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TECHNICAL SPECIFICATION

colour
inside

Fire hazard testing –
Part 5-2: Corrosion damage effects of fire effluent – Summary and relevance of test methods

IEC TS 60695-5-2:2021-06 RLV(en)

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INTERNATIONAL
ELECTROTECHNICAL
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INTERNATIONAL ELECTROTECHNICAL COMMISSION

FIRE HAZARD TESTING –

Part 5-2: Corrosion damage effects of fire effluent – Summary and relevance of test methods

FOREWORD

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This redline version of the official IEC Standard allows the user to identify the changes made to the previous edition IEC TS 60695-5-2:2002. A vertical bar appears in the margin wherever a change has been made. Additions are in green text, deletions are in strikethrough red text.

IECNORM.COM : Click to view the full PDF of IEC TS 60695-5-2:2021 RLV

IEC 60695-5-2, which is a technical specification, has been prepared by IEC technical committee 89: Fire hazard testing.

This third edition cancels and replaces the second edition published in 2002.

The main changes with respect to the previous edition are listed below:

- References to IEC TS 60695-5-3 (withdrawn in 2014) have been removed.
- ISO/TR 9122-1 has been revised by ISO 19706.
- References to ISO 11907-2 and ISO 11907-3 have been removed.
- Terms and definitions have been updated.
- Text in 5.4 has been updated.
- Text in 5.5.8 (5.7.8 in Ed. 2) has been updated.
- Text in Clause 6 (7 in Ed. 2) has been updated.
- Bibliographic references have been updated.

It has the status of a basic safety publication in accordance with IEC Guide 104 and ISO/IEC Guide 51.

The text of this technical specification is based on the following documents:

Draft	Report on voting
89/1473/DTS	89/1506/RVDTS

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Specification is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

In this technical specification, the following print types are used:

Arial bold: terms referred to in Clause 3

This technical specification is to be read in conjunction with IEC 60695-5-1.

A list of all parts in the IEC 60695 series, published under the general title *Fire hazard testing*, 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 webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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INTRODUCTION

~~The risk of fire should be considered in any electrical circuit. With regard to this risk, the circuit and equipment design, the selection of components and the choice of materials should contribute towards reducing the likelihood of fire even in the event of foreseeable abnormal use, malfunction or failure. The practical aim should be to prevent ignition caused by electrical malfunction but, if ignition and fire occur, to control the fire preferably within the bounds of the enclosure of the electrotechnical product.~~

In the design of an electrotechnical product the risk of fire and the potential hazards associated with fire need to be considered. In this respect the objective of component, circuit and equipment design, as well as the choice of materials, is to reduce the risk of fire to a tolerable level even in the event of reasonably foreseeable (mis)use, malfunction or failure. IEC 60695-1-10 [1][1], IEC 60695-1-11 [2], and IEC 60695-1-12 [3] provide guidance on how this is to be accomplished.

Fires involving electrotechnical products can also be initiated from external non-electrical sources. Considerations of this nature are dealt with in an overall fire hazard assessment.

The aim of the IEC 60695 series is to save lives and property by reducing the number of fires or reducing the consequences of the fire. This can be accomplished by:

- trying to prevent ignition caused by an electrically energised component part and, in the event of ignition, to confine any resulting fire within the bounds of the enclosure of the electrotechnical product.
- trying to minimise flame spread beyond the product's enclosure and to minimise the harmful effects of **fire effluent**s including heat, **smoke**, and toxic or corrosive combustion products.

All **fire effluent** is corrosive to some degree and the level of potential to corrode depends on the nature of the fire, the combination of combustible materials involved in the fire, the nature of the substrate under attack, and the temperature and relative humidity of the environment in which the corrosion is taking place. There is no evidence that **fire effluent** from electrotechnical products offers greater risk of **corrosion damage** than the **fire effluent** from other products such as furnishings, building materials, etc.

The performance of electrical and electronic components can be adversely affected by **corrosion damage** when subjected to **fire effluent**. A wide variety of combinations of small quantities of effluent gases, **smoke** particles, moisture and temperature may provide conditions for electrical component or system failures from breakage, overheating or shorting.

Evaluation of potential **corrosion damage** is particularly important for high value and safety-related electrotechnical products and installations.

Technical committees responsible for the products will choose the test(s) and specify the level of severity.

The study of **corrosion damage** requires an interdisciplinary approach involving chemistry, electricity, physics, mechanical engineering, metallurgy and electrochemistry. In the preparation of this part of IEC 60695, all of the above have been considered.

IEC 60695-5-1 defines the scope of the guidance and indicates the field of application.

IEC 60695-5-2 provides a summary of test methods including relevance and usefulness.

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[1] Numbers in square brackets refer to the bibliography.

~~IEC 60695-5-3 gives details of a small-scale test method for the measurement of leakage current and metal loss caused by fire effluent.~~

FIRE HAZARD TESTING –

Part 5-2: Corrosion damage effects of fire effluent – Summary and relevance of test methods

1 Scope

This part of IEC 60695, which is a technical specification, gives a summary of the test methods that are used in the assessment of the corrosivity of **fire effluent**. It presents a brief summary of test methods in common use, either as international standards or national or industry standards. It includes special observations on their relevance, for electrotechnical products and their materials, to real **fire scenario**s and gives recommendations on their use.

One of the responsibilities of a technical committee is, wherever applicable, to make use of basic safety publications in the preparation of its publications. The requirements, test methods or test conditions of this publication will not apply unless specifically referred to or included in the relevant publications.

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 60695-4:~~1993~~2012, *Fire hazard testing – Part 4: Terminology concerning fire tests for electrotechnical products*

IEC 60695-5-1~~:2002~~, *Fire hazard testing – Part 5-1: Corrosion damage effects of fire effluent - General guidance*

~~IEC/TS 60695-5-3, *Fire hazard testing – Part 5-3: Corrosion damage effects of fire effluent – Leakage current and metal loss test method*~~[2]

IEC GUIDE 104~~:1997~~, *The preparation of safety publications and the use of basic safety publications and group safety publications*

ISO Guide 51, *Safety aspects – Guidelines for their inclusion in standards*

ISO~~/IEC~~ 13943:~~2000~~2017*, Fire safety – Vocabulary*

ISO 19706:2011*, Guidelines for assessing the fire threat to people*

~~ISO/TR 9122-1:1989, *Toxicity testing of fire effluents – Part 1: General*~~

3 Terms and definitions

~~For the purposes of this part of IEC 60695, the definitions given in ISO/IEC 13943 and IEC 60695-4, as well as the following definitions, apply.~~

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[2] ~~To be published.~~

For the purposes of this document, the terms and definitions given in IEC 60695-4:2012 and ISO 13943:2017 (some of which are reproduced below), apply.

3.1
corrosion damage
physical and/or chemical damage or impaired function caused by chemical action

[SOURCE: ISO~~/IEC~~ 13943:2017, ~~definition 25~~ 3.69]

3.2
corrosion target
sensor used to determine the degree of **corrosion damage** (3.1), under specified test conditions

Note 1 to entry: This sensor may be a product, a component~~, or a reference material used to simulate them~~. It may also be a reference material or object used to simulate the behaviour of a product or a component.

[SOURCE: ISO~~/IEC~~ 13943:2017, ~~definition 26~~ 3.70]

~~**3.3**~~
~~**critical relative humidity**~~
~~level of relative humidity that causes leakage current to exceed a value defined in the product specification~~

3.3
fire effluent
~~totality of~~ all gases and~~/or~~ aerosols, ~~(~~including suspended particles~~)~~ created by combustion or **pyrolysis** (3.6) and emitted to the environment

[SOURCE: ISO~~/IEC~~ 13943:2017, ~~definition 45~~ 3.123]

~~**3.5**~~
~~**fire effluent decay characteristics**~~
~~physical and/or chemical changes in fire effluent due to time and transport~~

~~[IEC 60695-4, definition 2.34]~~

~~**3.6**~~
~~**fire effluent transport**~~
~~movement of fire effluent away from the location of the fire~~

~~[IEC 60695-4, definition 2.35]~~

3.4
fire scenario
~~detailed description of conditions, including environmental, of one or more stages from before ignition to after completion of combustion in an actual fire at a specific location or in a real-scale simulation~~

qualitative description of the course of a fire with respect to time, identifying key events that characterize the studied fire and differentiate it from other possible fires

Note 1 to entry: See **fire scenario cluster** (ISO 13943:2017, 3.154) and **representative fire scenario** (ISO 13943:2017, 3.153).

Note 2 to entry: It typically defines the ignition and fire growth processes, the fully developed fire stage, the fire decay stage, and the environment and systems that will impact on the course of the fire.

Note 3 to entry: Unlike deterministic fire analysis, where fire scenarios are individually selected and used as design fire scenarios, in fire risk assessment, fire scenarios are used as representative fire scenarios within fire scenario clusters.

[SOURCE: ISO~~/IEC~~ 13943:2017,~~ definition 58~~ 3.152]

~~**3.8**~~
~~**ignition source**~~
~~source of energy that initiates combustion~~

~~[ISO/IEC 13943, definition 97]~~

~~**3.9**~~
~~**leakage current**~~
~~electrical current flowing in an undesired circuit~~

3.5
physical fire model
laboratory process, including the apparatus, the environment and the fire test procedure intended to represent a certain phase of a fire

[SOURCE: ISO 13943:2017, 3.298]

3.6
pyrolysis
chemical decomposition of a substance by the action of heat

Note 1 to entry: Pyrolysis is often used to refer to a stage of fire before flaming combustion has begun.

Note 2 to entry: In fire science, no assumption is made about the presence or absence of oxygen.

[SOURCE: ISO 13943:2017, 3.316]

3.7
smoke
visible part of a fire effluent (3.3)

[SOURCE: ISO~~/IEC~~ 13943:2017,~~ definition 150~~ 3.347]

4 Classification of test methods

4.1 ~~Introduction~~ General

Test methods can be classified according to three criteria:

a) the nature of the test specimen which is burned;
b) the **physical fire model** used in the test;
c) the nature of the measurement of corrosivity.

4.2 Test specimen

4.2.1 Product testing

The test specimen is a manufactured product or a representative portion of a product. Examples include: a printed circuit board, a switchboard, a computer or a cable.

~~4.2.2 Simulated product testing~~

~~The test specimen is a representative portion of a product.~~

4.2.2 Material or composite sample testing

The test specimen is a basic material (solid or liquid), or composite of materials.

4.3 The physical fire model

Test methods use a wide variety of heat sources and geometries. The amount, the rate of production and the corrosive nature of **fire effluent** released from a given material or product is not an inherent property of that material or product, but is critically dependent on the conditions under which that material or product is burnt. In a **fire scenario** or a fire test, the chemical nature of the ~~test specimen~~ fuel, the decomposition temperature and the amount of ventilation are the main variables which affect the composition of **fire effluent**.

It is critical to show that the test conditions defined in a standardized test method ~~(the fire model)~~ are relevant to, and replicate, the desired stage of a real fire. ISO has published a general classification of fire stages in ~~ISO/TR 9122-1~~ ISO 19706, shown in Table 1. The important factors affecting effluent production are oxygen concentration and irradiance/temperature.

4.4 The nature of the corrosivity measurement

4.4.1 Product ~~testing~~ as target

In these cases the **corrosion target** is a manufactured product or a representative portion of a product. Examples include: printed wiring boards, switchboards, washing machines and computers.

The **corrosion damage** effects of **fire effluent** on the product can be assessed by degradation of function as determined by inspection or measurement.

4.4.2 Simulated product ~~testing~~ as target

~~In these cases the **corrosion target** is a printed circuit or a thin metal film which simulates a product.~~

When a simulated product is used as the target, the **corrosion target** is typically a reference circuit, a thin sheet of metal or a metal mirror. The **corrosion damage** effects of **fire effluent** on the target can be assessed by changes in appearance, mass or measurements of mechanical, physical or electrical characteristics.

Table 1 – Characteristics of fire stages (from Table 1 in ISO 19706:2011)

Fire stage	Heat flux to fuel surface kW/m^2	Max. temperature °C		Oxygen volume %		Fuel/air equivalence ratio (plume)	$\frac{[CO]}{[CO_2]}$ v/v	$\frac{100\times[CO_2]}{([CO_2]+[CO])}$ % efficiency
		Fuel surface	Upper layer	Entrained	Exhausted			
1 Non-flaming								
a self-sustaining (smouldering)	not applicable	450 to 800	25 to 85 [d]	20	20	–	0,1 to 1	50 to 90
b oxidative pyrolysis from externally applied radiation	–	300 to 600 a	[b]	20	20	< 1	[c]	[c]
c anaerobic pyrolysis from externally applied radiation	–	100 to 500	[b]	0	0	>> 1	[c]	[c]
2 Well-ventilated flaming [d]	0 to 60	350 to 650	50 to 500	≈ 20	≈ 20	< 1	< 0,05 [e]	> 95
3 Underventilated flaming [f]								
a small, localized fire, generally in a poorly ventilated compartment	0 to 30	300 to 600 [a]	50 to 500	15 to 20	5 to 10	> 1	0,2 to 0,4	70 to 80
b post-flashover fire	50 to 150	350 to 650 [g]	> 600	< 15	< 5	> 1 [h]	0,1 to 0,4 [i]	70 to 90

[a] The upper limit is lower than for well-ventilated flaming combustion of a given combustible.

[b] The temperature in the upper layer of the fire room is most likely determined by the source of the externally applied radiation and room geometry.

[c] There are few data, but for pyrolysis this ratio is expected to vary widely depending on the material chemistry and the local ventilation and thermal conditions.

[d] The fire's oxygen consumption is small compared to that in the room or the inflow, the flame tip is below the hot gas upper layer or the upper layer is not yet significantly vitiated to increase the CO yield significantly, the flames are not truncated by contact with another object, and the burning rate is controlled by the availability of fuel.

[e] The ratio can be up to an order of magnitude higher for materials that are fire-resistant. There is no significant increase in this ratio for equivalence ratios up to ≈ 0,75. Between ≈ 0,75 and 1, some increase in this ratio may occur.

[f] The fire's oxygen demand is limited by the ventilation opening(s); the flames extend into the upper layer.

[g] Assumed to be similar to well-ventilated flaming.

[h] The plume equivalence ratio has not been measured; the use of a global equivalence ratio is inappropriate.

[i] Instances of lower ratios have been measured. Generally, these result from secondary combustion outside the room vent.

4.4.3 Indirect assessment

An indirect method of assessment is one that uses no **corrosion target** but measures a characteristic of the gases and vapours evolved. For example, the amount of halogen acid produced, or the pH and/or the conductivity of a solution in which the gases and vapours evolved by combustion have been dissolved.

~~Table 1 – General classification of fire stages in accordance with ISO/TR 9122-1~~

~~Fire~~		**~~Oxygen*~~ ~~%~~**	**~~CO_2/CO ratio**~~**	**~~Temperature*~~ ~~°C~~**	**~~Irradiance***~~ ~~kW/m^2~~**
~~Stage 1~~	~~Non-flaming decomposition~~				
	~~a) Smouldering (self-sustaining)~~	~~21~~	~~Not applicable~~	~~<100~~	~~Not applicable~~
	~~b) Non-flaming (oxidative)~~	~~5 to 21~~	~~Not applicable~~	~~<500~~	~~<25~~
	~~c) Non-flaming (pyrolytic)~~	~~<5~~	~~Not applicable~~	~~<1 000~~	~~Not applicable~~
~~Stage 2~~	~~Developing fire (flaming)~~	~~10 to 15~~	~~100 to 200~~	~~400 to 600~~	~~20 to 40~~
~~Stage 3~~	~~Fully developed fire (flaming)~~				
	~~a) Relatively low ventilation~~	~~1 to 5~~	~~<10~~	~~600 to 900~~	~~40 to 70~~
	~~b) Relatively high ventilation~~	~~5 to 10~~	~~<100~~	~~600 to 1 200~~	~~50 to 150~~

~~* General environmental condition (average) within compartment.~~

~~** Mean value in fire plume near to fire.~~

~~*** Incident irradiance on to sample (average)~~

5 Published test methods

5.1 ~~Introduction~~ General

The test methods reviewed in this clause were selected on the basis that they are published in international, national or industry standards, and are in common usage in the electrotechnical field. It is not intended to review all possible test methods.

NOTE These summaries are intended as a brief outline of the test methods and ~~should~~ as such not meant to be used in place of full published standards.

5.2 Tests for the determination of halogen acid in combustion gases

5.2.1 Standards

~~An international standard, IEC 60754-1 [1] [3], and a European standard, EN 50267-2-1 [2], are based on the method described below.~~

International standard IEC 60754-1 [4], which is a test on cable materials, is based on the method described in 5.2.2 to 5.2.6.

5.2.2 Purpose and principle

The standard specifies the procedure for the determination of the amount of halogen acid gas, other than hydrofluoric acid, evolved during the combustion of compounds based on

---

~~[3] Figures in square brackets refer to the bibliography.~~

halogenated polymers, and compounds containing halogenated additives, taken from cable constructions.

~~For reasons of accuracy, the method is not recommended for use where the amount of halogen acid evolved is less than 5 mg/g of the test specimen.~~

For reasons of precision this method is not recommended for reporting values of halogen acid evolved less than 5 mg/g of the sample taken.

5.2.3 Test specimen

~~The test specimen consists of 500 mg to 1 000 mg of the material to be tested, cut into small pieces.~~

The test specimen has a mass of between 0,5 g to 1,0 g cut into a number of small pieces.

5.2.4 Test method

The test specimen is heated in a tube furnace in a stream of air. The temperature of the test specimen is raised at a uniform rate to 800 °C over a time of 40 min and held at 800 °C for 20 min. The air flow is $0{,}0157 \times (D/\mathrm{mm})^2$ litres per hour (where D is the diameter of the furnace tube) so as to give an air velocity in the tube of $20\ \mathrm{m} \times \mathrm{h}^{-1}$ ($0{,}56\ \mathrm{cm} \times \mathrm{s}^{-1}$). At the exit of the tube the gases produced by the thermal decomposition of the test specimen pass through two wash bottles each containing at least 220 ml of 0,1 M sodium hydroxide solution so that any acid gases are absorbed by the alkaline solution. The amount of halogen acid, expressed as hydrochloric acid, is found by titration with silver nitrate and ammonium thiocyanate.

5.2.5 Repeatability and reproducibility

No interlaboratory test data are currently available.

5.2.6 Relevance of test data to corrosion hazard assessment

The method is intended for the type testing of individual components used in cable construction. It is an analytical chemistry test for halogen acid (other than hydrofluoric acid) and does not directly measure **corrosion damage**. It is known that halogen acids cause corrosion, but many other chemical species are also corrosive and these will not be detected by this test. A high halogen acid production will therefore indicate a high corrosive potential, but a low halogen acid content will not necessarily mean a low corrosive potential.

The combustion conditions used in this test are designed to maximize the halogen acid production from materials which contain halogen. They are not designed to model any particular stage of a fire, but they most closely correspond to stage 1c of Table 1, i.e. non-flaming pyrolytic decomposition.

5.3 Tests for the determination of the acidity and conductivity of combustion gases dissolved in an aqueous solution

5.3.1 Standards

One international standard, IEC 60754-2 [5]~~, two European standards, EN 50267-2-2 [4] and EN 50267-2-3 [5]~~, and many national standards, for example, CAN/CSA C22.2 [6], DIN VDE 0472-Part 813 [7] and NF C 20-453 [8], are based on the method described in 5.3.2 to 5.3.6.

Annex A lists differences between some of these methods.

5.3.2 Purpose and principle

Fire effluent, evolved from the **pyrolysis** or combustion of a test specimen, is bubbled through distilled or demineralized water. The pH, or pH and conductivity, of the resulting aqueous solution is then measured.

Such an assessment has the advantage of being both relatively simple and cheap, but has the disadvantage that it does not directly measure **corrosion damage**. An assumption is made that a certain level of the measured parameter will correspond to an unacceptable corrosive potential. This will be valid for a given scenario only if independent measurements have been made to establish such a correlation.

5.3.3 Test specimen

The test specimen ~~typically~~ has a mass of ~~0,5 g or~~ about 1,0 g cut into a number of small pieces.

5.3.4 Test method

An annular furnace is set to a temperature specified in the relevant standard of between 750 °C and 950 °C. The test specimen is located in a porcelain boat inside a quartz glass combustion tube within the furnace. Air is injected upstream of combustion and the combustion gases are bubbled through wash bottles containing distilled or demineralized water.

5.3.5 Repeatability and reproducibility

Repeatability and reproducibility have been determined during interlaboratory trials used to develop the French standard, NF C 20-453:

- repeatability: 4 % to 7 %;
- reproducibility: 9 % to 11 %.

The values depend on test conditions and materials (see Annex B).

5.3.6 Relevance of test data to corrosion hazard assessment

For strong acids and bases, it is known by experience that within a generically similar family of materials the acid/basic gas test can rank materials in the order of their corrosive potential towards a given substrate. It is also known by experience that this may not be true in comparing different families of materials. It is also known by experience that the corrosive potential of an aqueous medium is related to its electrical conductivity.

5.4 Tests for the determination of corrosive gases by ~~using the copper mirror test in ASTM D 2671-00~~ ~~[9]~~ evaluation of copper corrosion in ASTM D 2671 – Sections 89 to 95 [9]

5.4.1 Purpose and principle

~~This test is performed on heat-shrinkable insulating tubing. The test method is used to detect material liable to evolve corrosion products when heated to elevated temperatures. The evolved products condense on to a copper mirror which is subsequently examined for corrosion damage.~~

Three tests are described for heat-shrinkable insulating tubing. Procedure A is a non-contact test using a copper mirror at elevated temperature. Procedure B is contact corrosion with heat. Procedure C is a cyclical-corrosion test using humidity and copper dust.

5.4.2 Test specimen

The test specimens are cut from the tubing (strips which have a total outside area of about 150 mm^2 if the diameter is less than 10,2 mm; a 6 mm × 25 mm strip if the diameter is greater than or equal to 10,2 mm).

5.4.3 Test methods

a) Procedure A

Metal mirrors are used as targets. These are 25 mm long by 6 mm wide. The mirror is vacuum deposited copper with a thickness which gives between 5 % and 15 % transmission of normal incident light of wavelength 500 nm. Corrosion is considered to be removal of the copper and is measured as the percentage of the original coated area which has become transparent. The copper mirror is prepared by depositing copper on a previously cleaned plate of glass in a vacuum. The test pieces are placed in the bottom of a dry test tube, the lower part of which is immersed in an oil bath at the temperature and time specified in the specification. The copper mirror, suspended inside this tube and kept at a temperature of less than 60 °C throughout the test, is used to assess the corrosivity of the products evolved.

b) Procedure B

Tubing is slid over bare copper conductors that are then heated under specified conditions. Afterwards the tubing is slit open and the copper is examined pitting and blackening.

c) Procedure C

Tubing is dusted with powdered copper and then temperature cycled under specified conditions. After this heat treatment the copper is examined for any evidence of extensive green or brown discolouration.

5.4.4 Special observations

These methods ~~is~~ are qualitative. Preparation of the copper mirror is a delicate operation (see ASTM D 2671, sections 85 to 95 [9]). ~~A test duration of 16 h is usually sufficient to determine whether the material is corrosive or not under the conditions of the test.~~ The degradation of the test specimen corresponds to stage 1b of Table 1, i.e. non-flaming oxidative decomposition.

5.4.5 Repeatability and reproducibility

No interlaboratory test results are currently available.

5.4.6 Relevance of test data to corrosion hazard assessment

The test method indicates the potential of a test specimen to generate species capable of corroding copper when undergoing non-flaming oxidative decomposition.

~~5.5 Static method (ISO 11907-2 [10])~~

~~5.5.1 Purpose and principle~~

~~This test is used to assess the potential corrosivity of effluents evolved during combustion of a 600 mg test specimen in a 20 l cylindrical sealed chamber. Corrosivity is assessed by measuring the variation in the resistance of a copper printed wiring board (PWB).~~

~~This variation is due to the corrosive action of effluents condensing on the board. The test is intended to reproduce a defined stage in an actual fire, that is, the combustion of material followed by the condensation of the effluents on a cooled surface.~~

~~5.5.2 Test specimen~~

~~A minimum quantity of 3 g is used to allow five tests to be carried out on individual test specimens of 600 mg ± 2 mg of material. The test specimens are in the form of granules or chips to ensure intimate contact with the ignition source.~~

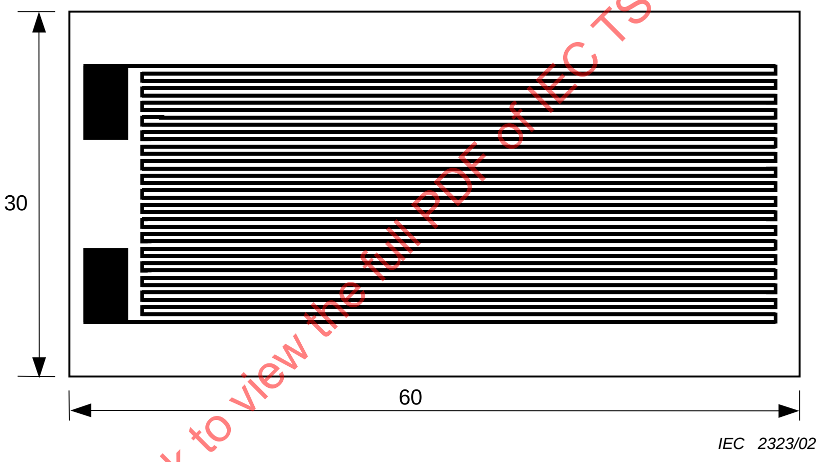
~~5.5.3 Corrosion damage detector~~

~~The corrosion damage detector is a copper printed wiring board with a serpentine geometry.~~

~~The target, shown in Figure 1, is made by etching a copper-plated laminate base to provide 36 conductor tracks each 52 mm long, 0,3 mm wide and 17 µm thick, with a spacing of 0,3 mm. The resistance of the circuit is 8,0 Ω ± 0,5 Ω.~~

~~Condensed combustion products react with the copper if they are corrosive and the corrosion damage is assessed by measurement of the resistance variation due to attack on the copper circuit. The corrosion damage is expressed as a parameter, R_{COR}, which is the percentage change in resistance normalized to a starting resistance of 8,0 Ω.~~

~~*Dimensions in millimetres*~~



~~**Figure 1 – Schematic drawing of a serpentine-track resistance target**~~

~~5.5.4 Test method~~

~~The test chamber is a sealed cylindrical enclosure with a total volume of about 20 l and a diameter of about 30 cm. It is maintained at a temperature of 50 °C and a relative humidity of 65 %. The test specimen is ignited in an inert crucible by an electrical resistance wire held at 800 °C for 3 min.~~

~~The PWB is normally maintained at 40 °C (condensing mode), but tests may also be run without control of the temperature of the PWB (non-condensing mode).~~

~~If required, the corrosion damage detector may be post-conditioned for a specified time at ambient temperature and 75 % relative humidity. Further resistance measurements are taken at 24 h intervals.~~

~~At the start of the test an initial resistance value, R_i, of the circuit is measured, and 60 min after the start of the test a final resistance value, R_f, is measured. A corrosivity value, R_{COR}, is calculated from these two values.~~

~~5.5.5 Special observations~~

~~This method was the product of a joint study between ISO and IEC~~ [4]~~, and is based on a method first developed by CNET ("Centre National d'Etudes des Télécommunications").~~

~~The method makes it possible to assess the direct corrosion damage effect of fire effluent and to observe corrosion deposits on a copper PWB. Although the method described refers only to copper corrosion, the test can be applied to other metallic and non-metallic materials in a variety of detector forms.~~

~~5.5.6 Repeatability and reproducibility~~

~~Only preliminary precision data are available at present. Results and conclusions from an interlaboratory trial of limited scope are given in Annex B of ISO 11907-2 [10]. ISO TC 61/SC 4 is currently conducting a interlaboratory test to assess the effect of temperature on the corrosion target and the internal humidity of the exposure chamber.~~

~~5.5.7 Relevance of test data to corrosion hazard assessment~~

~~The test method makes it possible to produce a ranking of materials in the order of the corrosivity of their combustion products under specific test conditions with regard to combustion temperature, available oxygen, ventilation and different humidity levels.~~

~~5.6 Travelling furnace method (ISO 11907-3 [11])~~

~~5.6.1 Purpose and principle~~

~~This test specifies a method of generating thermal decomposition products from plastic materials or products in an air stream and assessing the corrosion damage effects of these fire effluents on targets. It is not intended that the results be used to assess the corrosivity hazard of fire atmospheres. The decomposition model is suitable for simulating the main fire scenarios, such as a smouldering fire, a developing fire with flame formation, and a fully developed fire.~~

~~The procedure describes a dynamic decomposition test method for the assessment of the corrosion damage of a standardized target by the change in its electrical resistance.~~

~~An annular furnace is set to a specified temperature (normally 600 °C) and is moved at 10 mm × min~~$^{-1}$ ~~over a 400 mm long test specimen located in a quartz cuvette inside a quartz glass tube through which air is passed at a specified flow rate (normally 100 l × h~~$^{-1}$~~). Other temperatures and air flow rates may be used. A corrosion target consisting of a copper printed wiring board (PWB) is exposed to the fire effluents and condensation is enhanced by using a cooling system. After a 40 min exposure the target is placed in an environmental chamber at 23 °C and 75 % relative humidity. The resistance of the target is measured after 1 h and after 24 h. Longer post-exposure times may also be used. Condensed products react with the copper if they are corrosive, and the change in resistance of the target is used to denote the amount of corrosion damage.~~

~~The decomposition model is based on the DIN 53436-1 [12] travelling furnace and is suitable for simulating the main fire scenarios, such as a smouldering fire, a developing fire with flame formation, and a fully developed fire. The test method enables a constant flow of effluent to be maintained throughout the exposure time. The method is applicable to all combustible insulating materials with the exception of those which liberate effluent which may attack the surface of the apparatus.~~

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[4] ~~ISO TC 61/SC 4 and IEC TC 89/WG 11.~~

~~5.6.2 Test specimen~~

~~The test specimen typically consists of 4,8 g of the material to be tested. The sample length is 400 mm and the width is normally 15 mm. The sample may be homogeneous, made up from layers of film or fabric, or may be loose bulk material.~~

~~5.6.3 Corrosion targets~~

~~5.6.3.1 Serpentine-track resistance target~~

~~The corrosion target consists of a serpentine-track resistance target as described in 5.5.3.~~

~~5.6.3.2 Alternative targets~~

~~The following alternative targets may be used:~~

~~a) Metal sheets~~

~~Sheets consisting of any of the following metals: iron, steel, copper, aluminium, zinc. The dimensions of each sheet are 60 mm × 20 mm × the maximum available thickness between 0,7 mm and 1,0 mm. The sheets are cleaned before exposure and any loose corrosion products are carefully removed by brushing under flowing water after exposure. The change in mass, Δm, is measured and other parameters may be calculated such as metal loss per unit area, average reduction in thickness, and rate of mass loss per unit area. In some cases of corrosion, exposure will lead to accelerated oxidation, in which case Δm will be positive, indicating a mass gain. Otherwise Δm will be negative, indicating a loss in mass due to corrosion.~~

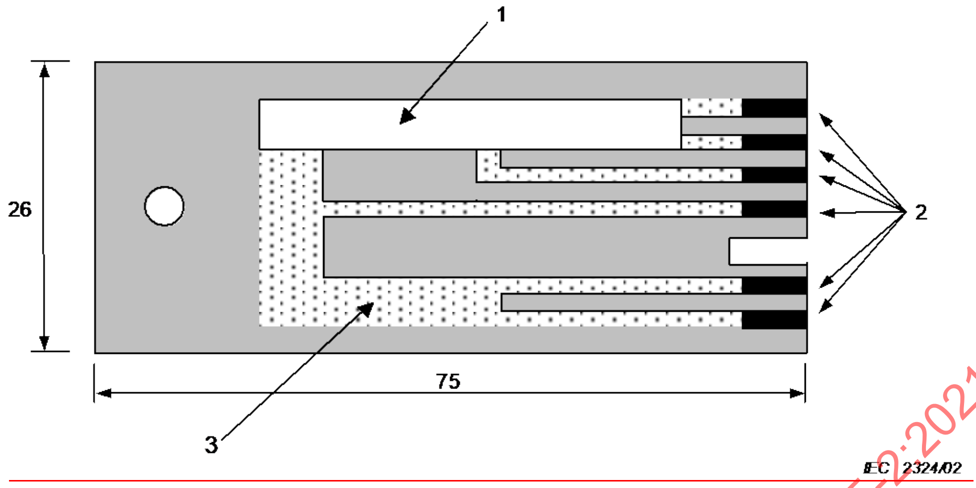
~~b) Resistance targets of defined metal thickness~~

~~The targets are composed of two circuit elements of identical metal assembled on a non-reactive substrate. One circuit element is active and is used for measuring corrosion damage; the other, with a protective coating, is used as a reference. Both of the elements of the target are exposed to combustion products during the test. The type of corrosion damage identified is an increase in electrical resistance due to conductive metal loss. The corrosion-damage measuring instrument consists of a Kelvin bridge, modified for the measurement of the change in electrical resistance of corrosion targets. The reduction in thickness of the metal is calculated from the increase in electrical resistance.~~

~~The type of target used is determined by the application and by the range of corrosion damage. Two copper targets have been used to develop data on the corrosivity of combustion products. A target of 250 nm nominal thickness has been found to be susceptible to complete corrosion in some tests. To measure corrosion in excess of 250 nm, a target of 4 500 nm nominal thickness is recommended in addition to, or instead of, the 250 nm target. With the 250 nm target, metal loss values have been found to be different from those of the 4 500 nm target for the same experiment. Data from each target should therefore be considered separately, and not combined in reporting results for a material or product without appropriate reference to the target used.~~

~~A schematic diagram of a 4 500 nm target is depicted in Figure 2.~~

~~*Dimensions in millimetres*~~



~~**Key**~~

~~1 Active element~~

~~2 Connectors to corrosion-measuring instrument~~

~~3 Reference element~~

~~NOTE The reference element is protected with a non-reactive material.~~

~~**Figure 2 – Schematic drawing of a typical corrosion target of defined metal thickness**~~

~~5.6.4 Test method~~

~~The apparatus continuously decomposes the strip-like test specimen in the 1 300 mm long quartz tube.~~

~~The quartz tube, which has an outside diameter of 40 mm and a wall thickness of 2 mm, is enclosed by a 100 mm long temperature controlled annular furnace. The furnace is moved at a constant speed (10 mm × min^{-1}) along the axis of the tube from a defined position 1 to a defined position 2. In doing so it passes over the test specimen, which is in a quartz glass cuvette at the bottom of the quartz tube. A stream of air is blown over the test specimen in a direction opposite to the direction in which the furnace moves.~~

~~The contrary motion of the furnace and air prevents the hot decomposition gases from unevenly preheating the not yet decomposed parts of the test specimen. The test temperature and its distribution are determined with the reference body described in DIN 53436, Part 1, Section 4.81 [12].~~

~~5.6.5 Special observations~~

~~Gas analysis is possible during the test.~~

~~5.6.6 Repeatability and reproducibility~~

~~No interlaboratory test results are currently available.~~

~~5.6.7 Relevance of test data to corrosion hazard assessment~~

~~Under consideration.~~

5.5 Cone corrosimeter method

5.5.1 Standards

Two standards are based on this method, ISO 11907-4 [11] and ASTM D 5485 [12].

5.5.2 Purpose and principle

This test measures the **corrosion damage** effect, by loss of metal from a target, of the combustion effluents of materials, components or products. The metal loss is calculated from the increase in electrical resistance of the target due to the decrease in conductive cross-sectional area.

5.5.3 Test specimen

The test specimen is limited to a material, component or finished product with a maximum size of 100 mm × 100 mm in area and normally 6 mm in thickness.

5.5.4 Corrosion target

~~The corrosion target is a resistance target of defined metal thickness as described in 5.6.3.2.~~

The target is composed of two circuit elements of identical metal assembled on a non-reactive substrate. One circuit element is active and is used for measuring **corrosion damage**; the other, with a protective coating, is used as a reference. Both of the elements of the target are exposed to combustion products during the test. The type of **corrosion damage** identified is an increase in electrical resistance due to conductive metal loss. The corrosion-damage measuring instrument consists of a Kelvin bridge, modified for the measurement of the change in electrical resistance of **corrosion targets**. The reduction in thickness of the metal is calculated from the increase in electrical resistance.

The type of target used is determined by the application and by the range of **corrosion damage**. Two copper targets have been used to develop data on the corrosivity of combustion products. A target of 250 nm nominal thickness has been found to be susceptible to complete corrosion in some tests. To measure corrosion in excess of 250 nm, a target of 4 500 nm nominal thickness is recommended in addition to, or instead of, the 250 nm target. With the 250 nm target, metal loss values have been found to be different from those of the 4 500 nm target for the same experiment. Data from each target should therefore be considered separately, and not combined in reporting results for a material or product without appropriate reference to the target used.

A schematic diagram of a 4 500 nm target is depicted in Figure 1.

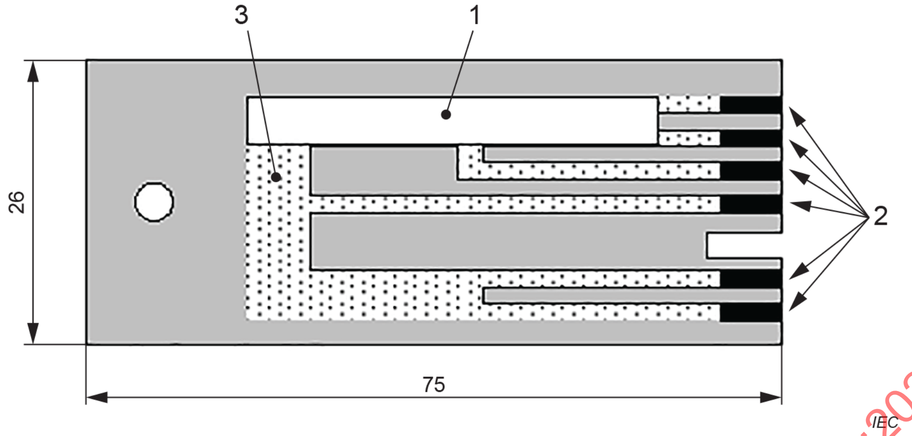
5.5.5 Test method

The test specimen is exposed to a radiant heat flux. A spark igniter is used to ignite the combustible vapours. The products of decomposition or combustion are channelled through a funnel, and a portion of them continuously flows through an exposure chamber which holds the **corrosion target**.

Two preliminary tests are run to determine the average 70 % mass loss value of the test specimen. In the subsequent **corrosion damage** test, if a 70 % mass loss is attained in less than 60 min, the target is exposed to the flowing gases until the 70 % mass loss value is obtained. The exposure chamber is then sealed and exposure continues until 60 min have elapsed from the start of the test. If a 70 % mass loss is not attained in less than 60 min, the target is exposed to the flowing gases until 60 min have elapsed from the start of the test.

After exposure, the metal loss is calculated from the increase in electrical resistance of the target. The target is then placed in a separate chamber, with a controlled relative humidity of 75 % and at a temperature of 23 °C, for 24 h after which the metal loss is again determined.

Dimensions in millimetres



Key

1 Active element

2 Connectors to corrosion-measuring instrument

3 Reference element

NOTE The reference element is protected with a non-reactive material.

Figure 1 – Schematic drawing of a typical corrosion target of defined metal thickness

5.5.6 Special observation

The method makes it possible to test some finished products and to assess the direct **corrosion damage** effects on copper in a printed circuit board.

ASTM D 5485 is intended for use in evaluations of electrical insulations or covering products, for additional data to assist in the design of electrical insulations or covering products, or for development and research of electrical insulations or coverings products. The ASTM test does not prescribe the heating flux level to be used but states that it should be relevant to the fire scenario being investigated (up to 100 kW × m^{-2}).

ISO 11907-4 is intended for the evaluation of materials or products, for additional data to assist in the design of products, and for development and research purposes. The ISO test recommends an irradiance of 50 kW × m^{-2} or other heating fluxes up to 100 kW × m^{-2}.

5.5.7 Repeatability and reproducibility

No interlaboratory test results are currently available.

5.5.8 Relevance of test data to corrosion hazard assessment

The method should be used to measure and describe the response of materials and/or products to heat and flame under controlled conditions but ~~should~~ shall not be used to describe or appraise the fire hazard or fire risk of materials under actual fire conditions. However, results of this test may be used as elements of a fire hazard or risk assessment, insofar as they relate to a particular end use.

~~6 Leakage current and metal loss (IEC 60695-5-3)~~

~~6.1 Purpose and principle~~

~~This test method allows the measurement of both leakage current [15] and metal loss corrosion damage. In leakage current tests, standardized interdigitated comb pattern printed~~

~~wiring board targets are used in order to determine the propensity of the test specimen's combustion products to develop leakage current paths in printed wiring board circuitry. Metal loss corrosion damage may be determined by measuring the mass loss of metal foils, or by measuring the electrical resistance of appropriate targets when they are exposed to the test specimen's combustion products.~~

~~The decomposition model is suitable for simulating stages 1a, 2 and 3a fires.~~

~~6.2 Test specimen~~

~~The test specimen comprises 1 g of material taken from a larger batch of raw material, or from a discrete product, or from a part of a product or from a component of a product.~~

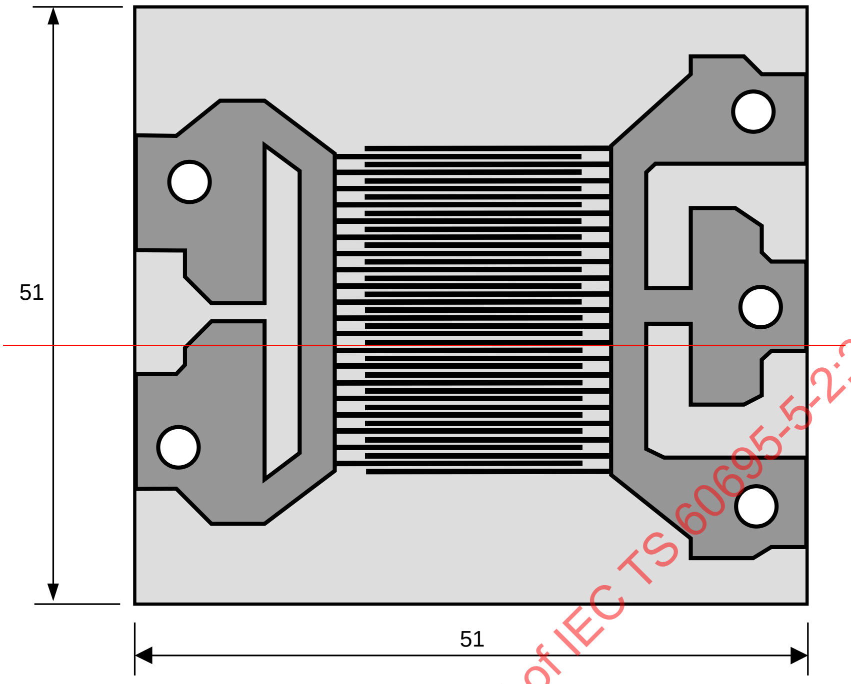
~~6.3 Corrosion targets~~

~~6.3.1 Leakage current measurement~~

~~The leakage current target is used to measure leakage current which can be caused by the deposition of electrically conductive combustion products on the surface of printed wiring boards. The target, as shown in Figure 3, is a copper interdigitated circuit. The width of the conducting elements and the spacing between the conducting elements is 0,32 mm. The copper surfaces are solder tinned and mounted on a 1,6 mm thick printed wiring board laminate.~~

~~After exposure to combustion products, the target is subjected to stepped increases in relative humidity while energized with a potential of 50 V d.c. The leakage current across the target's comb pattern circuit is measured at 10 % relative humidity increments ranging from 30 % relative humidity to 90 % relative humidity.~~

~~Dimensions in millimetres~~



IEC 2325/02

~~Figure 3 – Interdigitated leakage current target~~

~~6.3.2 Metal loss corrosion damage measurement~~

~~Metal loss is measured directly using metal foils, or indirectly from the measurement of appropriate electrical resistance targets. Details of these targets are given in 5.5.3 and 5.6.3.2.~~

~~6.4 Test method~~

~~Combustion products are generated by heating the test specimen in a flow of air in a tube furnace. Different temperatures and air flows are used to simulate different fire conditions. The targets are exposed to the combustion products under defined conditions and then measurements of metal loss or electrical resistance or leakage current are made.~~

6 Overview of methods and relevance of data

The methods outlined in Clause 5~~ and 6~~ are summarized in Table 2, in terms of limitations of the test method, and applicability to the fire stages defined in Table 1. These methods are based on a wide variety of **physical fire model**s and test specimen geometries, which can have a major effect on way in which **fire effluent** is produced.

Product committees intending to adopt or modify any of these test methods ~~should~~ shall ensure that the method is appropriate and suitable for the intended use.

The tests are intended to be used to evaluate the relative degree of possible **corrosion damage** effects of fire gases to exposed materials and products under controlled laboratory conditions, and should not be considered, or used, for describing or appraising the corrosion risk of materials, products or systems under actual fire conditions.

In order to assess the risk of **corrosion damage** when materials burn, the ranking of materials by corrosivity should be combined with their heat and flame response characteristics (for example, ignitability, surface spread of flame, rate of heat release). The assessment of risk of **corrosion damage** in the event of fire requires consideration of many factors including fuel load, intensity of burning, ventilation conditions, humidity levels and the nature of the exposed surfaces.

NOTE These methods are based on a wide variety of **physical fire models** and test specimen geometries, which can affect the nature of the corrosive species generated from a material or product. Therefore it cannot be assumed that the rank ordering of corrosion data from materials or products from one test will be the same as the rank ordering from another test.

Table 2 – Overview of corrosivity test methods

Test method	Clause reference	Type of test method	Limitations on test specimen	Relevance to stage of fire						Limitations on use as an isolated test ~~for regulatory purposes~~
				1(a)	1(b)	1(c)	2	3(a)	3(b)	
Determination of halogen acid in combustion gases	5.2	Indirect	500 mg to 1 000 mg of the material to be tested, cut into small pieces	No	No	Yes	No	No	No	Only where the correlation between the measured value and the corrosivity potential has been established
Determination of the acidity and conductivity of combustion gases dissolved in an aqueous solution	5.3	Indirect	~~500~~ 995 mg to ~~1 000~~ 1 005 mg of the material to be tested, cut into small pieces	No	No	Yes	No	No	No	Only where the correlation between the measured value and the corrosivity potential has been established
Copper ~~mirror test~~ corrosion	5.4	Simulated product (metal loss)	2,5 cm long samples cut from heat-shrinkable tubing	No	Yes	No	No	No	No	Only where metal loss is of concern
~~Static method~~	~~5.5~~	~~Simulated product (metal loss)~~	~~600 mg of the material to be tested, in the form of granules or chips~~	~~No~~	~~No~~	~~No~~	~~Yes~~	~~No~~	~~No~~	~~Only limited experimental work has been done and the applicability is unknown~~
~~Travelling furnace~~	~~5.6~~	~~Simulated product (metal loss)~~	~~400 mm long × 15 mm wide. Thickness to give a mass of 4,8 g~~	~~No~~	~~Yes~~	~~Yes~~	~~Yes~~	~~Yes~~	~~Yes~~	~~Only where metal loss is of concern~~
Cone corrosimeter	5.5	Simulated product (metal loss)	100 mm × 100 mm × 6 mm cut from a representative sample of the material or end product	No	Yes	No	Yes	No	Yes	Only where metal loss is of concern
~~IEC 60695-5-3~~	~~6~~	~~Simulated product (leakage current and metal loss)~~	~~1 g of the material to be tested~~	~~Yes~~	~~No~~	~~No~~	~~Yes~~	~~Yes~~	~~No~~	~~Only limited experimental work has been done and the applicability is unknown~~

Annex A
(informative)

Acidity and conductivity of aqueous solutions – Test methods

Table A.1 shows test methods for the measurement of acidity and conductivity of aqueous solutions obtained after bubbling combustion effluent through water.

Table A.1 – Test methods for the measurement of acidity and conductivity of aqueous solutions obtained after bubbling combustion effluent through water

Parameters	IEC 60754-2 [5]	CAN/CSA C22.2 [6]	DIN VDE 0472, Part 813 [7]	NF C20-453 [8]
Temperature of combustion (°C)	950 ± 15	800 ± 10	750 to 800	800 ± 10
Test specimen mass (mg)	1 000 ± 5	500 ± 50	1 000	500 ± 1
Nature of test specimen	Divided into small pieces	–	–	One piece only
Air flow rate ($dm^3 \times h^{-1}$)	15 to 30	Approximately 6	10 ± 3	15 to 30
Volume of water for absorption (cm^3)	1 000	600	170	75 ± 5
Final volume for measurement (cm^3)	1 000	1 000	170	500
Time of measurement	After combustion	After combustion	During and after combustion	After combustion

Annex B
(informative)

Determination of repeatability and reproducibility – Comparative tests of solutions of combustion gases

These tests were carried out during the study of the French standard NF C 20-453 [8]. It was found that the repeatability and the reproducibility were better when the tested materials were homogeneous, without filler.

In Tables B.1, B.2 and B.3 each numerical value is the average obtained from four measurements, except when a different number of measurements is indicated in brackets, after the value of the parameter. In some cases minimum values or maximum values are given instead of the average value. The procedure used is described in French standard NF C 20-453 (see also Annex A).

Repeatability and reproducibility

The estimated value of these parameters are:

- repeatability: 4 % to 7 %;
- reproducibility: 9 % to 11 %.

(see experimental results in Tables B.1, B.2 and B.3).

Table B.1 – Determination of repeatability and reproducibility – Comparative pH tests on solutions of combustion gases

Laboratory no.	pH	Material A	Material B	Material C	Material D	Material E	Material F	Material G	Material H
1	Average	2,87	8,1	8,1 max.	4,03	6,33 max.	4,93	8,03	2,2
	Standard deviation	0,12	0	0,06	0,06	0,49	0,12	0,23	0,1
2	Average	2,67 min.	–	5,93 min.	4	4,23 min.	4,26 min.	6,18	2,26
	Standard deviation	0,06	–	0,15	0,11	0,03	0,04	0,1	0,08
3	Average	2,85	7,53	7,32	4,1	5,75	–	8,34	2,2
	Standard deviation	0,13	0,16	0,48	0,1	0,33	–	0,77	0,1
4	Average	3,02 max.	7,7	7,6 ($n = 6$)	4,28 max.	5,14 ($n = 5$)	4,67 ($n = 7$)	8,3	2,31 ($n = 7$)
	Standard deviation	0,03	0,09	0,17	0,08	0,18	0,18	0,26	0,07
5	Average	2,87	–	–	3,8	4,47	4,33	6,33	2,35 ($n = 3$)
	Standard deviation	0,08	–	–	0,05	0,06	0,06	0,23	0
6	Average	2,79	6,44 min.	6,25	4,11 ($n = 14$)	4,6	4,52	8,5 max.	2,12
	Standard deviation	0,06	0,1	0,05	0,28	0,08	0,02	0,26	0,01
7	Average	2,81	7,28	6,53	4,25	5,1	4,75	6,8	–
	Standard deviation	0,035	0,65	0,82	0,05	0,04	0,05	0,13	–
8	Average	2,74 ($n = 1$)	8,36 ($n = 1$)	8,32 ($n = 1$)	3,65 ($n = 1$)	6,31 ($n = 1$)	5,49 ($n = 1$)	7,36	1,95 max. ($n = 2$)
	Standard deviation	0	0	0	0	0	0	0,3	0,01
9	Average	2,72	7,07	7,1	3,86	5,93	4,78	6,01 min.	–
	Standard deviation	0,06	0,04	0,18	0,12	0,26	0,06	0,21	–

Table B.2 – Determination of repeatability and reproducibility – Comparative resistivity tests on solutions of combustion gases

Laboratory no.	Resistivity Ω×cm	Material A	Material B	Material C	Material D	Material E	Material F	Material G	Material H
1	Average	2 200	15 600	20 330	21 000	437 000	97 700	9 800	480
	Standard deviation	520	2 780	577	1 000	142 000	6 350	1 320	40
2	Average	545 min.	–	59 000 max.	21 000	607 000	109 000	140 000	540
	Standard deviation	88	–	2 000	1 000	23 100	35 800	10 000	52,9
3	Average	2 450 max.	12 800	14 830	28 700	106 000	–	19 430	486
	Standard deviation	610	609	290	2 660	63 800	–	6 470	82
4	Average	1 573	17 410	18 742 (n = 6)	21 908	106 655 (n = 5)	51 756 (n = 7)	11 300	345 (n = 7)
	Standard deviation	50	997	2 335	1 914	22 546	7 729	2 076	8
5	Average	1 533	–	–	14 000	81 667	53 333	20 667	343
	Standard deviation	252	–	–	1 732	4 163	2 082	1 528	12
6	Average	1 660	10 070 min.	8 710	19 600 (n = 14)	63 500	28 500	9 230	356
	Standard deviation	102	1 975	1 680	9 452	9 125	5 577	2 665	24
7	Average	1 487	35 370	45 700	26 470	146 700	65 170	14 430	–
	Standard deviation	47,3	31 905	36 645	3 180	41 970	2 200	764	–
8	Average	1 700 (n = 1)	27 000 (n = 1)	18 000 (n = 1)	8 800 (n = 1)	17 600 (n = 1)	36 000 (n = 1)	13 300	320 (n = 2)
	Standard deviation	0	0	0	0	0	0	3 300	14
9	Average	1 922	61 010 max.	50 810	25 730	127 900	110 900	20 260	–
	Standard deviation	109	5 930	9 630	7 310	2 840	11 000	1 350	–

Table B.3 – Results obtained on brominated polycarbonate

Laboratory no.	Air flow l × h^{-1}	Resistivity Ω × cm			pH		
		Average	Standard deviation	Variance	Average	Standard deviation	Variance
1	30	21 000	1 000	0,048	4,03	0,06	0,014
2	30	21 000	1 000	0,048	4,00	0,11	0,027
3	30	28 700	2 660	0,093	4,10	0,10	0,023
4	30	21 900	1 900	0,087	4,28	0,08	0,018
5	30	14 000	1 730	0,124	3,80	0,05	0,013
6	11	19 600	[a]	[a]	4,11	[a]	[a]
7	30	26 500	3 200	0,121	4,27	0,05	0,011
8 [b]	–	–	–	–	–	–	–
9	60	25 700	7 300	0,284	3,86	0,12	0,031

[a] No data available.

[b] No test carried out.

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~~[2] EN 50267-2-1:1998, *Common test methods for cables under fire conditions – Tests on gases evolved during combustion of materials from cables – Part 2-1: Procedures – Determination of the amount of halogen acid gas*~~

~~[3] IEC 60754-2:1991, *Test on gases evolved during combustion of electric cables – Part 2: Determination of degree of acidity of gases evolved during the combustion of materials taken from electric cables by measuring pH and conductivity*~~
~~Amendment 1 (1997)~~

~~[4] EN 50267-2-2:1998, *Common test methods for cables under fire conditions – Tests on gases evolved during combustion of materials from cables – Part 2-2: Procedures – Determination of degree of acidity of gases for materials by measuring pH and conductivity*~~

~~[5] EN 50267-2-3:1998, *Common test methods for cables under fire conditions – Tests on gases evolved during combustion of materials from cables – Part 2-3: Procedures – Determination of degree of acidity of gases for cables by determination of the weighted average of pH and conductivity*~~

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~~[7] DIN VDE 0472, Part 813:1992, *Testing of cables, wires and flexible cords; corrosivity of combustion gases*~~

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IEC TS 60695-5-2

Edition 3.0 2021-06

TECHNICAL SPECIFICATION

Fire hazard testing –
Part 5-2: Corrosion damage effects of fire effluent – Summary and relevance of test methods

IEC TS 60695-5-2:2021-06(en)

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

FIRE HAZARD TESTING –

Part 5-2: Corrosion damage effects of fire effluent – Summary and relevance of test methods

FOREWORD

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IEC 60695-5-2, which is a technical specification, has been prepared by IEC technical committee 89: Fire hazard testing.

This third edition cancels and replaces the second edition published in 2002.

The main changes with respect to the previous edition are listed below:

- References to IEC TS 60695-5-3 (withdrawn in 2014) have been removed.
- ISO/TR 9122-1 has been revised by ISO 19706.
- References to ISO 11907-2 and ISO 11907-3 have been removed.
- Terms and definitions have been updated.
- Text in 5.4 has been updated.
- Text in 5.5.8 (5.7.8 in Ed. 2) has been updated.
- Text in Clause 6 (7 in Ed. 2) has been updated.

– Bibliographic references have been updated.

It has the status of a basic safety publication in accordance with IEC Guide 104 and ISO/IEC Guide 51.

The text of this technical specification is based on the following documents:

Draft	Report on voting
89/1473/DTS	89/1506/RVDTS

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Specification is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

In this technical specification, the following print types are used:

Arial bold: terms referred to in Clause 3

This technical specification is to be read in conjunction with IEC 60695-5-1.

A list of all parts in the IEC 60695 series, published under the general title *Fire hazard testing*, 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 webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

INTRODUCTION

In the design of an electrotechnical product the risk of fire and the potential hazards associated with fire need to be considered. In this respect the objective of component, circuit and equipment design, as well as the choice of materials, is to reduce the risk of fire to a tolerable level even in the event of reasonably foreseeable (mis)use, malfunction or failure. IEC 60695-1-10 [1][1], IEC 60695-1-11 [2], and IEC 60695-1-12 [3] provide guidance on how this is to be accomplished.

Fires involving electrotechnical products can also be initiated from external non-electrical sources. Considerations of this nature are dealt with in an overall fire hazard assessment.

The aim of the IEC 60695 series is to save lives and property by reducing the number of fires or reducing the consequences of the fire. This can be accomplished by:

- trying to prevent ignition caused by an electrically energised component part and, in the event of ignition, to confine any resulting fire within the bounds of the enclosure of the electrotechnical product.
- trying to minimise flame spread beyond the product's enclosure and to minimise the harmful effects of **fire effluent**s including heat, **smoke**, and toxic or corrosive combustion products.

All **fire effluent** is corrosive to some degree and the level of potential to corrode depends on the nature of the fire, the combination of combustible materials involved in the fire, the nature of the substrate under attack, and the temperature and relative humidity of the environment in which the corrosion is taking place. There is no evidence that **fire effluent** from electrotechnical products offers greater risk of **corrosion damage** than the **fire effluent** from other products such as furnishings, building materials, etc.

The performance of electrical and electronic components can be adversely affected by **corrosion damage** when subjected to **fire effluent**. A wide variety of combinations of small quantities of effluent gases, **smoke** particles, moisture and temperature may provide conditions for electrical component or system failures from breakage, overheating or shorting.

Evaluation of potential **corrosion damage** is particularly important for high value and safety-related electrotechnical products and installations.

Technical committees responsible for the products will choose the test(s) and specify the level of severity.

The study of **corrosion damage** requires an interdisciplinary approach involving chemistry, electricity, physics, mechanical engineering, metallurgy and electrochemistry. In the preparation of this part of IEC 60695, all of the above have been considered.

IEC 60695-5-1 defines the scope of the guidance and indicates the field of application.

IEC 60695-5-2 provides a summary of test methods including relevance and usefulness.

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[1] Numbers in square brackets refer to the bibliography.

FIRE HAZARD TESTING –

Part 5-2: Corrosion damage effects of fire effluent – Summary and relevance of test methods

1 Scope

This part of IEC 60695, which is a technical specification, gives a summary of the test methods that are used in the assessment of the corrosivity of **fire effluent**. It presents a brief summary of test methods in common use, either as international standards or national or industry standards. It includes special observations on their relevance, for electrotechnical products and their materials, to real **fire scenario**s and gives recommendations on their use.

One of the responsibilities of a technical committee is, wherever applicable, to make use of basic safety publications in the preparation of its publications. The requirements, test methods or test conditions of this publication will not apply unless specifically referred to or included in the relevant publications.

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 60695-4:2012, *Fire hazard testing – Part 4: Terminology concerning fire tests for electrotechnical products*

IEC 60695-5-1, *Fire hazard testing – Part 5-1: Corrosion damage effects of fire effluent - General guidance*

IEC GUIDE 104, *The preparation of safety publications and the use of basic safety publications and group safety publications*

ISO Guide 51, *Safety aspects – Guidelines for their inclusion in standards*

ISO 13943:2017*, Fire safety – Vocabulary*

ISO 19706:2011*, Guidelines for assessing the fire threat to people*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60695-4:2012 and ISO 13943:2017 (some of which are reproduced below), apply.

3.1
corrosion damage
physical and/or chemical damage or impaired function caused by chemical action

[SOURCE: ISO 13943:2017, 3.69]

3.2

corrosion target

sensor used to determine the degree of **corrosion damage** (3.1), under specified test conditions

Note 1 to entry: This sensor may be a product, a component. It may also be a reference material or object used to simulate the behaviour of a product or a component.

[SOURCE: ISO 13943:2017, 3.70]

3.3

fire effluent

all gases and aerosols, including suspended particles created by combustion or **pyrolysis** (3.6) and emitted to the environment

[SOURCE: ISO 13943:2017, 3.123]

3.4

fire scenario

qualitative description of the course of a fire with respect to time, identifying key events that characterize the studied fire and differentiate it from other possible fires

Note 1 to entry: See **fire scenario cluster** (ISO 13943:2017, 3.154) and **representative fire scenario** (ISO 13943:2017, 3.153).

Note 2 to entry: It typically defines the ignition and fire growth processes, the fully developed fire stage, the fire decay stage, and the environment and systems that will impact on the course of the fire.

Note 3 to entry: Unlike deterministic fire analysis, where fire scenarios are individually selected and used as design fire scenarios, in fire risk assessment, fire scenarios are used as representative fire scenarios within fire scenario clusters.

[SOURCE: ISO 13943:2017, 3.152]

3.5

physical fire model

laboratory process, including the apparatus, the environment and the fire test procedure intended to represent a certain phase of a fire

[SOURCE: ISO 13943:2017, 3.298]

3.6

pyrolysis

chemical decomposition of a substance by the action of heat

Note 1 to entry: Pyrolysis is often used to refer to a stage of fire before flaming combustion has begun.

Note 2 to entry: In fire science, no assumption is made about the presence or absence of oxygen.

[SOURCE: ISO 13943:2017, 3.316]

3.7

smoke

visible part of a **fire effluent** (3.3)

[SOURCE: ISO 13943:2017, 3.347]

4 Classification of test methods

4.1 General

Test methods can be classified according to three criteria:

a) the nature of the test specimen which is burned;
b) the **physical fire model** used in the test;
c) the nature of the measurement of corrosivity.

4.2 Test specimen

4.2.1 Product testing

The test specimen is a manufactured product or a representative portion of a product. Examples include: a printed circuit board, a switchboard, a computer or a cable.

4.2.2 Material or composite sample testing

The test specimen is a basic material (solid or liquid), or composite of materials.

4.3 The physical fire model

Test methods use a wide variety of heat sources and geometries. The amount, the rate of production and the corrosive nature of **fire effluent** released from a given material or product is not an inherent property of that material or product, but is critically dependent on the conditions under which that material or product is burnt. In a **fire scenario** or a fire test, the chemical nature of the fuel, the decomposition temperature and the amount of ventilation are the main variables which affect the composition of **fire effluent**.

It is critical to show that the test conditions defined in a standardized test method are relevant to, and replicate, the desired stage of a real fire. ISO has published a general classification of fire stages in ISO 19706, shown in Table 1. The important factors affecting effluent production are oxygen concentration and irradiance/temperature.

4.4 The nature of the corrosivity measurement

4.4.1 Product as target

In these cases the **corrosion target** is a manufactured product or a representative portion of a product. Examples include: printed wiring boards, switchboards, washing machines and computers.

The **corrosion damage** effects of **fire effluent** on the product can be assessed by degradation of function as determined by inspection or measurement.

4.4.2 Simulated product as target

When a simulated product is used as the target, the **corrosion target** is typically a reference circuit, a thin sheet of metal or a metal mirror. The **corrosion damage** effects of **fire effluent** on the target can be assessed by changes in appearance, mass or measurements of mechanical, physical or electrical characteristics.

Table 1 – Characteristics of fire stages (from Table 1 in ISO 19706:2011)

Fire stage	Heat flux to fuel surface kW/m^2	Max. temperature °C		Oxygen volume %		Fuel/air equivalence ratio (plume)	$\frac{[CO]}{[CO_2]}$ v/v	$\frac{100\times[CO_2]}{([CO_2]+[CO])}$ % efficiency
		Fuel surface	**Upper layer**	**Entrained**	**Exhausted**			
1 Non-flaming								
a self-sustaining (smouldering)	not applicable	450 to 800	25 to 85 [d]	20	20	–	0,1 to 1	50 to 90
b oxidative pyrolysis from externally applied radiation	–	300 to 600 a	[b]	20	20	< 1	[c]	[c]
c anaerobic pyrolysis from externally applied radiation	–	100 to 500	[b]	0	0	>> 1	[c]	[c]
2 Well-ventilated flaming [d]	0 to 60	350 to 650	50 to 500	≈ 20	≈ 20	< 1	< 0,05 [e]	> 95
3 Underventilated flaming [f]								
a small, localized fire, generally in a poorly ventilated compartment	0 to 30	300 to 600 [a]	50 to 500	15 to 20	5 to 10	> 1	0,2 to 0,4	70 to 80
b post-flashover fire	50 to 150	350 to 650 [g]	> 600	< 15	< 5	> 1 [h]	0,1 to 0,4 [i]	70 to 90

[a] The upper limit is lower than for well-ventilated flaming combustion of a given combustible.

[b] The temperature in the upper layer of the fire room is most likely determined by the source of the externally applied radiation and room geometry.

[c] There are few data, but for pyrolysis this ratio is expected to vary widely depending on the material chemistry and the local ventilation and thermal conditions.

[d] The fire's oxygen consumption is small compared to that in the room or the inflow, the flame tip is below the hot gas upper layer or the upper layer is not yet significantly vitiated to increase the CO yield significantly, the flames are not truncated by contact with another object, and the burning rate is controlled by the availability of fuel.

[e] The ratio can be up to an order of magnitude higher for materials that are fire-resistant. There is no significant increase in this ratio for equivalence ratios up to ≈ 0,75. Between ≈ 0,75 and 1, some increase in this ratio may occur.

[f] The fire's oxygen demand is limited by the ventilation opening(s); the flames extend into the upper layer.

[g] Assumed to be similar to well-ventilated flaming.

[h] The plume equivalence ratio has not been measured; the use of a global equivalence ratio is inappropriate.

[i] Instances of lower ratios have been measured. Generally, these result from secondary combustion outside the room vent.

4.4.3 Indirect assessment

An indirect method of assessment is one that uses no **corrosion target** but measures a characteristic of the gases and vapours evolved. For example, the amount of halogen acid produced, or the pH and/or the conductivity of a solution in which the gases and vapours evolved by combustion have been dissolved.

5 Published test methods

5.1 General

The test methods reviewed in this clause were selected on the basis that they are published in international, national or industry standards, and are in common usage in the electrotechnical field. It is not intended to review all possible test methods.

NOTE These summaries are intended as a brief outline of the test methods and as such not meant to be used in place of full published standards.

5.2 Tests for the determination of halogen acid in combustion gases

5.2.1 Standards

International standard IEC 60754-1 [4], which is a test on cable materials, is based on the method described in 5.2.2 to 5.2.6.

5.2.2 Purpose and principle

The standard specifies the procedure for the determination of the amount of halogen acid gas, other than hydrofluoric acid, evolved during the combustion of compounds based on halogenated polymers, and compounds containing halogenated additives, taken from cable constructions.

For reasons of precision this method is not recommended for reporting values of halogen acid evolved less than 5 mg/g of the sample taken.

5.2.3 Test specimen

The test specimen has a mass of between 0,5 g to 1,0 g cut into a number of small pieces.

5.2.4 Test method

The test specimen is heated in a tube furnace in a stream of air. The temperature of the test specimen is raised at a uniform rate to 800 °C over a time of 40 min and held at 800 °C for 20 min. The air flow is $0{,}0157 \times (D/\mathrm{mm})^2$ litres per hour (where D is the diameter of the furnace tube) so as to give an air velocity in the tube of $20\ \mathrm{m} \times \mathrm{h}^{-1}$ ($0{,}56\ \mathrm{cm} \times \mathrm{s}^{-1}$). At the exit of the tube the gases produced by the thermal decomposition of the test specimen pass through two wash bottles each containing at least 220 ml of 0,1 M sodium hydroxide solution so that any acid gases are absorbed by the alkaline solution. The amount of halogen acid, expressed as hydrochloric acid, is found by titration with silver nitrate and ammonium thiocyanate.

5.2.5 Repeatability and reproducibility

No interlaboratory test data are currently available.

5.2.6 Relevance of test data to corrosion hazard assessment

The method is intended for the type testing of individual components used in cable construction. It is an analytical chemistry test for halogen acid (other than hydrofluoric acid) and does not directly measure **corrosion damage**. It is known that halogen acids cause corrosion, but many other chemical species are also corrosive and these will not be detected by this test. A high halogen acid production will therefore indicate a high corrosive potential, but a low halogen acid content will not necessarily mean a low corrosive potential.

The combustion conditions used in this test are designed to maximize the halogen acid production from materials which contain halogen. They are not designed to model any particular stage of a fire, but they most closely correspond to stage 1c of Table 1, i.e. non-flaming pyrolytic decomposition.

5.3 Tests for the determination of the acidity and conductivity of combustion gases dissolved in an aqueous solution

5.3.1 Standards

One international standard, IEC 60754-2 [5], and many national standards, for example, CAN/CSA C22.2 [6], DIN VDE 0472-Part 813 [7] and NF C 20-453 [8], are based on the method described in 5.3.2 to 5.3.6.

Annex A lists differences between some of these methods.

5.3.2 Purpose and principle

Fire effluent, evolved from the **pyrolysis** or combustion of a test specimen, is bubbled through distilled or demineralized water. The pH, or pH and conductivity, of the resulting aqueous solution is then measured.

Such an assessment has the advantage of being both relatively simple and cheap, but has the disadvantage that it does not directly measure **corrosion damage**. An assumption is made that a certain level of the measured parameter will correspond to an unacceptable corrosive potential. This will be valid for a given scenario only if independent measurements have been made to establish such a correlation.

5.3.3 Test specimen

The test specimen has a mass of about 1,0 g cut into a number of small pieces.

5.3.4 Test method

An annular furnace is set to a temperature specified in the relevant standard of between 750 °C and 950 °C. The test specimen is located in a porcelain boat inside a quartz glass combustion tube within the furnace. Air is injected upstream of combustion and the combustion gases are bubbled through wash bottles containing distilled or demineralized water.

5.3.5 Repeatability and reproducibility

Repeatability and reproducibility have been determined during interlaboratory trials used to develop the French standard, NF C 20-453:

- repeatability: 4 % to 7 %;
- reproducibility: 9 % to 11 %.

The values depend on test conditions and materials (see Annex B).

5.3.6 Relevance of test data to corrosion hazard assessment

For strong acids and bases, it is known by experience that within a generically similar family of materials the acid/basic gas test can rank materials in the order of their corrosive potential towards a given substrate. It is also known by experience that this may not be true in comparing different families of materials. It is also known by experience that the corrosive potential of an aqueous medium is related to its electrical conductivity.

5.4 Tests for the determination of corrosive gases by evaluation of copper corrosion in ASTM D 2671 – Sections 89 to 95 [9]

5.4.1 Purpose and principle

Three tests are described for heat-shrinkable insulating tubing. Procedure A is a non-contact test using a copper mirror at elevated temperature. Procedure B is contact corrosion with heat. Procedure C is a cyclical-corrosion test using humidity and copper dust.

5.4.2 Test specimen

The test specimens are cut from the tubing (strips which have a total outside area of about 150 mm^2 if the diameter is less than 10,2 mm; a 6 mm × 25 mm strip if the diameter is greater than or equal to 10,2 mm).

5.4.3 Test methods

a) Procedure A

Metal mirrors are used as targets. These are 25 mm long by 6 mm wide. The mirror is vacuum deposited copper with a thickness which gives between 5 % and 15 % transmission of normal incident light of wavelength 500 nm. Corrosion is considered to be removal of the copper and is measured as the percentage of the original coated area which has become transparent. The copper mirror is prepared by depositing copper on a previously cleaned plate of glass in a vacuum. The test pieces are placed in the bottom of a dry test tube, the lower part of which is immersed in an oil bath at the temperature and time specified in the specification. The copper mirror, suspended inside this tube and kept at a temperature of less than 60 °C throughout the test, is used to assess the corrosivity of the products evolved.

b) Procedure B

Tubing is slid over bare copper conductors that are then heated under specified conditions. Afterwards the tubing is slit open and the copper is examined pitting and blackening.

c) Procedure C

Tubing is dusted with powdered copper and then temperature cycled under specified conditions. After this heat treatment the copper is examined for any evidence of extensive green or brown discolouration.

5.4.4 Special observations

These methods are qualitative. Preparation of the copper mirror is a delicate operation (see ASTM D 2671, sections 85 to 95 [9]). The degradation of the test specimen corresponds to stage 1b of Table 1, i.e. non-flaming oxidative decomposition.

5.4.5 Repeatability and reproducibility

No interlaboratory test results are currently available.

5.4.6 Relevance of test data to corrosion hazard assessment

The test method indicates the potential of a test specimen to generate species capable of corroding copper when undergoing non-flaming oxidative decomposition.