INTERNATIONAL STANDARD

ISO 14624-2

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Space systems — Safety and compatibility of materials —

Part 2: Determination of flammability of electrical-wire insulation and accessory materials

Systèmes spatiaux — Sécurité et compatibilité des matériaux —

Partie 2: Détermination de l'inflammabilité des systèmes d'isolation des fils électriques, et des matériaux accessoires

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Foreword

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

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 14624-2 was prepared by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 14, *Space systems and operations*.

ISO 14624 consists of the following parts, under the general title *Space systems — Safety and compatibility of materials*:

— *Part 1: Determination of upward flammability of materials*

— *Part 2: Determination of flammability of electrical-wire insulation and accessory materials*

— *Part 3: Determination of offgassed products from materials and assembled articles*

— *Part 4: Determination of upward flammability of materials in pressurized gaseous oxygen or oxygen-enriched environments*

— *Part 5: Determination of reactivity of materials with aerospace propellants*

— *Part 6: Determination of reactivity of processing materials with aerospace fluids*

— *Part 7: Determination of permeability of materials to aerospace fluids*

Introduction

Throughout this part of ISO 14624, the minimum essential criteria are identified by the use of the imperative or the key word “shall”. Recommended criteria are identified by the use of the key word “should” and, while not mandatory, are considered to be of primary importance in providing serviceable, economical and practical designs. Deviations from the recommended criteria may be made only after careful consideration, extensive testing and thorough service evaluation have shown an alternative method to be satisfactory.

Space systems — Safety and compatibility of materials —

Part 2: Determination of flammability of electrical-wire insulation and accessory materials

1 Scope

This part of ISO 14624 specifies two test methods for determining the flammability of electrical-wire insulation and accessory materials by exposure to an external ignition source in a static environment (Test A) and in a gas-flow environment (Test B).

2 Conformance

The tests shall be performed in an accredited test facility (see Annex A for guidelines).

The authority having jurisdiction, or the test requester, shall provide properly identified material(s) for testing. Alternatively, accredited test facilities may be authorized by the test requester to procure the appropriate material(s).

3 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 14624-1, *Space systems — Safety and compatibility of materials — Part 1: Determination of upward flammability of materials*

4 Terms and definitions

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

4.1
burn length
maximum distance over which the insulation has been damaged due to flame impingement

NOTE This distance includes areas of partial or complete combustion, charring or embrittlement, but does not include areas which are sooted, stained, warped or discoloured, or areas where the insulation has shrunk or melted away from the heat.

4.2
self-extinguishing
phenomenon wherein the burn length of a wire insulation system is less than 150 mm when exposed to an external ignition source

4.3
transfer of burning debris
movement of burning particles from a burning specimen to adjacent materials

4.4
good laboratory practice
GLP
practice which involves the testing of standard reference materials to verify data accuracy and repeatability

4.5
worst-case environment
combination of test pressure, oxygen concentration and temperature that make the material most flammable

5 Test materials

The minimum quantities of materials required to perform each test properly are summarized in Table 1. Actual test configurations and material quantities for material forms other than those listed (e.g. sleeving, cable clamps, etc.) shall be established and approved by the responsible procuring activity/user materials organization.

Table 1 — Minimum quantities of materials required for testing for each atmosphere

Form of material	Test	Minimum quantity
Insulated wire	A	10 m in length
	B	7 m in length

As a minimum, all materials used in testing shall meet or exceed user specifications.

Material and configured-system characteristics can be significantly compromised by sources of contamination, such as exposure to solvents, cleaning agents, abnormal temperatures, variations in humidity, environmental pollutants, particulates and handling. It is important that exposure of test material(s) to these and other contamination sources be sufficiently controlled to minimize variation in test results.

6 Electrical-wire insulation flammability test in a static environment (Test A)

6.1 Principle

The purpose of this test (Test A) is to determine if wire insulation and accessory materials, when exposed to an external ignition source, will self-extinguish and will not ignite adjacent materials by the transfer of burning debris. Electrical-insulation accessories include electrical wire, sleeving, heat-shrinkable tubing, solder sleeves, bundle ties, cable clamps, identification tape, etc. For a wire insulation system to be considered self-extinguishing, the burn lengths of at least three standard-sized replicate specimens (diameter 0,90 mm) shall be less than 150 mm at an internal wire temperature of 125 °C or at the maximum operating temperature of the wire. In addition, the ignited specimens shall not propagate a flame by the transfer of burning debris. Failure of any one specimen constitutes failure of the material. These tests shall be conducted on specimens of insulation use thickness. The test conditions (total pressure, wire temperature and oxygen concentration) shall simulate the worst-case environment in which the insulation material is to be used. The configuration (for example, wire bundles) or the use of another wire gauge can cause a variation in the test results.

6.2 Reagents

6.2.1 Test gases, premixed before exposing the specimen to them and verified for conformity with the specification (including accuracy) for oxygen concentration to within $^{+1}_{0}$ %.

6.3 Test system

6.3.1 Test chamber, large enough so that complete combustion of the specimen can occur with no more than a 5 % relative depletion of oxygen concentration. In addition, the test chamber shall not interfere chemically or physically with the test. The free space above and below the test fixture shall be at least 200 mm.

6.3.2 Measuring devices, properly calibrated.

6.3.3 Chemical ignition source, meeting the following specifications under ambient conditions:

a) energy: 3 000 J;

b) temperature: 1 100 °C ± 90 °C;

c) burning duration: 25 s ± 5 s;

d) maximum visible flame height: 65 mm ± 6,5 mm.

Annex B provides a procedure for preparing, certifying and storing chemical ignitors.

Alternative ignition mechanisms may be utilized if they meet the requirements outlined in a) to d) above.

6.3.4 AC power supply, capable of providing 15 A (RMS), connected to a bare 20 AWG nickel-chromium wire (6.3.5) to initiate the igniter.

6.3.5 Bare nickel-chromium wire 0,90 mm in diameter, with a nominal resistivity of 2,3 Ω·m and of sufficient length to wrap three equally spaced turns around the chemical igniter.

6.3.6 Suitable specimen holder, capable of supporting the centre third of the wire or wire bundle from one top corner of the fixture to the opposite bottom corner of the fixture at an angle of 15° ± 2° to the vertical (see Figure 1).

6.3.7 Scale, attached to one side of the specimen holder, for measurement of the burn length.

6.3.8 Sheet of paper, mounted horizontally approximately 200 mm below the specimen holder, having the following characteristics:

a) dimensions: 216 mm × 280 mm;

b) mass of 1 000 sheets (size 650 mm × 770 mm): between 100 kg and 150 kg;

c) type: chemical wood index;

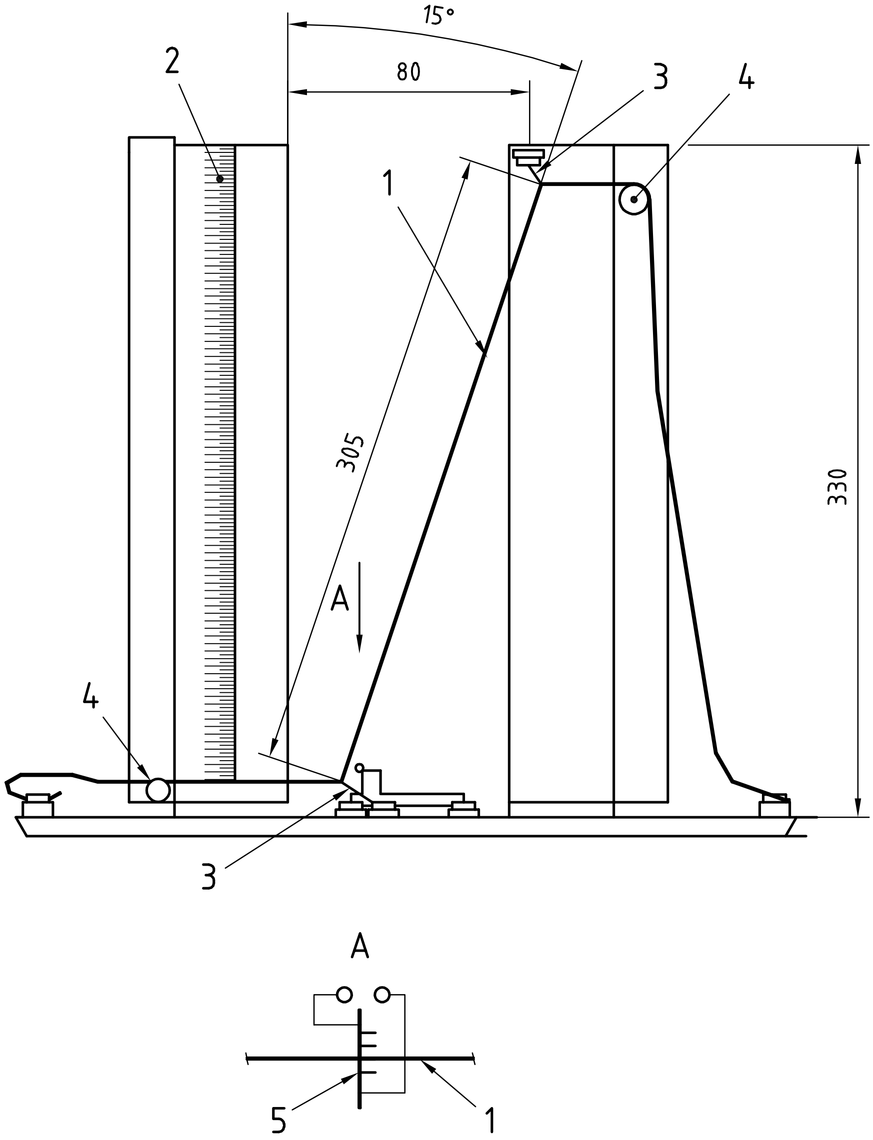
d) colour: uniformly white;

e) condition: clean, free from dirt spots, oil spots and foreign matter (lint, fuzz, etc.), free from holes, tears, cuts, folds and scuff marks, and containing no splices.

The sheet of paper is used to assess if burning debris from the specimen would cause ignition of adjacent materials.

6.3.9 DC power supply, capable of providing a regulated DC current (150 A maximum) to the conductor of the test specimen at the level required to reach the specified internal wire temperature.

Dimensions in millimetres



Key

1 specimen
2 scale
3 insulating ceramic-fibre thread
4 ceramic insulator
5 ignitor

Figure 1 — Standard specimen holder and specimen configuration

6.4 Test specimens

6.4.1 Reception and inspection of material

6.4.1.1 Receive and visually inspect the test material: when received, it shall be accompanied by proper identification. Any flaws shall be noted. Specimens should have been cleaned and dried to the end-use specifications prior to receipt at the test facility.

6.4.1.2 If required, prepare specimens to the proper dimensions.

6.4.1.3 If specimens are received with obvious contamination, clean them. All cleaning methods shall be approved by the test requester prior to use. Surface contamination should be removed by washing with deionized water and mild detergent, rinsing with deionized water and drying with filtered nitrogen gas. As a minimum, particulates on the surfaces of solid porous specimens should be removed with filtered nitrogen gas.

6.4.1.4 After preparation and/or cleaning at the test facility, inspect the specimens and note any flaws and any residual contamination. If the flaws result from specimen preparation at the test facility, new specimens shall be prepared. Specimens shall be weighed and individually identified.

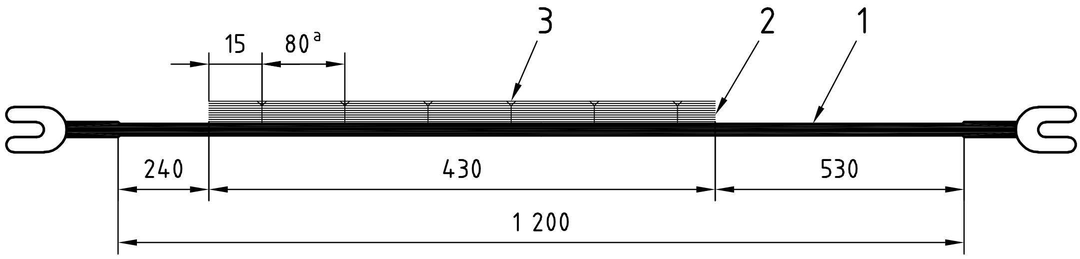
6.4.2 Preparation of test specimens

6.4.2.1 To prepare a standard test specimen, cut a single conductor to a length of 1,2 m and remove 10 mm of insulation from each end of the wire using an appropriate wire stripper. Attach appropriate non-insulated crimp spade lugs to the ends of the wire.

6.4.2.2 To prepare an optional variation of the standard test specimen using a multiwire configuration, cut out six additional wires of length 430 mm. Place the active conductor on the perimeter of the multiwire configuration. Lace the active conductor and the six additional wires tightly together using appropriate non-flammable wire ties placed 80 mm apart (see Figure 2).

6.4.2.3 Duplicates of actual-use electrical harnesses and accessories, with or without connections, may be used in lieu of the specimen described in 6.4.2.2. Mating connections shall be supplied where applicable.

Dimensions in millimetres



Key

1 active conductor
2 wire bundle
3 wire tie

[a] Typical distance.

Figure 2 — Optional wire bundle configuration

6.5 Procedure

WARNING — Burning of materials may produce smoke and toxic gases, which can affect the health of operators. The test area shall be cleared of smoke and fumes by suitable means.

6.5.1 Before testing

6.5.1.1 Before testing, record all pertinent information (including pressure, specimen identification, insulation thickness, pre-test mass, and wire gauge and configuration). All specimens should be photographed.

6.5.1.2 Determine the amount of current required to obtain the internal wire temperature specified for the test. This is done by mounting the specimen diagonally in the test fixture with the power supply attached to the conductor. The test fixture shall be in a draft-free environment at ambient temperature. Hypodermic microthermocouple probes (0,18 mm) shall have been inserted so that the microthermocouples are in contact with the active conductor. The wire temperature measurements should be performed in at least three locations: in the middle of the wire and at approximately 30 mm from centre in both directions. The electrical current should be raised until the test temperature of the wire is attained (as measured at the three locations).

This temperature should be maintained until stable to within ± 3 °C for 5 min. The test temperature of the wire shall not be exceeded. The voltage drop and current that produce the required temperature of the wire shall be recorded. This determination need only be made once for each wire having the same insulation material and insulation thickness, the same gauge and the same manufacturer.

6.5.1.3 After the wire current has been determined, mount a new 1,2 m length of wire as described in 6.3.6, and arrange the excess lengths of wire to be clear of any flames which could come from the specimen holder area. Place the ignitor 8 mm ± 3 mm below the diagonally mounted test specimen and 3 mm ± 1 mm to the right of the lower attached corner of the test specimen, as shown in Figure 1. The ignitor shall be placed perpendicular to and centred in the plane of the specimen (see Figure 1). Place the test fixture in the test chamber. Connect the ends of the conductor to the power supply and a voltmeter. Finally, mount the paper horizontally 200 mm and centred directly below the specimen.

6.5.1.4 All tests should be videotaped.

6.5.2 Test

6.5.2.1 At least three replicate test specimens shall be tested. Prior to ignition, expose the specimens to the proper test atmosphere for a minimum of 3 min (exposure of specimens to a vacuum shall be less than 3 min). Measure, verify and record the percentage oxygen concentration and the total pressure. Apply the previously determined current to the conductor with the DC power supply to obtain a temperature of 125 °C or the maximum operating temperature of the wire. Maintain this temperature steady for a minimum of 5 min (as indicated by a less than 5 % change in the voltage drop across the specimen), then activate the chemical ignitor. Immediately upon ignition of the ignitor, turn off the power to the ignitor.

6.5.2.2 During the test, observe the specimen and record any pertinent observations, such as transfer of burning debris causing ignition of the paper.

6.5.2.3 After all combustion has ceased, switch off the current to the wire. Record the final oxygen concentration and the burn length. Post-test photographs should be taken, as required, to document any abnormal occurrences.

6.6 Accuracy

Measurements shall be made within the following tolerance limits:

a) temperature: ± 1 °C;

b) absolute pressure: ± 1 % of reading;

c) oxygen concentration: ± 0,5 % of reading;

d) specimen mass: ± 0,1 % of reading;

e) time: ± 1 s;

f) current: ± 0,5 A;

g) voltage: ± 0,05 V;

h) length: ± 15 mm.

6.7 Test report

6.7.1 Standard tests

The test report shall include details of the specimen identification, the wire configuration, the wire diameter, the test conditions, the wire current, the burn length and any ignition of the paper. In addition, any unusual behaviour, such as wire fusion that may be indicated by loss of current, shall be included. The test report shall be submitted to the authority having jurisdiction and/or test requester.

6.7.2 Non-standard tests

When there is a deviation from the standard test parameters, such as non-standard specimen preparation, specimen dimensions, specimen orientation or ignition source, the test shall be identified as non-standard. In addition, all information in 6.7.1 shall be reported.

6.8 Good laboratory practice

At least every 2 years, the test facility should successfully demonstrate the ability to obtain accurate and repeatable data when testing selected insulated wires. The authority having jurisdiction shall choose appropriate GLP materials for its test facilities. The materials selected shall include both flammable and flame-resistant materials.

7 Alternative wire-insulation flammability test in a gas-flow environment (Test B)

7.1 Principle

7.1.1 This alternative test (Test B) is designed to screen wire insulation for flammability characteristics in a gas-flow environment. Failure of any one of three replicate specimens constitutes failure of the material. Failure occurs when any one of the conditions given in 7.1.2 to 7.1.4, is fulfilled. Testing shall be stopped upon failure of one specimen.

7.1.2 At the stabilized temperature prior to flame application there shall be no

— spontaneous combustion;

— splitting of the insulation;

— baring of the conductor.

7.1.3 During ignition and combustion, there shall be no flaming droplets or particles.

7.1.4 After the burner has been extinguished, the wire shall cease flaming within 10 s and a maximum burn length of 150 mm. The burn length is measured from the downward extent of propagation to the upward extent of propagation and includes damage caused by the burner itself.

7.2 Conditions and limits

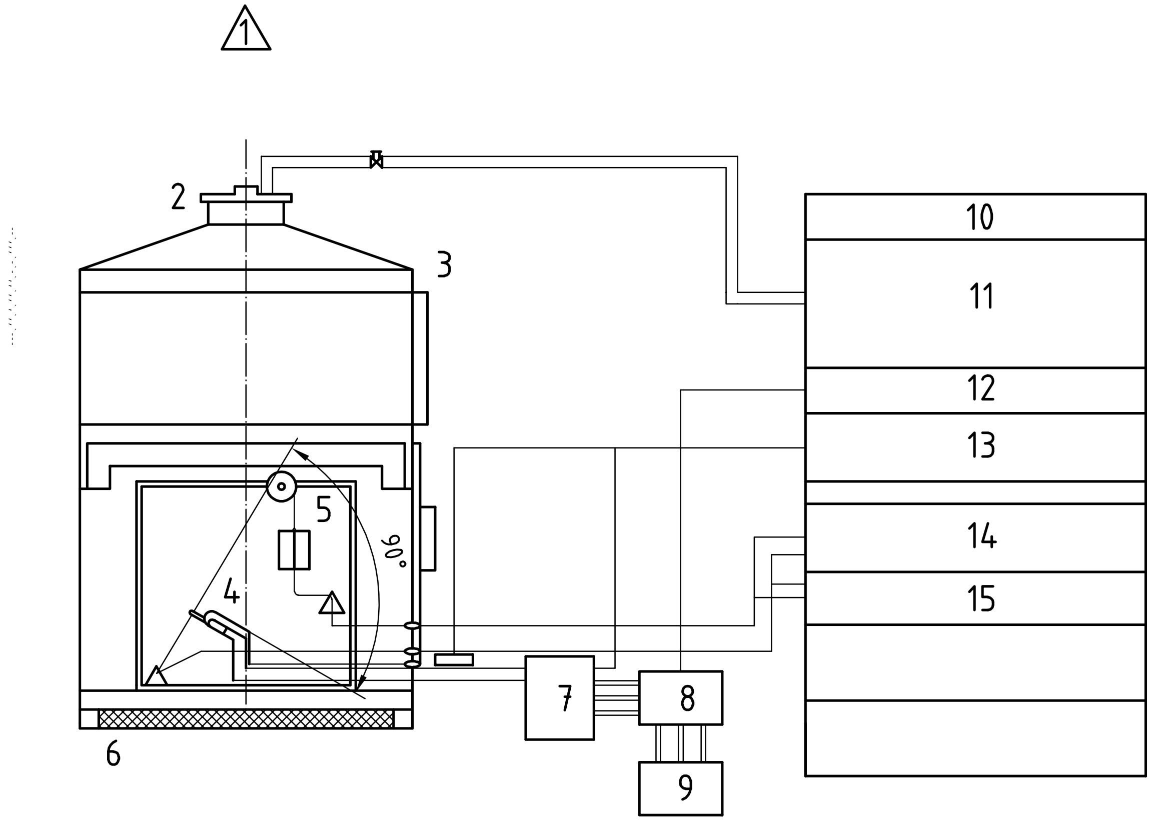
7.2.1 The test atmosphere shall be designated by the procuring activity/user programme office. These conditions shall represent the most hazardous atmosphere anticipated in the spacecraft, within the confines of this test.

7.2.2 The oxygen content of the standard test atmosphere used is 25 % by volume, at normal pressure.

7.2.3 The oxygen content is limited to between 21 % oxygen by volume and 25 % oxygen by volume. The test is limited to wire sizes from 0,90 mm to 2,60 mm with copper conductors. For wires to be used beyond these limits, Test A has been shown to provide comparable results, although testing is conducted in a static environment.

7.3 Test system

7.3.1 **Test chamber**, with a volume of 250 dm^3. A typical arrangement is shown in Figure 3.



Key

1 fume extractor, 1 400 m^3/h
2 upper adapter
3 test chamber
4 burner, Bunsen type
5 specimen and burner assembly
6 distribution unit
7 magneto-electric valves
8 mass flow controller (see also item 12)
9 gas supply
10 switch panel
11 oxygen analyser
12 power supply and display (see also item 8)
13 timer
14 power supply
15 current and voltage measurement

Figure 3 — General arrangement of test equipment

7.3.2 External electrical supply, capable of providing a steady DC current.

7.3.3 Voltmeter, capable of measuring the voltage drop in the wire in volts to two decimal places.

7.3.4 Ammeter, capable of measuring the current in the wire in amps to two decimal places.

7.3.5 Resistance meter, capable of measuring resistance in milliohms to two decimal places.

7.3.6 Burner, of the Bunsen type, mounted perpendicular to the specimen and at 30° to the vertical (see Figure 4), with a 9,5 mm bore modified to allow an external supply of air to be fed to the burner collar (see Figure 5), and with a spacer cone to give the correct stand-off distance between the burner and specimen.

The flame temperature shall be 1 100 °C ± 100 °C, measured at a point 35 mm from the end of the burner barrel. The burner is fuelled with commercial-grade propane gas (minimum 85 % purity) and forced air to produce a flame 75 mm high with an inner blue cone of height 25 mm.

7.3.7 Weights, for keeping the specimen taut (see Figure 4).

7.3.8 **Video camera**, for recording all the flammability tests.

7.3.9 **Timer**, positioned such that it is visible to the video camera (7.3.8).

7.4 Test specimens

7.4.1 Preparation of specimens for testing shall be in accordance with 6.4.2, but carrying out the additional tasks described in 7.4.2 and 7.4.3.

7.4.2 Three specimens, each 1 m in length, shall be cut consecutively from the same coil of wire. The specimens shall be weighed and individually identified. The specimens should be cleaned and dried to the end-use specifications. Visible contamination should be removed with distilled water and a lint-free cloth. Subsequently, the specimens shall be dried using filtered nitrogen gas. All cleaning procedures shall be verified to have no influence on the test results.

7.4.3 After cleaning, the specimens shall be handled wearing gloves. Prior to testing, the specimens shall be conditioned at (55 ± 10) % relative humidity and at a temperature of 20 °C ± 3 °C for a period of at least 16 h. Remove approximately 6 mm of the insulation from both ends of the test specimens and crimp a ring tongue with a typical single-ring tool onto each wire. Measure and record the conductor resistance at ambient temperature. Position the wire in the test chamber as shown in Figure 4.

7.5 Procedure

WARNING — Burning of materials may produce smoke and toxic gases, which can affect the health of operators. The test area shall be cleared of smoke and fumes by suitable means.

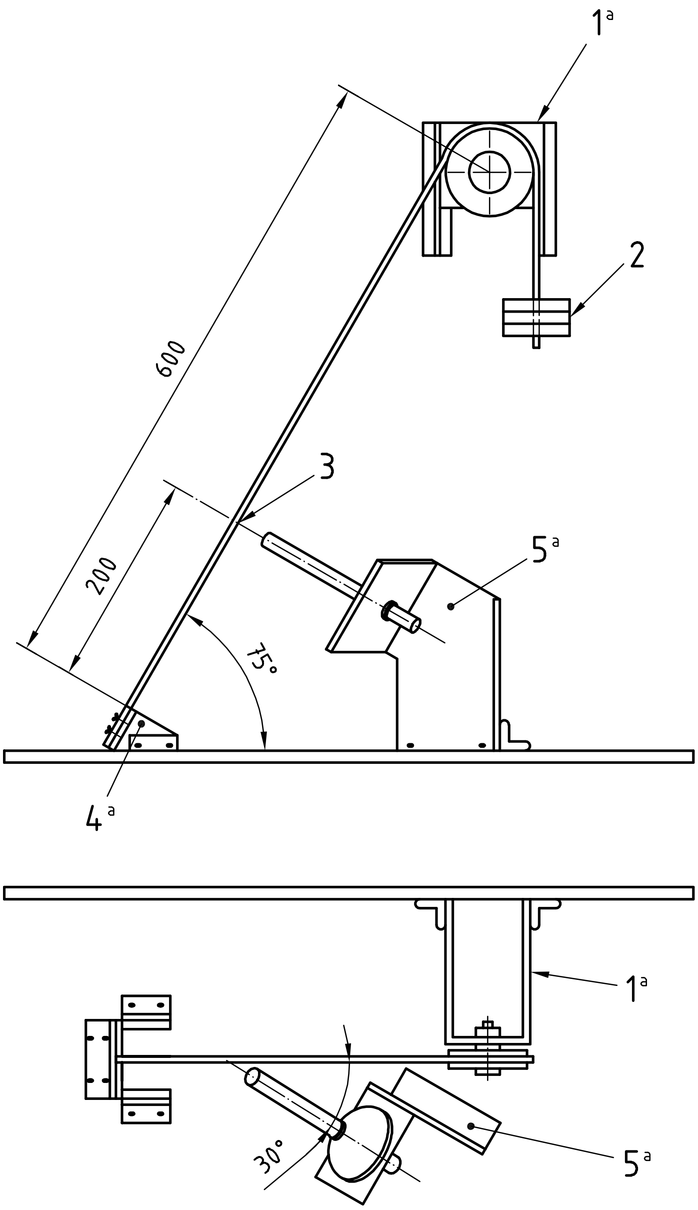
7.5.1 Before testing

7.5.1.1 Record all pertinent information (including specimen identification, insulation thickness, pre-test mass, wire diameter and wire configuration) and photograph all the specimens.

7.5.1.2 With the propane flow adjusted to 0,35 l/min and the air flow to 6 l/min, check the flame height and temperature for conformance to 7.3.6. Adjust the gas flows as necessary to ensure compliance with 7.3.6. Ensure that the burner can be switched on and off repeatedly, and that it automatically switches off after 15 s of burning time.

7.5.1.3 The oxygen and nitrogen supplies shall be adjusted to provide a flow of 25 l/min, and the proper test atmosphere concentration, and then turned off.

Dimensions in millimetres



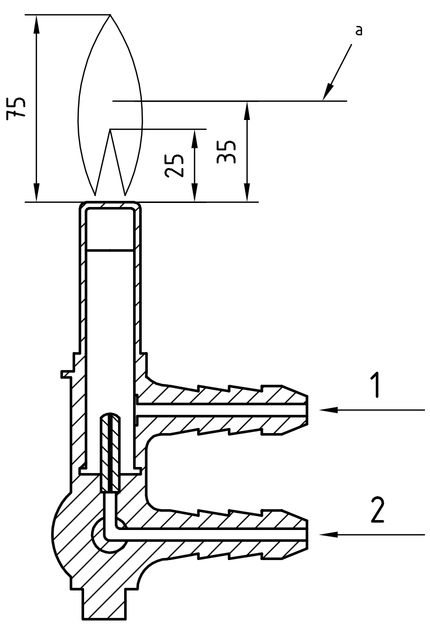
Key

1 pulley mounting bracket
2 weights as required
3 flame application point
4 bottom-clamp mounting
5 Bunsen burner mounting

[a] Low thermal conductivity.

Figure 4 — Test specimen and burner set-up

Dimensions in millimetres



Key

1 air inlet

2 propane gas inlet

[a] Flame temperature measurement point.

Figure 5 — Modified burner showing flame dimensions

7.5.1.4 Position a prepared specimen in the test chamber as shown in Figure 4. Clamp the conductor at the lower bottom left-hand side of the apparatus by means of the electrical connector block and pass the wire under the lower left-hand guide and over the upper right-hand guide pulley where a weight is attached to keep the specimen taut. Then connect up the other end electrically to complete the circuit.

7.5.1.5 Position the burner below the specimen. Place the spacer cone in the barrel of the burner so that it exceeds the length of the burner by 35 mm. Adjust the burner by its assembly screws. The burner is at the correct stand-off distance when the cone contacts the wire. Remove the cone.

7.5.1.6 Open the vent and switch on the extractor fan. Open the oxygen and nitrogen supply valves and allow the chamber to fill by purging the chamber at a constant flow rate. After 15 min, check the test atmosphere. If the specified concentration of oxygen has been reached, reduce the flow to a constant rate, and maintain this flow for the duration of the test phase.

7.5.1.7 Apply a DC electric current, I, to the conductor and measure the voltage drop, U. From the current and voltage values, calculate the resistance of the conductor at elevated temperature, R_1, from the equation:

$$R_1 = \frac{U}{I}$$

7.5.1.8 Determine the temperature, T, in degrees Celsius, of the conductor from the change in resistance, using the following equation based on the variation of the specific resistivity of the copper with the temperature:

$$R_1 = \left[\left(\frac{T-20}{250}\right)+1\right] \cdot R$$

where R is the resistance measured earlier at ambient temperature.

7.5.1.9 Adjust the current so that the conductor temperature stabilizes at the maximum operating temperature for the wire, taken from the manufacturer's specification. Maintain this temperature ± 3 % for 5 min before igniting the flame. No further alteration shall be made to the current until the test is completed.

7.5.2 Test

7.5.2.1 At least three replicate specimens shall be tested. Switch on the exhauster fan. The distance between the exhauster inlet and the top of the test chamber shall be at least 0,7 m. Start the video recorder and timer. Apply the flame to the specimen for a period of 15 s. After all flaming has ceased, note the time, continue to apply the current for an additional 60 s, and observe. If no further flaming occurs, switch off the current, close the oxygen supply valve and vent the chamber.

7.5.2.2 Record any observations, the post-test mass and the burn length.

7.6 Accuracy

Measurements shall be made to the same accuracy as in 6.6, with the exception of the current which shall be measured to within a tolerance of ± 0,05 A.

7.7 Test report

7.7.1 Standard tests

The test report shall include details of the specimen identification, the wire configuration, the test conditions, the wire diameter, the wire temperature and the burn length. The test report shall be submitted, in an acceptable format, to the authority having jurisdiction and/or test requester.

7.7.2 Non-standard tests

When there is a deviation from the standard test parameters, such as non-standard specimen preparation, specimen dimensions, specimen orientation or ignition source, the test shall be identified as non-standard. In addition, all information in 7.7.1 shall be reported.

7.8 Good laboratory practice

At least every 2 years, the test facility should successfully demonstrate the ability to obtain accurate and repeatable data when testing selected insulated wires. The authority having jurisdiction shall choose appropriate GLP materials for its test facilities. The materials selected shall include both flammable and flame-resistant materials.

Annex A
(informative)

Competency and accreditation of test facilities

A.1 Competency

Laboratories should be accredited to perform the flammability and/or combustion test methods contained within this part of ISO 14624. Accreditation is necessary because data from such testing is presented for aerospace flight material selection approval. Accreditation should be based on ISO/IEC 17025 and the specific requirements described in this part of ISO 14624.

The accreditation programme should include proficiency testing and should be consistent with ISO/IEC Guide 43-1.

A.2 Accreditation

Accreditation is the responsibility of the accreditation body recognized within its jurisdiction to administer laboratory accreditation. An acceptable laboratory accreditation body would be a signatory to the multi-lateral mutual recognition arrangement (MRA) of the International Laboratory Accreditation Cooperation (ILAC)[1] or a signatory to an ILAC-equivalent regional/national MRA that requires accreditation bodies to conform to ISO/IEC Guide 58.

A.3 Guidelines

An accredited laboratory should conform to the following guidelines:

a) For required tests, the test facility should have performed the test method at least once during the last eighteen months and participated in comparisons of results with other accredited test facilities (round-robin testing).

b) All instrumentation used in the test should be in proper calibration and bear the appropriate documentation to validate traceability to appropriate national or international measurement standards.

c) The test facility should ensure that all testing is accomplished in accordance with approved test plans and procedures, and that the data records and test results are complete and accurate.

d) Complete test records should be prepared by the test facility for each material tested and the test facility should maintain a permanent record of test data for a minimum of fifteen years for historical purposes.

1) Full information is available at the web site http://www.ilac.org of ILAC - International Laboratory Accreditation Cooperation or through the ILAC Secretariat, c/o NATA, 7 Leeds Street, Rhodes NSW 2138, Australia. Tel.: +61 2 9736 8374, Fax: +61 9736 8373, e-mail: ilac@nata.asn.au

Annex B
(informative)

Preparation and qualification of chemical ignitors

B.1 Safety requirements

All personnel associated with the manufacturing of these ignitors should be familiar with the safety requirements associated with the materials and equipment used.

B.2 Materials

B.2.1 Hexamethylenetetramine (HMT), 98 % pure reagent grade, in powder form, properly packaged and stored to prevent contamination by moisture.

B.2.2 Anhydrous sodium metasilicate, 98 % pure reagent grade, in granule form, properly packaged and stored to prevent contamination by moisture.

B.2.3 Gum arabic (acacia), in powder form.

B.2.4 Deionized water, for mixing with the dry ingredients to form the ignitor dough.

B.2.5 Certified breathing air, used in the certification of the ignitors (see ISO 14951-13).

B.3 Equipment

B.3.1 Hammer mill, for grinding the dry components of the ignitor mixture.

B.3.2 Glove box with a temperature/humidity meter, used when grinding some of the dry ingredients.

B.3.3 Bags, for storing the ground dry ingredients.

B.3.4 40-mesh (40 µm) screen, for sieving the ground dry ingredients.

B.3.5 Fume hood, used when grinding some of the dry ingredients, and for mixing the ignitor dough. The air flow rate in the fume hood should be at least 30 m/s.

B.3.6 Respirator with organic canisters, used when grinding the HMT.

B.3.7 250 ml burette, for holding the deionized water and gradually adding it to the mixture.

B.3.8 Heavy-duty electric mixer, for mixing the ignitor dough.

B.3.9 Spatula, for scraping the sides of the mixing bowl during preparation of the ignitor dough.

B.3.10 Plastic trays, non-stick, measuring approximately 76 mm × 380 mm × 1,5 mm, to catch the extruded ignitor dough and hold it while it dries.

B.3.11 Conveyor belt, to move the plastic trays at a constant rate so that the string of ignitor dough is not stretched or allowed to become too thick.

B.3.12 Extruder, for extruding the ignitor dough on to the plastic trays.

B.3.13 Cutting tools, for cutting the ignitor dough string to the proper lengths.

B.3.14 Drying racks, for holding the plastic trays containing the ignitor dough string.

B.3.15 Desiccator with desiccant, to ensure that the proper humidity is maintained during drying and storage of the ignitors.

B.3.16 Balance, for weighing the dried ignitors.

B.3.17 Corrugated plastic holder, used when cutting overweight dried ignitors to a length that ensures the correct mass.

B.3.18 Power supply, capable of providing 15 A (RMS), used in the certification of the ignitors.

B.3.19 Bare 20 AWG nickel-chromium wire, with a nominal resistivity of 2,3 Ω·m, used in the certification of the ignitors.

B.3.20 Graduated ruler, for measuring the length of the ignitors and the ignitor flame height during certification.

B.3.21 Test chamber (or fume hood), used during certification of the ignitors.

B.3.22 Calibrated stopwatch, for determining the burn time during certification of the ignitors.

B.3.23 Soft-bristled brush, for cleaning the ignitor coil between certification of individual ignitors.

B.3.24 Plastic container (box), for storing the ignitors.

B.3.25 Corrugated-foam wrap, for wrapping the stored ignitors.

B.4 Grinding the ignitor-mix ingredients

B.4.1 To ensure a homogeneous mixture, grind the raw materials using a hammer mill. Grinding is not necessary for the gum arabic.

B.4.2 Grind the sodium metasilicate in a glove box, as follows. Place the hammer mill, the material to be ground and any other necessary tools inside the glove box. Attach a bag to the output end of the hammer mill with tape to capture the ground material. In addition, place a 40-mesh screen inside the hammer mill. Seal the glove box and, before grinding the material, purge the glove box with dry air for approximately 4 h or until the humidity inside the glove box is below 10 %.

B.4.3 Grind the material. Detach the bag from the hammer mill, seal the bag, place it inside another bag and seal the second bag.

B.4.4 Clean the hammer mill between the grinding of different materials.

B.4.5 Grind the HMT in a fume hood. The air flow rate in the fume hood shall be at least 30 m/s, and a respirator with organic canisters shall be worn by the operator. Follow the same procedures as when grinding the sodium metasilicate described in B.4.2 to B.4.4.

B.4.6 After grinding, store each material separately, suitably identified.

B.5 Weighing and mixing the ignitor-mix ingredients

B.5.1 To make a 400 g mixture, the following amounts of each solid ingredient are necessary:

— (280,8 ± 0,2) g of HMT;

— (105,2 ± 0,2) g of anhydrous sodium metasilicate;

— (14,0 ± 0,2) g of gum arabic.

B.5.2 For other size batches, the mixture shall be comprised of 70,2 % ± 0,1 % HMT, 26,3 % ± 0,1 % sodium metasilicate and 3,5 % ± 0,1 % gum arabic.

B.5.3 Carry out the weighing and mixing on the day of extrusion (do not mix the dry ingredients prior to the day of extrusion).

B.6 Adding water

B.6.1 Pour 200 ml of deionized water at room temperature into a 250 ml burette.

B.6.2 Open the tap of the burette and allow approximately 10 ml of deionized water to flow into the mixing bowl of a heavy-duty electric mixer.

B.6.3 Place the dry ignitor mix in the mixing bowl. Ensure the ignitor mix is evenly distributed in the bowl.

B.6.4 Operating the electric mixer at low speed, slowly add deionized water to the mixture. Initially, the mixture will be very wet. As the sodium metasilicate absorbs the water, the mix will start to thicken, and will eventually achieve a dough-like consistency. This could take 20 min to 30 min, depending on the environmental conditions. During mixing, scrape the sides of the mixing bowl with a spatula.

B.6.5 As the proper dough-like consistency is achieved, the mix will start to pull away from the sides of the bowl. When this occurs, stop adding water. Too much water will cause the mixture to be too wet to extrude. Generally, 190 ml to 200 ml of deionized water will be added from the burette to the mixture.

B.7 Extruding the ignitors

B.7.1 Extruding the ignitors is a three-person operation. One person places the plastic trays on the conveyor belt. Another person controls the process by adjusting the conveyor belt speed and the extruder controller speed, and cuts the extruded ignitor dough between trays. The third person removes the trays from the conveyor belt and places them in drying racks.

B.7.2 Turn on the conveyor belt and make any necessary adjustments to belt tension to prevent any belt hesitations. In addition, for a 400 g mixture, make sure that there are approximately 75 plastic trays next to the beginning of the conveyor belt. More will be needed for a larger batch. Turn the conveyor belt off.

B.7.3 Assemble the extruder and fill with ignitor dough.

B.7.4 When extrusion starts, turn the conveyor belt on and be ready to place the plastic trays on the conveyor belt as the ignitor dough exits the extruder. Adjust the conveyor belt and extruder speed as required during this operation to ensure that the extruded ignitor dough comes out straight and unstretched. Cut the dough between trays, so that the trays may be placed individually in the drying racks.

B.7.5 After all the dough has been extruded onto the trays, and the trays removed to the drying racks, clean all the equipment.

B.8 Curing, cutting and weighing the ignitors

B.8.1 After all the ignitor dough has been extruded onto the plastic trays, place the ignitors in a well-ventilated area (relative humidity < 20 %) to dry. After approximately 24 h to 48 h, the ignitors should be dry enough to cut.

B.8.2 Cut all the ignitor strings on the plastic trays to a length of 28 mm ± 3,2 mm. Continue to dry the cut ignitors under the conditions described in B.8.1 for another 24 h to 48 h until they are dry to the touch.

B.8.3 Transfer the ignitors from the plastic trays to a desiccator (relative humidity < 15 %). Place them directly on the desiccant bed.

B.8.4 Continue to dry the ignitors inside the desiccator. After approximately seven days, select ten ignitors and weigh them. The mass specification for the ignitors is 190 mg to 240 mg. If the mass of eight out of the ten ignitors is within the specified range, the final dried state has been reached, and the ignitors are ready for certification. If more than two ignitors weigh over 240 mg, continue to dry the ignitors.

B.8.5 If more drying time is required, as described in B.8.4 above, wait approximately 24 h to 48 h, then select ten additional ignitors. If eight out of the ten meet the mass specification, the ignitors are ready for certification. Due to varying conditions in desiccators, this process may take as long as two weeks, or more.

B.9 Certifying the ignitors

B.9.1 Weigh all the ignitors in the desiccator. If an ignitor weighs less than 190 mg, it is underweight, and shall be discarded. If an ignitor weighs more than 240 mg, it may be cut down to 25 mm long to meet the mass specification. If the proper mass is not achieved within the length specification, the ignitor shall be discarded. Cutting and weighing of the ignitors shall be done in a dry environment (relative humidity $<$ 20 %), since the ignitors will absorb moisture when exposed to excess humidity. In addition, the ignitors shall remain circular, and not flatten out while curing, in order to fit inside the ignition coil. To ensure this, ignitors shall be placed in a rigid plastic corrugated holder while being cut.

B.9.2 To certify a 400 g mixture batch, randomly select a sample of 20 ignitors. If a larger mixture batch is made, the certification sample shall be increased accordingly. The 20 ignitors selected shall be tested for the peak flame temperature, burn time and peak flame height. Each ignitor tested shall develop a flame temperature of 1 100 °C $\pm$ 90 °C. The ignitor flame shall be sustained for 25 s $\pm$ 5 s with a peak flame height of 65 mm $\pm$ 6,5 mm.

B.9.3 Ignitors shall be tested in certified breathing air at 100 kPa. The temperature shall be measured by a type S thermocouple constructed with a 0,81 mm diameter wire. The thermocouple wire shall be centred geometrically 25 mm above the top of the ignitor. To initiate the ignitor, a power supply capable of providing 15 A (RMS) shall be connected to a bare 20 AWG nickel-chromium wire. The wire shall have a nominal resistivity of 2,3 $\Omega \cdot$m and shall have sufficient length to wrap three equally spaced turns around the ignitor. The nickel-chromium wire coil shall be replaced before certifying each batch of ignitors. In addition, the length of the leads to the nickel-chromium wire coil shall not exceed 32 mm to ensure proper ignition of the ignitor. A graduated ruler shall be placed in the test chamber to measure the flame height.

B.9.4 Before starting the certification, ensure that the thermocouple wires are not touching each other, and that the thermocouple is in proper calibration.

B.9.5 To certify a batch of ignitors, perform the following steps for each of the 20 randomly selected ignitors.

a) Place the ignitor in the nickel-chromium wire coil.

b) Pressurize the test chamber to 100 kPa with certified breathing air.

c) Turn on the power to the ignitor. When ignition is accomplished, turn the power off.

d) Record the peak flame temperature (from the thermocouple), the burn time and the flame height. The time from the moment of ignition to the moment of flame extinction (burn time) shall be obtained using a calibrated stopwatch. The flame height shall be determined by measuring the maximum height of the flame to the apex.

e) Allow the test chamber to stabilize. Before loading the next ignitor, clean the wire coil by removing any ash residue with a soft-bristled brush.

f) The batch of ignitors is acceptable for use when no more than one ignitor out of the 20 tested fails the specified criteria (see B.9.2). Once the batch of ignitors has been tested and certified, calculate the average peak flame temperature and average burn time, along with their standard deviations.

B.10 Waste disposal

Dispose of any waste generated from manufacturing, cutting or weighing ignitors, including an entire batch that fails, in accordance with applicable hazardous-waste/environmental regulations.

B.11 Packaging and storing ignitors

B.11.1 Package the ignitors in a plastic storage container between layers of 3-mm-thick corrugated-foam wrap. Place the ignitors in the grooves of the corrugated wrap. The order of placement in the storage container shall be:

1) corrugated wrap with grooved side up;

2) layer of ignitors, in grooves of corrugated wrap;

3) corrugated wrap with grooved side down.

Repeat steps 1) to 3) until the container is full. This order of placement will put two layers of corrugated wrap between each layer of ignitors, and minimize movement when the box is moved or stored. To absorb any excess moisture which might affect the performance of the ignitors, place packets of desiccant on top of the ignitors, inside the container.

B.11.2 To prevent the ignitors from absorbing moisture during an extended storage period, place the packaged ignitors in a desiccator with a colour-changing desiccant or another type of humidity indicator. The ignitors may be stored for an indefinite period of time, provided the desiccant is changed regularly and/or the humidity in the desiccator is kept below 18 %.

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