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Protective clothing against heat and flame —

Part 2: Skin burn injury prediction — Calculation requirements and test cases

Vêtements de protection contre la chaleur et les flammes —

Partie 2: Prédiction de blessure par brûlure de la peau — Exigences de calculs et cas d'essai

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Contents

Page

Foreword ..... **iv**

Introduction ..... **v**

1 Scope **1**

2 Normative references **1**

3 Terms and definitions **1**

4 General **3**

5 Apparatus, specimen preparation and test procedure **4**

6 Predicted skin burn injury calculation **4**

6.1 Skin model 4

6.1.1 General 4

6.1.2 Manikin sensor heat flux values as function of time 4

6.1.3 Determination of the predicted skin and subcutaneous tissue (adipose) internal temperature field 4

6.1.4 Initial and boundary conditions 7

6.1.5 Determination of the *Ω* value for the prediction of skin burn injury 7

6.1.6 Time to pain 8

7 Skin burn injury calculation test cases and *in situ* calibration **9**

7.1 Test cases and ***in situ*** calibration 9

7.2 Skin layer temperature prediction test cases 9

7.2.1 General 9

7.2.2 Case one 9

7.2.3 Case two 9

7.2.4 Accuracy requirement 9

7.3 Skin burn injury calculation test cases 10

7.4 ***In situ*** calibration of burn injury prediction 11

8 Test report **12**

8.1 General 12

8.2 Skin model 12

8.3 Calculated results 13

8.3.1 General 13

8.3.2 Predicted area (%) of manikin injured based on the total area of the manikin containing heat flux sensors 13

8.3.3 Predicted area (%) of manikin injured based only on the area of manikin covered by the test specimen 13

8.3.4 Other information 13

Annex A (normative) **Skin model with temperature-dependent thermal conductivity, *k*(*x*,*T*)** **14**

Annex B (informative) **Inter-laboratory test data burn injury prediction** **16**

Bibliography **18**

Foreword

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

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

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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

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

This first edition of ISO 13506-2, together with ISO 13506-1, cancels and replaces the first edition of ISO 13506:2008, which has been technically revised.

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

Introduction

The purpose of heat and flame-resistant protective clothing is to shield the wearer from hazards that can cause skin burn injury. The clothing can be made from one or more materials, which can be made into a garment or protective clothing ensemble for testing on a manikin fire exposure system.

This document is a companion document to ISO 13506-1. It replaces ISO 13506:2008, Annex C and specifies in a normative way the method of calculating and reporting test results for ISO 13506-1 in the form of skin burn injury prediction. The data gathered by tests according to ISO 13506-1 are used as input for this calculation.

In the test method standard ISO 13506-1, a stationary, upright, adult-sized manikin is dressed in a garment or protective clothing ensemble 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. Thermal energy sensors are fitted to the surface of the manikin. The output from the sensors is used to calculate 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 will no longer be rising. The information obtained from the calculation of skin burn injury prediction (see Annex B) can be used to assist in evaluating the performance of the garment or protective clothing ensemble under the test conditions. It can also be used as a model-based tool to estimate the extent and nature of potential skin damage resulting from the exposure of the test garment.

Fit of the garment or protective clothing ensemble on the manikin is important. Thus, variations in garment or protective clothing ensemble design and how the manikin is dressed by the operator may influence the test results and skin burn injury prediction. Experience suggests that testing a garment one size larger than the standard can reduce the percentage of predicted body burn by up to 5 %.

The ISO/TC 94/SC 13 and SC 14 committees and the European Committee for Standardization CEN/TC 162 specify the method described in this document as an optional part in the fire fighter standards ISO 11999-3 and EN 469 and as an optional part in the industrial heat and flame protective clothing standard ISO 11612.

The National Fire Protection Association standard NFPA 2112[6] (specifies ASTM F1930-17[7], which is a test method similar to the one described in ISO 13506-1 and which contains skin burn injury prediction calculations similar to the one described in this document.

Protective clothing against heat and flame —

Part 2:
Skin burn injury prediction — Calculation requirements and test cases

1 Scope

This document provides technical details for calculating predicted burn injury to human skin when its surface is subject to a varying heat flux, such as may occur due to energy transmitted through and by a garment or protective clothing ensemble exposed to flames. A series of test cases are provided against which the burn injury prediction calculation method is verified. It also contains requirements for the *in situ* calibration of the thermal energy sensor — skin injury prediction system for the range of heat fluxes that occur under garments.

The skin burn injury calculation methods as presented in this test method do not include terms for handling short wavelength radiation that may penetrate the skin. The latter include arc flashes, some types of fire exposures with liquid or solid fuels, and nuclear sources.

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/TR 11610, *Protective clothing — Vocabulary*

ISO 13506-1:2017, *Protective clothing against heat and flame — Part 1: Test method for complete garments — Measurement of transferred energy using an instrumented manikin*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 13506-1 and ISO/TR 11610 and the following apply.

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

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

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

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

Note 1 to entry: Burn injury in human tissue occurs when the tissue is heated and kept at an elevated temperature (>44 °C) for a critical period of time. In this document, it is assumed that skin has three layers: the epidermis, which is the tough outer layer, the dermis, which is the layer below the epidermis, and the subcutaneous tissue (adipose), which is the fatty layer of tissue deeper than the dermis. In this document, it is assumed that the thicknesses of the layers are the same everywhere on the human body. Variations in thickness that occur with age, location and sex are not included. The severity of damage, referred to as predicted first-, second-, or third-degree (or partial thickness or full thickness) burn injury, depends upon the magnitude of the elevated temperature above 44 °C and the time during which it remains at or above 44 °C.

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

Note 1 to entry: The skin turns red, but does not blister or actually burn through. First-degree burn injury is reversible. In this document, the time for a predicted first-degree burn injury to occur is indicated when the value of $\Omega = 0{,}53$ [see Formula (3)] at a skin depth of 75×10^{-6} m (75 µm), i.e. at the epidermis/dermis interface.

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

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

Note 1 to entry: Second-degree burn injury is more serious than first-degree burn injury, resulting in complete necrosis (living cell death) of the epidermis layer, usually accompanied with a blister, but is reversible especially if the affected area is small. In this document, the time for a predicted second-degree burn injury to occur is indicated when the value of $\Omega = 1{,}0$ [see Formula (3)] at a skin depth of 75×10^{-6} m (75 µm), i.e. at the epidermis/dermis interface.

3.1.2.1
second-degree burn injury area
second-degree burn area
sum of the areas represented by heat flux sensors for which a calculated second-degree burn injury is the most severe injury predicted to occur

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

Note 1 to entry: Third-degree burn injury is not reversible. In this document, the time for a predicted third-degree burn injury to occur is indicated when the value of $\Omega = 1{,}0$ [see Formula (3)] at a skin depth of $1\,200 \times 10^{-6}$ m (1 200 µm), i.e. at the dermis/subcutaneous interface.

3.1.3.1
third-degree burn injury area
third-degree burn area
sum of the areas represented by the heat flux sensors for which a calculated third-degree burn injury is predicted to occur

3.1.4
total burn injury area
total burn area
sum of the areas represented by the heat flux sensors for which at least a second-degree burn injury is predicted to occur

3.2
omega value
Ω
burn injury parameter, the value of the damage integral [see Formula(3)], which indicates predicted *burn injury* (3.1) at specific skin depths and temperature regimes

3.3
pain area
sum of the areas represented by the heat flux sensors for which pain is predicted to occur

3.4
time to pain
time taken for the pain receptors to reach 43,2 °C

Note 1 to entry: In this document, the pain receptors are located 195 × 10^{-6} m (195 µm) below the surface of the skin.

4 General

The calculation of predicted skin burn injury is a desirable result when used to compare the relative performance of protective clothing using test methods that measure heat to the manikin surface for a defined thermal energy exposure. This document outlines the calculation method that shall be used for this purpose when conducting the tests as described in ISO 13506-1. ISO 13506-1 specifies the method for the measurement of the energy transfer, which can be used as a basis for evaluation of the relative thermal protective performance of the test specimen. The performance is a function of both the materials of construction and design and of fit of clothing onto the test manikin. The average exposure heat flux is 84 kW/m^2 with durations from 3 s to 12 s.

Predicted burn injury determined in this test method uses a simplified mathematical model that does not directly translate into actual human skin burn injury for any exposure test conditions. The model is based on measurements on human fore arms.

The test specimen is placed on an adult-size manikin at ambient atmospheric conditions and exposed to a laboratory simulation of a fire with controlled heat flux, duration and flame distribution. The test procedure, data acquisition, result calculations and preparation of the test report are performed with computer hardware and software programs.

Thermal energy transferred through the test specimen and from the test specimen to the surface of the manikin during and after the exposure is measured by heat flux sensors positioned in the surface of the manikin. The amount of heat varies with time. The method specified in this document uses these heat flux measurements of ISO 13506-1 to calculate the predicted time to pain for each thermal energy sensor, the second- and third-degree burn injury areas, and the total burn injury area resulting from the exposure. It can also be used to predict the time to first-degree burn injury.

Identification of the test specimen, test conditions, comments and remarks about the test purpose and response of the test specimen to the exposure are recorded and are included as part of the test report. The total energy transferred and/or the predicted skin burn injury area, and the way the test specimen responds to the flame exposure are indicators for the performance of the test specimen for this test method. The skin burn injury prediction method can be used with other test methods that produce similar exposures.

Clause 6 gives the details of the required calculation of predicted skin injury, while Clause 7 lists a series of test cases against which the calculation method shall be tested to demonstrate compliance with the specified accuracy.

5 Apparatus, specimen preparation and test procedure

The apparatus details, test specimen preparation and dressing and the test procedure are given in ISO 13506-1:2017, Clauses 5 to 8. In addition to the calibration procedures given in ISO 13506-1:2017, Annex C, laboratories shall carry out the calibration described in Clause 7.

6 Predicted skin burn injury calculation

6.1 Skin model

6.1.1 General

This document contains the specifications for two skin models.

— The skin property values for the skin model with temperature-dependent thermal conductivity (Skin Model A) are specified in the Table 1, Table 2 and Annex A.

— The skin property values for the skin model with temperature-independent thermal conductivity (Skin Model B) are specified in Table 1 and Table 3.

NOTE 1 The skin property values listed in Table 1 to Table 3 and Annex A and the calculation test cases specified in Clause 7 were determined by a task group within ASTM (American Society for Testing and Materials) working on ASTM F1930[7], a test method developed in concert with ISO 13506. The task group reverse engineered the Stoll and Greene[8] experiments so as to match within 10 % the $\Omega = 1{,}0$ Formula (3) condition for all the Stoll partial blister test cases. The values for the thicknesses of the three layers (*in vivo*) in the forearms of adult males were found in the literature, as was the initial temperature gradient through the layers in the forearm (1 °C). Using this information, the formulae given in 6.1.3 and 6.1.5 and the values of P and ΔE determined by Weaver and Stoll[9] shown below, trial and error and optimization techniques were used to find the values of thermal conductivity, specific heat and density of the individual layers so that, with one set of values, all the Stoll and Greene[8] experimental skin injury measurements plus extensions calculated by Weaver and Stoll[9] could be predicted with $\Omega = 1 \pm 0{,}1$. The values determined are representative of the living tissue (*in vivo*). As such, blood flow and its potential effect on the results/predictions are implicit in the solution using the formulae and parameters given in below.

NOTE 2 ASTM F1930 contains detailed historical information on the development of skin injury prediction due to thermal influx from hot fluids and pure radiant sources.

6.1.2 Manikin sensor heat flux values as function of time

The absorbed heat flux values, $\dot{q}_i\,(t_\mathrm{n})$, in kW/m^2 for each manikin sensor, i, at each time step, t, as provided by ISO 13506-1 shall be taken as data input for the calculation of skin burn injury prediction.

6.1.3 Determination of the predicted skin and subcutaneous tissue (adipose) internal temperature field

6.1.3.1 General

The thermal exposure shall be represented as a transient one-dimensional heat diffusion problem in which the temperature within the epidermis and dermis layers of skin and subcutaneous tissue (adipose) varies with both position (depth) and time, and is described by the parabolic differential equation (Fourier's Field Equation):

$$\rho C_p \frac{\partial T}{\partial t} = k \frac{\partial^2 T}{\partial x^2} \qquad (1)$$

where

ρC_p	is the volumetric heat capacity, in J/m³·K;
t	is the time, in s;
x	is the depth from skin surface, in m;
$T(x,t)$	is the temperature at depth x and time t, in K;
$k(x,T)$	is the thermal conductivity at depth x and temperature T, in W/m·K.

The parameters specified for Skin Model A (i.e. in Table 1, Table 2 and Annex A) or for Skin Model B (i.e. in Table 1 and Table 3) shall be used when solving Formula (1).

Table 1 — Skin model — Thickness of layers and depth of the interface between layers

Parameter	Skin surface	Epidermis	Epidermis/ dermis interface	Dermis	Dermis/ subcutaneous tissue interface	Subcutaneous tissue
Depth from skin surface (µm)	0		75		1 200	
Thickness of layer (µm)		75		1 125		3 885

6.1.3.2 Physical properties for skin model with temperature-dependent thermal conductivity, *k* (Skin Model A)

The thermal conductivity of each of the layers of the skin is known to vary with temperature due to the generalized thermo-physical characteristics of the layer components (simplified composition: water, protein and fat). Cooper and Trezek[10] and Knox, et. al.[11] have developed relationships for estimating the thermo-physical properties of the skin and subcutaneous (adipose) layers based on the percentage of water, protein and fat in each layer. Annex A identifies values for the layer compositions, layer volumetric heat capacity, ρC_p (x), and temperature-dependent thermal conductivity, $k(x,T)$ as function of generalized skin layer components (water, protein and fat) that meet the requirements of Clause 7 and can be used for solving Formula (1). The initial values of thermal conductivity (temperature at time = 0), layer volumetric heat capacity and layer compositions are identified in Table 2. See Annex A for the calculation of the values of the thermal conductivity, k, at other depths and temperatures than at $T(0,0)$ = 32,5 °C.