INTERNATIONAL STANDARD

ISO 13506

First edition
2008-05-01

Protective clothing against heat and flame — Test method for complete garments — Prediction of burn injury using an instrumented manikin

Vêtements de protection contre la chaleur et la flamme — Méthode d'essai pour vêtements complets — Estimation de la probabilité de brûlure à l'aide d'un mannequin instrumenté

Reference number
ISO 13506:2008(E)

Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 13506 was prepared by Technical Committee ISO/TC 94, *Personal safety — Protective clothing and equipment*, Subcommittee SC 13, *Protective clothing*.

Introduction

The purpose of heat- and flame-resistant protective clothing is to shield the wearer from hazards that can cause burn injury. The clothing can be made from one or more materials. The evaluation of materials for potential use in this type of clothing generally involves two steps. First, the materials are tested to gauge their ability to limit flame spread. They are then tested to determine the rate of heat transferred through them when exposed to a particular hazard. A variety of test methods are used in these two steps, depending on the intended end use of the materials.

The first test conducted is the one described in ISO 15025. In this test, a flame of prescribed size is applied to one or several vertically suspended fabric layer(s) for a prescribed time, and then removed. The location of the flame can be at the lower edge of the specimen or on the face of the material. The length of the flame spread on the material is observed and used as an indicator of the material's ability to support combustion.

The second test, that for heat transmission, can involve one or more tests, depending on the intended end use of the materials. For situations where the potential hazard is a contact with a flame, the method used is the one described in ISO 9151. If the hazard is exposure to thermal radiation only, then the method used is the one described in ISO 6942. Materials to be used in structural fire-fighting clothing can also be tested using ISO 17492. All these test methods use exposure heat flux density levels ranging from 20 kW/m^2 to 80 kW/m^2. The value depends on the test method and the potential hazard. These tests are transient and of short duration. The tests are terminated when a particular end point is reached, such as the temperature rise in a heat sensor located behind the material layer(s). Because these tests are transient, the endothermic and exothermic properties, the material density, the specific heat and the thermal conductivity of the material(s) are all important parameters in determining the outcome. The samples are conditioned before testing.

It is advisable that the specimens tested as outlined above be representative of the garment or ensemble material or component specimens. While these tests are able to allow a ranking of garment or ensemble materials and components, the tests do not allow a complete assessment of a garment or ensemble made of the materials.

All of the above test methods use small amounts of material, up to 150 mm x 150 mm in area, and hold the material initially flat, either in a vertical or in a horizontal plane. Multiple layers are used where appropriate (e.g. structural fire-fighting ensembles). In this case, the layer normally worn on the exterior is exposed directly to the energy source, while the layer normally worn on the inside is away from the energy source. With the planar orientation and alignment of materials, shrinkage has little effect on the outcome of the test, unless the shrinkage is so severe as to cause holes to form in the material during the exposure to the energy source. Sagging, however, does directly affect the results, as an air gap can form or grow in size, adding an insulating effect. While it is possible to test with the aforementioned test methods seams, zippers, pockets, buttons or other closures, metal and plastic clips or other features that can be included in a full garment like heraldry, company logos, etc., this is not frequently done because it is difficult to do. These aspects and the overall design features of a garment or ensemble that can affect the performance are best evaluated by testing full garments or ensembles on a manikin, and it is for this purpose that this International Standard was established.

In the test method in this International Standard, a stationary, full-sized male form (female forms are under development) is dressed in a complete garment and exposed for a prescribed short duration to a laboratory simulation of a flash fire. The average incident heat flux density to the exterior of the garment is 84 kW/m^2, a value similar to those used in ISO 9151, ISO 6942 and ISO 17492. The data-gathering period is 60 s for single-layer garments and 120 s for any other type of test specimen. Heat sensors fitted to the surface of the manikin are used to measure the heat flux density variation with time and location on the manikin and to determine the total energy absorbed over the data-gathering period. This information can be used to assist in evaluating the performance of the garment or protective clothing ensembles under the test conditions. It can also be used to estimate the extent and nature of skin damage that a person would suffer if wearing the test garment under similar exposure conditions.

The manikin is tested in a standing position in initially quiescent air. Controlled air motion for simulating wind effects or body movement is not presently possible, but it is possible to move the manikin through a stationary flame. Motion of this nature is not within the scope of this International Standard. Variations in the fit of the test garment that can occur when sitting or bending are not evaluated.

The fire simulations are dynamic. As such, the exposure is more representative of an actual industrial accident or structural fire than the exposures used in the bench scale tests mentioned above. The heat flux density resulting from the exposure is neither constant nor uniform over the surface of the manikin/garment. Under these conditions, the results are expected to have more variability than carefully controlled bench scale tests. In addition, the garment is not constrained to be a flat surface, but is allowed to have a natural drape on the manikin. The effect these variables have on a garment can be seen in several ways: ignition and burning of the garment and heraldry, shrinkage or sagging in all directions after flaming, hole generation, smoke generation and structural failure of seams. Many of these failures rarely appear in the bench scale testing of the materials because they are a result of garment design variables, interaction between material properties and design variables, construction techniques and localized exposure conditions that are more severe.

Fit of the garment on the manikin is important. A standard garment is specified to minimize the effect of this variable. Experience suggests that testing a garment one size larger than the standard will reduce the total energy transferred and percentage body burn by about 5 %.

This International Standard is not designed to measure material properties directly, but to evaluate the interaction of material behaviour and garment design. One can compare relative material behaviour by making a series of test garments out of different materials using a common pattern. The performance of the full garments will not necessarily be ranked in the same order as might be obtained when the materials are tested using ISO 9151, for example. Correlations between small scale tests and results from single-layer garments have been examined (see Reference [9]). The best correlation was obtained when three-dimensional shrinkage effects were allowed to occur with the fabric, just as occurs with garments on the manikin.

The hands and feet of the manikin do not contain sensors, but it is possible to assess some aspects of hand protection depending upon the specific design of the hands. The head, however, does contain heat sensors. The reason for this is that many outer garments include an integral hood, but not gloves or footwear. Tests for gloves and footwear are covered by other ISO documents for specific end uses.

The protection offered by the test specimens is evaluated through quantitative measurements and observations. Heat sensors fitted to the manikin are used to measure the energy transferred to the manikin surface during the data-gathering period. This information can be reported directly or used to calculate the nature and extent of the damage that would occur to human skin from the exposure. The latter information is reported as time to pain, first-, second- or third-degree burn injury (see Clause 3 and Annex C). Unlike skin on a human, the model used for evaluating damage to the skin assumes it to be the same at all locations. The reason for this is the limited amount of thermo-physical data on human skin and how skin responds to thermal insult. The published data is specific to the skin samples tested and is not intended to apply to significantly different thicknesses such as occur on a human.

Documents listed in the Bibliography give full details of manikin and sensor construction, data acquisition, computer software requirements, flame exposure chamber and fuel and delivery system. They also suggest numerical techniques that can be used to carry out the calculations required.

The European Committee for Standardization (CEN) specifies the test method described in this International Standard as an optional part of EN 469:2005. This test method is also specified in ISO 11612:1998 as an optional test.

The National Fire Protection Association (NFPA) specifies a test method similar to the one described in this International Standard as part of a certification process for garments (see Reference [10]).

Protective clothing against heat and flame — Test method for complete garments — Prediction of burn injury using an instrumented manikin

1 Scope

This International Standard provides the general principles of a test method for evaluating the performance of complete garments or protective clothing ensembles in a flash fire or other short duration exposures. This test method characterizes the thermal protection provided by garments, based on the measurement of heat transfer to a full-size manikin exposed to a laboratory simulation of a fire with controlled heat flux density, duration and flame distribution. The heat transfer measurements can also be used to calculate the predicted skin burn injury resulting from the exposure. In addition, observations are recorded on the overall behaviour of the test specimen during and after the exposure.

This method is useful for three types of evaluation:

a) comparison of garment or ensemble materials;

b) comparison of garment or ensemble design; and

c) evaluation of any garment or ensemble prototype for a particular application or to a specification.

Each type of evaluation has different garment or ensemble requirements because the test results are dependent on the test material performance, on the garment size, on the garment design and on the use of ensemble components.

The results obtained apply only to the particular garments or ensembles, as tested, and for the specified conditions of each test, particularly with respect to the heat flux density, duration and flame distribution. For the purposes of this test method, the incident heat flux density is limited to a nominal level of 84 kW/m^2.

This International Standard is intended to be used to measure and describe the behaviour of complete garments or protective clothing ensembles in response to convective and radiant energy under controlled laboratory conditions, with the results used to optimize garment combinations and designs. This International Standard is not intended to be used to compare the properties of garment materials or combinations of materials unless the test specimens are absolutely identical in size and design. Furthermore, this International Standard is not intended to be used to describe or appraise the fire hazard or fire risk under actual fire conditions. However, the results of this test can be used as elements of a fire risk assessment which takes into account all of the factors that are pertinent to an assessment of the fire hazard of a particular end use. Considerations for the use of this test method are provided in Annex A. Inter-laboratory data for the test method are provided in Annex B.

NOTE 1 This test method provides information on material behaviour and a measurement of garment performance on a stationary upright manikin. The effects of body position and movement are not addressed in this test method.

NOTE 2 This test method does not apply to the evaluation of protection for the hands or the feet.

NOTE 3 This test method is complex and requires a high degree of technical expertise in both the test setup and operation.

NOTE 4 Deviations from the instructions in this test method can lead to significantly different test results. Technical knowledge concerning fabric behaviour and the theory of heat transfer and testing practices is needed in order to evaluate which deviations are significant with respect to the instructions given in this test method. Standardization of the test method reduces, but does not eliminate, the need for such technical knowledge. Any deviations from this test method are reported with the results.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 6330, *Textiles — Domestic washing and drying procedures for textile testing*

ISO 7941, *Commercial propane and butane — Analysis by gas chromatography*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
burn injury
burn damage which occurs at various levels of depth within human tissue due to elevated temperatures resulting from heat transfer to the surface

NOTE Burn injury in human tissue occurs when the tissue is heated and kept at an elevated temperature (> 44 °C) for a critical period of time. For the purposes of this International Standard, it is assumed that skin has three layers: the epidermis, which is the tough outer layer, the dermis, which is the layer below the epidermis, and the subcutaneous tissue, which is the fatty layer of skin deeper than the dermis. This tissue varies in thickness in different parts of the body, from person to person and with age. The severity of damage, referred to as first-, second-, or third-degree (or partial thickness or full thickness) burn injury, depends upon the level of the elevated temperature above 44 °C and the time during which it remains above 44 °C. Annex C gives details of the model and criteria used in calculating the damage.

3.1.1
first-degree burn injury
first-degree burn
burn in which only the superficial part of the epidermis has been injured

NOTE The skin turns red, but does not blister or actually burn through. First-degree burn damage is reversible.

3.1.1.1
first-degree burn injury area
first-degree burn area
sum of the areas represented by heat flux sensors for which only a calculated first-degree burn injury occurs

3.1.2
second-degree burn injury
second-degree burn
partial thickness burn
burn in which the epidermis and a varying extent of the dermis are burned, but the entire thickness of the dermis is not destroyed and the subcutaneous layer is not injured

NOTE Second-degree burn damage is more serious than first-degree burn damage, but is reversible.

3.1.2.1
second-degree burn injury area
second-degree burn area
sum of the areas represented by heat flux sensors for which only a calculated second-degree burn injury occurs

3.1.3
third-degree burn injury
third-degree burn
full thickness burn
burn which extends through the dermis, into or beyond the subcutaneous fat

NOTE Third-degree burn damage is irreversible.

3.1.3.1
third-degree burn injury area
third-degree burn area
sum of the areas represented by the heat flux sensors for which only a calculated third-degree burn injury occurs

3.2
complete garments
any single garment or combination of garments designed to protect the torso, arms and legs of the wearer

NOTE Both a single garment and a combination of garments can include protection for the head of the wearer by means of a hood (integral or separate) or balaclava. A combination of garments can include undergarments and outer garments.

3.3
flame distribution
spatial distribution of incident flames from test facility burners which provides a controlled heat flux density over the manikin surface.

3.4
flash fire
fire that spreads rapidly through a diffuse fuel-air mixture without the production of damaging pressure

NOTE The fuel can be a dust, a gas or vapours of an ignitable liquid. The duration is typically less than 3 s.

3.5
garment ease
difference between body (manikin) dimensions and garment dimensions

3.6
heat flux sensor
device capable of directly measuring the heat flux density to the manikin's surface under test conditions, or of providing data that can be used to calculate the heat flux density

NOTE In either case, the created data needs to be in a form that can be processed by a computer program to assess the total energy transferred over the recording period and the potential burn injury.

3.7
instrumented manikin
model representing an adult-sized human and fitted with heat flux sensors on the surface for use in testing

3.8
predicted total area of burn injury
total area of predicted burn injury
sum of the areas represented by the heat flux sensors which calculate at least a second-degree burn injury

3.9
protective clothing ensemble
any combination of complete protective garments.

NOTE Although this International Standard does not require sensors in the hands of the manikin, gloves can be included in the protective clothing ensemble to be tested. This will allow representation of a realistic interface between arm and hand protective items.

3.10
thermal protection
overall protective performance of a garment or protective clothing ensemble relative to how it limits the transfer of heat to the manikin over the data-gathering period

NOTE In fire testing of clothing, thermal protection of a garment or ensemble and the consequential predicted burn injury (first-, second- or third-degree) can be quantified by the measured heat flux sensor response which indicates how well the garment or protective clothing ensemble limits heat transfer to the manikin surface. In addition to the measured sensor response, the physical response and degradation of the garment or ensemble are observable phenomena which are associated with the heat flux sensor calculation and are useful in understanding garment or protective clothing ensemble thermal protection.

3.11
time to pain
time taken for the interface of the epidermis and dermis layers to reach 43,2 °C

4 General

The method evaluates the protective performance of the test specimen, which is either a garment or an ensemble. The performance is a function of both the materials of construction and design. The test specimen is placed on an adult-size manikin at ambient atmospheric conditions and exposed to a laboratory simulation of a fire with controlled heat flux, duration and flame distribution. The test procedure, data acquisition, result 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 heat flux sensors. These measurements shall be used to calculate the second- and third-degree and total burn injury areas resulting from the exposure. They may also be used to calculate the time to pain and first-degree burn injury. Identification of the test garment, 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 test report. The performance of the test specimen is indicated by the calculated total energy transferred, the burn injury area and the way the test specimen responds to the test exposure.

5 Apparatus

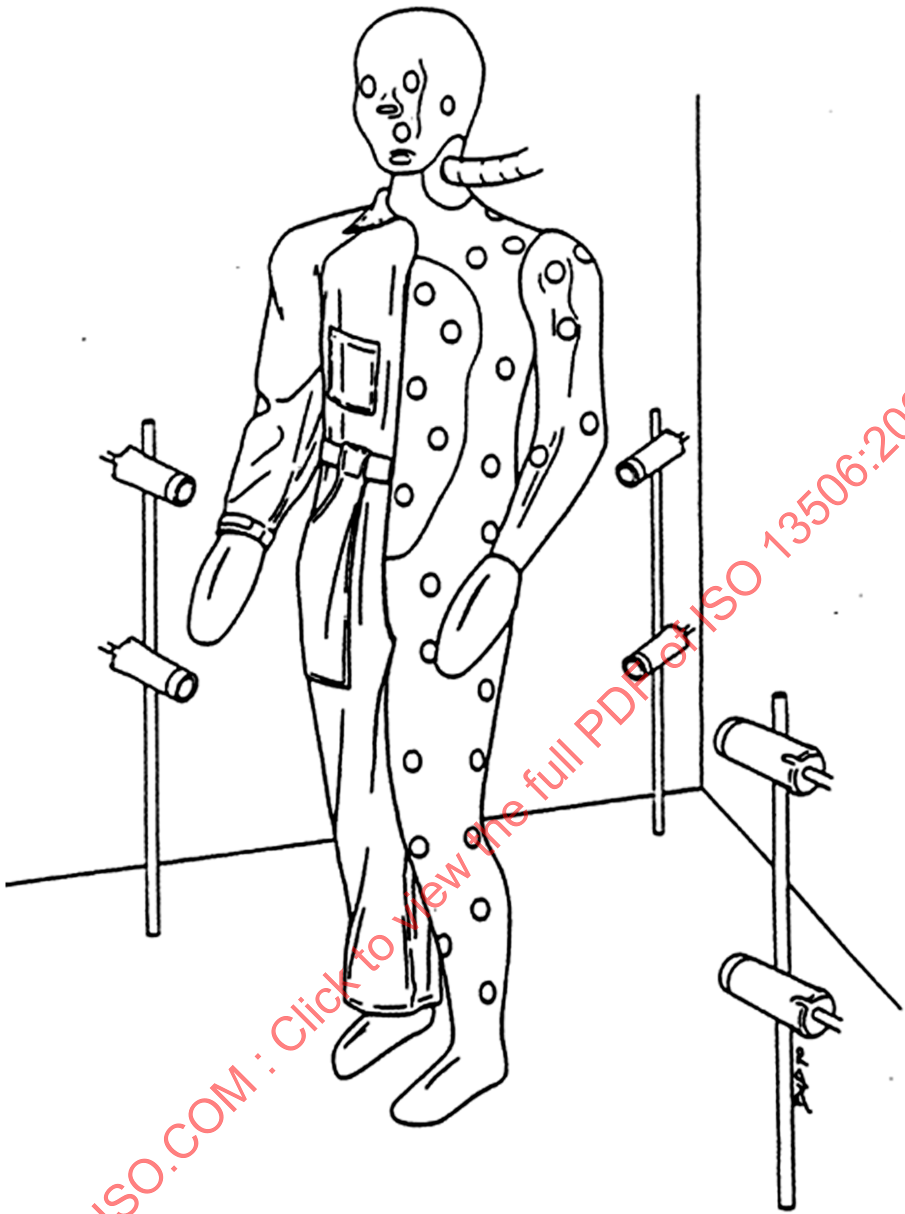
5.1 Instrumented manikin

An upright manikin the shape and size of an adult human form shall be used (see Figure 1). The manikin shall be constructed to simulate the body of a human being and shall consist of a head, a chest/back, an abdomen/buttocks, arms, hands, legs and feet. The manikin should be constructed of flame-resistant, thermally stable materials, such as ceramics or glass-reinforced vinyl ester resin. The shell thickness should be at least 3 mm.

A reproducible positioning system is required for the manikin. It may consist of pin locators in the floor, a portable rigid positioning frame and light or laser beams for setting vertical orientation and arm position.

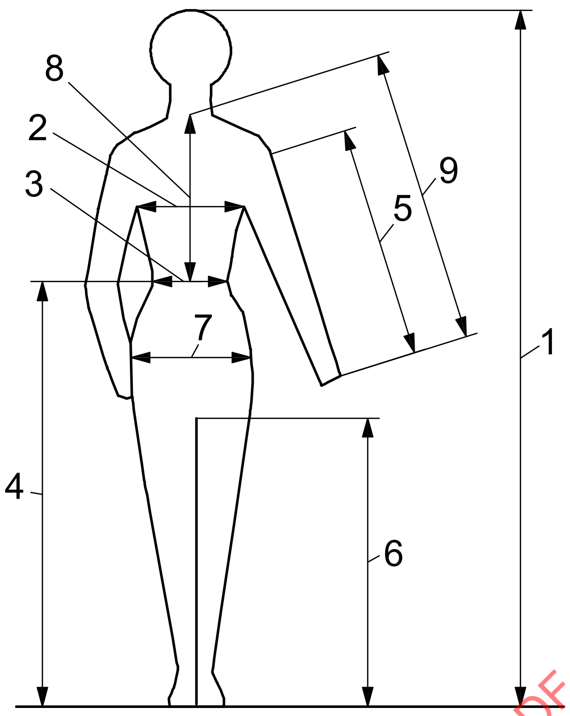
The instrumented manikin[1)] shall match the dimensions indicated in Table 1.

1) A manikin meeting these requirements is available from Composites USA, 1 Peninsula Drive, Northeast, Maryland, USA. Ph. +1 302 834 7712. This information is given for the convenience of users of this International Standard and does not constitute an endorsement by ISO of the product named. Equivalent products may be used if they can be shown to lead to the same results.



a) Instrumented manikin

Figure 1 — Representation of an instrumented manikin



b) Measurements for male manikin

Figure 1 *(continued)*

Table 1 — Measurements for male manikin

	Measurement location	Dimension mm	Tolerance mm
1	Total height	1 830	± 40
2	Chest circumference at largest value	1 025	± 20
3	Waist circumference at narrowest position	850	± 15
4	Waist to base of heel	1 150	± 50
5	Top of shoulder to wrist along arm	610	± 30
6	Crotch to sole of foot along the inside of the leg	860	± 40
7	Hip circumference at the largest dimension	1 015	± 20
8	Base of centre of rear neck to waist	425	± 20
9	Centre of base of rear neck to wrist measured across the shoulder and along the outside of the arm	830	± 30

5.2 Heat flux sensors

5.2.1 Principle

The burn injury prediction system shall use a number of heat flux sensors which are capable of directly measuring the incident heat flux density or providing data that can be used to calculate the heat flux density to the manikin's surface under test conditions. This information is then processed by a computer program to predict burn injury. The burn injury calculations are described in Annex C.

5.2.2 Number of heat flux sensors

The burn injury prediction system shall use a minimum of 100 heat flux sensors. They shall be distributed as uniformly as possible in each area on the manikin, as indicated in Table 2.

Table 2 — Sensor distribution

Body area	Percentage
Head	7
Trunk	40
Arms	16
Thighs	22
Lower legs (Shanks)	15
Hands/feet	0
Total	100

NOTE The number of sensors presently used in manikins range from 110 to 126. Extra sensors can be added to the hands and feet if desired.

5.2.3 Heat flux sensor-measuring capacity

Each heat flux sensor shall have the capacity to measure the incident heat flux density over a range of 0 kW/m^2 to 200 kW/m^2. This range permits the use of the heat flux sensors to set the exposure level by flame tests of a nude manikin, and also to measure the heat transfer to the manikin with a test specimen in place.

5.2.4 Heat flux sensor construction

The heat flux sensors shall be constructed of a material with known thermal characteristics which can directly indicate the heat flux density or be used with sensor temperature measurement to indicate heat flux density and temporal variation received by the sensor. The outer surface shall be covered with a thin layer of flat black high-temperature paint (with an absorptivity greater than 0,9). The time response for the heat flux sensors shall be equal to or less than 0,1 s. A procedure is described in D.1.8.

NOTE Sensors that have been used successfully include Gardon gauges, slug calorimeters and skin-simulant sensors.

5.2.5 Heat flux sensor calibration

Calibration of sensors shall follow the procedure in Annex D.

5.3 Data acquisition system

A system shall be provided which is capable of acquiring and storing the results of the measurement from each sensor at least twice per second for a data acquisition period of up to 120 s. Additional requirements for data acquisition are included in Annex D.

NOTE The data acquisition rate of two readings per second from each sensor is the minimum necessary to obtain adequate information. Sampling rates of five per second per sensor are advisable during the flame exposure period. Some laboratories sample at up to 10 measurements per second per sensor during this period. The minimum rate of two measurements per second per sensor is adequate after the flame exposure.

5.4 Computer software program

5.4.1 General

A computer software program shall be utilized which is capable of receiving the output of the sensors, of calculating the incident heat flux density (see 5.4.2), of predicting the occurrence of time to pain, first-, second- and third-degree burns (see 5.4.3) and of predicting the area of first-degree, second-degree, third-degree, and total burn (see 5.4.4). Annex C provides background information for the prediction of burn injury, while Annex E provides the necessary elements of the computer software program. Bibliographical reference [7] provides additional details of an operating system and numerical methods to complete the necessary calculations.

5.4.2 Incident heat flux calculation

The incident heat flux density shall be determined by a computer software program during a nude burn. Each heat flux sensor has an associated manikin surface area over which the measured heat flux density applies. The value reported is the average of the area-weighted averages for each heat flux sensor for the steady portion of the nude exposure. The procedure is described in D.2.2.

The area associated with any heat flux sensor shall be determined by locating points equidistant to the surrounding heat flux sensors. These points are joined by straight lines. The area so formed around a particular heat flux sensor is its associated surface area.

5.4.3 Predicted burn injury calculations

The time to pain and the time predicted at which first-, second- and third-degree burn injury begins for each sensor shall be calculated by the computer software program.

5.4.4 Calculation of predicted area of burn injury

The sum of the area represented by the sensors which received sufficient heat to result in a predicted second-degree burn shall be the predicted second-degree burn injury area. The sum of the area represented by the sensors which received sufficient heat to result in a predicted third-degree burn injury area shall be the predicted area of the third-degree burn injury. The sum of these two areas shall be the predicted total area of burn injury resulting from the exposure to the flash fire condition.

NOTE The first-degree burn injury prediction is not included in this area calculation because the skin remains intact and receives relatively minor damage compared with the second- and third-degree burn injury. The first-degree burn injury prediction and/or time to pain can be provided as optional information.

5.4.5 Additional computer software features

Computer software may also be used to specify and control the operating procedure (see Clause 8), to record the test conditions (see 8.2.3), to ensure that safety requirements are met (see 8.2.4), to enter specimen response remarks (see 8.2.8) and to prepare the test report (see 8.2.9).

5.5 Flame exposure chamber

5.5.1 General

A ventilated, fire-resistant enclosure with viewing windows and access door(s) shall be provided to contain the manikin and exposure apparatus. It shall be designed to allow natural air to flow into the chamber for the exposure, and it shall be equipped with an exhaust system that enables rapid removal of the room gases after the exposure and data acquisition times have expired.

5.5.2 Chamber size

The chamber size shall be large enough to provide flame exposure over the surface of the test specimen and to allow safe movement around the manikin for dressing without accidentally jarring and displacing the burners. Minimum interior dimensions of 2,1 m wide by 2,1 m long by 2,1 m high are necessary to allow sufficient air for combustion and control of the flames.

5.5.3 Chamber air flow

The air within the chamber and any free flow that occurs either into or out of the chamber during an exposure shall be sufficient to permit the combustion process needed for the required heat flux density. Immediately after the data acquisition period, a forced air exhaust system shall be used for rapid removal of combustion gas products. Prior to the exposure and during the data acquisition, the forced air exhaust system shall be shut off so as to provide a quiet atmosphere. Openings to the exterior of the test chamber may be required for the pressure relief and passive supply of air necessary for complete combustion of the fuel during the exposure.

5.5.4 Chamber isolation

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

5.5.5 Chamber air exhaust system

The forced air exhaust system shall have a minimum capacity equal to the volume of the chamber per minute in order to remove the gaseous products which result from the test exposure. In addition, the forced air exhaust system may be run at a lower capacity to provide cooling air for the manikin and heat flux sensors after the chamber has been exhausted of combustion gases.

5.5.6 Chamber safety devices

The exposure chamber shall be equipped with sufficient safety devices and detectors to provide safe operation of the test apparatus. These may include propane gas detectors, motion detectors, door closure detectors, fire extinguishers, emergency stops, flame detectors and any other device deemed necessary.

5.6 Fuel and delivery system

5.6.1 General

The chamber shall be equipped with fuel supply, delivery, and burner systems to provide reproducible fire exposures.

5.6.2 Fuel

The fuel shall be a propane that satisfies the requirements of ISO 7941.

5.6.3 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 density of at least 84 kW/m^2 $\pm$ 2,5 % for an exposure time of at least 8 s. Fuel delivery shall be controlled to provide an exposure duration within $\pm$ 0,1 s of the set exposure time.

NOTE 1 It is advisable that the delivery system conforms to local fire and electrical codes and standards.

NOTE 2 An exposure time of 5 s or less is sufficient for testing single-layer garments such as coveralls. If structural fire-fighting ensembles are to be tested, longer exposures can be required.

5.6.4 Burner system

5.6.4.1 General

The burner system shall consist of one ignition pilot flame for each exposure burner, and sufficient burners to provide the range of heat fluxes with a flame distribution uniformity to meet the requirements of 5.6.4.4 and Annex D.

NOTE The number and position of the burners is specific to the flame exposure chamber, depending on the dimensions of the chamber and the location of the passive air supply inlets. A minimum of eight burners is necessary, but some laboratories use twelve burners in order to achieve a satisfactory flame distribution.

5.6.4.2 Ignition pilot flame

Each exposure burner shall be equipped with an ignition pilot flame positioned near the exit of the burner, but not in the direct path of the flames so as not to interfere with the exposure flame pattern. The pilot flame is ignited with a spark ignition system 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 in order to prevent premature or erroneous opening of these valves.

5.6.4.3 Burner style

Large, induced combustion air, industrial style propane burners shall be positioned around the manikin to produce a uniform laboratory simulation of a flash fire. These burners shall produce a large yellow flame. If necessary, the gas jet may be modified or removed to yield a fuel to air mixture for a yellow flame. A single jet nozzle with an internal diameter of 0,8 mm to 1,0 mm has been found to produce an appropriate flame.

The burners [2)] shall be used and positioned so as to yield the exposure level and uniformity specified in Annex D. 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 Figure 1). Additional burners may be added if a satisfactory flame distribution can not be obtained with eight burners.

5.6.4.4 Burner positioning

The burners shall be positioned so that the average heat flux density measured for the arms, trunk, thighs and lower legs (shanks) is in each case within ± 15 % of the average heat flux density measured for the entire manikin during a 4 s nude calibration exposure.

A record of the location and orientation of the burners shall be kept and a procedure established to check their alignment and to reposition them if necessary. A method for the original positioning of the burners is given in Clause D.2.

5.6.4.5 Burner operating instructions

Procedural operating instructions shall be provided by the testing laboratory and strictly followed to ensure safe testing. These shall include exhaust of the chamber prior to any test series, checking gas detection meters to ensure that there is no accumulation of fuel due to leaks, making sure that there is no personnel within the chamber when the ignition system is activated to start a test, isolating the chamber during the test to contain the heat of the exposure and the resulting combustion products, and ventilating the chamber after the test exposure.

2) Burners meeting these requirements are available from Tiger Torch Co., 508, Centre Avenue East, Airdrie, Alberta, T4B 1P8, Canada, Ph. +1 403 948 5528, Fax. +1 403 948 9598. This information is given for the convenience of users of this International Standard and does not constitute an endorsement by ISO of the product named. Equivalent products may be used if they can be shown to lead to the same results.

5.6.4.6 Fire suppression system

The chamber may be equipped with a fire suppression system consistent with appropriate local fire safety codes.

5.6.4.7 Personal protection of test operators

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

5.7 Image recording equipment

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 as an option.

5.8 Safety checklist

A checklist shall be included in the computer operating system 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:

a) confirmation that the manikin has been properly dressed in the test specimen;

b) confirmation that the chamber doors are closed;

c) confirmation that no person is in the flame exposure chamber; and

d) confirmation that all safety requirements are met.

5.9 Specimen conditioning area

An area maintained at (20 ± 2) °C and (65 ± 5) % relative humidity shall be provided. It shall be large enough to hang test specimens with good air circulation around them.

6 Sampling and test specimens

6.1 General

6.1.1 Type of test specimen

The type of test specimen depends on the purpose of the test, as described in 6.1.2 to 6.1.4.

6.1.2 Garment/ensemble material evaluation/comparison

When used to evaluate materials, the test specimens shall be of identical design and size. A standard garment design and size suitable for use is described in 6.3.

6.1.3 Garment/ensemble design evaluation/comparison

When used to evaluate a design, the test specimens shall be constructed of the same material, be of a standard size and have the design characteristics of interest.

6.1.4 Garment/ensemble specification evaluation

When used to evaluate garments or ensembles for a particular application or to a specification, the test specimens shall be of a material and garment/ensemble design representing the anticipated application.

6.2 Number of test specimens

Test at least three specimens from the laboratory sampling unit.

6.3 Standard garment design

The standard garment shall be a coverall having a full length metal zipper closure in the front, without pockets, sleeve or pant cuffs and with no elastic at the waist, meeting the dimensional requirements provided in Table 3 after laundering (for those specimens that are not designated for limited use). The garment ease specified in Table 3 shall be relative to dimensions of the specific manikin used in testing. The construction is intentionally simple in order to minimize manufacturing costs. The standard garment should be used for evaluating/comparing materials, as in 6.1.2. Other designs can be tested, as outlined in 6.1.3 and 6.1.4.

Table 3 — Standard garment dimensions for comparing materials

Measurement/location	Minimum garment ease (difference from manikin size) mm	Maximum garment ease (difference from manikin size) mm
Chest circumference at largest value	200	230
Waist circumference at narrowest position	95	115
Hip circumference at largest value	210	230
Sleeve length (top of shoulder to wrist along arm)	0	5
Inseam (crotch to hem along the inside of the leg)	0	−20
Side length (waist to hem along the outside of the leg)	0	−20

7 Specimen preparation

7.1 Pretreatment

Each test specimen not designated for limited use shall be laundered and dried once in accordance with ISO 6330, following the procedure as specified in the referencing performance standard or the manufacturer's instructions.

Other pretreatments may be used, so long as they are fully described in the test report and all specimens tested during the test series are exposed to the same pretreatment conditions. If assessing performance against an end use specification, pretreatment shall be in accordance with the specification. Clothing designated for limited use shall not be laundered or dried prior to conditioning.

NOTE 1 Laundering is done to remove residuals from finishing processes that may have been used in the preparation of the textile materials before construction of the garments/ensembles.

NOTE 2 Limited use garments are ones that can be donned for a specific purpose, such as cleaning tanks, working with pesticides or other harmful chemicals, etc. They are usually worn over other protective clothing and discarded after one use.

7.2 Conditioning

Each test specimen shall be conditioned in the conditioning area for 24 h at (20 ± 2) °C and at a relative humidity of (65 ± 5) %. The time between removal from the conditioned area and testing shall be less than 10 min.

If the specimen cannot be tested within 10 min, the test specimen shall be sealed in a polyethylene bag (or other material with low water vapour permeability) until testing. Test specimens stored in bags shall be tested within 10 min after removal from the bag. Test specimens shall not remain in the bags for more than 4 h.

8 Procedure

8.1 Preparation of test apparatus

8.1.1 General

Safely exposing the instrumented manikin to a test flash fire requires a start-up and exposure sequence which is specific to the test apparatus. Each laboratory shall establish a start-up check-list which is employed for every exposure. As a minimum the list should include the elements below.

8.1.2 Flame exposure chamber purging

Ventilate the chamber for a period of time sufficient to remove a volume of air at least 10 times the volume of the chamber. The purge is intended to remove any fuel that may have leaked from the supply lines and that is capable of producing an explosive atmosphere.

8.1.3 Gas line charging

Close the supply line vent valves and open the valves to the fuel supply in order to charge the system with propane gas at the operating pressure up to, but not into, the chamber. Propane to the burners shall be provided by opening the last system valve just prior to each test exposure. High- and low-pressure detectors shall be set as close as feasible to the operating pressure in order to provide system shut down with a gas supply failure.

8.1.4 Confirmation of exposure conditions

Using the procedure described below for specimen testing, expose the nude manikin to the test flash fire for at least 4 s, or for the duration of the planned test exposure if less than 4 s. Confirm that the calculated incident heat flux density and its standard deviation are within specified values (see Clause D.2). If the calculated heat flux density or the variability is not within specifications, determine the cause of the deviations and correct before proceeding with specimen testing.

8.2 Specimen testing

8.2.1 General

Perform the following steps to conduct an instrumented manikin test and prepare the test report. Prior to dressing the manikin, confirm that the temperature of all the heat flux sensors is below 32 °C.

8.2.2 Dressing the manikin

Dress the manikin in the test specimen specified for the test. The specimen 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 non-flammable closure, such as metal staples. Arrange the specimen components on the manikin in the same way as they are used by the user. Use the same fit and placement of the specimen on each test to minimize variability in the test results. If a T-shirt and briefs are specified, it may be necessary to cut the T-shirt up the back for easy donning. Repair the cut with a non-flammable closure, such as metal staples or flame-resistant thread. Confirm the position of the manikin and its arms.

8.2.3 Recording the specimen identification, test conditions and test observations

The following elements shall be recorded:

a) purpose of test;

b) test series or log number;

c) specimen identification, including undergarments;

d) test conditions;

e) test observations;

f) exposure duration;

g) data acquisition time;

h) a visual image record of the front and rear of the test specimen when it has been put on the manikin;

i) any other information relevant to the test series.

8.2.4 Confirmation of safe operation conditions and lighting of pilot flames

Ensure that all the safety requirements have been met and that it is safe to proceed with the specimen exposure.

When all the safety requirements are met, light the pilot flames and confirm that the ignition pilot flame on each burner that will be used in the test exposure is actually lit. It is recommended that existence of all the pilot flames be confirmed visually before proceeding further with the test.

8.2.5 Starting the image recording system

Start the image recording system used to visually document each test.

8.2.6 Exposure of the test specimen

Initiate the test exposure by pressing the appropriate computer key. The computer program shall start the data acquisition, open the torch 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. Observe and record any after-flame duration, intensity and location on the test specimen.

8.2.7 Acquisition of the heat transfer data

Enter the time period selected for the length of data acquisition into the appropriate exposure condition field. This time shall be long enough to ensure that all of the energy stored in the specimen has been released into the atmosphere and around the manikin. Confirm that the acquisition time is sufficient by inspecting the calculated burn injury versus time information to determine that the predicted total burn injury from all the sensors has levelled 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 and retest with a new specimen. For single-layer garments, 60 s have been found to be satisfactory, while 120 s are needed for multi-layer garments and ensembles.

8.2.8 Recording of specimen response remarks

Record any remarks on the reaction of the test specimen to the exposure. These may include, but are not limited to, the relative after-flame intensity and length of time it exists on the test specimen, smoke generation, material shrinkage, charring, or observed degradation. These remarks shall become a permanent part of the test record.

8.2.9 Initiation of heat transfer and burn injury calculation

Initiate the computer program to perform the calculations needed to determine the amount of heat transferred to the surface of the manikin, the time to pain and the time at which first-, second- and third-degree burn injury begins (see 5.4.3), and to print out these results, which form part of the test report (see Clause 9).

NOTE These operations can be performed immediately after the test, or deferred for later processing.

8.3 Preparation for the next test exposure

Before disturbing the test specimen, make a visual image record of at least the front and rear of the test specimen on the manikin. Make any additional visual image records during the removal of the test specimen from the manikin. If the heat flux sensors are too hot, run the ventilating fan(s) to cool them to less than 32 °C. Inspect the manikin and heat flux sensors to be sure that they are clean of any decomposition materials. If deposits are present, clean the manikin and heat flux sensors as specified in Annex D. Ensure that the manikin and heat flux sensors are dry and, if necessary, dry them, e.g. with the ventilating fan(s) before conducting the next test.

9 Test report

9.1 General

The information described in 9.2. to 9.6 shall be included in the test report.

9.2 Type of test

State the purpose of the test. See Clause 1.

9.3 Specimen identification

Describe the specimen(s) in terms of the following information: garment/ensemble type, size, fabric basis weight, fibre type, colour, and non-standard garment features and design characteristics. Include a description of any pretreatment of the garment/ensemble components, such as laundering, and any holes or cuts in the garment/ensemble to accommodate cable connections.

9.4 Exposure conditions

Record the information which describes the exposure conditions, including

a) the total number and general arrangement of the burners used to create the flash fire exposure; a description (such as symmetrical placement at thigh and knee level, two burners per quadrant at knee and chest level) or a simple sketch is sufficient,

b) the average of the exposure heat flux density level and the standard deviation determined from the nude exposure before and after each test series (see 8.1.4 and Clause D.2),

c) the nominal heat flux density, the duration of the exposure and the duration of the data acquisition time for each test,

d) any other information relating to the exposure conditions that may assist in interpreting the test specimen results.

9.5 Calculated results

9.5.1 General

The results can be based on two measurements: the total surface area of the manikin receiving second- and third-degree burn injury, and/or the total energy transferred to the surface of the manikin during the data acquisition period. These two measurements are directly related.

For all material, garment evaluation and specification test reports, include at least the information indicated in 9.5.2 and 9.5.3 from the results of the computer program. Base the predicted burn injury both on the total area of the manikin containing heat flux sensors and on the total area of the manikin covered by the test specimen. For certification purposes, it is preferable to use the burn injury based on the total area of the manikin containing heat flux sensors.

NOTE Other useful measurements are the time it takes for the onset of pain and first-degree burn injury.

9.5.2 Predicted total area (%) of manikin injured based on the total area of the manikin containing heat flux sensors

a) Predicted manikin area of second-degree burn injury (%).

b) Predicted manikin area of third-degree burn injury (%).

c) Predicted total manikin area of burn injury [sum of second-degree and third-degree burn injury (%) and associated variation statistic, such as the standard deviation].

9.5.3 Predicted total area (%) of manikin injured based on area of manikin covered by the test specimen

a) Predicted covered area of second-degree burn injury (%).

b) Predicted covered area of third-degree burn injury (%).

c) Predicted total covered area of burn injury [sum of second-degree and third-degree burn injury (%) and associated variation statistic, such as the standard deviation].

9.5.4 Other information that may be reported

a) Total energy received by all heat flux sensors as the sum of the energy transferred to each heat flux sensor over the data sampling period.

b) Diagram of the manikin showing location and burn injury levels as predicted second-degree and third-degree burn areas.

c) Table of individual heat flux sensor results.

9.6 Observations

Record on the test report any observations about the results of the exposure on the test specimen. These observations may include, but are not limited to

a) intensity, duration and location of after-flame and/or afterglow,

b) smoke and/or toxic fume generation,

c) physical stability of the test specimen, including dimensional change (if any),

d) any other observation that may be used to interpret the results which describes the performance of the test specimen.

Support the observations with a visual image record (see 5.7, 8.2.3, 8.2.5 and 8.3).

Annex A
(informative)

Considerations for conducting tests and using test results

A.1 Special care shall be taken in the design of tests and the interpretation of test results using this test method. Clauses A.2 to A.8 outline some of the matters that should be considered in designing tests and/or interpreting results from this test method.

A.2 The fit of the specimen on the manikin will have a significant effect on the specimen's performance. The air layer between garment layer(s) and the manikin surface provides a significant amount of insulation. This air layer may vary throughout the garment with respect to the manikin surface. For this reason, it is essential that the cut of the garment and its sizing be identical when comparing different garment or ensemble materials. Experience from testing single-layer coveralls suggests that increasing the size of the garment by one nominal size decreases the total area of the manikin receiving second- and third-degree burn injury by 5 %.

A.3 The design of the garment or ensemble in terms of closure placement, collar height, sleeve ends, trouser cuff ends, pockets and the presence of inner linings or reinforcements will have a significant effect on the garment's performance. Areas having additional materials are likely to provide more insulation than other areas of the garment. For this reason, it is essential to use the same base material in a garment to isolate differences in garment performance which are related to specific designs. Note that with some materials there can be a strong interaction between the material and the design. This may necessitate evaluation of more than one design using several different materials in order to achieve the desired performance.

A.4 The use of undergarments or other accessory clothing will affect test results. For example, the use of underwear for garment testing may provide additional thermal insulation and result in increased performance when compared to tests where no underwear is used. Therefore, in comparing test results between different garments, it is essential that all test conditions, including the use of undergarments, be identical. Examination of inter-laboratory test results presented in Annex B, Conditions 2 and 3, suggests that a significant reduction in predicted total burn injury will occur when T-shirt and briefs are worn under a single-layer coverall.

A.5 Testing is performed under static conditions only. There is no movement of the manikin, whereas in actual use conditions, wearing of the garment(s) may involve significant movement and affect test results.

A.6 While the test method is designed to provide uniform heat flux exposure of the manikin, variations in flame impingement and heat levels can introduce variability of garment performance for the same test conditions and test garments. This variation can only be determined by conducting multiple tests of the same garment (design and material) under the same exposure conditions.

A.7 Test results can be used for comparing different materials, garment designs, prototype garments and potential exposures. The tests evaluate garments under controlled laboratory conditions. The accidental exposure of protective garments to fire in the field involves a variety of exposure conditions which may not be modelled by this test method.

A.8 Statistics on survival rates when people receive skin damage from burns are gathered by medical authorities in various parts of the world. One source that may be of interest when interpreting the results is the Journal of Burn Care Rehabilitation. In 1995 and 1996, this journal contained articles on survival statistics for burn victims in the U.S.A.

Annex B
(informative)

Inter-laboratory test data

B.1 An inter-laboratory test was conducted using this test method involving seven different laboratories, three different materials and four exposure conditions. The laboratories were located in Europe (2), Japan (2), and North America (3). One of the North American laboratories used two different types of sensors, giving an additional set of results for a total of eight.

B.2 The three materials were the following:

— Material A: Indura® Flame Retardant Treated Cotton at a nominal fabric basis weight of 305 g/m^2;

— Material B: Nomex® IIIA at a nominal fabric basis weight of 203 g/m^2;

— Material C: Kevlar®/Pbi® (60 %/40 %) at a nominal fabric basis weight of 153 g/m^2.

B.3 The four exposure conditions were the following:

— Condition 1: 3 s at 84 kW/m^2 with a manikin dressed only in the test coverall;

— Condition 2: 4 s at 84 kW/m^2 with a manikin dressed only in the test coverall;

— Condition 3: 4 s at 84 kW/m^2 with a manikin dressed in 100 % cotton T-shirt and briefs under test coverall;

— Condition 4: 5 s at 84 kW/m^2 with a manikin dressed in 100 % cotton T-shirt and briefs under test coverall.

B.4 All testing was performed on garments using an identical coverall design. Each laboratory conducted three separate tests on each coverall at each condition (a total of 36 tests for each laboratory).

B.5 The overall inter-laboratory test results achieved are listed in Table B.1.

Table B.1 — Instrumented manikin test precision summary

Material	Condition 1			Condition 2			Condition 3			Condition 4		
	avg.	S_r	S_R	avg.	S_r	S_R	avg.	S_r	S_R	avg.	S_r	S_R
A	11,4	3,0	4,4	67,8	7,5	17,1	54,2	7,1	20,5	82,8	3,5	6,9
B	30,1	5,7	13,1	63,7	3,1	14,1	43,9	3,5	7,7	54,8	3,7	6,9
C	37,9	3,9	15,1	64,3	2,5	8,8	48,9	4,1	7,7	62,9	1,9	5,6

avg. is the mean of the mean total percent body burn reported by each laboratory based on the area covered by sensors.

S_r is the repeatability standard deviation (for intra-laboratory precision).

S_R is the reproducibility standard deviation (for inter-laboratory precision).

NOTE The method used to report the S_R values in this table means that they are also percentages. The average of all the S_R values in the above table is 10,7 %. By comparison, when the testing was done for ISO 9151, the standard deviation was 10 %.

Annex C
(informative)

Estimation of skin burns

The estimation of skin burning should be done based on work by Henriques and Moritz [1]. Their work, combined with others, especially Stoll et al. [2], [3], have shown 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 is critical. It has been found that the destruction rate could be closely modelled by a first order chemical reaction, as follows:

$$\frac{\mathrm{d}\Omega}{\mathrm{d}t} = P\mathrm{e}^{\frac{-\Delta E}{RT}} \tag{C.1}$$

where

Ω is a quantitative measure of burn damage at the basal layer or deeper;

P is the frequency factor, s^{-1};

ΔE is the activation energy for skin, J/mole;

R is the universal gas constant, 8,315 J/mole K;

T is the absolute temperature at the basal layer or deeper, K;

t is the total time for which T is above 44 °C (317,15 K).

The total burn damage is found by integrating Equation (D.1) over the time interval during which the basal or a deeper layer is above 44 °C, as follows:

$$\Omega = \int P\mathrm{e}^{\frac{-\Delta E}{RT}}\,\mathrm{d}t \tag{C.2}$$

Henriques and Moritz [1] found that if Ω is less than or equal to 0,53, no damage will occur at the basal layer. If Ω is between 0,53 and 1,0, first-degree burns will occur, while 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. For this test method, a second-degree burn injury is defined as an $\Omega > 1{,}0$ at the epidermis/dermis interface or deeper, and a third-degree burn injury as an $\Omega > 1{,}0$ at the dermis/subcutaneous interface or deeper.

Morse et al. [4] have examined the various values of P and ΔE available in the literature and suggest that the criteria developed by Stoll and Chianta [3] be used in the epidermal layer and that those of Takata [5] be used in the dermal and subcutaneous layers. The values of P and ΔE developed by Stoll and Chianta [3] are the following:

for $T < 50$ °C $\quad P = 2{,}185 \times 10^{124}\ \mathrm{s}^{-1}$
$\Delta E/R = 93\ 534{,}9$ K

for $T > 50$ °C $\quad P = 1{,}823 \times 10^{51}\ \mathrm{s}^{-1}$
$\Delta E/R = 39\ 109{,}8$ K

while those of Takata [5] are the following:

for $T < 50$ °C $P = 4{,}32 \times 10^{64}$ s^{-1}
$\Delta E/R = 50\ 000$ K

for $T > 50$ °C $P = 9{,}39 \times 10^{104}$ s^{-1}
$\Delta E/R = 80\ 000$ K

In order to predict the extent of damage that would result in a fire, it is necessary to know the temperature history at the epidermis/dermis interface and the dermis/subcutaneous interface. The heat flux density sensors in the manikin are used for this purpose. They permit the surface heat flux density and its variation with time to be predicted. This information is then used to predict the temperature history at the two interfaces in the skin and the extent of skin damage that would result for each sensor location.

The physical properties to be used in the skin burn model are listed in Table C.1.

Table C.1 — Physical properties to be used in the skin burn model

Parameter	Skin location		
	Epidermis	Dermis	Subcutaneous tissue
Thickness of layer (m)	8×10^{-5}	$1{,}5 \times 10^{-3}$	1×10^{-2}
Thermal conductivity, λ (W/m K)	0,255	0,523	0,167
Volumetric heat capacity, c_{vol} (J/m^3 K)	$4{,}32 \times 10^6$	$3{,}87 \times 10^6$	$2{,}76 \times 10^6$

Additional information on the use of a skin burn model suitable for computer programming using the finite element method can be found in Torvi and Dale [6]. A complete numerical model using the finite difference method to predict the temperature history in skin and burn injury is presented in a report from the Protective Clothing and Equipment Research Facility, University of Alberta [7].

General information on manikin testing is provided by Dale et al. [8].