ASTM

Standard Test Method for
Determining the Ignitability of Non-flame-Resistant Materials for Clothing by Electric Arc Exposure Method Using Mannequins[1]

This standard is issued under the fixed designation F 1958/F 1958M; 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 identify materials that are ignitable and that can continue to burn when exposed to an electric arc, and determines (*a*) the incident exposure energy that causes ignition, and (*b*) the probability of ignition.

1.2 The specimens tested in this test method are materials fabricated in the form of shirts.

1.3 This test method shall be used to measure and describe the properties of materials, products, or assemblies in response to convective and radiant energy generated by an electric arc under controlled laboratory conditions.

1.4 The values stated in either SI units or in other units shall be regarded separately as standard. The values stated in each system may not be exact equivalents, therefore each system must be used independently of the other, without combining values in any way.

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

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.7 For specific precautions, see Section 7.

2. Referenced Documents

2.1 *ASTM Standards:*
D 123 Terminology Relating to Textiles[2]
D 4391 Terminology Relating to the Burning Behavior of Textiles[3]

F 1494 Terminology Relating to Protective Clothing[4]
F 1506 Performance Specification for Textile Materials for Wearing Apparel for Use by Electrical Workers Exposed to Momentary Electric Arc and Related Thermal Hazards.
F 1959/F 1959M Test Method for Determining The Arc Thermal Performance Value Of Materials for Clothing[5]

2.2 *ANSI/IEEE Standards:*
Standard Dictionary of Electrical and Electronics Terms[6]

3. Terminology

3.1 *Definitions:*

3.1.1 See also Terminology D 4391.

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, 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.

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.

3.1.9 *delta peak temperature*, *n*—difference between the maximum temperature and the initial temperature of the sensor during the test, °C.

3.1.10 *heatflux*, *n*—the thermal intensity indicated by the amount of energy transmitted per unit area and time (cal/cm^2s)(W/cm^2).

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

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[1] This test method is under the jurisdiction of ASTM Committee F-18 on Electrical Protective Equipment for Workers and is the direct responsibility of Subcommittee F18.65 on Wearing Apparel.
Current edition approved April 10, 1999. Published November 1999. Originally published as PS 57 – 97.
[2] *Annual Book of ASTM Standards*, Vol 07.01.
[3] *Annual Book of ASTM Standards*, Vol 07.02.

[4] *Annual Book of ASTM Standards*, Vol 11.03.
[5] *Annual Book of ASTM Standards*, Vol 10.03.
[6] Available from the Institute of Electrical and Electronic Engineers, Inc., 345 E. 47th St., New York, NY 10017.

3.1.12 *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.

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

3.1.14 *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.

3.1.15 *incident energy monitoring sensors*—sensors mounted on each side of the mannequins.

3.1.15.1 *Discussion*—Sensors use the calorimeters described in Test Method F 1957/F 1957M.

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

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

3.1.18 *time to delta peak temperature, n*—the time from beginning of the initiation of the arc to the time the delta peak temperature is reached, s.

3.1.19 *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.

3.2 For definitions of other textile terms used in this test method, refer to Terminologies D 123 and F 1494.

4. Summary of Test Method

4.1 This test method exposes a material to heat energy from an electric arc, and determines (*a*) the incident exposure energy that causes ignition, and (*b*) the probability of ignition.

4.1.1 During this procedure, a material is observed for ignitability during and after exposure to an electric arc.

4.2 Material performance is determined from the ignitability of the specimen(s).

5. Significance and Use

5.1 This test method determines the ignitability of materials in single or multiple layers.

5.1.1 Material performance shall be determined from the ignitability of the specimen(s) and shall be reported as a probability of ignition at various incident energy levels.

5.1.2 Materials which meet the flame resistance requirements of Specification F 1506 do not require testing by this test method unless the mechanism of passing Specification F 1506 involves melting and escape from the flame source (for example, coated fabrics, certain rainwear fabrics).

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

5.3 This test method specifies a standard set of exposure conditions. Different exposure conditions may produce different results. In addition to the standard set of exposure conditions, other conditions representative of the expected hazard may be used.

6. Apparatus

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

6.1.1 *Arrangement of the Mannequins*—A minimum of two mannequins with two monitoring sensors each shall be used for each test. Position monitor sensors on each side of the mannequins as shown in Fig. 1. An additional mannequin with monitoring sensors may be placed around the arc as shown in Fig. 2 to evaluate multiple samples of the same materials at the same distance from the arc. Each mannequin shall be visually observed for ignition.

6.1.2 *Specimen Holder*—Use a male mannequin torso, size large, made from non-conductive fiberglass construction. (A mannequin, such as Model 7001 D, Morgese Soriano or equivalent is acceptable). The mannequin shall be constructed in an erect posture. The mannequin head may be removable. The mannequins shall have detachable arms that are straight and mount in a vertical position to allow the test specimen at the chest to be the closest point to the centerline of the arc. The arms of the mannequins may be shortened to 4 in. [102 mm] to permit ease of specimen mounting. The position of the mannequins from the centerline of the arc electrodes shall be adjustable from 8 in. [203 mm] to 24 in. [610 mm] as shown in Figs. 1 and 3.

6.1.3 The mannequins may be instrumented. Refer to Appendix X1.

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

6.2.1 *Electrodes*—Make the electrodes from stainless steel (Alloy Type 303 or Type 304) rod of a nominal ¾–in. [19–mm] diameter. Lengths of 18 in. [450 mm] long initially have been found to be adequate.

6.2.2 *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 no greater than 0.02 in. [0.05 mm].
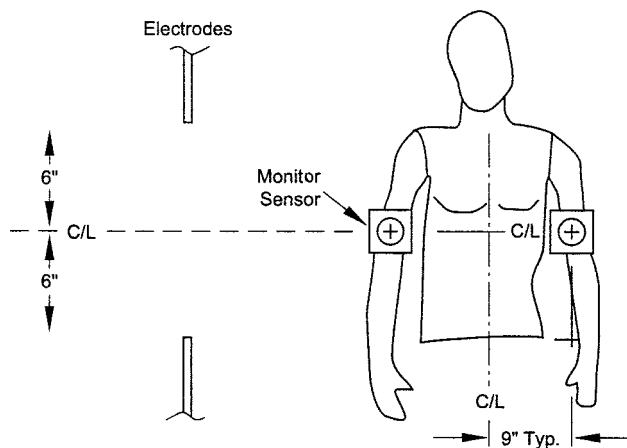

FIG. 1 Mannequin With Monitor Sensors

Monitor sensor   Monitor sensor

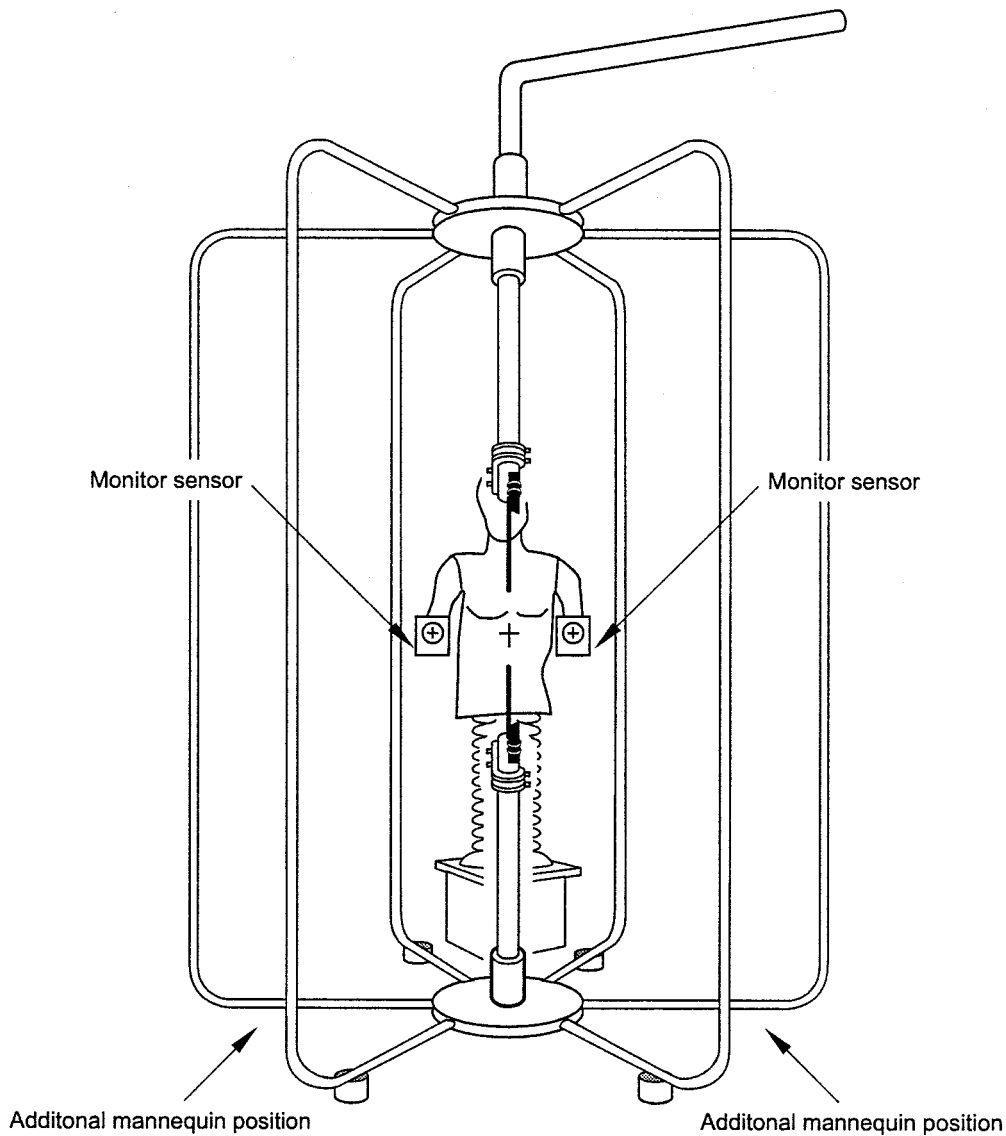Additonal mannequin position   Additonal mannequin position

FIG. 2 Supply Bus and Arc Electrodes Showing Mannequin(s) Position(s)

6.3 *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. [305 mm], with alternating arc current from 4000 up to 25 000 amperes 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.

6.4 *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 6.3. 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.

6.5 *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 F 1957/F 1957M.

6.6 *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. 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 heatflux at the surface of any of the calorimeters. The test apparatus should be shielded by non-combustible
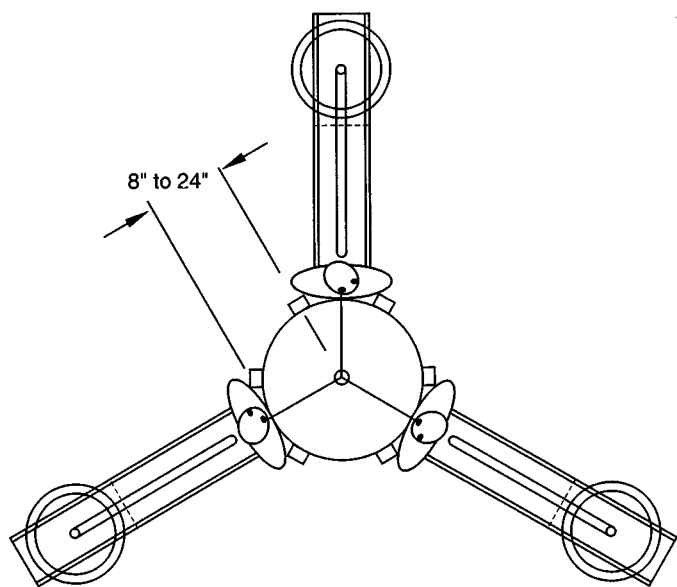
a dryer on a setting appropriate for the fabric. Remove specimens when dry.

8.2.1.3 Samples may be restored to a flat condition by pressing.

8.2.2 For those materials that require cleaning other than laundering, follow the manufacturer's recommended practice and note the procedure used in the test reports.

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. 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 30s. 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.[7]

9.3 *Arc Exposure Calibration*—Prior to each calibration, position the electrodes of the test apparatus to produce a 12–in. [305–mm] 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 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. [305 mm] 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

8" to 24"

FIG. 3 Arrangement of Mannequin(s)

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 lab 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 Mannequin Test*—From the material to be tested, make specimens according to standards for large men's long sleeve shirts. Body measurements in inches are: neck size, 16 ½; chest, 44; waist, 39; hip, 45; and sleeve length 34. Reference McCall's pattern No. 4641 size 16 ½. Front pockets are to be eliminated.

8.1.1 The fabric direction shall be that normally used for constructing shirts.

8.2 *Conditioning of Test Specimens*:

8.2.1 Launder the required number of test specimens.

8.2.1.1 Launder three times in a washing machine using commercially available detergent without chlorine bleach and with a warm 120°F (50°C) water setting.

NOTE 1—Drying is not required following the first two launderings.

8.2.1.2 Following the three laundering cycles, tumble dry in

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[7] 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).

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.

9.4.1 Because the arc does not follow a path which 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 which 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 *Mannequin and Incident Energy Monitoring Sensor Care*—The mannequins and monitoring sensors shall be kept dry. For outdoor tests the mannequins 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 Test parameters shall be 8 ± 1 kA arc current, 12 in. electrode gap, stainless steel electrodes, 12 in. distance between the arc center line and the test specimen surface. Additional test parameters may also be used and the results reported on an optional basis.

11.2 *Ignition Testing/Ignition Energy Determination - Method 1 and Method 2*— The user may use either method described in 11.2.1 or 11.2.2 to conduct the tests.

11.2.1 *Method 1–Up and Down Method*—Each test shall

consist of one shirt specimen per test mannequin, each made of the same material. The first step in the determination of the relationship between incident exposure energy, E_i, level and the probability of ignition of a material is to estimate the E_i level correlating to a 50 % probability of ignition. Once this point is approximately known, a series of tests around this level of E_i can be run and sufficient data collected to define the relationship between E_i and ignition.

NOTE 3—For example, for a 7 oz cotton shirt exposed to an arc of 8 000 A, with the specimen positioned 12 in. from the arc, and a series of arc durations from 6 to 12 cycles, the following results have been observed as shown in Table 1. The approximate value of the 50 % ignition probability would be between 7.8 and 8.6 cal/cm^2.

11.2.1.1 Estimate the 50 % probability level of E_i by running tests for a series of energy levels at equally spaced intervals from low to high energy. At least 5 tests will be needed in this survey to locate the energy near the 50 % probability level.

11.2.1.2 Use an up-down technique, as described here, to conduct the remaining tests. Start at the energy level estimated as the 50 % probability level. If the result is non-ignition for all mannequins then increase the energy level for the next test. If the result is ignition on any mannequin then decrease the energy level for the next text.

11.2.1.3 The magnitude of the increase or decrease of energy level shall be chosen to sample the probability of ignition throughout the region from 10 to 90 % probability level. If the change is too large then the test results will alternate on several successive shots between ignition and no ignition. If the change is too small then the test results will be a long series of either ignition or no ignition.

11.2.1.4 Conduct a minimum of 50 tests with a minimum of 15 test specimens that result in ignition and a minimum of 15 test specimens that result in no ignition. Include in the counts the initial tests used to estimate the 50 % probability level.

11.2.2 *Method 2*—Each test shall consist of one shirt specimen per test mannequin each made of the same material. The first step in the determination of the relationship between incident exposure energy, E_i, level and the probability of ignition of a material is to estimate the E_i levels correlating to the entire range of ignition probability. Once this range is approximately known, a series of tests around these E_i levels can be run and sufficient data collected to define the relationship between E_i and ignition.

11.2.2.1 Estimate the probability range levels of E_i by running a series of tests at equally spaced intervals from low arc duration time to high arc duration time. At least 10 tests will be needed in this survey to locate the energy range of E_i corresponding to the approximate 10 to 90 % probability of ignition.

TABLE 1 Results from Example

Cycles	E, cal/cm^2	Ignition	Nonignition
6	5.2	0	1
7	6	0	1
8	6.9	0	1
9	7.8	0	1
10	8.6	1	0
11	9.5	1	0
12	10.4	1	0

NOTE 4—For example, for a 7 oz cotton shirt begin the initial series of tests at a fault duration of 3 cycles below the nominal weight of the fabric. Execute 10 tests starting at 4 cycles and increasing the arc duration by 1 cycle for each subsequent test up through 13 cycles.

11.2.2.2 Perform the statistical logistic regression as outlined in 12.2 on the results of the initial 10 tests to approximate the 10 to 90 % probability of ignition.

11.2.2.3 Determine the duration times (in cycles) which correspond to the 10 to 90 % probability of ignition energy levels determined from the initial analysis in 11.2.2.2.

11.2.2.4 Duration times shall be chosen to sample the probability of ignition throughout the 10 to 90 % probability levels. Determine the increments of cycles at which tests will be conducted by dividing the total sample over the range of cycles. In order to achieve more confident estimates of the energy points at low probability of ignition, perform more tests at the lower cycles levels.

11.3 Adjust the temperature of the monitor sensors to between 25 to 35°C.

11.4 *Specimen Mounting*—Each mannequin shall be dressed with the test specimen. All buttons shall be fastened. A 1500 g weight in the shape of a semi-circle shall be attached to the folded bottom edge of the test specimen with the five clips on the semi-circle weight. No edges of the material shall be exposed to the arc. The test specimen shall be smoothed over the front of the mannequin and the excess material shall be gathered behind the mannequin. The arms shall not protrude closer to the arc than the chest area. The sleeves shall be fastened behind the mannequin without stretching the material.

11.5 *Specimen Data*—Record specimen data including: (*1*) identification number, (*2*) garment style identification, (*3*) the order of layering with outer layer listed first, (*4*) material type, (*5*) actual basis weight after laundering and before testing, (*6*) weave/knit type, (*7*) color, and (*8*) number of specimens tested.

11.6 Mount the fuse wire on the electrodes.

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

11.8 Expose test specimens to the electric arc.

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

11.10 Extinguish any flames or fires unless it was predetermined to let the specimens burn until consumed.

11.11 Record the thermal and electrical data.

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

12. Interpretation of Results

12.1 *Incident Energy (E_i) Monitor Sensor Responses*—For each mannequin in an arc exposure, calculate the average of the maximum rise, $\Delta TC_{avg/max}$, for the two adjacent monitor sensors. Convert this $\Delta TC_{avg/max}$ into cal/cm^2 by multiplying by the copper calorimeter conversion constant of 0.135 cal/cm^2 °C to determine the incident energy, E_i, for each mannequin in an arc exposure.

12.2 *Ignitability*:

12.2.1 *Ignition Occurrence*—Determine and record ignition/nonignition of the test specimen during exposure to the arc and the corresponding incident arc energy.

12.2.2 Analyze the set of data pairs, energy and ignition/nonignition, by logistic regression (use a statistical analysis computer program). For the logistic regression, the result of ignition shall be coded as a 1 and nonignition as a 0. The regression, by maximum likelihood, works on a transformed value of the probability function called a logit. For example, if p is the probability of ignition then

$$Y = \ln[p/(1-p)] \tag{1}$$

is the logit. The logistic regression provides best estimates of the parameters of a linear fit to Y as a function of the arc energy

$$Y = a + bE \tag{2}$$

Note that the observations do not need to be grouped to provide initial estimates of the probabilities. The logistic regression will provide the best-fit probability (in the sense of maximum likelihood) for each of the observed results. An example will illustrate the analysis.

12.2.3 A set of observations is shown in Fig. 4 for an up-down determination of ignition probability. There are 17 ignitions out of 50 observations. Logistic regression provides the parameters and their standard deviations:

Parameter	Value	Std dev.
Constant = a	−22.17	6.62
Slope = b	1.915	0.581

12.2.4 The energy values for given levels of probability are calculated from the parameters using Eq 1 and 2:

Probability	Logit, Y	Energy
10 %	−2.20	10.43
50 %	0.00	11.58

12.2.5 A plot of the fitted probability function and the data provides a visual check of the fit and energy values for given levels of probability. If the statistical analysis program provides the lower and upper 95 % confidence intervals for the fit then their inclusion on the plot will provide estimates of the confidence of the energy value for a given probability.

12.2.5.1 The data should not be grouped for the logistic fit, as grouping reduces the precision of the fit. Nevertheless, grouping the data provides a means to judge the quality of the fit.
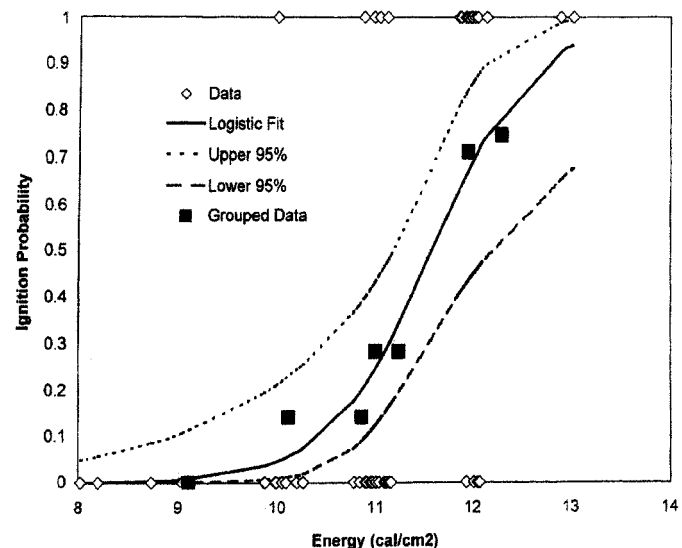

FIG. 4 Ignition Probability

12.2.5.2 The groups should be selected by sorting the original data points by energy, then dividing into equal size groups as much as possible to create a minimum of six groups. For example, a set of 50 points could be divided into 6 groups of 7 points and one group of 8 points. Within each group, calculate the average energy of the group and the average ignition probability of the group. Plot these data points on the graph with the original data and the logistic fit.

12.2.6 To calculate the confidence intervals for any level of ignition probability, the logistic regression must provide the variances, V_a and V_b, of the two parameters in the fit and their covariance, V_{ab}. The variances are the squares of the standard deviations mentioned in 12.2.2. In the limit of a large data set, the asymptotic standard error (ASE) of a logit Y at a given energy level E is

$$ASE = (V_a + 2V_{ab}E + V_bE^2)^{1/2} \qquad (3)$$

At the 95 % confidence level, the confidence interval of the logit is bounded by

$$Y_{lower} = Y - 1.96\,ASE \qquad (4)$$

and

$$Y_{upper} = Y + 1.96\,ASE. \qquad (5)$$

The corresponding probabilities, obtained by inverting Eq 1, are

$$P_{lower} = \exp(Y_{lower})/[1 + \exp(Y_{lower})] \qquad (6)$$

and

$$P_{upper} = \exp(Y_{upper})/[1 + \exp(Y_{upper})]. \qquad (7)$$

These two probabilities define the confidence interval for the probability of ignition at the given energy level E. A plot of the values of P_{lower} and P_{upper} for all energies defines the lower and upper 95 % confidence curves for the logistic regression fit. The confidence curves may then be used to provide the confidence interval of energy at a given level of probability. The confidence intervals may also be calculated by solving Eq 4 and 5 for the energies that yield the desired probability.

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 11.4.

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 including; (*1*) test ID number, (*2*) test specimen type, (*3*) order of layers, (*4*) distance from the arc center line to the body of the mannequin, (*5*) objective results in accordance with 12.2.2, specifically, the number of trials and ignitions, the parameters of the fit of the logistic regression and their standard deviations, the energy levels for 10 and 50 % ignition probability, and a plot of the data with the fit.

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 specimens, plots, test data, and unused specimens to the person requesting the test, 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 *Single User Determination*—At the only available testing facility for the dual mannequin arc test method, a series of fabrics in a single layer configuration was tested. These test results were used as the basis of a temporary precision statement, in which only within-laboratory precision is addressed.

14.1.1 Nine fabrics were tested as single layers, using a current of 8 kA, with stainless steel electrodes, an electrode gap of 12 in., and a distance from the electrodes of 12 in. Each of these nine data sets required at least 25 test shots, in which cycles were varied to produce different exposure energy levels, so that the fabrics either ignited or failed to ignite. Although the up-down method described by the test method was not in use at the time of these tests, the cycles were varied to provide a range of energies around the 50 % ignition probability. The data sets were analyzed by logistic regression, as directed by the test method. The fitted parameters, their variances and their covariance are listed in Table 2.

14.2 *Precision*:

14.2.1 Precision parameters for the energy levels corresponding to the 10 and 50 % ignition probability, based on a single laboratory (user) determination, are given in Table 2.

TABLE 2 Two Mannequin Arc Test – Within-laboratory Precision Parameters– 95 % Confidence Level

Fabric	Ignition s/Tests	Fitted Parameters					10 % Probability of Ignition				50 % Probability of Ignition			
		a	b	V_a	V_b	V_{ab}	Energy (cal/cm²)	–CI[A]	+CI[A]	CD[A]	Energy (cal/cm²)	–CI	+CI	CD
1	24/52	–24.98	4.16	52.84	1.45	–8.73	5.48	–0.08	0.28	0.65	6.01	–0.30	0.29	0.38
2	27/56	–9.42	1.01	6.15	0.07	–0.65	7.14	–2.42	0.92	2.06	9.31	–0.78	0.85	1.07
3	23/50	–16.54	2.58	21.06	0.52	–3.28	5.56	–1.09	0.42	0.93	6.41	–0.42	0.48	0.58
4	22/50	–16.25	2.07	23.66	0.40	–3.08	6.80	–1.42	0.49	1.12	7.86	–0.47	0.75	0.76
5	21/50	–13.69	0.82	14.10	0.05	–0.85	13.98	–3.10	1.13	2.57	16.66	–0.97	1.25	1.44
6	21/50	–40.84	5.19	241.53	3.93	–30.78	7.44	–1.24	0.25	0.69	7.87	–0.29	0.37	0.37
7	20/50	–14.11	0.80	16.65	0.06	–0.95	14.91	–3.52	1.15	2.75	17.66	–0.95	1.30	1.43
8	21/50	–32.62	1.71	95.66	0.27	–5.04	17.74	–1.90	0.63	1.48	19.02	–0.61	0.71	0.84
9	20/50	–39.92	2.08	152.42	0.42	–8.00	18.14	–1.54	0.50	1.18	19.20	–0.48	0.69	0.73

[A]CI = negative confidence interval. +CI = positive confidence interval. CD = critical difference. Confidence interval calculated as the difference in energy from the fitted curve for a logit of $Y \pm 1.96ASE$ at the specified probability. Critical difference calculated as the range of energy for a logit of $Y \pm 1.4ASE$ at the specified probability. Testing was conducted at the only practicing laboratory, for a test method user.

14.2.2 The results from each of the nine test sets (at least 50 points in each) are given separately.

14.2.3 Precision, stated as a 95 % confidence interval, is given for each test set for the energy levels corresponding to the 10 and 50 % ignition probabilities.

14.2.4 Precision, stated as a critical difference, is given for each test set for the energy levels corresponding to the 10 and 50 % ignition probabilities.

14.3 *Interpretation*:

14.3.1 *Confidence Interval*—The energy values of the 10 and 50 % ignition probabilities derived within a laboratory from use of this test method may be expected to lie within the stated interval in 95 of 100 similar tests of the same material. In the course of running an individual test set, a test result that lies outside the estimated confidence interval indicates a causative factor other than chance, on a certainty of 95 %.

14.3.2 *Critical Difference*—Within a laboratory, differences between test results of the same material in similar tests should not exceed the critical difference in 95 of 100 comparisons. In the course of running individual test sets of the same material, a difference between two such test results that exceeds the estimated critical difference indicates a causative factor other than chance, on a certainty of 95 %.

14.3.3 This is an estimate of within-laboratory precision obtained by one test method user in one testing facility. It is included as guidance. Users of the test method are urged to exercise appropriate statistical caution in comparisons of test results derived from its application. A more comprehensive precision determination must be completed within five years, including an estimate of between-laboratory precision.

14.4 *Bias*:

14.4.1 The probability of ignition of clothing by electric arc exposure 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.

APPENDIXES

(Nonmandatory Information)

X1. MANNEQUINS WITH MONITORING SENSORS

X1.1 Apparatus

X1.1.1 The apparatus as described in 6.1 shall be used.

X1.1.2 The mannequin*s*, if instrumented, shall use the sensors described in Test Method F 1957/F 1957M mounted as shown in Fig. X1.1. If the sensors are utilized, record the data. The data may be considered in the development of another standard. At that time, a method of analysis of such data will be included in that standard.

X1.2 Apparatus Care and Maintenance

X1.2.1 Apparatus care and maintenance as described in Section 10 shall apply.

X1.3 Interpretation of Results

X1.3.1 If instumented mannequins are used, record the ΔTC curve and the maximum temperature rise ΔTC_{max} for each of the sensors. At this time, the test method does not provide an interpretation of the data.

X1.4 Sensored Mannequin Data Analysis

X1.4.1 For each mannequin arc exposure, compare the temperature rise curve for each mannequin sensor to the Stoll curve. Then, for each mannequin sensor report the following items: sensor location, the $\Delta T_{max} C$, the time in seconds at which the $\Delta T_{max} C$ occurred, and whether or not the ΔTC temperature rise curve exceeded the Stoll curve.

X1.4.2 The test results from an instrumented mannequin are not fully understood with regard to the measurement of heat transfer. Use of this method for such tests serves to report test conditions and test results only.
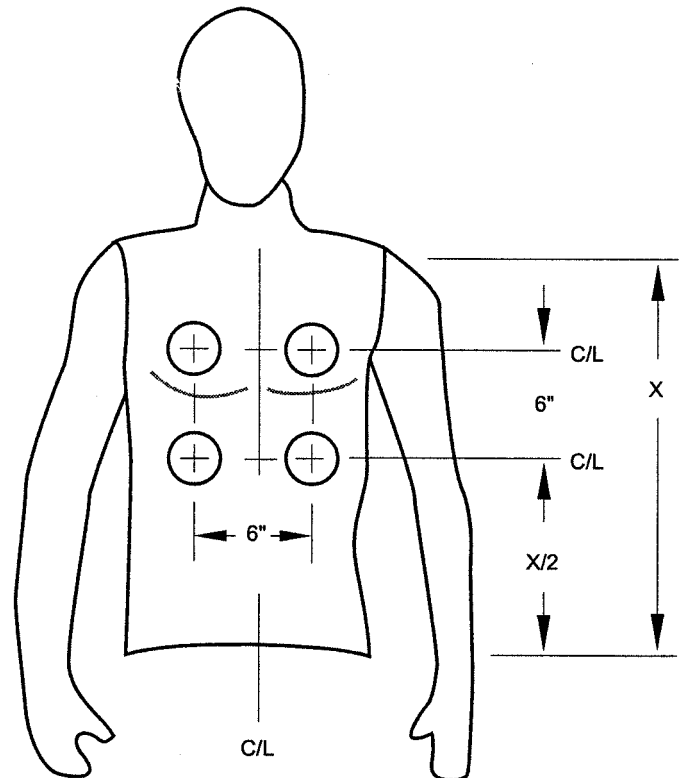

FIG. X1.1 Four Sensor Face View

X2. LAYERED TEST SPECIMENS OR GARMENTS

X2.1 Either an instrumented or non-instrumented mannequin may be used to evaluate the effect of layered clothing ensembles. Each specimen shall be described fully and the order of the layers noted.

X2.2 The effect of multiple layers on ignitability is not fully understood. Use of this test method for such tests serves to report test conditions and test results only.