Designation: F2522 – 12

Standard Test Method for Determining the Protective Performance of a Shield Attached on Live Line Tools or on Racking Rods for Electric Arc Hazards[1]

This standard is issued under the fixed designation F2522; 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 heat attenuation factor (HAF), the effective heat attenuation factor (EHAF), and the shields mechanical strength (SMS) of a shield attached on live line tools or racking rods intended for protection of workers exposed to electric arcs.

1.2 The materials used in this test method of worker protection are in the form of a shield attached on live line tools or on the racking rods.

1.3 The protective shield described in this test method shall be transparent and shall be easily attached and removed from live line tools or from racking rods.

1.4 The protective shield described in this test method has 24-in. (0.61-m) diameter and can be used for most applications, however for special cases, the shield can have different sizes to suit the protective requirements of the application.

1.5 This standard shall be used to measure and describe the properties of materials, products, or assemblies in response to incident energies (thermal-convective, and radiant and pressure wave) generated by an electric arc under controlled laboratory conditions and does not purport to predict damage from light, resultant pressure impact other than the pressure and thermal aspects measured.

1.6 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

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

1.8 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety 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]

D4391 Terminology Relating to The Burning Behavior of Textiles

F1959/F1959M Test Method for Determining the Arc Rating of Materials for Clothing

3. Terminology

3.1 *Definitions:*

3.1.1 *arc, n*—conductive path in air for the electric current caused by ionization of air between two electrodes.

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

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

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

3.1.5 *arc voltage, n*—voltage across the gap caused by the current flowing through the resistance created by the arc gap, V. See also Terminology D4391.

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

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

3.1.8 *closure, n*—point on supply current wave form where arc is initiated.

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[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 F18.35 on Tools & Equipment.

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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.

3.1.9 *effective heat attenuation (EHAF)/cone of protection (COP) factor, n*—the percentage of the incident heat energy that is attenuated by the shield at the location of the worker.

3.1.10 *fragmentation, n*—molten metal fragments or other fragments emitted from an electric arc.

3.1.11 *heat attenuation factor (HAF), n*—the percentage of the incident heat energy that is blocked by the safety shield material.

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

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

3.1.14 *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.

3.1.15 *ignition, n*—the initiation of combustion.

3.1.16 *incident energy* (E_i)*, n*—the amount of energy (total heat, cal/cm^2) received at a surface as a direct result of an electrical arc discharge as measured by temperature rise on copper calorimeters.

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

3.1.18 *pressure wave, n*—a certain force over an area created by air movement caused by an electric arc.

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

3.1.20 *sensors, n*—copper calorimeter, instrumented with a thermocouple contained in a dielectric, heat protective housing for use in measuring energy.

3.1.21 *shield mechanical strength value (SMS) factor, n*—the mechanical ability of the shield to withstand the electric arc pressure wave and fragmentation.

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

4. Summary of Test Method

4.1 This test method determines the heat attenuation factor (HAF) of the shield material, the effective heat attenuation factor (EHAF) at the location where the worker may be while holding the hot stick or racking rod to which the shield is attached, and the shield mechanical strength (SMS). The copper calorimeters (incident energy monitoring sensors) are placed for the HAF at the shield (front and back), and for the EHAF test at the probable location of the worker's hand, head, side of the face, chest, and legs when exposed to the heat energy from a controlled electric arc. The SMS value of the shield is obtained from visual observations of the HAF test for the ability of the shield to absorb and deflect the fragmentation shrapnel, not break or ignite, not to move from its attachment, and not to bend more then 20 degrees.

4.2 During HAF and EHAF tests, the center of the shield is aligned with the mid point of the arc gap. During this procedure, the amount of heat energy reduced (blocked) by the shield is measured during exposure to an electric arc.

4.3 The heat energy of the arc exposure is measured with calorimeters. The rate at which the temperature of the calorimeters increases is a direct measure of the heat energy received.

4.4 The shield protective performance for this test method is determined from the heat attenuation factor (in percent) at the shield location, and from the effective heat attenuation factor at the worker location. The effective heat attenuation factor in percent is the difference in the incident energy generated by the arc flash before and after the shield was used.

4.5 Heat transfer data can be used to predict the onset of second degree burn using the Stoll curve.

4.6 This procedure incorporates incident heat energy monitoring sensors.

4.7 Further description of the shield reduction of the electric arc exposure on the worker is presented in Sections 12 and 13.

5. Significance and Use

5.1 This test method is intended for determining the heat attenuation factor (HAF) of a shield material and the effective heat attenuation factor (EHAF) at the location of the worker. This can be obtained by measuring the reduction of the arc incident energy levels caused by a shield attached on a live line tool (hot stick) or on a racking rod and designed for protection for workers exposed to electric arcs. The shield mechanical strength (SMS) can be obtained from visual observations of the high speed video recordings of each shot during HAF tests.

5.1.1 Because of the variability of the arc exposure, different heat transmission values and pressure may result for individual sensors. The results of each sensor are evaluated in accordance with Section 12.

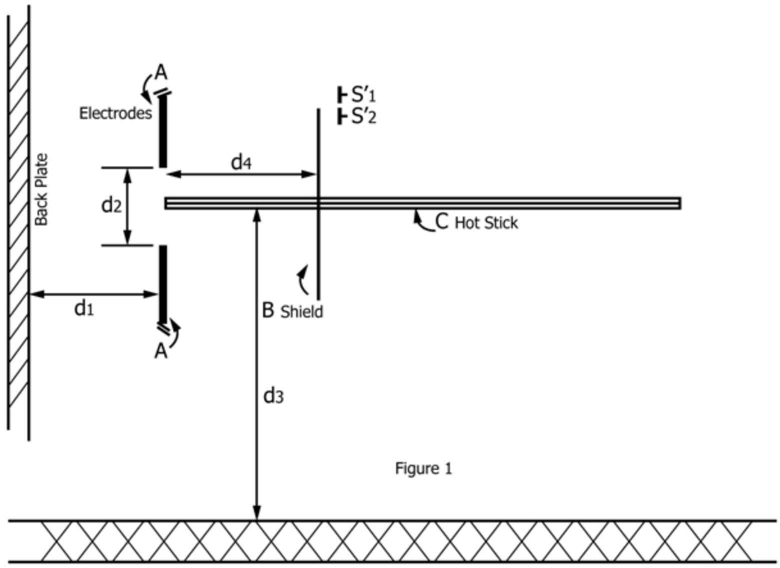
5.2 This test method maintains the shield and the heat sensors in a static, vertical position and does not involve movement except that resulting from the exposure.

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

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

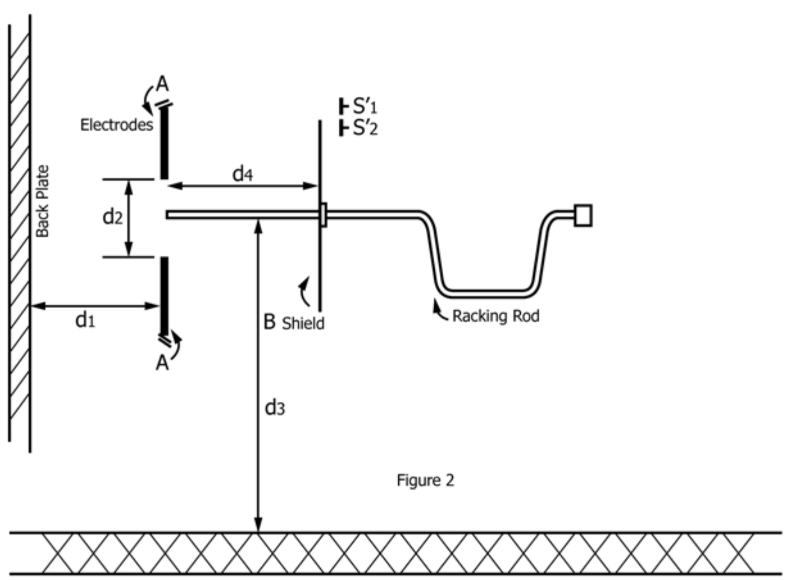
6. Apparatus

6.1 *General Arrangement for Determining Heat Attenuation Factor (HAF) of the Shield*—The test apparatus shall consist of supply bus, arc controller, recorder, arc electrodes, the shield, and incident energy monitoring sensors. The arc exposure in the form of heat attenuation factor at the shield location shall be monitored with two incident energy monitoring sensors. Figs. 1 and 2 show the test set-up and the location of the shield on the hot stick and on the racking rod and the location of



d1 = 24 in. (0.61 m), distance from the wall (back plate) to the arc electrodes
d2 = 6 in. (0.15 m) (gap) between electrodes
d3 = 53 in. (1.35 m), parallel distance of the hot stick or the racking rod above the floor
d4 = 24 in. (0.61 m), distance of the shield from the electrodes
d5 = 4 in. (0.10 m), vertical distance between centers of S'1 and S'2
S'1 and S'2 = 24.5 in. (0.62 m), approximate horizontal distance of the sensors from the electrodes
S1, S2, S3, S4, S5, and S6 are located vertically, and S1 is 5 ft (1.52 m) from the arc center

FIG. 1 Test Set-up for HAF Measurements with Shield on a Live Line Tool

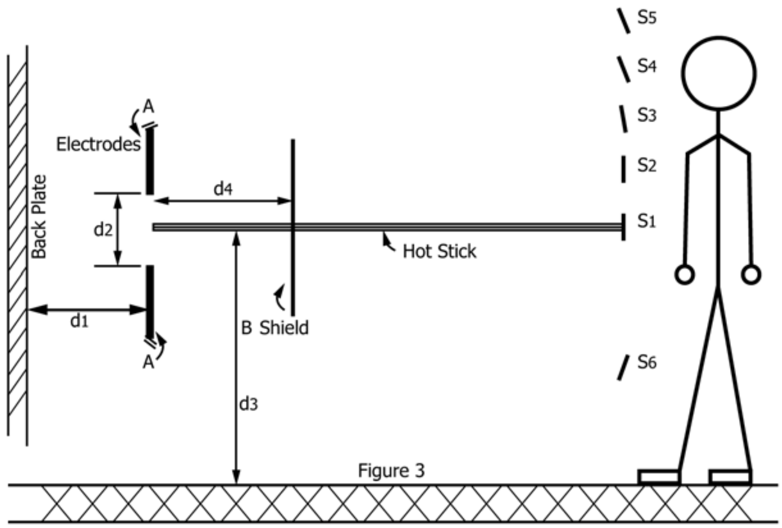


d1 = 24 in. (0.61 m), distance from the wall (back plate) to the arc electrodes
d2 = 6 in. (0.15 m) (gap) between electrodes
d3 = 53 in. (1.35 m), parallel distance of the hot stick or the racking rod above the floor
d4 = 24 in. (0.61 m), distance of the shield from the electrodes
d5 = 4 in. (0.10 m), vertical distance between centers of S'1 and S'2
S'1 and S'2 = 24.5 in. (0.62 m), approximate horizontal distance of the sensors from the electrodes
S1, S2, S3, S4, S5, and S6 are located vertically, and S1 is 5 ft (1.52 m) from the arc center

FIG. 2 Test Set-up for HAF Measurements with Shield on a Racking Rod

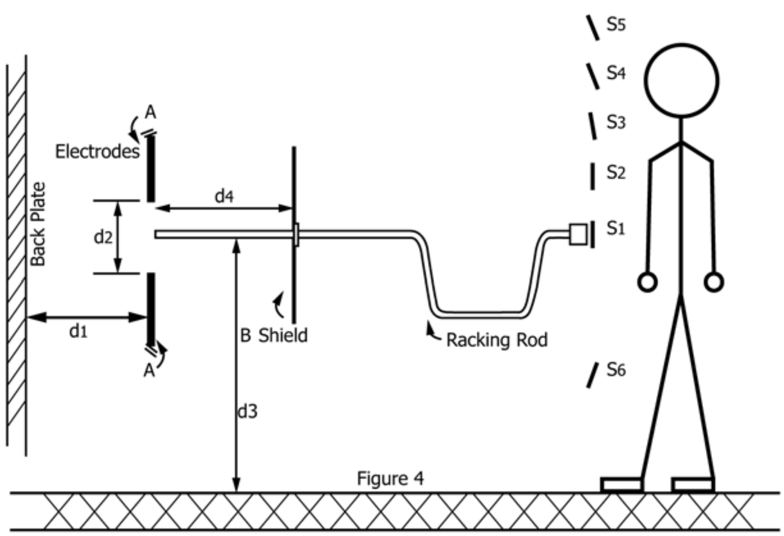
sensors. Fig. 2 has the same test set-up as Fig. 1, except the shield is attached on the racking rod.

6.2 *General Arrangement for Determining Effective Heat Attenuation Factor (EHAF) at the Location of the Worker*—The test apparatus shall consist of supply bus, arc controller, recorder, arc electrodes, a shield, and incident energy monitoring sensors. The arc exposure in the form of effective heat attenuation factor at the location of the worker shall be monitored with a minimum of six incident energy monitoring sensors. Figs. 3 and 4 show the test set-up and the location of



d1 = 24 in. (0.61 m), distance from the wall (back plate) to the arc electrodes
d2 = 6 in. (0.15 m) (gap) between electrodes
d3 = 53 in. (1.35 m), parallel distance of the hot stick or the racking rod above the floor
d4 = 24 in. (0.61 m), distance of the shield from the electrodes
d5 = 4 in. (0.10 m), vertical distance between centers of S'1 and S'2
S'1 and S'2 = 24.5 in. (0.62 m), approximate horizontal distance of the sensors from the electrodes
S1, S2, S3, S4, S5, and S6 are located vertically, and S1 is 5 ft (1.52 m) from the arc center

FIG. 3 Test Set-up for EHAF Measurement with Shield on a Live Line Tool



d1 = 24 in. (0.61 m), distance from the wall (back plate) to the arc electrodes
d2 = 6 in. (0.15 m) (gap) between electrodes
d3 = 53 in. (1.35 m), parallel distance of the hot stick or the racking rod above the floor
d4 = 24 in. (0.61 m), distance of the shield from the electrodes
d5 = 4 in. (0.10 m), vertical distance between centers of S'1 and S'2
S'1 and S'2 = 24.5 in. (0.62 m), approximate horizontal distance of the sensors from the electrodes
S1, S2, S3, S4, S5, and S6 are located vertically, and S1 is 5 ft (1.52 m) from the arc center

FIG. 4 Test Set-up for EHAF Measurement with Shield on a Racking Rod

the shield and the sensors. The shield for the EHAF test is at the same location as in the HAF tests (Figs. 1 and 2) and the sensors are located approximately 5 ft (1.52 m) from the electric arc center. Fig. 4 has the same test set-up as Fig. 3, except the shield in Fig. 4 is attached on the racking rod, and in Fig. 3 the shield is attached on a hotstick.

6.3 *General Arrangement for Determining Shield's Mechanical Strength (SMS)*—The evaluation of shield's mechanical strength value (SMS) is based on visual observations of the high speed video recordings of the arc tests made in 6.1 (HAF tests). The purpose of the SMS test is to determine the mechanical ability of the shield to withstand the electric arc pressure wave and fragmentation. The SMS value is determined by observing the HAF tests for the ability of the shield to absorb and deflect the fragmentation shrapnel, not break or ignite, not to move from its attachment, and not to bend more then 20 degrees.

6.4 *Electrodes*—A typical arrangement of the arc electrodes is shown in Fig. 1. The arc shall be in a vertical position as shown.

6.5 *Electrodes*—Make the electrodes from electrical grade copper (alloy type 110) rod of a nominal ¾-in. (0.019-m) diameter. Lengths of 18 in. (0.460 m) long have been found to be adequate.

6.6 *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 no greater than 0.02 in. (0.0005 m).

6.7 *Electric Supply*—The electric supply should be sufficient to allow for the discharge of an electric arc with a gap of up to 12 in. (0.305 m), with alternating arc current from 4000 up to 25 000 A and with arc duration from 3 cycles (0.05 s) up to 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 times the symmetrical RMS value.

6.8 *Test Circuit Control*—Repeat exposures of the arc currents shall not deviate more than 2 % per test from the selected test level. The make switch shall be capable of point on wave closing within 0.2 cycles 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 6.7. 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.

6.9 *Data Acquisition System*—The system shall be capable of recording voltage, current, and sufficient calorimeter outputs as required by the test. The sensitivity and accuracy of the data acquisition system shall be as described in Test Method F1959/F1959M.

6.10 *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.

6.11 *Sensors*—Refer to the calorimeters as described in Test Method F1959/F1959M.

7. Precautions

7.1 The test apparatus discharges large amounts of energy. In addition, the electric arc produces very intense light. Care should be taken to protect personnel working in the area. Workers should be behind protective barriers or at a safe distance to prevent electrocution and contact with molten metal. Workers wishing to directly view the test should use very heavily tinted glasses such as ANSI/ASC Filter Shade 12 welding glasses. 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. The test apparatus should 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 should be positioned to prevent blowout of the electric arc. The test apparatus should be insulated from ground for the appropriate test voltage.

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

7.3 Use care when the specimen ignites or releases combustible gases. An appropriate fire extinguisher should 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 laboratory equipment used to generate the arc. The apparatus and other laboratory equipment shall be isolated and grounded. After data acquisition has been completed, appropriate methods shall be used to ventilate the test area before it is entered by personnel. No one should enter the test area prior to exhausting all smoke and fumes.

8. Sampling and Specimen Preparation

8.1 *Test Specimens for Shield Test*—From the shields to be tested, select a new shield with a given size (shield diameter). Shields of the same size should be replaced after each set of tests.

9. Calibration and Standardization

9.1 *Data Collection System Pre-calibration*—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 foxed radiant energy source for 30 s. At 30 s, 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 2—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 10.5 in. from the calorimeter. The spot shall be centered on and perpendicular to the calorimeter.[3]

9.3 *Arc Exposure Calibration*—Prior to each calibration, position the electrodes of the test apparatus to produce a 12-in. (0.305-m) gap. The face of the monitor sensors shall be parallel and normal to, the centerline of the electrodes. The midpoint of the electrode gap shall be at the same elevation as the center

[3] A 500-W light source is available from the Strand Electric and Engineering Co. Ltd. as Part No. 83 (500 W, 120 V light source).

point of the monitor sensors (see Fig. 1). 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 shall be pulled tight and the excess trimmed. The test controller should be adjusted to produce the desired arc current and duration.

9.4 *Apparatus Calibration Check*—Position each monitor sensor so that the surface of each sensor is 12 in. (0.305 m) from, parallel and normal to the centerline of the electrodes. Set the symmetrical arc exposure current to the test amperage level and the arc duration at 10 cycles (0.167 s). Discharge the arc. Determine the maximum temperature rise for each of the sensors, and multiply by the sensor constant 0.135 (cal/cm^2 C) to obtain the incident energy (total heat) (cal/cm^2) measured by each sensor. Compare the highest sensor reading and the average value obtained for all sensors, for example, with the measured result of 10.1 cal/cm^2 for the calibration exposure of 8000 A for 0.167 s. Compare the total heat value determined by the sensors to the value shown. The average total heat calculated for the sensors shall be at least 60 % of the value determined by calculation or that shown. The highest measured total heat of any one sensor shall be within 10 % of the calculated value. If these values are not obtained, inspect the test setup and correct any possible problems that could produce less than desired results. An arc exposure calibration test should be conducted at the desired test level after each adjustment, and prior to the start and end of each day's testing and after any equipment adjustment or failure. Detailed and most recent procedure for calculation of heat flux from copper sensors is found in Test Method F1959/F1959M.

9.4.1 Because the arc does not follow a path that is equidistant from each sensor, the results will vary. At 8000 A, the highest total heat measured with a single sensor shall be between 9 and 11 cal/cm^2 and the average total heat for all sensors shall be at least 6 cal/cm^2. If these values are not achieved, check the calibration of the sensor system, electrical conditions, and the physical setup of the apparatus and repeat the calibration exposure until the required results are obtained.

9.4.2 If during testing the exposure values specified in 9.4 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, then the data from the last three tests shall be rejected.

9.5 *Confirmation of Test Apparatus Setting*—Confirm the test apparatus setting for each test from the controller equipment. Values reported should be peak arc current, RMS arc current, arc duration, arc energy, and arc voltage. A graph of the arc current should be plotted to ensure proper wave form. In addition, the ambient temperature and relative humidity shall be recorded.

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 future error. If a deposit collects and appears to be thicker than a thin layer of paint, or the surface is irregular, the sensor surface requires reconditioning. Carefully clean the cooled sensor with acetone or petroleum solvent, making certain to follow safe handling practices. Repaint the surface with a thin layer of flat black high temperature spray paint. Use the same paint on all sensors and ensure that the paint is dry before running the next test.

10.3 *The Shield and Incident Energy Monitoring Sensor Care*—The shield and monitoring sensors shall be kept dry. For outdoor tests the shield and monitoring sensors shall be covered during long periods between tests to prevent excess temperature rise resulting from exposure to any heat source. Due to the destructive nature of the electric arc, the monitoring sensor holders should be covered with the same paint as the sensors. The sensor holders should be re-coated periodically to reduce deterioration.

11. Procedure

11.1 *Heat Attenuation Factor (HAF)*—As shown in Figs. 1 and 2, two heat sensors, (S'1 and S'2), shall be used to measure HAF. The approximate horizontal distance of sensors S'1 and S'2 shall be about 24.5 in. (0.62 m) from the arc electrodes, with sensor S'2 behind the shield. The shield attached to an 8-ft (2.44-m) long hot stick or a 5 ft (1.52 m) long racking rod shall be located 24 in. (0.61 m) from the center of the arc electrodes. The hot stick or the racking rod shall be placed parallel and 53 in. (1.35 m) above the floor. The type copper calorimeters to be used in the incident energy monitoring sensors are described in Test Method F1959/F1959M. The center of the shield shall be aligned with the mid point of the arc gap. The relationship of the sensor locations to the mid point of the arc and the distance from the arc center is shown in Figs. 1 and 2.

11.1.1 *Procedure to Obtain the Heat Attenuation Factor (HAF):*

11.1.1.1 *For a Shield Attached on a Hot Stick:*

(1) Calibration Test, no shield

(a) Test set-up per Fig. 1. Copper electrodes with 6 in. (0.15 m) gap.

(b) One shot shall be made at I = 10 kA @ 30 cyc.

(2) HAF Tests, with a shield

(a) Test set-up per Fig. 1. Copper electrodes with 6 in. (0.15 m) gap.

(b) Three shots shall be made at 8 kA @ 15 cyc.

(c) One shot shall be made at 40 kA @ 60 cyc.

11.1.1.2 *For a Shield Attached to a Racking Rod:*

(1) Calibration Test, no shield

(a) Test set-up per Fig. 2. Copper electrodes with 6 in. (0.15 m) gap.

(b) One shot shall be made at I = 10 kA @ 30 cyc.

(2) HAF Tests, with a shield

(a) Test set-up per Fig. 2. Copper electrodes with 6 in. (0.15 m) gap.

(b) Three shots shall be made at 8 kA @ 15 cyc.

(c) One shot shall be made at 40 kA @ 60 cyc.

11.1.1.3 The range of energies for the HAF test shall be approximately between 2 and 60 calories. This will determine how the shield behaves when exposed to such a difference in arc energy and its effect on the percentage of the incident heat energy that is blocked by the shield material. Also, the test will determine the Shield Mechanical Strength (SMS) value, described as the shield's ability to absorb and deflect the fragmentation shrapnel and withstand the pressure wave, without moving from its attachment or deflecting more than 20 degrees.

11.1.2 *Procedure to Calculate the HAF (in Percent Attenuation):*

11.1.2.1 The HAF (in percent attenuation) value is the percent of the incident heat energy attenuated (blocked) by the shield material. HAF = (S'2/S'1 – 1) 100. It shall be obtained by calculating the average value of the measured heat energy levels for sensors S'1 and S'2. Expression S'2/S'1 is the division of the heat energy (in calories per centimeter square) values of S'2 (the sensor behind the shield) over S'1 (the sensor above the shield).

11.2 *To Obtain the Effective Heat Attenuation (EHAF)/Cone of Protection (COP)*—The shield attached to an 8-ft (2.44-m) long hot stick or a 5-ft (1.52-m) long racking rod shall be located 24 in. (0.61 m) from the center of the arc electrodes. The hot stick or the racking rod shall be placed parallel and 53 in. (1.35 m) above the floor. As shown in Figs. 3 and 4, sensors #1, 2, 3, 4, 5, and 6 shall be in a vertical position simulating a worker and provide a thermal exposure value at 5 ft (1.52 m) distance from arc. Sensor #5 (worker's head location) and Sensor # 6 (at the knees) shall be about 4.75 ft (1.45 m) apart, with Sensor #6 about 25 in. (0.63 m) below the hot stick or the racking rod. Sensors #1–5 (starting up from the hot stick) shall be 8 in. (0.20 m) apart. The type copper calorimeters to be used in the incident energy monitoring sensors are described in Test Method F1959/F1959M. The center of the shield shall be aligned with the mid point of the arc gap. The relationship of the sensor locations to the mid point of the arc and the distance to the sensors from the arc is shown in Figs. 3 and 4.

11.2.1 *Procedure to Obtain Effective Heat Attenuation (EHAF) / Cone of Protection (COP):*

11.2.1.1 *For a Shield Attached on a Hot Stick:*

(1) Calibration Test, no shield

(a) Test set-up per Fig. 3. Copper electrodes with 6 in. (0.15 m) gap.

(b) One shot shall be made at I = 10 kA @ 30 cyc.

(2) EHAF/COP Tests, no shield

(a) Test set-up per Fig. 3. Copper electrodes with 6 in. (0.15 m) gap.

(b) Three shots shall be made of the following:

(c) I = 24 kA @ 30 cyc.

(3) EHAF/COP Tests, with a shield

(a) Test set-up per Fig. 2. Copper electrodes with 6 in. (0.15 m) gap.

(b) Three shots shall be made of the following:

(c) I = 24 kA @ 30 cyc.

11.2.1.2 *For a Shield Attached to a Racking Rod:*

(1) Calibration Test, no shield

(a) Test set-up per Fig. 4. Copper electrodes with 6 in. (0.15 m) gap.

(b) One shot shall be made at I = 10 kA @ 30 cyc.

(2) EHAF/COP Tests, with shield

(a) Test set-up per Fig. 4. Copper electrodes with 6 in. (0.15 m) gap.

(b) Three shots shall be made of the following:

(c) I = 24 kA @ 30 cyc.

11.2.2 *Procedure to Calculate the EHAF/COP (in Percent Attenuation):*

11.2.2.1 The effective heat attenuation value/cone of protection (EHAF/COP) is the percent of the incident heat energy attenuated (blocked) by the shield at the location of the worker. The EHAF value depends on several factors such as the location of the worker, the shield's diameter and the distance of the shield from the electric arc. EHAF = (S'/S – 1) 100. It shall be obtained by calculating the average value of the measured heat energy levels for sensors S' and S. Expression S'/S is the division of the heat energy (in calories per centimeter square) values of S' (the sensor with the shield) over S (the same sensor without the shield).

11.2.2.2 The EHAF/COP for each of the six incident energy monitor sensors shall be obtained by: calculating the average value of the three measured heat energy levels for each of the tests, the test with the shield, and the other test without the shield At each sensor location, the measured incident energy levels in cal/cm^2 , shall be corrected to the value reflecting an equal distance from each sensor to the arc center. For example, if for sensor X the actual distance to the arc center is 62 in. (1.57 m), and the base distance is 60 in. (1.52 m), then the correction factor for sensor X equals to 62 divided by 60 and the quantity squared or a factor of 1.07.

NOTE 3—The reason for choosing 24 kA @ 30 cyc. with 6 in. (0.15 m) gap, is to obtain at the 5 ft (1.52 m) distance from the arc center, measurable heat energy levels for the six sensors in the range of 1.5 to 3 cal/cm^2, and to provide an arc energy source that has a safety margin over the majority of applications. The 6 in. (0.15 m) electrode separation (gap) was chosen to represent the near average gap between the short (2 in. (0.05 m)) and the long (12 in. (0.30 m)) gaps.

11.3 *Shield Mechanical Strength (SMS) Value:*

11.3.1 The SMS value shall be obtained from the HAF tests. The range of energies for the HAF test is between 2 and 60 cal. This will determine how the shield behaves when exposed to such a difference in arc energy and its effect on the percentage of the incident heat energy that is blocked by the shield material.

11.3.2 The SMS value provides the minimum performance level of a shield and shall be obtained from visual observations of the high speed video recordings of each shot during HAF tests, where the shield must:

11.3.2.1 Absorb and deflect the fragmentation shrapnel,

11.3.2.2 Not break or ignite,

11.3.2.3 Withstand the pressure wave without moving from its attachment on the hot stick or on the racking rod, and

11.3.2.4 Limit the deflection, caused by the arc pressure wave, to 20 degrees or less.

12. Interpretation of Results

12.1 *HAF Tests:*

12.1.1 The minimum value of 50 % HAF shall be the pass/fail criterion for the shield material.

12.2 *EHAF Tests:*

12.2.1 The EHAF values for the sensors depend on several factors such as the location of the worker, the shield's diameter, the distance of the shield from the electric arc and the movement of the heat wave. No specific pass/fail criterion can be given. Tests from a 24 in. (0.61 m) diameter shield located 24 in. (0.61 m) from the arc center showed that EHAF at 5 ft (1.52 m) location for the six sensors ranged from 34 to 68 %.

12.3 *SMS Value from HAF Tests:*

12.3.1 The shield shall pass the SMS value requirement when the visual observations from the HAF test confirm that the shield:

12.3.1.1 Has absorbed or deflected the fragmentation shrapnel, or both,

12.3.1.2 Did not break or ignite,

12.3.1.3 Withstood the pressure wave without moving from its attachment on the hot stick or on the racking rod, and

12.3.1.4 Has limited the deflection, caused by the arc pressure wave, to 20 degrees or less.

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 Shield test data for a given shield size (shield diameter) from tests in 11.1 to 11.3,

13.1.2 Conditions of each test, including the following: *(1)* test number, *(2)* RMS arc current, *(3)* peak arc current, *(4)* arc gap, *(5)* arc duration, *(6)* arc energy, and *(7)* plot of RMS arc current,

13.1.3 Test data to include: *(1)* test ID number, *(2)* diameter of the shield, *(3)* distance from the arc center line to the shield and to the location of the worker. Report the HAF, EHAF values and SMS observation results, and

13.1.4 Any variation to the prescribed test conditions.

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

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

14. Precision and Bias

14.1 *Single User Determination*—At the only available testing facility for the shield arc test method, a number of 24 in. (0.61 m) diameter shields was tested. These test results were used as the basis of a temporary precision statement, in which only within-laboratory precision is addressed.

14.2 *Precision:*

14.2.1 Precision parameters for the energy levels between 2 and 60 calories reflect the precision of the laboratory measurements. Precision, stated as a critical difference is stated as a 95 % confidence level.

14.3 *Bias:*

14.3.1 The protective performance of a shield on live line tool or on a racking rod can only be defined 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 may be determined. The test method has no known bias.

15. Keywords

15.1 cone of protection; effective heat attenuation factor (EHAF); heat attenuation factor (HAF); protective performance of a shield; shield mechanical strength (SMS) value