International Standard

# ISO 13506-1

Second edition
2024-06

# Protective clothing against heat and flame —

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

*Habillement 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*



Reference number
ISO 13506-1:2024(en)

# Contents

Page

# Foreword

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

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).

ISO draws attention to the possibility that the implementation of this document may involve the use of (a) patent(s). ISO takes no position concerning the evidence, validity or applicability of any claimed patent rights in respect thereof. As of the date of publication of this document, ISO had not received notice of (a) patent(s) which may be required to implement this document. However, implementers are cautioned that this may not represent the latest information, which may be obtained from the patent database available at www.iso.org/patents. ISO shall not be held responsible for identifying any or all such patent rights.

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

For an explanation of 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 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*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 162, *Protective clothing including hand and arm protection and lifejackets,* in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This second edition cancels and replaces the first edition (ISO 13506-1:2017), which has been technically revised.

The main changes are as follows:

— revision of definitions (see Clause 3);

— heat flux, requirements and its definition (see Clauses 4 and 5);

— female manikin (see Clause 5 and rest of document);

— manikin sensor calibration (see Clause 5);

— heat flux symmetry (see Clause 5);

— thermal manikin protection factor (TMPF) (see Clause 5);

— transferred energy and its calculation (see Clause 5);

— interlaboratory test data analysis results (see Annex B);

— calibration and validation procedure (see Annex C).

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

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

# 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 is 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 bench scale test methods are used in these two steps. Bench scale test methods permit testing fabrics, seams, zippers, pockets, badges, buttons or other closures, metal and plastic clips or other features that can be included in a complete garment. Once suitable materials are identified, they are made into complete garments or ensembles. The overall design and performance of the garment can be assessed on a manikin-fire exposure system. This test method is not designed to measure material properties directly, but to evaluate the interaction of material behaviour and garment design.

In this test method, a stationary, upright adult-sized manikin (male or female) 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. The protection offered by the test specimens is evaluated through quantitative measurements and observations. 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. These measurements are suitable for use in predicting skin burn injury (see ISO 13506-2).

The fire simulations are dynamic. 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 (interlaboratory results are found in Annex B).

Fit of the garment on the manikin is important. 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 properly fit the laboratory's manikin. Variations in the fit of the test garment that can occur when sitting, bending or moving are not evaluated.

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. All manikins contain heat flux sensors in the head. 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 method described in this document as an optional part in the fire fighter standards ISO 11999-3, 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. 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 is summed over a prescribed time to give the total transferred energy. Transferred energy and thermal manikin protection factor (TMPF) assessment methods provide a means to quantify product performance.

The exposure heat flux is limited to a nominal level of 84 kW/m$^2$ and durations of 3 s to 20 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 covers visual evaluation, observation, inspection and documentation on the overall behaviour of the test specimen(s) before, during and after the exposure. 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 This test method is complex and requires a high degree of technical expertise in both the test setup and operation. 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 3801, *Textiles — Woven fabrics — Determination of mass per unit length and mass per unit area*

ISO 11610, *Protective clothing — Vocabulary*

ISO 13506-2:2024, *Protective clothing against heat and flame — Part 2: Skin burn injury prediction — Calculation requirements and test cases*

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 11610 and the following apply.

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

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

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

**3.1**
**absorbed energy**
$q_{net}$
net *energy* (3.7) absorbed by the sensor that accounts for all modes of heat transfer interacting with the sensor surface when exposed to the *incident energy* (3.16)

Note 1 to entry: The energy balance including losses unique for each sensor type are detailed in the respective sensor technology documents.

Note 2 to entry: See Figure 1 in 4.2 for a schematic representation of this definition.

**3.2**
**associated area**
area of body region per sensor

Note 1 to entry: See Table 3.

**3.3**
**data acquisition period**
time elapsed during which data is recorded during a test

**3.5**
**data calculation period**
defined time over which data are used for a calculation

**3.6**
**conditioning**
keeping samples under standard conditions of temperature and relative humidity for a minimum period of time

**3.7**
**energy**
*heat flux* (3.13) integrated over a specified time period multiplied by *associated area* (3.2)

Note 1 to entry: Energy is expressed in joules (J).

**3.8**
**exposure duration**
**exposure time**
time from the initial opening of the valves nearest to the burner to the closing of the same valve (8.2.6.)

**3.9**
**exposure heat flux**
incident heat flux averaged among the manikin sensors during data calculation period

**3.10**
**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 form of solid, dust, aerosol or a gas of an ignitable substance. The fire will last as long as there is a combustible fuel-air mixture.

**3.11**
**flame distribution**
spatial distribution of the flame engulfment from the test facility burners which provides a controlled *exposure heat flux* (3.9) over the manikin surface

**3.12**
**garment ease**
difference between body (manikin) dimensions and garment dimensions

**3.13**
**heat flux**
heat through a surface area perpendicular to the direction of heat flow

Note 1 to entry: Heat flux is expressed in $kW/m^2$. For any conversion from $kW/m^2$ to $cal/cm^2.s$; the following ratio is to be used 4,184 J = 1 cal.

**3.13.1**
**absorbed heat flux**
net *heat flux* (3.13) absorbed by the sensor that accounts for all modes of heat transfer interacting with the sensor surface when exposed to the *incident heat flux* (3.13.2)

**3.13.2**
**incident heat flux**
*heat flux* (3.13) to which a test item or sensor is exposed

Note 1 to entry: for incident heat flux to manikin sensors, see fig on energy balance (4.2)

**3.14**
**heat flux sensor**
**manikin sensor**
device, fulfilling the requirements of this document, capable of measuring the *heat flux* (3.13) to the manikin's surface under test conditions, or of providing data that can be used to calculate the heat flux

**3.15**
**incident energy**
*energy* (3.7) to which a sensor is exposed during a *nude exposure* (3.18)

**3.15.1**
**total incident energy**
sum of the *incident energy* (3.16) of a specified set of *manikin sensors* (3.15) during the nude exposure for the specified time period

**3.16**
**instrumented manikin**
model representing an adult-sized human (male or female) which is fitted with *manikin sensors* (3.15) in the surface

**3.17**
**nude exposure**
test performed on the uncovered surface of the *instrumented manikin* (3.17)

**3.18**
**maximum absorbed heat flux**
highest value of *absorbed heat flux* (3.13.1) calculated from the recorded output of a *manikin sensor* (3.15) during a test

**3.19**
**transferred energy**
*absorbed energy* (3.1) by a single sensor under the test item

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.

**3.19.1**
**total transferred energy**
sum of the *transferred energy* (3.20) of a specified set of covered *manikin sensors* (3.15) over the *data calculation period* (3.5)

Note 1 to entry: Total transferred energy can refer to either the whole covered area of the manikin or to a specific covered manikin region.

**3.20**
**thermal manikin protection factor**
**TMPF**
factor representing the overall protective garment or ensemble performance as a function of exposure and test specimen mass

## 4 Overview

### 4.1 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 20 s.

The performance standard shall indicate all the necessary boundary conditions of the test such as but not limited to pass/fail criteria, the exposure time, test garment preparation, the minimum number of samples to be tested, etc. (see Clause 7).

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 (see Annex E).

Energy transferred through the test specimen during and after the exposure is measured by manikin sensors[15][16]. These measurements shall be used to calculate the total energy transferred to the surface of the manikin.

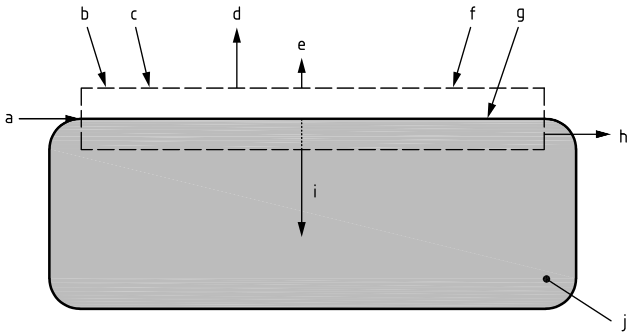
NOTE 1 The results are used to calculate the degree of predicted skin burn injury and total predicted skin burn injury areas resulting from the exposure as described in ISO 13506-2. The predicted skin burn injury information is used in the calculation of the thermal manikin protection factor.

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, thermal manikin protection factor (TMPF) 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.

### 4.2 Heat flux - energy balance on the sensor

When energy from flames impinges a manikin sensor, its energy balance of convective heat and radiant heat on the surface of the manikin sensor and the losses - it is critical to using the right calibration techniques and making the adequate correction (see Annex C). The energy definitions in clause 3 are better understood when looking at Figure 1. When a garment covers the sensor or even touches the sensor, a number of additional factors apply which are described in more detail in C.3.




a Control volume.
b $q_{inc,radiant}$.
c $q_{inc,radiant\ walls}$.
d $q_{inc,radiant\ reflected}$.
e $q_{emitted,radiant}$.
f $q_{convection}$.
g $T_{surface}$.
h $q_{losses}$.
i $q_{net}$.
j Sensing surface.

**Figure 1 — Energy balance on the surface of a manikin sensor**

$$q_{net} = \alpha q_{inc,radiant} + \alpha q_{inc,radiant,walls} + q_{inc,convective} - q_{radiant,emitted} - q_{losses} \quad (1)$$

where

| | |
|---|---|
| $q_{net}$ | net absorbed heat flux by the surface; |
| $\alpha$ | absorptivity of the surface; |
| $q_{inc,radiant}$ | the radiant heat flux striking the sensor surface from the flame; |
| $q_{inc,radiant,walls}$ | the radiant heat flux striking the sensor surface from the walls; |
| $q_{inc,convective}$ | convection heat from the flame to the sensor surface [$h(T_{flame} - T_{surface})$, where $h$ = convection heat transfer coefficient, W/m$^2$·°C]; |
| $q_{radiant,emitted}$ | radiant heat flux emitted by the sensor surface to the flame and surroundings [$\varepsilon\sigma T^4$, where $\varepsilon = \alpha$ (Kirchhoff's law), $\sigma$ = Stefan Boltzmann constant, and $T$ is in K]; |
| $q_{losses}$ | heat losses from the side and back of the sensor due to its mounting in the manikin shell (specific to each sensor technology). |

The $q_{inc,radiant}$ reflected shown in Figure 1, does not heat the sensor surface. It is included in Figure 1 for completeness of the energy flows between the flame and the sensor surface. The amount reflected equals $(1 - \alpha)\ q_{inc,radiant}$.

## 4.3 Assumptions to achieve the required heat flux

For the purposes of this test, the following conditions are assumed when calculating the incident heat flux:

— the heat is 60 % radiative and 40 % convective (Kemp et al.)[18];

— the temperature of the flame on the manikin is 1 100 °C;

— the paint used to cover the surface of the thermal energy sensor has an $\alpha$ = 0,9.

NOTE Different sensors react differently to the incident energy (approximately 40 % convective energy in the incident nude exposure). Take care when making corrections for absorbed energy under the test specimen as the air gap between the inside of the garment and the sensor as the distribution of heat flux (conduction, radiant, and convection) is unknown and could result in a higher or lower protection value attributed to the fabric or ensemble.

# 5 Apparatus

## 5.1 Instrumented manikin

An upright manikin in the shape and size of a female or male adult human shall be used [see Figure 2]. The manikin shall consist of a head, a chest/back, an abdomen/buttocks, arms, hands, legs and feet. Representative dimensions are provided for the male form in Table 1 and for the female form in Table 2. Figure 3 contains a visual key of dimension locations

The arms should be able to rotate through a sufficient arc at the shoulder to ease the garment donning and doffing on the manikin.

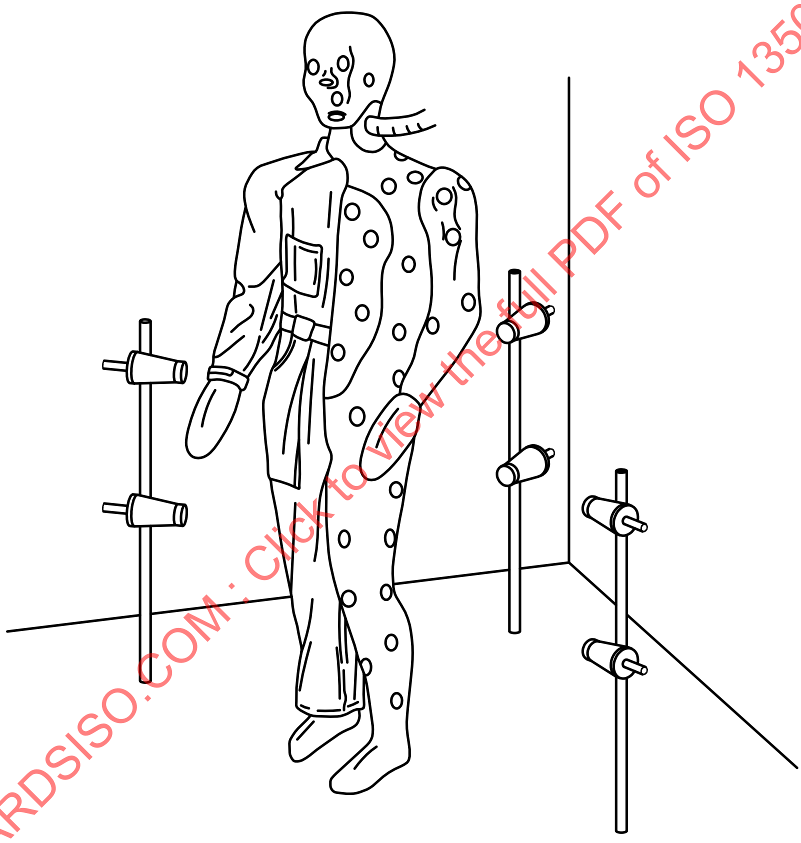
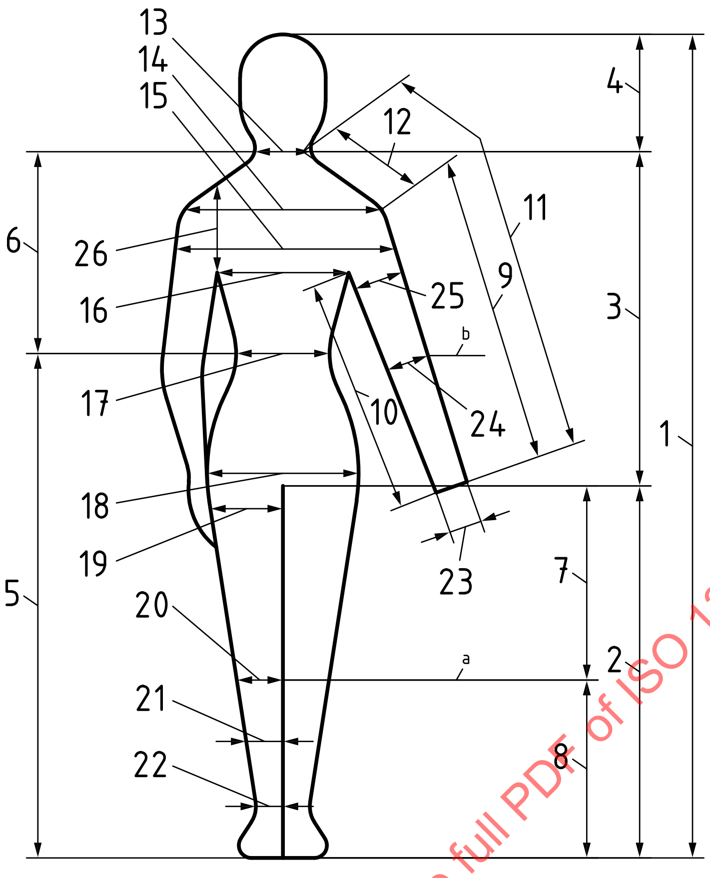


**Figure 2 — Example of an instrumented thermal manikin and partial view of torch stands (burner system)**

NOTE 1 Only six burners of the total are shown in Figure 2 (see 5.7.4).




a Knee level.

b Elbow level.

**Figure 3 — Manikin measurement locations**



NOTE 2 The instrumented manikin matches the dimensions given in Table 1 (male form), Table 2 (female form). The key to the numbers referenced in Figure 3 correspond to the measurements in both Tables.

**Table 1 — Measurements for an adult male manikin**

| No | Description of male manikin[a] | Measurement mm | Tolerance mm |
|---|---|---|---|
| 1 | Stature/total height | 1 810 | ±60 |
| 2 | Inside leg height (crotch height, from heel) (about 7+8) | 880 | ±75 |
| 3 | Center trunk length (from back of neck to crotch back to front neck) | 1 560 | ±60 |
| 4 | Head height, including neck (Top point of head to side of neck point) | 255 | ±45 |
| 5 | Waist height, from heel | 1 125 | ±50 |
| 6 | Collarbone to back waist (Front neck point to waist) | 480 | ±70 |
| 7 | Crotch to knee | 330 | ±45 |
| 8 | Knee height, standing | 530 | ±70 |
| 9 | Top of shoulder to wrist along arm (shoulder to wrist, elbow bent) | 585 | ±75 |
| 10 | Under arm length (Arm inseam) | 470 | ±40 |
| 11 | Back neck point to wrist length, 3-point measurement from between collarbones to wrist 3 (shoulder to elbow, elbow bent) (about 9+12) | 785 | ±65 |
| 12 | Shoulder length (from side of neck to shoulder point) | 170 | ±75 |
| 13 | Neck girth (circumference) | 420 | ±60 |

**Table 1** *(continued)*

| No | Description of male manikin[a] | Measurement mm | Tolerance mm |
|---|---|---|---|
| 14 | Across back shoulder width (from one shoulder across back to other shoulder through back of neck point) | 500 | ±90 |
| 15 | Chest girth, (100 mm down from front neck point) | 475 | ±95 |
| 16 | Chest circumference, at the armpits | 995 | ±105 |
| 17 | Waist girth | 870 | ±25 |
| 18 | Maximum hip girth | 1 015 | ±15 |
| 19 | Thigh girth below the gluteal fold | 590 | ±40 |
| 20 | Knee girth | 390 | ±50 |
| 21 | Calf girth (maximum horizontal girth) | 400 | ±30 |
| 22 | Ankle girth(measured at minimum leg girth) | 280 | ±30 |
| 23 | Wrist girth | 205 | ±30 |
| 24 | Elbow girth | 290 | ±25 |
| 25 | Upper arm girth, at midpoint between shoulder point and elbow point | 320 | ±35 |
| 26 | Armscye girth | 410 | ±50 |

NOTE The descriptions for measurements areas are based on the ISO 8559-series.

[a] Manikins meeting these requirements are available from:

- 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,
- 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.



**Table 2 — Measurements for an adult female manikin**

| No | Description of female manikin[a] | Measurement mm | Tolerance mm |
|---|---|---|---|
| 1 | Stature/total height | 1 612 | ±55 |
| 2 | Inside leg height (crotch height, from heel) (about 7+8) | 788 | ±50 |
| 3 | Center trunk length (from back of neck to crotch back to front neck) | 1 503 | ±55 |
| 4 | Head height, including neck (Top point of head to side of neck point) | 230 | ±45 |
| 5 | Waist height, from heel | 981 | ±45 |
| 6 | Collarbone to back waist (Front neck point to waist) | 405 | ±60 |
| 7 | Crotch to knee | 352 | ±40 |
| 8 | Knee height, standing | 437 | ±40 |
| 9 | Top of shoulder to wrist along arm (shoulder to wrist, elbow bent) | 580 | ±50 |
| 10 | Under arm length (Arm inseam) | 422 | ±30 |
| 11 | Back neck point to wrist length, 3-point measurement from between collarbones to wrist (shoulder to elbow, elbow bent) (about 9+12) | 685 | ±65 |
| 12 | Shoulder length (from side of neck to shoulder point) | 104 | ±55 |
| 13 | Neck girth (circumference) | 373 | ±45 |
| 14 | Across back shoulder width (from one shoulder across back to other shoulder through back of neck point) | 445 | ±75 |
| 15 | Across chest, (100 mm down) | | |
| 16 | Chest circumference, at the armpits | 952 | ±80 |
| 17 | Waist girth | 827 | ±60 |

**Table 2** *(continued)*

| No | Description of female manikin[a] | Measurement<br>mm | Tolerance<br>mm |
|---|---|---|---|
| 18 | Maximum hip girth | 1 022 | ±30 |
| 19 | Thigh girth below the gluteal fold | 627 | ±40 |
| 20 | Knee girth | 331 | ±40 |
| 21 | Calf girth (maximum horizontal girth) | 331 | ±30 |
| 22 | Ankle girth (measured at minimum leg girth) | 250 | ±30 |
| 23 | Wrist girth | 180 | ±25 |
| 24 | Elbow girth | 268 | ±25 |
| 25 | Upper arm circumference, at the midpoint | | |
| 26 | Armscye girth | 371 | ±45 |

NOTE The descriptions for measurements areas are based on the ISO 8559-series.

[a] The sizing is based on the anthropometric survey of US military female personnel (ANSUR II). The development of the female manikin size has been done in cooperation between ASTM and ISO with intent to have identical sizing. Currently ASTM is still preparing their revision of ASTM F1930. Depending on the result at ASTM this table is subject to amendment including the tolerances.



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 at least 3 mm and no thicker than 12 mm, other than in localized areas (e.g. joints).

NOTE 3 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

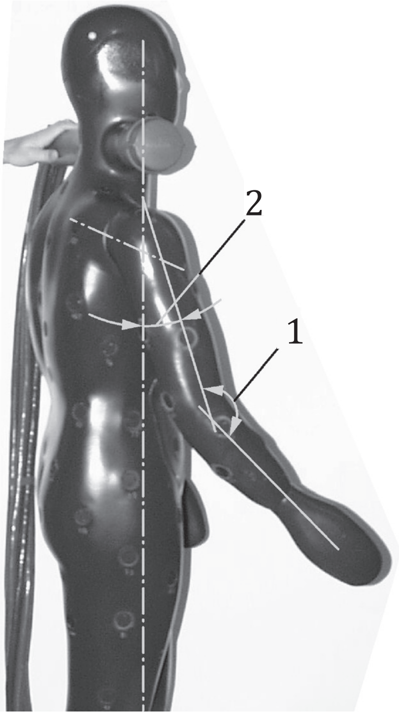
A reproducible positioning system is required for the manikin.

NOTE 1 This can be achieved using 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 4) shall be set in the range of 150° to 165°. The angle of the shoulder (see Figure 4) 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 4. Manikin legs are permitted to be static. A slight twist of the torso as compared to the legs is permitted. The legs are less than 10° apart from the centre line and at the ankles, and they are about 120 mm to 250 mm apart.

NOTE 2 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.




**Key**

1 angle between upper arm and lower arm

2 angle between line shoulder and hip to shoulder and elbow

**Figure 4 — Definition of arm position**



## 5.3 Manikin sensors

### 5.3.1 Principle

The measurement system shall use manikin sensors which produce an output, which can be used to measure absorbed heat flux, $q_{net}$, and calculate the incident 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 of the manikin. If the sensor layout has sensors with equal sensor area distribution, the heat flux is calculated using equal distribution of each sensor. If a manikin system has sensors with inequal sensor area distribution, the data shall be area weighted when calculating heat flux.

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 5). 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.

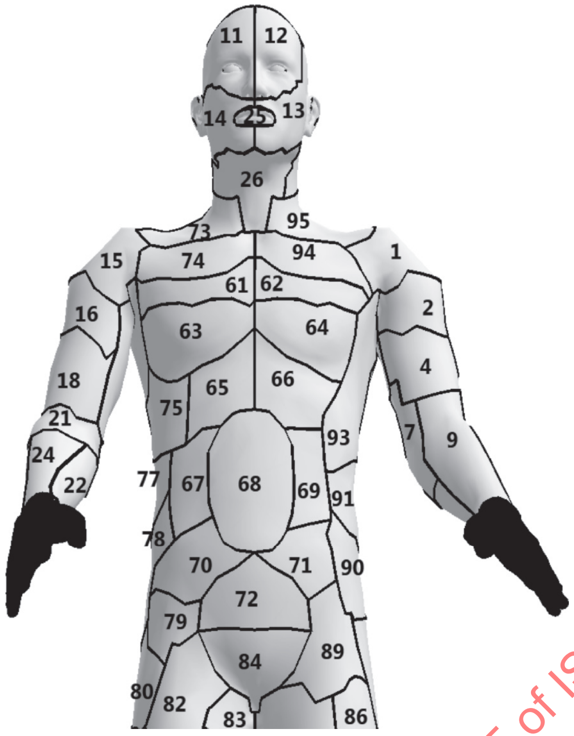



**Figure 5 — Example of manikin sensor location and their associated area**

The incident heat flux is not equivalent to the absorbed heat flux during a nude exposure. The incident heat flux is calculated from the absorbed heat flux at each manikin sensor taking into account the ability of the manikin sensor surface to absorb thermal energy from the flames as specified in Annex C (see also 5.5).

### 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 3 sets an acceptable manikin sensor distribution.

NOTE 1 Some existing manikins currently in use have as low as 110 sensors (excluding hands and feet) and as high as 135 including sensors in hands and feet.

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 3 — Sensor distribution**

| **Body region** | **Body area** | **Minimum number of manikin sensors** | **Percentage of total sensored area, without sensors in hands or feet** (guidance) % | **Area in m$^2$ based on an assumed body surface area of 2 m$^2$; see Note 3** **Male/female** |
|---|---|---|---|---|
| Head | Head | 8 | 7 | 0,13/0,12 |
| Chest and abdomen | Chest | 10 | 40 (Trunk) | 0,77/0,58 (Trunk) |
| | Abdomen | 11 | | |
| Back | Upper back | 11 | | |
| | Lower back | 11 | | |
| Right arm | Arms | 18 | 16 | 0,26/0,23 |
| Left arm | | | | |

**Table 3** *(continued)*

| Body region | Body area | Minimum number of manikin sensors | Percentage of total sensored area, without sensors in hands or feet (guidance) % | Area in m² based on an assumed body surface area of 2 m²; see Note 3 Male/female |
|---|---|---|---|---|
| Right leg | Thighs and lower legs (Shanks) | 41 | 37 | 0,61/0,55 |
| Left leg | | | | |
| If sensor used include in arms | Hands | 0 | — | 0,1/0,1 |
| If sensor used include in legs | Feet | 0 | — | 0,13/0,12 |
| | Total | 110 | 100 | 2/1,7 |

NOTE 2 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 using the percentages in Table 3, column 5.

NOTE 3 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] assume a total surface area of approximately 2 m²/1,7 m² for a male/female of approximately 1,85 m/1,69 m in height and with average mass. Subtracting the area not covered by sensors (hands and feet) results in a surface area of approximately 1,8 m²/1,5 m² respectively for a male/female.

### 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 1 The reference sensor is critical in the calibration of the manikin. Therefore ensure that the reference sensor is well maintained, checked and re-calibrated regularly as any variation of the reference sensor will have a cascading effect across the sensor calibration, manikin calibration all the way to the results of testing as demonstrated during the round robin.

NOTE 2 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, that is performed from about 5 to up about 70 kW/m², extrapolation from the linear region is possible below and above this level (ISO 14934-2:2013, 4.3, Method 2 (spherical black-body cavity method)).

NOTE 3 RISE Research Institutes of Sweden AB (Brinellgatan 4, 504 62 Boras) is capable to perform calibrations in this range of Note 2, but they indicated calibrations as high as 75 kW/m² and even below 2 kW/m² are possible. 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 services may be used if they can be shown to lead to the same results as described in ISO 14934-2.

NOTE 4 According to NIST, absolute accuracy for radiant heat flux measurement up to 250 kW/m² is ±8 % (NIST Special Report Publication N 1031[16]). The required margins of ±4,2 kW/m² in this test method for the average 84 kW/m² need to be seen relative to calibration of the applied manikin sensors.

### 5.3.4 Manikin sensor specification

#### 5.3.4.1 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)].

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

#### 5.3.4.2 Manikin sensor calibration

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

A record shall be kept of the manikin sensor calibrations and manikin sensor system validation during their operating life.

#### 5.3.4.3 Reactivity

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). Sensor response time shall be 0,5 s or less to go from 10 % to 90 % of steady state (see Figure 6) reading during the calibration of manikin sensor.


**Key**

X time (in s)

Y heat flux (in %)

manikin sensor

ref. sensor

**Figure 6 — Example of reactivity of sensor during sensor calibration with a typical steady state**

NOTE 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 effusivity. For sensors based on thermocouples, designs that minimize the thermal effusivity 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).



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.

### 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 heat flux validation

#### 5.3.6.1 Heat flux definition

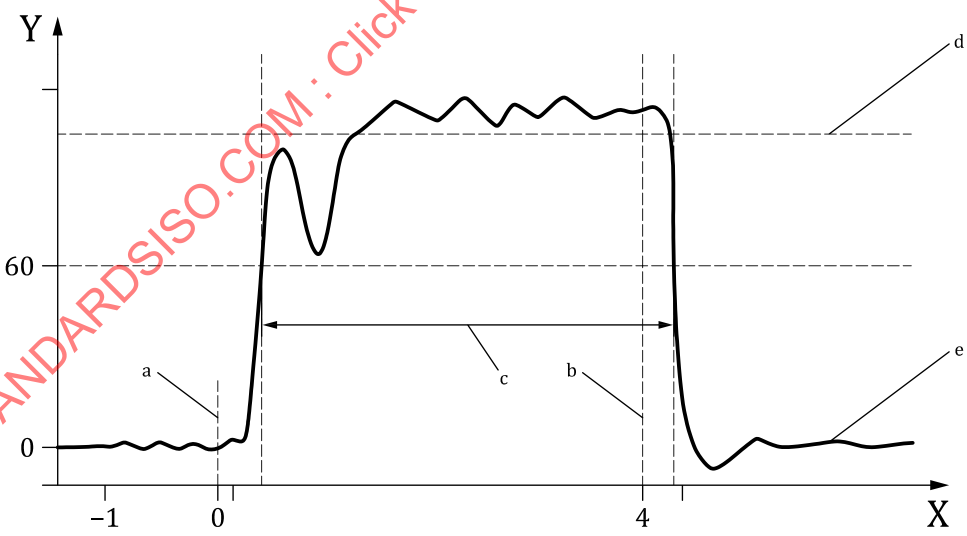
The nude manikin exposure heat flux shall be within (84 ± 2) kW/m$^2$ for the initial manikin heat flux validation of the day. All other nude manikin exposure shall meet the (84 ± 4,2) kW/m$^2$ (tolerance of 5 %) as also indicated in 8.1.6. Both the initial validation and any subsequent validation of the heat flux shall not be subject to uncertainty of measurement requirements.

The nude manikin exposure heat flux calculation period shall be defined as (see Figures 7 and 8):

a) starting when the average heat flux of all sensors ≥60 kW/m$^2$ (nearest 0,1 s data increments) is reached;

b) ending when the average heat flux average of all sensors ≥60 kW/m$^2$ (nearest 0,1 s data increments) after exposure.

All the heat flux data between the start and the end of the heat flux calculation period, even when those fall below 60 kW/m$^2$, shall be used for the calculation.




**Key**

X $t_{sec}$ (time in s)

Y heat flux, in kW/m$^2$

a Start of exposure.

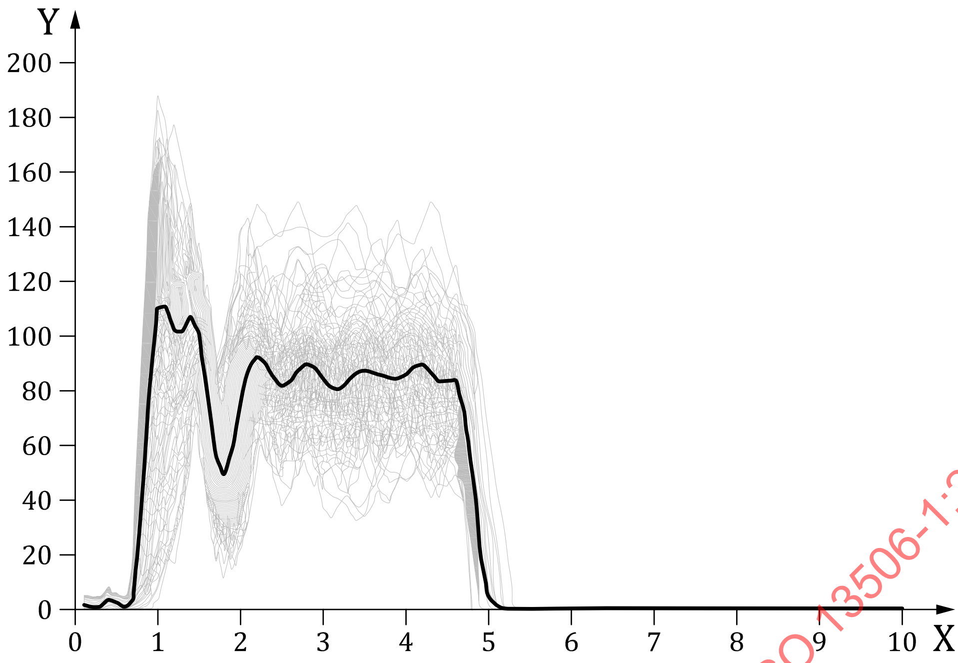
b End of exposure.

c Exposure heat flux calculation period.

d Nude manikin exposure heat flux.

e Average heat flux of sensors.

**Figure 7 — Heat flux calculation period for a 4 s nude exposure for manikin validation**




**Key**

X time, in s

Y heat flux, in kW/m²

**Figure 8 — Example of manikin nude exposure with all sensors are in grey and in black the average of the overall manikin exposure**

NOTE In the above figures, the individual sensor heat flux curves and the average heat flux of all sensors are examples, the shape of these heat flux curves depend on the installation and the sensor technology.

### 5.3.6.2 Exposure heat flux requirements

The following heat flux distribution requirements during nude manikin heat flux calculation period shall be met for all the sensors on the manikin, except sensors positioned in the hands and feet.

a) The average $q'_{incident}$ heat flux of each sensor shall be calculated over the heat flux calculation period. The average of those values shall be within of (84 ± 2) kW/m² for the initial validation and (84 ± 4,2) kW/m² (tolerance of 5 %) for subsequent validation of the heat flux, with a standard deviation less than or equal 21 kW/m²;

b) the average incident heat flux measured for each body region (including head) (see 5.3 and 5.5.3) shall be in each case within ±15 % of the average in a) (See Annex C and D).

### 5.3.6.3 Symmetry

Symmetry assessment shall be performed based on the initial nude burn prior to testing the garment. They shall meet the conditions mentioned below (one of the three may be at ±10 %).

a) Symmetry of left (left arm and leg only) and of right of the manikin (right arm and leg only) ±5 % with the average heat flux of those body parts;

b) symmetry of upper manikin (arms, torso (front and back) only, excluding head) and of lower of the manikin (legs only) ±5 % with the average heat flux of those body parts;

c) symmetry of front (front torso only, excluding head) and of back of the manikin (back torso only, excluding head) ±5 % with the average heat flux of those body parts.

## 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 maximum data acquisition period of 240 s.

The precision of the measurement system (sensor, cable and data acquisition) shall be better than 0,5 % of the reading or ±0,2 °C, if a temperature sensor is used.

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 0,1 °C;

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

e) cold junction compensation (if thermocouples are used).

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 (see Annex E).

#### 5.5.1.1 For calibration of the flame engulfment from the nude exposure

a) Measure absorbed heat flux of sensor, $q_{net}$, over time or transform manikin sensor data into incident heat flux over time;

b) calculate incident heat flux based on the absorbed heat flux, $q_{net}$, (see 5.3.1, 5.5.2, C.3);

NOTE Calculating the incident energy needs 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 Annex C, 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 (see also Annex D);

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 5.3.6.2);

f) verify that symmetry requirements according to 5.3.6.3 are met.

#### 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;

— calculate transferred energy per manikin sensor (see 5.5.5) and total transferred energy for the whole system.

### 5.5.2 Incident heat flux

Determine the incident heat flux from the heat flux absorbed, $q_{net}$, 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 heat flux calculation period as described in 5.3.6.

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 sensor-weighted averages for each manikin sensor for the exposure heat flux calculation period of the nude exposure. The procedure is described in Annex D.

NOTE 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 3 and 5.7.4.4, 5.3.6.2 b)].

### 5.5.4 Thermal manikin protection factor (TMPF)

The TMPF is set to compare garments and potentially setting cut-off values for product standards. The TMPF is a factor using percentage of the body protected from second and third degree burns (using ISO 13506-2) for a given thermal manikin exposure for a fabric mass. The head data shall be excluded as it is usually not protected during the garment exposure.

The calculation is given by Formula (2):

$$f_{\mathrm{TMPF}} = (100\ \% - B) \cdot \frac{t}{G} / b \qquad (2)$$

where

- $B$ % body-burns (2nd and 3rd degree on body without head if not protected);
- $t$ exposure time;
- $G$ total garment mass (in g);
- $b$ body surface (see Note 2).

Garment ensemble (all the garment together) mass shall be measured in accordance with ISO 3801 and based on the conditions as required by Clause 7.

NOTE 1 The garment mass is not the same as fabric basis mass per area multiplied by covered body surface area. The garment mass is at least a factor 2,3 higher for a simple garment.

NOTE 2 The covered body surface area of a male manikin has been rounded to 1,6 $m^2$ without head, feet and hands and 1,74 $m^2$ if the head is included (For female manikin, the body surface needs to be amended to 1,36 $m^2$ without head, feet and hands and 1,58 $m^2$ if the head is included (see Table 3).

NOTE 3 Based on the assessments made for various garments based on the fabric basis mass at different exposures, for industrial and wildland garments with exposure at 3 s: 0,42 < TMPF <0,73; at 4 s: 0,23 < TMPF < 0,69 and fire firefighter at 8 s: 0,34 < TMPF ≤0,65. See also data from the ILT in table B.2. It is difficult to compare TMPF factors of different exposures for the same garments as the burn prediction is not linear with exposure durations, and not enough data is currently available to validate this.

### 5.5.5 Transferred energy

#### 5.5.5.1 General

The transferred energy per manikin sensor is equal to the absorbed energy per manikin sensor, and 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.

The transferred energy is the integral of the absorbed heat flux for each manikin sensor over the calculation period, taking into account that each manikin sensor represents a finite area of the surface of the manikin.

#### 5.5.5.2 Clipping rules

To avoid over- or under-estimation of transferred energy due to offset of heat flux readings after the exposure the following clipping rules shall be applied:

— Heat flux values below 1 kW/m$^2$ (including negative heat fluxes) shall be set to 0;

— If the slope of heat flux over a period of 5 s, earliest 5 s after end of exposure, is below 100 W/m$^2$/s the heat flux shall be set to 0.

NOTE Insufficient or excessive clipping can be an indication of calculation error or sensor fault.

#### 5.5.5.3 Calculation of transferred energy

The transferred energy can be calculated using Formula 3 below:

$$Q_i = A_i \int_0^T q'_i(t) \cdot \mathrm{d}t \qquad (3)$$

where

| | |
|---|---|
| $T$ | is the total data acquisition time $T$ in s; |
| $Q_i$ | is the transferred energy of manikin sensor $i$ in J; |
| $q'_i(t)$ | is the heat flux of manikin sensor $i$ at time $t$ in W/m$^2$; |
| $A_i$ | is the area attributed to manikin sensor $i$ in m$^2$. |

For a discrete data set, the transferred energy for a manikin sensor $i$ over the time period $T$ (with time steps $\Delta t$) can be calculated using Formula 4 below:

$$Q_i = 0 \quad \text{for } t = 0$$

$$Q_i = A_i \sum_{j=1}^{N} \left[ \frac{1}{2} \left( q'_j + q'_{j-1} \right) \left( t_j - t_{j-1} \right) \right] \text{ for } t > 0 \qquad (4)$$

Total transferred energy is the sum of transferred energy of all manikin sensors and can be calculated using Formula 5 below:

$$Q_{tot} = \sum_{i=1}^{n} Q_i \qquad (5)$$

where

| | |
|---|---|
| $Q_{\mathrm{tot}}$ | is the total transferred energy in J; |
| $n$ | is the number of manikin sensors. |

## 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 and maximum dimensions of 10,7 m wide by 16,4 m long by 6,7 m high to ensure good flame engulfment of the manikin.

NOTE The justification for the size of the room are based on the round robin tests to set upper and lower limits. The lowest volume chamber size was 23,5 $m^3$ and the largest volume size chamber was 1 174 $m^3$.



### 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 draft free 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.

NOTE The external environmental conditions are a factor that can influence the air flow into the chamber. The pilot flames can be an indicator of how quiescent the air is in the burn chamber.

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 required.

## 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 Annex D).

### 5.7.2 Fuel

The fuel shall be propane of >85 % purity to achieve the required heat flux defined in 5.3.6.

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 ± 4,2) kW/m$^2$ (tolerance of 5 %) over the exposure duration for 3 s to 20 s depending on the equipment requirements for the duration of the test and the environmental conditions.

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 pressure or 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 3 s to 5 s is sufficient for testing single-layer garments, such as coveralls. If multilayer garment, such as structural 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.

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 5.3.6, 5.7.4.4 and Annexes C and D.

NOTE 1 The justification for performance requirements are met by 8 burners, but 12 burners are used by most labs.

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 5.3.6, 5.7.4.4 and Annex D.

NOTE 1 Essentially, these burners are designed to produce luminous (reddish-yellow to orange) delayed mixing diffusion flames with flame temperatures from 1 000 °C to 1 400 °C (ILT data).

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 4) shall be used and positioned to yield the exposure level and uniformity specified in 5.3.6 and Annex D.

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

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 Annex D, 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 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 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.

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.

### 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;

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

   3) perform tests on at least one of the garments in Table 4, at least 3 replicates shall be tested at either 3 s or 4 s. The results shall be within the test precision summary set out in Table B.2, excluding sample B (B200X3).

   NOTE When choosing a reference garment it is necessary to understand the potential variation of the result due to the garment see Table B.2 and detailed round robin report which is available from the secretariat (see B.7).

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 the 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, creation of 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 manufacturer from their size range to fit the laboratory's manikin form (male or female) or selected based on the performance standard. 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 the manikin correctly with sufficient garment ease as one would choose clothing for a person. The laboratory shall assess the garment fit prior to performing the test, and record the observation in the test report.

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 larger than required on the manikin, one can get ingress of flame under the jacket influencing negatively the results.

## 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

A 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 of the manikin system.

A 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.

The garment size requirement shall be based on 6.3 and Table 1 and 2 on manikin forms.

**Table 4 — Potential reference garments**

| Nr | Material | Reference number | Mass |
|---|---|---|---|
| 1 | Aramid (DuPont™ Nomex® Comfort [a]), light blue | B200X1 | 220 g/m$^2$ |
| 2 | FRT Cotton, navy blue | B200X3 | 335 g/m$^2$ |
| 3 | PBI® Matrix [b] | B200X8 | 205 g/m$^2$ |
| 4[c] | Aramid (DuPont™ Nomex® Comfort [a]), light blue | B200X2 | 260 g/m$^2$ |
| 5[c] | 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 PBI® Matrix is the trade name of a product supplied by PBI Performance Products, Inc. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of the product named.

c The two last garments where used in the previous round robin 2014-2015 [N108 Final Draft RR ISO 13506-1 Non Confidential (16.02.2016)].

NOTE 1 During the round robin held in 2015 to 2021, the first three coveralls made of three different fabrics listed in Table 4 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]. The results of the round robin can be found in Annex B.

NOTE 2 When choosing a reference garment it is important to review the fit, and any variation in results. Also when making a new purchase of an existing reference garment, a check needs to be made of consistency of results. As a change in fabric lot of the same fabric may have a slightly different mass, and therefore a different result which will have an effect on the consistency of the results. This is relevant not only with respect to the fabric (different lot of fabric can have minimum difference in mass) 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, size, thickness, and basis mass).

h) definition on how closure systems should be implemented and tested (e.g. zippers, snaps, hook and loop closures)

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 8.1.6.

#### 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 routine check (minimum daily)

Check that prior to any test series or at least at the beginning of each day, 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. The temperature validation shall not be subject to uncertainty of measurement requirements.

If any manikin sensor is suspected to be defective, verify each suspected defective manikin sensor by exposure to a reference heat source (see Annex C). 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 fitted in the manikin shall be calibrated at a minimum of once per 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 (see specific reporting requirement in Clause 9, these sensors covered in this manner shall be excluded from the analysis).

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). Check if sensor functions appropriately (see 8.1.6) and at nude testing.

### 8.1.3 Flame exposure chamber purging

Prior to testing, 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 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.

### 8.1.5 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.

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. Charge main burner headers.

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.

### 8.1.6 Confirmation of nude and garment exposure conditions

Prior to nude manikin or garment exposures, confirm that the temperature of all the manikin sensors is stable for at least 1 min (see 8.3, Annex D):

— All sensors shall be below 38 °C;

— Average temperature of all sensors shall be between 15 °C and 34 °C;

— No sensor shall change more than 1 °C.

In garment exposures, only covered sensor shall meet these requirements.

NOTE 1 In regions where extreme high or low temperatures can be expected, the system will seek thermal equilibrium with local conditions. The room temperature can be adjusted as necessary (see 9.3).

Nude calibration shall expose nude manikin to the test fire for 4 s or as specified by the performance standard with a minimum of 3 s and a maximum of 5 s. The initial nude calibration of the testing period shall meet all criteria as specified in 5.3.6, subsequent nude test shall meet the heat flux of 84 kW/m$^2$, with a relative tolerance of ±5 % ((84 ± 4,2) kW/m$^2$), of that testing period and the requirement of 5.3.6.1 and 5.3.6.2 (not 5.3.6.3).

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 according to 5.3.6. A nude burn is required after sensor cleaning, if the series of testing is not complete to be able to use the garment results.

NOTE 2 Environmental conditions (wind, humidity, temperature) play a significant role in the stability of the exposure.

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 8.1.6 (see 8.3, Annex C).

### 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 (single garment, or assembly of multiple garments) being evaluated, a product standard or due to other requirements, no undergarments shall be used. 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 possibly specification of mass, construction to male or female form, if required T-shirt, briefs, or other undergarments;

d) test conditions, male or female manikin (including deviation if any);

e) test observations (including garment fit and sizing);

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 8.2.9);

i) a real-time visual image (i.e. video) of the test exposure and after flaming, if any (see 8.2.4);

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) if backside ignition occurred on fabric and location

n) if break open occurred on fabric, denote location and number of occurrences

o) any other information relevant to the test series.

### 8.2.4 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.

### 8.2.5 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 mass 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).

### 8.2.6 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.

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.

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

### 8.2.7 Recording of specimen response remarks

Record any remarks on the reaction of the test specimen to the during and after 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.

### 8.2.8 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 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.

### 8.2.9 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 8.1.6 and meets the requirements of 5.3.6.1.

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 ventilation fan(s) or a heating, ventilation and air conditioning (HVAC) system is permitted to be used to cool them below the requirements of 8.1.6. 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 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: for each garment of an ensemble type, layer ordering in multilayer specimens, size, actual fabric mass per unit area of each garment (using ISO 3801), the actual garment weight (used for the TMPF calculation), fibre type, colour, and non-standard garment features and design characteristics. Also provide equivalent information on underwear (e.g. shorts, T-shirt) if used in the test.

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 that is being used during the test, any holes, and/or cuts that were made in the garment/ensemble to accommodate cable connections.

NOTE The specimen identification is important as the test reflects the actual garment design, even from the same design description and pattern but made by a different manufacture has been seen to have different results as the ease may be different. Therefore, as much information is to be included to be able to trace origin of the sample.

### 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 duration, data acquisition period and data calculation period;

b) 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;

c) a confirmation during the nude exposure (male or female form) that the three heat flux distribution requirements from 5.3.6 and 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:

a) the exposure time;

b) the duration of the data acquisition;

c) any information or other relevant issues relating to the exposure conditions that may assist in interpreting the test specimen results (see 8.2.3 and 8.2.7);

d) any information other relevant issues (see also 8.1.6 and 8.1.2.1)

## 9.4 Results for each specimen

### 9.4.1 General

All results according to 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, recorded and some have to be 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.

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 Thermal manikin protection factor

Provide TMPF based on 5.5.4, using actual garment weight (not fabric mass per unit area), burn prediction information, and exposure time.

### 9.4.4 Transferred energy

Provide transferred energy, calculated according to 5.5.5, including the following information:

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.

### 9.4.5 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.

If T-shirts and briefs are used under a test specimen, these garments need to be representative of those used. It is recommended that polyester-based underwear is not 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)

# Interlaboratory test data analysis

**B.1** An inter-laboratory exercise using the test methods of this document and ISO 13506-2 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.

## B.2 Tested materials

During the round robin, three coveralls were used of size 52 from PWG Bedrijfveilige Kleding B.V (www.pwg.nl) and one firefighter pants and coat, both of size 54, from NOVOTEX-ISOMAT Schutzbekleidung GmbH, www.Novotex-isomat.de, email: info@novotex-isomat.de.[5] The results can be found in Table B.1.

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

| Nr | Material | Reference number | Mass |
|---|---|---|---|
| A | Aramid (DuPont™ Nomex® [a] Comfort), light blue | B200X1 | 220 $g/m^2$ |
| B | FRT Cotton, navy blue | B200X3 | 335 $g/m^2$ |
| C | PBI Matrix [b] | B200X8 | 205 $g/m^2$ |
| 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 11–334 & 11-300 | Coat: 2,3 kg<br>Pants: 1,5 kg<br>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] PBI® Matrix is the trade name of a product supplied by PBI Performance Products, Inc. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of the product named.

[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, at both 4 s and 3 s exposure at 84 $kW/m^2$, 120 s measurement time;

— Garment B: Single layer, at both 4 s and 3 s exposure at 84 $kW/m^2$, 120 s measurement time;

— Garment C: Single layer, at both 4 s and 3 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 testing 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 | Exposure time | Transferred energy in kJ | | | | Burn risk prediction according to ISO13506-2 in % of covered area | | | | TMPF |
|---|---|---|---|---|---|---|---|---|---|---|
| | | avg. | $S_r$ | $S_R$ | No of labs | avg. | $S_r$ | $S_R$ | No of labs | |
| A | 3 s | 161,6 | 9,3 | 25,6 | 12 | 11,8 | 2,6 | 5,5 | 11 | 0,76 |
| A | 4 s | 229,0 | 9,1 | 27,6 | 11 | 52,2 | 4,9 | 8,0 | 11 | 0,38 |
| B | 3 s | 117,5 | 6,4 | 24,8 | 12 | 2,6 | 1,4 | 2,9 | 11 | 0,50 |
| B | 4 s | 230,5 | 18,4 | 67,6 | 11 | 54,8 | 10,1 | 27,1 | 12 | 0,23 |
| C | 3 s | 138,3 | 9,9 | 23,3 | 12 | 5,9 | 1,4 | 3,5 | 11 | 0,83 |
| C | 4 s | 194,0 | 7,9 | 24,9 | 11 | 34,3 | 4,0 | 9,7 | 11 | 0,56 |
| D | 8 s | 154,7 | 11,6 | 59,2 | 8 | 7,6 | 2,1 | 11,3 | 8 | 0,29 |

Statistical analysis according ISO 5725 was applied avg. is the mean of the mean total transferred energy reported by each laboratory based on the area covered by sensors or burn risk prediction.

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

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

For garment A, and C for the burn prediction one lab is excluded from the statistical assessment as an outlier

**B.7** A detailed report is available from the secretariat [N267 Non-Confidential Report Round Robin ISO 13506-1:2017 and ISO 13506-2:2017 on thermal manikin system, sensors and manikin calibration, standard overalls and structural firegfighter testing (2022-03-30)]. 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.