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Protective clothing against heat and flame —

Part 1: Test method for complete garments — Measurement of transferred energy using an instrumented manikin

Vêtements de protection contre la chaleur et les flammes —

Partie 1: Méthode d'essai pour vêtements complets — Mesurage de l'énergie transférée à l'aide d'un mannequin instrumenté

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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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html

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

This first edition of ISO 13506-1, together with ISO 13506-2, cancels and replaces the first edition of ISO 13506:2008, which has been technically revised. The assessment of skin burn injury has been transferred to ISO 13506-2.

A list of all parts in the ISO 13506 series can be found on the ISO website.

Introduction

The purpose of heat and flame-resistant protective clothing is to shield the wearer from hazards that can cause skin 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 transferred energy through them when exposed to a particular hazard. A variety of test methods are used in these two steps. The test method selected depends on the nature of the potential hazards and the intended end use of the materials. Once suitable materials have been identified, they can be made into complete garments or ensembles for testing on a manikin-fire exposure system.

Laboratory bench scale transferred energy tests are used to select suitable materials for a protective clothing ensemble. While these tests can allow 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.

Bench scale transferred energy test methods use small amounts of material, up to 150 mm × 150 mm in area, and hold the material initially flat, either in a vertical or horizontal plane. Multiple layers are used where appropriate (e.g. 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. With the aforementioned test methods, it is possible to test seams, zippers, pockets, buttons or other closures, metal and plastic clips or other features that can be included in a complete garment such as heraldry, company logos, etc. However, it is often considered easier to evaluate these aspects together with the overall design features of a garment or ensemble that can affect the performance by testing complete garments or ensembles on a manikin. It is for this purpose that this document was established.

In the test method in this document, a stationary, upright adult-sized manikin is dressed in a complete garment and exposed to a laboratory simulation of a fire with controlled heat flux, duration and flame distribution. The average incident heat flux 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. Heat flux sensors fitted to the surface of the manikin are used to measure the heat flux variation with time and location on the manikin and to determine the total energy absorbed over the data-gathering period. The data gathering period is selected to ensure that the total energy transferred has been completed. The information obtained 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 (see ISO 13506-2).

The manikin is used in a standing position in initially quiescent air. Controlled air motion for simulating wind effects or body movement is not presently possible. It is possible to move the manikin through a stationary flame but motion of this nature is not within the scope of this document. 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 fire than the exposures used in bench scale tests (see Annex B). The heat flux 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, sagging or shrinkage 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. Thus variations in garment design and how the manikin is dressed by the operator can influence the test results. A test garment or specimen size is selected by the laboratory from the size range provided by the manufacturer to fit the laboratory's manikin. 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 document 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 complete garments will not necessarily be ranked in the same order as might be obtained when the materials are tested using ISO 9151. Correlations between small scale tests and results from single-layer garments have been examined[15].

Most manikins do not have sensors on the hands and feet, 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 flux 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 flux 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 (this document) or used to calculate the nature, location and extent of the damage that would occur to human skin from the exposure (see ISO 13506-2).

References [16] and [17] give 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 ISO/TC 94, SC 13 and SC 14 committees and European Committee for Standardization (CEN TC 162) specify the method described in this document as an optional part in the fire fighter standards ISO 11999-3 and EN 469[11], and as an optional part in the industrial heat and flame protective clothing standard ISO 11612. The National Fire Protection Association (NFPA) specifies a test method similar to the one described in this document as part of a certification process for garments (see NFPA 2112[13]).

Protective clothing against heat and flame —

Part 1:
Test method for complete garments — Measurement of transferred energy using an instrumented manikin

1 Scope

This document specifies the overall requirements, equipment and calculation methods to provide results that can be used for evaluating the performance of complete garments or protective clothing ensembles exposed to short duration flame engulfment.

This test method establishes a rating system to characterize the thermal protection provided by single-layer and multi-layer garments made of flame resistant materials. Any material construction such as coated, quilted or sandwich can be used. The rating is based on the measurement of heat transfer to a full-size manikin exposed to convective and radiant energy in a laboratory simulation of a fire with controlled heat flux, duration and flame distribution. The heat transfer data are summed over a prescribed time to give the total transferred energy.

For the purposes of this test method, the incident heat flux is limited to a nominal level of 84 kW/m^2 and limited to exposure durations of 3 s to 12 s dependant on the risk assessment and expectations from the thermal insulating capability of the garment. 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, duration and flame distribution.

This test method requires a visual evaluation, observation and inspection on the overall behaviour of the test specimen during and after the exposure as the garment or complete ensemble on the manikin is recorded before, during and after the flame exposure. Visuals of the garment or complete ensemble on the manikin are recorded (i.e. video and still images) before, during and after the flame exposure. This also applies to the evaluation of protection for the hands or the feet when they do not contain sensors. For the interfaces of ensembles tested, the test method is limited to visual inspection. The effects of body position and movement are not addressed in this test method.

The heat flux measurements can also be used to calculate the predicted skin burn injury resulting from the exposure (see ISO 13506-2).

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

NOTE 1 This test method provides information on material behaviour and a measurement of garment performance on a stationary upright manikin. The relative size of the garment and the manikin and the fit of the garment on the shape of the manikin have an important influence on the performance.

NOTE 2 This test method is complex and requires a high degree of technical expertise in both the test setup and operation.

NOTE 3 Even minor deviations from the instructions in this test method can lead to significantly different test results.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 6942, *Protective clothing — Protection against heat and fire — Method of test: Evaluation of materials and material assemblies when exposed to a source of radiant heat*

ISO 9162, *Petroleum products — Fuels (class F) — Liquefied petroleum gases — Specifications*

ISO/TR 11610, *Protective clothing — Vocabulary*

ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/TR 11610 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at http://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
absorbed energy
energy (3.5) absorbed by each *manikin sensors* (3.14) mounted in the surface of the manikin when exposed to the *incident energy* (3.12)

Note 1 to entry: This does not account for radiant or convective losses unique for each style of sensor.

3.2
associated area
area of body region divided by the number of sensors in that body region

Note 1 to entry: See Table 2.

3.3
complete garments
single garment or combination of garments designed to protect the torso, arms and legs of the wearer

Note 1 to entry: 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.

3.4
conditioning
keeping samples under standard conditions of temperature and relative humidity for a minimum period of time

3.5
energy
heat flux (3.10) multiplied by the time period of measurement and by *associated area* (3.2)

3.6
energy transmission factor
ratio of the *transferred energy* (3.18) to the *incident energy* (3.12), for the energy calculation period

3.7
fire
rapid oxidation process which is a chemical reaction of fuel and oxygen resulting in the evolution of light, heat and combustion products in varying intensities

Note 1 to entry: The fuel can be a solid, dust, a gas or vapours of an ignitable liquid. The fire will last as long as there is a combustible fuel-air mixture.

3.8
flame distribution
spatial distribution of incident flames from the test facility burners which provides a controlled *heat flux* (3.10) over the manikin surface

3.9
garment ease
difference between body (manikin) dimensions and garment dimensions

3.10
heat flux
thermal intensity indicated by the amount of energy transmitted divided by time and by area to the surface

Note 1 to entry: Heat flux is expressed in kW/m^2.

3.10.1
absorbed heat flux
heat flux (3.10) absorbed by the *manikin sensors* (3.14) mounted in the surface of the manikin when exposed to the *incident heat flux* (3.10.2)

3.10.2
incident heat flux
heat flux (3.10) to which a test item or nude manikin is exposed

Note 1 to entry: The incident heat flux is determined from the characteristics of the *manikin sensors* (3.14) and their measured output during a nude manikin exposure.

3.11
heat flux sensor
device capable of directly measuring the *heat flux* (3.10) to the manikin's surface under test conditions, or of providing data that can be used to calculate the heat flux

Note 1 to entry: 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/or the predicted skin burn injury.

3.12
incident energy
energy (3.5) to which a test item or nude manikin is exposed

3.12.1
total incident energy
sum of the *incident energy* (3.12) of all the *manikin sensors* (3.14) during the nude exposure

3.13
instrumented manikin
model representing an adult-sized human which is fitted with *manikin sensors* (3.14) in the surface

3.14
manikin sensor
heat flux sensor (3.11) fulfilling the requirements of this document

Note 1 to entry: See 3.11 and 5.3.

3.15
maximum heat flux
highest value of *absorbed heat flux* (3.10.1) calculated from the recorded output of a *manikin sensor* (3.14) during a test

3.16
protective clothing ensemble
combination of complete protective garments

Note 1 to entry: This document does not include energy transferred to the hands and feet. Gloves and footwear can be included in the ensemble for visual inspection. This will allow a more realistic representation of interfaces and make possible a visual inspection of gloves and footwear during and after the test.

3.17
thermal protection
overall protective performance of a garment or *protective clothing ensemble* (3.16) relative to how it limits the transfer of energy to the manikin surface over the defined calculation period

Note 1 to entry: In fire testing of clothing, thermal protection of a garment or ensemble can be quantified by the measured *manikin sensor* (3.14) 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 manikin sensor calculation and are useful in understanding garment or protective clothing ensemble thermal protection.

3.18
transferred energy
energy (3.5) transferred through the test item and absorbed by a *manikin sensor* (3.14) over the defined calculation period

3.18.1
total transferred energy
sum of the *transferred energy* (3.18) of all *manikin sensors* (3.14) over the *transferred energy calculation period* (3.18.2)

Note 1 to entry: Each manikin sensor has an *associated area* (3.2). It is assumed that the measured energy transferred for each manikin sensor is uniform over this associated area. Some manikins have a sensor layout that has the same area associated with each manikin sensor, others do not.

3.18.2
transferred energy calculation period
measurement time when *transferred energy* (3.18) is gathered

Note 1 to entry: See 8.2.6.

4 General

The method evaluates the thermal protective performance of the test specimen, which is either a garment or an ensemble. The protective performance is a function of both the materials of construction and design. The average incident heat flux is 84 kW/m^2 with an exposure duration of 3 s to 12 s.

The product standard shall indicate the minimum exposure time and the minimum number of samples to be tested.

The conditioned test specimen is placed on a stationary upright adult-size manikin 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.

Energy transferred through the test specimen during and after the exposure is measured by manikin sensors. These measurements shall be used to calculate the total energy transferred to the surface of the manikin and the energy transmission factor.

NOTE 1 The purpose of this test method is to measure the heat flux and calculate transferred energy. The results can also be used to calculate the degree of predicted skin burn injury and total predicted skin burn injury areas resulting from the exposure as described in ISO 13506-2.

Identification of the test garment, test conditions, comments 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 transferred energy through the test specimen over the data acquisition period, the total energy transmission factor and the way the test specimen responds to the test exposure.

NOTE 2 This test method can be used for other purposes such as for research on fabrics and garment designs, comparison of garment ensembles, or evaluation of any garment or ensemble to particular applications or end use standards or specifications.

5 Apparatus

5.1 Instrumented manikin

An upright manikin, which is the shape and size of an adult human, shall be used [see Figure 2 a) and b)]. The manikin shall be constructed to simulate the body of a human and shall consist of a head, a chest/back, an abdomen/buttocks, arms, hands, legs and feet. The arms should be able to rotate through a sufficient arc at the shoulder to ease the garment donning and doffing on the manikin.

NOTE 1 Figure 2 illustrates a male shape and the dimensions of Table 1 are for a male manikin. A standard female form has not yet been determined.

The manikin shall be constructed of flame-resistant, thermally stable, non-metallic materials such as ceramics or glass-reinforced vinyl ester resin that will not contribute to the combustion process. The shell thickness shall be in the range of 3 mm to 6 mm other than in localized areas (e.g. joints).

NOTE 2 The manikin thickness is dependent on structural requirements needed to maintain a stable physical form related to the thermal properties of the manikin material and it has been historically observed to affect the operability of the manikin rather than the reproducibility of results. For example, the variance of thickness of a manikin has been found to affect its durability due to differential thermal stresses that increase the risks of cracking. In addition, the greater the thickness of the manikin, the longer it takes to cool. The manikin utilizes a hollow structure to allow for the electrical wiring of the sensors.

The manikin shall not be made of a material, which may be affected by humidity or any cleaning liquid (e.g. water, acetone, etc.), which may be used for the cleaning of the manikin sensors.

5.2 Posture of the manikin

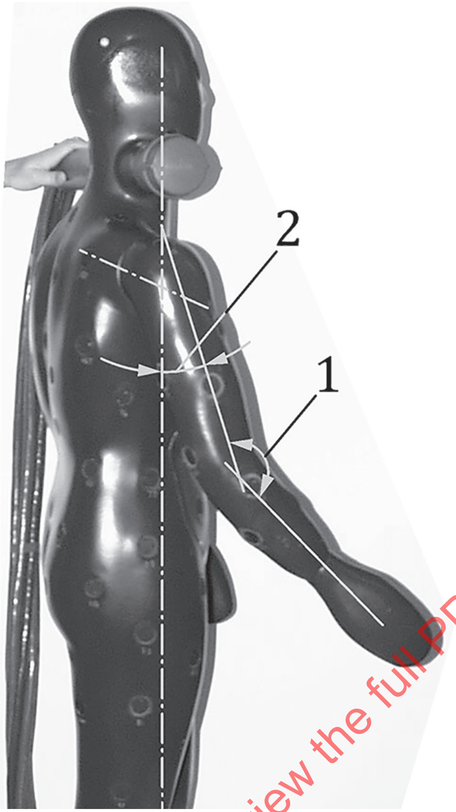
A reproducible positioning system is required for the manikin. It may consist of pin locators in the floor, a portable rigid positioning frame and/or light or laser beams for setting vertical orientation and arm position.

The elbow angle between the upper and lower arm (see Figure 1) shall be set in the range of 150° to 165°. The angle of the shoulder (see Figure 1) shall be set in the range of 25° to 35° from the centreline of the manikin. These angles apply to all manikin exposures (nude and with test items). Reference lines and angles are identified in Figure 1.

NOTE 1 Tape can be used to increase the friction of the joints of the arm to ensure that the position is maintained during the exposure[1)].

1) Gore® Joint Sealant is an example of a suitable product available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of this product. Equivalent products may be used if they can be shown to lead to the same results.

NOTE 2 Most manikins have legs that cannot move. Some manikins have a slight twist of the torso as compared to the legs. The legs are less than 10° apart from the centre line and at the ankles, they are about 120 mm to 250 mm apart.

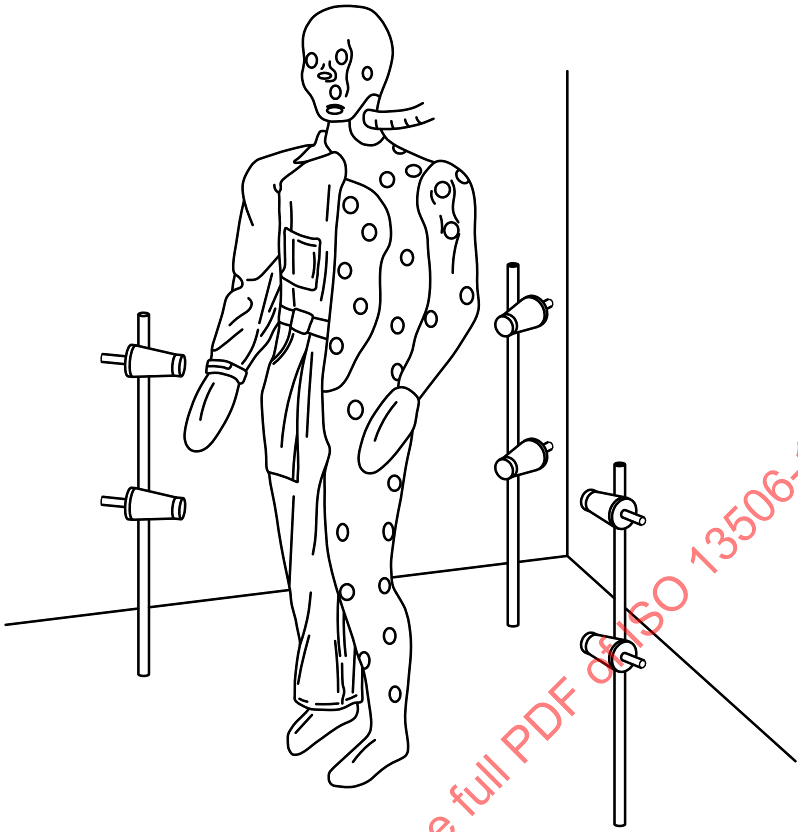


Key

1 angle between upper arm and lower arm

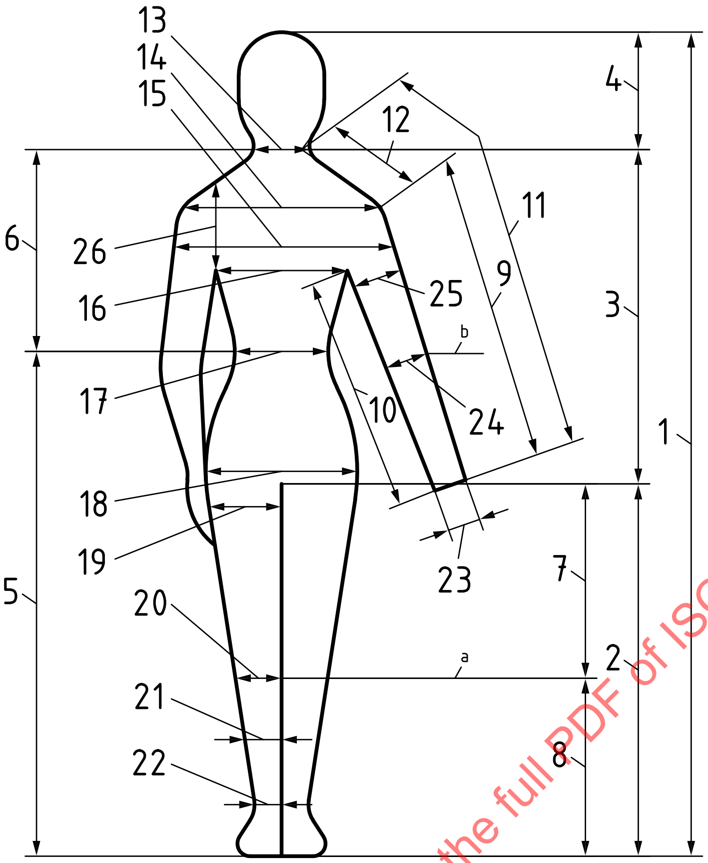
2 angle between line shoulder and hip to shoulder and elbow

Figure 1 — Definition of arm position



a) Instrumented manikin and torch stands (burner system)

Figure 2 *(continued)*



b) Measurements for adult manikin

Key

a Knee level.

b Elbow level.

NOTE 1 Only six burners of the total are shown in Figure 2 a) (see 5.7.2)

NOTE 2 The instrumented manikin matches the dimensions given in Table 1 and the key to the numbers referenced in Figure 2 b) correspond to the measurements in Table 1.

Figure 2 — Representation of an instrumented manikin

Table 1 — Measurements for an adult manikin

No	Description	Measurement mm	Tolerance mm
1	Stature/total height	1 810	±60
2	Crotch height, from heel	880	±75
3	Trunk (from back of neck to crotch back to front neck)	1 560	±60
4	Head height, including neck	255	±45
5	Waist height, from heel	1 125	±50
6	Collarbone to back waist	480	±70
7	Crotch to knee	330	±45
8	Knee height, standing	530	±70
9	Top of shoulder to wrist along arm	585	±75
10	Arm inseam	470	±40
11	Sleeve length, 3-point measurement from collarbone to wrist	785	±65
12	Shoulder length (from base of back of neck to arm hole-union)	170	±75
13	Neck circumference	420	±60
14	Across shoulder (from one shoulder across back to other shoulder)	500	±90
15	Across chest, (100 mm down)	475	±95
16	Chest circumference, at the armpits	995	±105
17	Waist circumference	870	±25
18	Hip circumference, maximum	1 015	±15
19	Thigh circumference just below buttock	590	±40
20	Knee circumference	390	±50
21	Calf circumference	400	±30
22	Ankle circumference	280	±30
23	Wrist circumference	205	±30
24	Elbow circumference	290	±25
25	Upper arm circumference, at the midpoint	320	±35
26	Shoulder circumference	410	±50

NOTE Manikins meeting these requirements is available from either of:

— Composites USA, 1 Peninsula Drive, Northeast, Maryland, USA. Ph. +1 302 834 7712,

— Precision Products LLC, 7400 Whitepine Road, Richmond, Virginia, USA, Ph. +1 804 561 0777,

— Measurement Technology Northwest,/Thermetrics, LLC, 4220 - 24th Avenue West, Seattle, WA 98199, USA,

— MYAC Consulting Inc., 23046 Township Road 514, Sherwood Park, AB, T8B 1K9, Canada.

This information is given for the convenience of users of this document and does not constitute an endorsement by ISO. Equivalent products may be used if they can be shown to lead to the same results.

5.3 Manikin sensors

5.3.1 Principle

The measurement system shall use manikin sensors which produce an output, which can be used to calculate the incident heat flux, or absorbed heat flux, at its surface under the test conditions. The incident heat flux measurement is used to set the exposure conditions for testing (nude exposure); the absorbed heat flux is used in the calculation of the energy transferred through the test specimen.

Each manikin sensor has an associated area. Some manikins have a sensor layout that has the same area associated with each manikin sensor; others do not. If a manikin system has unequal sensor areas, the results calculated from the manikin sensor data shall be permitted to be area weighted.

The area associated with any manikin sensor shall be determined by locating points to the surrounding sensors. These points are joined by straight lines on the curved surface of the manikin. The area so formed around a particular manikin sensor is its associated surface area (see Figure 3). The design layout of the manikin sensors can be such that each associated surface area has approximately the same value. The test results report both the individual sensor results and the calculated average of the body parts of the manikin. The number of sensors per area needs to be sufficient to be able to describe the garment performance.

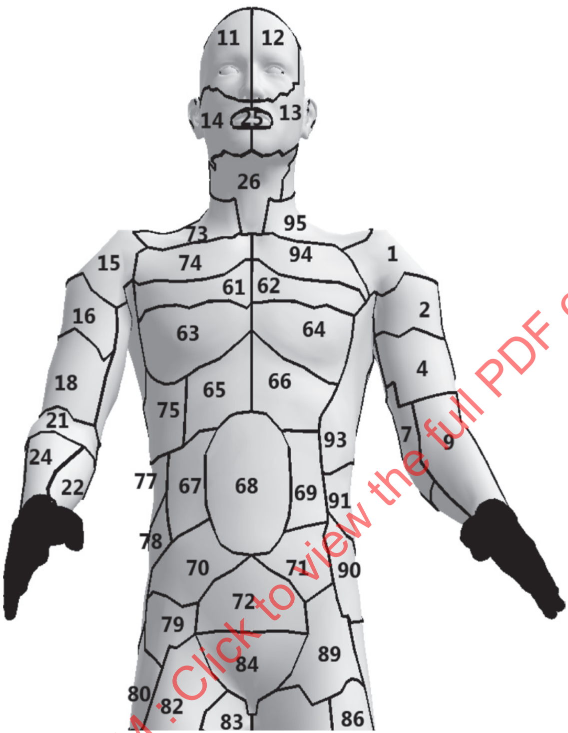


Figure 3 — Example of manikin sensor location and their associated area

The incident heat flux is not equivalent to the absorbed heat flux during a nude exposure. The incident heat flux is calculated from the calculated absorbed heat flux at each manikin sensor taking into account the ability of the manikin sensor surface to absorb thermal energy from the flames and how much is exchanged with to the walls of the room (see also 5.5.1).

NOTE All the convective energy present at the surface of the sensor is absorbed by the sensor. Only radiant energy is lost from the sensor surface during the nude exposure. The calculation from the incident energy to the absorbed is not currently defined and is often assumed that they are equivalent.

5.3.2 Number of manikin sensors

The system shall use a minimum of 110 manikin sensors distributed as uniformly as practical over the surface of the manikin (which excludes hands and feet). Table 2 describes an acceptable manikin sensor distribution.

The manikin used in this test method is composed of a complex, three-dimensional surface topography. Minor trade-offs are required in order to locate sensors over its surface that approaches a distribution that is as uniform as practical given the geometry of the manikin form.

Table 2 — Sensor distribution

Body region	Body area	Minimum number of manikin sensors	Percentage of total sensored area without sensors in hands or feet %	Percentage area of body (area in m² based on an assumed body surface area of 2 m²); see Note 2 %
Head	Head	8	7	7,8 (0,156)
Chest and abdomen	Chest	10	40 (Trunk)	35,5 (0,71) (Trunk)
	Abdomen	11		
Back	Upper back	11		
	Lower back	11		
Right arm	Arms	18	16	13,9 (0,278)
Left arm				
Right leg	Thighs and lower legs (Shanks)	41	37	30,5 (0,6)
Left leg				
If sensor used include in arms	Hands	0	—	5,4 (0,108)
If sensor used include in legs	Feet	0	—	6,9 (0,138)
	Total	110	100	100 (2)

NOTE 1 The number of manikin sensors presently used in manikins range from 110 to 126. Depending on the number of manikin sensors and their location, column 3 (110 sensors used) or column 4 (more than 110 sensors used) is used. Extra sensors can be added to the hands and feet if desired. Adding manikin sensors to the hands and feet will require the percentages in Table 2, column 5.

NOTE 2 Several sources [e.g. US. EPA. Exposure Factors Handbook (1997 Final Report). US. Environmental Protection Agency, Washington, DC, EPA/600/P-95/002F a-c, 1997 (partially being updated)] assume a total surface area of approximately 2 m² for a male of approximately 1,85 m in height and with average weight. Subtracting the area not covered by sensors (hands and feet) results in a surface area of approximately 1,8 m².

5.3.3 Manikin sensor measuring capability

Each manikin sensor shall have the capability to determine an incident heat flux over the range from 0 kW/m² to 130 kW/m². The manikin sensor shall tolerate heat fluxes up to 200 kW/m² and withstand rapid heat flux changes (e.g. 4 s nude exposure) without being destroyed. This range permits the use of the manikin sensors to set the testing exposure level by exposing the nude manikin directly to flame and also to measure the heat transferred to the exposed manikin surface with a test specimen.

NOTE Sensor functioning in the range of 0 kW/m² to 130 kW/m² and resisting destruction at heat fluxes up to 200 kW/m² depends on manufacturer's specification and stated calibration curves and other response correction factors. Calibration with a traceable reference sensor and a radiant heat source are only good to about 40 kW/m² as accepted traceable references are not available above this level.

5.3.4 Manikin sensor construction

The manikin sensors shall be constructed of a material with known thermal characteristics that can directly indicate the heat flux or be calculated from sensor temperature responses to indicate heat flux and its variation with time as received by the sensor. The outer surface of the sensor shall have an absorptivity greater than or equal to 0,9 or shall be covered with a thin layer of flat black high-temperature paint with an absorptivity greater than or equal to 0,9[2]. The manikin sensor, data acquisition system combination, when calibrated with a NIST (National Institute of Standards and Technology) or equivalently certified reference sensor, shall respond within 0,2 s of the start of the exposure and reach a minimum of 80 kW/m^2 within 1 s when exposed to 84 kW/m^2 .

NOTE 1 Manikin sensors that have been used successfully include Gardon gauges, slug calorimeters and skin-simulant sensors with buried or surface temperature sensors.

NOTE 2 The dynamic response of the heat flux sensor used for thermal manikin testing is dependent on many elements including the sensing element's design and its thermal inertia. For sensors based on thermocouples, designs that minimize the thermal inertia in the thermocouple component are desired. These include intrinsic designs (the junction is based on surface contact area of each wire connected independently through an intermediate thermal conducting material — to achieve ms time scale with large wire diameters, e.g. 0,3 mm and less, fastest design), wire joining by butt junction welding (transient response related to wire diameter — values of 0,18 mm and less result in response times of ~150 ms or better) and wire joining by welding resulting in a beaded junction (bead size of 0,12 mm and less result in response times of ~150 ms or better).

The time response of the manikin sensor design shall be verified by exposing representative samples to a sudden change in heat flux. An allowed technique uses a calibration heat source and a shutter system (use the shutter system to expose the manikin sensor to a sudden change in incident heat flux). Other methods are allowed that provide appropriate timing information. The calculated incident heat flux of the manikin sensor shall reach at least 60 % of the calibration heat source value within 0,5 s or less after the shutter is opened.

5.3.5 Manikin sensor positioning

The manikin sensors installed on the manikin surface shall be recessed from the surface no greater than 1,5 mm or protruding from the surface no greater than 2 mm on opposite sides in high curvature regions where a central axis is flat to the manikin surface.

NOTE 1 Some differences can be expected for manikin sensors in small radius curved surface locations (for example, locations on the arms and legs). The position of the manikin sensor surface with respect to the manikin surface has been demonstrated to influence its readings. Manikin sensor edges cannot protrude beyond the above requirements to manikin surface. This typically results in the heat flux being higher if the sensor protrudes or being lower than expected if the sensor is below the surface of the manikin.

NOTE 2 The sensor heat flux reading could be increased or decreased due to the fact of a bridge or insulation being created at the sensor surface due to the accumulation of soot or deposit between the sensor and the manikin. Cleaning of the sensor socket needs to be completed on the regular basis in case of testing of garment that leave such a residue.

5.3.6 Manikin sensor calibration

Calibration of each individual manikin sensor shall be carried out according to the procedure of C.2.

5.4 Data acquisition system

A system shall be provided which is capable of acquiring and storing the results of the output from each manikin sensor at a minimum sampling rate of 10 samples per second during the whole data acquisition period of at least 240 s.

The accuracy of the measurement system shall be better than 2 % of the reading or ±1,0 °C, if a temperature sensor is used.

2) Krylon # 1618 BBQ and Stove; Krylon #1316 Sandable Primer; Krylon #1614 High Heat and Radiator paint and PyroMark 1200 have been found to be effective. See ASTM Study, "Evaluation of Black Paint and Calorimeters used for Electric Arc Testing", ASTM contract #F18-103601, Kinectrics Report: 8046-003-RC-0001-R00, August 22, 2000. This information is given for the convenience of users of this document 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.

The data acquisition system for both manikin and calibration systems (if different) shall have at least the following specifications:

a) analog-to-digital conversion resolution ≥16 bit;

b) individual channel sampling frequency ≥10 Hz;

c) temperature resolution greater than 0,01 °C;

d) hardware filtering, if used 2 Hz to 50 Hz, (typically 15 Hz).

NOTE Hardware filtering is optional, as this is also accomplished through software means. The purpose of filtering is to minimize sampling artefacts arising from induced electrical noise in the sensor responses generated from electrical-mechanical interferences (EMI) such as solenoid valves opening and closing, chamber lighting sources, ignition equipment, etc. High EMI or noise environments have been observed to add biases to the measured sensor responses.

5.5 Computer software program

5.5.1 General

A computer software program which is capable of calculating the following shall be utilized.

5.5.1.1 For calibration of the flame engulfment from the nude exposure

a) Measure absorbed heat flux over time or transform manikin sensor data into absorbed heat flux over time.

b) Calculate incident heat flux based on the absorbed heat flux (see 5.3.1 and 5.5.2).

NOTE Calculating the incident energy requires knowledge of the convective heat transfer to the sensor surface, sensor emissivity, partitioning of the radiant and convective heat transfer modes and an accepted 84 kW/m^2 value based on an accepted reference heat flux. Additional sensor response corrections are needed for certain sensor designs that address materials of construction induced heat losses, heat gains and baseline offsets.

c) Calculate the exposure heat flux for each manikin sensor according to C.2, providing the resulting heat flux over time to calculate the exposure heat flux.

d) Calculate the total average exposure heat flux for the whole manikin.

e) Verify that the exposure heat flux values for each body region (head, right arm, left arm, chest and abdomen, back, left leg and right leg) and the whole manikin meet the described criteria (see 5.7.4.4).

f) Calculate transferred energy for each manikin sensor and total transferred energy for the whole system (see Annex D).

5.5.1.2 For test specimen measurement

— Measure the absorbed heat flux over time or transform the manikin sensor data into absorbed heat flux over time.

— Transferred energy per manikin sensor (see 5.5.4) and total transferred energy for the whole system.

— Energy transmission factor per manikin sensor (see 5.5.5) and total transmission factor.

5.5.2 Incident heat flux

Determine the incident heat flux from the heat flux absorbed by each manikin sensor using a computer software program during a nude manikin flame exposure (see Annex C). The incident heat flux shall be recorded as specified in 9.3.

5.5.3 Exposure heat flux

In nude manikin exposures, the exposure heat flux shall be calculated for each manikin sensor as the average incident heat flux calculated for that sensor during the steady region of the exposure as described in C.4.

Calculate the exposure heat flux for each body region and the whole manikin by averaging the manikin sensor data. The value reported is the average of the body region-weighted averages for each manikin sensor for the steady portion of the nude exposure. The procedure is described in C.4.

NOTE Treatment of noise in heat flux readings and negative heat flux values are addressed according to the correction applied for the transferred energy (see Annex D). The body regions (head, right arm, left arm, chest and abdomen, back, left leg and right leg) are necessary to compare the heat flux over the different planes and heights of the body to ensure that the flame engulfment is similar over the whole manikin [see Table 2 and 5.7.4.4 c)].

5.5.4 Transferred energy (see D.1)

The transferred energy per manikin sensor, which, for the purpose of this document, is equal to the absorbed energy per manikin sensor, shall be determined for each manikin sensor accounting for the area associated with each sensor. The total transferred energy shall be the sum of the transferred energy of all manikin sensors. Details on calculating total transferred energy can be found in D.2.2.

5.5.5 Energy transmission factor (see D.2.1)

The energy transmission factor shall be determined by a computer program calculating the ratio of the transferred energy during the measurement to that measured during the nude exposure.

NOTE This ratio provides the best information when the exposure times for nude exposure and test specimen exposure are identical. Having equal times for the nude exposure flame and the test specimen exposure is not always possible. Thicker garments, such as those worn by fire fighters, are designed for longer exposures, requiring 8 s or more of exposure in order to see significant energy transfers to the manikin surface. Testing experience shows that exposing uncovered manikin sensors for these longer durations at the high heat flux values results in a high sensor failure rate.

The calculation shall take two testing situations into account.

a) Nude exposure and test specimen exposure times are identical.

b) Nude exposure is a 4 s exposure in duration, while the exposure for the test specimen is equal to or longer than 4 s (see 5.7.3).

For case a), the calculation is straightforward. For case b), assume that the average exposure heat flux calculated for each manikin sensor for the 4 s nude exposure is representative for the full exposure for the test specimen exposure time.

In the report, it shall be stated which exposure and calibration times were selected (see 9.3).

The total energy transmission factor is the average of the energy transmission factors for all the manikin sensors. Details on calculating the overall energy transmission factor can be found in D.2.2.

NOTE When testing according to b) above, the fuel flow rate is monitored for the entire exposure in order to gauge how well the exposure conditions are maintained. Fuel flow measuring meters and pressure monitors have proven to be adequate for this purpose (see 5.7.3).

5.6 Flame exposure chamber

5.6.1 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 air to flow naturally into or out of the chamber during 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.

5.6.2 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 2,2 m wide by 3,3 m long by 2,4 m high are necessary to allow sufficient air for combustion and control of the flames.

5.6.3 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.

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 are required for pressure relief and passive supply of air necessary for combustion of the fuel during the exposure.

Immediately after the data acquisition period, a forced air exhaust system shall be used for rapid removal of combustion products prior to entering the chamber.

5.6.4 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.

5.6.5 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 combustion products that 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 manikin sensors after the chamber has been exhausted of combustion gases.

5.6.6 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. Compliance with appropriate local fire safety codes is recommended.

5.7 Fuel and delivery system

5.7.1 General

The chamber shall be equipped with fuel supply, delivery and burner systems to provide reproducible fire exposures (see C.3 and C.4.2).

5.7.2 Fuel

The fuel shall be propane that satisfies the requirements of ISO 9162 to achieve the required heat flux.

NOTE Most laboratories use as fuel at least 90 % propane. Certain regions do not have this concentration due to lack of availability or due to permit requirements that limit the ability to use propane at such high concentrations. The butane content fuel mix and other factors, such as altitude, can have an effect on the heat flux if not calibrated accurately.

5.7.3 Fuel delivery and shut-off 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 an average heat flux of 84 kW/m^2 ± 5 % over the steady-state portion of the exposure for the duration for 3 s up to 12 s depending on the equipment requirements for the duration of the test. The average heat flux shall be calculated over all sensors over time. Fuel delivery shall be controlled to provide an exposure duration within ±0,1 s of the set exposure time.

The fuel mass flow rate to the burners shall be checked regularly to ensure that it does not vary by more than 10 % during exposure (other than at the start where an instantaneous dip may occur).

NOTE 1 Volumetric flow meters along with corresponding temperature and pressure measurements or various propane mass flow meters have been successfully used to confirm the fuel mass flow rate. For example, Micro Motion Inc., Coriolis Mass Flow Sensor (NIST traceable), Model CMF100. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of the product named. Equivalent products can be used if they can be shown to lead to the same results.

The delivery system shall be in accordance with the local fire and electrical codes and standards independent of the requirement of this document.

NOTE 2 As an example, an exposure time of 5 s or less is sufficient for testing single-layer garments, such as coveralls. If fire-fighting ensembles are to be tested, longer exposures are permitted. For reasons that are inherent to this test method, tests are not carried out at less than 3 s due to problems of repeatability.

NOTE 3 According to NIST, absolute accuracy for radiant heat flux measurement up to 250 kW/m^2 is ±8 % (NIST Special Report Publication N 1031[16]). The required margins of ±5 % for the average 84 kW/m^2 need to be seen relative to calibration of the applied manikin sensors.

The remaining gas between the last valve and the burner shall not exceed 200 cm^3 and the remaining excess gas in pipe, after the valve closure, shall not continue to flame more than 0,1 s at the burner.

5.7.4 Burner system

5.7.4.1 General

The burner system shall consist of at least eight nozzle torch burners to provide the range of heat fluxes with a flame distribution uniformity to meet the requirements of 5.7.4.4 and C.3 and C4.

NOTE 1 The requirements of 5.7.4.4, C.3 and C.4 are met by most laboratories with 12 burners. Few use eight burners.

NOTE 2 The position and/or arrangement of the burners is specific to the flame exposure chamber, the dimensions of the chamber and the location of the passive air supply inlets.

5.7.4.2 Ignition system

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 so as not to interfere with the exposure flame pattern. The pilot flame is ignited with 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 equipment shall be provided with a light or thermal sensor. This light or thermal sensor shall be interlocked to the burner gas supply valves in order to prevent premature or erroneous opening of these valves.

5.7.4.3 Burner style

Large, nozzle mixed, induced combustion air, industrial style propane burners rated >60 kW per burner shall be positioned around the manikin to produce a uniform laboratory simulation of a flame engulfment. The flame engulfment shall meet the specification laid out in 5.7.4.4 and C.3.

NOTE 1 Essentially, these burners are designed to produce luminous (reddish-yellow to orange) delayed mixing diffusion flames with flame temperatures ~1 225 °C ± ~150 °C.

NOTE 2 A single jet nozzle with an internal diameter of 10 mm to 15 mm has been found to produce an appropriate flame (L.B. White Bertha 500 with modified orifice size by removing the insert)[3]. Although depending on the size of the chamber, removing the orifice insert results in a reduced jet velocity creating buoyancy controlled flame profile. This can give a delayed, long luminous, slow diffusion flame with an improved, fairly uniform coverage fireball.

5.7.4.4 Burner positioning

The burners (see footnote 3) shall be used and positioned to yield the exposure level and uniformity specified below and C.4.

NOTE Burners positioned at approximately the knee and thigh level on each stand have been found to be effective (see Table 1).

The burner shall be positioned, adjusted and aligned so that during nude manikin exposures, all the three heat flux distribution requirements shall be met based on all the sensors on the manikin, excluding any sensors that may be positioned in the hands and feet.

a) Average exposure incident heat flux is within ±5 % of 84 kW/m². The average incident heat flux shall be calculated over all sensors from the absorbed energy responses during the appropriate time interval (essentially, where a steady-state condition has been established).

b) Standard deviation of the average incident heat flux calculated for all the manikin sensors is equal to or less than 20 kW/m².

c) The average incident heat flux measured for each body region (see 5.3 and 5.5.2) shall be in each case within ±15 % of the average incident heat flux measured for the entire manikin during a 4 s nude 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 alignment of the burners is given in C.4, so that the three heat flux distribution requirements for nude manikin exposures can be met.

5.7.4.5 Fire suppression system

The chamber shall be permitted to be equipped with a fire suppression system consistent with appropriate local fire safety codes.

5.8 Image recording equipment

A system for recording still images and a real-time visual image of the manikin [see 8.2.3 h), i) and j)] before, during and after the flame exposure shall be provided. The front of the manikin shall be the

3) Burners meeting these requirements are available from L.B. White (model Bertha 500), W6636 L.B. White Road, Onalaska, Wisconsin, 54650, USA, Ph. +1 608 783 5691 and Tiger Torch Co., 508, Centre Avenue East, Aridrie, Alberta, T4B 1P8, Canada, Ph.+1 403 948 9598. The burners are capable of greater than 60 kW. This information is given for the convenience of users of this document 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.

primary record of the flame exposure. A record of the rear of the manikin may be as an additional recording option.

5.9 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 prepared for the test;

b) confirmation that the chamber doors are closed;

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

d) confirmation that all safety requirements are met.

5.10 Laboratory capability demonstration

The laboratory organization performing the test method in this document shall have demonstrated its capability to perform this test in a repeatable and reproducible manner. To demonstrate this, the laboratory shall carry out a round robin with a laboratory of its choice that meets the requirements of ISO/IEC 17025.

The round robin shall also include the following.

a) Both laboratories shall

   1) meet sensor calibration requirements from Annex C,

   2) meet flame engulfment exposure results as described in this document and in Annex C, and

   3) compare garments to at least one of the four specifications in B.2. The results shall be within the test precision summary set out in Table B.2.

b) The laboratory organization performing the ISO 13506-1 test method shall meet all the requirements of this document.

c) The laboratory organization performing the ISO 13506-1 test method shall have laboratory facilities and equipment available for conducting proper tests to determine product compliance to ISO standard making reference to this document.

d) The laboratory organization performing the ISO 13506-1 test method shall have a program in place and functioning for calibration of this test method and related relevant instruments, and procedures shall be in use to ensure proper control of testing.

e) The laboratory organization performing the ISO 13506-1 test method shall follow good practice regarding the use of laboratory manuals, form data sheets, documented calibration and calibration routines, performance verification, proficiency testing, and staff qualification and training programs.

6 Sampling and test specimens

6.1 General

The test specimen, to be tested according to this document, shall be made into a garment/ensemble provided by the manufacturer as intended for the market or as defined by the product standard.

NOTE This test method can be used for other purposes such as for research on fabrics and garment designs, comparison of garment ensembles or evaluation of any garment or ensemble to particular applications or end use standards or specifications.

6.2 Number of test specimens

If not otherwise specified by a product standard or a product specification, three specimens shall be tested.

6.3 Size of test specimen

Fit of the garment on the manikin is important. A test garment or specimen size shall be selected by the laboratory from the size range provided by the manufacturer to fit the laboratory's manikin. The garment size relative to dimensions of the specific manikin used for testing shall be the basis for choosing the standard size garment to fit correctly the manikin with sufficient ease as one would choose clothing for a person.

Variations in garment design and how the manikin is dressed by the operator can influence the test results. Therefore, when donning the garment, care shall be taken to adjust the specimen so that it hangs as evenly as possible on the manikin, i.e. with as few wrinkles as possible and where the garment is not twisted, pinched or stretched.

NOTE Experience suggests that testing a coverall garment one size larger than the standard garment size will reduce the total energy transferred and percentage body burn by about 5 %. For jackets, one can get ingress of flame under the open bottom of a one-size larger jacket than required on the manikin.

6.4 Specimen preparation

6.4.1 Conditioning

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

If the specimen cannot be tested within 20 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 20 min after removal from the bag. Test specimens shall not remain in the bags for more than 4 h.

6.4.2 Optional laundering

One cleaning cycle (one wash and one dry cycle) is recommended to remove manufacturing finishes, if not otherwise defined in applicable product standards. If cleaning takes place, it shall be in line with the manufacturer's instructions on the basis of standardized processes. If the garment can be washed and dry-cleaned, it shall only be washed. If only dry-cleaning is allowed, the garment shall be dry-cleaned in accordance with the manufacturers' instructions.

NOTE Manufacturer's instructions typically indicate one or several of the various methods and processes of ISO 6330, ISO 15797, ISO 3175-2 or equivalent as standardized processes for cleaning.

6.5 Standard reference garment design

The standard reference garment may be used for quality control of the test equipment (e.g. monitoring changes in performance of the manikin system, ensuring full homogeneous flame engulfment of the manikin and in inter-laboratory testing) and to ensure repeatability and reproducibility.

The standard reference garment shall be a coverall having a full-length metal slide fastener closure in the front and a full-length fabric cover on the interior of the slide fastener to prevent direct contact of the slide fastener with any manikin sensors. A design without pockets, sleeve or pant cuffs and with no elastic at the waist is preferable, as the proposed construction is intentionally simple in order to minimize manufacturing costs.

The garment size requirement shall be based on 6.3.

Table 3 — Proposed reference garments

Nr	Material	Reference number	weight
1	Aramid (DuPont™ Nomex®[a] Comfort), light blue	B200X2	260 g/m^2
2	FRT Cotton (Proban®[b]), navy blue	B200X3	335 g/m^2
3	Modacrylic/cotton FR/antistat (54/45/1 %), orange	B200X4	325 g/m^2

[a] Nomex is the trade name of a product supplied by DuPont. This information is given for the convenience of users of this document 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.

[b] Proban is the trade name of a product supplied by Solvay. This information is given for the convenience of users of this document 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.

NOTE 1 During the round robin held in 2014 to 2015, three coveralls made of three different fabrics listed in Table 3 were tested at the participating laboratories. The size used was European 52. The coveralls were manufactured by PWG Bedrijfveilige Kleding B.V (www.pwg.nl)[4].

NOTE 2 Comparison are made between different reference garments using the same fabric lots change to ensure consistency. This is relevant not only with respect to the fabric (different lot of fabric can have minimum difference in weight) but also with respect to the garment (manufacturer dependence) as different manufacturers can cut and sew garments differently).

7 Pre-requisites for products implementing this test method

In order to implement this document, at least the following parameters shall be specified in the relevant product standard:

a) performance requirements and/or pass-fail criteria;

b) exposure conditions;

c) number of specimens (minimum three);

d) pretreatment of specimen;

e) conditioning;

f) fitting instructions;

g) if used, use of under garments (including specification of undergarment, e.g. length and weight).

NOTE Use of undergarments will reduce the heat transfer and adds to uncertainty of the results; see Annex A.

4) This information is given for the convenience of users of this document 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.

8 Procedure

8.1 Preparation of test apparatus

8.1.1 General

Safely exposing the instrumented manikin to a test fire requires a start-up and exposure sequence which is specific to the test apparatus. Each laboratory shall establish a startup checklist which is employed for every exposure. As a minimum, the list should include the elements in 8.1.2 to 8.1.5.

8.1.1.1 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 are no personnel in the chamber when the ignition system is activated to start a test, isolating the chamber during the test to contain the energy released by the exposure and the resulting combustion products, and ventilating the chamber after the test exposure.

8.1.1.2 Personal protection of test operators

Care shall 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 shall 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.

8.1.2 Manikin sensor check

8.1.2.1 Manikin sensor daily check for each series

Check that prior to any test series, the temperature reading of each manikin sensor, if applicable, should be within ± 2 °C around the average reading of all manikin sensors. In addition, the average temperature reading of all manikin sensors should be within ±2 °C of the actual measured temperature inside the chamber.

If any manikin sensor is suspected to be defective, verify each suspected defective manikin sensor by exposure to a reference heat source (see C.2.1). A non-functional sensor is a sensor that does not respond as expected. Defective manikin sensors shall be repaired or replaced before the next test (e.g. nude exposure or specimen test). Repaired or replaced manikin sensors shall be calibrated. Individual sensors shall be calibrated at a minimum once a year.

If more than 3 % of the total number of manikin sensors are no longer functioning properly and the non-functional manikin sensors are located under the test garment, the test shall not be considered as valid.

With long duration exposures during garment tests, the uncovered sensors in the head can be damaged. Covering these head sensors is permitted.

NOTE Mobile reference heat sources (e.g. appropriate lamp and heat-gun) can be used to verify proper functioning of the manikin sensors. Also, tracing the response of a manikin sensor during nude exposures might be used to determine its status. Alternatively, the use of reference garments tested in defined intervals has been found to be a suitable procedure to track the status and performance of the manikin system and its sensors (see also 6.5 and Annex C).

8.1.2.2 Sensor check after each specimen test

After each specimen test, the sensors shall be inspected for any build-up of decomposition products on the surface. If detected, the sensor shall be cleaned with soap and water, petroleum solvent, methanol, or other appropriate means. Use the gentlest method that is effective in cleaning the manikin sensor. If necessary, repaint the surface of the manikin sensor and dry the paint as required (see 5.3.4).

8.1.3 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 toxic combustion products and any fuel that may have leaked from the supply lines and that is capable of producing an explosive atmosphere.

8.1.4 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.

8.1.5 Confirmation of nude exposure conditions

Prior to nude manikin exposure, confirm that the temperature of all the manikin sensors is stable for at least 1 min (see 8.3, C.3 and C.4).

— All sensors shall be below 38°C.

— Average temperature of all sensors shall be ≤32°C.

— All sensors shall be above 15°C.

NOTE In regions where extreme high or low temperatures can be expected, the system will seek thermal equilibrium with local conditions and therefore, adjustment of the start temperature can be necessary. The room temperature can be adjusted as necessary.

Nude calibration shall expose nude manikin to the test fire for 4 s, or for the test duration as specified by the product standard, if less than 4 s. Confirm that the calculated incident heat flux values for the manikin sensors meet all the three distribution requirements specified in 5.7.4.4.

If the calculated incident heat flux or the variability is not within the specifications, determine the cause of the deviations and correct before proceeding with specimen testing.

As a minimum, check the incident heat flux from a nude exposure at the beginning and end of the workday. If the average exposure incident heat flux for the test conditions differs by more than ±5 % between the initial nude exposure calibration and the next nude exposure calibration (e.g. if an initial calibration of 82 kW/m^2 was completed, the next calibration shall be within ±5 % of 82 kW/m^2), report this finding and give consideration to repeating the sequence of specimen tests conducted between the exposure calibrations. Any average exposure heat flux beyond this limit shall not be considered as valid. It may be necessary to repeat the nude manikin exposures to determine the causes. Potential problems include dirty sensors, dirt clogging flow orifices, pressure regulators not holding the set values and solenoid valves not responding properly.

It has been found useful to periodically monitor the overall system performance by testing a reference garment. This needs to be done during a testing sequence of garments. It is recommended that the reference garment be tested as the first test item after the required nude exposure has been set. If the calculated heat flux or the variability of the heat flux values of the manikin sensors are not within the statistical acceptable two sigma limits obtained from previous testing of same reference garments, determine the cause of the deviations and correct before proceeding with specimen testing. The optimal frequency of such periodical testing of reference garments is established and based on experience.

The total incident energy from the nude exposures needs to be recorded as an indicator of repeatability. If the total incident energy changes by ±5%, investigate the reasons why and repeat the nude exposure to show compliance.

8.2 Specimen testing procedure

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 manikin sensors except those that will not be included in the analyses meet the requirements of 8.1.5 (see 8.3, C.3 and C.4).

8.2.2 Dressing the manikin

The following guidelines shall be used when dressing the manikin. Where deviations are necessary or appropriate to accommodate particular garment systems, represent a specific end-use, or evaluate specific garment features, the deviations shall be noted. Deviations from the dressing requirements shall be included in the test report.

Garment systems consisting of shirt and trousers shall be configured with the shirt tucked into the waist of the trousers.

All available garment closures, including, but not limited to primary front closures, collar closures and cuff closures at the wrists and ankles shall be closed. Closures should be fastened completely where possible. Adjustable closures shall be adjusted for snug fit within the intended range of the closure.

Waistbands shall fit snugly on the waist of the manikin. Where size or features of a garment prevent proper positioning or fit of the waist, the waist shall be permitted to be taken in or let out as necessary.

When testing garment systems with consistent sets of adjustable features, including replications of a single garment system, appropriate measurements shall be performed to ensure that each feature is being adjusted consistently for each test. Appropriate measurements will vary for different adjustment types but shall be permitted to include position or length of overlap for hook and loop closures, pulled length for drawstrings, or reduction in garment measurement for adjustable elastics.

Garment systems which have air-permeable areas (vents) which can be functionally opened or closed shall be closed.

Unless specified as part of the garment system being evaluated, a product standard or due to other requirements, no undergarments shall be used.

NOTE If it has been specified for a particular application or required by the manufacturer of the garment or ensemble to be tested that the garment or ensemble needs to be tested with a T-shirt and briefs or other undergarments underneath, dress the manikin in the T-shirt and briefs or the specified other undergarments. It can be necessary to cut the T-shirt or other undergarments up the back for easy donning. Repair the cut with a non-flammable closure, such as metal staples or a flame-resistant thread. Ensure that the staples will not be in direct contact with a manikin sensor.

Garments which need to be cut in order to accommodate dressing the manikin shall be cut in such a way that the alteration interferes with as few sensors on the manikin as possible. When, due to specific requirements or garment configuration, a different alteration is performed, both the alteration and the purpose shall be noted. Repair the cut in the garment or ensemble with a non-flammable closure, such as metal staples or a flame-resistant thread, as similar as possible to the real wearing conditions.

Confirm the position of the manikin and its arms as required in 5.2.

Make a visual image record of the front and rear of the test specimen when it has been put on the manikin.

8.2.3 Recording the specimen identification, test conditions and test observations

The following elements shall be recorded:

a) product standard or purpose of test;

b) test identification number;

c) specimen identification, including specification of required T-shirt, briefs, or other undergarments;

d) test conditions;

e) test observations;

f) exposure duration;

g) data acquisition time;

h) a still image (i.e. photo) of the front and rear of the test specimen when it has been put on the manikin (see 8.2.10);

i) a real-time visual image (i.e. video) of the test exposure and after flaming, if any (see 8.2.5);

j) a still image (i.e. photo) of the front and rear of the test specimen after the flame exposure;

k) if an ensemble test is performed, observations of interfaces shall be recorded prior to and after the test to assess movement, shrinkage, etc.;

l) if the flame has entered inside or under the garment;

m) any other information relevant to the test series.

8.2.4 Confirming 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 real-time image (i.e. video) recording system used to visually document each test at the initiation of the test and end at the end of data acquisition period.

8.2.6 Setting time for heat transfer data acquisition

The data acquisition time for specimen exposure shall be a minimum of 60 s. The data acquisition time nude exposure shall be 20 s.

The data acquisition time can be adjusted and shall be long enough to ensure that all of the energy stored in the specimen has been released to the manikin and into the atmosphere surrounding the manikin. Confirm that the acquisition time is sufficient by inspecting the calculated transferred energy from all the manikin sensors to confirm that it has levelled off and is not continuing to rise at the end of the data acquisition time. If the amount of transferred energy is not constant for the last 20 s of acquisition time, increase the time of acquisition to achieve this requirement and retest with a new specimen.

NOTE Experience with testing single-layer coveralls (approximately 300 g/m^2) shows that a 60 s data acquisition time is usually sufficient most of the time. Heavier weight garments, e.g. fire fighter garments, typically require longer data acquisition times for the energy stored in the garments to be dissipated to the surroundings and the manikin shell, therefore, data acquisition system needs to be capable for acquiring at least 240 s of data (see 5.3).

8.2.7 Exposure of the test specimen

The time of exposure, for which the garment or ensemble shall be evaluated, shall be specified either in the relevant product standard or shall be the time specified by the manufacturer or user for a particular application or specification.

NOTE This test method can be used for other purposes such as for research on fabrics and garment designs, comparison of garment ensembles, or evaluation of any garment or ensemble to particular applications or end use standards or specifications.

Initiate the test exposure on the control system, e.g. by pressing the appropriate computer key. The burner management system shall work together with a data acquisition system to open/close the required gas valves, start/stop the data acquisition and turn on the ventilation fans after the exposure is completed. A single "command" shall function to start the exposure sequence and data acquisition. Observe and record any after-flame duration, intensity and location on the test specimen after burners are extinguished.

The exposure time is the time from the initial opening of the valves nearest to the burner to the closing of the same valve.

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 and material shrinkage, charring, or observed degradation. These remarks shall be part of the test record.

8.2.9 Calculation of surface incident heat flux and transferred energy

Perform the calculations needed to determine the heat flux and the transferred energy on the surface of the manikin (see 5.5, Annex C and Annex D) and place this information into a test result database file and/or 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.

8.2.10 Still images

Before touching the test specimen or undressing the manikin, make a still visual image record (i.e. photo) of at least the front and rear of the test specimen on the manikin. Additional visual image records during the removal of the test specimen from the manikin are optional. See 8.2.3 with respect to the elements to be recorded.

8.3 Preparing for the next test exposure

Ensure that the calibrations using the fire exposure on the nude manikin have been completed in line with 8.1.5.

After each specimen test, the manikin sensors shall be inspected for damage and/or build up of decomposition products on the surface.

If the manikin sensors are too hot, running a ventilating fan(s) or a heating, ventilation and air conditioning (HVAC) system is permitted to be used to cool them below the requirements of 8.1.5. Monitor the sensor conditions; they shall remain stable after the mechanical cooling system stops to minimize a potential bias due to elevated internal temperature or temperature gradients in the manikin form. Inspect the manikin and its sensors to be sure that they are clean of any decomposition materials and that the manikin sensors do not show any visual indication of damage.

If deposits are present, clean the manikin and its sensors according to 8.1.2.2.

NOTE 1 Nude cleaning exposures can be carried out not just after each test series, but more frequently to detect the effect of potential deposit built up, and act accordingly to clean sensors to remain within the specification of 5.7.4.4 at the end of your test series.

Damaged or inoperative manikin sensors shall be repaired or replaced when discovered (see 8.1.2.1).

NOTE 2 Mobile reference heat sources can be used to verify proper functioning of the manikin sensors. Also, tracing the response of a manikin sensor during nude exposures can be used to determine its status. Alternatively, the use of reference garments tested in defined intervals might help to monitor the status of the manikin system and its sensors.

Ensure that the manikin and manikin sensors are dry and, if necessary, dry them, e.g. with the ventilating fan(s), before conducting the next test, i.e. before repeating the testing procedure from 8.1 onwards.

For a full evaluation of a garment or ensemble, the testing procedure shall be repeated for each of the number of test specimens required according to 6.2.

9 Test report

9.1 General

State that the test was carried out in accordance with this document, i.e. ISO 13506-1, and report any deviations from this test method.

The test report shall be permitted to include information of the local atmospheric pressure, exterior temperature, relative humidity, wind direction and speed from a local weather station within 10 km of the test facility. If this is not available, the starting interior chamber temperature and relative humidity can be recorded.

The information described in 9.2 through 9.5 shall be included in the test report.

9.2 Specimen identification

Describe the specimen(s) in terms of the following information, when available: garment/ensemble type, layer ordering in multilayer specimens, size, actual fabric mass per unit area, fibre type, colour, and non-standard garment features and design characteristics. Include a description with respect to the condition of the specimen such as pre-treatment of the garment/ensemble components, laundering has taken place, any underwear is being used during the test, any holes, and/or cuts that were made in the garment/ensemble to accommodate cable connections.

NOTE Use the procedure in ISO 3801 if the actual fabric mass per unit area is required.

9.3 Exposure conditions

Record and report the information that describes the nude test exposure conditions and the obtained results, including the following:

a) the nude exposure, exposure time;

b) the nude exposure duration of the data acquisition;

c) the average exposure heat flux for the whole manikin from the nude exposure and the standard deviation determined from the nude exposure before and after each test series;

d) a confirmation during the nude exposure that the three heat flux distribution requirements from 5.7.4.4 have been fulfilled (i.e. the values showing compliance should be recorded or reported).

For each specimen exposure test, record and report the information, which describes the exposure conditions, including:

— the exposure time;

— the duration of the data acquisition;

— any other information relating to the exposure conditions that may assist in interpreting the test specimen results (see 8.2.3 and 8.2.8).

9.4 Results for each specimen

9.4.1 General

All results according this document are based on the absorbed heat flux to the surface of the manikin during the data acquisition period. For each exposure (see 6.2), absorbed heat flux data shall be stored in intervals suitable to be further evaluated (e.g. burn risk assessment according to ISO 13506-2). This implies that a minimum of 10 readings per second per sensor shall be available. The sample rate shall be recorded.

From the stored incident heat flux data, the test result data and values specified in 9.4.2 to 9.4.5 shall be calculated and reported.

9.4.2 Heat flux data of each manikin sensor

a) Table of average absorbed heat flux per manikin sensor over the whole data acquisition time shall be recorded.

Note Treatment of noise in incident heat flux readings and negative heat flux values are addressed according to the correction applied for the transferred energy (see Annex D).

b) Table of maximum absorbed heat flux per manikin sensor (excluding the uncovered manikin sensors) shall be recorded.

c) Table of absorbed heat flux data and standard deviation per body part (excluding the uncovered manikin sensors) shall be reported.

9.4.3 Transferred energy

Transferred energy according to Annex D.

a) Table of transferred energy per manikin sensor over the whole data acquisition time (ignoring negative heat flux values for the calculation of the average and excluding the uncovered manikin sensors) shall be recorded.

b) Table of total transferred energy per body part (excluding the uncovered manikin sensors) shall be reported.

c) Total transferred energy of the manikin (excluding the uncovered manikin sensors) shall be reported.

9.4.4 Energy transmission factor

Energy transmission factor according to Annex D.

a) Table of energy transmission factor per manikin sensor over the whole data acquisition time (ignoring negative heat flux values for the calculation of the average and excluding the uncovered manikin sensors) shall be recorded.

b) Table of energy transmission factor per body part (excluding the uncovered manikin sensors) shall be reported.

c) Total energy transmission factor of the manikin (excluding the uncovered manikin sensors) shall be reported.

9.4.5 Other information that may be reported

a) Diagram of the manikin showing location of each manikin sensor and amount of transferred energy to each manikin sensor.

b) Diagram of the manikin showing location and amount of energy transmission factor.

9.5 Observations

Record in 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 generation;

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

d) any other observations that serve to interpret the results which describes the performance of the test specimen;

e) in cases where an ensemble is tested, report any observations through visual evaluation with respect to the areas covered by the test specimen whether or not containing sensors. For the interfaces of ensembles tested, the test method is limited to visual inspection. Other observations and inspections are collected on the overall behaviour of the test specimen during and after the exposure as the garment or complete ensemble on the manikin from both the still images and video records from before, during and after the flame exposure.

Support the observations with a visual image record [see 8.2.3 h), i) and j)].

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. A.2 to A.7 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.

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 that are related to specific designs. Note that with some materials there can be a strong interaction between the material properties and the garment 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. It is expected that a significant reduction in the transferred energy will occur when T-shirt and briefs are worn under a single-layer coverall. If T-shirts and briefs are used under a test specimen, it is recommended from a safety perspective that the fabric used in their construction be non-melting, e.g. cotton or fire resistant fabrics. The use of underwear can increase the uncertainty in the results.

NOTE If T-shirts and briefs are used under a test specimen, these garments need to be the representative of those used in practice, realizing that if, for example, polyester-based underwear is used, it can melt during testing and therefore reduce the transferred energy to the manikin.

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 the same average heat flux exposure of the manikin, variations in flame impingement and heat flux levels can introduce variability in 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.

Annex B
(informative)

Inter-laboratory test data analysis

B.1 An inter-laboratory test using this test method was conducted with single-layer test garments made of three different materials and a firefighter turnout gear. Twelve laboratories worldwide took part in the round robin organized by ISO/TC 94/SC 13.

B.2 Tested materials

NOTE During the round robin, three coverall were used of size 52 from PWG Bedrijfveilige Kleding B.V (www.pwg.nl) and one firefighter pants and coat from NOVOTEX-ISOMAT Schutzbekleidung GmbH, www.Novotex-isomat.de, email: info@novotex-isomat.de. 5)

Table B.1 — Garments tested during inter-laboratory test

Nr	Material	Reference number	Mass
A	Aramid (DuPont™ Nomex®[a] Comfort), light blue	B200X2	260 g/m^2
B	FRT Cotton (Proban®[b]), navy blue	B200X3	335 g/m^2
C	Modacrylic/cotton FR/antistat (54/45/1 %), orange	B200X4	325 g/m^2
D	Turnout firefighter coat and pants (75 % Nomex® Tough 23 % Kevlar®[c] 2 % Anti-stat Sympatex Membrane and Carbon fibre fleece with interior 50 % Aramid 50 % viscose FR)	Art 11–336	Coat: 2,3 kg Pants: 1,5 kg Total: 3,8 kg

[a] Nomex is the trade name of a product supplied by DuPont. This information is given for the convenience of users of this document 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.

[b] Proban is the trade name of a product supplied by Solvay. This information is given for the convenience of users of this document 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.

[c] Kevlar is the trade name of a product supplied by DuPont. This information is given for the convenience of users of this document 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.

— Garment A: Single layer, 4 s exposure at 84 kW/m^2, 120 s measurement time;

— Garment B: Single layer, 4 s exposure at 84 kW/m^2, 120 s measurement time;

— Garment C: Single layer, 4 s exposure at 84 kW/m^2, 120 s measurement time;

— Garment D: Firefighter ensemble, 8 s exposure at 84 kW/m^2, 240 s measurement time.

B.4 All testing by laboratories was performed on garments with an identical design. Each laboratory conducted on three samples of each of the four different material samples in a specified random order (a total of 12 tests for each laboratory).

B.5 Evaluation time for the assessment of transferred energy for single-layer garments was 120 s and for the firefighter ensemble, 240 s.

5) This information is given for the convenience of users of this document 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.

B.6 The overall inter-laboratory test results for transferred energy are listed in Table B.2. Statistical analysis according ISO 5725 (all parts) was applied.

Table B.2 — Instrumented manikin test precision summary

Garment	Transferred energy in kJ			
	avg.	S_r	S_R	No of laboratories
A	271,2	11,0	69,3	12
B	279,2	29,7	98,9	12
C	291,5	8,4	70,6	12
D	236,4	7,8	50,1	12

avg. is the mean of the mean total transferred energy 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 standard deviations are exacerbated due to off-set errors in the data and some laboratories having had exposures of 0,2 s to 0,4 s beyond the required exposure.

B.7 A detailed report is available from the secretariat of ISO/TC 94/SC 13/WG 2 [N108 Final Draft RR ISO 13506-1 Non Confidential (16.02.2016)]. The report includes a detailed protocol of testing, as well as more detailed information on the garments and where they were ordered from. The round robin also included additional assessments regarding sensor calibration, sensor response and nude exposure which can help to setup a test system according to this document and ISO 13506-2.

Annex C
(normative)

Calibration procedure

C.1 Calibration Principles

Due to the complexity of the manikin system, calibration is critical to achieve reproducible and repeatable results across various laboratories in the world. Calibration is divided in four parts that shall be completed in the following order to achieve the optimum results: sensor calibration, burner stand alignment for flame engulfment, manikin exposure calibration and finally, a check on the system output when a sensor is exposed to a known input.

The manikin sensors are used to measure the fire exposure intensity and the thermal energy transferred to the manikin during the exposure

C.2 Sensor calibration

C.2.1 Manikin sensors are used to set the fire exposure intensity and provide data for calculating the energy transferred to the manikin during and after the exposure. Calibrate the manikin sensors with single mode energy sources, such as a gas-fired radiant heat panel, a calibrated incandescent lamp, or a radiation black body, all of which shall be calibrated with the help of a calibrated Schmidt-Boelter or Gardon-Gauge heat flux gauge.

NOTE Although not recommended, a heat gun or a Meker burner (with significant convective heat) can be used but an additional calibration is required. A determination of gun exit air temperature or flame temperature as a function of time, the surface temperature of the sensor under calibration as a function of time and the sensor convective heat transfer coefficient as a function of time are required along with the appropriate computational mode fixation required to measure convective heat transfer. Many manikin heat flux sensor designs have temperature dependent convective heat transfer coefficients that require additional thermal information in order to perform a calibration.

C.2.2 The range of heat flux values required shall match the exposure conditions experienced during test setup and specimen testing. As a minimum, the calibration device shall provide heat flux values to ensure calibration in the range of 8 kW/m^2 to 30 kW/m^2 under the garment and between 80 kW/m^2 to 100 kW/m^2 for nude exposures. Calibration of the sensors shall be completed at about 8 kW/m^2, 15 kW/m^2 and 30 kW/m^2 to show that it reproduces the heat curve of the reference sensor (see Figure C.1) and verify linearity, and that it reacts appropriately to the heat source using ISO 6942, a quartz lamps system or a gas fired radiant panels.

Below 8 kW/m^2, corrections for convective heat losses due to free space geometry (a bare sensor in vertical orientation exposed to a radiant heat source) shall be made, essentially as a percentage of the total energy input is lost at the sensor surface. Even though this is in the expected heat flux regime of the manikin test, the sensor is in a completely different geometry (no fabric over the surface) with a different partitioning of heat transfer modes. One would not perform this correction on the manikin under tested specimens so any generated “calibration curve” done this way with bare sensors would not represent the performance behind fabric.

Above the range of about 40 kW/m^2, there is no appropriate calorimeter with a traceable response; therefore, calibrating this way is problematic to a reference standard. As a minimum, sensors shall be calibrated with a purely radiant source at three points range of the expected range of the manikin exposure between (8 kW/m^2 and 30 kW/m^2). If low exposures are used, a correction should be made for convective losses. Sensors shall have a tested accuracy of ±5 % to the reference sensor. The manikin sensor, when calibrated with a NIST or equivalent reference sensor, shall be within 0,2 s response time of the reference sensor and shall reach a minimum of 80 kW/m^2 heat flux when exposed to a pure radiant exposure of 84 kW/m^2 within 1 s.

NOTE 1 The dynamic response of the heat flux sensor used for thermal manikin testing is dependent on many elements including the sensing element's design and its thermal inertia. For sensors based on thermocouples, designs that minimize the thermal inertia in the thermocouple component are desired. These include intrinsic designs (junction is based on surface contact area of each wire connected independently thru an intermediate thermal conducting material — ms time scale with large wire diameters, e.g. 0,3 mm and less, fastest design), wire joining by butt junction welding (transient response related to wire diameter — values of 0,18 mm and less result in response times of ~150 ms or better), and wire joining by welding resulting in a beaded junction (bead size of 0,12 mm and less result in response times of ~150 ms or better).

NOTE 2 Different sensors react differently to the incident energy (approx. 60 % convective energy in the incident nude exposure). Take care not to make correction for absorbed energy under the garment test specimen as it lacks the large convective component in the nude exposure.

NOTE 3 Depending on how heat flux is calculated for each specific sensor, appropriate corrections can be required to account for different heat transfer modes or offset corrections (see Annex D).

Example of heat flux curves at 15 kW/m^2 (x-axis, left: heat flux (kW/m^2), right: temperature (°C), y-axis: time (s)

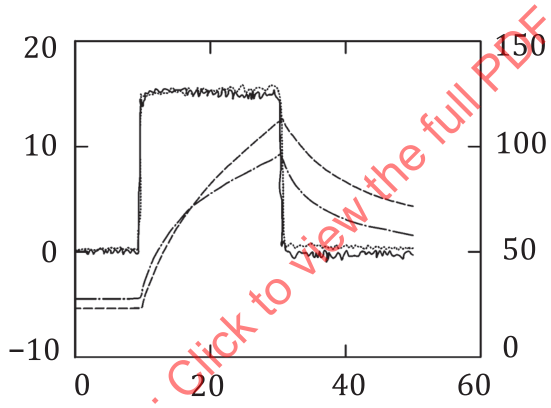


Figure C.1 — Good sensor response

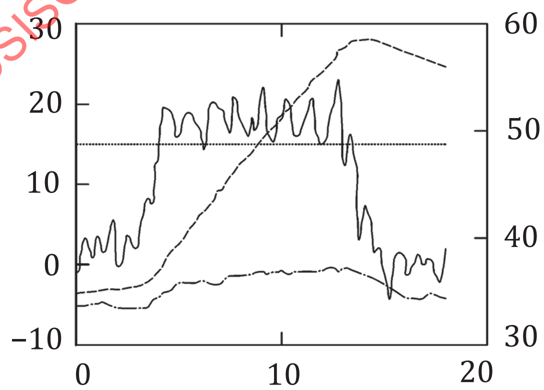


Figure C.2 — Poor sensor response

The reference sensor and the manikin sensor shall be measured either

a) in parallel to allow a better assessment of baseline, sensor response and the heat flux measured to show the following (if testing is conducted with sensors in parallel, a separate study shall be conducted showing that the heat flux at each location where the sensors are mounted are within ±2,5 % of each other), or

b) in sequence (if testing is conducted in sequence, it shall be shown by a separate study that consecutive heat flux measurements are within 2,5 % of each other and verify at the end of a calibration series the heat flux is still the same as in the beginning).

The measurements of the reference sensor and the manikin sensor need to show consistency in a rectangular shape.

Both the baseline and the sensor curves shall not show excessive noise (see Figure C.2).

Once this good repeatability has been shown, a single heat flux can be selected to calibrate all the sensors using the above system. For the same sensor, good repeatability shall be within 5 % to 10 % variation of the calibration value obtained.

A record shall be kept of the manikin sensor calibrations during their operating life with only the latest used during nude exposures for setting the exposure conditions and specimen testing.

NOTE 4 Some manikin sensor designs exhibit different sensitivities and responses to the expected modes of heat transfer experienced in this test method (conduction, convection and radiation). A thorough understanding of the manikin sensor technology in use is required to adequately assess and perform calibrations, recognizing that the heat flux at the manikin surface consists of complex, time varying proportions of each heat transfer mode.

NOTE 5 By traceable, it is meant that the commercial heat flux measuring device has its calibration traced to national laboratories that set standards for temperature and heat flux measurement, e.g. NIST, BSI, DIN etc.

NOTE 6 Manikin sensor calibration according to C.2.1 is done in a single step situation with a constant heat flux. Sensor behaviour might be different in dynamic situations from the manikin nude exposure.

NOTE 7 Radiation blackbodies with operating temperatures up to 900 °C have been found to cover this range.

C.2.3 Test the type of manikin sensor used in the manikin to ensure that the heat flux response is calibrated for use within the range of incident by nude exposure and absorbed heat fluxes produced and under the test specimen (see C.2.1 and C.2.2). If the response is linear but not within 2,5 % of the known calibration exposure energy, include a correction factor for the specific energy regime that the heat flux calculations apply to (incident nude exposure or absorbed heat flux expected under a test specimen). If the response is not linear and not within 5 % of the known calibration exposure energy, determine a correction factor curve for each manikin sensor for use in the heat flux calculations.

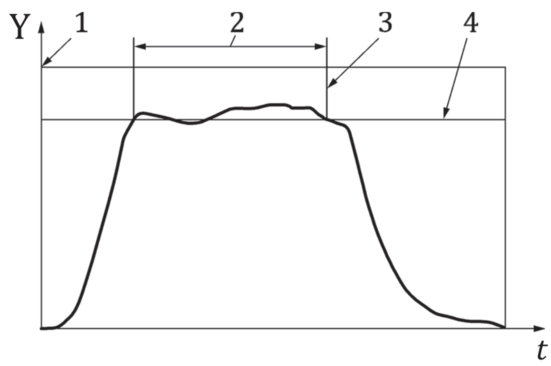
NOTE 1 There are currently known operational limits on the National Laboratory Calibration Certification reference devices that preclude coverage of the entire heat flux range possible in this test method (~30 kW/m^2 for convective/radiative heat reference standards). Extrapolations made by commercial heat flux measuring device manufacturers beyond the National Laboratory is acceptable for use in calibrating the manikin sensors over the expected intensity range.

NOTE 2 According to a round robin conducted by NIST, the response variabilities between labs for radiant heat flux measurements up to 126kW/m^2 are between 2,2 % to 17 %. (NIST Special Report Publication N1031[17]. The required margins of ±5 %, in this test method, need to be seen relative to calibration of applied manikin sensors.

C.2.4 Perform a calibration for each manikin sensor prior to using a new manikin, whenever a manikin sensor is repaired or replaced, and whenever the results appear to have shifted or differ from expected values.

NOTE A one-point calibration of the manikin sensors is suitable if the sensor behaviour over the heat flux range defined in C.2.2 was determined according to C.2.3.

Calculate an average incident heat flux from the absorbed energy response each heat flux sensor during the steady period, as shown in Figure C.3. Both methods of simple averaging and shape fitting are permitted.



Key

X time

Y average heat flux

1 start of exposure

2 steady region

3 end of exposure

4 desired setting

Figure C.3 — Incident Heat flux determination for sensor calibration

C.2.5 Verify that the incident heat flux values produced by the calibration device are within ±5 % of the required exposure levels during calibration when testing is conducted in sequence (see C.2.2 reference sensors).

C.2.6 If the individual manikin sensors have been calibrated external to the manikin and then installed into the manikin, one shall perform a heat flux measurement with at least three randomly selected manikin sensors on the manikin. In such a case, check the manikin sensor according to C.5. The heat flux calculated for each of the randomly selected manikin sensors shall be within ±5 % of the expected result. Expose the selected manikin sensors on the manikin system to a known constant heat flux with a duration representative of the testing conditions for a nude exposure or under a test specimen and calculate the heat flux using the steady period of the exposure as shown in Figure C.3.

C.2.7 Exposure heat flux is to be calculated either through two methods:

a) as the average of the heat flux over the steady period of the exposure as shown in Figure C.3. The pseudo steady period of the measured heat flux is defined as the time period starting approximately at 1 s after start of exposure to the end of exposure;

b) using fitting function with individual sensors having temperature dependent thermo-physical properties (see below).

Heat flux is permitted to be calculated using the steady period of the exposure as shown in Figure C.3. The steady period of the measured heat flux can be assessed by applying an appropriate numerical fitting function that models the typically observed exponential behaviour of measured heat flux at the manikin surface over time. This approach allows an automated evaluation and can be used to detect irregularities or faulty manikin sensors in case the result will not converge. The fitting function could be adapted to the type of manikin sensor used.