

# INTERNATIONAL STANDARD

## NORME INTERNATIONALE



**Live working – Protective clothing against the thermal hazards of an electric arc –  
Part 1-1: Test methods – Method 1: Determination of the arc rating (ELIM, ATPV  
and/or EBT) of clothing materials and of protective clothing using an open arc**

**Travaux sous tension – Vêtements de protection contre les dangers thermiques  
d'un arc électrique –  
Partie 1-1: Méthodes d'essai – Méthode 1: Détermination de la valeur assignée  
d'arc (ELIM, ATPV et/ou EBT) des matériaux pour vêtements et des vêtements de  
protection utilisant un arc ouvert**



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## INTERNATIONAL ELECTROTECHNICAL COMMISSION

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**LIVE WORKING –  
PROTECTIVE CLOTHING AGAINST  
THE THERMAL HAZARDS OF AN ELECTRIC ARC –****Part 1-1: Test methods –  
Method 1: Determination of the arc rating (ELIM, ATPV and/or EBT)  
of clothing materials and of protective clothing using an open arc**

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International Standard IEC 61482-1-1 has been prepared by IEC technical committee 78: Live working.

This second edition cancels and replaces the first edition published in 2009. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- addition of the *Incident energy limit (ELIM)* as a further *arc rating* performance property value;
- replacement of char length requirement in the scope by indication that Procedure A is applicable for testing of *materials* meeting the limited flame spread requirements of IEC 61482-2;

- clarification of the definition and the meaning of the *Stoll curve*;
- modification of specification of positioning of *monitor sensors* with respect to the *electric arc* as function of intended high *incident energy* exposure of test specimens;
- modification of specifications of *monitor sensor* construction;
- specification of black paint;
- elimination of *calorimeters* from the chest of the mannequin;
- specification for possible positioning of mannequin(s) at a height different from the centre of the *electric arc* and possible turning in order to adequately expose all parts of the *garment* or clothing which would affect performance;
- more explicit description of requirements for data acquisition system;
- preconditioning of the samples;
- modification of requirements for apparatus and arc exposure verification by *bare shots*;
- more explicit description of test procedures A and B, in particular the subclauses dealing with “sequence of test”, “test parameter” and “test criteria”;
- addition of determination of *arc rating* values of *garments* and/or *garment* assemblies.

The text of this International Standard is based on the following documents:

| FDIS         | Report on voting |
|--------------|------------------|
| 78/1256/FDIS | 78/1262/RVD      |

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

In this standard terms defined in Clause 3 appear in *italics*.

A list of all parts in the IEC 61482 series, published under the general title *Live working – Protective clothing against the thermal hazards of an electric arc*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "<http://webstore.iec.ch>" in the data related to the specific document. At this date, the document will be

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# **LIVE WORKING – PROTECTIVE CLOTHING AGAINST THE THERMAL HAZARDS OF AN ELECTRIC ARC –**

## **Part 1-1: Test methods – Method 1: Determination of the arc rating (ELIM, ATPV and/or EBT) of clothing materials and of protective clothing using an open arc**

### **1 Scope**

This part of IEC 61482 specifies test method procedures to determine the *arc rating of flame resistant clothing materials and garments or assemblies of garments* intended for use in clothing for workers if there is an *electric arc* hazard.

An *open arc* under controlled laboratory conditions is used to determine the values of *ELIM*, *ATPV* or *EBT* of *materials*, *garments* or assemblies of *garments*.

NOTE 1 The user can, if he desires, classify the arc protective performance into *arc rating* protection levels based on *ELIM*, *ATPV* and/or *EBT* values which correspond best to the different hazard and risks levels that can result from the user's risk analysis.

NOTE 2 This document is not dedicated to classifying the arc protective performance of the *material* and clothing into arc protection classes. Procedures determining these arc protection classes APC1 and APC2 are specified in IEC 61482-1-2, which uses a constrained arc for testing.

NOTE 3 This test method is not intended and not appropriate to evaluate whether *materials* or *garments* are *flame resistant* or not, as this is covered in IEC 61482-2.

Other effects than the thermal effects of an *electric arc* like noise, light emissions, pressure rise, hot oil, electric shock, the consequences of physical and mental shock or toxic influences are not covered by this document.

*Protective clothing* for work intentionally using an *electric arc*, e.g. arc welding, plasma torch, is not covered by this document.

### **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.

IEC 60584-1, *Thermocouples – Part 1: EMF specifications and tolerances*

IEC 61482-2:2018, *Live working – Protective clothing against the thermal hazards of an electric arc – Part 2: Requirements*

ISO/IEC 17025:2017, *General requirements for the competence of testing and calibration laboratories*

ISO/TR 11610, *Protective clothing – Vocabulary*

ISO 11612:2015, *Protective clothing – Clothing to protect against heat and flame – Minimum performance requirements*

### 3 Terms, definitions, symbols and units

#### 3.1 Terms and definitions

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

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

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

##### 3.1.1

##### **ablation**

<electric arc testing> *material response* evidenced by formation of one or more openings in one or several outer layers, but not in all layers of a *material assembly specimen*

Note 1 to entry: for the use of this document the opening is defined as follows:

- a) with an opening in the layer of at least 1 600 mm<sup>2</sup> in area or at least 80 mm in any planar direction,
- b) with one or several individual threads across an opening not reducing the size of the opening.

##### 3.1.2

##### **arc duration**

time duration of the arc

Note 1 to entry: *Arc duration* is expressed in milliseconds (ms).

##### 3.1.3

##### **arc energy**

$W_{\text{arc}}$

<electric arc testing> electrical energy supplied to the arc and converted in the arc

Note 1 to entry: *Arc energy* is calculated as the sum of the instantaneous *arc voltage* values multiplied by the instantaneous *arc current* values multiplied by the incremental time values during the *arc duration*.

Note 2 to entry: *Arc energy* is expressed in kilojoules (kJ).

##### 3.1.4

##### **arc gap**

distance between the arc electrodes

Note 1 to entry: *Arc gap* is expressed in millimetres (mm).

##### 3.1.5

##### **arc rating**

<electric arc testing> numerical value attributed to a product, that describes its protective performance when tested in accordance with the *open arc test*

Note 1 to entry: The arc rating can be the arc thermal performance value (*ATPV*), the breakopen threshold energy (*EBT*) or the incident energy limit (*ELIM*).

Note 2 to entry: The arc rating values are expressed in kJ/m<sup>2</sup> (cal/cm<sup>2</sup>).

##### 3.1.6

##### **arc thermal performance value**

*ATPV*

<electric arc testing> numerical value of *incident energy* attributed to a product that describes its thermal properties of attenuating (reducing) a *heat flux* generated by an *electric arc*

Note 1 to entry: The *ATPV* of a *material* or *material assembly* is calculated using logistic regression analysis applied to the data points obtained from testing a set of test specimens. It is the value of *incident energy* at which the heat transfer through the test specimens is enough to reach the Stoll criteria with 50 % probability.

Note 2 to entry: The *ATPV* attributed to a *garment* or *garment assembly* is either equal to or lower than the *ATPV* of the *material* or *material assembly* of which it is made, depending on whether the tested specimen(s) fulfil also additional visual design and performance assessment criteria.

### 3.1.7

#### **arc voltage**

voltage across the arc

Note 1 to entry: *Arc voltage* is expressed in volts (V).

### 3.1.8

#### **bare shot**

<electric arc testing> *electric arc* event during which panels or mannequins are bare, i.e. they are not covered by test specimens

### 3.1.9

#### **breakopen**

<electric arc testing> *material response* evidenced by the formation of an opening in the *material* specimen

Note 1 to entry: For the use of this document the opening is defined as follows:

- a) with a size of at least 300 mm<sup>2</sup> in area or at least 25 mm in any planar direction,
- b) with one or several individual threads across an opening not reducing the size of the opening.

Note 2 to entry: A *material assembly* specimen is considered to exhibit *breakopen* when all layers show formation of one or more openings.

Note 3 to entry: *Shrink-open* is considered as a particular form of *breakopen*.

### 3.1.10

#### **breakopen threshold energy**

##### ***EBT***

<electric arc testing> numerical value of *incident energy* attributed to product (*material* or clothing) that describes its *breakopen* properties when exposed to *heat energy* generated by an *electric arc*

Note 1 to entry: The *EBT* of a *material* or *material assembly* is calculated using logistic regression analysis applied to the data points obtained from testing a set of test specimens. It is the value of *incident energy* at which *breakopen* occurs with 50 % probability.

Note 2 to entry: The *EBT* attributed to a *garment* or *garment assembly* is either equal to or lower than the *EBT* of the *material* or *material assembly* of which it is made, depending on whether the tested specimen(s) fulfil also additional visual design and performance assessment criteria.

### 3.1.11

#### **burning time**

#### **afterflame time**

time for which a flaming of the test specimen is visible after the end of the *electric arc duration*

Note 1 to entry: *Burning time* is expressed in seconds (s).

### 3.1.12

#### **calorimeter**

assembly of a copper disc with attached thermocouple, used for measuring the *heat energy* and *incident energy*

**3.1.13**  
**calorimetric sensor**  
**sensor**

assembly of a *calorimeter* and a non-conductive heat resistant *material*, in which the *calorimeter* is mounted

Note 1 to entry: The term *sensor* is used in this document to mean *calorimetric sensor*.

**3.1.14**  
**charring**

*material response* evidenced by formation of carbonaceous residue as the result of pyrolysis or incomplete combustion

**3.1.15**  
**dripping**

*material response* evidenced by formation of polymer droplets that fall from the *material* or *garment*

**3.1.16**  
**electric arc**

self-maintained gas conduction for which most of the charge carriers are electrons supplied by primary-electron emission

Note 1 to entry: During live working, the *electric arc* is generated by gas ionization arising from an unintentional electrical conducting connection or breakdown between live parts or a live part and the earth path of an electrical installation or an electrical device. During testing, the *electric arc* is initiated by the blowing of a fuse wire.

[SOURCE: IEC 60050-121:1998, 121-13-12, modified – Note 1 to entry has been added to refer specifically to live working and arc testing.]

**3.1.17**  
**embrittlement**

formation of a brittle residue as the result of pyrolysis or incomplete combustion

**3.1.18**  
**flame resistant**

<*electric arc* testing> property evidenced by clothing *materials* which meet the limited flame spread requirements of IEC 61482-2

**3.1.19**  
**garment**

single item of clothing which may consist of single or multiple layers of *materials*

**3.1.20**  
**garment assembly**  
**assembly of garments**

clothing consisting of two or more *garments* worn together, which may individually cover different parts of the wearer's body and/or which may be worn fully or partially on top of each other

Note 1 to entry: For example, *garment assembly* can be a combination of jacket and trousers, combination of shirt, trousers and jacket or overcoat which have been designed in such a way as to fit together.

**3.1.21**  
**heat flux**

*q*  
<*electric arc* testing> thermal intensity transmitted by an *electric arc* indicated by the amount of heat energy transfer per unit surface area and time

**3.1.22****ignition**

initiation of flaming and combustion

**3.1.23****incident energy**

$E_i$

<electric arc testing> heat energy  $Q$  resulting from an *electric arc*, received at a unit surface area at a specified distance from the *electric arc*

**3.1.24****incident energy limit**

*ELIM*

<electric arc testing> numerical value of *incident energy* attributed to a product (*material* or clothing), below which value all product responses are below the *Stoll curve* and without *breakopen*

Note 1 to entry: The *ELIM* of a *material* or *material assembly* is calculated from data points obtained from testing a set of test specimens, which are also used for the determination of the *ATPV* and/or *EBT*.

Note 2 to entry: The *ELIM* attributed to a *garment* or *garment assembly* is either equal to or lower than the *ELIM* of the *material* or *material assembly* of which it is made, depending on whether the tested specimen(s) fulfil also additional visual design and performance assessment criteria.

**3.1.25****material**

substances, excluding hardware, of which an item of clothing is made

**3.1.26****material assembly**

assembly of *materials*, which is representative for the build-up of layers of a *garment* or *garment assembly*

Note 1 to entry: The *arc rating* of a *material assembly* of which an *assembly of garments* worn on top of each other is made, cannot be determined from the *arc rating* of each *material*, of which the individual *garments* are made but can only be determined by testing of *material assembly* specimens representative for the *garment assembly*.

**3.1.27****material response**

reaction of the *material* to an *electric arc* characterised by *ignition*, *burning time (afterflame time)*, *breakopen*, *melting*, *dripping*, *shrinkage*, etc.

**3.1.28****melting**

*material response* evidenced by softening and deformation

Note 1 to entry: *Materials* which melt are normally polymers.

**3.1.29****mix zone**

<electric arc testing> range of measured *incident energies* (the independent variable  $X$ ), in which a binary response (i.e. either the value "0" or "1") (the dependent variable  $Y$ ) is attributed to a studied parameter of the measured *material response* or to a combination of several studied parameters

Note 1 to entry: A *mix zone* of a data point distribution is established when the highest *incident energy* with binary response "0" is greater than the lowest *incident energy* with binary response "1". The *mix zone* of a data point distribution is empty when the highest *incident energy* with a binary response "0" is lower than the lowest *incident energy* with a binary response "1".

Note 2 to entry: For the *material response* parameters studied for the determination of the *ATPV*, see 11.1.3.1 and 12.2.

Note 3 to entry: For the *material response* parameters studied for the determination of the *EBT*, see 11.1.3.2 and 12.3.

Note 4 to entry: For the *material response* parameters studied for the determination of the *ELIM*, see 11.1.3.3 and 12.4.

### 3.1.30

#### **monitor sensor**

<*electric arc* testing> *calorimetric sensor* mounted on each side of the panel or mannequin, not covered by a test specimen and used to measure *incident energy* at a specified distance from the *electric arc*

### 3.1.31

#### **open arc**

<*electric arc* testing> *electric arc* between two vertically opposing electrodes intended to provide an equal distribution of emitted energy around the centreline formed by the electrodes and where the emitted energy is not directed by means of any physical constraints (e.g. enclosure, wall)

[SOURCE: IEC 61482-2:2018, 3.1.13]

### 3.1.32

#### **panel sensor**

<*electric arc* testing> *calorimetric sensor* mounted in the panel, which, when covered by test specimen, is used to measure energy transmitted through a test specimen

### 3.1.33

#### **protective clothing**

clothing which covers or replaces personal clothing, and which is designed to provide protection against one or more hazards

[SOURCE: ISO 13688:2013, 3.5, modified – The definition has been modified to clarify by removing the unclear term “protector”.]

### 3.1.34

#### **shrinkage**

*material response* evidenced by reduction in specimen size

### 3.1.35

#### **shrink-open**

<*electric arc* testing> *material response* caused by excessive *shrinkage* with the result that the test specimen dislodging from the clamping and exposing the panel

Note 1 to entry: *Shrink-open* is considered as a particular form of *breakopen*.

### 3.1.36

#### **Stoll curve**

empirical predicted second-degree skin burn-injury model

Note 1 to entry: *Stoll curve* defines a relationship between the absorbed energy rate and the human skin tolerance time.

Note 2 to entry: See Stoll, A.M. and Chianta, M.A. Method and rating system for evaluation of thermal protection.

### 3.1.37

#### **test shot**

<*electric arc* testing> *electric arc* event during which one or more test specimens are mounted on the specimen support(s) of the test apparatus, with the specimen(s) covering some or all *sensors* except *monitor sensors* and being exposed to the effects of the *electric arc*

**3.1.38*****X/R ratio***

ratio of system inductive reactance to resistance

Note 1 to entry: The *X/R ratio* is proportional to the *L/R ratio* of time constant, and is, therefore, indicative of the rate of decay of any DC offset. A large *X/R ratio* corresponds to a large time constant and a slow rate of decay.

**3.2 Symbols and units**

|             |                                      |                                       |
|-------------|--------------------------------------|---------------------------------------|
| <i>ATPV</i> | <i>arc thermal performance value</i> | $\text{kJ/m}^2$ ( $\text{cal/cm}^2$ ) |
| $C_p$       | heat capacity                        | $\text{J/g } ^\circ\text{C}$          |
| <i>EBT</i>  | <i>breakopen threshold energy</i>    | $\text{kJ/m}^2$ ( $\text{cal/cm}^2$ ) |
| $E_i$       | <i>incident energy</i>               | $\text{kJ/m}^2$                       |
| $E_t$       | transmitted energy                   | $\text{kJ/m}^2$                       |
| <i>ELIM</i> | <i>incident energy limit</i>         | $\text{kJ/m}^2$ ( $\text{cal/cm}^2$ ) |
| $Q$         | heat energy                          | $\text{kJ/m}^2$                       |
| $q$         | <i>heat flux</i>                     | $\text{kW/m}^2$                       |
| $T$         | temperature                          | K                                     |
| $t$         | time                                 | s                                     |
| $t_0$       | arc initiation time                  | s                                     |

## NOTE

$$1 \text{ kJ/m}^2 = 1 \text{ kW} \cdot \text{s/m}^2 = 0,1 \text{ J/cm}^2 = 0,0239006 \text{ cal/cm}^2$$

$$1 \text{ cal/cm}^2 = 41,840 \text{ kJ/m}^2 = 41,840 \text{ kW} \cdot \text{s/m}^2$$

**4 Principle of test procedures A and B****4.1 Procedure A – *Material open arc test procedure***

Procedure A specified in this document is used to determine the *arc rating* of a *material or material assembly*, expressed by the value of *ATPV* or *EBT*, whichever is the lower one, or expressed by the value of the *ELIM* if specified by the person requesting testing, that the *arc rating* shall be expressed by the *ELIM*. The *ATPV*, *EBT* and *ELIM* are determined by comparing the amount of heat transmitted through the specimen(s) with Stoll criteria and the possible observation of *breakopen* when exposed to various levels of *incident energy* measured by the *monitor sensors*.

The test specimens used in this procedure are in the form of flat specimens of *material* or of *material assembly*, mounted on test panels.

The *arc rating* of a *material assembly* of which an *assembly of garments* worn on top of each other is made cannot be determined from the *arc rating* of each *material or material assembly* of which the individual *garments* are made, but can only be determined by testing of a *material assembly* specimen representative of the *garment assembly*.

During the tests, the amount of heat energy transmitted through the *material* or *material assembly* is measured during and after exposure to an *electric arc*.

During each single arc exposure test (i.e. during each single *test shot*), the *heat energy* of the exposure and that transferred through the test specimen(s) are both measured with copper *calorimeter sensors*. The change in temperature versus time is used, along with the known

thermo-physical properties of copper, to determine the respective heat energies delivered to and through the specimens.

*Material response* shall be further described by recording the observed effects of the *electric arc* exposure on the specimens and using the terms given in 3.1.27.

## 4.2 Procedure B – *Garment open arc test procedure*

Procedure B specified in this document is used to assign the *arc rating* to an item of clothing. The *arc rating* is based on the *arc rating* of the *garment material* as determined by Procedure A and assigned by evaluation of design and performance of the clothing (consisting of one *garment* or an *assembly of garments*). This procedure consists of exposing the clothing to an *open arc*, causing an *incident energy* onto the outer surface of the clothing approximately equal to or greater than (see 11.2) the *arc rating*, determined according to Procedure A, of the *material* or the total assembly of *materials* of which the clothing is made. The *garment* or *garment assembly* shall be evaluated with findings, pockets and closures positioned as manufactured and fastened according to the manufacturer's use instructions; the tested specimen of the *garment* or *garment assembly* shall fulfil the visual assessment criteria (see 12.6.2, Table 3). In this case, the *arc rating* of the *material* or *material assembly* can be attributed to the clothing as its *arc rating* (see 11.2.2).

If a specimen of *garment* or *garment assembly*, tested at a given level of *incident energy*, does not fulfil the visual criteria for the assessment of the design and performance (see 12.6.2, Table 3), this value of *incident energy* cannot be attributed to the clothing as its *arc rating*.

However, one may test one or several further specimens of the *garment* or *garment assembly* at reduced *incident energy/energies*. If a specimen of the *garment* or *garment assembly* tested at a reduced *incident energy* and also all specimens eventually tested at even lower *incident energies* fulfil the visual assessment criteria (see 12.6.2, Table 3), this value of reduced *incident energy* may be attributed to the *garment* or *garment assembly* as its *arc rating* (see 11.2.2).

The test ordering party may deliberately specify an *incident energy* value, which may be (considerably) lower than the *arc rating* of the *material* or *material assembly*, and may require that it be tested, to determine if this specified value can be attributed to the clothing as its *arc rating*. In this case, testing may deliberately be carried out only at incident exposure energy (considerably) lower than the *arc rating* of the *material* or *material assembly*.

The test specimens used in this procedure are in the form of *garments* or *assembly of garments* mounted on test mannequins.

## 5 Significance and use of the test procedures A and B

### 5.1 General

The test procedures A and B are used to determine the *arc rating* of *flame resistant* clothing *materials* and clothing used for electrotechnical work if there is an *electric arc*.

The test procedures maintain the specimen in a static vertical position and do not involve movement, except that resulting from the exposure.

**IMPORTANT** – This test method and the procedures are not intended and not appropriate to evaluate whether *materials* or *garments* are *flame resistant*.

**NOTE** The test procedures specify standard exposure conditions. Different exposure conditions can produce different test results.

## 5.2 Procedure A – *Material open arc test procedure*

Procedure A specified in this document is used for the determination of the *incident energy limit (ELIM)*, the *arc thermal performance value (ATPV)* and/or the *breakopen threshold energy (EBT)*, of a *material* or a *material assembly*.

Because of the variability of the arc exposure and fabric construction, different values of transferred heat energy may be measured by the *sensors* covered by test specimens when exposed to an *electric arc*. The heat transfer measurement results for a sufficiently large number of test specimens (at least 20 test specimens) is statistically analysed in accordance with Clause 12.

## 5.3 Procedure B – *Garment open arc test procedure*

Procedure B specified in this document is usually used for evaluation of *protective clothing* design and the determination of the *arc rating* of the clothing, when the *material* or *material assembly* of the clothing, i.e. of a *garment* or *assembly of garments*, has first been tested and its *arc rating* determined following Procedure A.

The *arc rating* of clothing is either equal to or lower than the *arc rating* of the *material* or of the total *material assembly*, or no *arc rating* can be attributed to the clothing, depending on whether the visual assessment criteria for *garments* and *garment assemblies* are fulfilled.

# 6 Test apparatus

## 6.1 General

The test apparatus shall consist of the following elements:

- supply bus;
- arc controller;
- recorder or data acquisition system;
- arc electrodes;
- three specimen supports around the centre line of the *electric arc*, of which one to three can be panels (used for Procedure A) or one to three can be mannequins (used for Procedure B). For Procedure A all three positions shall be occupied by a panel. For Procedure A it is not permissible to replace panels made of different shape or of different *materials* during a sequence of *test shots*, because such alterations may change the heat distribution;
- two *monitor sensors* for each panel or for each mannequin, one to the left and one to the right side of each panel or mannequin.

## 6.2 Calorimetric sensors

### 6.2.1 Calorimeter construction

The *calorimeters* shall be constructed from electrical grade copper with one thermocouple wire installed in the arrangement as shown in Figure 1 a).

An example of securing the thermocouple mechanically in the copper disc is shown in Figure 1 b). Soldering of the thermocouple into the disc is not allowed.

The copper discs and the filler, if used, shall be electrical grade copper with a purity greater than 99,90 %, IACS grade C110 (UNS11000). The copper discs shall have thickness of 1,6 mm  $\pm$  0,1 mm, a diameter of 40,0 mm  $\pm$  0,1 mm and a mass of 18 g  $\pm$  1 g. There shall be a hole in the centre of the copper disc, with a depth of 1,3 mm  $\pm$  0,1 mm and with a diameter of 1,2 mm  $\pm$  0,3 mm.

NOTE 1 The IACS (International Annealed Copper Standard) grade gives the level of the electrical conductivity of the copper.

The mass of each disc shall be determined to a precision of  $\pm 0,05$  g and the diameter and thickness shall be determined to a precision of  $\pm 0,03$  mm. For the calculations of each *sensor* response according to 12.1.2, Formula (3), the actual diameter (for the area calculation) and mass values of each individual disc shall be used. If average values for all *calorimeters* are used for calculations, their mass/area ratio shall be within  $\pm 0,008$  g/cm<sup>2</sup> of their mean value.

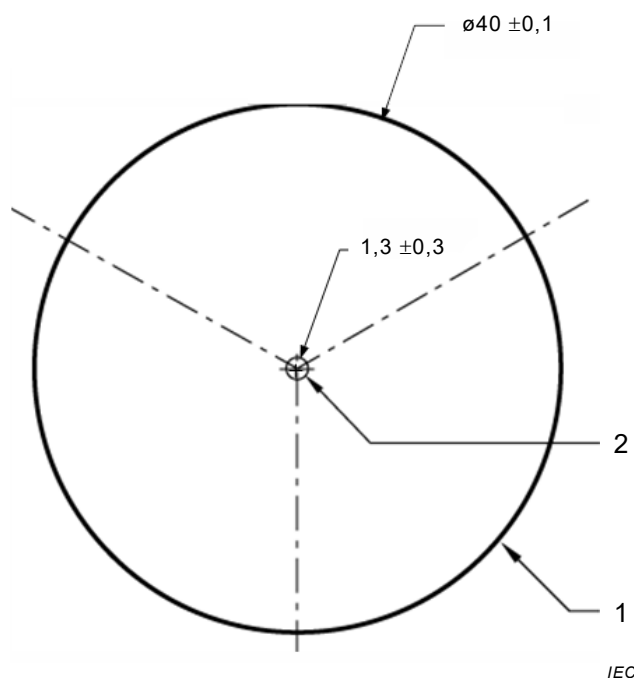
NOTE 2 Selecting copper discs for the *calorimeters* using the “average value” for the mass/area ratio [Formula (3)] can ease the operation and the replacement of *calorimeters*.

The thermocouples shall be an exposed bead Type K (NiCr – NiAl), having a cross-section area of 0,05 mm<sup>2</sup> (N° 30 AWG) but never larger, or equivalent, according to IEC 60584-1. The thermocouple wire shall be installed in the *calorimeter* as shown in Figure 1 b). Inside the hole of the copper disc, the thermocouple wires – having an outer diameter of 0,5 mm after removal of insulation, i.e. two times the single-wire diameter of 0,254 mm – shall be bare for the whole length inside the hole in the copper disc and the thermocouple wires shall be in full contact between themselves and with the surrounding copper disc, if necessary with the help of copper filler added into the hole. The thermocouple wires shall be separated (e.g. by help of fine tool) immediately upon exiting the copper disc.

NOTE 3 A visual magnifier can be used for verification that the copper wires are properly separated at the back of the copper disc and the wires have not been damaged.

NOTE 4 Each thermocouple wire exiting the copper disc is typically bare for some short distance after having exited the hole of the disc.

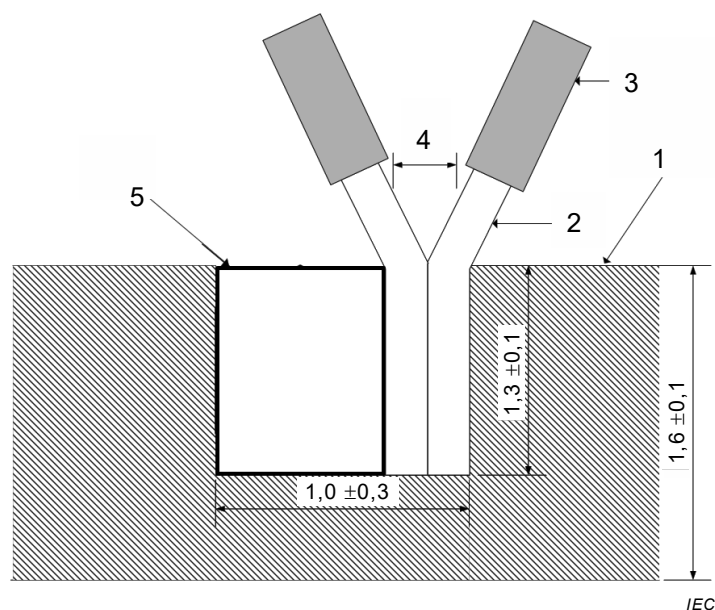
Dimensions in millimetres



**Key**

- 1 copper disc
- 2 thermocouple location

**a) Position for installation of the thermocouple in the back side of copper disc**



#### Key

- 1 copper disc
- 2 bare part of thermocouple wire
- 3 insulation of thermocouple wire
- 4 separation of thermocouple at the surface of the copper disc
- 5 filler to secure and maintain full contact of the thermocouple

#### b) Thermocouple wire installation – Details of hole and method of securing thermocouple

**Figure 1 – Example of calorimeter construction**

### 6.2.2 Panel sensor construction

The panel sensor is a *calorimetric sensor* constructed from a *calorimeter* mounted into a surrounding insulating board with specific physical properties (Figure 2). The insulating board shall surround the copper disc by at least 5 mm in all directions.

NOTE 1 In *calorimetric sensors* according to, for example, ISO 9151, the copper disc is surrounded by a ring of insulating board with an outer diameter of 89 mm. Another typical solution is to embed the copper disc into a quadratic insulating board of 130 mm × 130 mm.

The insulating board shall have the following physical properties.

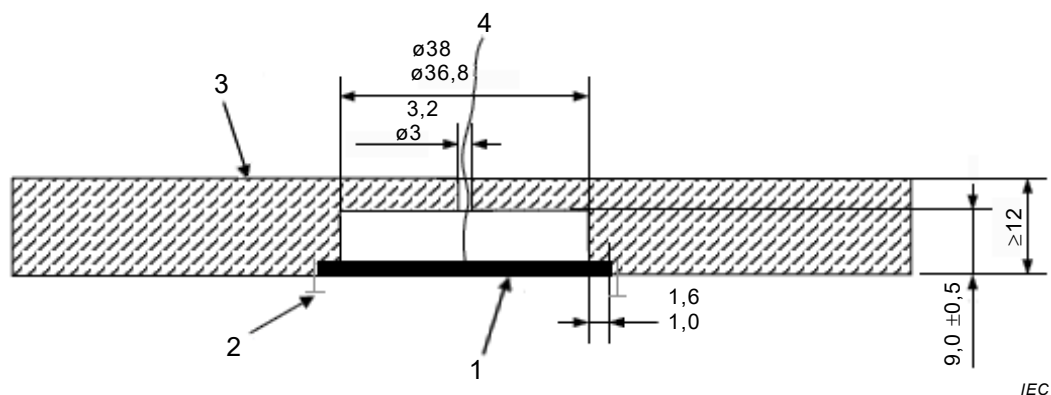
- It shall be a piece of asbestos-free non-combustible heat insulating board.
- It shall have a permissible operating temperature of at least up to 760 °C.
- The thermal conductivity shall be less than or equal to 0,20 W/(m·K) at temperatures up to 500 °C.

For practical reasons, because of the brittle nature of insulating board, a thickness of at least 12 mm has been found sufficient for mechanical rigidity.

Alternatively, the copper disc of the *calorimeter* may be installed directly into the front board of the panel (see Figure 4), if the front board is made of an insulating *material* which meets the physical property requirements for the insulating board used for a *calorimetric sensor*.

NOTE 2 An example of an insulating board *material* is a calcium silicate insulating *material*, e.g. Marinite® Grade P, Grade C or Grade I&M, or Monolux® 500 <sup>1</sup>. For further information about suitable *materials* see Annex D.

Dimensions in millimetres



#### Key

- |   |             |   |                                              |
|---|-------------|---|----------------------------------------------|
| 1 | calorimeter | 3 | insulating board                             |
| 2 | steel pin   | 4 | thermocouple signal wire to data acquisition |

The disc shall be held in place by at least three pins along the circumference of the disc

**Figure 2 – Example of the panel sensor construction**

A circular cavity is machined in the front board to accommodate the copper disc, so that the surface of the copper disc will be flush with the surface of the mounting board. The cavity, when new, shall have a diameter which provides friction fit of the copper disc. The supporting shoulder shall be equal to or greater than 1,0 mm, but not be more than 1,6 mm, i.e. the inner diameter shall be not less than 36,8 mm and not greater than 38 mm.

NOTE 3 “Friction fit” means that when the disc has been put in place and then the front board turned upside down, the disc will not fall out.

NOTE 4 A friction fit of the copper disc into the insulating board avoids that heat and hot gases heat up the side of the copper or even enter behind the disc and deteriorate the sides of the cavity.

NOTE 5 To minimize the contact area between the shoulder of the ledge and the backside of the copper disc, the shoulder of the ledge can be machined slightly angled inwards (e.g. by a few degrees), i.e. away from the backside of the copper disc.

NOTE 6 After having verified that the disc has been mounted flush with the surface of the mounting board and has the required friction fit to the board, the disc can be secured in place by pins (e.g. at least three pins) equally spaced around the circumference of the disc.

NOTE 7 An example of successfully used pins are straight stainless steel shirt pins (e.g. with a diameter of 0,6 mm) with a flat stainless steel head, cut to a practical length (e.g. 5 mm) and hammered straight or slightly inclined into the board, with the head flattened by the hammering sitting half on the disc and half on the board.

The exposed surface of the copper disc shall be painted with a thin, smooth coating of a flat black high-temperature spray paint<sup>2</sup> with an intermittent operating temperature up to 600 °C and with an emissivity coefficient greater than 0,9 at standard laboratory temperature for the wavelength range from 400 nm to 2000 nm.

<sup>1</sup> Marinite P (and also Marinite C or I&M) and Monolux 500 are examples of suitable products available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by IEC of these products.

<sup>2</sup> Krylon™ BBQ & Stove paint 1618 and ARCHITECT Grillspray, 400ml, Tec-Art Art.Nr./Code: J32 4 694 are examples of suitable products available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by IEC of these products.

The paint shall be applied as thin as possible until the copper is no longer visible.

NOTE 8 If the paint is too thick, the expansion of the disc during the arc exposure can cause the coating to crack and reduce the adhesion of the coating to the copper disc, thus leading to incorrect measurements by the *calorimeter*.

The painted *sensor* shall be dried before use and present a uniformly applied coating; there shall be no visual thick spots or surface irregularities.

NOTE 9 An external heat source, for example an external heat lamp, can be used to completely drive off any remaining organic carriers in a freshly painted surface more rapidly.

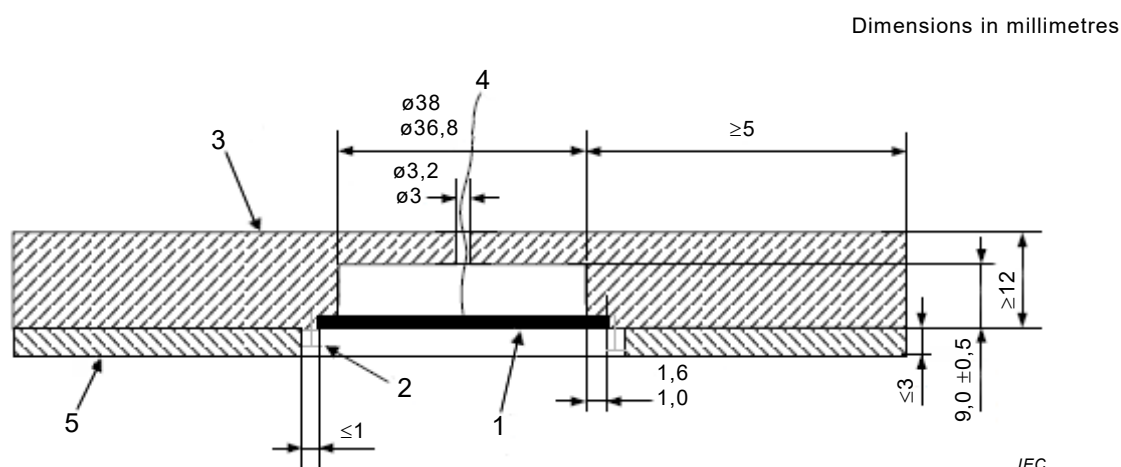
## 6.2.3 Monitor *sensor* construction and positioning

### 6.2.3.1 Monitor *sensor* construction

A *monitor sensor* shall be constructed to protect fully the side and back of the copper disc from the effect (e.g. heat, contamination) of and any damage caused by the arc event.

A *monitor sensor* consists of a *calorimetric sensor* like a panel *sensor* according to 6.2.2, but may be covered with an additional insulating board of not more than 3 mm thickness and made of *material* with higher temperature rating than the insulating board of the *calorimetric sensors*. The thermal conductivity of the additional insulating board shall not be more than 10 times higher than the thermal conductivity of the insulating board of the *calorimetric sensors*.

The additional insulating board shall have a hole slightly larger in diameter (not more than 2 mm larger) than the copper disc to protect the face of the *monitor sensor*. The thin shield may be fixed by screws or pins or by other ways onto the surface of the *sensor* (Figure 3).



#### Key

- |   |                                                                                                          |   |                                              |
|---|----------------------------------------------------------------------------------------------------------|---|----------------------------------------------|
| 1 | <i>calorimeter</i>                                                                                       | 4 | thermocouple signal wire to data acquisition |
| 2 | steel pin<br>The disc shall be held in place by at least three pins along the circumference of the disc. | 5 | insulating cover board (optional)            |
| 3 | insulating board                                                                                         |   |                                              |

**Figure 3 – Example of monitor *sensor* construction, with optional cover plate**

A high temperature rated covering shall be used to protect the thermocouple wire on the back side of the *monitor sensor*.

A *monitor sensor* shall be free standing or affixed to the unmovable part of the panel or mannequin or to the panel or mannequin support.

NOTE Having *monitor sensors* mounted at the moving clamps introduces an error as the *sensors* are displaced from their calibrated position, notably even more so when multilayer fabric specimen is installed.

### 6.2.3.2 Positioning of monitor sensors

The *monitor sensor* shall be positioned perpendicular to radius drawn from the centre line of the electrodes to the centre of the *monitor sensor*. The angle  $\alpha$  between the radius drawn to the centre of the *monitor sensors* and the radius drawn to the centre line of the panel or of the mannequin surface shall be  $35^{+5}_0$  degrees, and it shall be possible to position the *monitor sensor* at the distances  $340 \text{ mm} \pm 5 \text{ mm}$  ( $D_1$ ) or  $410 \text{ mm} \pm 5 \text{ mm}$  ( $D_2$ ) from the centre line of the arc electrodes (see Figure 6). Distances  $D_1$  and  $D_2$  shall be indicated in Table 1, thus shall be selected for different *incident energy* exposures.

Experience has shown that for testing at other *incident energy* ranges or for purposes of research, the positioning support for the *monitor sensors* should be built in such a way that the *monitor sensor* distance is adjustable; for example, from 200 mm to 600 mm.

A pair of *monitor sensors* shall be installed, they should be positioned symmetrical to the panel.

The actual distance of each *monitor sensor* shall be measured to a precision of  $\pm 2 \text{ mm}$  and the values recorded for use for the *incident energy* calculation according to 12.1.4.

Examples of arrangements of six *monitor sensors*, i.e. with one *monitor sensor* in Position 1 on each side of the panel(s) or mannequin(s), are shown in Figures 6, 7 a) and 7 b).

**Table 1 – Positioning of monitor sensors depending on *incident energy* exposure**

| Parameter                                                                                                              | Monitor sensor position                                        |                                                          |
|------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------|----------------------------------------------------------|
|                                                                                                                        | Position 1                                                     | Position 2                                               |
| <i>Incident energy</i> onto surface of panel or mannequin at 300 mm distance from vertical centre line of electrodes   | 0 to 55 cal/cm <sup>2</sup><br>(0 to 2 300 kJ/m <sup>2</sup> ) | > 40 cal/cm <sup>2</sup><br>(> 1 675 kJ/m <sup>2</sup> ) |
| Distance between vertical centre line of electrodes and centre of <i>monitor sensor calorimeter</i> surface            | $D_1$<br>340 mm $\pm$ 5 mm                                     | $D_2$<br>410 mm $\pm$ 5 mm                               |
| Angle $\alpha$ between perpendicular line to panel surface and perpendicular line to <i>monitor sensor</i> surface     | $35^{+5}_0$ degrees                                            | $35^{+5}_0$ degrees                                      |
| Angle $\alpha$ between perpendicular line to mannequin surface and perpendicular line to <i>monitor sensor</i> surface | $35^{+5}_0$ degrees                                            | $35^{+5}_0$ degrees                                      |

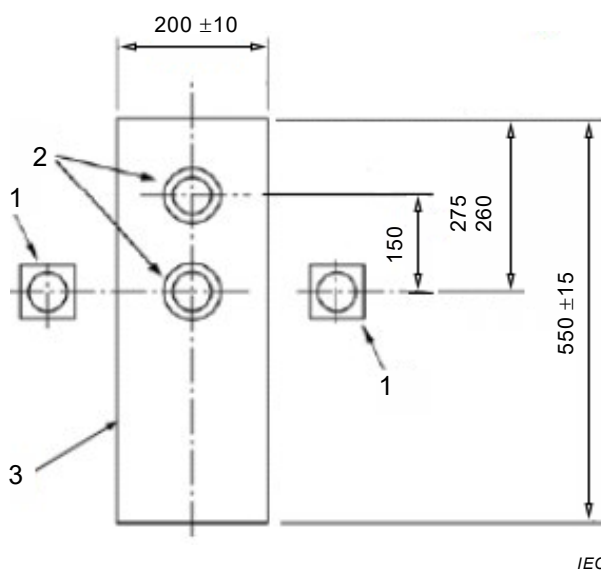
## 6.3 Panel construction

Each panel shall consist of a front board, a panel body and a *material* clamping system. The front board shall be constructed from electrical and thermal non-conductive, heat-resistant board *material*. The front board of a panel shall be 200 mm  $\pm$  10 mm by 550 mm  $\pm$  15 mm.

Two *calorimetric sensors* according to 6.2.2 shall be inserted into the front board of the panel. The two *sensors* shall be placed on the vertical centre line of the front board. The positioning of the two *sensors* is given in Figure 4 a). The *sensors* shall be inserted into the front board flush with the surface of the board.

NOTE Figure 4 a) shows as an example two *sensors*, each consisting of a copper disc surrounded by a ring made of insulating board, inserted into the front board of a panel.

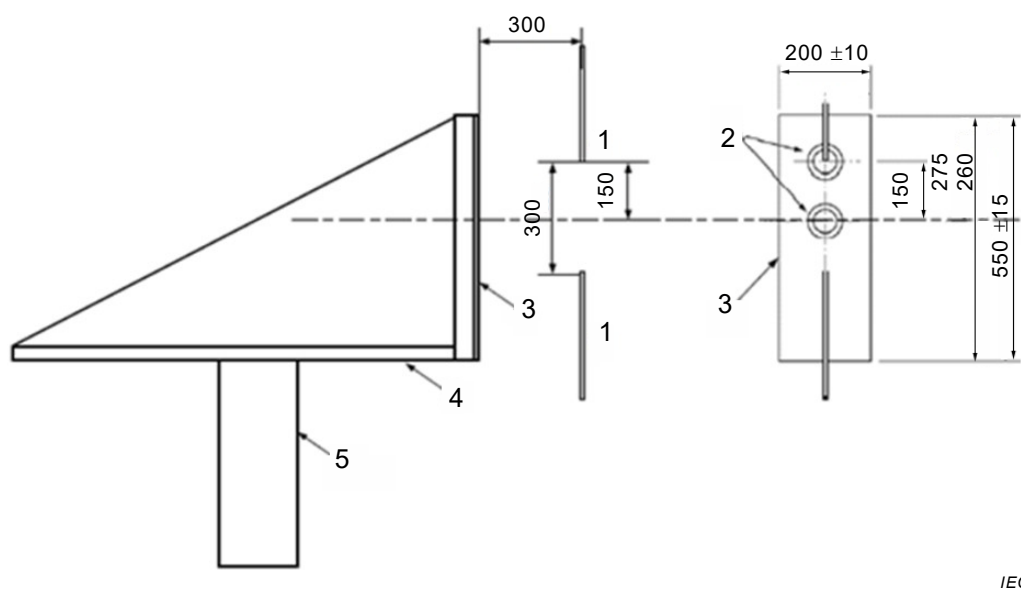
Dimensions in millimetres

**Key**

- 1 monitor *sensors*
- 2 panel *sensors*
- 3 panel front board with its two panel *sensors*

**a) Relative positioning of the two panel *sensors* in the front board of the panel body (front view) and of the adjacent two monitor *sensors***

Dimensions in millimetres

**Key**

- |   |                          |   |                                                                                                                                                                                                  |
|---|--------------------------|---|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1 | electrodes               | 3 | panel front board, containing two panel <i>sensors</i>                                                                                                                                           |
| 2 | panel <i>sensors</i>     | 4 | panel body includes all sides other than front board (optionally movable by help of sliding system for adjusting distance between electrodes and <i>panel sensors</i> , e.g. from 200 to 600 mm) |
| 5 | insulating panel support |   |                                                                                                                                                                                                  |

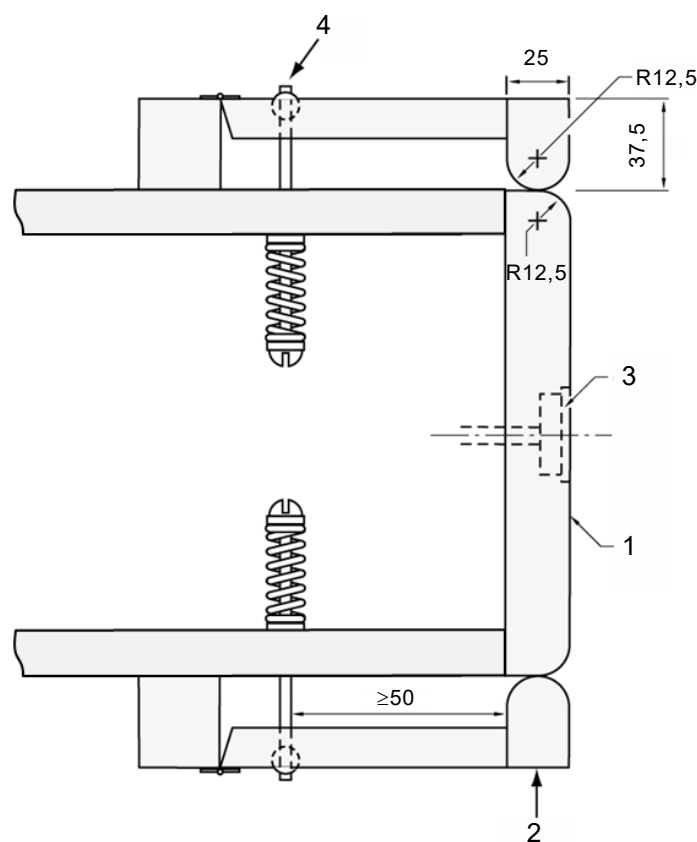
**b) Panel and relative positioning of panel to electrodes (side view)**

**Figure 4 – Panel**

Alternatively, two *calorimeters* can be mounted directly into the front board, without a ring made of insulating board. In this case the front board *material* of the panel shall meet the insulating board *material* property requirements of 6.2.2 and the *calorimeters* shall be mounted and fitted into the front board according to the requirements of 6.2.2. The panel shall be constructed to protect the two copper discs and two thermocouple wires from the effect (e.g. heat, contamination) of and any damage caused by the arc event.

Each panel shall have a *material* clamping system (see Figure 5). The clamping system shall consist of four clamps, which hold the specimen to the panel front board (which contains two panel *sensors*) and allows the specimen to shrink during arc exposure. Each clamp within the clamping system applies between 4,4 N and 6,7 N to secure the *material* to the edges of the panel front board. Other means of mounting, which meet the above objectives, may also be employed.

Dimensions in millimetres



#### Key

- |   |             |   |                               |
|---|-------------|---|-------------------------------|
| 1 | front board | 3 | <i>calorimeter</i>            |
| 2 | side clamp  | 4 | typical spring clamp assembly |

Place one clamp on each edge of the panel front board. Four clamps are required per panel.

**Figure 5 – Example of *material* clamping assembly of a panel**

## 6.4 Mannequin construction

A male or female mannequin, as appropriate for the clothing to be tested, consisting of torso and optionally also arm stubs or arms, leg stubs or legs and/or head and made from non-conductive, fibre glass construction with a high-temperature resin or other non-conductive, non-flammable high-temperature *materials* shall be used.

It has been found practical and preferable that the mannequin can be dismounted into separate body parts for the purpose of facilitating the mounting and doffing of *garments*.

The mannequin shall be constructed in an erect posture. The mannequin shall be straight and mounted in a vertical position to allow the test specimen at the sternum to be the closest point to the centre line of the arc [see 6.6, Figure 8 a)].

It is recommended to foresee also the capability for positioning the mannequin at heights, so that not the sternum but the navel or the crotch will be at the height of the mid-point of the gap between the electrodes [see 6.6, Figures 8 b) and 8 c)].

NOTE 1 An example are mannequins with chest circumference  $1\,000\text{ mm} \pm 100\text{ mm}$ .

In order, for example, to facilitate the performance evaluation of all parts of a garment or clothing which may affect its performance (e.g. doffing closures and/or accessories on the side or the back of the clothing), it should be possible to rotate the mannequin(s) by an amount of degrees which will expose each of such parts adequately to the electric arc (e.g. by  $90^\circ$  for exposure from the side or by  $180^\circ$  for exposure from the back). It should also be possible to reposition the rotated mannequin(s) in such a way that the closest distance between the surface of the mannequin, which will be exposed to the electric arc, and the centre line of the electrodes is 300 mm.

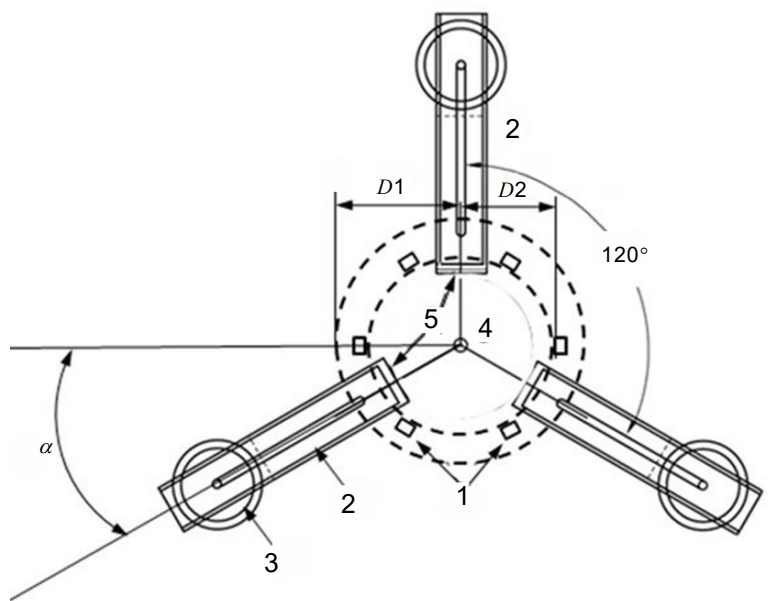
NOTE 2 It has been found practical to have the distance between the centre line of the electrodes and the mannequin(s) horizontally adjustable, for example from 200 mm to 600 mm.

## 6.5 Arrangement of panels and monitor sensors for testing according to Procedure A

When testing according to Procedure A, a configuration of three panels, each containing two panel *sensors* (i.e. a configuration of three two-*sensor* panels) shall be used for each test and the panels shall be spaced at  $120^\circ$  as shown in Figure 6. One *monitor sensor* shall be positioned on each side of a two-*sensor* panel as – for example – shown in Figures 5. For further specifications about the positioning of the *monitor sensors* with respect to the centre line of the electrodes and/or to the side of the panels, see 6.2.3.2.

For standard testing, the distance from the panel to the arc shall be 300 mm.

Dimensions in millimetres



IEC

#### Key

|       |                                                                                                                              |          |                                                                             |
|-------|------------------------------------------------------------------------------------------------------------------------------|----------|-----------------------------------------------------------------------------|
| 1     | monitor <i>sensors</i> in position 1                                                                                         | 4        | centre line of arc electrodes                                               |
| 2     | panel body with slide system for adjusting the distance of panel to electrodes                                               | 5        | front board of panel, into which two panel <i>sensors</i> are mounted       |
| 3     | support for panel body with slide system                                                                                     | $\alpha$ | angle between centre lines of panel and monitor <i>sensor</i> (see Table 1) |
| $D_1$ | Distance between vertical centre line of electrodes and centre of surface of monitor <i>sensor calorimeter</i> in position 1 |          |                                                                             |
| $D_2$ | Distance between vertical centre line of electrodes and centre of surface of monitor <i>sensor calorimeter</i> in position 2 |          |                                                                             |

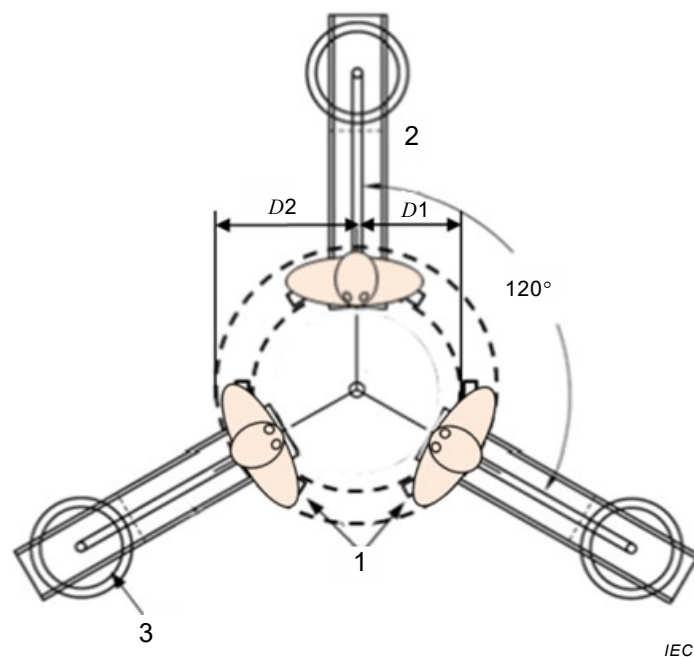
**Figure 6 – Arrangement of three two-sensor panels with monitoring *sensors* (top view) for testing according to Procedure A**

#### 6.6 Arrangement of mannequin(s) and monitor *sensors* for testing according to Procedure B

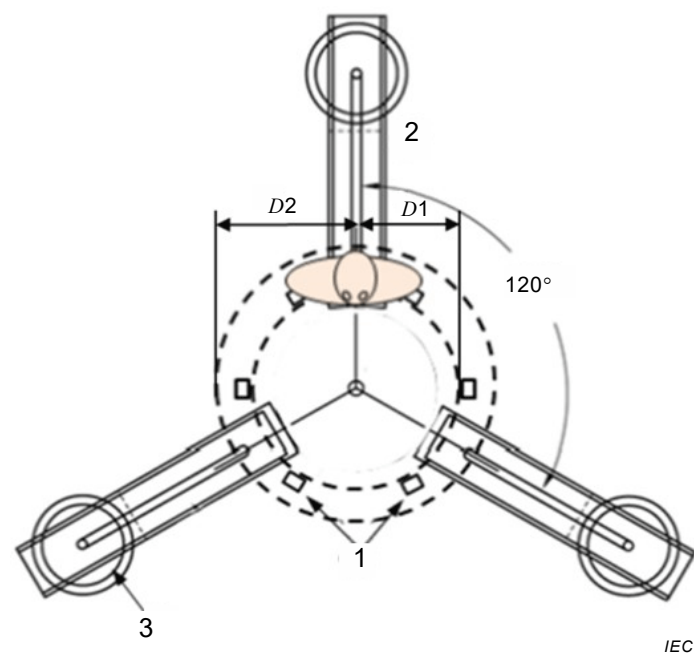
At least one mannequin shall be used for testing according to Procedure B. If more than one mannequin is used (i.e. two or three mannequins), the mannequins shall be spaced at a minimum of 120° as shown in Figure 7. One *monitor sensor* shall be positioned on each side of a mannequin. For further specifications about the positioning of the *monitor sensors* with respect to the centre line of the electrodes and/or to the side of the mannequin(s) or panel(s) see 6.2.3.2.

For standard testing, the distance between the arc and the point on the mannequin surface closest to the arc shall be 300 mm.

The space around the arc electrodes can dictate the number of mannequins used. It has been found that two mannequins provide good ample working space when dressing the mannequins. The minimum 120° spacing should be maintained.



a) Top view of arrangement with three mannequins and six monitor sensors



b) Top view of arrangement with one mannequin and two panels and six monitor sensors

#### Key

- 1 monitor sensors in position 1
- 2 support with slide system for turning/rotating position of mannequin and for adjusting its distance to electrodes
- 3 support for panel body or mannequin with slide system
- $D_1$  distance between vertical centre line of electrodes and centre of surface of monitor sensor calorimeter in position 1
- $D_2$  distance between vertical centre line of electrodes and centre of surface of monitor sensor calorimeter in position 2

**Figure 7 – Relative positioning of arc electrodes and of mannequin(s) and monitor sensors for testing according to Procedure B**

It shall be possible to position a mannequin, consisting of at least the torso in such a way that the sternum is at the centre of the gap between the electrodes [see Figure 8 a)].

NOTE 1 A mannequin-torso with arm stubs in the position as shown in Figure 8 a) is typically used for testing of *garments* which are intended to protect the torso and arms (e.g. shirts, jackets).

It shall be permitted to position a mannequin, consisting of at least the lower part of the torso and the upper part of the legs, at the following heights:

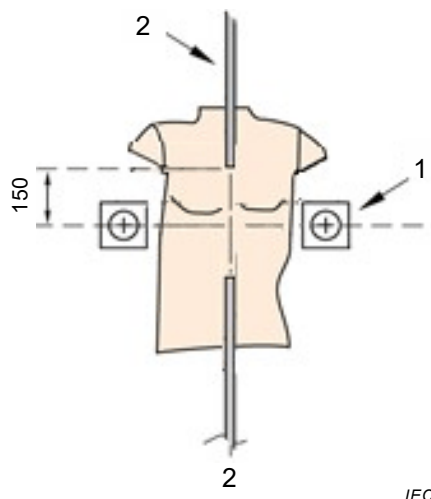
- a) positioning of the mannequin vertically in such a way that its navel is at the height of the centre of the electrode gap [see Figure 8 b)];

NOTE 2 A mannequin-torso with arm stubs and leg stubs in the position as shown in Figure 8 b) can be used for testing of *garments* intended for the protection of the lower part of the torso and/or with additional design features at the waist (e.g. coverall with (elastic) waist band) and/or for testing the interface between jacket and trousers.

- b) positioning of the mannequin vertically in such a way that its crotch is at the height of the centre of the electrode [see Figure 8 c)].

NOTE 3 A mannequin with hips and knee-up legs in the position as shown in Figure 8 c) can be used for testing of *garments* intended for the protection of the lower part of the torso and legs (e.g. trousers).

Dimensions in millimetres



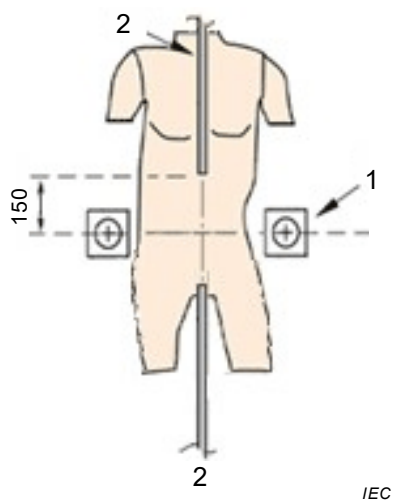
#### Key

- 1 monitor *sensor*
- 2 electrodes

NOTE Length of arm stubs can be as short as 100 mm for ease of specimen mounting.

- a) **Torso mannequin with or without arm stubs, with position of centre of electrode gap at height of sternum**

Dimensions in millimetres

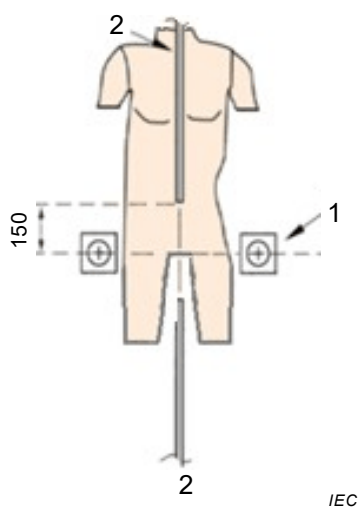
**Key**

- 1 monitor *sensor*
- 2 electrodes

NOTE Length of arm stubs and leg stubs can be as short as 100 mm for ease of specimen mounting.

**b) Torso mannequin with leg stubs, with position of centre of electrode gap at height of navel**

Dimensions in millimetres

**Key**

- 1 monitor *sensor*
- 2 electrodes

NOTE Length of knee-up legs can be as short as 300 mm for ease of specimen mounting.

**c) Mannequin with hips and knee-up legs, with position of centre of electrode gap at height of crotch**

**Figure 8 – Examples of mannequin configuration**

## 6.7 Supply bus and electrodes

### 6.7.1 General

The supply bus and arc electrodes shall be part of the structural arrangement, which is designed to reduce the electromagnetic forces on the arc and thus centres the rotation of the arc along the centre line between the electrodes. Figures 9 and 10 give examples of an appropriate structural arrangement that includes a cage with six conductive bus tubes. The arc shall be in a vertical position as shown.

### 6.7.2 Structural cage arrangement

The structural cage arrangement shall be made of conductive tubes (e.g. metallic tubes such as aluminium or steel tubes). There shall be at least six bus tubes (examples shown in Figures 9 and 10); the arrangement of nine bus tubes has been found to be also practicable.

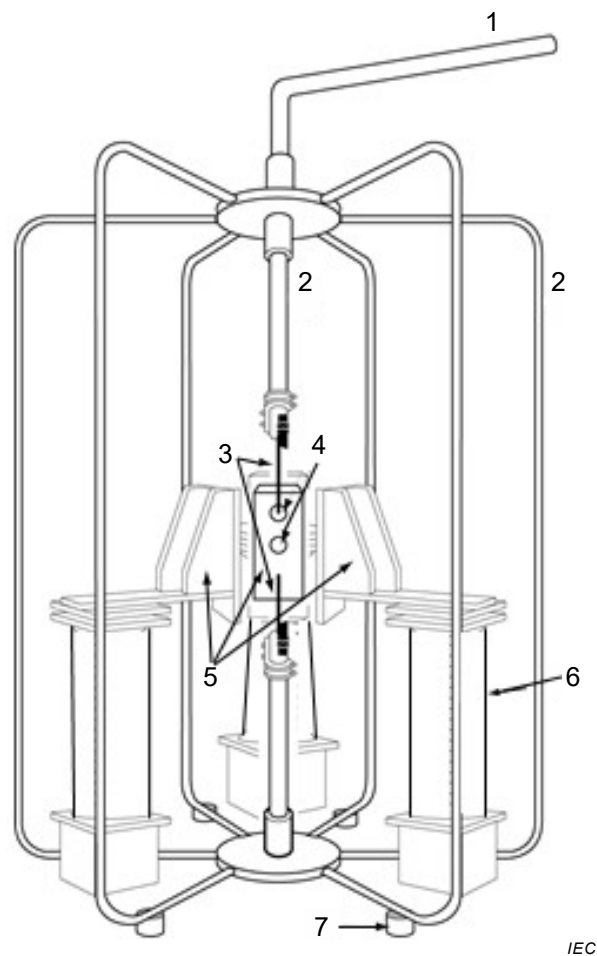
The diameter of the cage shall be between 2,0 m and 2,5 m.

The height of the cage shall be at least equal to the diameter of the cage and between 2,3 m and 4 m.

NOTE 1 Based on modelling, the greater the ratio between the height and the diameter, the better the arc will be centred on the centre line between the electrodes. The electromagnetic forces within the test apparatus keep the arc in the centre line of the *arc gap*.

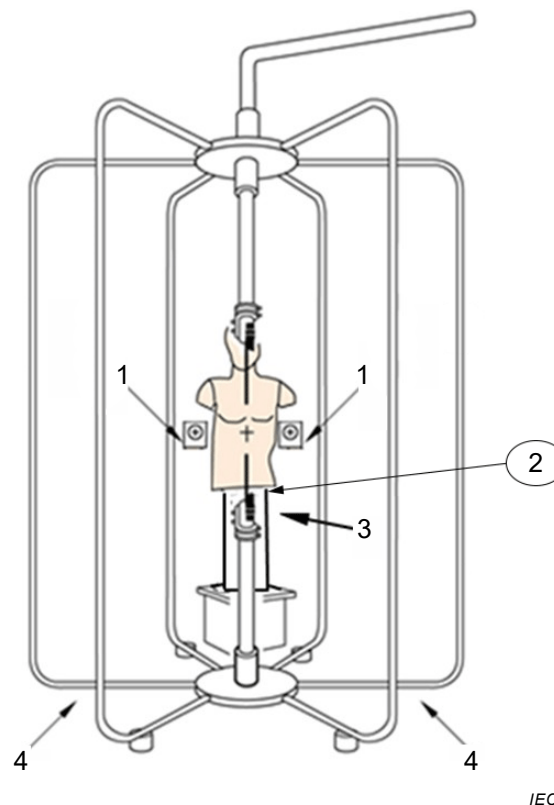
The mid-point of the electrode gap shall be at half the height of the cage  $\pm 50$  mm.

NOTE 2 A platform made of non-conductive *material*, eventually reaching into the cage, can be positioned at a height so as to allow for easy access to the electrodes, panels, mannequins and monitor *sensors*.

**Key**

- |   |                    |   |                              |
|---|--------------------|---|------------------------------|
| 1 | coaxial bus supply | 5 | panels                       |
| 2 | bus                | 6 | insulating support for panel |
| 3 | electrode          | 7 | insulator                    |
| 4 | panel sensors      |   |                              |

**Figure 9 – Example of cage arrangement (supply bus, bus tubes and arc electrodes) shown together with three panels for testing according to Procedure A (monitor sensors are not shown)**



**Key**

- |   |                                                                                                                    |   |                                      |
|---|--------------------------------------------------------------------------------------------------------------------|---|--------------------------------------|
| 1 | monitor <i>sensors</i>                                                                                             | 3 | support for mannequin (or for panel) |
| 2 | slide system for turning/rotating position of mannequin and for adjusting its distance to electrodes (not visible) | 4 | bus bars                             |

The additional at most two mannequins or panels and their adjacent monitor *sensors* are not shown.

**Figure 10 – Relative positioning of cage arrangement (supply bus, bus tubes and arc electrodes) and of one torso mannequin and its monitor *sensors* for testing according to Procedure B**

### 6.7.3 Electrodes

The electrodes are made from a stainless steel rod (alloy type UNS-S30300 or type UNS-782 S30400 or S31603/316L) with a nominal diameter in the range from 15 mm to 25 mm.

### 6.7.4 Fuse wire

A fuse wire, connecting the ends of opposing electrodes tips, shall be used to initiate the arc. This wire is consumed during the test; therefore, its mass shall be very small to reduce the chance of molten metal burns. The fuse wire shall be a conductive wire (e.g. copper) with a nominal diameter of 0,5 mm or less.

## 6.8 Electric supply

The electric supply shall be sufficient to allow for the discharge of an *electric arc* initiated with a fuse wire, across a gap of up to 315 mm, with alternating arc current, which has a symmetrical steady state r.m.s component of 8 kA ± 0,5 kA and with *arc duration* up to at least 1 s from a power-frequency supply.

The voltage shall be sufficient to maintain the arc for the whole duration of the test. An open circuit voltage of at least 2 000 V and an *X/R ratio* of the test circuit such that the test current contains a DC component resulting in the first peak of the test current having a magnitude of 2,3 times the symmetrical r.m.s. value, have proven to be sufficient.

A switch for arc initiation shall meet the requirements of 6.9, as this capability has shown to provide closing angles, which will produce asymmetrical currents with an *X/R ratio* as stated above.

NOTE 1 Discussions and research have taken place to investigate if other than fully asymmetric test currents with voltage of at least 2000 V can be considered. Further investigations are pursued with the intention to clarify whether testing with symmetrical currents and lower open circuit voltages will have an effect on *ATPV*, *EBT* or *ELIM*.

In order to be able to test *materials* and clothing with *arc ratings* up to 4 184 kJ/m<sup>2</sup> (100 cal/cm<sup>2</sup>), the electric supply shall be sufficient to allow for longer *arc duration*.

NOTE 2 If the electric supply is capable of allowing only *electric arcs* with shorter duration, testing will be limited to only *materials* and clothing with lower *arc rating*.

## 6.9 Test-circuit control

The switch for arc initiation shall be capable of point-on-wave closing time with a tolerance of  $\pm 0,5$  ms between subsequent bare and/or arc shots. The circuit control system shall be capable of measuring and recording the actual arc current, voltage and duration. The arc current, voltage and energy shall be displayed in graph form for the whole time of *arc duration* and stored in digital form.

## 6.10 Data acquisition and data processing system

### 6.10.1 General

The system shall be capable of measuring *arc voltage*, arc current and *calorimeter* outputs as required by this test method.

The measuring system may require the use of separate waveform recorders having different acquisition rate.

### 6.10.2 Data acquisition

#### 6.10.2.1 Data acquisition calorimeters

The acquisition system (for analog to digital conversion) of signals from *calorimeters*, which may consist of the converter (including the isolating system), the recorder, computer and software, shall be able to record *calorimeter* output corresponding to temperature range from 0 °C to 500 °C. The temperature acquisition system shall have at least a resolution of 0,1 °C and an accuracy of  $\pm 0,75$  °C (this does not include the accuracy of the thermocouple and the *calorimeter*). It shall be capable of making cold junction corrections and converting the millivolt signals from the type K thermocouple to temperature (complies with IEC 60584-1).

The waveform recorder for recording data from the *calorimeters* shall be capable of recording all channels simultaneously at a sampling rate of at least 100 samples per second per channel and the entire system shall have a –3 dB bandwidth of at least 20 Hz.

NOTE 1 A too low sampling rate would prevent the accurate synchronization of the temperature curves with the arc initiation time  $t_0$ . A minimum sampling rate of 100 ensures that the time resolution is 10 ms or better. A combined minimum bandwidth of 20 Hz for the digital recorder module and all analog and digital filters if used has been found sufficient to avoid introducing significant error in the signal rise time.

NOTE 2 Filtering can be necessary to remove some of the noise on the thermocouple signals.

The filter shall preserve the wave shape and shall not introduce a time shift.

NOTE 3 An acceptable way to filter arc noise is to detect its initial and final point on the synchronized digital signal, and to remove the noise by replacing the digitized signal points which contain noise with an interpolated piecewise polynomial (spline) preserving the original sampling rate. In this way noise-free signal points will be obtained.

The use of analog or digital filters such as Bessel, Butterworth, Chebyshev or similar algorithms is not recommended as they can introduce time shift behaviour and compromise energy and Stoll criteria evaluations.

The acquisition system shall be capable of continuously recording:

- a) pre-arc exposure temperature data to obtain the initial *sensor* temperatures, and
- b) temperature data from the monitor *sensors* and panel *sensors* up to at least 30 s after arc initiation.

#### 6.10.2.2 Data acquisition voltage and current

The acquisition system used for measuring the arc current and voltage may consist of isolating transformers, shunts, dividers, a waveform recorder, computer and software. The waveform recorder shall have a minimum sampling rate of 2000 samples per second and a –3 dB bandwidth of at least 200 Hz. The arc current and voltage measurement system shall have an accuracy of at least 3 % of the applied current and voltage.

#### 6.10.3 Signal synchronization

All waveform recorders used in the data acquisition system for measuring the arc current, *arc voltage* and all the temperatures (i.e. temperature rise versus time) of all the *calorimeters*, shall be synchronized to ensure the real time relationship between all the waveforms is maintained.

The data acquisition system shall measure an electrical arc signal which is suitable for the determination of the arc initiation time and all the temperatures (i.e. temperature rise versus time) of all the *calorimeters* of the monitor and panel *sensors* in a synchronized way.

The arc initiation time  $t_0$ , which corresponds to the time of the start of the arc, shall be reliably determined from this electrical arc signal (e.g. current).

NOTE 1 A reliable way is to define a minimum threshold value level, slightly higher than the usual (no arc) electrical noise and to determine then the arc initiation time  $t_0$  as the time of the sampling point previous to the first sampling point above the noise threshold.

NOTE 2 Instead of arc current wave, the signal from a specific, separate *sensor* (which measures, for example, the voltage induced by the arc in a coil) can be used as the arc signal for the determination of the arc initiation time.

NOTE 3 A reliable way to synchronize the start of the data acquisition systems is to use the arc signal as a trigger for each waveform recorder.

NOTE 4 One can use the following procedure for verifying that the measurements of all *calorimeters* of the *sensors* are synchronized amongst themselves, i.e. use the same time base: One determines for the response of each *sensor*  $i$  the time  $t_{0,i}$  as the time of the earliest sampled signal showing a consistent variation of the temperature (i.e. higher than any fluctuation due to the equipment resolution or environmental causes prior to or after arc events). One can consider that all the *sensors* are synchronized, if the difference between the earliest and latest individual *sensor* signal time  $t_{0,i}$  values is less than 20 ms. This procedure can be used for panel *sensors* only when they are not covered by test specimens. This procedure is not reliable for verifying whether panel *sensors*, when covered with test specimens, are synchronized with each other and with the monitor *sensors*.

## 7 Operator safety

During the duration of the *electric arc*, the test apparatus discharges large amounts of energy. In addition, the *electric arc* produces very intense light. Care shall be taken to protect personnel working in the area.

Hazards such as, but not limited to, the following can occur:

- very intense light;
- contact with molten and vaporized metal;
- extreme sound pressure;
- combustion products, smoke and fumes;
- the test apparatus, electrodes and *calorimeter* assembly become hot during testing;
- risk of fire due to ignited specimens and combustion gases;
- risk of electrocution during reconditioning or changes, etc.

Safety of persons shall be guaranteed according to national legislation.

NOTE 1 Protective barriers or safe distance can help to prevent electrocution and contact with molten and vaporized metal. Heavy tinted glasses may help to protect viewers of tests. In case of indoor tests, combustion products, smoke and fumes are carried away by ventilation after testing and before entering.

NOTE 2 Respiratory protective devices (e.g. power assisted filtering devices with hood or whole mask and appropriate filter) can be needed when taking down or changing the specimens directly after each test if combustion products, smoke and fumes remain.

NOTE 3 A method to ventilate the area can be used in order to carry away combustion products, smoke and fumes.

## 8 Specimen preparation

### 8.1 Description of the test specimens

#### 8.1.1 Test specimens for Procedure A

Test specimens in the form of flat *material* or flat *material assembly* shall be cut from *garment* samples or samples of the *garment assembly*, or shall be constructed to be representative of the *garment* or *garment assembly*.

The size of the specimens after the laundering pre-treatment according to 8.2 shall be at least 100 mm longer and wider than the actual panel length and width, and shall not be more than 130 mm longer and wider than the panel length and width.

An exact observance of the requirement for a maximal length and width of test specimens is particularly important for *materials* which will shrink as consequence of arc exposure to such a high extent that *shrink-open* may occur.

At least 20 rectangular test specimens shall be cut with the specimen length in the warp direction of the *material*. Depending on 11.1.2 and 11.1.3, more than 20 test specimens may be needed.

It is advisable to prepare about 30 test specimens. In case that *materials* are not homogenous and/or if the *EBT* of a *material* is far above its *ATPV*, even more test specimens may be needed in order to be able to determine both *ATPV* and *EBT*.

NOTE Usually, once the *ATPV* has been determined, there is no need for testing of further specimens for the determination of the *ELIM*.

#### 8.1.2 Test specimens for Procedure B

Test specimens shall be finished *garments* (i.e. with findings, pockets and closures, etc.) or *assemblies of garments* as worn together and/or worn on top of each other according to the manufacturer's instructions as intended for use.

The size of the *garments* or assembly of *garments* shall be appropriate for the mannequin.

Depending on 11.2.2 and 11.4.2, more than one test specimen may be needed.

## 8.2 Pre-treatment of test specimens by cleaning

Before testing, the individual test specimens or the amount of *material* samples from which test specimens can be constructed shall be pre-treated by cleaning if cleaning is permitted according to the manufacturer's instructions.

The cleaning shall be in line with the manufacturer's instruction on the basis of standardized processes. The tests shall be carried after the number of cleaning cycles specified by the manufacturer. If the number of cleaning cycles is not specified, the tests shall be carried out after five cleaning cycles (a cleaning cycle is one wash and a dry cycle).

If washing is permitted as well as dry cleaning, then the specimens shall only be washed. Products which are labelled as dry cleaning only shall be dry cleaned only.

NOTE The manufacturer's instruction typically indicates one or several of the various methods and processes of ISO 6330, ISO 15797, ISO 3175-2 or equivalent standardized processes for washing.

Specimens may be restored after cleaning to a flat condition by pressing.

## 8.3 Pre-conditioning of the test specimens

Before testing the specimens shall be pre-conditioned. The conditioning atmosphere shall be the temperature between 18 °C and 28 °C and the relative humidity between 45 % and 75 % for at least 24 h.

# 9 Calibration and verification

## 9.1 Data acquisition system pre-calibration

The complete data acquisition system shall be calibrated. Its temperature measurement system shall be calibrated by using a thermocouple calibrator/simulator. This will allow calibrations to be made at multiple points and at levels above 100 °C. Due to the nature of the tests, frequent calibration checks are recommended.

## 9.2 Verification of *calorimeters*

*Calorimeters* shall be checked to verify proper operation. The verification can be done before or after all the needed *calorimetric sensors* or *calorimeters* for the panels are put in their final positions in the panels and all the needed monitor *sensors* are in the final position needed for the determination of the *arc rating* (see Table 1).

One acceptable verification method is to expose each *calorimeter* to radiant energy from a 500 W spot light for 30 s as follows.

- The front surface of the spot light shall be placed at a same distance of 250 mm  $\pm$  50 mm from each *calorimeter*. The spot light beam shall be centred on, and perpendicular to the *calorimeter*.
- When carrying out this method on *calorimeters* which are in their final position for panels and monitor, ensure the same initial temperature  $\pm$  2 °C at each *calorimeter*, i.e. avoid pre-heating of neighbouring *calorimeters* while checking one *calorimeter*.
- The spot light shall emit a stable *heat flux* for at least the duration needed for checking all the *calorimeters*. Each *calorimeter* shall be exposed to a fixed radiant energy source for 30 s.
- The temperature rise of each *calorimeter* and data acquisition system response shall be measured and graphed.
- At 30 s, no one *calorimeter* response shall have varied by more than 4 °C from the average of all *calorimeters*.

- Any *calorimeter* not meeting this requirement shall be replaced or repaired.

Other methods to adequately verify the operation of each *calorimeter* against the average of a group of known good *sensors* are acceptable, provided that these methods are documented, repeatable and have been proven to provide the same results.

### 9.3 Arc exposure and apparatus verification for the two-sensor panels and the monitoring sensors

#### 9.3.1 Set-up of electrodes and fuse wire

Prior to each verification, the electrodes of the test apparatus shall be positioned to produce a  $300 \text{ mm} \pm 5 \text{ mm}$  gap. The mid-point of the electrode gap shall be at the same elevation as the centre points of the monitor *sensors* and of the lower panel *sensors* (see Figure 4). Connect the fuse wire to the end of one electrode by making several wraps and twists and then to the end of the other electrode by the same method. The fuse wire shall be pulled tight and the excess trimmed.

#### 9.3.2 Positioning of the two-sensor panels, mannequins and monitor sensors

Each two-sensor panel or each mannequin shall be positioned so that the surface of each is perpendicular to the line between the centre line of the electrodes and the surface of the panel or mannequin. The distance between the centre line of the electrodes and the panel or mannequin shall be  $300 \text{ mm} \pm 5 \text{ mm}$ .

It shall be verified that the *monitor sensors* are positioned as required in 6.2.3.2 (i.e. the *monitor* shall be at a distance of  $340 \text{ mm} \pm 5 \text{ mm}$  from the centre line of the electrodes (position 1 according to Table 1 in 6.2) or at a distance of  $410 \text{ mm} \pm 5 \text{ mm}$  from the centre line of the electrodes (position 2 according to Table 1 in 6.2)). If necessary, the position shall be adjusted. For the purpose of exposure and apparatus calibration, the *monitor sensors* may alternatively be positioned so that the surface of each is  $300 \text{ mm} \pm 5 \text{ mm}$  from the centre line of the electrodes.

In any case, the actual distance of each *monitor sensor* shall be measured to a precision of  $\pm 2 \text{ mm}$ , and the values recorded and used for the *incident energy* calculation according to 12.1.4 shall be corrected by an *incident energy* correction factor, in order to obtain from each *monitor sensor* an array of *incident energy* versus time values at a distance of  $300 \text{ mm}$  from the centre line of the electrodes, i.e. at the position of the panel *sensors*. This *incident energy* correction factor for a *monitor sensor* shall be the square of the ratio of the actual distance of the *monitor sensor* divided by the actual distance of the panel or mannequin next to which the *monitor sensor* is positioned.

#### 9.3.3 Verification bare shot

The test parameters for the *bare shot* for the arc exposure and apparatus verification shall be as follows:

- an arc current of  $8 \text{ kA} \pm 0,5 \text{ kA}$ , as indicated in 6.8;
- a  $300 \text{ mm} \pm 5 \text{ mm}$  electrode gap;
- stainless steel electrodes;
- a  $300 \text{ mm} \pm 5 \text{ mm}$  distance between the arc centre line and the surface of the panels;
- a  $340 \text{ mm} \pm 5 \text{ mm}$  or  $410 \text{ mm} \pm 5 \text{ mm}$  distance between the arc centre line and the surface of the *monitor sensor*;
- an *arc duration* of  $167 \text{ ms} \pm 2 \text{ ms}$  (i.e. nominal 10 cycles) from 60 Hz supply or  $170 \text{ ms} \pm 2 \text{ ms}$  (i.e. nominal 8,5 cycles) from 50 Hz supply.

The arc shall be ignited and the temperature versus time response from each *sensor* shall be converted into an *incident energy* versus time response according to 12.1, i.e. an array of *incident energy* values at a distance of  $300 \text{ mm}$  from the centre line of the arc versus time. The

maximum of the *incident energy* response for each *sensor* shall be determined and considered as the *incident energy* (total heat) in  $\text{kJ/m}^2$  measured by each *sensor*. Because the arc does not follow a path that is equidistant from each *sensor*, the resulting *incident energy* values vary between *sensors*.

The average of the *incident energies* of all the calorimetric *sensors* located at the height of the middle of the *arc gap*, i.e. of all the six monitor *sensors* and all the *sensors* in the centre of each panel, which is part of the test apparatus setting, shall be  $313,8 \text{ kJ/m}^2 \pm 41,8 \text{ kJ/m}^2$  ( $7,5 \text{ cal/cm}^2 \pm 1,0 \text{ cal/cm}^2$ ).

The highest measured *incident energy* of any of the *sensors* located at the height of the middle of the *arc gap* shall not be more than 30 % greater than the average of the incident energies of these *sensors* and the lowest measured *incident energy* of any of these *sensors* shall not be more than 30 % lower than average.

If three panels are part of the test apparatus setting, the highest measured *incident energy* of any of the top panel *sensors* shall not be more than 25 % greater than the average of the *incident energies* of these *sensors* and the lowest measured *incident energy* of any of these *sensors* shall not be more than 25 % lower than the average.

If the above *incident energy* distribution requirements are not fulfilled, inspect the test set-up and check the verification of the *sensors* system and the electrical conditions, correct the problems and repeat the apparatus verification procedure until the above requirements are fulfilled.

It is advisable that an arc exposure apparatus verification test is conducted prior to the start and end of each day's testing and after any equipment adjustment or failure and that the results are recorded. It is further advisable that a synchronization check as described in Note 2 of 6.10.2.1 is carried out at the same time.

#### 9.3.4 Verification *bare shot* test protocol

The parameters of the test apparatus setting shall be checked, confirmed and recorded for each *bare shot* used for the purpose of arc exposure and apparatus verification.

In addition, the ambient temperature and relative humidity shall be measured and reported prior to each verification *bare shot*.

Values to be measured, recorded and reported for each verification *bare shot* shall be peak arc current, r.m.s. arc current, *arc duration*, *arc energy*, and r.m.s. *arc voltage*. A graph of the arc current shall be plotted to show proper waveform.

## 10 Test apparatus care and maintenance

### 10.1 Surface reconditioning

Each *sensor* surface shall be visually inspected after each test and, based on the surface condition, may be wiped immediately after each test, while still hot, to remove any decomposition products which condense and could dry-in and be a source of future error. If a deposit collects and appears to be thicker than a thin layer of paint, or is irregular, the reconditioning of the *sensor* surface is required.

Immediate cleaning of *calorimeters* can be commonly accomplished with water. If the deposits are not water dissolvable, the cooled *sensor* shall be carefully cleaned with a cleaning liquid and/or a paint remover, making certain to follow safe handling practices. The surface shall be repainted with a thin layer of the same paint as in 6.2.2. The same paint shall be used on all *sensors* and the paint shall be dry before running the next test.

It is recommended to carry out a *bare shot* according to 9.3.3 after each surface reconditioning of *sensors*, for the purpose of curing new paint and of apparatus verification.

Alternatively, instead of removing the paint, it might be sufficient to burn off the contamination on the surface of the copper disc during a *bare shot* after having cleaned the *calorimeter* with water prior to the *bare shot*.

NOTE 1 Mixture of three volume parts of 1,1,1-trichloroethane and one volume part of ethanol has been found suitable as *calorimeter* cleaning liquid.

NOTE 2 Acetone or petroleum solvents have been found suitable as paint remover.

It is recommended to carry out verification also according to 9.2 prior to verification according to 9.3.3.

## 10.2 Care of panels, mannequins and sensors

*Sensor* panels and mannequins shall be kept dry.

For outdoor tests, panels, mannequins and *sensors* may be covered between tests shots to prevent excess heating or cooling resulting from exposure to the environmental conditions.

## 10.3 Care of electrodes

The electrode gap shall be maintained to the required distance before each *bare shot* or *test shot*. The electrodes shall be changed when the required distance cannot be maintained (electrodes too short).

# 11 Test procedures

## 11.1 Procedure A – testing with panels

### 11.1.1 Test parameter and settings

The r.m.s. value of the symmetrical component of the arc current shall be  $8 \text{ kA} \pm 0,5 \text{ kA}$ , a  $300 \text{ mm} \pm 15 \text{ mm}$  electrode gap, stainless steel electrodes and a  $300 \text{ mm} \pm 5 \text{ mm}$  distance between the arc centre line and the surface of the panel. The duration of the arc shall be varied to produce the required series of test exposures over a range of *incident energies*, which shall meet the criteria of 11.1.3.

The *monitor sensors* shall be adjusted to position 1 for *incident energy* exposures needed for the determination of an expected value of *ATPV*, *EBT*, or *ELIM* of up to  $2\,300 \text{ kJ/m}^2$  (about  $55 \text{ cal/cm}^2$ ) or position 2 for an expected value of *ATPV*, *EBT*, or *ELIM* above  $1\,675 \text{ kJ/m}^2$  (about  $40 \text{ cal/cm}^2$ ), with positions 1 and 2 indicated in Table 1. For the lateral position of the *monitor sensors* with respect to a panel or mannequin see Table 1.

It is recommended not to change the positions of the *monitor sensors* during a series of tests needed for the determination of the *arc rating* of a *material*.

The recording of temperature data from the monitor and *panel sensors* shall start prior to arc initiation to establish a reliable initial temperature of the *sensors* and shall continue at least 30 s after arc initiation.

### 11.1.2 Sequence of tests with test specimens of *material* or *material assembly*

For the determination of the *ATPV*, *EBT* or *ELIM* of a *material* or *material assembly*, a series of the tests shots necessary to produce data from at least 20 test specimens shall be run, with the specimens exposed to a range of *incident energies*. The sets of measured *incident energy* data points (see 12.1.4) shall meet the distribution criteria of 11.1.3. If the distribution criteria are not met, additional specimens shall be tested to fulfil the distribution criteria.

All valid data points shall be used. A data point shall not be used when a copper *calorimeter* temperature exceeds 500 °C.

NOTE 1 Each test of the series usually consists of three specimens of the same *material* or *material assembly*, one for each of the three two-sensor panels. Thus in order to obtain at least data for 20 test specimens, the test series will consist of at least seven *test shots*.

In the sequence of tests for the determination of the *arc rating*, the first aim is to determine the *ATPV*.

If during the testing for the determination of the *ATPV* two or more occurrences of *material breakopen* are noted at *incident energies* below a value of 20 % above the *ATPV* determination, the *EBT* shall also be determined.

NOTE 2 This is a typical case, where more than 20 test specimens can be required so that also the *breakopen* response can be evaluated (see 12.3 for the determination of the *EBT* as result of the *breakopen* response of test specimens).

### 11.1.3 Criteria for set of data obtained from iterative process of *test shots*

#### 11.1.3.1 *Test shots* for determination of the *ATPV*

For the determination of the *ATPV* (see 12.2), the set of data points shall be distributed in the following way:

- a) at least 3 data points shall be below the *mix zone*;
- b) at least 3 data points shall be above the *mix zone*;
- c) at least 10 data points shall be in the range of  $\pm 20$  % of the final *ATPV*.

NOTE Data points in this energy range typically are in the *mix zone*, i.e. some data points exceed and some data points do not exceed the Stoll criteria.

A sequence of *test shots*, which shall provide at least 20 data points, shall be carried out in such an order as to fulfil the above data point distribution requirements.

The sequence of *test shots* is best carried out as an iterative process, i.e. in such a way that the results from an increasing number of *test shots* allow to fulfil the data point distribution requirements increasingly better, thus to determine an always increasingly better estimate of the *ATPV* (see, for example, Annex C).

In case that the obtained minimum 20 data points are not sufficient for fulfilling the data point distribution requirements, further *test shots* shall be carried out.

In addition, in case of a multilayer *material*:

- at least three data points shall also be obtained where the *incident energy* has not caused *ablation* of the layer on top of the innermost layer of the *material*.
- at least three data points shall also be obtained where the *incident energy* has caused *ablation* of the layer on top of the innermost layer.

#### 11.1.3.2 *Test shots* for the determination of the *EBT*

For the determination of the *EBT* (see 12.3), the set of data points shall be distributed in the following way:

- a) at least three data points shall be below the *mix zone*;
- b) at least three data points shall be above the *mix zone*;
- c) at least 10 data points shall be in the range of  $\pm 20$  % of the final *EBT*.

NOTE Data points in this energy range typically are in the *mix zone*, i.e. some data points do or do not show *breakopen* in case of the determination of the *EBT*.

An iterative process similar to the process used for the determination of the *ATPV* shall be carried out in order to fulfil the above data point distribution requirements for the determination of the *EBT*. For the calculation of the iteratively estimated values of the *EBT* according to 12.3, the binary responses “0” and “1” are determined by the information of *material breakopen* and/or *shrink-open* (i.e. “1” meaning occurrence of *breakopen* and/or *shrink-open*).

#### 11.1.3.3 Test shots for the determination of the *ELIM*

For the determination of the *ELIM* (see 12.4), it is sufficient to have the set of data points required for the determination of the *ATPV* or of the *EBT*, if the *EBT* is lower than the *ATPV*.

However, it is not necessary to determine the *EBT* with the statistical precision as required by 11.1.3.2 (i.e. based on a set of data points obtained from at least 20 specimens) if, after testing of a few specimens, it has become evident that the *EBT* is at least 20 % greater than the *ATPV*.

### 11.2 Procedure B – testing with mannequins

#### 11.2.1 Test parameters and settings

The r.m.s. value of the symmetrical component of the arc current shall be  $8 \text{ kA} \pm 0,5 \text{ kA}$ , a  $300 \text{ mm} \pm 15 \text{ mm}$  electrode gap, stainless steel electrodes and a  $300 \text{ mm} \pm 5 \text{ mm}$  distance between the arc centre line and the surface of the mannequin.

If the manufacturer indicates that an *arc rating* shall be attributed to a *garment* or clothing, made of a *material* of which the *arc rating* determined according to Procedure A is known, the duration of the arc shall be selected such that the resulting *incident energy* exposure value shall be in the range  $^{+25}_0$  % of the *arc rating* of the *material*.

However, the duration of the arc may be selected to be shorter than indicated above, if the test ordering party is not aiming to obtain an *arc rating* attributed to a *garment* or assembly of *garments* as high as the *arc rating* of the *material*.

The *monitor sensors* shall be adjusted as function of incident exposure energies as specified in 11.1.1 and in 6.2.3.2 and Table 1.

The recording of temperature data from the *monitor sensors* shall start prior to arc initiation to establish a reliable initial temperature of the *sensors* and shall continue at least 30 s after arc initiation.

#### 11.2.2 Single test or sequence of tests with test specimen(s) of *garment* or *garment assembly*

For the evaluation of the response of a *garment* or an *assembly of garments*, at least one specimen of *garment* or *garment assembly* mounted on a mannequin shall be tested.

It may be necessary to carry out a sequence of tests at different *incident energy* exposures, with each test carried out on a new test specimen, in order to fulfil the following requirement for attributing an *arc rating* to a *garment* or *garment assembly*:

- Amongst the number of tested specimens, at least the specimen tested at the lowest *incident energy* shall meet the visual inspection criteria given in 12.6.2.

If the above requirement is not fulfilled, further tests at lower incident energies need to be carried out until the above requirement is fulfilled; otherwise no *arc rating* can be attributed to the *garment* or *garment assembly*.

It is recommended to test a specimen of *garment* or *garment assembly* at a targeted level of *incident energy* equal to (e.g. in the range  $^{+10}_0$  % of) the *arc rating* of the *material* or *assembly*.

*assembly* which it is made of, in order to evaluate whether an *arc rating* as high as the *arc rating* of the *material* or *material assembly* can be attributed to the *garment* or *garment assembly*.

NOTE 1 Usually, testing of further specimens at lower *incident energy* exposure will be carried out only if the previously tested specimens do not meet the visual inspection criteria. However, a manufacturer can also want to attribute an *arc rating* to a *garment* or *garment assembly*, which is (considerably) lower than the *arc rating* of the *material* or *material assembly*; in this case testing can deliberately be carried out at an incident exposure energy (considerably) lower than the *arc rating* of the *material* or *material assembly*.

NOTE 2 Experience has shown that *garments* and *garment assemblies* are usually designed and manufactured in such a way that testing of one, two or eventually three specimens is sufficient for attributing an *arc rating* to a *garment* or *garment assembly*.

If the above requirement for attributing an *arc rating* is fulfilled, the value of the *arc rating* shall be determined as follows.

- From the number of tested specimens, the specimen tested at the highest *incident energy*, which meets the visual inspection criteria given in 12.6.2, and for which it is also true, that all specimens tested at lower *incident energies* – if any – meet the visual inspection criteria, shall be selected.
- The value of the *incident energy* to which the selected specimen has been exposed during the test, shall be compared with the value of the *arc rating* of the *material* or *material assembly*, of which it is made,
- At most the lower of these two values shall be attributed to the *garment* or *garment assembly* as its *arc rating*.

Therefore, the *arc rating* of a *garment* or *garment assembly* will never be equal to or greater than the exposure *incident energy*, at which any tested specimen of the *garment* or *garment assembly* has failed the visual inspection criteria given in 12.6.2.

And therefore the *arc rating* of a *garment* or *garment assembly* will never be higher than the *arc rating* of the *material* or *material assembly* of which the *garment* or *garment assembly* is made.

### 11.3 Air ventilation and initial temperature of sensors

Testing shall be carried out in an essentially still air environment. If a forced ventilation system is used to ventilate the area in order to carry away combustion products, smoke and fumes, this ventilation shall not be turned on during exposure and until data acquisition is completed.

The temperature of the *sensors* before each *test shot* shall be between 15 °C and 35 °C.

The *sensors* may be cooled or heated for example after exposure with a jet of air or by contact with a cold or hot surface. It shall be confirmed by reading the *sensors* that their initial temperature is between 15 °C and 35 °C.

### 11.4 Specimen mounting

#### 11.4.1 Procedure A – testing with panels

The specimen shall be fixed to the panel without stretching the *material* and in a manner that permits the specimen to shrink during arc exposure by help of the clamping system of the panel. If multiple-layer specimens are used, they shall be mounted in a manner that represents normal layering of clothing.

#### 11.4.2 Procedure B – testing with mannequins

A *garment* intended to protect the torso and arms (e.g. shirts, jackets, vests, coveralls, bib combined with jacket) shall be mounted on a mannequin consisting of at least a torso, and shall be tested with the centre of the electrode gap at the height of the sternum, as shown in Figure 8 a).