

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

Part 5: Procedures for assessment of ageing in service

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National foreword

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**Electrical insulating materials -
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Part 5: Procedures for assessment of ageing in service
(IEC 60544-5:2003)**

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Détermination des effets
des rayonnements ionisants
Partie 5: Procédures pour l'estimation
du vieillissement en service
(CEI 60544-5:2003)

Elektroisolierstoffe -
Bestimmung der Wirkung
ionisierender Strahlung
Teil 5 : Bewertungsverfahren für die
Alterung während des Einsatzes
(IEC 60544-5:2003)

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Foreword

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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.

Endorsement notice

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CONTENTS

INTRODUCTION.....	5
1 Scope and object.....	6
2 Normative references	6
3 Abbreviations	6
4 Background	7
4.1 Diffusion limited oxidation (DLO)	7
4.2 Dose rate effects (DRE)	8
4.3 Accelerated ageing.....	8
4.4 Approaches to ageing assessment	9
5 Condition monitoring techniques.....	9
5.1 Introduction	9
5.2 Establishment of correlation curves for CM methods	10
5.3 Indenter.....	10
5.4 Oxidation induction time (OIT).....	12
5.5 Oxidation induction temperature (OITP).....	13
5.6 Thermogravimetric analysis (TGA)	15
5.7 Density measurements	16
6 Equipment deposit.....	18
6.1 Requirements of a deposit.....	19
6.2 Installation of an equipment deposit	19
6.3 Testing of samples from the deposit	20
6.4 Determination of sampling intervals.....	20
6.5 Real-time aged equipment and operating experience	21
Annex ZA (normative) Normative references to international publications with their corresponding European publications	30
Bibliography.....	31
Figure 1 – Development of ageing data on changes in tensile elongation and a condition indicator (for example, indenter modulus) – Schematic	23
Figure 2 – Correlation curve derived from data in Figure 1 – Schematic.....	24
Figure 3 – Correlation curve for indenter modulus against tensile elongation for a CSPE cable jacket material [7].....	24
Figure 4 – Typical force – Displacement curve from indenter measurements, showing definition of indenter modulus	25
Figure 5 – Typical shape of thermogram from an OIT test, showing baseline and onset determination (method B) – Schematic	25
Figure 6 – Shape of thermogram from an OIT test with no well-defined baseline – Schematic.....	26
Figure 7 – Shape of thermogram from an OIT test with multiple onsets – Schematic.....	26
Figure 8 – Shape of thermogram from a typical OITP test on a semi-crystalline material (for example, XLPE) – Schematic	27
Figure 9 – Shape of test data plot from a typical TGA test – Schematic	27

Figure 10 – Example of correlation curve for TGA data against tensile elongation,
for a PVC sheath material [7] 28

Figure 11 – Reverse temperature effect during radiation ageing of XLPE cable
insulation material during radiation ageing at elevated temperature [20] 28

Figure 12 – Determination of lead times for a cable deposit – Schematic [21] 29

Table 1 – Recommended test parameter values for indenter measurements 22

Table 2 – Recommended test temperatures for OIT measurements 22

INTRODUCTION

Organic materials provide a significant proportion of insulations used in electrical systems. These materials are sensitive to the effects of irradiation and the response varies widely between different types. It is therefore important to be able to assess the degree of degradation of these insulating materials during their service lifetimes. This part of IEC 60544 provides recommended procedures for monitoring ageing of insulating materials in service.

There are a number of approaches to the assessment of ageing of polymer-based components exposed to radiation environments [1], [2]¹. These are based on better understanding of the factors affecting ageing degradation which has been developed over the last 15 years. In a nuclear power plant, qualification programmes are normally used for selection of components, including those based on polymeric materials. These initial qualification procedures, such as IEEE-323 [3], were written before ageing was well understood. Most of the methods discussed in this document are therefore used to address the limitations of the initial qualification process.

This part is the fifth in a series dealing with the effect of ionizing radiation on insulating materials.

Part 1 (Radiation interaction) constitutes an introduction dealing very broadly with the problems involved in evaluating radiation effects. It also gives 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.

Part 2 (Procedures for irradiation and test) describes procedures for maintaining seven different types of exposure conditions during irradiation. It also specifies the controls that shall be maintained over these conditions so that when test results are reported, reliable comparisons of material performance can be made. It also defines certain important irradiation conditions and test procedures to be used for property change determinations and corresponding end-point criteria.

Part 3 has been incorporated into Part 2.

Part 4 (Classification system for service in radiation environments) provides a recommended classification system for categorizing the radiation endurance of insulation materials.

¹ Figures in square brackets refer to the bibliography.

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

Part 5: Procedures for assessment of ageing in service

1 Scope and object

This part of IEC 60544 covers ageing assessment methods which can be applied to components based on polymeric materials (for example, cable insulation and jackets, elastomeric seals, polymeric coatings, gaiters) which are used in environments where they are exposed to radiation.

The object of this part of IEC 60544 is to provide guidelines on the assessment of ageing in service. The approaches discussed cover ageing assessment programmes based on condition monitoring (CM), the use of equipment deposits in severe environments and sampling of real-time aged components.

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

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

IEC/TR2 61244-1:1993, *Determination of long-term ageing in polymers – Part 1: Techniques for monitoring diffusion-limited oxidation*

IEC/TR2 61244-2:1996, *Determination of long-term ageing in polymers – Part 2: Procedures for predicting ageing at low dose rates*

IEC/TR2 61244-3:1998, *Long-term radiation ageing in polymers – Part 3: Procedures for in-service monitoring of low-voltage cable materials*

3 Abbreviations

BR	Butyl rubber
BWR	Boiling water reactor
CM	Condition monitoring
CSPE	Chlorosulphonated polyethylene
DLO	Diffusion limited oxidation
DRE	Dose-rate effect
DSC	Differential scanning calorimeter
EPR	Ethylene propylene rubber
EPDM	Ethylene propylene diene copolymer

ETFE	Ethylene tetrafluoroethylene copolymer
EVA	Ethylene vinyl acetate copolymer
IM	Indenter modulus
LOCA	Loss of coolant accident
NBR	Nitrile rubber
OIT	Oxidation induction time
OIT/OITP	Oxidation induction temperature
PE	Polyethylene
PEEK	Polyether ether ketone
PPO	Polyphenylene oxide
PVC	Polyvinyl chloride
PWR	Pressurized water reactor
SIR	Silicone rubber
TGA	Thermo-gravimetric analysis
XLPE	Cross-linked polyethylene
XLPO	Cross-linked polyolefin

4 Background

There are a number of alternative methods offered for ageing assessment as described in their respective subclauses. Each of these methods has its own advantages and limitations. Selection of the appropriate method will be dependent on the requirements of the individual users.

There are a number of factors that need to be considered when assessing ageing of polymeric components in radiation environments. In the following subclauses, some of these factors are briefly discussed and reference made to more detailed information. To accelerate radiation-ageing environments, the normal approach is to increase the radiation dose rate, often combined with an increase in temperature. The two most important potential complications arising from such increases involve diffusion limited oxidation (DLO), which is described in 4.1, and chemical dose-rate effects (DRE), which are described in 4.2. The implications of these factors on the use and interpretation of CM techniques are also discussed. Accelerated ageing programmes briefly discussed in 4.3 and 4.4 introduce the approaches available for ageing assessment in-service.

4.1 Diffusion limited oxidation (DLO)

When polymers are exposed to an oxygen-containing environment (for example, air), a certain amount of oxygen will be dissolved in the material. In the absence of oxygen-consuming reactions (oxidation), the amount of dissolved oxygen will be proportional to the oxygen partial pressure surrounding the polymer (well known from Henry's law). Ageing will lead to oxidation reactions in the polymer, whose rate will increase significantly as the dose rate and temperature of ageing are increased. If the rate of consumption of dissolved oxygen in the polymer is faster than the rate at which oxygen can be replenished by diffusion from the surrounding air atmosphere, the concentration of dissolved oxygen in the interior regions will decrease with time (the oxygen concentration at the sample surface will remain at its equilibrium value). The reduction in internal oxygen concentration can lead to reduced or negligible oxidation, which is referred to as diffusion limited oxidation.

The importance of this effect is dependent on the sample thickness (thinner samples giving smaller DLO effects) and the ratio of the oxygen consumption rate to the oxygen permeability coefficient P , which equals the product of the oxygen diffusion and solubility parameters. Accelerated radiation environments involve increases in dose rates, which increase the oxygen consumption rate. If the temperature remains constant as the dose rate is increased, the oxygen permeability coefficient will be unchanged. This means that DLO effects will become more important as the dose rate is raised. These effects are described in more detail in IEC 61244-1.

The effects of diffusion limited oxidation also need to be considered when carrying out condition monitoring tests. This is not an issue for the many CM techniques which measure properties at room temperature, such as those based on density and modulus measurements. On the other hand, several CM techniques such as oxidation induction time (OIT) and thermogravimetric analysis (TGA) use quite elevated temperatures during the measurements. For these techniques, it is quite possible to have DLO effects present during measurement of the CM parameter. DLO also needs to be addressed when developing correlation curves for condition monitoring methods, to ensure that representative data are obtained for both radiation and thermal ageing.

4.2 Dose-rate effects (DRE)

The existence of radiation dose-rate effects and methods for dealing with these effects are described in IEC 61244-2. Generally, DRE are separated into two types. The first type, which is commonly observed in accelerated radiation ageing experiments, is due to the DLO effects described above. These DLO-based effects represent a physical, geometry-dependent DRE. The second type concerns chemical DRE. Such chemically based DRE are much less common. A documented case of chemical DRE is found in PVC and low-density polyethylene materials, caused by the slow breakdown of hydroperoxide intermediate species in the oxidation reaction [4].

4.3 Accelerated ageing

Accelerated ageing programmes in the laboratory sometimes use acceleration factors much lower than are normally used in equipment qualification. This may avoid some of the problems associated with diffusion limited oxidation and dose-rate effects. The ageing produced may then be a better simulation of the long-term ageing that occurs under service conditions. The data that are obtained in accelerated ageing tests can be used with predictive models which enable assessments to be made of the behaviour of the materials under service conditions.

Accelerated ageing programmes normally require a matrix of test data to be generated over a range of environmental conditions as described in IEC 61244-2. As a minimum, data are needed for at least three different dose rates at the normal operating temperature but additional data on thermal ageing and radiation ageing at elevated temperature enables better use to be made of the available predictive modelling methods. The dose rates and temperatures used for accelerated ageing shall be selected using the principles described in IEC 60544-2 to ensure that homogeneous oxidation occurs. For each environmental condition used, test data need to be obtained at several different ageing times, the longest of which shall be sufficient to introduce significant degradation. A typical test programme could take up to 18 months to complete, depending on the radiation resistance of the materials being tested.

The type of data required in the test matrix will be determined by the type of component being evaluated. The types of test parameters which are appropriate are given in IEC 60544-2 for various types of polymeric material.

Analysis of the data generated in the experimental test matrix in terms of predictive modelling methods is described in detail in IEC 61244-2 for three different predictive models which are currently available.

4.4 Approaches to ageing assessment

Two approaches to ageing assessment in service are described in this part of IEC 60644. These are

- condition monitoring using non-destructive test methods,
- sampling of materials from an equipment deposit.

Condition monitoring techniques are used to assess the condition of materials which have aged for extended time periods under actual use environments, such as in nuclear power plants, accelerators, reprocessing plants, etc. The approach makes use of non-destructive or micro-sampling test methods which have been shown to correlate well with ageing degradation. Condition monitoring methods are described in detail in Clause 5.

The use of samples from an equipment deposit in the plant is an alternative approach to assessment of ageing in service. This makes use of samples specifically installed in the plant for destructive testing as part of an ageing management programme. This approach is described in detail in Clause 6.

5 Condition monitoring techniques

5.1 Introduction

There exists a wide range of methods which have been evaluated for condition monitoring of polymeric components, particularly for cable materials [5], [6]. Of the many methods examined, only a few have been identified as being potentially suitable for practical use. These are summarized in IEC 61244-3. For these methods, data correlating the monitoring parameter with degradation of the polymeric component have been built up and the practical limitations explored over the last few years. The most developed methods are as follows.

- Indenter
- Oxidation induction time (OIT)
- Oxidation induction temperature (OITP)
- Thermogravimetric analysis (TGA)
- Density

The recommended test procedures for each of these techniques are given in 5.3 to 5.7, respectively.

Condition monitoring in ageing assessment can be used in a number of ways, ranging from short-term trouble-shooting to long-term on-going qualification programmes. In short-term tests, the emphasis of condition monitoring tends to be on identifying the extent of a problem or in demonstrating that a problem does not exist. For example, the indenter has been used to determine the extent of damage to cables from degradation arising from damaged thermal insulation on a steam line near a cable run in a BWR nuclear power plant. By carrying out indenter measurements along this cable, it was possible to obtain a profile of the damaged area.

In some cases, the use of design criteria (for example, calculation of self-heating of power cable from current loading) can be very conservative, indicating that a power cable should be showing significant degradation. Checks on the component using CM methods can be used to demonstrate that the materials have not degraded to the extent predicted, avoiding unnecessary replacement.