BRITISH STANDARD

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60544-4:2003

Electrical insulating materials — Determination of the effects of ionizing radiation —

Part 4: Classification system for service in radiation environments

The European Standard EN 60544-4:2003 has the status of a British Standard

ICS 17.240; 29.035.01

National foreword

This British Standard is the official English language version of EN 60544-4:2003. It is identical with IEC 60544-4:2003. It supersedes BS 7811-4:1995 which is withdrawn.

The UK participation in its preparation was entrusted by Technical Committee GEL/15, Insulating material, to Subcommittee GEL/15/5, Methods of test, which has the responsibility to:

— aid enquirers to understand the text;

— present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;

— monitor related international and European developments and promulgate them in the UK.

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English version

Electrical insulating materials - Determination of the effects of ionizing radiation Part 4: Classification system for service in radiation environments
(IEC 60544-4:2003)

Matériaux isolants électriques -
Détermination des effets
des rayonnements ionisants
Partie 4: Système de classification
pour l'utilisation dans un environnement
sous rayonnement
(CEI 60544-4:2003)

Elektroisolierstoffe -
Bestimmung der Wirkung
ionisierender Strahlung
Teil 4: Klassifikationssystem
für den Einsatz unter Strahlung
(IEC 60544-4:2003)

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Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CENELEC member.

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Foreword

The text of document 15E/218/FDIS, future edition 2 of IEC 60544-4, prepared by SC 15E, Methods of test, of IEC TC 15, Insulating materials, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 60544-4 on 2003-10-01.

The following dates were fixed:

– latest date by which the EN has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2004-07-01
– latest date by which the national standards conflicting with the EN have to be withdrawn	(dow)	2006-10-01

Annexes designated "normative" are part of the body of the standard.
In this standard, annex ZA is normative.
Annex ZA has been added by CENELEC.

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Endorsement notice

The text of the International Standard IEC 60544-4:2003 was approved by CENELEC as a European Standard without any modification.

In the official version, for Bibliography, the following notes have to be added for the standards indicated:

IEC 60093	NOTE	Harmonized as HD 429 S1:1993 (not modified).
IEC 60167	NOTE	Harmonized as HD 568 S1:1990 (not modified).
IEC 60243	NOTE	Harmonized as EN 60243 series (not modified).
ISO 178	NOTE	Harmonized as EN ISO 178:2003 (not modified).
ISO 179	NOTE	Harmonized as EN ISO 179 series (not modified).
ISO 527	NOTE	Harmonized as EN ISO 527 series (not modified).
ISO 868	NOTE	Harmonized as EN ISO 868:2003 (not modified).

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CONTENTS

INTRODUCTION

Organic insulating materials occupy a role of major significance in electrical technology. They rank with metals and ceramics as the principal category of materials used in the construction of components in this field. Of all materials, organics are amongst those that are most sensitive to the effects of radiation, and the response varies widely for different materials. Thus, when selecting insulating materials for specific service applications in radiation environments, information on the radiation tolerance of the candidate materials is required. The purpose of this part of IEC 60544 is to define an internationally recommended classification system to categorize the radiation endurance of insulating materials for such applications.

This standard is the fourth in a series dealing with the effect of ionizing radiation on insulating materials. IEC 60544-1 constitutes an introduction dealing very broadly with the problems involved in evaluating radiation effects. It also provides a guide to dosimetry terminology, several methods of determining exposure and absorbed dose, and methods of calculating absorbed dose in any specific material from the dosimetry method applied.

IEC 60544-2 describes procedures for maintaining seven different types of exposure conditions during the irradiation. It also specifies the controls that are maintained over these conditions so that when test results are reported, reliable comparisons of material performances can be obtained. In addition, it defines certain important irradiation conditions and the test procedures to be used for property change determinations and the corresponding end-point criteria.

IEC 60544-3 has been incorporated into the second edition of IEC 60544-2.

IEC 60544-5 deals with procedures for the assessment of ageing in service.

ELECTRICAL INSULATING MATERIALS – DETERMINATION OF THE EFFECTS OF IONIZING RADIATION –

Part 4: Classification system for service in radiation environments

1 Scope and object

This part of IEC 60544 provides a classification system that serves as a guide for the selection and indexing of insulating materials intended to serve in the radiation environment of nuclear reactor facilities, reactor fuel-processing facilities, irradiation facilities, particle accelerators, and X-ray apparatus.

The classification system provides a set of parameters defining the utility of the three types of polymeric materials (rigid plastics, flexible plastics, elastomers) for use in devices which are exposed to ionizing radiation.

This part of IEC 60544 forms the basis for a quantitative statement of the suitability of such materials for radiation environments and therefore provides a guide for material specifications and for procurement agreements between suppliers and users.

2 Normative references

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

IEC 60212:1971, *Standard conditions for use prior to and during the testing of solid electrical insulating materials*

IEC 60544-1:1994, *Electrical insulating materials – Determination of the effects of ionizing radiation – Part 1: Radiation interaction and dosimetry*

IEC 60544-2:1991, *Guide for determining the effects of ionizing radiation on insulating materials – Part 2: Procedures for irradiation and test*

IEC 61244-1:1993, *Determination of long-term radiation ageing in polymers – Part 1: Techniques for monitoring diffusion-limited oxidation*

IEC 61244-2:1996, *Determination of long-term radiation ageing in polymers – Part 2: Procedures for predicting ageing at low dose rates*

3 Classification system

The classification of a particular material for a specific application is established by the results of testing for changes in the appropriate mechanical and/or electrical properties by measuring them before and after irradiation to the indicated absorbed dose under selected conditions described in IEC 60544-2. On the basis of these tests, the material is assigned a “radiation index”. To qualify for a particular radiation index, a material shall satisfy an end-point criterion after being irradiated to the classification dose under specified conditions.

The end-point criterion may be expressed as an absolute property value or a percentage of the initial value. Either method may be used to classify materials for radiation resistance. Table 1 provides recommendations for properties and percentages of initial values.

All measurements shall be made after removal from the radiation exposure unless otherwise stated in the “qualifiers of the radiation index”. Post-irradiation treatment of test specimens shall be conducted as specified in 3.5 of IEC 60544-2.

3.1 Definition of radiation index

The radiation index shall be determined by the logarithm ($\log_{10}$ rounded off to two significant figures) of the absorbed dose in grays above which the appropriate critical property value has reached the end-point criterion under specified conditions. For example, a material which satisfies a particular end-point criterion to a dose of 2×10^4 Gy has a radiation index of 4,3 (i.e. $\log_{10} (2 \times 10^4) = 4{,}301$). The values shall be taken from the series given in Table 2.

The radiation index shall include the dose rate (see 3.2.1), or the notation “vac” (see 3.2.2), and include special qualifiers, when applicable, such as the critical property (see 3.3), temperature (see 3.4), and the medium (see 4.2.3). For further qualification see Clause 4.

As recommended in IEC 60544-2, it is preferable to use gamma-rays, X-rays or electrons for the test irradiation. The type of radiation to which the material was exposed shall be specified.

3.2 Dose rate

3.2.1 Depending on the material and the irradiation conditions, different values of radiation index may be obtained when the test is carried out at different dose rates in atmospheres containing oxygen. Also, dose rate effects caused by diffusion-limited oxidation (see IEC 61244-1) can depend on sample thickness. Therefore, under long-term exposure conditions (see 3.6 of IEC 60544-2), the radiation index shall be given with qualifiers indicating the dose rate and the sample thickness at which the radiation index was obtained. For example: radiation index 4,3 (50 Gy/s, 1 mm).

3.2.2 In the absence of a reactive medium (e.g. in a vacuum or an inert gas), no dose-rate effect needs be considered. In this case the dose rate qualifier may be replaced by the notation (vac). For example: radiation index 4,3 (vac).

3.2.3 In the presence of oxygen, there may be decomposition reactions with radiation-induced reactive states of some polymers. This effect depends on the amount of oxygen which penetrates by diffusion into the material and, consequently, it depends on the permeability of the polymer to gaseous oxygen, the thickness of the sample, and the rate of oxygen consumption (see IEC 61244-1). In this case a radiation dose-rate effect often occurs.

If a dose-rate dependence has not been excluded by prior experiments, it is necessary to test as closely as possible to the service dose rate.

For irradiation in air, the dose rate and sample thickness according to 3.2.1 means that the radiation index is valid for this dose rate or higher and for this thickness.

3.2.4 If the required radiation time is excessive, it is recommended that the dose-rate effect be estimated by one of the procedures given in IEC 61244-2.

3.3 Critical properties

3.3.1 For normal applications, the most restrictive property is the flexural stress at maximum load for rigid plastics and the percentage elongation at break for flexible plastics and elastomers. Unless otherwise stated, the radiation index will assume the application of the end-point criteria associated with these properties. This does not necessarily refer to an end-of-life condition.

3.3.2 Should the application warrant it, the user may specify an alternative property taken from Table 1 to determine the radiation index. Under these conditions, the actual property tested shall be specified.

3.4 Temperatures

3.4.1 The normal test temperature for determining the radiation index shall be room temperature (23 ± 5) °C.

3.4.2 Service at elevated temperatures adds an additional factor to the estimation of the useful lifetime of materials in radiation environments. Each material is affected differently; in general, materials show an accelerated deterioration of properties at elevated temperatures. There are, however, a few which have a longer life in some combinations of temperature and dose rate. Each parameter and the significant property controlling service life shall be considered when determining the radiation index because the rates of degradation reactions vary with temperature, and their relative importance can depend on the physical state of the polymer at the specified temperature. The ratio of such rates may change sharply at the glass transition temperature or at other transition temperatures. Therefore, the changes in properties which are affected by these reactions are influenced by the irradiation temperature, differently for each material.

If the service temperature is other than room temperature, the material shall also be tested at one of the closest standardized temperatures given in IEC 60212 and following 3.4.2 of IEC 60544-2.

3.5 Additional considerations

3.5.1 The changes in properties are typically not linear with dose. Therefore, extrapolation of the values of dose to the end-point criteria is not advisable.

3.5.2 The original values of the properties of the unirradiated material shall be stated. The radiation index of specific polymers provides an indication of their resistance to radiation when compared with the values of their original properties. An approximate estimate of service lifetime can be made from the dose rate of the service environment and the dose corresponding to the radiation index when the property requirements of the application can be related to an end-point criterion. However, the existence of important dose rate effects may substantially reduce the actual service lifetime compared to this initial estimate (see IEC 60544-1 and IEC 60544-2).

3.5.3 The determined radiation index may only be valid for the specific material which has been submitted to the test. This is because the changes in chemical composition (including fillers and additives), in physical structure, fabrication methods, etc., may cause variations in the radiation-induced changes in properties. Therefore, it may not be acceptable to assume a classification for one material merely because it is of the same chemical type as another material that has been classified by testing.

The related material may generally be assigned to the same category of radiation resistance as that determined for the specified material that has been tested under certain conditions. For example, if the variant is an additive not believed to affect the radiation effect and the difference in mass concentration is within 10 % of the component used in the compound, then this is acceptable.

4 Designation of radiation index and special service qualifiers

4.1 Radiation index

The radiation index value taken from Table 2 designates a material for application at the specified dose rate and thickness in air (see 3.2.1), or with the notation “vac” in the absence of a reactive medium at any dose rate (see 3.2.2), at room temperature (see 3.4.1). In addition, the radiation index has been determined by testing for

– flexural stress at maximum load for rigid plastics, or

– elongation at break for flexible plastics and elastomers,

in accordance with 3.3.1 and the appropriate end-point criteria of Table 1.

4.2 Radiation index with qualifications

4.2.1 When an alternative critical property, other than indicated in 4.1, is used to evaluate the radiation endurance of a material, the actual property tested shall be added to the radiation index as a qualifier (see 3.3.2).

4.2.2 For application at other than room temperature, a qualifier shall be added to the radiation index indicating the maximum service temperature (see 3.4.2).

4.2.3 In the case of a reactive medium other than air, this specific medium shall be added to the radiation index as a qualifier.

4.3 Examples

Three examples of the use of this classification and index scheme are given below:

- designation “PVC, Type XY, radiation index 6,0 (50 Gy/s, 1 mm)”

This designation means that the PVC, Type XY, of thickness less than or equal to 1 mm, has reached 50 % of its initial value for elongation at break after irradiation to an absorbed dose of 1×10^6 Gy at 23 °C and at a dose rate of 50 Gy/s and higher, in air;

- designation “epoxy resin, Type XY, radiation index 7,0 (vac, insulation resistance)”

This designation means that the epoxy resin, Type XY, has reached an insulation resistance of 10 % of its initial value after irradiation to an absorbed dose of 1×10^7 Gy at room temperature (23 ± 5) °C, in vacuum;

- designation “silicon rubber, Type XY, radiation index 5,3 (0,1 Gy/s, 1 mm, surface resistivity, 80 °C)”

This designation means that the silicon rubber, Type XY, of thickness less than or equal to 1 mm, maintains a surface resistivity of at least 0,1 times of its initial value after irradiation to an absorbed dose of up to 2×10^5 Gy at a service temperature of 80 °C and lower and at dose rates of 0,1 Gy/s and above in air.

Table 1 – Critical properties and end-point criteria to be considered in evaluating the classification of insulating materials in radiation environments

Type of material	Properties to be tested	Test procedures	End-point criteria [a]
Rigid plastics	Flexural strength	ISO 178	50 %
	Tensile strength at yield	ISO 527	50 %
	Tensile strength at break	ISO 527	50 %
	Impact strength	ISO 179	50 %
	Volume and surface resistivity	IEC 60093	10 %
	Insulation resistance	IEC 60167	10 %
	Electric strength	IEC 60243	50 %
Flexible plastics	Flexural strength	ISO 527	50 %
	Elongation at break	ISO 37	50 %
	Tensile strength at yield	ISO 527	50 %
	Tensile strength at break	ISO 527	50 %
	Impact strength	ISO 179	50 %
	Volume and surface resistivity	IEC 60093	10 %
	Insulation resistance	IEC 60167	10 %
	Electric strength	IEC 60243	50 %
Elastomers	Elongation at break	ISO 37	50 %
	Tensile strength at break	ISO 37	50 %
	Hardness/IRHD	ISO 48	Change of 10 units
	Hardness/Shore A	ISO 868	Change of 10 units
	Compression set	ISO 815	50 %
	Volume and surface resistivity	IEC 60093	10 %
	Insulation resistance	IEC 60167	10 %
	Electric strength	IEC 60243	50 %

[a] The values given in per cent are expressed as a percentage of the initial value.

Table 2 – Values for radiation index

Radiation index values	Absorbed dose (Gy) up to which the end-point criteria are satisfied
4,0	$1,0 \times 10^4$
4,1	$1,3 \times 10^4$
4,2	$1,6 \times 10^4$
4,3	$2,0 \times 10^4$
4,4	$2,5 \times 10^4$
4,5	$3,2 \times 10^4$
4,6	$4,0 \times 10^4$
4,7	$5,0 \times 10^4$
4,8	$6,3 \times 10^4$
4,9	$8,0 \times 10^4$
5,0	$1,0 \times 10^5$
5,1	$1,3 \times 10^5$
5,2	$1,6 \times 10^5$
:	:
:	:
5,9	$8,0 \times 10^5$
6,0	$1,0 \times 10^6$
6,1	$1,3 \times 10^6$
6,2	$1,6 \times 10^6$
:	:
:	:
6,9	$8,0 \times 10^6$
7,0	$1,0 \times 10^7$
7,1	$1,3 \times 10^7$
7,2	$1,6 \times 10^7$
:	:
:	:
7,9	$8,0 \times 10^7$
8,0	$1,0 \times 10^8$
:	:
:	:
etc.	etc.

NOTE For radiation index qualifiers, see 4.2.

Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

This European Standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies (including amendments).

NOTE When an international publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

Publication	Year	Title	EN/HD	Year
IEC 60212	1971	Standard conditions for use prior to and during the testing of solid electrical insulating materials	HD 437 S1	1984
IEC 60544-1	1994	Electrical insulating materials - Determination of the effects of ionizing radiation Part 1: Radiation interaction and dosimetry	EN 60544-1	1994
IEC 60544-2	1991	Part 2: Procedures for irradiation and test	-	-
IEC/TR2 61244-1	1993	Determination of long-term radiation ageing in polymers Part 1: Techniques for monitoring diffusion-limited oxidation	-	-
IEC/TR2 61244-2	1996	Part 2: Procedures for predicting ageing at low dose rates	-	-

Bibliography

IEC 60093, *Methods of test for volume resistivity and surface resistivity of solid electrical insulating materials*

IEC 60167, *Methods of test for the determination of the insulation resistance of solid insulating materials*

IEC 60243 (all parts), *Electrical strength of insulating materials – Test methods*

ISO 37, *Rubber, vulcanized or thermoplastic – Determination of tensile stress-strain properties*

ISO 48, *Rubber, vulcanized or thermoplastic – Determination of hardness (hardness between 10 IRHD and 100 IRHD)*

ISO 178, *Plastics – Determination of flexural properties*

ISO 179 (all parts), *Plastics – Determination of Charpy impact properties*

ISO 527 (all parts), *Plastics – Determination of tensile properties*

ISO 815, *Rubber, vulcanized or thermoplastic – Determination of compression set at ambient, elevated or low temperatures*

ISO 868, *Plastics and ebonite – Determination of indentation hardness by means of a durometer (Shore hardness)*

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