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Clothing for protection against heat and flame — Determination of heat transmission on exposure to both flame and radiant heat

Vêtements de protection contre la chaleur et la flamme — Détermination de la transmission de chaleur lors de l'exposition simultanée à une flamme et à une source de chaleur radiante

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Contents

Page

Foreword ... iv

Introduction ... v

1 Scope ... 1

2 Normative references ... 1

3 Terms and definitions ... 1

4 Principle ... 3

5 Apparatus ... 4

6 Precautions ... 5

7 Sampling ... 6
7.1 Specimen dimensions ... 6
7.2 Number of specimens ... 6

8 Conditioning and testing atmospheres ... 6
8.1 Conditioning atmosphere ... 6
8.2 Testing atmosphere ... 6

9 Test procedure ... 6
9.1 Calibration procedures ... 6
9.2 Sensor care ... 7
9.3 Specimen holder care ... 8
9.4 Preparation of heat transfer/burn intersection overlay ... 8
9.5 Test specimen mounting ... 8
9.6 Test-specimen exposure ... 9

10 Expression of results ... 9
10.1 Selection of analysis method ... 9
10.2 Thermal-threshold index (TTI) analysis method ... 10
10.3 Heat-transfer index (HTI) analysis method ... 10
10.4 Response to convective and radiant heat exposure ... 11

11 Interlaboratory test data ... 11

12 Test report ... 11

Annex A (informative) **Availability of materials** ... 16

Annex B (informative) **Basis of sensor calibration** ... 17

Annex C (informative) **Interlaboratory test data** ... 18

Bibliography ... 19

Foreword

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

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

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

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

ISO 17492 was prepared by Technical Committee ISO/TC 94, *Personal safety — Protective clothing and equipment*, Subcommittee SC 13, *Protective clothing*. It is based on Section 6-10 of NFPA 1971:2000 [2].

Introduction

The transfer of heat from the exterior of a material to the interior can be a significant factor in the level of protection or insulation provided by an assembly. While full-scale test methods are a better means of determining how an assembly performs, small scale tests such as those described in ISO 6942 and ISO 9151 can be used in establishing benchmarks of performance for the materials from which these assemblies are made. These tests enable the user of a material to anticipate how the properties of a particular material could impact the performance of the assembly when exposed to a high heat flux.

The purpose of an assembly for thermal protection is to prevent or reduce the potential for burn injury to the wearer. The performance of a product is determined by comparing the heat-transferred through the protective material to a known point where the thermal exposure would produce a burn injury. The total energy transferred that would cause a second-degree burn in human tissue is determined as the thermal protection index (TPI). In the TPI analysis of the data, the specimen is stressed by exposure to heat until the energy transferred through the specimen is equivalent to the energy that could cause a second-degree burn.

Other uses may require comparison of the insulation from a high-temperature exposure in terms other than the response of human tissue to heat. For these uses, an alternate method of evaluating the heat-transfer is provided. The total energy transferred that would cause the temperature rise of the copper sensor of 12 °C and 24 °C is determined as the heat-transfer index (HTI). In the HTI analysis of the data, the specimen is stressed by exposure to heat until the energy causes a specified amount of heat-transfer. This is a measure of the insulation performance of the specimen.

Unlike what is described in ISO 6942 or ISO 9151, the heat source in this test method is produced by 50 % radiant energy and 50 % convective energy. This equalized output is set to a thermal energy exposure having a heat flux of 80 kW/m^2. The intensity of this heat flux is intended to determine the performance of the specimen when exposed to both the high temperature radiation and hot gases that may exist in actual fire situations. The intensity level of this heat flux represents a moderately high industrial or emergency fire-fighting exposure that requires the use of a protective material, and thus, measures the performance of the specimen under realistic conditions relatively close to a realistic exposure intensity.

NOTE 1 The performance of materials made of flame-resistant fibres can be determined by the amount of heat energy transferred through the specimen and by observing any changes affected by the exposure on the specimen. The thermal protection index and the heat-transfer index measure the accumulated heat energy received which is an indication of the ability of the material to inhibit the transfer of heat.

NOTE 2 A human tissue burn will result when the total thermal energy transmitted by the material reaches the second-degree burn threshold.

NOTE 3 The thermal protection index or the heat-transfer index for flame-resistant materials can be used to establish anticipated performance levels of thermal resistance for single layer or multilayer constructions or assemblies.

NOTE 4 Different specimen-mounting conditions, which are determined by the number of layers of material in the test specimen, are provided in this method. Each condition emphasizes a different thermal property of the sample and represents the way in which the material is used in the end-use application.

NOTE 5 The spaced configuration, with a spacer placed between the back surface of the specimen and the sensor, reflects applications in which there is an air space or gap between the specimen and the protected surface. This spaced configuration also eliminates the cooling effect which occurs due to specimen contact with the sensor and allows the specimen to heat to a temperature during the test the same as that which might occur in actual exposure during a flash fire. This mounting condition measures the thermal resistance of the specimen plus the air gap and barrier performance of the specimen.

NOTE 6 The contact configuration, with the sensor in contact with the specimen, measures the insulation property of the specimen and reflects applications in which the textile is in contact with the protected surface.

Clothing for protection against heat and flame — Determination of heat transmission on exposure to both flame and radiant heat

1 Scope

This International Standard specifies a test method for measuring the heat-transfer of horizontally mounted flame-resistant textile materials when exposed to a combination of convective and radiant energy.

NOTE This test method may not correlate to the heat-insulative performance of vertically oriented flame-resistant textile materials when exposed to convective and radiant heat energy or used in actual clothing configurations.

This test method can be used for any type of sheet material used either as a single layer or in a multilayer construction when all structures or sub-assemblies are made of flame-resistant materials. It is not intended to be used on materials that are not flame resistant.

This test method is not intended for evaluating materials exposed to any other type of thermal-energy sources, such as radiant heat only or flame contact only. Use ISO 6942 when evaluating heat-transfer through materials due to radiant heat only and use ISO 9151 when evaluating heat-transfer through materials due to flame contact only.

This test method may not identify textile materials that can ignite and continue to burn after exposure to convective and radiant energy.

This International Standard should be used to measure and describe the properties of materials, products or assemblies in response to both convective and radiant energy under controlled laboratory conditions and should not be used to describe or appraise the fire hazard or fire risk of materials, products or assemblies under actual fire conditions. However, the results of this test method may be used as elements of a fire-risk assessment which takes into account all of the factors which are pertinent to an assessment of the fire hazard of a particular end-use.

2 Normative references

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

ISO 139, *Textiles — Standard atmospheres for conditioning and testing*

ISO 6942, *Protective clothing — Protection against heat and fire — Method of test: Evaluation of materials and material assemblies when exposed to a source of radiant heat*

ISO 9151, *Protective clothing against heat and flame — Determination of heat transmission on exposure to flame*

3 Terms and definitions

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

3.1
break-open
formation of a hole in the material during thermal exposure

3.2
burn injury
burn damage which occurs at various levels of depth within human tissue

NOTE Burn injury in human tissue occurs when the tissue is heated and kept at an elevated temperature for a critical period of time. The amount of burn injury, first, second or third degree, depends upon both the level of the elevated temperature and the duration. The material performance in this International Standard is related to second-degree burn injury, and is determined by the amount of thermal energy transferred through the specimen which is sufficient to cause a second-degree burn. A second-degree burn injury involves the epidermis/dermis interface.

3.3
charring
formation of carbonaceous residue as the result of pyrolysis or incomplete combustion

3.4
dripping
material response shown by flow of the material and formation of falling droplets

3.5
embrittlement
formation of a brittle residue as the result of pyrolysis or incomplete combustion

3.6
exposure energy
incident energy
maintained thermal energy that is incident to the test specimen

3.7
exposure time
total time over which the exposure energy is applied to the test material

3.8
heat flux
thermal intensity indicated by the amount of energy transmitted per unit area and per unit time

NOTE Heat flux is expressed in kilowatts per square metre (kW/m^2).

3.9
heat-transfer index-thermal
HTI-T
time, in seconds, to cause a temperature rise of the copper sensor by 12 °C and 24 °C from a combined convective and radiant heat (thermal) exposure

NOTE The time to cause a 12 °C temperature rise is indicated with a subscript of 12, and that for a 24 °C rise with a subscript of 24, e.g. HTI-T_{12} and HTI-T_{24}. The relative value between these two indices indicates the characteristic of the heat-transfer. If HTI-T_{24} is twice that of HTI-T_{12}, the rate of heat-transfer is constant. If HTI-T_{24} is greater than twice that of HTI-T_{12}, the rate of heat-transfer is increasing, showing a loss in insulation performance. If HTI-T_{24} is less than twice that of HTI-T_{12}, the rate of heat-transfer is decreasing, showing increasing insulation performance.

3.10
heat-transfer burn intersection
point at which the thermal energy transferred through the material intersects the point on a Stoll Curve where a second-degree burn injury is predicted to take place

3.11
heat-transfer burn time
time from the start of the thermal exposure to heat-transfer burn intersection

NOTE Heat-transfer is measured using a copper calorimeter as the sensor. The sensor diameter is large enough to average the heat received through the exposed specimen. The sensor thickness causes the temperature rise of the sensor to be similar to that of human tissue when exposed to heat. The sensor is painted a dull black to cause it to receive radiant energy with a coefficient of absorption similar to human tissue.

3.12
human-tissue heat tolerance
amount of thermal energy transferred to human tissue which predicts a reaction in human tissue, such as a pain sensation or a second-degree burn

NOTE The tolerance of human tissue to heat exposure was developed by Stoll et al. (see Table 1) and is referred to as the Stoll Curve. It is used in this method as the heat-transfer criteria in determining the thermal-threshold index (TTI) value of the test material.

3.13
ignition
initiation of combustion

3.14
inherent flame resistance
flame resistance that derives from the essential characteristics of the fibre from which the textile is made

3.15
melting
liquefaction of a material when exposed to heat resulting in a non-reversible change

3.16
response to heat exposure
observable response of the textile to the energy exposure as indicated by break-open, melting, dripping, charring, embrittlement, shrinkage, sticking or ignition

3.17
shrinkage
decrease in one or more dimensions of an object or material

3.18
sticking
response evidenced by softening of a material and adherence of one material to the surface of itself or another material

3.19
Stoll curve
relationship between the amount of thermal energy transferred to human tissue and the time of exposure which predicts a second-degree burn in human tissue

See Table 1.

3.20
thermal-threshold index
TTI
time, in seconds, for the heat transmitted through a material to just cause a second-degree burn in human tissue

4 Principle

A flame-resistant specimen, mounted in a static horizontal position is placed a specific distance from a combined convective/radiant heat source and exposed until sufficient heat energy passes through the specimen to cause the equivalent of a second-degree burn injury in human tissue, or indicate a temperature rise of 24 °C in the sensor.

The specimen is mounted either in contact with the sensor, designated as contact configuration, or with a 6,5 mm space between the specimen and the sensor, designated as spaced configuration.

The test exposure is composed of convective energy supplied by two gas burners, and radiant energy from nine quartz radiant tubes.The combined total energy of the exposure is calibrated using a total calorimeter and radiometer combination.The total energy exposure is then confirmed with the copper sensor.

The amount of heat transferred by the specimen is measured with a heat sensor and analysed by one of the following two methods.

— The heat transferred may be compared with times for 12 °C and 24 °C temperature rises in the sensor to determine the heat transfer index (HTI) of the specimen to indicate the thermal insulation performance. The rate at which the temperature of the heat sensor rises is a direct measurement of the heat energy transferred.

— The heat transfer may also be compared with the times for the heat energy transferred through the specimen to cause a second-degree burn, the thermal threshold index (TTI), as based on human-tissue tolerance data.

The effect of the exposure on the physical appearance of the specimen can also be noted.

5 Apparatus

5.1 General, the test apparatus shall consist of

— a thermal-flux source,

— a specimen holder support,

— a protective shutter,

— a specimen holder assembly, and

— a sensor assembly.

The apparatus shall also have a gas supply, gas rotameter and recorder. A diagram of the test apparatus is provided in Figure 1.

See Annex A for possible suppliers.

5.2 Thermal-flux source, consisting of a convective thermal-flux source and a radiant thermal-flux source. The convective thermal-flux source shall consist of two Meker or Fisher burners affixed beneath the opening of the specimen holder assembly opening, and subtended at a nominal 45° angle from the vertical so that the flames converge at a point immediately beneath the specimen. The radiant thermal-flux source shall consist of nine quartz T-500 infrared tubes affixed beneath and centred between the burners as shown in Figure 1. The burners shall be Meker or Fisher burners with a 40 mm diameter top and with an orifice size appropriate to the gas used.

5.3 Specimen holder support, consisting of a steel frame that rigidly holds and positions, in a reproducible manner, the specimen support frame and specimen relative to the thermal-flux.

5.4 Protective shutter, placed between the thermal-flux source and the specimen. The protective shutter shall be capable of completely dissipating the thermal load from the thermal-flux source (usually by means of water cooling) for the time period before and after each specimen exposure. A microswitch shall be connected to the shutter or manually operated to indicate the start of the exposure to the chart recorder or computer.

5.5 Specimen mounting plate, consisting of a piece of steel 150 mm square and 1,6 mm thick, with a 100 mm square hole in its centre. Angles of 6,5 mm shall be welded to each corner perpendicular to the plane of the plate (see Figure 2).

5.6 Specimen holding plate, 149 mm × 149 mm × 15 mm thick metal with a 130 mm × 130 mm centred square hole. The spacer and sensor assembly shall fit without binding into the hole of the specimen holding plate.

5.7 Spacer, 128 mm × 128 mm × 6,4 mm (0,25 in) thick metal with a 110 mm × 110 mm centred square hole.

5.8 Sensor assembly, a copper calorimeter assembled in a mounting block.

The assembly consists of the following components.

— Copper-disc calorimeter, consisting of a disc of copper of at least 99 % purity, having a diameter of 40 mm and thickness of 1,6 mm with three thermocouples connected as specified in Figure 3.

— Calorimeter mounting block consisting of a 128 mm × 128 mm square piece of asbestos-free noncombustible heat-insulating board of nominal thickness 13 mm machined as specified in Figure 4.

— The calorimeter disk shall be bonded in position around its circumference with an adhesive capable of withstanding temperatures of about 200 °C. The face of the copper disk shall be flush with the surface of the mounting block. The face of the copper disc shall also be coated with a thin layer of flat black paint by spraying.

— The complete sensor assembly, including the copper calorimeter shall be uniformly weighted such that it weighs (1 000 ± 10) g in total.

5.9 Recorder, any strip-chart recorder with a full-scale deflection of at least 150 °C or 10 mV and sufficient sensitivity and scale divisions to read the sensor response to 1 °C or 0,05 mV and exposure time to ± 0,1 s (a chart speed of 12 mm/s is satisfactory). Alternatively, an equivalent automated data-acquisition system meeting or exceeding the sensitivity and accuracy requirements of the strip-chart recorder shall be permitted to be used instead of a strip-chart recorder.

5.10 Gas supply, propane, methane or natural gas with appropriate reducer and valving arrangements to control the gas-supply pressure at (55 ± 1) kPa and capable of providing a flow equivalent to 2 l/min air at standard conditions (conditions are set for air and then an appropriate gas is used at those settings).

5.11 Gas rotameter, any gas rotameter with a range which gives flow equivalent to 2 l/min air at standard conditions.

5.12 Radiometer, a Gardon-type radiation transducer with a diameter of 25 mm, a minimum 150° view angle, and a heat flux operating range from 0 kW/m^2 to 80 kW/m^2. If the radiometer is water cooled, the cooling-water temperature shall be above the ambient dew-point temperature (for the laboratory environment).

5.13 Solvent, acetone or petroleum, to clean the sensor.

WARNING — Exercise care in using these solvents around heat sources.

6 Precautions

Perform the test in a hood or ventilated area to exhaust the combustion products, smoke and fumes. When currents disturb the flame, shield the apparatus or turn off the hood while running the test; turn the hood on to clear fumes following a test.

Exercise care in handling materials around the quartz tubes or the burner with the open flame.

Maintain adequate separation between heat sources and combustible materials (e.g. cleaning solvents).

The specimen holder and sensor assembly become heated during prolonged testing. Allow to cool or use protective gloves when handling these hot objects.

Some test specimens may be hazardous when exposed to direct flames. Take care if the specimen ignites or releases combustible gases.

Shut off the gas supply at the cylinder and allow the flame to burn the gas from the lines when testing is completed.

7 Sampling

7.1 Specimen dimensions

Cut each specimen, (150 ± 2) mm × (150 ± 2) mm, with two of the sides parallel to the machine direction of the material, where known, for all layers and include all layers representative of the clothing item to be tested.

7.2 Number of specimens

A minimum of three specimens shall be tested for each material or assembly of materials.

8 Conditioning and testing atmospheres

8.1 Conditioning atmosphere

Prior to testing, the specimens shall be conditioned for at least 24 h at a temperature of (20 ± 2) °C and a relative humidity of (65 ± 2) % in accordance with ISO 139. If testing is not carried out immediately after conditioning, place the conditioned specimens in a sealed container. Begin the testing of each specimen within 3 min of removing it from the conditioning atmosphere or sealed container.

8.2 Testing atmosphere

Perform the test in an atmosphere having a temperature of 10 °C to 30 °C and a relative humidity of 15 % to 80 % and which is free from draughts.

9 Test procedure

9.1 Calibration procedures

9.1.1 Regulation of radiant-energy exposure

Set the rheostat on the radiant exposure to yield (55 ± 2) V input to the radiant tubes for a radiant heat flux of (40 ± 10) kW/m^2. Allow the unit to preheat for at least 30 min before continuing the exposure calibration.

9.1.2 Regulation of convective-energy-test exposure

Adjust the heat flux of the total combined exposure to (80 ± 2) kW/m^2 by setting the gas flow through the rotameter and adjusting the flame with the needle valve in the base of the burners. Adjust for a low gas flow to prevent placing the hottest portion of the flame above the sensor. The correct convective exposure results from a flame with a clearly defined stable blue tip firmly positioned on the burner grid, with a larger diffuse blue flame of approximately 150 mm height measured along the axis of the flame beyond the burners.

9.1.3 Regulation and adjustment of exposure energy

Confirm the total exposure level of the combined convective and radiant energy source by measuring the total heat flux. Mount a total calorimeter/radiometer combination (5.12) in the centre and flush with the surface of an insulating block similar to the one used to hold the copper sensor. Connect the output of these sensors to a recorder or data acquisition unit capable of reading the output of the sensors.

With the water cooled shutter in position over the burners and radiant tubes, place the specimen holder, without a specimen, on its support and place the total calorimeter/radiometer combination on top of the holder, with the calorimeter facing down. Retract the shutter to expose the calorimeter/radiometer directly to the combined exposure energy.

Record the output of the total calorimeter/radiometer combination. Simultaneously adjust the gas flow to the burners, and the voltage to the quartz tubes to achieve a total heat flux of (80 ± 2) kW/m^2 for the exposure energy, and half of that amount for the radiant component.

To prevent overheating and damage, do not expose the total calorimeter/radiometer for longer than 20 s.

CAUTION — Because radiant energy is generated by both the flame portion of the exposure and the radiant tubes, do not adjust the quartz-tube radiant component without the presence of the flames.

9.1.4 Confirmation of total exposure energy using the copper sensor

After the total and radiant energy exposure levels have been set to the required level using the total calorimeter/radiometer combination, confirm the total exposure energy level with a copper calorimeter sensor. If a computer is used, design the program to determine the total heat energy using the technique described below.

The total-exposure-energy level must be confirmed using the same sensor which is used to measure the heat transferred through the specimen to eliminate errors introduced by using two different sensors for the exposure energy and the heat transfer. Alternatively, use a matched pair of calorimeters that provide results that are within 2 % of each other. Differences in the readings between the copper calorimeter and the combination total/radiant calorimeter of greater than 5 % must be reconciled. Annex B provides the basis of this procedure and information about determining adequate performance for the calibration calorimeter.

With the water-cooled shutter in position over the burners and radiant tubes, place the specimen holder, without the specimen, on its support and place the sensor on top of the holder with the blackened face of the calorimeter facing down. Then retract the shutter to expose the sensor directly to the total exposure energy from the combined convective and radiant sources.

Record the response of the sensor for at least 10 s and identify the initial portion of the curve with a linear (straight line) response. Extend this straight-line portion of the curve for at least 10 s of response and take sensor readings for the 0 s and 10 s times. Subtract the 0 s reading from the 10 s reading to obtain the increase. The response should be (148 ± 3,7) °C equivalent to a flux of (80 ± 2) kW/m^2. At the end of each exposure, to ensure accuracy of results, close the shutter to dissipate all the energy.

After each exposure, cool the sensor to less than 38 °C or 1,0 mV before the next heat-flux determination.

9.2 Sensor care

9.2.1 Initial temperature

Cool the sensor after exposure with a jet of air or by contact with a cold, dry surface. Reheat the sensor to approximately body temperature by contact with the palm of the hand just prior to positioning over the test specimen. Do not adjust the zero setting of the recorder.

9.2.2 Acceptability of sensor

If the measurement from the tested copper calorimeter does not agree within ± 4 kW/m^2 of the measurement of the calibration calorimeter, the tested copper calorimeter shall be repaired, reconditioned or replaced to achieve agreement.

9.2.3 Sensor repair

The copper disk may be removed from its support board and checked to ensure that all thermocouple-to-disk connections are securely made. Any loose connections should be repaired. To repair loose connections, the thermocouple data-transfer wire should be removed, while leaving the short thermocouple wires extending from the sensor's back side. The sensing surface should be smoothed, cleaned and repainted with a high-quality flat black paint of known emissivity, with a value of no less than 0,95. It may take two or three light coats to completely and evenly cover the surface. After the paint has thoroughly dried, the finished calorimeter should be carefully weighed, and its total mass recorded to an accuracy of 0,01 g. The total mass should include the copper-disk mass with the short thermocouple wires attached, and also includes the mass of flat black paint applied to the calorimeter's surface. The calorimeter's finished mass should be determined by subtracting the sensor's thermocouple-wire mass from the sensor's total mass. This is accomplished by measuring the sensor's thermocouple-wire lengths from their ends down to the calorimeter's back surface. Then the total wire mass should be calculated based on the number of wires and their lengths. This value should then be subtracted from the total mass of the calorimeter assembly to obtain the finished mass. After the finished mass is determined, the data-transfer wires should be securely reconnected, and the sensor repositioned in its support board.

9.2.4 Surface reconditioning

Wipe the sensor face, while hot, immediately after each run, using a soft wiping cloth or paper towel to remove any decomposition products which condense and could be a source of error. If a deposit collects and appears to be thicker than a thin layer of paint, or is irregular, the sensor surface requires reconditioning. Carefully clean the cooled sensor with acetone or petroleum solvent, making certain there is no ignition source nearby. If bare copper is showing, repaint the surface with a thin layer of flat black spray paint. Perform at least one calibration run before using a reconditioned sensor in a test run.

9.3 Specimen holder care

Use dry specimen holders, at room temperature, for each test run. Alternate with several sets of holders or cool with water and then dry, or cool with forced air. When required, clean condensed tars and soot from holders with acetone or a petroleum solvent as in 9.2.2.

9.4 Preparation of heat transfer/burn intersection overlay

9.4.1 Strip chart recorder

On recorder chart paper, plot the sensor equivalent from Table 1 which corresponds to the recorder scale, with ΔT °C or ∆mV (columns 4 or 5 of Table 1) on the vertical axis and the corresponding time (column 1) on the horizontal axis. Use chart units based on the recorder full-scale deflection and the chart speed for a graph directly comparable to the recorder sensor trace. If the pen deflection is from left to right and the paper moves downwards, plot from right to left with the origin at lower right. If the recorder trace differs, adjust the graph accordingly. Make an exact transparent duplicate for the over-lay. Compare the overlay with the original to ensure no change in the overlay size as a result of the copying process.

9.4.2 Computer processing of data

The information provided in Table 1 may be used as the criteria of performance in the software of a computer program. In this case, the sensor response is compared with the human-tissue heat-tolerance criteria to determine the heat-transfer burn intersection. The product of the heat-transfer burn time and the exposure-energy heat flux is the TPI. The report includes a plot of the heat-sensor response for each specimen.

9.5 Test specimen mounting

9.5.1 Single-layer specimens

Test materials, used primarily as a single layer in an application, may be tested in the contact configuration or the spaced configuration.

In the contact configuration, the sensor is positioned in contact with the specimen.

In the spaced configuration, a 6,4 mm (0,25 in) thick spacer is positioned between the sensor and the specimen.

Centre the specimen on the mounting plate with the surface that will be the inside facing up.

9.5.2 Multilayer assembly specimens

Test materials used in a multilayer assembly shall be tested with the sensor in contact with the backface of the assembly. This condition measures the barrier characteristic of the surface material and the insulation characteristics of the total assembly.

Place the surface of the material to be used as the outside of the assembly face down on the mounting plate. Place the subsequent layers on top in the order and position used in the assembly, with the inside surface facing up, to form the specimen-holder assembly. The sensor will later be placed directly on the specimen in contact with this surface.

9.6 Test-specimen exposure

9.6.1 Place the specimen-holder assembly (9.5.1 or 9.5.2) on the support, and position the sensor on the assembly with the black surface facing downward. Place the sensor weight on top of the sensor to secure the specimen.

9.6.2 Start the chart movement on the recorder. Retract the shutter to start the exposure. Indicate the start of the exposure (chart recorder or computer). Continue until the sensor response exceeds the human-tissue heat-tolerance criteria of a second-degree burn, which is equal to a sensor temperature rise of 35 °C to 40 °C or 1,7 mV to 2,0 mV. When the physical response of several specimens are to be compared, maintain the same exposure time for all specimens.

9.6.3 The exposure begins when the shutter is retracted and can be indicated on the recorder chart with an event marker connected to a microswitch that is closed by hand, foot, or opening of the water cooled-shutter. Other effective indicators to show that the shutter is retracted include

a) a permanent mark on the same time line as the recorder pen,

b) switching the recorder scale, or

c) momentarily lifting the pen.

The start of the exposure should be an input to the computer program, if used.

9.6.4 Close the shutter, stop the recorder and remove the sensor weight. Remove the sensor and start cooling it. Remove the specimen holder and allow it to cool.

9.6.5 Remove the specimen from the holder and examine it as directed in 10.4.

9.6.6 Test the remaining specimens.

10 Expression of results

10.1 Selection of analysis method

The heat transferred through the specimen to the sensor may be analysed by either, or both, of two methods. The performance of protective clothing is evaluated with either the thermal-threshold index or the heat-transfer index.

10.2 Thermal-threshold index (TTI) analysis method

10.2.1 Heat-transfer burn time

Graphically determine the heat-transfer burn time, from the start of the exposure to the burn-injury threshold, using the recorder chart of the sensor response and the heat transfer/burn overlay prepared in 9.4. Position the overlay on the recorder chart, matching the zero of the overlay with the exposure start. Place the horizontal axis (time) in line with the initial trace of the pen. Keep the overlay square with the recorder chart. Read the heat-tolerance time to the nearest 0,1 s from the overlay chart when the sensor-response curve and the human-tissue heat-tolerance curves cross. If a computer software program is used, the sensor response should be compared with the data describing the human-tissue heat tolerance to determine like values. The time from the start of the exposure to the time when these values are the same is the heat-transfer burn time.

Calculate the average heat-transfer burn time of all the specimens tested for the same material or material assembly.

10.2.2 Thermal-threshold index

Calculate the thermal-protection index, to the nearest 1 kWs/m^2, using Equation 1:

$$\text{TTI} = F \times T \qquad (1)$$

where

TTI is the thermal-protection index, in kilowatt seconds per square metre;

F is the exposure heat flux (from 9.1.4), in kilowatts per square metre;

T is the heat-transfer burn time, in seconds.

Calculate the average TTI of all specimens tested for the same material or material assembly.

10.3 Heat-transfer index (HTI) analysis method

10.3.1 Time for heat transfer to cause a 12 °C and 24 °C temperature rise

Graphically determined the time for heat transfer to cause a 12 °C and 24 °C temperature rise in the heat sensor. Determine the starting temperature of the sensor from the recorder chart and add the values of 12 °C and 24 °C. Identify the points on the heat-transfer curve on the recorder chart which equal these values. Determine the time required from the start of the exposure to the 12 °C and 24 °C sensor temperature-rise points to the nearest 0,1 s. If a computer software program is used, the time for the sensor temperature-rise to equal 12 °C and 24 °C should be determined to the nearest 0,1 s.

Calculate the average time for heat transfer to cause a 12 °C and 24 °C temperature rise of all specimens tested for the same material or material assembly.

10.3.2 Heat-transfer index

Calculate the heat-transfer index, to the nearest 1 kWs/m^2, using Equation (2).

$$\text{HTI}_x = F \times t_x \qquad (2)$$

where

HTI is the heat-transfer index, in kilowatt seconds per square metre;

F is the exposure heat flux (from 9.1.4), in kilowatts per square metre;

t_x is the heat-transfer time, in seconds to x °C;

x is the 12 or 24.

Calculate the average HTI at 12 °C and 24 °C of all specimens tested for the same material or material assembly.

10.4 Response to convective and radiant heat exposure

Test operators may optionally provide observations on the condition of the test specimen following exposure, including on individual layers of a multilayer specimen. Specimens conditions include, but are not limited to, the following: break open, charring, dripping, embrittlement, ignition, melting, shrinkage, sticking.

11 Interlaboratory test data

See Annex C.

12 Test report

The test report shall contain the following information:

a) name of the test laboratory;

b) date of report;

c) reference to this International Standard;

d) identification reference of the material or material assembly tested;

e) description of the test materials and the arrangement in which they were tested (for multilayer specimens), if possible, details of generic names, mass per unit area and thickness at a pressure of 3,4 kPa;

f) the conditions of testing, including the type of gas used, calibrated exposure energy, and the specimen/sensor configuration, contact or spaced;

g) the method of heat transfer analysis used;

h) if the thermal-protection-index analysis was used, the heat-transfer burn time and the TPI for each specimen and the average for all specimens;

i) if the heat-transfer-index analysis was used, the time for the heat transfer to cause a temperature rise of 12 °C and 24 °C and the HTI_{12} and HTI_{24} for each specimen, and the average for all specimens;

j) if desired, the observations of the effect of exposure energy on each specimen;

k) a statement as follows: “These results have been obtained by a test method intended to solely rank the material or material assembly and are not necessarily applicable to actual fire or flashover conditions”.

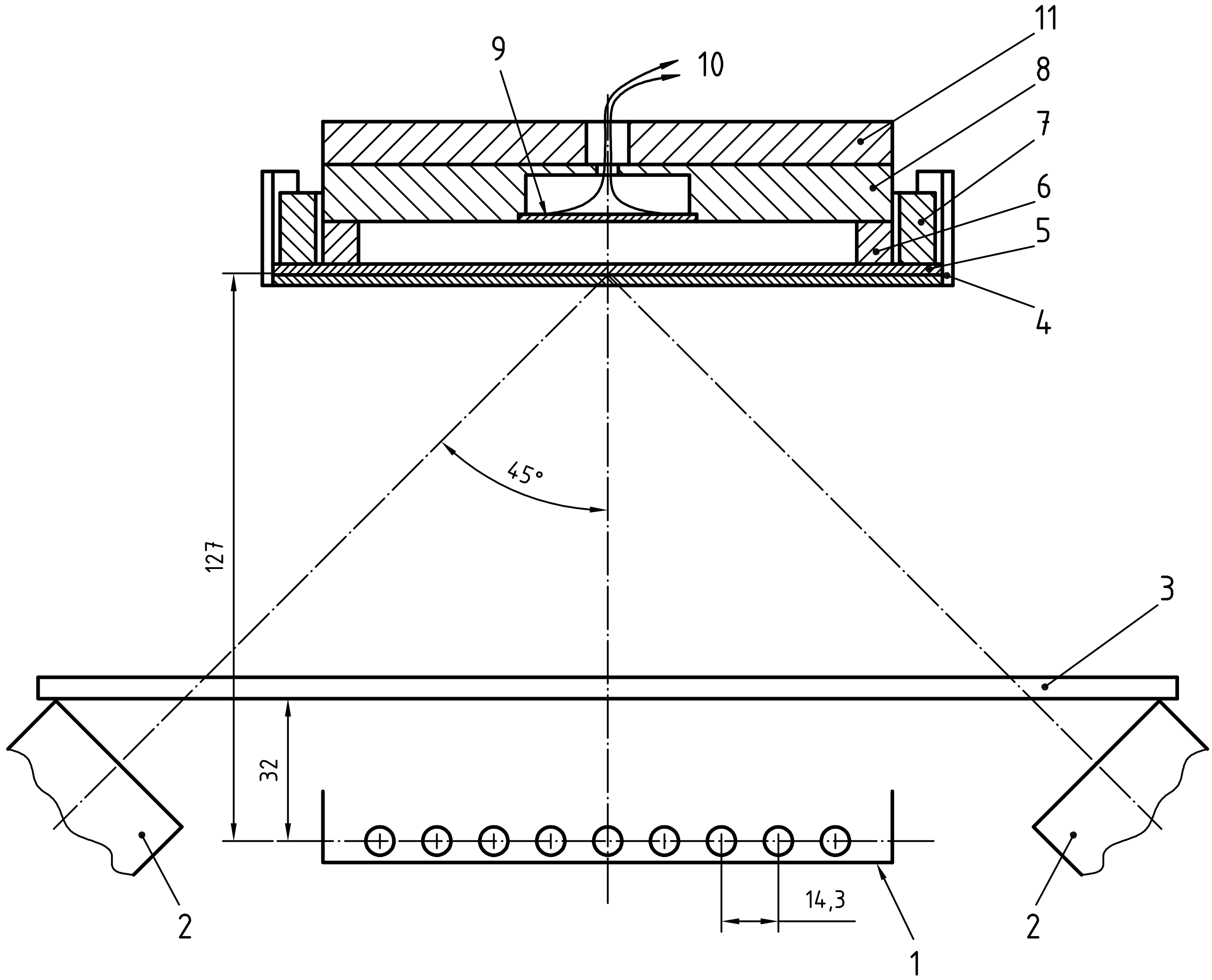
Table 1 — Human-tissue[a] tolerance to second-degree burn

Exposure time s	Heat flux[a] kW/m^2	Total heat kW s/m^2	Calorimeter[b] equivalent ΔT °C	 ΔmV
1	50	50	8,9	0,46
2	31	61	10,8	0,57
3	23	69	12,2	0,63
4	19	75	13,3	0,69
5	16	80	14,1	0,72
6	14	85	15,1	0,78
7	13	88	15,5	0,80
8	11,5	92	16,2	0,83
9	10,6	95	16,8	0,86
10	9,8	98	17,3	0,89
11	9,2	101	17,8	0,92
12	8,6	103	18,2	0,94
13	8,1	106	18,7	0,97
14	7,7	108	19,1	0,99
15	7,4	111	19,7	1,02
16	7,0	113	19,8	1,03
17	6,7	114	20,2	1,04
18	6,4	116	20,6	1,06
19	6,2	118	20,8	1,08
20	6,0	120	21,2	1,10
25	5,1	128	22,6	1,17
30	4,5	134	23,8	1,23

[a] See [1] in the Bibliography.

[b] Iron/constantan thermocouple.

Dimensions in millimetres



Key

1 radiant thermal flux source
2 Meker or Fisher burner
3 water-cooled protective shutter
4 specimen mounting plate
5 test fabric
6 spacer (if used)
7 specimen holding plate
8 sensor assembly
9 copper calorimeter
10 thermocouple wires to recorder or computer
11 weight

NOTE The specimen holder support is not shown.

Figure 1 — Diagram test apparatus

Dimensions in millimetres

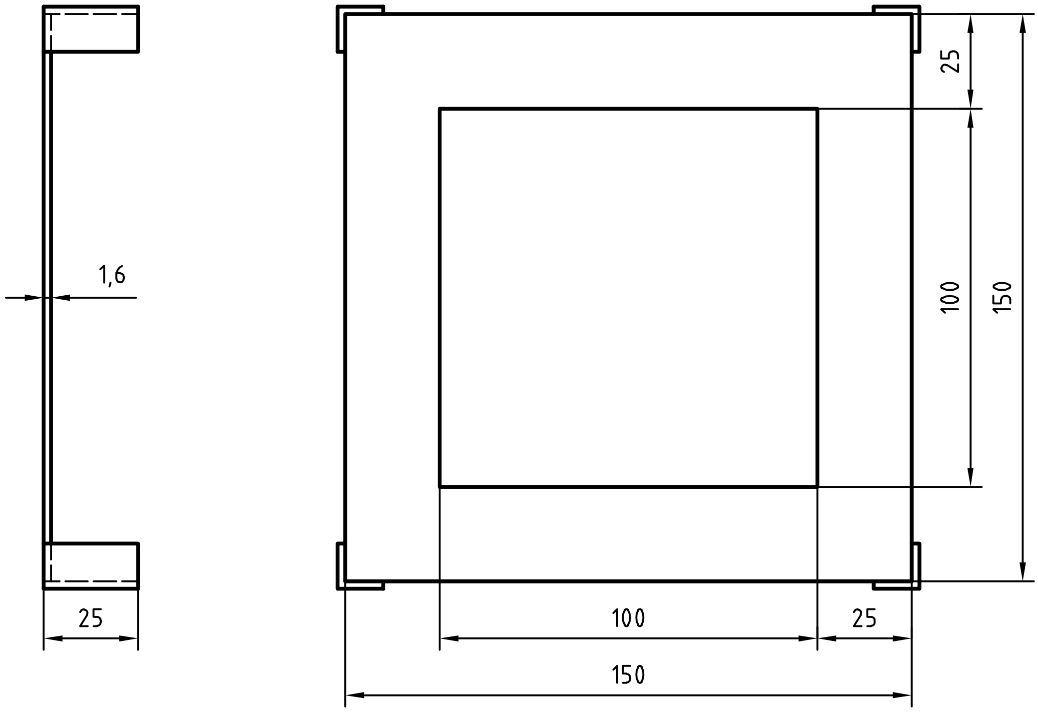
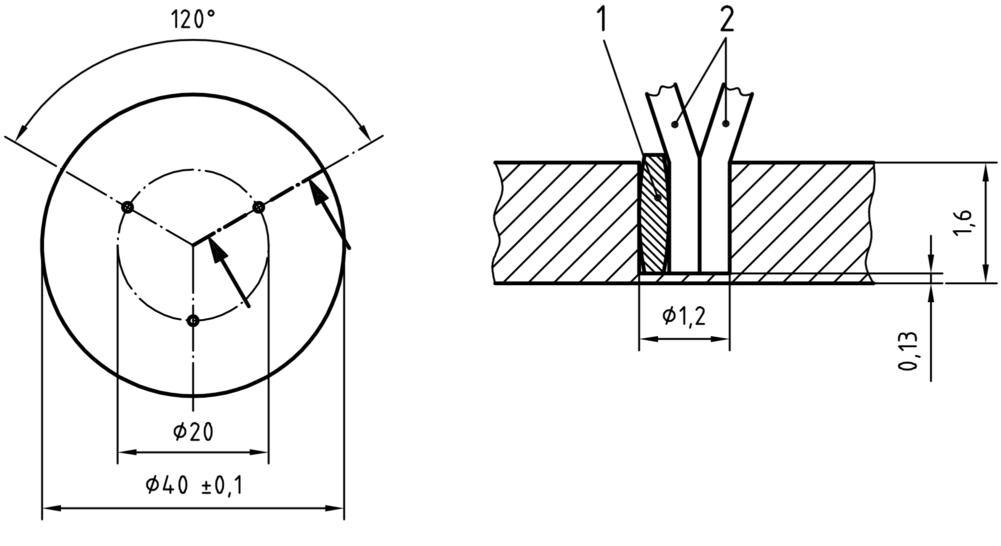


Figure 2 — Specifications for specimen mounting plate

Dimensions in millimetres



Key

1 18 gauge copper plug used to secure thermocouples within hole

2 30 gauge thermocouple wires secured in hold with copper plug (item 1)

Figure 3 — Calorimeter

Dimensions in millimetres

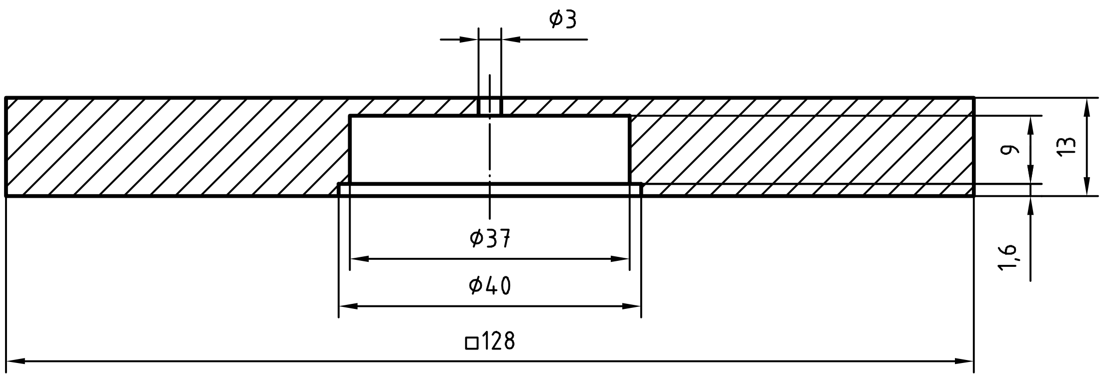


Figure 4 — Calorimeter mounting block

Annex A
(informative)

Availability of materials

The following are examples of possible suppliers for materials specified in this International Standard. Equally suitable alternatives are available from other suppliers. This information is given for the convenience of users of this International Standard and does not constitute an endorsement by ISO of these products.

Test apparatus (Clause 5)

Alan Swain/Rick Williams
Wilmington, DE USA
(++1-302-292-1409)

Black paint for sensor assembly (5.8)

Medtherm flat black paint having an absorptivity of 0,96 and temperature rating of 182 °C (350 °F) available from:

Medtherm Corporation
P. O. Box 412
Huntsville, AL 35804, USA
(1-205-837-2000).

Combination total calorimeter/radiometer (5.12)

Model 64P-5-24
Medtherm Corporation
P. O. Box 41
Huntsville, AL 35804, USA
(1-205-837-2000)

Annex B
(informative)

Basis of sensor calibration

The calibration of the copper calorimeter is based on the following equation:

$$I = 4{,}184 \times \left(\frac{m \times C}{K \times A_{\varepsilon}} \right) \times \left(\frac{\mathrm{d}T}{\mathrm{d}t} \right)$$

where

I	is the incident heat flux, in watts per square centimetre;
4,184	is the conversion factor, calories per square centimetre second to watts per square centimetre;
$\mathrm{d}T/\mathrm{d}t$	is the rate of temperature rise for the calorimeter indicated by millivolts per degree Celsius;
$m \times C/K \times A_{\varepsilon}$	represents the calorimeter's physical constant which includes the variables A, ε and m;
m	is the finished mass, in grams, of the calorimeter, which includes the copper disk and flat black paint mass on the sensing surface minus the thermocouple mass;
C	is the heat capacity of pure copper which is 0,092 7 cal/g °C;
K	is the thermocouple conversion constant (0,053 mV/°C) for the Type J iron-constantan thermocouple at an average test temperature of 65 °C;
A	is the surface area (12,49 cm^2) for the calorimeter's front surface which is exposed to the test heat flux;
ε	is the emissivity or absorptivity of the black paint used on the calorimeter's front surface, usually with a value not less than 0,95. The physical constant used in calibration calculations with these sensors is sensitive to changes in mass and/or emissivity values.

For the copper-disk calorimeter used in this test, the punched out and drilled copper slug mass must be between 17,5 g and 18,0 g to meet the temperature rise over the 10 s rate requirement. The calorimeter's physical constant can be calculated based on the above discussion. Check the repaired calorimeter's performance by substituting it with the calibration calorimeter. After proving equivalence, the test calorimeter may be put back into service.

Annex C
(informative)

Interlaboratory test data

A total of three assemblies of materials components were tested by seven different laboratories.

Component assembly A consisted of a 254 g/m^2 woven Kevlar/PBI[1)] outer material, with a 132 g/m^2 permeable film on Nomex E89[1)] moisture barrier, and 275 g/m^2 innermost lining consisting of Nomex III[1)] face cloth and batting.

Component assembly B consisted of a 254 g/m^2 woven Nomex IIIA[1)] outer material, with a 331 g/m^2 impermeable film on Nomex E89[1)] moisture barrier, and 315 g/m^2 innermost lining consisting of Nomex III[1)] face cloth and batting.

Component assembly C consisted of five layers of 203 g/m^2 woven Nomex material.

Table C.1 provides the individual laboratory measurements for the component assembly TTI.

Table C.1 — Interlaboratory test data

Component assembly	Measurement	TTI Laboratory							Average[a]
		1	2	3	4	5	6	7	
A	Average	19,2	20,7	20,7	19,4	22,2	18,4	20,1	20,1
	Standard deviation	0,3	0,6	0,4	0,6	0,4	0,4	0,2	1,1
B	Average	24,6	24,8	25,4	24,3	25,9	23,4	25,4	24,8
	Standard deviation	0,3	0,5	0,5	0,6	0,9	0,4	0,5	0,8
C	Average	20,9	20,6	19,5	18,2	20,7	15,9	17,8	19,1
	Standard deviation	0,2	0,8	0,3	0,5	0,4	0,1	0,1	1,7

[a] The average standard deviation is the interlaboratory standard deviation.

1) Kevlar/PBI, Nomex E89, Nomex IIIA and Nomex III are examples of suitable products available commercially. This information is given for the convenience of users of this International Standard and does not constitute an endorsement by ISO of these products.

Bibliography

[1] STOLL, A.M. and CHIANTA, M.A., Method and Rating System for Evaluation of Thermal Protection. *Aerospace Medicine*, Vol. 40, 1968, pp. 1232-1238

[2] NFPA 1971:2000, *Standard on Protective Ensembles for Structural Fire Fighting*

ICS 13.340.10

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