Designation: ~~F1930 – 18~~ F1930 – 23

Standard Test Method for Evaluation of Flame-Resistant Clothing for Protection Against Fire Simulations Using an Instrumented Manikin[1]

This standard is issued under the fixed designation F1930; 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 provide predicted human skin burn injury for single-layer garments or protective clothing ensembles mounted on a stationary upright instrumented manikin which are then exposed in a laboratory to a simulated fire environment having controlled heat flux, flame distribution, and duration. The average exposure heat flux is 84 kW/m^2 (2 $cal/s{\cdot}cm^2$), with durations up to 20 s.

1.2 The visual and physical changes to the single-layer garment or protective clothing ensemble are recorded to aid in understanding the overall performance of the garment or protective clothing ensemble and how the predicted human skin burn injury results can be interpreted.

1.3 The skin burn injury prediction is based on a limited number of experiments where the forearms of human subjects were exposed to elevated thermal conditions. This forearm information for skin burn injury is applied uniformly to the entire body of the manikin, except the hands and feet. The hands and feet are not included in the skin burn injury prediction.

1.4 The measurements obtained and observations noted can only apply to the particular garment(s) or ensemble(s) tested using the specified heat flux, flame distribution, and duration.

1.5 This standard is used to measure and describe the response of materials, products, or assemblies to heat and flame under controlled conditions, but does not by itself incorporate all factors required for fire hazard or fire risk assessment of the materials, products, or assemblies under actual fire conditions.

1.6 This method is not a fire test response test method.

1.7 The values stated in SI units are to be regarded as standard. The values given in parentheses are mathematical conversions to inch-pound units or other units commonly used for thermal testing. If appropriate, round the non-SI units for convenience.

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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.9 Fire testing is inherently hazardous. Adequate safeguards for personnel and property shall be employed in conducting these tests.

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[1] This test method is under the jurisdiction of ASTM Committee F23 on Personal Protective Clothing and Equipment and is the direct responsibility of Subcommittee F23.80 on Flame and Thermal.

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1.10 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]
D123 Terminology Relating to Textiles
D1835 Specification for Liquefied Petroleum (LP) Gases
D3776/D3776M Test Methods for Mass Per Unit Area (Weight) of Fabric
D5219 Terminology Relating to Body Dimensions for Apparel Sizing
E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods
E457 Test Method for Measuring Heat-Transfer Rate Using a Thermal Capacitance (Slug) Calorimeter
E511 Test Method for Measuring Heat Flux Using a Copper-Constantan Circular Foil, Heat-Flux Transducer
E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method
E2683 Test Method for Measuring Heat Flux Using Flush-Mounted Insert Temperature-Gradient Gages
F1494 Terminology Relating to Protective Clothing

2.2 *AATCC Standards:*[3]
Test Method 135 Dimensional Changes of Fabrics after Home Laundering
Test Method 158 Dimensional Changes on Dry-Cleaning in Perchloroethylene: Machine Method

2.3 *Canadian Standards:*[4]
CAN/CGSB-4.2 No. 58-M90 Textile Test Methods Colorfastness and Dimensional Change in Domestic Laundering of Textiles
CAN/CGSB-3.14 M88 Liquefied Petroleum Gas (Propane)

2.4 *NFPA Standards:*[5]
NFPA 54 National Fuel Gas Code, 2009 Edition
NFPA 58 Liquefied Petroleum Gas Code 2008 Edition
NFPA 85 Boiler and Combustion Systems Hazards Code, 2007 Edition
NFPA 86 Standard for Ovens and Furnaces, 1999 Edition

3. Terminology

3.1 For definitions of terms used in this test method, use the following documents. For terms related to textiles, refer to Terminology D123; for terms related to protective clothing, refer to Terminology F1494; and for terms related to body dimensions, refer to Terminology D5219.

3.2 *Definitions:*

3.2.1 *burn injury, n*—thermal damage which occurs to human skin at various depths and is a function of local temperature and time.

3.2.1.1 *Discussion*—
Burn injury in human tissue occurs when the tissue is heated above a critical temperature (44 °C (317.15 K or 111 °F)). Thermal burn damage to human tissue depends on the magnitude of the temperature rise above the critical value and the duration that the temperature is above the critical value. Thus, damage can occur during both the heating and cooling phases of an exposure. The degree of burn injury (second or third degree) depends on the maximum depth within the skin layers to which tissue damage occurs. The first-degree burn injury is considered minor relative to second-degree and third-degree burn injuries. It is not included in the evaluation of test specimens in this test method (see Appendix X1).

3.2.2 *fire exposure, n*—in the fire testing of clothing, the fire exposure is a propane-air diffusion flame with a controlled heat flux and spatial distribution, engulfing the manikin for a controlled duration.

3.2.2.1 *Discussion*—
The flames are generated by propane jet diffusion burners. Each burner produces a reddish-orange flame with accompanying black smoke (soot).

[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 American Association of Textile Chemists and Colorists (AATCC), P.O. Box 12215, Research Triangle Park, NC 27709, http://www.aatcc.org.

[4] Available from Standards Council of Canada, Suite 1200, 45 O'Conor St., Ottawa, Ontario, K1P 6N7.

[5] Available from National Fire Protection Association (NFPA), 1 Batterymarch Park, Quincy, MA 02169-7471, http://www.nfpa.org.

3.2.3 *flame distribution, n*—in the fire testing of clothing, a spatial distribution of incident flames from burners to provide a controlled heat flux over the surface area of the manikin.

3.2.4 *heat flux, n*—the heat flow rate through a surface of unit area perpendicular to the direction of heat flow (kW/m^2) ($cal/s \cdot cm^2$).

3.2.4.1 *Discussion*—

Two different heat fluxes are referred to in this test method: incident and absorbed. The incident heat flux refers to the energy striking the nude manikin, or the exterior of the test specimen when mounted on the manikin, during flame engulfment. The absorbed heat flux refers to only the portion of the incident heat flux which is absorbed by each thermal energy sensor based on its absorption characteristics. The incident heat flux is used in setting the required exposure conditions, while the absorbed heat flux is used in calculating the predicted skin burn injury.

3.2.5 *instrumented manikin, n*—in the fire testing of clothing, a structure designed and constructed to represent an adult-size human and which is fitted with thermal energy (heat flux) sensors at its surface.

3.2.5.1 *Discussion*—

The manikin is fabricated to specified dimensions from a high-temperature-resistant material (see 6.1). The instrumented manikin used in fire testing of clothing is fitted with at least 100 thermal energy sensors, distributed over the manikin surface. The feet and hands are not normally fitted with sensors. If the feet and hands are equipped with sensors, it is up to the user to define a procedure to interpret the results.

3.2.6 *predicted second-degree burn injury, n*—a calculated second-degree burn injury to skin based on measurements made with a thermal energy sensor.

3.2.6.1 *Discussion*—

For the purposes of this standard, predicted second-degree burn injury is defined by the burn injury model parameters (see Section 12 and Appendix X1). Some laboratories have unequally spaced sensors and assign an area to each sensor over which the same burn injury prediction is assumed to occur; others, with equally spaced sensors, have equal areas for each sensor.

3.2.7 *predicted third-degree burn injury, n*—a calculated third-degree burn injury to skin based on measurements made with a thermal energy sensor.

3.2.7.1 *Discussion*—

For the purposes of this standard, predicted third-degree burn injury is defined by the burn injury model parameters (see Section 12 and Appendix X1). Some laboratories have unequally spaced sensors and assign an area to each sensor over which the same burn injury prediction is assumed to occur; others, with equally spaced sensors, have equal areas for each sensor.

3.2.8 *predicted total burn injury, n*—in the fire testing of clothing, the manikin surface area represented by all thermal energy sensors registering a predicted second-degree or predicted third-degree burn injury, expressed as a percentage (see 13.5).

3.2.9 *second-degree burn injury, n*—complete necrosis (living cell death) of the epidermis skin layer (see Appendix X1).

3.2.10 *thermal energy sensor, n*—a device which produces an output suitable for calculating incident and absorbed heat fluxes.

3.2.10.1 *Discussion*—

Types of sensors which have been used successfully include slug calorimeters, surface and buried temperature measurements, and circular foil heat flux gauges. Some types of sensors approximate the thermal inertia of human skin and some do not. The known sensors in current use have relatively small detection areas. An assumption is made for the purposes of this method that thermal energy measured in these small areas can be extrapolated to larger surrounding surface areas so that the overall manikin surface can be approximated by a minimum number of sensors. The resulting sensor-predicted burn injury applies to the extrapolated coverage area. Some laboratories assign different coverage areas to each sensor over which the same burn injury prediction is assumed to apply; others, with equally spaced sensors, have equal areas for each sensor (see 6.2.2.1).

3.2.11 *thermal protection, n*—the property that characterizes the overall performance of a garment or protective clothing ensemble relative to how it retards thermal energy that is sufficient to cause a predicted second-degree or predicted third-degree burn injury.

3.2.11.1 *Discussion*—

Thermal protection of a garment or ensemble and the consequential predicted burn injury (second-degree and third-degree), is quantified from the response of the thermal energy sensors and use of a skin burn injury prediction model. In addition to the calculated results, the physical response and degradation of the garment or protective clothing ensemble is an observable phenomenon useful in understanding garment or protective clothing ensemble thermal protection.

3.2.12 *third-degree burn injury, n*—complete necrosis (living cell death) of the epidermis and dermis skin layers (see Appendix X1).

4. Summary of Test Method

4.1 This test method covers quantitative measurements and subjective observations that characterize the performance of single-layer garments or protective clothing ensembles mounted on a stationary upright instrumented manikin. The conditioned test specimen is placed on the instrumented manikin at ambient atmospheric conditions and exposed to a propane-air diffusion flame with controlled heat flux, flame distribution, and duration. The average incident heat flux is 84 kW/m^2 (2 $cal/s \cdot cm^2$), with durations up to 20 s.

4.2 The test procedure, data acquisition, calculation of results, and preparation of parts of the test report are performed with computer hardware and software programs. The complexity of the test method requires a high degree of technical expertise in the test setup and operation of the instrumented manikin and the associated data collection and analysis software.

4.3 Thermal energy transferred through and from the test specimen during and after the exposure is measured by thermal energy sensors located at the surface of the manikin. A computer-based data acquisition system is used to store the time varying output from the sensors over a preset time interval.

4.4 Computer software uses the stored data to calculate the incident heat flux and the absorbed heat flux and their variation with time for each sensor. The calculated absorbed heat flux and its variation with time is used to calculate the temperature within human skin and subcutaneous layers (adipose) as a function of time. The temperature history within the skin and subcutaneous layers (adipose) is used to predict the onset and severity of human skin burn injury. The computer software calculates the predicted second-degree and predicted third-degree burn injury and the total predicted burn injury resulting from the exposure.

4.5 The overall percentage of predicted second-degree, predicted third-degree, and predicted total burn injury is calculated by dividing the total number of sensors indicating each of these conditions by the total number of sensors on the manikin. Alternately, the overall percentages are calculated using sensor area-weighted techniques for facilities with nonuniform sensor coverage. A reporting is also made of the above conditions where the areas that are not covered by the test specimen are excluded (see 13.5.1 and 13.5.2). This test method does not include the ~12 % of body surface area represented by the unsensored manikin feet and hands. No corrections are applied for their exclusion.

4.6 The visual and physical changes to the test specimen are recorded to aid in understanding overall performance and how the resulting burn injury results can be interpreted.

4.7 Identification of the test specimen, test conditions, comments and remarks about the test purpose, and response of the test specimen to the exposure are recorded and are included as part of the report.

4.8 The performance of the test specimen is indicated by the calculated burn injury area, expressed as a percentage, and subjective observations of material response to the test exposure.

4.9 Appendix X1 contains a general description of human burn injury, its calculation, and historical notes.

5. Significance and Use

5.1 Use this test method to measure the thermal protection provided by different materials, garments, clothing ensembles, and systems when exposed to a specified fire (see 3.2.2, 3.2.3, 4.1, and 10.4).

5.1.1 This test method does not simulate high radiant exposures, for example, those found in electric arc flash exposures, some types of fire exposures where liquid or solid fuels are involved, nor exposure to nuclear explosions.

5.2 This test method provides a measurement of garment and clothing ensemble performance on a stationary upright manikin of specified dimensions. This test method is used to provide predicted skin burn injury for a specific garment or protective clothing ensemble when exposed to a laboratory simulation of a fire. It does not establish a pass/fail for material performance.

5.2.1 This test method is not intended to be a quality assurance test. The results do not constitute a material's performance specification.

5.2.2 The effects of body position and movement are not addressed in this test method.

5.3 The measurement of the thermal protection provided by clothing is complex and dependent on the apparatus and techniques used. It is not practical in a test method of this scope to establish details sufficient to cover all contingencies. Departures from the instructions in this test method have the potential to lead to significantly different test results. Technical knowledge concerning the theory of heat transfer and testing practices is needed to evaluate if, and which departures from the instructions given in this test method are significant. Standardization of the test method reduces, but does not eliminate, the need for such technical knowledge. Report any departures along with the results.

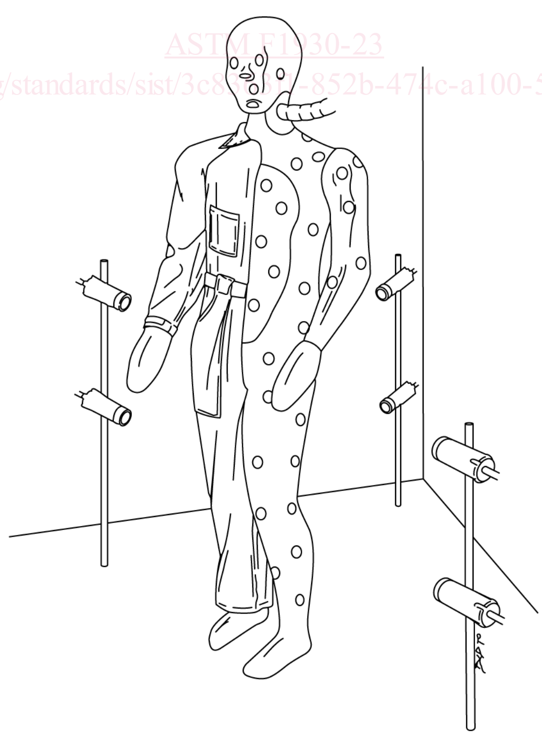
6. Apparatus

6.1 *Instrumented Manikin*—An upright manikin with specified dimensions that represents an adult human form shall be used (see Fig. 1).

6.1.1 *Size and Shape*—The manikin shall be constructed with a head, neck, chest/back, abdomen/buttocks, arms, hands, legs, and feet. The manikin's dimensions shall correspond to those required for standard sizes of garments because deviations in fit will affect the results. A male manikin consisting of the sizes given in Table 1 has been found satisfactory to evaluate garments or protective ensembles. The sizes for a female manikin have not yet been set.

6.1.2 The manikin shall be constructed of flame-resistant, thermally stable, nonmetallic materials which will not contribute fuel to the combustion process. A flame-resistant, thermally stable, glass fiber-reinforced vinyl ester resin at least 3 mm (1⁄8 in.) thick has proven effective.

6.2 *Apparatus for Burn Injury Assessment:*



NOTE 1—Only six of eight burners are shown.

FIG. 1 Schematic of Instrumented Manikin and Burner Placement

TABLE 1 Measurements for Male Manikin

Measurement Location	Centimetres	Inches
Height	180.3 ± 1.3	71 ± 0.5
Chest circumference at largest value (chest girth)	102.9 ± 1.9	40.5 ± 0.75
Center of base of rear neck to wrist measured across shoulder and along outside of arm (cervicale to wrist length)	79.4 ± 2.5	31.25 ± 1.0
Top of shoulder to wrist along arm (arm length).	61 ± 2.5	24 ± 1.0
Arm circumference at largest diameter between shoulder and elbow (upper-arm girth)	30.5 ± 0.6	12 ± 0.25
Waist circumference at narrowest position (waist girth)	85 ± 1.3	33.5 ± 0.5
Crotch to heel along the inside of the leg (crotch height minus ankle height)	86.4 ± 2.5	34 ± 1.0
Hips circumference at the largest dimension (hip girth)	101.6 ± 1.9	40 ± 0.75
Base of center of rear neck to waist (center back waist length)	42.5 ± 1.9	16.75 ± 0.75
Waist to base of heel (waist height)	115.6 ± 5.0	45.5 ± 2.0
Thigh circumference at largest dimension between crotch and knee (thigh girth)	58.4 ± 1.3	23 ± 0.5

6.2.1 *Thermal Energy Sensors*—Each sensor shall have the capacity to measure the incident heat flux over a range from 0.0 to 165 kW/m^2 (0.0 to 4.0 $cal/s{\cdot}cm^2$). This range permits the use of the sensors to set the exposure level by directly exposing the instrumented manikin to the controlled fire in a test without the test specimen and also have the capability to measure the heat transfer to the manikin when covered with a test specimen.

6.2.1.1 The sensors shall be constructed of a material with known thermal and physical characteristics that shall be used to indicate the time varying heat flux received by the sensors. Types of sensors which have been used successfully include slug calorimeters, surface and buried temperature measurements, and circular foil heat flux gauges. Some types of sensors approximate the thermal inertia of human skin and some do not. The minimum response time for the thermal energy sensor-data acquisition system shall be ≤0.2 s.

NOTE 1—Technical information on the different types of sensors can be found in Test Methods E457, E511, and E2683.

6.2.1.2 The sensor surface shall have an absorptivity of at least 0.9. Coating the sensor with a thin layer of ~~flat,~~flat black, high-temperature paint with an absorptivity of at least 0.9[6] has been found effective.

6.2.2 *Manikin Thermal Energy Sensor Layout*—A minimum of 100 thermal energy sensors shall be used. The percentage distribution is given in Table 2. They shall be distributed as uniformly as possible within each area on the manikin.

6.2.2.1 It is acceptable to have the sensor layout as one of uniform spacing or of nonuniform spacing. With uniform spacing, each sensor is located in the center of an area, the areas being of uniform size over the surface of the manikin. The nonuniform spacing results in sensors being located in the center of an area, but the areas are not uniform over the surface of the manikin. With the nonuniform spacing, laboratories shall report area-weighted values of predicted second-degree, predicted third-degree, and predicted total burn injury and the percentages as required in 13.5. Laboratories shall state the basis on which the calculations are made.

6.3 *Apparatus for Calibration of the Thermal Energy Sensors:*

TABLE 2 Percentage Area of Male Manikin Form Represented by Sensors

Body Area	Percent
Head	7
Trunk[A]	40
Arms	16
Thighs	22
Lower legs/Shanks	15
Hands/Feet	0
Total	100

[A] The trunk of the body includes the back, buttocks, chest, and pelvic areas.

[6] Krylon #1618 BBQ and Stove, Krylon #1316 Sandable Primer, and Krylon #1614 High Heat and Radiator Paint have been found to be effective. See ASTM Study "Evaluation of Black Paint and Calorimeters used for Electric Arc Testing," ASTM contract #F18-103601, Kinectrics Report:8046-003-RC-0001-R00, August 22, 2000.

6.3.1 *Energy Sources*—Pure radiant or a combination convective-radiant energy source has been found effective for these calibrations.

6.3.1.1 Understanding the interaction between the energy source and the thermal energy sensor is critical to obtaining accurate calibrations. If the temperature of either the source or the sensor changes during calibration, this will affect the energy transfer to the sensor and the resulting calibration.

6.3.2 *Calibration Heat Flux Sensor*—A traceable heat flux measuring device[7] used to confirm the output of the energy source used to calibrate the thermal energy sensors over a range of heat fluxes.

6.3.2.1 Understanding the interaction between the energy source and the calibration heat flux sensor is critical to obtaining accurate calibrations. Different calibration heat flux sensor designs respond differently to different modes of heat transfer. For example, a thin foil or Gardon heat flux gauge responds well to pure radiant heat transfer, but not convection heat transfer. Schmidt-Boelter gauges respond well to both modes of heat transfer.

6.3.3 The calibrations determined in 10.2 for each thermal energy sensor shall be recorded and the most recent calibration results used to carry out the burn injury analysis.

6.4 *Data Acquisition Hardware*—A system shall be provided with the capability of acquiring and storing the results of the measurement from each sensor at least five times per second for the data acquisition period.

6.4.1 The data acquisition rate of five readings per second from each sensor is the minimum necessary to obtain adequate data. Higher sampling rates are desirable during the flame exposure period. Laboratories sample up to ten samples per sensor during this period. The minimum rate of five samples per second per sensor is adequate after the flame exposure. The accuracy of the measurement system shall be less than 2 % of the reading or ±1.0 °C (±1.8 °F) for temperature measurements.

[7] National Institute of Standards and Technology (NIST) or similar standards body.

6.5 *Software Programs:*

6.5.1 *Logging of Recorded Data*—The software shall log the output from the thermal energy sensors in identifiable files for the preset time at or above the minimum specified data acquisition rate.

6.5.2 *Heat Flux Calculations*—The software shall convert the recorded thermal sensor outputs into a measured heat flux using a method appropriate for the thermal energy sensor design. This shall include accounting for the heat losses from the surface and sides of the sensor, as appropriate.

6.5.2.1 *Incident Heat Flux*—The incident heat flux at each sample point for each thermal energy sensor shall be calculated using the calibration characteristics determined in 10.2. These values shall be stored for use in calculating the average incident heat flux and its standard deviation for nude exposures as required in 10.4.

6.5.2.2 *Absorbed Heat Flux*—Using the absorption characteristics of the thermal energy sensors, calculate and store the absorbed heat flux for each sensor for each sample point.

6.5.3 *Burn Injury Calculations*—The computer software program used shall have the capability of using the calculated time-dependent absorbed heat flux files to calculate the temperatures within the skin and subcutaneous layers (adipose) as a function of depth and time, and calculating the time when a predicted second-degree or third-degree burn injury will occur for each sensor utilizing a skin burn injury model. The total predicted burn injury and the percentage predicted burn injury shall be calculated using only the sensors having a calculated second-degree and third-degree burn injury. The calculation requirements of this program are identified in Section 12.

6.5.3.1 The computer software program shall, as a minimum, calculate the predicted skin burn injury at the epidermis/dermis interface and the dermis/subcutaneous (adipose) interface (see Section 12 and Appendix X1).

6.5.4 *Burn Injury Assessment*—The area-weighted sum of the sensors that received sufficient energy to result in a predicted second-degree burn shall be the predicted second-degree burn assessment. The area-weighted sum of the sensors that received sufficient energy to result in a predicted third-degree burn shall be the predicted third-degree burn assessment. The area-weighted sum of all sensors registering a second-degree or third-degree burn injury shall be the total predicted burn injury resulting from the exposure to the fire condition.

6.5.4.1 The calculated results report the burn injury assessment as a percentage (%) based on the total number of sensors (entire manikin) and the total covered by the test specimen only (see 13.5). For manikin systems that do not have a uniformly spaced sensor layout, the laboratory shall area weight the results.

6.5.5 *Additional Computer Software Requirements*—In addition to monitoring and controlling the operation of the fire, data acquisition systems, and carrying out the incident heat flux, absorbed heat flux, and skin burn injury calculations, the computer software shall be used to prepare some of the materials for the report, sensors calibrations, etc. Appendix X2 is a list of recommended safety, control, data acquisition, calculation, report preparation, and supporting programs.

6.6 *Exposure Chamber*—A ventilated, fire-resistant enclosure with viewing windows and access door(s) shall be provided to contain the manikin and exposure apparatus.

6.6.1 *Exposure Chamber Size*—The chamber size shall be sufficient to provide a uniform flame engulfment of the manikin and shall have sufficient space to allow safe movement around the manikin for dressing without accidentally jarring and displacing the burners. The minimum interior dimensions of the chamber shall be 2.1 by 2.1 by 2.4 m (7.0 by 7.0 by 8.0 ft). There is no limitation on a maximum chamber size, provided the operators are safely isolated from the chamber during and after the exposure, when combustion products and toxic gases are likely to be present. All chambers and burner systems shall meet the requirements in 4.1 and 10.4 in repeated exposures.

6.6.2 *Burner and Manikin Alignment*—Apparatus and procedures for checking the alignment of the burners and manikin position prior to each test shall be available.

6.6.3 *Chamber Temperature*—The chamber temperature prior to a test shall be between 15 and 30 °C (58 and 85 °F).

6.6.4 *Chamber Air Flow*—The chamber shall be isolated from air movement other than the natural air flow required for the combustion process so that the pilot flames, if fitted, and the exposure flames are not affected before and during the test exposure. The isolation from air movement shall continue during the data acquisition period after the exposure flames are extinguished. A forced-air exhaust system for rapid removal of combustion products after the data acquisition period shall be provided.

6.6.4.1 The unaided air flow within the chamber shall be sufficient to permit the combustion process needed for the required heat flux during the exposure period and shall be controlled to provide a quiet atmosphere for the data acquisition period. Openings to the exterior of the test chamber shall be provided for the passive supply of adequate amounts of air for safe combustion of the fuel during the exposure. The forced-air exhaust system for rapid removal of combustion products after the data acquisition period shall conform to NFPA 86 (1999), Section 5–4.1.2. Due to their nature, the products of combustion from diffusion flames contain toxic materials such as unburned fuel, carbon monoxide, and soot.

6.6.5 *Chamber Safety Devices*—The exposure chamber shall be equipped with sufficient safety devices, detectors, and suppression systems to provide safe operation of the test apparatus. Examples of these safety devices, detectors, and suppression systems include propane gas detectors, motion detectors, door closure detectors, handheld fire extinguishers, and any other devices necessary to meet the requirements of local codes. A water deluge system and an interlocked "LEL/Exhaust" system have been found effective. LEL is the Lower Explosion Limit. For pure propane gas in air, the value is 2.1 % by volume **(1)**.[8]

6.6.5.1 Additional information on safety devices is available from NFPA 54 and NFPA 85 or equivalent local standards.

6.7 *Fuel and Delivery System*—The chamber shall be equipped with fuel supply, delivery, and burner systems to provide reproducible fire exposures.

6.7.1 *Fuel*—The propane fuel used in the system shall be from a liquefied petroleum (LP) gas supply with sufficient purity and constancy to provide a uniform exposure.

NOTE 2—Fuels meeting the HD-5 specifications (See Specification D1835, CAN/CGSB 3.14 M88, or equivalent) have been found satisfactory. Liquefied petroleum (LP) gas is commonly referred to as propane fuel or propane gas. "Propane gas" are the words used in this standard to identify the LP gas.

6.7.2 *Delivery System*—A system of piping, pressure regulators, valves, and pressure sensors, including a double block and bleed burner management scheme (see NFPA 58) or similar system consistent with local codes, shall be provided to safely deliver gaseous propane to the ignition system and exposure burners. This delivery system shall be sufficient to provide an average heat flux of at least 84 kW/m^2 (2.0 $cal/s{\cdot}cm^2$) for an exposure time of at least 8 s. Fuel delivery shall be controlled to provide known exposure duration within ±0.1 s of the set exposure time.

6.7.3 *Burner System*—The burner system shall consist of one ignition system for each exposure burner and sufficient burners to provide the required range of heat fluxes, with a flame distribution uniformity to meet the requirements in 10.4, 10.4.1, 10.4.2, and 10.4.3.

6.7.3.1 *Exposure Burners*—Large, induced combustion air, industrial-style propane burners are positioned around the manikin to produce a uniform laboratory simulation of a fire. These burners produce a large, fuel-rich, reddish-yellow flame. If necessary, enlarge the burner gas jet, or remove it, to yield a fuel-to-air mixture for a long luminous reddish-yellow flame that engulfs the manikin. A minimum of eight burners shall be used and positioned to yield the exposure level and uniformity as described in 10.4, 10.4.1, 10.4.2, and 10.4.3. A satisfactory exposure has been achieved with eight burners, one positioned at each quadrant of the manikin at the knee level, and one positioned at each quadrant at the upper thigh level (see Fig. 1). Variations in exposure chamber size and air flow detail might require use of additional burners to achieve the desired flame distribution. Some laboratories have found it necessary to use twelve burners with two each on six stands positioned at approximately 60° intervals around the manikin to achieve the desired flame distribution.

6.7.3.2 *Ignition System*—Each exposure burner shall be equipped with a remotely operated ignition system positioned near the exit of the burner, but not in the direct path of the flames so as to interfere with the exposure flame pattern. The ignition system shall be interlocked to the burner gas supply valves to prevent premature or erroneous opening of these valves. Any electrical magnetic field generated by the ignition system shall be small enough so as not to interfere with the quality of the data acquisition and recording process. Standing pilot flames have been found to perform satisfactorily.

[8] The boldface numbers in parentheses refer to a list of references at the end of this standard.

6.8 *Image Recording System*—A video system for recording a visual image of the manikin before, during, and after the flame exposure shall be provided. The front of the manikin shall be the primary record of the burn exposure, with a manikin rear record optional.

6.9 *Safety Checklist*—A checklist shall be included in the computer operating program to ensure that all safety features have been satisfied before the flame exposure can occur. This list shall include, but is not limited to, the following: confirm that the manikin has been properly dressed in the test specimen; confirm that no person is in the burn chamber; confirm that the chamber doors are closed and all safety requirements are met. The procedural safety checks shall be documented.

6.10 *Test Specimen Conditioning Area*—The area shall be maintained at 21 ± 2 °C (70 ± 5 °F) and 65 ± 5 % relative humidity. It shall be large enough to have good air circulation around the test specimens during conditioning.

NOTE 3—The permitted variation in the conditioning temperature and relative humidity is larger than other ASTM textile testing standards. This larger range was set to reflect present practice. Some manikin-fire laboratories are at isolated sites and do not have conditioning rooms that can meet the more stringent requirements.

7. Hazards

7.1 Procedural operating instructions shall be provided by the testing laboratory and strictly followed to ensure safe testing. These instructions shall include, but are not limited to: exhaust of the chamber prior to any test series; no personnel within the chamber when the ignition system is checked and activated; isolation of the chamber during the test to contain the combustion process and the resulting combustion products; ventilation of the chamber after the test exposure.

7.2 The exposure chamber shall be equipped with an approved fire suppression system.

7.3 Care shall be taken to prevent personnel contact with combustion products, smoke, and fumes resulting from the flame exposure. Exposure to gaseous products shall be prevented by adequate ventilation of the chamber. Appropriate personal protective equipment shall be worn when working in the exposure chamber, handling the exposed garments, and cleaning the manikin after the test exposure.

8. Types of Tests, Test Specimens, and Sampling

8.1 *Types of Tests*—This test method is useful for three types of evaluations: comparison of the materials of garment construction, garment design, and end-use garment specification. Each type of appraisal has different garment type and style requirements.

8.1.1 *Materials of Garment Construction Evaluation*—This evaluation requires garments of the standard garment design (see ~~8.2.1~~8.2.2) and size (Table 3), constructed with the different materials.

8.1.2 *Garment Design Evaluation*—This evaluation requires garments constructed of the same material, of the standard size (Table 3), and with the different design characteristics of interest.

8.1.3 *End-Use Garment Specification*—This specification requires garments of the standard size (Table 3), constructed with the material and design representing the anticipated end use.

8.2 *Test Specimen*—A specimen is a garment (for example, a single-layer coverall) or protective clothing ensemble.

8.2.1 *Fit of Test Specimen*—Garment or ensemble fit on the manikin (the amount of ease) can be an important issue, especially for lightweight specimens. Increasing the ease adds to the thickness of the insulating layer of air between the garment and the manikin surface. Experiments suggest that for a single-layer coverall, increasing the coverall by one size above the nominal value for the manikin reduces the skin burn injury prediction by about 5 %. When using a manikin with the dimensions given in Table 1, size 42R coveralls (Table 3) have been found satisfactory.

8.2.2 *Standard Garment Design*—The standard garment shall be a long-sleeved ~~coverall, with a full-length metal~~ coverall with set-in sleeves and full-length slide fastener in the ~~front and without pockets or pant cuffs. A full-length fabric cover on the interior of the slide fastener shall be provided to cover the slide fastener, and slide fastener tape to prevent direct contact of the slide fastener with any manikin sensors. The garment seams shall be sewn with nonmelting, noncombustible thread. The test specimens~~

TABLE 3 Standard Coverall Size Requirements

~~Measurement Location~~	~~Centimetres~~	~~Inches~~
~~Chest~~	~~125 ± 4.0~~	~~49.0 ± 1.5~~
~~Waist~~	~~105 ± 2.5~~	~~41.5 ± 1.0~~
~~Sleeve~~	~~86 ± 2.5~~	~~34.0 ± 1.0~~
~~Trunk~~	~~190 ± 5.0~~	~~74.75 ± 2.0~~
~~Inseam~~	~~72 ± 2.5~~	~~28.5 ± 1.0~~
~~Seat~~	~~130 ± 4.0~~	~~51.0 ± 1.5~~
~~Thigh~~	~~79 ± 2.5~~	~~31.0 ± 1.0~~

TABLE 3 Standard Coverall Size Requirements

<u>NOTE 1—All measurements shall be taken with the coverall fully zippered, laid flat, smooth, and before preconditioning. See Fig. 2 for graphical details.</u>

Measurement Location	Centimeters (Inches)	Description
Chest (A)	57.8 ± 1.9 (22.75 ± 0.75)	Across the front at 2.54 cm (1.0 in.) below the armholes from folded edge to folded edge
Waist (B)	51.4 ± 1.9 (20.25 ± 0.75)	At the waist of the coverall where the top and bottom sections are joined from folded edge to folded edge
Hip (C)	61.6 ± 1.9 (24.25 ± 0.75)	20.3 cm (8.0 in.) below the waist of the coverall from folded edge to folded edge
Thigh (D)	36.8 ± 1.3 (14.5 ± 0.5)	2.54 cm (1.0 in.) below crotch seam, from folded edge to folded edge
Sleeve Length (E)	87.6 ± 1.9 (34.5 ± 0.75)	From the center back neck to cuff edge
Trouser Leg; Inseam (F)	74.9 ± 1.9 (29.5 ± 0.75)	From the crotch seam along leg inseam to bottom of leg
Torso Back Length (G)	96.5 ± 2.5 (38 ± 1.00)	From the crotch seam to high point shoulder
Torso Front Length (H)	92.4 ± 3.2 (36.25 ± 1.25)	From the crotch seam to high point shoulder
Sleeve Cuff Width (I)	14.0 ± 0.6 (5.5 ± 0.25)	From folded edge to folded edge along the bottom of the sleeve
Leg Bottom Width (J)	21.6 ± 0.6 (8.5 ± 0.25)	From folded edge to folded edge along the bottom of the leg
Front Rise Length (K)	38.7 ± 0.6 (15.25 ± 0.25)	From the front waist seam to the center of the crotch

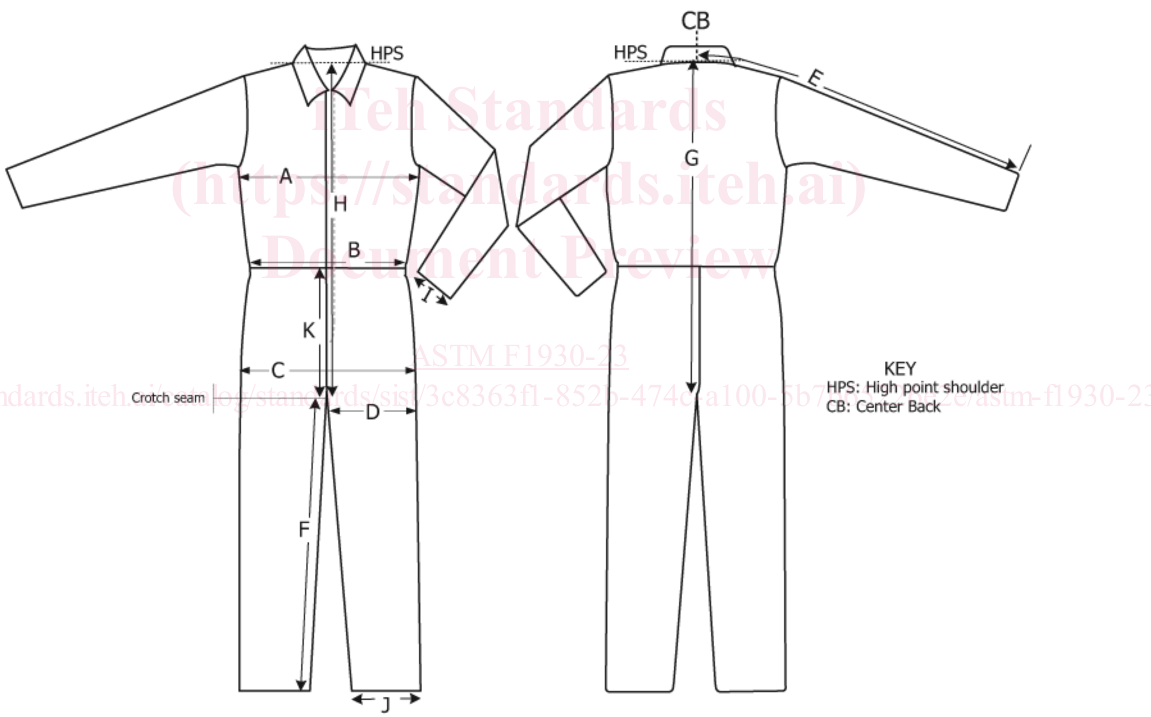


FIG. 2 Standard Coverall Measurement Locations

~~shall meet the size requirements of~~ <u>front.</u> ~~Table 3.~~ Use the digitized pattern available from ASTM headquarters to create a more reproducible standard garment consistent with the dimensions in Table 3. <u>The coverall design shall meet the following requirements:</u>

<u>*(1)* The coverall shall have a two-pointed collar (Note 4).</u>

(2) The slide fastener shall extend vertically from the collar line to a point above the coverall crotch seam (Note 5). <u>A full-length fabric placket on the interior of the slide fastener permanently attached to the garment body shall be provided to cover the back of the slide fastener, and slide fastener tape to prevent direct contact of the slide fastener with any manikin sensors. The slide fastener cover shall be no more than 2.54 ± 0.6 cm (1.0 ± 0.25 in.) wide and shall be no more than two layers of self-fabric with no interfacing. The full length of the metal fastener shall be exposed on the exterior of the garment.</u>

(3) The coverall shall not have pockets or sleeve/pant cuffs.

<u>*(4)* The coverall shall be a single-layer garment with no patches.</u>

(5) The coverall shall have a waist seam but not a waistband. There shall be no closures in the waist area such as elastic or strap-type closures to tighten up the waist area.

(6) There shall be no other closures on the coverall except for the front zipper closure, that would include buttons, snaps, elastic, or strap-type closures.

(7) The garment seams shall be sewn with non-melting, noncombustible thread.

(8) The test specimens shall meet the size requirements of Table 3.

(9) The coverall shall not have a biswing in the back.

(10) The coverall shall not have a crotch gusset.

NOTE 4—It is recommended that the two-pointed collar length be 6.35 ± 1.3 cm (2.5 ± 0.5 in.).

NOTE 5—The slide fastener extending vertically from the collar line to a point 12 cm (5.0 in.) above the coverall crotch seam has shown to be satisfactory.

8.2.2.1 The standard garment shall have a 150 by ~~150-mm~~ 150 mm (6 by ~~6-in.)~~ 6 in.) swatch attached inside to a seam. This swatch shall be used for measuring the area density using Option C of Test Methods D3776/D3776M. The swatch shall be cut from the same lot of material used to make the outer layer of the test specimen.

8.2.3 Garment styles that deviate from the type or dimensions outlined in Table 3 can be used, but shall be described in detail in the test report (see 8.2.1).

8.3 *Laboratory Sample*—Garments or ensembles meeting the purpose of the evaluation requirements of 8.1.1, 8.1.2, or 8.1.3 shall be the laboratory sampling unit.

8.3.1 Test a minimum of three specimens from the laboratory sampling unit. A greater number of specimens can be used to improve precision of test results.

9. Preparation of Test Specimen and Cutting Samples for Area Density Measurements

9.1 *Laundering*—Launder each garment one wash and dry cycle prior to conditioning, unless designated not to be laundered.

9.1.1 For garments that are designated on the flame-resistant garment label to be washed, use the AATCC or CAN/CGSB procedure identified in 9.1.4.

9.1.2 For garments that are designated on the flame-resistant garment label to be dry cleaned, use the AATCC procedure identified in 9.1.5.

9.1.3 For garments that are designated on the flame-resistant garment label to be either washed or dry cleaned, specimens shall be tested after one cycle of washing and drying as specified in 9.1.4, or after one cycle of dry cleaning as specified in 9.1.5.

9.1.4 Use laundry conditions of AATCC Test Method 135, (1, V, A, iii) or CAN/CGSB-4.2 No. 58-M90.

9.1.5 Use dry cleaning procedures of Sections 9.2 and 9.3 of AATCC Test Method 158.

9.2 *Conditioning*—Condition each specimen for at least 24 h in an environment controlled to 21 ± 2 °C (70 ± 5 °F) and 65 ± 5 % relative humidity (see 6.10 and Note 3). Each specimen shall be tested within 30 min of removal from the conditioning area. If the specimen cannot be tested within 30 min, seal it in a manner that restricts moisture loss or gain until immediately prior to testing. Test such garments within 20 min after removal from the bag. Garments shall not remain isolated for longer than 4 h prior to testing.

9.3 Standard garments come with an attached swatch from which samples shall be taken for making area density measurements (8.2.2.1). With nonstandard garments, cut samples for area density measurements from behind pockets or inside collars before exposure on the manikin. **Warning—**Cut samples only from locations that are not directly over a sensor.

10. Calibration and Preparation of Apparatus

10.1 *Calibration Principles*—The thermal energy sensors and the burn injury calculation routine are calibrated using energy sources of known characteristics. Pure radiant and combined convection and radiation sources have been found effective. A