as shown in Fig. 2. The centers of all sensors shall be at 28 cm [11 in.] elevation relative to the horizontal mount plate. The surface of each sensor shall be parallel and normal to the centerline of the arc electrodes. The distance from the center of the monitor sensor to the center of each hand protective product holder shall be 12.7 cm [5 in.]. Each sensor shall be mounted flush with the surface of the standoffs.

6.1.6 Additional sensors are allowed for installation as monitor and panel sensors for experimental purposes. The information from these sensors shall not be used as substitutes for the current test apparatus in the determination of ATPV, breakopen, or ignition$_{50}$ performance.

6.2 *Sensors:*

6.2.1 The hand protective product holder and monitor heat sensors are 4 ± 0.05 cm diameter circular copper slug

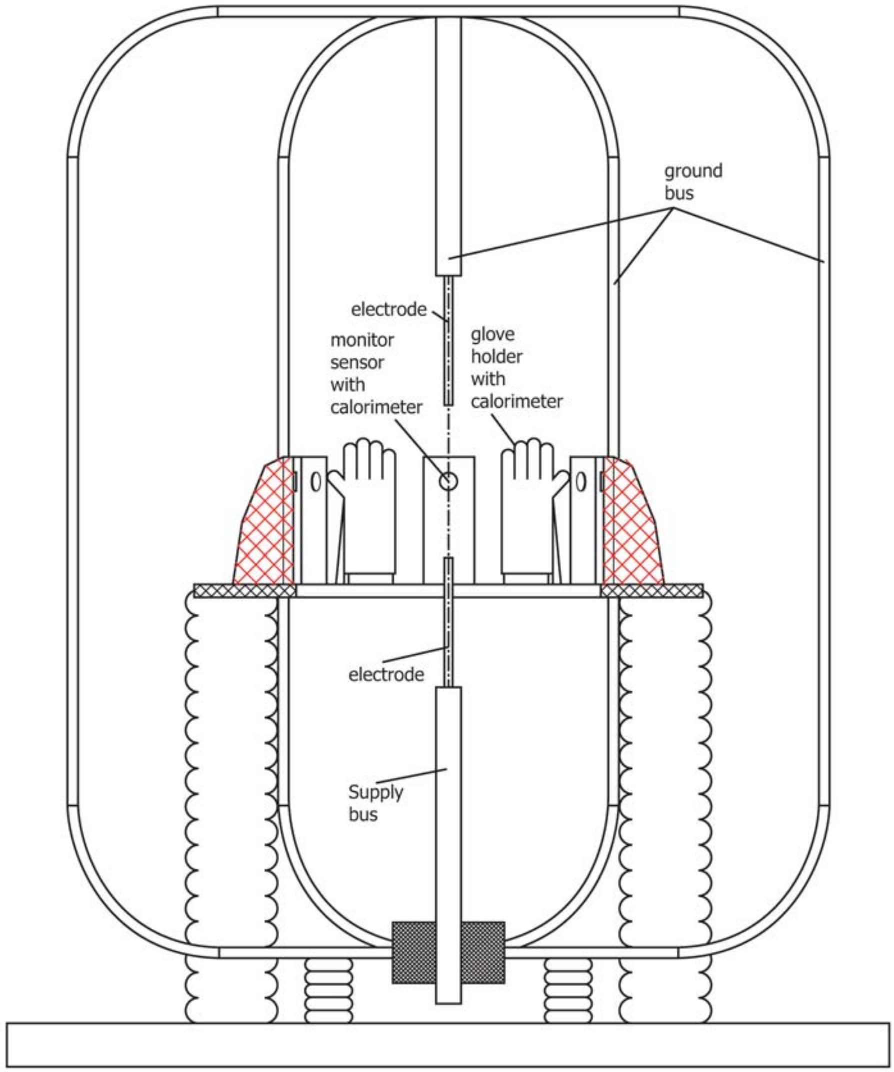

FIG. 1 Test Set Up Illustration

calorimeters constructed from electrical grade copper, each with a mass of 18 ± 0.05 g (prior to drilling) with a single ANSI type J (Fe/Cu-Ni) or ANSI type K (Ni-Cr/Ni-Al) thermocouple wire bead (0.254 mm wire diameter or finer – equivalent to 30 AWG) installed as indicated in 6.1 and shown in Figs. 2-5 (see Test Method E457 for information regarding slug calorimeters). Each sensor holder assembly shall be constructed from non-conductive heat resistant material with a thermal conductivity value of <0.15 W/mK, high temperature stability, and resistance to thermal shock. The board face containing the sensor shall be nominally 1.3 cm [0.5 in.] or greater in thickness. The sensor is held into the recess of the board by pinning, for example by using three straight pins, trimmed to a nominal length of 5 mm and placing them equidistant around the edge of the sensor so that the heads of the pins hold the sensor to the surface.

6.2.2 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). Use an external heat source, for example, an external heat lamp, as required to completely drive off any remaining organic carriers in a freshly painted surface.

6.2.2.1 *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." This report contains information on paint(s) successfully used.[5]

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

6.2.4 Alternate calorimeters are permitted for use as monitor sensors provided they are calibrated and have a similar response to those in 6.2.1. 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.

[5] Available from ASTM International Headquarters. Request RR:F18-1001.

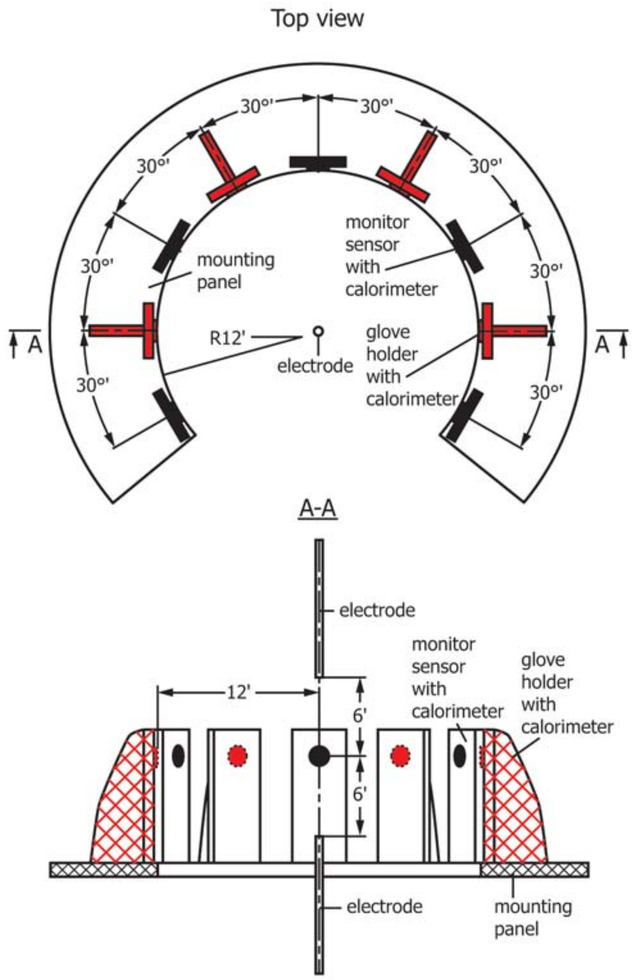

FIG. 2 Test Rig Illustration

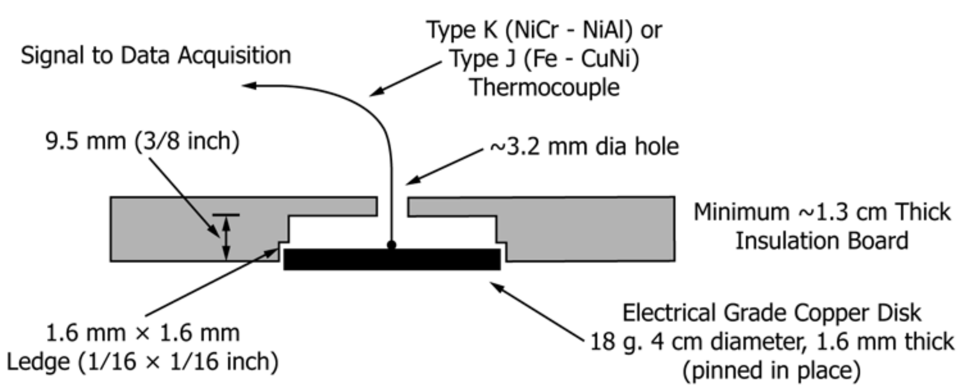

FIG. 3 Calorimeter and Thermocouple Detail

6.3 *Supply Bus and Electrodes*—A typical arrangement of the supply bus and arc electrodes is shown in Fig. 1. The arc shall be in a vertical position as shown.

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

6.3.2 *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 the chance of molten metal burns. The fuse wire shall be a copper wire with a diameter not greater than 0.05 mm [0.02 in.].

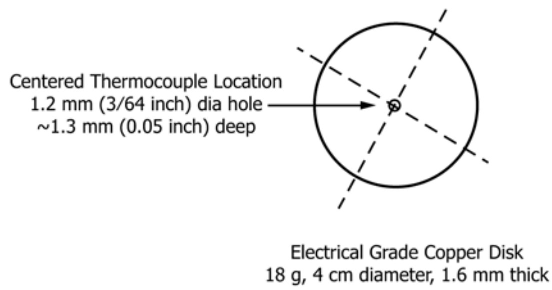

FIG. 4 Copper Calorimeter Detail

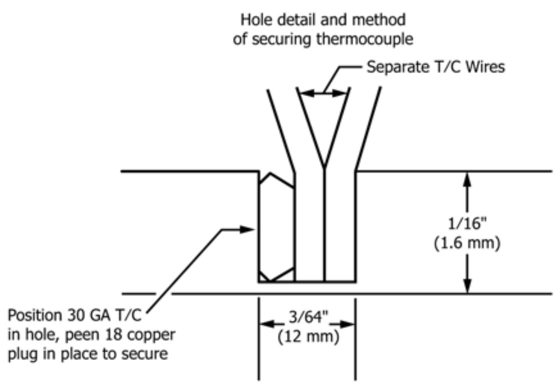

FIG. 5 Thermocouple Installation

6.4 *Electric Supply*—Electric supply shall be sufficient to sustain symmetrical alternating arc current of 8000 ± 500 A RMS value within electrode gap of 300 ± 10 mm for a duration from 0.05 s up to 2.5 s [from 3 to 150 cycles of 60 Hz power frequency, from 2.5 to 125 cycles of 50 Hz power frequency]. 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 times the symmetrical RMS value.

6.5 *Test Circuit Control*—The symmetrical and peak components of an arc current in several consecutive exposures constituting one rating (series of test trials necessary to achieve set of 20 data points) shall not deviate more than 5 % from the selected test level. A make switch shall be capable of point on wave closing within ± 10 electrical degrees in several consecutive exposures constituting one rating. Arc current, arc duration, and arc voltage shall be measured for each arc exposure. Arc energy shall be calculated for each arc exposure. Arc current and arc voltage shall be displayed in graph form and stored in digital format.

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

6.6.1 The temperature data (copper slug calorimeter outputs) shall be acquired at a minimum sampling rate of 20 samples per second per calorimeter. The acquisition system shall be able to record temperatures to 400°C. The temperature acquisition system shall have at least a resolution of 0.1°C and an accuracy of ±0.75°C.

6.6.2 The system current and voltage data shall be acquired at a minimum rate of 2000 samples per second. The current and voltage acquisition system shall have at least a resolution of 1 % of the applied voltage and current.

6.7 *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.

7. Precautions

7.1 The test apparatus discharges large amounts of energy. In addition, the electric arc produces very intense light. Take care to protect personnel working in the area. Position workers behind protective barriers or at a safe distance to prevent electrocution and contact with molten metal. Workers wishing to directly view the test shall use tinted glasses such as ANSI/ASC Filter Shade 12 protection and be at least 25 m [75 ft] away. If the test is conducted indoors there shall be a means 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. Non-combustible materials suitable for the test area shall shield the test apparatus. 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 the ground for the appropriate test voltage.

7.2 The test apparatus, electrodes, and calorimeter assemblies become hot during testing. Use protective gloves and sleeves when handling these hot objects.

7.3 Use care if the specimen ignites or releases combustible gases. An appropriate fire extinguisher shall be readily available. Ensure all materials are fully extinguished.

7.4 Immediately after each test, the electric supply shall be shut off from the test apparatus and all other lab equipment used to generate the arc. The apparatus and other lab equipment shall be isolated and grounded. After data acquisition has been completed, appropriate methods shall be used to ventilate the test area before personnel entry. No one shall enter the test area prior to exhausting all smoke and fumes.

8. Sampling and Specimen Preparation

8.1 *Test Specimens for Hand Protective Product Holder Test*—New (unused) hand protective products of size 10 (when the hand protective product is numerically sized) shall be used in arc rating test, because a size 10 hand protective product fits the hand protective product holder snugly and in contact with the calorimeter. If the hand protective products are not numerically sized, use a hand protective product that can be adjusted to fit the hand protective product holder snugly and in contact with the calorimeter. A visual integrity check shall be performed before each test to ensure no damage, cuts or holes are on the hand protective product surface. If hand protective product size is not numerical, the size tested shall be reported.

8.2 Thickness of each hand protective product specimen shall be measured with a micrometer to ± 0.1 mm in the area of the hand where the calorimeter contacts the hand protective product. Average hand protective product thickness shall be calculated and upper and lower measurement of thicknesses shall be determined. Other methods for measuring thickness may be reported if reported with the standard number used. The 8.2 requirement shall also be reported if another method is also used.

8.3 Hand protective products shall be selected by the manufacturer at random or by another means to represent common hand protective products manufactured.

9. Calibration and Standardization

9.1 *Data Collection System Precalibration*—The data collection system shall be calibrated by using a thermocouple calibrator/simulator. This will allow calibrations to be made at multiple points and at levels above 100°C. Due to the nature of the tests frequent calibration checks are recommended.

9.2 *Calorimeter Calibration Check*—Calorimeters shall be checked to verify proper operation. Measure and graph the temperature rise of each calorimeter and system response when exposed to a known heat source. At 30 seconds no one calorimeter response shall vary by more than 4°C from the average of all calorimeters. Any calorimeter not meeting this requirement shall be suspected of faulty connections and shall be replaced or repaired.

NOTE 3—One acceptable method is to expose each calorimeter to a fixed radiant energy source for 30 s. For example, place the front surface of a 500 W spot light 26.7 cm [10.5 in.] from the calorimeter. The spot shall be centered on and perpendicular to the calorimeter.

9.3 *Arc Exposure Calibration*—Prior to each calibration, position the electrodes of the test apparatus to produce a 30.5 cm. [12 in.] gap. The face of the monitor sensors is set parallel and normal to the centerline of the electrodes. The midpoint of the electrode gap shall be at the same elevation as the center point of the monitor sensors (see Fig. 2). Connect the fuse wire to the end of one electrode by making several wraps and twists and then to the end of the other electrode by the same method. The fuse wire is pulled tight and the excess trimmed. The test controller is then adjusted to provide the desired arc current and duration.

9.4 *Apparatus Calibration*—Position each hand protective product holder and monitor so that the surface of each calorimeter sensor is 30.5 cm [12 in.] from, parallel and normal to the centerline of the electrodes. No test samples or any kind of cover are allowed for any sensor during calibration process.

9.4.1 Set the asymmetrical arc exposure current to the 8 kA level and the arc duration at 10 cycles (0.167 s) from 60 Hz supply or at 8.5 cycles (0.170 s) from 50 Hz supply. The theoretical value of incident energy calculated for this arc exposure is equal to 42.3 J/cm^2 [10.1 cal/cm^2].

9.4.2 Discharge the arc. The arc generated in the testing apparatus is not equidistant from each sensor that results in a variation in measured values.

9.4.3 Determine the maximum temperature rise for each of the sensors, and multiply by the appropriate factor, determined in 11.10, to obtain the total incident energy in J/cm^2 [cal/cm^2] measured by each sensor.

9.4.4 Calculate the average value of incident energies for all sensors.

9.4.5 The average value of incident energies for the sensors shall be at least 75 % of the theoretical value determined by calculation or at least 31.7 J/cm^2 [0.75*10.1=7.6 cal/cm^2]. The highest and lowest measured incident energy of any single sensor shall be within 15 % of the average value. If these values are not obtained, inspect the test setup and correct any possible problems that could produce less than desired results. To be considered calibrated, test apparatus shall meet the requirements of this paragraph for average, highest, and lowest values of measured incident energies.

9.4.6 An arc exposure calibration test shall be conducted at the 8 kA, 0.167 s/0.170 s level prior to the start of each day's testing and after each and any adjustment or failure of equipment.

9.4.7 During testing the highest and lowest values of incident energies measured by uncovered monitor sensors shall be within 15 % of the average value of all monitor sensors. If the exposure values are not achieved in three consecutive tests, then suspend testing and re-calibrate the system. If a change is made as a result of the re-calibration, reject the data from the last three tests.

9.5 *Confirmation of Test Apparatus Setting*—Confirm and report the test apparatus setting for each test from the controller equipment. Values to be reported are peak arc current, RMS arc current, arc duration, arc energy, and arc voltage. A graph of the arc current is plotted to ensure proper waveform. Record the ambient temperature and relative humidity.

10. Apparatus Care and Maintenance

10.1 *Initial Temperature*—Cool the sensors after exposure with a jet of air or by contact with a cold surface. Confirm that the sensors are at a temperature of 25 to 35°C.

10.2 *Surface Reconditioning*—While the sensor is hot, wipe the sensor face immediately after each test to remove any decomposition products that condense and could be a source of measurement error. The sensor surface requires reconditioning if a deposit collects and appears to be thicker than a thin layer of paint or the surface is irregular. Carefully clean the cooled sensor with acetone or petroleum solvent, making certain to follow safe handling practices. Repaint the surface as noted in 6.2.2. Ensure that the paint is dry before running the next test.

10.3 *Hand Protective Product Holder and Monitor Sensor Assembly Care*—The holders shall be kept dry. For outdoor tests the panels and monitoring sensors shall be covered during long periods between tests to prevent excess temperature rise resulting from exposure to the sun. Due to the destructive nature of the electric arc, the monitoring sensor holders shall be covered with the same paint as the sensors. Re-coat the holders periodically to reduce deterioration.

11. Procedure

11.1 Test parameters shall be: 8 ± 1 kA arc current, 30.5 cm [12 in.] electrode gap, stainless steel electrodes, 30.5 cm [12 in.] distance between the arc centerline and the sensor surface. Additional test parameters are also permitted and the results reported on an optional basis.

11.2 *Order of Tests:*

11.2.1 An arc rating of a hand protective product is the statistical value in nature. A minimum of 20 data points is required for arc rating value to be determined in a statistically reliable way. The test data obtained from one test trial constitutes all data points of the statistical analysis. An average of two adjacent monitor sensors is used to determine the incident energy (E_i) for each hand protective product holder. The test apparatus may have as many test stands as is practically possible. Four have been found to be effective but more or less are allowed as long as the positioning, distance and other requirements are met.

11.2.2 Each test trial shall consist of all hand protective product specimens of the same construction and materials, one hand protective product for each of four hand protective product holders. Each test trial constitutes all data points of the statistical analysis.

11.2.3 To evaluate one hand protective product arc rating, a series of test trials shall be run over a range of incident energies to achieve the minimum of 20 data points. The incident energy range shall be achieved by increasing or decreasing the arc duration (cycles).

11.2.3.1 A minimum of 20 incident energy results of monitor sensor and respective 20 energy results of two hand protective product holders' sensors are required for an ATPV, E_{BT} or ignition probability determination (ignition$_{50}$). Results shall meet conditions of 11.2.3.2 through 11.2.3.4.

11.2.3.2 The measured incident energy (an average value of the respective monitor sensors) on at least 15 % of hand protective product holders exposed to the arc must result in values that always exceed the Stoll curve predicted second-degree burn injury criteria (as determined by 12.2.1). In other words, values in this energy range always exceed the Stoll criteria.

11.2.3.3 The measured incident energy (an average value of the respective monitor sensors) on at least 15 % of hand protective product holders exposed to the arc must result in values that never exceed the Stoll curve predicted second-degree burn injury criteria (as determined by 12.2.1). In other words, values in this energy range never exceed the Stoll criteria.

11.2.3.4 The measured incident energy (an average value of the respective monitor sensors) on at least 50 % of the hand protective product holders exposed to the arc must result in values that are approximately equally populated within ±20 % of the final ATPV or E_{BT} (as determined by 12.2.1; see 11.2.6 discussion). Values in this energy range typically have mixed results—some values exceed and some values do not exceed the Stoll criteria.

11.2.4 All data points are valid unless a copper calorimeter temperature exceeds 400°C for the monitor sensor described in 6.2.1, or there is a malfunction of the test or data acquisition equipment, or the specimen mounting fails.

11.2.5 If more than the minimum number of test trials were performed, for whatever reason, all valid data points shall be used (see 11.2.7 discussion).

11.2.6 Handling data from specimens that exhibit breakopen or ignition.

11.2.6.1 Specimens that exhibit breakopen or ignition are valid data points for ATPV determination.

11.2.6.2 If any specimen ignites, the ignition$_{50}$ shall be determined and reported.

11.2.6.3 If two or more occurrences of hand protective product material breakopen are noted at incident energies below a value of 20 % above the ATPV determination, a breakopen response shall be determined. In this case, use more than five tests if required to meet the Stoll curve data criteria for evaluating the breakopen response (see 12.2 for data criteria of breakopen).

11.2.7 *Discussion*—An iterative process will be needed to achieve the requirement that 50 % of the data points are within 20 % of the hand protective product material ATPV/E_{BT}. After the first few arc exposures (min. four pairs of hand protective products) are completed, assuming response above and below the Stoll curve criteria, an estimated ATPV/E_{BT} can be determined. Using this estimation, the remaining tests can be selected so that 50 % of the hand protective product holders sensor data fall within 20 % of the ATPV/E_{BT}. For example, if the approximated ATPV/E_{BT} is 27.2 J/cm^2 [6.5 cal/cm^2] then test parameters are selected so that the incident energies on the hand protective product holders will fall with the range of 21.8 to 32.7 J/cm^2 [5.2 to 7.8 cal/cm^2]. As each successive test is performed, the accuracy of the ATPV/E_{BT} estimation will improve so that the incident energy target range of ATPV/E_{BT} ±20 % can also be more accurately established. The goal is to achieve the required 50% of the data within 20 % of ATPV/E_{BT} by the time the required 20 data points are complete. Generally, assuming all data points are valid, this would mean that 11 of the 20 data points would need to have incident energy values within 20 % of the ATPV/E_{BT}. In the example above, 11 of the data points would need to have incident energy values within the range of 21.8 to 32.7 J/cm^2 [5.2 to 7.8 cal/cm^2] for a hand protective product material with an ATPV/E_{BT} of 27.2 J/cm^2 [6.5 cal/cm2^2]. If less than 11 data points fall in this range, additional tests will be needed until 50 % of the total data points have incident energy values within 20 % of the ATPV/E_{BT}.

11.2.7.1 A least-squares fit of the maximum difference between the measured hand protective product holder sensor thermal energy response and the corresponding Stoll response (independent value) and the measured incident energy for each hand protective product holder (dependent variable) can be used to guide the selection of appropriate incident exposure energies. The *y*-intercept value is the approximate ATPV/E_{BT}.

11.3 *Specimen Data*—Record specimen data including: *(1)* identification number, *(2)* the order of layering with outer layer listed first, *(3)* material type for hand protective product layers, *(4)* color, and *(5)* number of specimens tested.

11.4 *Specific Test Trial Procedure*—Mount the hand protective product specimens on hand protective product holder and fuse wire on the electrodes.

11.4.1 Exercise all safety precautions and ensure all persons are in a safe area.

11.4.2 Expose test specimens to the electric arc.

11.4.3 Shut off the electric supply, ventilate the test area at the completion of the data acquisition period and apply the protective grounds. (Refer to Section 7).

11.4.4 Extinguish any flames or fires unless it is predetermined to let the specimen(s) burn until consumed.

11.4.5 Observe the effect of the exposure on the hand protective product material systems and, after the exposed specimens have cooled, carefully remove the hand protective products from the hand protective product holder noting any additional effects from the exposure. Use one or more of the following terms which are defined in Section 3, as needed, to describe material response: *(1)* breakopen, *(2)* melting, *(3)* dripping, *(4)* charring, *(5)* embrittlement, *(6)* shrinkage, and *(7)* ignition.

11.4.6 Record the thermal and electrical data and material response as required in Section 13.

11.4.7 Inspect and recondition the sensors if required and adjust the electrodes to proper position and gap.

11.5 *Sensor Response*—The sensor response of each calorimeter is determined shortly before, during, and for 30 s after an arc thermal exposure has been initiated.

11.5.1 *Determining Time Zero*—Due to the electrical noise typically associated with conducting tests of this type, it is difficult to get a reliable trigger signal at the initiation of the arc. The starting time of the arc can be reliably determined however, for each test through the following analysis. For each sensor's curve, plot the difference between the curve and a line drawn from the start of the data stream to some point on the rising temperature region of the curve. Find the maximum of this difference plot. The point at which this maximum occurs is the best estimate of the arc initiation time for that sensor. These arc initiation points are usually very consistent within a test. The median of these points for all sensors shall be used as the initiation point for all of the sensors.

NOTE 4—Other satisfactory methods are available to determine time zero.

11.5.2 Once the arc initiation point is determined, the temperature data collected from the calorimeters before and up to the initiation point are averaged to obtain a starting calorimeter temperature, $T_{initial}$ (°C) for each respective sensor.

11.5.3 The heat capacity in J/g°C of each copper slug calorimeter at the initial temperature is calculated using:

$$C_p = \frac{4.1868 \times (A + B \times t + C \times t^2 + D \times t^3 + E / t^2)}{63.546 \ \ \text{g/mol}} \quad (1)$$

where:

t = (measured temperature °C + 273.15) / 1000,
A = 4.237312,
B = 6.715751,
C = –7.46962,
D = 3.339491, and
E = 0.016398.

11.5.3.1 *Discussion*—The heat capacity of copper in J/g°C at any temperature between 289 K and 1358 K is determined via Eq 1 (Shomate equation with coefficients from NIST). The value in cal/g°C can be obtained by dividing the result in Eq 1 by 4.1868 J/cal.

11.5.4 The copper slug heat capacity is determined at each time step for all the copper slug calorimeters (monitor and hand protective product holder sensors). This is done by calculating an average heat capacity for each sensor using the initial temperature determined in 11.5.2 for the initial heat capacity and the time step measured temperature for the final heat capacity in Eq 2 below.

$$\bar{C_p} = \frac{C_p@Temp_{initial} + C_p@Temp_{final}}{2} \quad (2)$$

11.5.5 The measured incident energy at each time step is determined using the initial temperature value determined in 11.5.2, the temperature at the respective time step, and the copper slug heat capacity determined in 11.5.4, in J/cm^2 [cal/cm^2] by using the relationship:

$$\text{Total Heat Energy, } Q = \frac{\text{mass} \times \bar{C_p} \times (Temp_{final} - Temp_{initial})}{\text{area}} \quad (3)$$

where:

Q = heat energy in J/cm^2 [cal/cm^2],
mass = mass of the copper disk/slug (g),
$\bar{C_p}$ = average heat capacity of copper during the temperature rise J/g C [cal/g°C],
$Temp_{final}$ = final temperature of copper disk/slug at time$_{final}$ (°C),
$Temp_{initial}$ = initial temperature of copper disk/slug at time$_{initial}$ (°C), and
area = area of the exposed copper disk/slug (cm^2).

11.5.6 For a copper disk/slug that has a mass of 18.0 g and exposed area of 12.57 cm^2, the determination of heat energy reduces to:

$$\text{Total Heat Energy,} Q = 1.432 \times \bar{C_p} \times (Temp_{final} - Temp_{initial}) \quad (4)$$

11.5.6.1 *Discussion*—If a copper disk/slug with a different mass or exposed area, or both, is used for the calorimeter, the constant factor in Eq 5 must be adjusted correspondingly.

11.5.7 *Incident Energy (E_i) Monitor Sensor Responses*—The total incident thermal energy versus time at each hand protective holder is determined from the respective adjacent monitor sensors at each time interval. Record the maximum heat energy value from the monitor sensor for each hand protective product holder. The resulting maximum values are the incident heat energies, E_i, delivered to each respective hand protective product holder(s) in each test trial.

11.5.8 *Hand Protective Product Holder Sensor Responses*—The total thermal energy transmitted through the hand protective product specimen versus time for each exposed hand protective product holder is determined individually from each respective hand protective product sensor at each time interval. All responses of transmitted energy versus time are resulted from each test trial and plotted together with Stoll Curve for comparison.

12. Interpretation of Results

12.1 *Heat Transfer:*

12.1.1 *Predicted Second-Degree Skin Burn Injury Determination (Stoll Curve Comparison)*—The time-dependent averaged heat energy response for each hand protective product holder (from the sensors under the hand protective product specimen being tested) determined in 11.5.8 is compared to the Stoll Curve empirical human predicted second-degree skin burn injury model:

$$\text{Stoll Response, J/cm}^2 = 5.0204 \times t_i^{0.2901} \quad (5)$$

where t_i is the time value in seconds of the heat energy determination and elapsed time since the initiation of the arc exposure. A second-degree skin burn injury is predicted if either panel sensor heat energy response exceeds the Stoll Response value (at time t_i).

12.1.1.1 Note that the Stoll Response can also be expressed in cal/cm^2 via:

$$\text{Stoll Response, cal/cm}^2 = 1.1991 \times t_i^{0.2901} \quad (6)$$

12.1.1.2 Record a value of 1 for each hand protective product specimen that at any time exceeds the Stoll criteria, and a value of 0 for those that do not.

12.1.2 *Determining Arc Thermal Performance Values (ATPV)*—Utilize a minimum of 20 measured individual hand protective product responses following the procedure outlined in 11.2 to calculate an ATPV value. If more than 20 points are collected during a specific test exposure sequence, all valid results shall all be used in determining ATPV.

12.1.2.1 Perform a nominal logistic regression on the resulting test data. The maximum incident energy of monitor sensor response is used as the continuous variable, *X* for each panel. The corresponding nominal binary *Y* value response is the individual hand protective product holder sensor response, exceeding = 1/not exceeding = 0, the Stoll criteria (from 12.1.1.2). See Appendix X1 for discussion of the logistic regression technique.

12.1.2.2 Use the logistic regression determined values of slope and intercept to calculate (inverse prediction) the 50 % probability value of exceeding the Stoll curve criteria. This is the ATPV result, or the incident energy value that would just intersect the Stoll curve criteria. The value is determined as:

$$ATPV = \left| \frac{\text{Intercept}}{\text{Slope}} \right| \quad (7)$$

12.1.3 *Determination of Heat Attenuation Factor (HAF)*—Determine the maximum heat energy response for each of the hand protective product sensors from the plots generated in 11.5.8, and divide these responses by their respective maximum incident energy of monitor sensor responses, from 11.5.8. Identify each of these values as $E_{\text{transmitted}}$ (fraction of the incident energy which is transmitted through the specimen) for each hand protective product holder.

12.1.3.1 A HAF data point (haf) for each panel is calculated according to the formula: haf = 100 × (1 – $E_{\text{transmitted}}$).

12.1.3.2 The HAF factor is then determined by calculating the average of all the haf values. At least 20 data points representing 10 hand protective product holders shall be used.

12.1.3.3 Calculate the standard deviation of the points (Std), the standard error of the average (given by the ratio of the standard deviation to the square root of the number of hand protective product holders used), and the 95 % confidence interval using:

$$\text{Upper Confidence Limit} = \text{HAF value} + \frac{t_{95\%} \times \text{Std}}{\sqrt{N}}$$
$$\text{Lower Confidence Limit} = \text{HAF value} - \frac{t_{95\%} \times \text{Std}}{\sqrt{N}} \quad (8)$$

where:

$t_{95\ \%}$ = Student's *t* 95 % confidence interval value for *N*-1 degrees of freedom, and
N = number of individual hand protective product sensor values used (for $N = 20$; $t_{95\%} = 2.093$).

12.2 *Determination of Breakopen Energy*—Breakopen energy response is evaluated in a similar manner to an ATPV determination. This is done using the hand protective product material breakopen information (see 3.1.11) correlated with the incident energy, E_i, determined in 11.5.8.

12.2.1 The breakopen responses of hand protective product material shall be distributed such that:

(1) at least 15 % of the hand protective product samples seeing lower incident energy values show no breakopen,

(2) at least 15 % of the hand protective product samples seeing higher incident energy values always breakopen, and

(3) 50 to 70 % of the hand protective product samples have incident energy values that are within 20 % of the determined E_{BT} value.

12.2.1.1 If there is not enough data in these ranges, perform additional hand protective product holders test trials at the respective incident energy range and record the hand protective product material response. A minimum of 20 data values with incident energy values distributed, as noted above, is required.

12.2.2 Record a value of 1 for each hand protective product that at any time exhibits breakopen, and a value of 0 for those that do not.

12.2.3 Perform a nominal logistic regression on the resulting test data. The maximum incident energy monitor sensor response is used as the continuous variable, *X*. The corresponding nominal binary *Y* value response is the individual hand protective product breakopen response, breakopen = 1/no breakopen = 0.

12.2.4 Use the logistic regression determined values of slope and intercept to calculate (inverse prediction) the 50 % probability value of material breakopen. This is the E_{BT} value, or the incident energy value that would just predict breakopen. The value is determined as:

$$E_{BT} = \left| \frac{\text{Intercept}}{\text{Slope}} \right| \quad (9)$$

12.3 *Arc Rating*—Report the ATPV as the hand protective product Arc Rating (ATPV), if no breakopen occurs below or within the mix zone during determination of the ATPV. Otherwise, perform sufficient panel tests, as identified in 12.2 to allow determination of the E_{BT} value.

12.3.1 If an E_{BT} value is determined and it is found to be equal to or below a determined ATPV, then the E_{BT} value shall be reported as the arc rating value of the tested hand protective product or hand protective product system and noted in the test report as Arc Rating (E_{BT}).

12.3.2 If an E_{BT} value is determined and it is found to be above a determined ATPV, then the ATPV result shall be reported as the Arc Rating (ATPV) of the tested hand protective product or hand protective product system.

12.4 *Determination of a Flammable Ignition*—A 50 % probability of ignition response ($ignition_{50}$) can be determined, if desired, in a similar manner to the breakopen determination. This is done using the test hand protective product or hand protective product system ignition information (see 3.1.11) coupled with the incident energy, E_i, determined in 12.1.3. $Ignition_{50}$ shall be determined on samples which do not meet vertical flammability requirements of 1.2.

12.4.1 The hand protective product or hand protective product system ignition responses shall be distributed such that:

(1) at least 15 % of the hand protective product holder's incident energy values are in a range that never ignite the hand protective products,

(2) at least 15 % of the hand protective product holders incident energy values are in a range that always ignite the hand protective products, and

(3) 50 to 70 % of the hand protective product holders have incident energy values that are within 20 % of the determined flammable ignition energy value.

12.4.1.1 If there is not enough data in these ranges, perform additional hand protective product holders test trials at the respective incident energy range and record the hand protective product material response. A minimum of 20 data values with incident energy values distributed, as noted above, is required.

12.4.2 Record a value of 1 for each individual hand protective product test sample that exhibits ignition, and a value of 0 for those that do not.

12.4.3 Perform a nominal logistic regression on the resulting test data. The maximum of each hand protective product holder incident energy monitor sensor response is used as the continuous variable, *X*. The corresponding nominal binary *Y* value response is the hand protective product material ignition response, ignition = 1/no ignition = 0.

12.4.4 Use the logistic regression determined values of slope and intercept in Eq 9 to calculate (inverse prediction) the 50 % probability value of hand protective product or hand protective product system ignition. This is the $Ignition_{50}$ value, or the incident energy value that would just predict hand protective product or hand protective product system ignition.

12.5 *Electrical Data*—Consistency in maintaining the arc current, arc duration and closing may vary from test laboratory to test laboratory. Section 6.5 requires no more than 5 % variation from test to test, given identical test parameters. Tests that exceed this 5 % variation shall be investigated.

12.6 *Subjective Data*—Evaluate and record subjective additional data and observations about hand protective product material response. Use any or all of the following terms which are defined in Section 3 as needed to describe the material response: *(1)* breakopen, *(2)* melting *(3)* dripping, *(4)* shrinkage, and *(5)* ignition.

13. Report

13.1 State that the test has been performed as directed in this test method, and report the following information:

13.1.1 Specimen data as indicated in 11.3.

13.1.2 Conditions of each test trial, including:

13.1.2.1 Electrical parameters: *(1)* test trial number, *(2)* RMS arc current, *(3)* peak arc current, *(4)* arc gap, *(5)* arc duration, *(6)* arc energy, and *(7)* plot of arc current and arc voltage.

13.1.2.2 Thermal parameters: *(1)* plot of the response of the monitor sensor for each hand protective product holder.

13.1.3 Report test data and results including; *(1)* test number, *(2)* distance from the arc center line to the hand protective product holder sensor's surface, *(3)* order of layers, *(4)* applicable subjective evaluation as outlined in 12.6, *(5)* heat attenuation factor (HAF) and HAF 95 % confidence intervals, *(6)* plot of HAF on E_i, *(7)* plot of the incident energy distribution E_i from the calibration trial analysis, *(8)* the breakopen value, E_{BT}, if determined in addition to ATPV, but not used as the arc rating, *(9)* the ignition value, $ignition_{50}$ (if determined during testing), *(10)* the burn injury probability plot versus E_i used for the determination of ATPV, *(11)* the breakopen probability plot versus E_i used for the determination of E_{BT} (if determined), and *(12)* the ignition probability plot versus E_i used for the determination of ignition (if determined) *(13)* Average hand protective product thickness and upper and lower measurement of thickness as determined with a micrometer to ± 0.1 mm in the area of the hand where the calorimeter contacts the hand protective product, *(14)* Any other thickness measurement performed and the standard number used to determine the measurement, *(15)* Hand protective product color(s), *(16)* Hand protective product material type (for example, fabric composition, polymer composition, etc), *(17)* Hand protective product tracking ID number, *(18)* Hand protective product size as indicated by the manufacturer.

13.2 Report any abnormalities relating to the test apparatus and test controller.

13.3 Return the exposed specimens, plots, test data, and unused specimens to the person requesting the test, if in accordance with any prior arrangement. All test specimens shall be marked with a reference to the test number, date, etc.

14. Precision and Bias

14.1 An intra-laboratory test program to determine method precision was sponsored by ASTM and funded by industry donations. The testing was conducted by the F18.65.01 working group at Kinectrics Inc., Toronto, Ontario, Canada. The data were generated Feb. 18-19, 2009 at the High Current testing facility using the test method and apparatus specified in this standard.

14.1.1 The results of the intra-laboratory precision study are shown in Table 1.

14.1.2 *Repeatability*—The repeatability, *r*, of this test method has been established as the value tabulated in Table 1. Two single test results, obtained in the same laboratory under normal test method procedures that differ by more than this

TABLE 1 Precision of the Test Method

Test Number	Glove A ATPV, cal/cm^2	Glove A HAF, %	Glove B ATPV, cal/cm^2	Glove B E_{BT}, cal/cm^2	Glove B HAF, %
Test 1	41.1	92.3	20.7	27.7	90.9
Test 2	42.6	91.6	24.5	27	91.1
Test 3	43.9	92.0	24.9	22.3	91.7
Test 4	41.7	91.4	25.7	29	91.4
Test 5	42.9	91.4	26.8	31.9	92.2
Average	42.44	91.74	24.52	27.58	91.46
Standard *r*	1.1	0.4	2.31	3.50	0.51
Standard Deviation, %	2.6	0.43	9.42	12.68	0.56
r	3.0	1.1	6.47	9.79	1.44

r = repeatability standard deviation pooled within lab standard deviation

tabulated *r* must be considered as derived from different or non-identical sample populations.

14.1.3 *Reproducibility*—The reproducibility of this test method was not established as there is only one testing facility in North America currently capable of performing the test.

14.2 *Bias:*

14.2.1 Values of ATPV, E_{BT}, HAF, $Ignition_{50}$, and Arc Rating can be defined only in terms of a test method. There is no independent test method, nor any established standard reference material, by which any bias in the test method can be determined. The test method has no known bias.

APPENDIX

(Nonmandatory Information)

X1. LOGISTIC REGRESSION TECHNIQUE

X1.1 Binomial logistic regression is a form of regression used when the dependent variable is limited to two states (dichotomy) and the independent variable is continuous (it can also be applied to multiple continuous independent variables). The logistic regression technique applies maximum likelihood estimation after transforming the dependent variable into a probability variable, the natural log of the odds of the dependent occurring or not. It thus generates an estimate of the probability of a certain event occurring by solving the following:

$$\ln\left[\frac{p}{1-p}\right] = a + bx + error \qquad (X1.1)$$

or

$$\left[\frac{p}{1-p}\right] = e^{a} \times e^{bx} \times e^{error} \qquad (X1.2)$$

where:

ln	=	natural logarithm,
p	=	probability that the event *Y* occurs, *p* (*Y* = 1),
p/(1–p)	=	odds ratio; (1–*p*) is the probability that event *Y* does not occur, and
ln[p/(1–p)]	=	log odds ratio.

NOTE X1.1—The right hand side of the equation is the standard linear regression form.

X1.2 The logistic regression model is simply a non-linear transformation of the linear regression model. The logistic distribution is an S-shaped distribution function that is somewhat similar to the standard normal distribution. The logit distribution estimated probabilities lie between 0 and 1. This can be seen by rearranging the equation above and solving for *p*:

$$p = \left[\frac{e^{(a+bx)}}{1+e^{(a+bx)}}\right] \qquad (X1.3)$$

or

$$p = \frac{1}{\left[1 + e^{(-a-bx)}\right]} \qquad (X1.4)$$

X1.3 If ($a + bx$) becomes large, p tends to 1, when ($a + bx$) becomes small, p tends to 0, and when ($a + bx$) = 0, $p = 0.5$ (the value used for ATPV and E_{BT} in the methods above). The 50 % probability value is the point where the probability of occurring/not occurring is identical and would represent, in the case of the ATPV measurement, the point at which you just crossed the Stoll curve.

X1.4 The analysis technique makes no assumptions about linearity of the relationship between the independent variable and the dependent, does not require normally distributed variables, does not assume the error terms are homoskedastic (the variance of the dependent variable is the same with different values of the independent variable—a criteria for ordinary least squares regression), and in general has less stringent requirements.

X1.5 Operationally, a dummy variable of 1 or 0 is utilized to represent the particular state of the dependent item measured. In the ATPV example above, the coding of the dependent variable corresponds to:

Y = 1 if the heat response of the calorimeter exceeded the Stoll curve
Y = 0 if the heat response of the calorimeter did not exceed Stoll curve

X1.6 The independent, continuous variable in this case is the incident energy from the thermal arc exposure.

X1.7 A logistic regression is performed from a series of measurements and the values for *a* and *b* are determined (plus a host of other descriptive features—see the particular documentation for the software package used). The Stoll criteria (or breakopen response) is then determined by calculating *x* at the $p = 0.5$ or 50 % probability value, which from above is simply where ($a + bx$) = 0 or:

$$x = \left| \frac{a}{b} \right| \quad (X1.5)$$

The absolute value is used here since some packages express their model calculation in the reverse manner (p = probability not occurring, etc.), which flips the S-shaped distribution. This can introduce a negative sign on the value of a or b, however the value at the 50 % probability point is the same.

X1.8 There are several commercial and free software packages that can be used to perform this analysis.