IEC 60544-5

Edition 2.0 2011-12

INTERNATIONAL STANDARD

NORME INTERNATIONALE

colour inside

Electrical insulating materials – Determination of the effects of ionizing radiation –
Part 5: Procedures for assessment of ageing in service

Matériaux isolants électriques – Détermination des effets des rayonnements ionisants –
Partie 5: Procédures pour l'estimation du vieillissement en service

IEC 60544-5:2011

Documents
Document Sharing Hub

Full document details: IEC 60544-5 2011

THIS PUBLICATION IS COPYRIGHT PROTECTED

Copyright © 2011 IEC, Geneva, Switzerland

All rights reserved. Unless otherwise specified, no part of this publication may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying and microfilm, without permission in writing from either IEC or IEC's member National Committee in the country of the requester.
If you have any questions about IEC copyright or have an enquiry about obtaining additional rights to this publication, please contact the address below or your local IEC member National Committee for further information.

Droits de reproduction réservés. Sauf indication contraire, aucune partie de cette publication ne peut être reproduite ni utilisée sous quelque forme que ce soit et par aucun procédé, électronique ou mécanique, y compris la photocopie et les microfilms, sans l'accord écrit de la CEI ou du Comité national de la CEI du pays du demandeur.
Si vous avez des questions sur le copyright de la CEI ou si vous désirez obtenir des droits supplémentaires sur cette publication, utilisez les coordonnées ci-après ou contactez le Comité national de la CEI de votre pays de résidence.

IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland
Email: inmail@iec.ch
Web: www.iec.ch

About the IEC

The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

About IEC publications

The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigenda or an amendment might have been published.

- Catalogue of IEC publications: www.iec.ch/searchpub
The IEC on-line Catalogue enables you to search by a variety of criteria (reference number, text, technical committee,…). It also gives information on projects, withdrawn and replaced publications.
- IEC Just Published: www.iec.ch/online_news/justpub
Stay up to date on all new IEC publications. Just Published details twice a month all new publications released. Available on-line and also by email.
- Electropedia: www.electropedia.org
The world's leading online dictionary of electronic and electrical terms containing more than 20 000 terms and definitions in English and French, with equivalent terms in additional languages. Also known as the International Electrotechnical Vocabulary online.
- Customer Service Centre: www.iec.ch/webstore/custserv
If you wish to give us your feedback on this publication or need further assistance, please visit the Customer Service Centre FAQ or contact us:
Email: csc@iec.ch
Tel.: +41 22 919 02 11
Fax: +41 22 919 03 00

A propos de la CEI

La Commission Electrotechnique Internationale (CEI) est la première organisation mondiale qui élabore et publie des normes internationales pour tout ce qui a trait à l'électricité, à l'électronique et aux technologies apparentées.

A propos des publications CEI

Le contenu technique des publications de la CEI est constamment revu. Veuillez vous assurer que vous possédez l'édition la plus récente, un corrigendum ou amendement peut avoir été publié.

- Catalogue des publications de la CEI: www.iec.ch/searchpub/cur_fut-f.htm
Le Catalogue en-ligne de la CEI vous permet d'effectuer des recherches en utilisant différents critères (numéro de référence, texte, comité d'études,…). Il donne aussi des informations sur les projets et les publications retirées ou remplacées.
- Just Published CEI: www.iec.ch/online_news/justpub
Restez informé sur les nouvelles publications de la CEI. Just Published détaille deux fois par mois les nouvelles publications parues. Disponible en-ligne et aussi par email.
- Electropedia: www.electropedia.org
Le premier dictionnaire en ligne au monde de termes électroniques et électriques. Il contient plus de 20 000 termes et définitions en anglais et en français, ainsi que les termes équivalents dans les langues additionnelles. Egalement appelé Vocabulaire Electrotechnique International en ligne.
- Service Clients: www.iec.ch/webstore/custserv/custserv_entry-f.htm
Si vous désirez nous donner des commentaires sur cette publication ou si vous avez des questions, visitez le FAQ du Service clients ou contactez-nous:
Email: csc@iec.ch
Tél.: +41 22 919 02 11
Fax: +41 22 919 03 00

Documents
Document Sharing Hub

Full document details: IEC 60544-5 2011

IEC 60544-5

Edition 2.0 2011-12

INTERNATIONAL STANDARD

NORME INTERNATIONALE

colour inside

Electrical insulating materials – Determination of the effects of ionizing radiation –
Part 5: Procedures for assessment of ageing in service

Matériaux isolants électriques – Détermination des effets des rayonnements ionisants –
Partie 5: Procédures pour l'estimation du vieillissement en service

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

COMMISSION
ELECTROTECHNIQUE
INTERNATIONALE

PRICE CODE
CODE PRIX S

ICS 17.240; 29.035.01

ISBN 978-2-88912-836-5

® Registered trademark of the International Electrotechnical Commission
Marque déposée de la Commission Electrotechnique Internationale

Documents
Document Sharing Hub

Full document details: IEC 60544-5 2011

CONTENTS

FOREWORD ... 3
INTRODUCTION ... 5
1 Scope and object ... 6
2 Normative references ... 6
3 Terms and definitions ... 7
4 Background ... 7
4.1 General ... 7
4.2 Diffusion limited oxidation (DLO) ... 7
4.3 Dose rate effects (DRE) ... 8
4.4 Accelerated radiation ageing ... 8
4.5 Accelerated thermal ageing ... 9
5 Approaches to ageing assessment ... 9
6 Identifying components of concern ... 9
6.1 General ... 9
6.2 Priorities for ageing management ... 9
6.3 Environmental monitoring ... 10
6.4 Localized severe environments ... 10
6.5 Worst case components ... 10
7 Condition monitoring techniques ... 10
7.1 General ... 10
7.2 Establishing correlation curves for CM methods ... 11
7.3 CM methods ... 11
7.4 Using CM for short-term troubleshooting ... 11
7.5 Using CM for long-term degradation assessment ... 13
8 Predictive modelling ... 14
9 Sample deposit ... 15
9.1 General ... 15
9.2 Requirements of a deposit ... 15
9.3 Pre-ageing samples for a deposit ... 15
9.4 Installation of an sample deposit ... 15
9.5 Testing of samples from the deposit ... 16
9.6 Determination of sampling intervals ... 16
9.7 Real time aged materials ... 17
Annex A (informative) Example of a CM correlation curve ... 18
Annex B (informative) Use of a deposit ... 19
Bibliography ... 20

Figure 1 – Development of ageing data on changes in tensile elongation and a condition indicator (e.g. indenter modulus) – Schematic ... 12
Figure 2 – Correlation curve derived from data in Figure 1 – Schematic ... 13
Figure 3 – Estimation of elongation from a correlation curve ... 14
Figure 4 – Modification of sampling interval dependent on values of the CM indicator ... 17
Figure A.1 – Correlation curve for indenter modulus against tensile elongation for a CSPE cable jacket material [18] ... 18

Documents
Document Sharing Hub
Full document details: IEC 60544-5 2011

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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

Part 5: Procedures for assessment of ageing in service

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
6) All users should ensure that they have the latest edition of this publication.
7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

International Standard IEC 60544-5 has been prepared IEC technical committee TC 112: Evaluation and qualification of electrical insulating materials and systems.

This second edition cancels and replaces the first edition, published in 2003, and constitutes an editorial revision to align it with standards recently developed by SC 45A as well as with other parts in the IEC 60544 series.

The text of this standard is based on the following documents:

CDV	Report on voting
112/171/CDV	112/191/RVC

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

Documents
Document Sharing Hub

Full document details: IEC 60544-5 2011

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 60544 series, published under the general title *Electrical insulating materials – Determination of the effects of ionizing radiation*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

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

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

Documents
Document Sharing Hub

Full document details: IEC 60544-5 2011

INTRODUCTION

Organic and polymeric materials provide a significant proportion of the insulation 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 assessing 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 [1–4][1]. These are based on the better understanding of the factors affecting ageing degradation which has been developed over several decades. In nuclear power plants, qualification programmes are normally used for selection of components, including those based on polymeric materials. These initial qualification procedures, such as IEEE-323 [5] and IEEE-383 [6], were originally written before there was sufficient understanding of ageing mechanisms. Most of the methods discussed in this part of IEC 60544 are therefore used to supplement 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 and dosimetry) constitutes an introduction dealing very broadly with the problems involved in evaluating radiation effects. It also provides guidance 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 should be maintained over these conditions so that when test results are reported, reliable comparisons of material performance can be made. In addition, it 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 the second edition of IEC 60544-2.

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.

Documents
Document Sharing Hub

Full document details: IEC 60544-5 2011

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 (e.g. cable insulation and jackets, elastomeric seals, polymeric coatings, gaiters) which are used in environments where they are exposed to radiation.

The object of this standard is aimed at providing methods for the assessment of ageing in service. The approaches discussed in the following clauses cover ageing assessment programmes based on condition monitoring (CM), the use of sample deposits in severe environments and sampling of real-time aged components.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. 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, *Electrical insulating materials – Determination of the effects of ionizing radiation – Part 1: Radiation interaction and dosimetry*

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

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

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

IEC 60780, *Nuclear power plants – Electrical equipment of the safety system – Qualification*

Documents
Document Sharing Hub

Full document details: IEC 60544-5 2011

3 Terms and definitions

For the purposes of this document, the following abbreviations, taken from IEC 60780, apply.

BWR	Boiling water reactor
CBQ	Condition based qualification
CM	Condition monitoring
CSPE	Chlorosulphonated polyethylene
DBE	Design basis event
DLO	Diffusion limited oxidation
DRE	Dose rate effect
DSC	Differential scanning calorimeter
EPR	Ethylene propylene rubber
EQ	Environmental qualification
EVA	Ethylene vinyl acetate copolymer
IM	Indenter modulus
LOCA	Loss of coolant accident
NPP	Nuclear power plant
OIT	Oxidation induction time
OITP	Oxidation induction temperature
PE	Polyethylene
PVC	Polyvinyl chloride
PWR	Pressurized water reactor
TGA	Thermo-gravimetric analysis
VVER	Water-cooled, water-moderated energy reactor (type of pressurized water reactor developed by Russia)
XLPE	Cross-linked polyethylene

4 Background

4.1 General

There are a number of factors that need to be considered when assessing ageing of polymeric components in radiation environments. In the following clauses some of these factors are briefly discussed and references 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, which is described in 4.2, and chemical dose rate effects (DRE), which are described in 4.3. The implications of these factors on the use and interpretation of condition monitoring (CM) techniques are also discussed. Accelerated ageing programmes are briefly discussed in 4.4 and 4.5.

4.2 Diffusion limited oxidation (DLO)

When polymers are exposed to an oxygen-containing environment (e.g. air), some 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

AVA Documents
Document Sharing Hub
Full document details: IEC 60544-5 2011

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 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, 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 is 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 DLO may also need to be considered when carrying out CM measurements. This is not an issue for the many CM techniques which measure properties at ambient 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. For this reason, detailed test methods for CM have been developed [8] to ensure that the sample preparation and test procedure avoid DLO effects. DLO shall be addressed when developing correlation curves for CM methods, to ensure that representative data are obtained for both radiation and thermal ageing.

4.3 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 in 4.2. These DLO-based effects represent a physical, geometry-dependent DRE.

The second type, of interest to the current discussion, 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 [10]. The existence of such chemical DRE shall be checked at the start of any accelerated ageing programme.

4.4 Accelerated radiation ageing

Accelerated ageing programmes in the laboratory tend to use acceleration factors much lower than are normally used in equipment qualification. This may avoid some of the problems associated with DLO and DRE. 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 to enable assessments to be made of the behaviour of the materials under service conditions.

Accelerated ageing programmes 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 3 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 should be selected using the principles described in IEC 60544-2 to ensure that homogeneous oxidation occurs. For each environmental condition used, test data shall be obtained at several different ageing times, the longest of which should be sufficient to introduce significant degradation. A typical test programme could take more than 18 months to complete, dependent on the radiation resistance of the materials being tested.

Documents
Document Sharing Hub

Full document details: IEC 60544-5 2011

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

4.5 Accelerated thermal ageing

When carrying out thermal ageing as part of an accelerated ageing programme, it is important that an appropriate value of the activation energy is used in assessing the temperature and timescale of the accelerated test. In some materials, the ageing mechanism at high temperatures is different to that which would occur under plant conditions and in many materials the activation energy decreases significantly at lower temperatures [10,11].

Samples which been exposed to accelerated thermal ageing shall be allowed to stabilize before any CM tests are carried out. Some polymeric materials are hygroscopic and show a marked dependence of their properties on the moisture content [8]. This is primarily of concern for a few materials used in older nuclear plant, but may also be important for those CM methods that are sensitive to the moisture content of the material.

5 Approaches to ageing assessment

There are a number of complementary methods available for ageing assessment as described in their respective clauses. Each of these methods has its own advantages and limitations. Selection of one or more of the methods will be dependent on the requirements of the individual users.

Several approaches to ageing assessment in-service are described in this standard. These are:

- identifying components of concern to prioritize the application of ageing management programmes (see Clause 6);
- condition monitoring to assess the condition of materials which have aged for extended time periods under actual use environments (see Clause 7);
- predictive modelling to use data from laboratory based accelerated ageing programmes to estimate ageing under real-time ageing conditions (see Clause 8);
- sample deposit to provide samples for the measurement of ageing under real-time ageing conditions (see Clause 9).

6 Identifying components of concern

6.1 General

Within a nuclear power plant there are many components containing polymeric insulating materials, e.g. there are >1 000 km of electrical cables in a typical NPP. It is not practical to assess the ageing of every individual component, and many will not be exposed to significant environmental ageing conditions. It is therefore necessary to prioritize any ageing management programme by identifying those components which are of most concern.

6.2 Priorities for ageing management

Not all components have the same priority for ageing management. In general, those components performing safety functions during and following an accident are of most concern, together with those important to continued operation. Any components outside of these categories would initially be assigned to a low priority for ageing management activities.

The normal operating environment of the components shall be examined to identify the expected impact of the environment on their ageing. Those components identified as being

AVA Documents
Document Sharing Hub
Full document details: IEC 60544-5 2011

subject to severe ageing are assigned the highest priority, whereas those subject to moderate ageing can then be assigned to a medium priority.

For this prioritization to be carried out effectively, environmental monitoring is essential (see 6.2), combined with knowledge of the ageing behaviour of the components. Initial assessment may make use of design calculations for temperatures and dose rates. The ageing information may come from equipment qualification data or from supplementary accelerated ageing tests carried out in the laboratory.

6.3 Environmental monitoring

Ageing of insulating materials in a NPP is dominated by temperature, radiation dose and radiation dose rate for organic and polymeric materials. A major requirement for ageing management is a detailed knowledge of the actual temperatures and dose rates at locations within the plant where high priority components are situated.

The temperature and dose rate distribution within the plant shall be obtained using temperature recorders and dosimeters. Operational fluctuations and seasonal variations shall be included by carrying out these measurements over several fuel cycles. It may be necessary to repeat such measurements when changes are made to the plant, e.g. power upgrades.

Small self-contained temperature recorders are available and are a practical and flexible method for localized temperature recording to supplement bulk temperature monitoring equipment that is already installed in the plant.

Radiation monitoring is best achieved with alanine dosimeters, which are suitable for long term measurements. These dosimeters are not significantly affected by temperature, can be sealed to avoid the influence of humidity and are suitable for monitoring over a wide dose range. The radicals formed under irradiation in alanine are stable over time periods in excess of a year and can be measured using electron spin resonance (IEC 60544-1).

6.4 Localized severe environments

Identification of localized severe environments (hotspots) where high priority components are located is an important aspect of ageing assessment. Such locations can be identified in a number of ways, including interviews of plant personnel, operational reviews, review of plant layout drawings and plant walkdowns [11,12]. Each will provide a different perspective on hotspot conditions. Feedback from plant maintenance personnel is an important aspect of identifying early signs of degradation.

6.5 Worst case components

Having prioritized the components most likely to be affected by ageing, carried out environmental monitoring and identified localized severe environments, the components will have been assigned to either a high, medium or low priority for further ageing management. All components assigned to a high priority shall be subject to ageing management activities such as CM or planned replacement.

The evaluation process can be refined as more information becomes available. For example, if CM of high priority cables indicates that degradation is much less severe than expected, it may be appropriate to move these components to a lower priority category.

7 Condition monitoring techniques

7.1 General

CM 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,

Documents
Document Sharing Hub
Full document details: IEC 60544-5 2011

reprocessing plants, etc. The approach makes use of test methods which have been shown to correlate well with ageing degradation.

CM in ageing assessment can be used in a number of ways, ranging from short term trouble shooting to long term on-going qualification programmes.

7.2 Establishing correlation curves for CM methods

In order to use CM methods effectively, it is important to develop correlation curves between the monitoring parameter measured and the prime indicator of degradation or functionality. For polymeric cable materials, the prime indicator of degradation is generally considered to be tensile elongation at break, since changes in electrical properties are small before physical failure of the cable in many cases. In seal materials, the compression set has proved to be a useful indicator of the degradation in sealing properties introduced by ageing. Suitable degradation parameters for other components are given in IEC 60544-2.

Correlation curves shall be determined by measurements of the prime indicator and the relevant CM parameter on samples aged under identical conditions, as shown schematically in Figure 1. The measurements shall cover a range of degradation levels, from the unaged condition to a severely degraded condition. It is recommended that at least 5 sets of data at different ageing times be used in establishing the correlation curve (Figure 2), preferably for several different temperatures and radiation dose rates. An example of a correlation curve for a CSPE cable sheath material is given in Annex A.

Correlation curves are normally established using accelerated testing. Such tests shall be carried out using the procedures described in IEC 60544-2. Alternatively, correlation curves can be established as part of the sample deposit procedure for ageing assessment, as described in Clause 9, or as part of the initial equipment qualification process.

7.3 CM methods

There is a wide range of methods which have been evaluated for CM of polymeric components, particularly for cable materials [4]. Of the many methods examined, several have been identified as being potentially suitable for practical use. Measurement standards for the most developed of these methods are described in detail in the various parts of IEC 62582 [8]. For these methods, data correlating the monitoring parameter with degradation of the polymeric component have been built up and the practical limitations explored. The most developed methods are

- indenter modulus,
- oxidation induction time (OIT) and oxidation induction temperature (OITP),
- elongation at break.

NOTE There are many other methods which have been investigated for CM and suitable measurement standards for some of these are expected to be developed over the next few years. A number of these are described in IAEA-NP-T-3.6 [4].

Visual inspection (including tactile and other sensory inspection) is a qualitative monitoring method which can be a valuable tool in assessing localized ageing degradation within nuclear plant using walkdowns. The practical considerations for in-plant visual inspections (walkdowns) are described in more detail in [11,12].

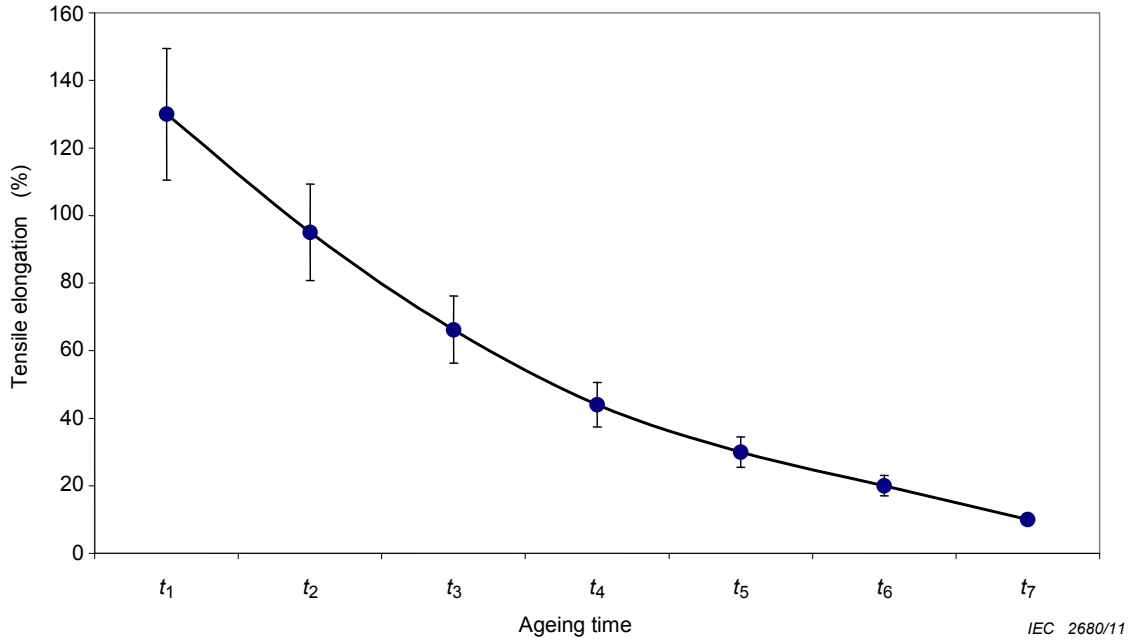
Electrical methods for assessing degradation in cable systems and their associated end-devices are described in IEC 62465 [14]. These methods primarily relate to cable systems (connectors, penetrations etc.) rather than degradation of the insulating materials.

7.4 Using CM for short-term troubleshooting

In short-term tests, the emphasis of CM is in identifying the extent of a problem or in demonstrating that a problem does not exist. For example, the indenter has been used to

AVA Documents
Document Sharing Hub
Full document details: IEC 60544-5 2011

determine the extent of damage to cables from degradation arising from damaged thermal insulation on a steam line near a cable in a BWR nuclear power plant. By carrying out indenter measurements along this cable, a profile of the damaged area was obtained. This enabled replacement of a limited section of cable rather than replacing the entire cable run.



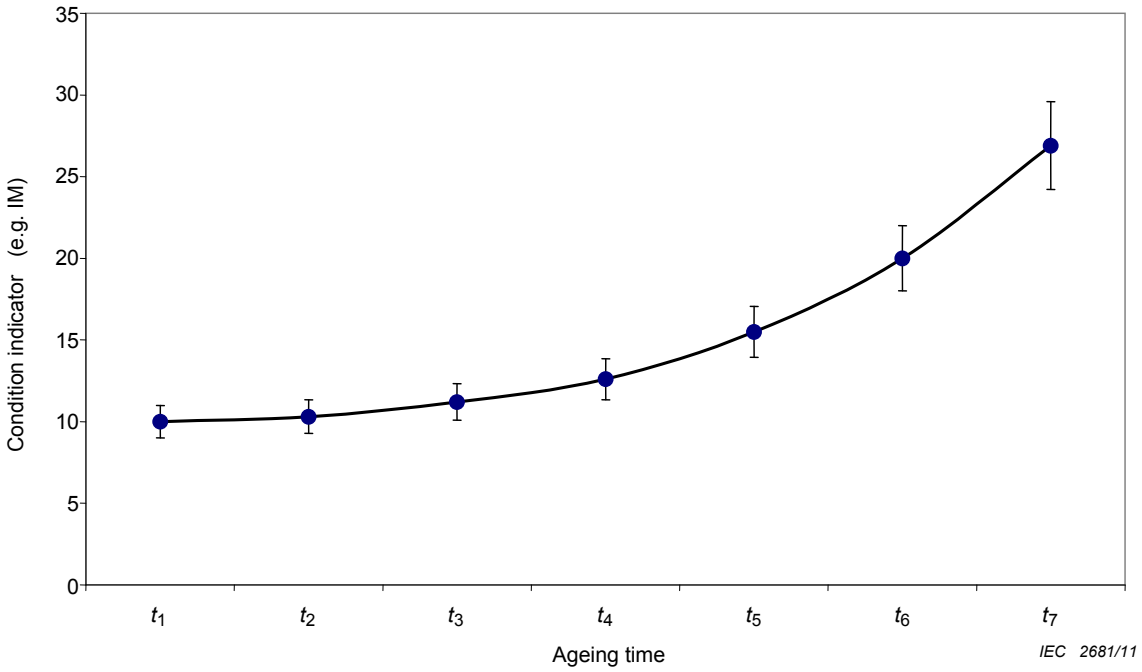


Figure 1 – Development of ageing data on changes in tensile elongation and a condition indicator (e.g. indenter modulus) – Schematic

Documents
Document Sharing Hub
Full document details: IEC 60544-5 2011

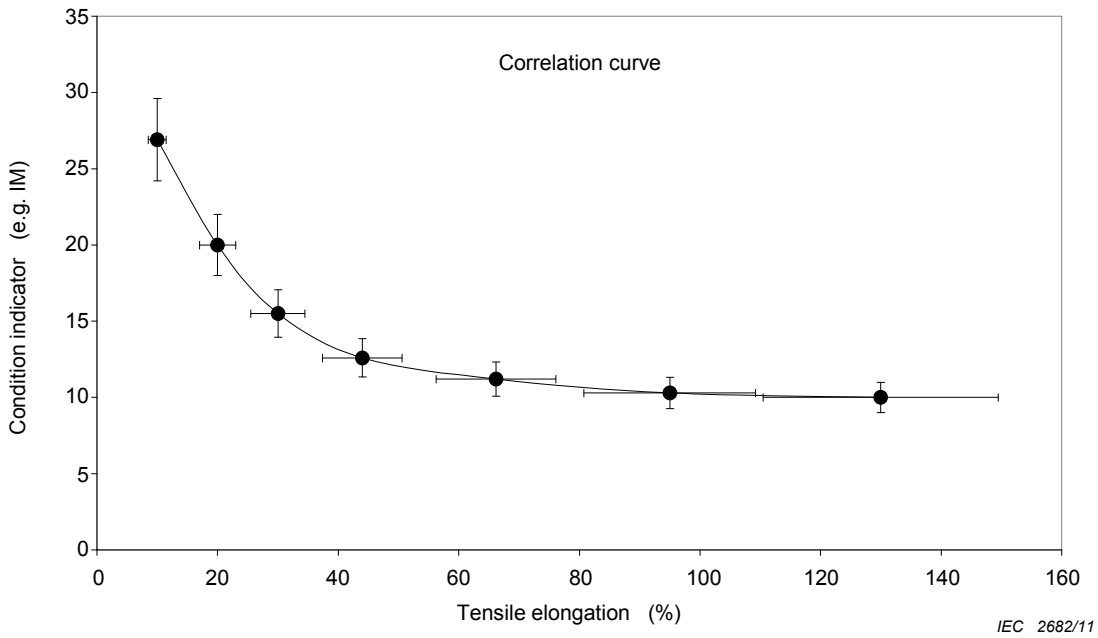


Figure 2 – Correlation curve derived from data in Figure 1 – Schematic

In some cases, the use of design criteria (e.g. calculation of self-heating of power cable from current loading) can be very conservative, indicating that the insulation would be expected to show 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. This is particularly important where a short qualified life has been determined during EQ.

7.5 Using CM for long-term degradation assessment

CM methods can also be used in on-going test programmes which span the lifetime of the plant. Typical uses of CM methods in such programmes are

- trending of component condition relative to a qualified condition determined during initial EQ procedures,
- comparison of CM data with predictive modelling, based on accelerated ageing data in the laboratory and a knowledge of the environmental conditions seen by the component,
- monitoring of components in a sample deposit located in a severe environment in the plant (this is most frequently used for cables and small electrical components).

Figure 3 illustrates how the elongation at break can be estimated from a CM parameter such as indenter modulus.

Condition based qualification (CBQ) is becoming the recommended method for equipment qualification for new NPPs [12, 13]. For this approach to EQ to be used, CM techniques shall be applied during the pre-ageing phase of qualification to determine the shape of the ageing curve and the limiting value of CM parameters at which the component can survive a DBE, i.e. the qualified condition. Trending of the condition of the component relative to this qualified condition is an essential part of CBQ.

Documents
Document Sharing Hub
Full document details: IEC 60544-5 2011