Designation: F 1930 – 9900

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

This standard is issued under the fixed designation F 1930; 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 covers quantitative measurements and subjective observations that characterize the performance of single layer garments or protective clothing ensembles in a simulated flash fire environment having controlled heat flux, flame distribution, and duration. This test method is extremely complex and requires a high degree of technical expertise in both the test setup and operation.

1.1.1 Heat transmitted to each sensor location on the surface of an instrumented manikin is converted to show the corresponding predicted degree of burn injury to human tissue.

1.1.2 The sum of these values can then be converted to a percentage to show the total area of predicted burn injury.

1.1.2.1 Use of the predicted burn injury to evaluate the heat transferred to the manikin does not constitute a material's performance specification.

1.1.3 The visual and physical changes to the single layer garment or protective clothing ensemble are recorded to aid in understanding how the burn injury results can be interpreted.

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

1.3 This standard should be used to measure and describe the response of materials, products, or assemblies to heat and flame under controlled conditions and should 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-hazard assessment or a fire-risk assessment which takes into account all of the factors which are pertinent to an assessment of the fire hazard or fire risk of a particular end use.

1.4 This test method is a fire-test-response test method.

1.5 The values stated in customary units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units.

1.6 *This standard does not purport to address 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.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 123 Terminology Relating to Textiles[2]

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[1] This test method is under the jurisdiction of ASTM Committee F-23 on Protective Clothing and is the direct responsibility of Subcommittee F23.80 on Instrumented Manikin Test.

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D 1835 Specification for Liquefied Petroleum (LP) Gases[3]
F 1494 Terminology Relating to Protective Clothing[4]
2.2 *AATCC Standard:*
Test Method 135 Dimensional Changes in Automatic Home Laundering of Woven and Knit Fabrics[5]
2.3 *Canadian Standards:*
CAN/CGSB-4.2 No. 58-M90 Textile Test Methods Colourfastness and Dimensional Change in Domestic Laundering of Textiles[6]
CAN/CGSB-3.14 M88 Liquefied Petroleum Gas (Propane)[6]

3. Terminology

3.1 *Definitions:*

3.1.1 *burn injury*, *n*—burn damage that occurs at various levels of depth within human tissue.

3.1.1.1 *Discussion*—burn injury in human tissue occurs when the tissue is heated and kept at an elevated temperature for a critical period of time. The amount of burn injury, first, second, or third-degree, depends upon both the level of the elevated temperature and the duration of time.

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

3.1.3 *instrumented manikin*, *n*—a model representing an adult-size human and fitted with sensors on the surface for use in testing.

3.1.3.1 *Discussion*—The instrumented manikin used in flash fire testing of clothing is fitted with at least 100 heat sensors, excluding hands and feet.

3.1.4 *predicted total area of burn injury*, *n—in the flash fire testing of clothing*, the sum of areas represented by the sensors that calculate at least a second degree burn injury.

3.1.5 *second-degree burn injury*, *n*—irreversible burn damage at the epidermis/dermis interface in human tissue. (Synonym second-degree burn)

3.1.6 *second-degree burn injury area*, *n—in the flash fire testing of clothing*, the sum of the areas represented by sensors that calculate a burn injury at the epidermis/dermis interface in human tissue. (Synonym second-degree burn area)

3.1.7 *heat sensor*, *n*—a device capable of measuring incident heat to the manikin's surface under test conditions and creating data that can be processed by a computer program to assess burn injury.

3.1.8 *thermal protection*, *n*—the property that characterizes the overall performance of a garment or protective clothing ensemble relative to how it prevents the transfer of heat that is sufficient enough to cause burn injury.

3.1.8.1 *Discussion*—In flash fire testing of clothing, thermal protection of a garment or ensemble and the consequential predicted burn injury (second-degree or third-degree), can be quantified by the measured sensor response that indicates how well the garment or protective clothing ensemble blocks heat from the manikin surface. In addition to the measured sensor response, the physical response and degradation is an observable phenomenon that can be correlated to the sensor calculations and is useful in understanding garment or protective clothing ensemble thermal protection.

3.1.9 *third-degree burn injury*, *n*—the irreversible burn damage at the dermis/subcutaneous interface in human tissue (Synonym third-degree burn).

3.1.10 *third-degree burn injury area*, *n—in the flash fire testing of clothing*, the sum of the areas represented by sensors that calculate a burn injury at the dermis/subcutaneous interface in human tissue. (Synonym third-degree burn area)

3.1.11 For definitions of other protective clothing related terms used in this test method, refer to Terminology F 1494. For definitions for other textile related terms used in this test method, refer to Terminology D 123.

4. Summary of Test Method

4.1 The test method evaluates the protective performance of the materials of construction and design of the test specimen, which is either a garment or an ensemble. The test specimen is placed on an adult-size manikin at ambient atmospheric conditions and exposed to a laboratory flash fire simulation with controlled heat flux, duration, and flame distribution. The test procedure, data acquisition, results calculations, and preparation of the test report are performed with computer hardware and software programs. Heat, which is transferred through the test specimen during and after the exposure, is measured by sensors. These measurements are used to calculate the second-degree, third-degree, and total burn injury areas resulting from the flash fire exposure. 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. The performance of the test specimen is indicated by the calculated burn injury area and the way the specimen responds to the test exposure.

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[2] *Annual Book of ASTM Standards*, Vol 07.03.
[3] *Annual Book of ASTM Standards*, Vol 05.01.
[4] *Annual Book of ASTM Standards*, Vol 11.03.
[5] Available from American Association of Textile Chemists and Colorists, PO Box 12215, Research Triangle Park, NC 27709.
[6] Available from Standards Council of Canada, Suite 1200, 45 O'Connor St., Ottawa, Ontario, K1P 6N7.

5. Significance and Use

5.1 This test method can be used to measure and compare the thermal protection provided by different materials, garments, clothing ensembles, and systems.

5.2 This test method provides a measurement of garment and clothing ensemble performance on a stationary upright manikin.

5.2.1 This test method is not intended to be a quality assurance test.

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 may 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. Any departures should be reported with the results.

6. Apparatus

6.1 *Instrumented Manikin*—An upright manikin that is in the shape and size of an adult male human form shall be used. (see Fig. 1)

6.1.1 *Size and Shape*— The manikin shall be constructed with a head, chest/back, abdomen/buttocks, arms, hands, legs, and feet. The manikin's dimensions should 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.

6.1.2 The manikin should be constructed of flame resistant, thermally stable, nonmetallic materials.

6.2 *Apparatus for Burn Injury Assessment* :

6.2.1 *Manikin Construction*—At least 100 heat sensors shall be distributed as uniformly as possible in each area on the manikin as given in Table 2.

6.2.2 *Heat sensor construction*—Each heat sensor shall have the capacity to measure the incident heat flux over a range from 0.0 to 4.0 $cal/cm^2 \cdot s$ (167 kW/m^2). This range permits the use of the sensors to set the exposure level by directly exposing the manikin to the flames in a test without the garment and also having the capability to measure the heat transfer to the manikin with exposure of the test garment or protective clothing ensemble.

6.2.2.1 The sensors shall be constructed of a material with known thermal characteristics that can be used to indicate heat flux and temporal variation received by the sensors. The outer surface shall be covered with a thin layer of flat black high temperature paint. The minimum response time for the sensors shall be ≤ 0.1 s.

6.2.2.2 The calibration constants determined in 10.2.1.4 for each sensor shall be recorded, and the most recent calibration results used to carry out the burn injury analysis.

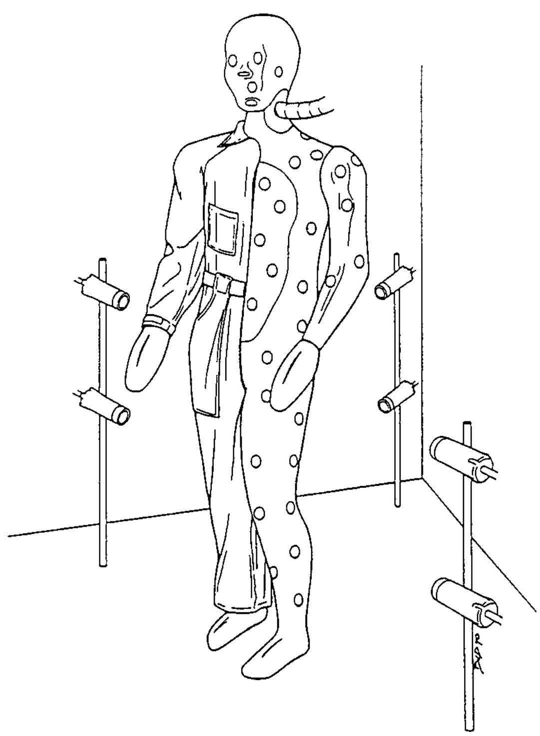

FIG. 1 Instrumented Manikin

TABLE 1 Measurements for Male Manikin

Measurement Location	Inches	Centimetres
Total height	71 ± 0.5	180.3 ± 1.3
Chest circumference at largest value	40.5 ± 0.75	102.9 ± 1.9
Center of base of rear neck to wrist measured across shoulder and along outside of arm.	31.25 ± 1.0	79.4± 2.5
Top of shoulder to wrist along arm	24 ± 1.0	61 ± 2.5
Arm circumference at largest diameter between shoulder and elbow	12 ± 0.25	30.5 ± .6
Waist circumference at narrowest position	33.5 ± 0.5	85 ± 1.3
Crotch to ankle bone along the inside of the leg	34 ± 1.0	86.4 ± 2.5
Hips circumference at the largest dimension	40 ± 0.75	101.6 ± 1.9
Base of center of rear neck to waist	16.75 ± 0.75	42.5 ± 1.9
Waist to base of heel	45.5 ± 2	115.6 ± 5.0
Thigh circumference at largest dimension between crotch and knee	23 ± 0.5	58.4 ± 1.3

TABLE 2 Sensor Distribution

Body Area	Percent
Head	7
Trunk	40
Arms	16
Thighs	22
Legs	15
Hands/Feet	0
	100

6.3 *Heat Flux Calibration Sensor* —A device[7], which is traceable to the National Institute of Standards and Technology (NIST), for measuring heat flux directly and accurately.

6.4 *Data Acquisition System*—A system shall be provided with the capability of acquiring and storing the results of the measurement from each sensor at least once per 0.5 s for the data acquisition period.

6.5 *Burn Assessment Program*—A computer software program that has the capability of receiving the output of the sensors, calculating the heat flux, and predicting the burn injury level at each sensor, and the total predicted burn injury area as a result of the thermal exposure shall be utilized (see Annex A1 and Annex A2).

6.5.1 *Incident Heat Calculation*—The incident heat shall be determined with exposure to the nude manikin by a computer software program. The value reported is the average of the area weighted averages for each of the sensors covered by the test garment for the exposure duration.

6.5.2 *Burn Injury Calculation*—The time predicted to cause second-degree and third-degree burn injury for each sensor shall be calculated.

6.5.3 *Burn Injury Assessment*—The sum of the areas represented by the sensors that received sufficient heat to result in a calculated second-degree burn shall be the second-degree percentage burn area assessment. The sum of the area represented by the sensors that received sufficient heat to result in a calculated third-degree burn shall be the third-degree percentage burn area assessment. The sum of these two areas shall be the total percentage burn injury assessment resulting from the exposure to the flash fire condition.

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 *Chamber Size*— The chamber size shall be sufficient to provide a uniform flame exposure over the surface of the test garment and shall have sufficient space to allow safe movement around the manikin for dressing without accidentally jarring and displacing the burners. A chamber with minimum interior dimensions of 7.0 by 7.0 by 8.0 ft (2.1 by 2.1 by 2.4 m) has been found satisfactory.

6.6.2 *Chamber Air Flow*— The unaided air flow within the chamber shall be sufficient to permit the combustion process needed for the required heat flux during the exposure time and shall be controlled to provide a quiet atmosphere for the data acquisition

[7] Combination total calorimeter/radiometer Model No. C-1803-A-15-072 from HyCal Engineering, 12105 Los Nietos Rd., Santa Fe Springs, CA 90670.

period, and the forced air exhaust system shall be sufficient for rapid removal of combustion gas products after the data acquisition period. Openings to the exterior of the test chamber may be required for the passive supply of adequate amounts of air for complete combustion of the fuel during the exposure.

6.6.2.1 *Static Conditions*—The chamber shall be isolated from air movement other than the natural air flow required for the combustion process so that the pilot flames and exposure flames are not affected before and during the test exposure and data acquisition periods.

6.6.2.2 *Chamber Ventilation*—The forced exhaust system shall have a minimum capacity equal to two times the volume of the chamber per minute to remove the gaseous products that result from the test exposure. In addition, the forced exhaust system may be run at a lower capacity to provide cooling air for the manikin and sensors after the chamber has been exhausted of combustion gases.

6.6.3 *Chamber Safety Devices*—The exposure chamber shall be equipped with sufficient safety devices and detectors to provide safe operation of the test apparatus. These safety devices and detectors may include propane gas detectors, motion detectors, door closure detectors, and any other devices deemed necessary.

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

6.7.1 *Fuel*—The propane used shall be liquid with sufficient purity and constancy to provide a uniform flame from the exposure burners. It is recommended that the fuel meet the HD-5 specifications (see Specification D 1835, CAN/CGSB-3.14 - M88, or equivalent).

6.7.2 *Delivery System*— A system of piping, pressure regulators, valves, and pressure sensors shall be provided to safely deliver gaseous fuel to the ignition system and exposure torches. This delivery system shall be sufficient to provide a uniform heat flux of at least 2.0 $cal/cm^2 \cdot s$ (84 kW/m^2) for an exposure time of at least 5 s. Fuel delivery shall be controlled to provide known exposure duration within $\pm$ 0.1 s of the set exposure time. A delivery system adhering to local fire and electrical codes and standards and equipped with controlled burners has been found satisfactory.

6.7.3 *Burner System*— The burner system shall consist of a safety pilot flame, one ignition pilot flame for each exposure burner, and sufficient burners to provide the required range of heat fluxes with a flame distribution uniformity to meet the requirements of 10.3.2.

6.7.3.1 *Safety Pilot Flame*—The safety pilot flame shall be a small flame located near the floor of the chamber and adequately shielded to prevent being extinguished by the ventilation flow. After the chamber has been ventilated during start-up, the safety pilot flame shall be automatically and simultaneously lit with the gas line charging and remain lit throughout the test series. When the safety pilot flame is extinguished, either accidentally or at shut down, the start-up procedure shall be initiated and completed to re-ignite the safety pilot flame to continue or start a new burn series.

6.7.3.2 *Ignition Pilot Flame*—Each exposure burner shall be equipped with a pilot flame positioned near the exit of the burner, but not in the direct path of the flames to interfere with the exposure flame pattern. The pilot flame is ignited and the presence of a pilot flame for each functioning exposure burner shall be visually confirmed prior to opening the exposure fuel supply valve. The pilot flame shall be interlocked to the burner gas supply valves to prevent premature or erroneous opening of these valves.

6.7.3.3 *Exposure Burners*— Large, induced combustion air, industrial style propane burners are positioned around the manikin to produce a uniform laboratory simulation of a flash fire. These burners produce a large yellow flame. If necessary, the gas jet may be enlarged, or removed, to yield a fuel to air mixture for a yellow flame. A minimum of eight burners shall be used and positioned to yield the exposure level and uniformity as described in 10.3.1 and 10.3.2. 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 thigh level (see Fig. 1).

6.8 *Image Recording System*—A 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 Check List*—A check list 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 may include, but is not limited to, the following: confirm that the manikin has been properly dressed in the test garment; confirm that the chamber doors are closed; confirm that no person is in the burn chamber; and all safety requirements are met.

6.10 *Conditioning Area*—An area maintained at 70 $\pm$ 5°F (20 $\pm$ 2°C) and 65 $\pm$ 5 % relative humidity that is large enough to have good air circulation around the hanging test specimens.

7. Hazards

7.1 Procedural operating instructions shall be provided by the testing laboratory and strictly followed to ensure safe testing. These instructions may include, but are not limited to, exhaust of the chamber prior to any test series, lighting of a safety pilot to prevent accumulating an explosive mixture of fuel, no personnel within the chamber when the ignition system is activated to start a test, isolation of the chamber during the test to contain the heat of the exposure and the resulting combustion products, and ventilation of the chamber after the test exposure.

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

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 personnel protective equipment shall be worn when handling the exposed garments and cleaning the manikin after the test exposure.

8. Sampling and Test Specimen

8.1 *Purpose of the Test*—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 evaluation has different garment requirements because the test results are dependent upon the test material performance, garment size, and garment design.

8.1.1 *Material of Construction Evaluation* —This evaluation requires garments of the standard garment design and size.

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

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

8.2 *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 *Test Specimen*— A specimen is a garment or protective clothing ensemble.

8.3.1 Test three specimens from the laboratory sampling unit.

8.3.2 The standard garment shall be a coverall, size 42 regular with a full length metal zipper closure in the front and without pockets, sleeves, or pant cuffs. The test specimens shall meet the size requirements of Table 3.

9. Preparation of Test Specimen

9.1 *Laundering*—Launder each garment not designated for limited use one wash and dry cycle prior to conditioning. Use laundry conditions of AATCC Test Method 135, IIVAiii or CAN/CGSB-4.2 No. 58-M90.

9.2 *Conditioning*— Condition each specimen for at least 24 h at 70 ± 5°F (20 ± 2°C) and 65 ± 5 % relative humidity. The specimen should be tested within 30 min of removal from the conditioning area. If the specimen cannot be tested within 30 min, they should be sealed in polyethylene bags (or other material with low water vapor permeability) until immediately prior to testing. Such garments should be tested within 20 min after removal from the bag. Garments should not remain in the bags for longer than 4 h prior to testing.

10. Preparation and Calibration of Apparatus

10.1 *Preparation of Apparatus*—Exposing the instrumented manikin to a test flash fire in a safe manner and evaluating the test specimen requires a startup and exposure sequence that is specific to the test apparatus. Some of the steps listed may be manually executed or initiated by the computer program, depending upon the individual apparatus. Perform the steps as specified in the operating procedure provided for the apparatus to be used. Some of the steps that may be included are

10.1.1 *Burn Chamber Purging*—Ventilate the chamber for a period of time sufficient to remove a volume of air at least ten times the volume of the chamber. This purge is intended to remove any fuel that may have leaked from the supply lines that may produce an explosive atmosphere.

10.1.2 *Gas Line Charging*—Close the supply line vent valves and open the valves to the fuel supply to charge the system with propane gas at the operating pressure up to, but not into, the chamber. To provide propane to the burners, open the last system valve just prior to each test exposure. Set the high and low pressure detectors as close to the operating pressure as feasible to provide system shut down with a gas supply failure.

10.1.3 *Ignition of the Safety Pilot* —Ignite the safety pilot after chamber is ventilated and simultaneous to the gas line charging. This pilot flame is maintained until the apparatus exposure flame system is safely shut down and secured. If the safety pilot flame goes out, the valves in the fuel supply line will automatically close and lines will be vented.

10.1.4 *Confirmation of Exposure Conditions* —Using the procedure described below for specimen testing, expose the nude manikin to the test flash fire for 4 s or for the duration of the test if less than 4 s. Confirm that the calculated heat flux standard deviation is not greater than 0.5 $cal/cm^2 \cdot s$ (2.1 kW/m^2) and the exposure is within ± 5 % of the specified test condition. If the calculated heat flux or standard deviation are not within these specifications, determine the cause of the deviations and correct before proceeding with garment testing.

10.2 *Calibration of Sensor and Data System*:

10.2.1 *Calibration Principles*:

TABLE 3 Garment Size Requirements

Measurement Location	Inches	Centimetres
Chest	44.5 ± 1.5	113.0 ± 3.8
Waist	37.375 ± 1.0	95.0 ± 2.5
Sleeve	33.375 ± 1.0	84.8 ± 2.5
Trunk	70.5 ± 2.0	179.1 ± 5.1
Inseam	28.5 ± 1.0	72.4 ± 2.5
Seat	48.25 ± 1.5	122.6 ± 3.8
Thigh	28.625 ± 1.0	72.7 ± 2.5

10.2.1.1 Manikin sensors are used to measure flash fire exposure intensity and the heat transferred to the manikin during the exposure. Calibrate the sensors with a convective or radiant heat source of known value, or both. The range of calibration heat fluxes should match the exposure and heat transfer conditions experienced during test setup and garment testing. As a minimum the calibration device shall provide heat fluxes for calibration in the range from 0.2 cal/cm^2·s to 2.0 cal/cm^2·s (8.4 kW/m^2 to 84 kW/m^2).

10.2.1.2 Verify the heat fluxes produced by the calibration device to within ± 5 % of the required exposure level with the heat flux calibration sensor.

10.2.1.3 Test the type of sensor used in the manikin to ensure that the heat flux response is accurate over the range of heat fluxes produced by the exposure and under the test specimen. (see 10.2.1.1) If the response is linear but not within 5 % of the known calibration exposure energy, include a correction factor in the heat flux calculations. If the response is not linear and not within 5 % of the known calibration exposure energy, determine a correction factor curve for each sensor for use in the heat flux calculations.

10.2.1.4 In addition to individual sensor calibration, calibrate the sensor, data acquisition, and burn model as a unit. Expose each sensor to a known heat flux and duration that will result in a second-degree burn injury to be calculated by the computer program. Use the known exposure heat flux, and determine the time to a second-degree burn using the human tissue response as described by Stoll and Chianta.[8] The results produced by the computer shall predict a second-degree burn injury within ± 5 % of the time found by Stoll and Chianta. Include a calibration factor in the burn injury calculations to compensate for sensor variations and permit achieving the necessary burn injury result. The calibration constants for each sensor shall be recorded, and the most recent calibration results used to carry out the burn injury analysis.

10.2.1.5 Perform calibration of each sensor prior to start up of a new manikin, whenever a sensor is repaired or replaced and whenever the results appear to have shifted or to differ from the expected values.

10.3 *Exposure Flame Calibration* :

10.3.1 Measure the intensity and uniformity of the flash fire exposure by exposing the nude manikin to the flames. Software capable of converting the measured data into time varying heat fluxes at each sensor is required. Calculate an average heat flux during the exposure for each sensor. Calculate the area weighted average of these values and the standard deviation. The weighted average is the average exposure heat flux level for the test conditions, and the standard deviation is a measure of the exposure uniformity.

10.3.2 Position the exposure burners and adjust the flames so that the standard deviation of the average exposure heat flux level of all of the manikin sensors does not exceed 0.5 cal/cm^2·s (2.1 kW/m^2). Confirm the standard deviation of the average heat flux level to be equal to or less than 0.5 cal/cm^2·s (2.1 kW/m^2) for each nude manikin exposure, and if necessary, adjust the burners to obtain the exposure uniformity.

10.3.3 Expose the nude manikin to the flames before testing a set of specimens and repeat the exposure at the conclusion of the testing of the set. If the average exposure heat flux for the test conditions differs by more than ± 5 % between the before and after measurements, report this and give consideration to repeating the sequence of specimen tests conducted between the exposure calibrations. As a minimum, check the exposure level at the beginning and at the end of the work day.

10.3.4 Use a 4 s flash fire exposure for these calibrations, and monitor the fuel pressure of the supply line close to the burn fuel supply header. The measured absolute fuel pressure at this location should not fall more than 10 % during a single flash fire exposure. Control the duration of the flash fire exposure by the internal clock of the data acquisition system. The measured duration of the gas flow should be the specified value ± 5 % or 0.1 s, whichever is smaller.

10.3.5 The average heat flux calculated in 10.3.1 should be the specified test condition ± 5 %. If not, adjust the fuel flow rate by modifying the gas pressure at the burner heads. Repeat the calibration run(s) until the specified value is obtained. Repeat nude calibrations can only be conducted when all the sensors have cooled to less than 100°F (38°C) to eliminate the effect of any elevated internal temperature or temperature gradients on calculation of second- and third-degree burn injury.

10.3.6 The computer controlled data acquisition system shall be capable of recording the output from each sensor at least five times per second during the calibration. The accuracy of the measurement system should be less than 2 % of the reading or ± 1.0°F (± 0.6°C) if a temperature sensor is used. The sampling rate during an exposure should provide a minimum of two readings for each sensor every second.

10.3.7 Calibrate the flash fire exposure on the nude manikin as the first and last test for each test day. Report the results of this exposure as the average exposure heat flux is cal/cm^2·s (kW/m ^{2}) and exposure duration in seconds. Also report the standard deviation of the manikin sensors, the percent of sensors indicating second-degree and third-degree burns, and total percent burn.

11. Procedure

11.1 *Dress the Manikin*—Dress the manikin in the test specimen. The garment(s) may need to be cut to provide a large enough opening for dressing around the obstruction of the data cables. If cutting is required, repair the cut in the garment with a nonflammable closure, such as metal staples. Arrange the garment(s) on the manikin in the same way they are used by the consumer. Use the same fit and placement of the garment(s) on each test to minimize variability in the test results.

[8] Stoll, A.M. and Chianta, A.M., "Method and Rating System for Evaluation of Thermal Protection," *Aerospace Medicine*, Vol 40, 1969, pp. 1232-1238.

11.2 *Record the Test Attributes* —Record the information that relates to the test, which may include: Purpose of test, test series, garment identification, test conditions, test remarks, exposure duration, data acquisition time, persons observing the test, and any other information relevant to the test series. As a minimum, provide the information listed in Section 4 and Section 12.

11.3 *Confirm Safe Operation Conditions* —Follow the operating instructions in the computer program and fill in the fields on the safety screen to ensure that all of the safety requirements have been met and that it is safe to proceed with the garment exposure.

11.4 *Light Pilot Flames*—When all of the safety requirements are met, light the pilot flames and confirm that all of the pilot flames on the burners that will be used in the test exposure are actually lit. ~~**Caution:**~~**Warning:** Visually confirm the presence of each pilot flame in addition to the panel light or computer indication. The test exposure may be initiated when all of the safety requirements are met, the pilot flames are ignited and confirmed, and the final valve in the gas supply line is opened.

11.5 *Start Image Recording System* —Start the video or film system used to visually document each test.

11.6 *Expose the Test Garment*—Initiate the test exposure by pressing the appropriate computer key. The computer program will start the data acquisition, open the burner gas supply solenoid valves for the time of the exposure, stop the data acquisition at the end of the specified time, and if part of the program, turn on the fan(s) to ventilate the exposure.

11.7 *Acquire the Heat Transfer Data* —Enter the time period for data acquisition into the appropriate exposure condition field. This time shall be long enough to ensure that all of the heat stored in the garment has been released to the atmosphere and the manikin. Confirm that the acquisition time is sufficient by inspecting the calculated burn injury versus time information to determine that the total burn injury of all of the sensors has leveled off and is not continuing to rise at the end of the data acquisition time. If the amount of burn injury is not constant for the last 10 s of acquisition time, increase the time of acquisition to achieve this requirement.

11.8 *Enter Garment Response Remarks* —Enter any remarks on the reaction of the test garment or protective clothing ensemble to the exposure into the appropriate field in the computer. These remarks may include but are not limited to the following: the subjective relative after-flame intensity and length of time it exists on the test garment, material shrinkage, and charring or observed degradation. These remarks become a permanent part of the test record.

11.9 *Initiate Test Report Preparation* —Initiate the computer program to perform the calculations to determine the amount of total burn injury and to prepare the test report. These operations may be performed immediately following the test or delayed for later processing.

11.10 *Prepare for the Next Test Exposure* —Carefully remove the exposed garment or protective clothing ensemble from the manikin. If the sensors are too hot, run the ventilating fan(s) to cool them to less than 100°F (38°C). Inspect the manikin and sensors to be sure that they are clean of any decomposition materials, and if a deposit is present, carefully clean the manikin and sensors with soap and water or a petroleum solvent. Use the gentlest method that is effective in cleaning the sensor. If required, repaint the surface of the sensor and dry the paint. Ensure that the manikin and sensors are dry, and if necessary, dry them, for example with the ventilating fan(s), before conducting the next test.

11.11 *Sensor Inspection*—Repair or replace damaged or inoperative sensors when a maximum of two sensors no longer function properly and the nonfunctional sensors are located under the test garment. Calibrate repaired or replaced sensors before using.

11.12 *Test Remaining Specimen*—Test the remaining specimen at the same conditions used.

12. Report

12.1 State that the specimens were tested as directed in Test Method F 1930. Describe the material sampled and the method of sampling used.

12.1.1 In the material description include garment type, size, fabric weight, fiber type, color, and non-standard garment features and design characteristics.

12.2 Report the information in 12.3-12.6

12.3 *Type of Test*— Material of construction evaluation, garment design evaluation, or end-use garment specification.

12.4 *Exposure Conditions*—The information that describes the exposure conditions, including:

12.4.1 The average of the exposure heat flux and the standard deviation of the average heat flux from each sensor determined from the nude exposures taken before and after each test series.

12.4.2 The nominal heat flux, the duration of the exposure, and the duration of the data acquisition time for each test.

12.4.3 The temperature and relative humidity in the room where the garments were held prior to testing and in the test chamber, if different.

12.4.4 Any other information relating to the exposure conditions may be included to assist in interpretation of the test specimen results.

12.5 *Calculated Results*—For all garment evaluation and specification test reports, include results of the computer program. Base the predicted burn injury on the total area of the manikin containing sensors (see 12.5.1) and on the total area of the manikin covered by the test garment (see 12.5.2).

12.5.1 Total area (%) of manikin containing sensors.

12.5.1.1 Manikin area of second-degree burn injury (%).

12.5.1.2 Manikin area of third-degree burn injury (%).

12.5.1.3 Total manikin area of burn injury (sum of second- and third-degree burn injury) (%), and associated variation statistic.

12.5.2 Total area (%) of manikin covered by the test garment.

12.5.2.1 Covered area of second-degree burn injury (%).
12.5.2.2 Covered area of third-degree burn injury (%).
12.5.2.3 Total covered area of burn injury (sum of second- and third-degree burn injury) (%) and associated variation statistic.
12.5.3 Other calculated information used in assessing performance.
12.5.3.1 Total heat received by all sensors as the sum of the accumulated heat received by each sensor.
12.5.3.2 Diagram of the manikin showing location and burn injury levels as second- and third-degree areas.
12.5.3.3 Tables of individual and summary sensor results.

12.6 *Objective Observation*—The results of the exposure on the test specimen in narrative form. Support the observations with a video and film record. These observations may include, but are not limited to:
12.6.1 Intensity and duration of after flame.
12.6.2 Amount of smoke generated.
12.6.3 Physical stability of the test garment.
12.6.4 Any other observation that may be used to interpret the results that describe the performance of the test garment.

13. Precision and Bias

13.1 A round robin test of standard uniforms is being performed by three[9]

13.1 *Interlaboratory Study*—Three laboratories with instrumented manikin testing capability, the existing laboratory universe in North America, ran trials in 1998 to establish precision for the test method, based upparaon this universe. Three readily available commercial flame resistant fabrics suitable for high temperature exposures, with nominal fabric basis weights of 9.0, 6.0, and 4.5 oz/sq yd were made into coveralls of a standard size and construction for testing. After one washing, the coveralls were distributed to the laboratories, allowing three replications in each laboratory for each of four exposure conditions selected for testing.

13.1.1 *Exposure Conditions*—The four exposure conditions were a combination of the garment specimen configuration used and the time of garment specimen exposure to generate a standardized flame source at a nominal flux of 2.0 cal/cm2s, representing both lower and higher chances of survivability:

Condition 1 - higher survivability - 3 s exposure - coverall only
Condition 2 - lower survivability - 4 s exposure - coverall only

Condition 3 - higher survivability - 4 s exposure - coverall over cotton t-shirt and brief
Condition 4 - lower survivability - 5 s exposure - coverall over cotton t-shirt and brief

13.1.2 *Data Accumulation*—Each laboratory exposed each of the three sets of specimens in their individual manikin systems, using the four conditions described, accumulated data through similar acquisition systems, and submitted it for analysis.

13.1.3 *Analysis*—The analysis was made using the total burn area percentage shown by the manikin data for a test run to produce at least second degree burn, as predicted by the Stoll curve.[8] Because of differences in calculation techniques for third degree burn, and observed variabilities in calculation results for third degree burn, the analysis was confined to a determination of precision based on total burn area percentage. Because of significant differences in error variances of the fabrics both within and between the four conditions, the precisions for the four conditions are reported separately, and the results for the three fabrics are reported separately within each condition. Single factor analysis of variance was used to derive components of variance, from which standard errors and critical differences were calculated.

13.2 *Precision*—Components of variance and critical differences are stated for each condition.

13.2.1 *Components of Variance*—Components of variance, shown both as variances and standard deviations, are stated for each condition (see Table 4).

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[9] Henriques, F.C. and Moritz, A.R., "Studies
[9] Results of Thermal Injury: I The Conduction of Heat to and Through Skin and the Temperatures Attained Therein. A Theoretical and Experimental Investigation," *American Journal of Pathology*, Vol 23, 1947, p. 531. interlaboratory study can be obtained from ASTM. Request RR: F23–1004.

TABLE 4 Components of Variance and Critical Differences

	Component of Variance		Fabric A		Fabric B		Fabric C	
			Variance	Standard Deviation	Variance	Standard Deviation	Variance	Standard Deviation
Condition 1	Lab	VL	84.00	9.17	10.81	3.29	33.22	5.78
	Error	V	8.11	2.85	1.67	1.29	8.33	2.89
Condition 2	Lab	VL	0	0	0	0	0	0
	Error	V	6.88	2.62	120.11	10.96	3.53	1.88
Condition 3	Lab	VL	0	0	0	0	16.15	4.02
	Error	V	14.78	3.84	39.36	6.27	4.23	2.08
Condition 4	Lab	VL	0	0	55.26	7.43	15.67	3.96
	Error	V	9.00	3.00	2.67	1.63	1.78	1.33

13.2.2 *Precision*—Precision is stated as critical differences, at the 95 % probability level (see Tables 5 and 6).

13.2.3 As more laboratories conduct the test, the precision of this procedure will be redetermined.

13.3 The values for the properties obtained can only be defined in terms of a test method. Within this limitation, Test Method F 1930 has no bias.

14. Keywords

14.1 fire, flash; flame testing; flammability, textile; manikin, instrumented flammability testing; protective clothing; thermal testing

TABLE 5 Precision

NOTE 1—Legend: N is the number of specimens in an average; SE is the associated standard error for the average; CD is the calculated critical difference; the unit for SE or CD is percent total burn area

Within-Laboratory Precision							
		Fabric A		Fabric B		Fabric C	
	N	SE	CD	SE	CD	SE	CD
Condition 1	1	2.85	8.0	1.29	3.6	2.89	8.1
	3	1.84	4.6	0.75	2.1	1.67	4.7
	5	1.27	3.6	0.58	1.6	1.29	3.6
Condition 2	1	2.62	7.3	10.96	30.7	1.88	5.3
	3	1.51	4.2	6.33	17.7	1.08	3.0
	5	1.17	3.3	4.90	13.7	0.84	2.4
Condition 3	1	3.84	10.8	6.27	17.6	2.08	5.6
	3	2.22	6.2	3.62	10.1	1.20	3.4
	5	1.72	4.8	2.81	7.9	0.93	2.6
Condition 4	1	3.00	8.4	1.63	4.6	1.33	3.7
	3	1.73	4.8	0.94	2.6	0.77	2.2
	5	1.34	3.8	0.73	2.0	0.60	1.7
Between-Laboratory Precision							
		Fabric A		Fabric B		Fabric C	
	N	SE	CD	SE	CD	SE	CD
Condition 1	1	9.60	26.9	3.53	9.9	6.45	18.0
	3	9.31	26.1	3.37	9.4	6.00	16.8
	5	9.25	25.9	3.34	9.3	5.91	16.5
Condition 2	1	2.62	7.3	10.96	30.7	1.88	5.3
	3	1.51	4.2	6.33	17.7	1.08	3.0
	5	1.17	3.3	4.90	13.7	0.84	2.4
Condition 3	1	3.84	10.8	6.27	17.6	4.53	12.7
	3	2.22	6.2	3.62	10.1	4.19	11.7
	5	1.72	4.8	2.81	7.9	4.12	11.5
Condition 4	1	3.00	8.4	7.61	21.3	4.18	11.7
	3	1.73	4.8	7.49	21.0	4.03	11.3
	5	1.34	3.8	7.47	20.9	4.00	11.2

TABLE 6 Precision Expressed as Repeatability (r) and Reproducibility (R) at 95 % Level

	Condition 1 - 3 s					Condition 2 - 4 s				
Fabric	Av	Sr	r	SR	R	Av	Sr	r	SR	R
A	32.9	2.85	8.0	9.6	26.9	59.1	2.62	7.3	2.62	7.3
B	11.6	1.29	3.6	3.53	9.9	79.1	10.96	30.7	10.96	30.7
C	35.0	2.89	8.1	6.45	18.1	57.6	1.88	5.3	1.88	5.3

	Condition 3 - 4 s + underwear					Condition 4 - 5 s + underwear				
Fabric	Av	Sr	r	SR	R	Av	Sr	r	SR	R
A	42.6	3.84	10.8	3.84	10.8	52.3	3.0	8.4	3.0	8.4
B	62.9	6.27	17.6	6.27	17.6	80.9	1.63	4.6	7.61	21.3
C	42.8	2.08	5.8	4.53	12.7	53.6	1.33	3.7	4.18	11.7

ANNEXES

(Mandatory Information)

A1. TISSUE BURN INJURY COMPUTER MODEL

A1.1 The estimation of tissue burn injury in this test method is based on work by Henriques and Moritz.[10] Their work, combined with others, shows that destruction of the growing layer located at the epidermis/dermis interface in human skin begins when the temperature of this layer (sometimes called the basal layer) rises above 44°C, the total time that the layer is above this temperature being critical. It was found that the destruction rate could be closely modeled by a first order chemical reaction; that is:

$$\frac{d\Omega}{dt} = Pe^{\frac{-\Delta E}{RT}} \quad \text{(A1.1)}$$

where:
Ω = a quantitative measure of burn damage at the basal layer or at any depth in the dermis,
P = frequency factor, s^{-1},
e = natural exponential = 2.7183,
E = the activation energy for skin, J/mol,
R = the universal gas constant, 8.315 J/kmol · K,
T = the absolute temperature at the basal layer or at any depth in the dermis, K, and
t = total time for which T is above 44°C (317.15 K).

A1.2 The total burn damage is found by integrating Eq A1.1 over the time interval that the basal layer is above 44°C, using Eq A1.2.

$$\Omega = \int_0^t Pe^{\frac{-\Delta E}{RT}}\, dt \quad \text{(A1.2)}$$

A1.2.1 Henriques found that if Ω is less than, or equal to, 0.5 no damage will occur at the basal layer. If Ω is between 0.5 and 1.0, first-degree burns will occur, whereas if $\Omega > 1.0$, second-degree burns will result. This total damage criteria can be applied to any depth of skin provided the appropriate values of P and ΔE are used. Mathematically, a second-degree burn injury has been defined as an $\Omega > 1.0$ at the epidermis/dermis interface and a third-degree burn injury as an $\Omega > 1.0$ at the dermis/subcutaneous tissue interface.

A1.2.2 Morse, Tickner, and Brown[11] examine the various values of P and ΔE available in the literature and suggest that the criteria developed by Stoll and co-workers be used in the epidermal layer and that of Takata be used in the dermal and subcutaneous layers. The values of P and ΔE developed by Stoll are:

for $T < 50°C$ $\quad$ $P = 2.185 \times 10^{124}\ s^{-1}$ and $\Delta E/R = 93\ 534.9$ K

~~[10] Morse, H., Tickner, G.,~~

[10] Henriques, F.C. and ~~Brown, R., "Burn Damage~~ Moritz, A.R., "Studies of Thermal Injury: I The Conduction of Heat to and ~~Burn Depth Criteria," Aerotherm Projects 6269~~ Through Skin and ~~6393, Aerotherm TN-75-26, 1975.~~ the Temperatures Attained Therein. A Theoretical and Experimental Investigation," *American Journal of Pathology*, Vol 23, 1947, p. 531.

[11] This test method is under the jurisdiction of ASTM Committee F23 on Protective Clothing and is the direct responsibility of Subcommittee F23.80 on Instrumented Manikin Test.

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for $T \geq 50°C$ — $P = 1.823 \times 10^{51}\ s^{-1}$ and $\Delta E = 39\ 109.8$ K

while those of Takata are:

for $T < 50°C$ — $P = 4.32 \times 10^{64}\ s^{-1}$ and $\Delta E/R = 50\ 000$ K

for $T \geq 50°C$ — $P = 9.39 \times 10^{104}\ s^{-1}$ and $\Delta E = 80\ 000$ K

A1.3 To predict the extent of damage that would result in a flash fire, it is necessary to know the temperature history of the basal layer. The sensors in the manikin are used for this purpose. They permit the surface heat flux and its variation with time to be predicted. This information is then used to predict the temperature history of the basal layer and the extent of skin damage for each of the sensors. Exemplars of the physical properties to be used in the skin burn model are given in Table A1.1.

A2. ELEMENTS OF COMPUTER SOFTWARE PROGRAM

A2.1 The sections and elements of a computer software program that may be included, but are not limited to, are given in A2.1.1-A2.1.6.

A2.1.1 *Monitor Status of Apparatus and Then Control the Process as Required*:

A2.1.1.1 Temperature of Sensors.

A2.1.1.2 Position of fuel supply line and vent valves.

A2.1.1.3 Position of fuel supply pressure sensors.

A2.1.1.4 Safety pilot flame sensor.

A2.1.1.5 Exposure burner pilot light sensors.

A2.1.1.6 Ventilation flow sensor.

A2.1.1.7 Keyboard queries and commands.

A2.1.1.8 Safety devices, such as propane sensors, chamber door, and so forth.

A2.1.2 *Process Control*:

A2.1.2.1 Chamber air purge - ventilation fans.

A2.1.2.2 Fuel line charging.

A2.1.2.3 Safety pilot light ignition.

A2.1.2.4 Exposure burner pilot ignition and detection.

A2.1.2.5 Exposure burner fuel solenoid control.

A2.1.2.6 Data acquisition.

A2.1.2.7 Exhaust fan control.

A2.1.2.8 Emergency shut-down.

A2.1.3 *Data Acquisition*:

A2.1.3.1 Record sensor temperatures every 0.5 s and create a table of sensor response versus time for each sensor for the duration of the data acquisition period.

A2.1.3.2 Record time that the exposure burner fuel solenoids are open - exposure duration.

A2.1.3.3 Garment identification field comments.

A2.1.3.4 Exposure conditions field comments.

A2.1.3.5 Exposure remarks field comments.

A2.1.3.6 Garment reaction remarks field comments.

A2.1.3.7 Garment after-flame intensity and duration.

A2.1.4 *Calculations*:

A2.1.4.1 Calculate heat flux at manikin surface from sensor response readings.

A2.1.4.2 Calculate tissue temperature from manikin surface heat flux calculations or measurements.

TABLE A1.1 P~~HYSICAL~~hysical P~~ROPERTIES FOR~~roperties for B~~URN~~urn M~~ODEL~~odel

Parameter	Epidermis	Dermis	Subcutaneous Tissue
Thickness of layer (m)	5×10^{-5}	1.5×10^{-3}	1×10^{-2}
Thermal conductivity, k (W/m · K)	0.255	0.523	0.167
Volumetric heat capacity, cp (J/m^3·K)	4.32×10^6	3.87×10^6	2.76×10^6

A2.1.4.3 Calculate burn injury from tissue temperature calculations.

A2.1.4.4 Summarize results in detailed data table.

A2.1.5 *Report Preparation*—Summarize and create a test report that includes, but is not limited to, the requirements of Section 12 of test method and the following as needed: (1) Contents of remarks fields, and (2) detailed tables including heat flux, time to second- and third-degree burns, sensor temperatures, and calculated skin temperatures versus time for each sensor.

A2.1.6 *Supporting Programs*:

A2.1.6.1 Sensor calibration exposure and data collection.

A2.1.6.2 Sensor calibration factor calculation.

A2.1.6.3 Manual exposure of manikin using auxiliary heat source.

A2.1.6.4 Burn injury and sensor response diagnostics.

A2.1.6.5 Manikin diagram with sensor areas.