BS EN 60544-5:2012

BSI Standards Publication

Electrical insulating materials – Determination of the effects of ionising radiation

Part 5: Procedures for assessment of ageing in service

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National foreword

This British Standard is the UK implementation of EN 60544-5:2012. It is identical to IEC 60544-5:2011. It supersedes BS EN 60544-5:2003 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee GEL/112, Evaluation and qualification of electrical insulating materials and systems.

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English version

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

(IEC 60544-5:2011)

Matériaux isolants -
Détermination des effets des rayonnements ionisants -
Partie 5: Procédures pour l'estimation du vieillissement en service
(CEI 60544-5:2011)

Elektroisolierstoffe -
Bestimmung der Wirkung ionisierender Strahlung -
Teil 5: Bewertungsverfahren für die Alterung während des Einsatzes
(IEC 60544-5:2011)

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European Committee for Electrotechnical Standardization
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Foreword

The text of document 112/171/CDV, future edition 2 of IEC 60544-5, prepared by IEC TC 112, "Evaluation and qualification of electrical insulating materials and systems", was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 60544-5:2012.

The following dates are fixed:

• latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2012-10-18
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This document supersedes EN 60544-5:2003.

EN 60544-5:2012 constitutes an editorial revision to align it with standards recently developed by SC 45A as well as with other parts in the EN 60544 series.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CENELEC [and/or CEN] shall not be held responsible for identifying any or all such patent rights.

Endorsement notice

The text of the International Standard IEC 60544-5:2011 was approved by CENELEC as a European Standard without any modification.

In the official version, for Bibliography, the following note has to be added for the standard indicated:

IEC 60544-4 NOTE Harmonized as EN 60544-4.

Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

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.

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 60544-1	-	Electrical insulating materials - Determination of the effects of ionizing radiation - Part 1: Radiation interaction and dosimetry	EN 60544-1	-
IEC 60544-2	-	Guide for determining the effects of ionizing radiation on insulating materials - Part 2: Procedures for irradiation and test	-	-
IEC 60780	-	Nuclear power plants - Electrical equipment of the safety system - Qualification	-	-
IEC/TR 61244-1	-	Determination of long-term radiation ageing in polymers - Part 1: Techniques for monitoring diffusion-limited oxidation	-	-
IEC/TR 61244-2	-	Determination of long-term radiation ageing in polymers - Part 2: Procedures for predicting ageing at low dose rates	-	-

CONTENTS

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.

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[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 (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*

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 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.

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 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, 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.

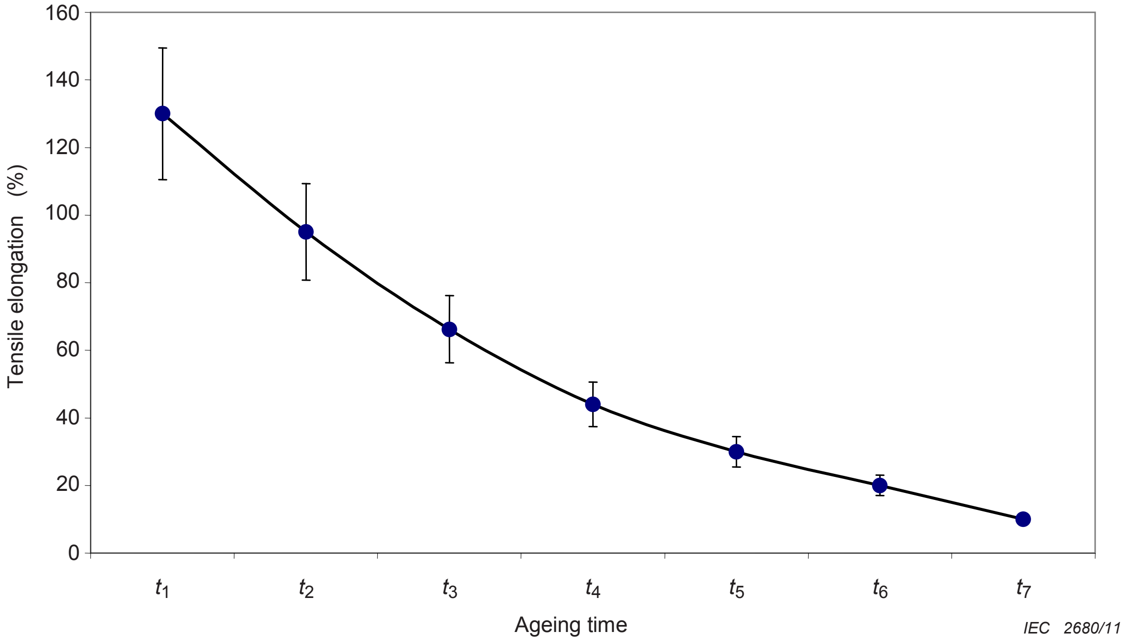
NOTE There are many other methods which have been investigated for CM and suitable measurement standards for some of these are expected to be developed over the next few years. A number of these are described in IAEA-NP-T-3.6 [4].

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 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.



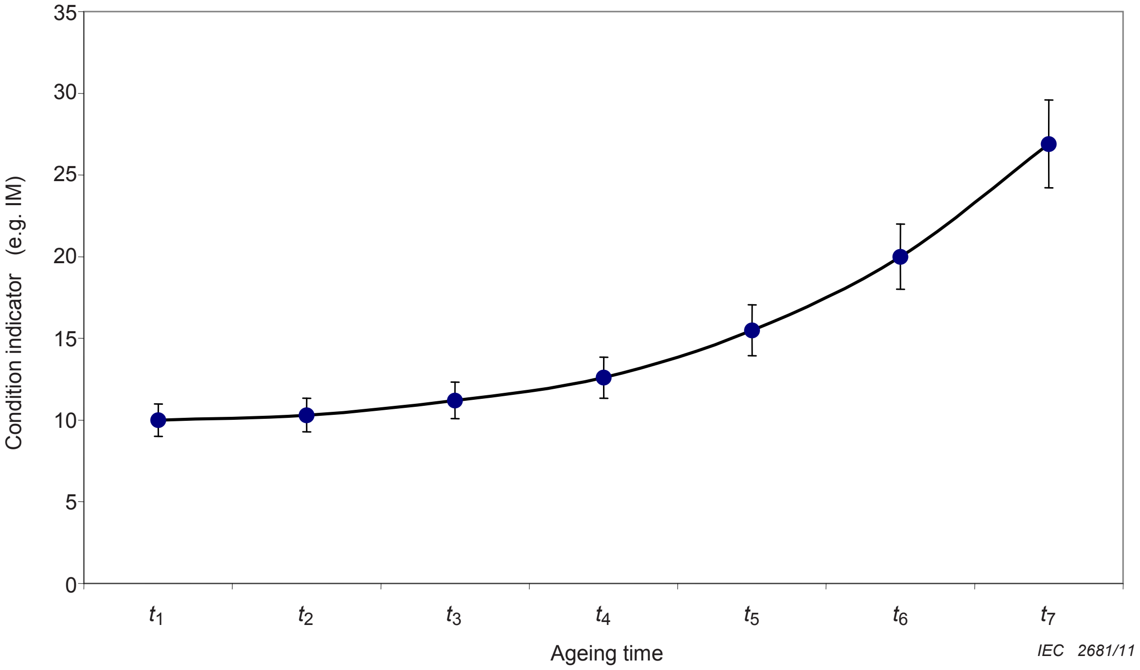


Figure 1 – Development of ageing data on changes in tensile elongation and a condition indicator (e.g. indenter modulus) – Schematic

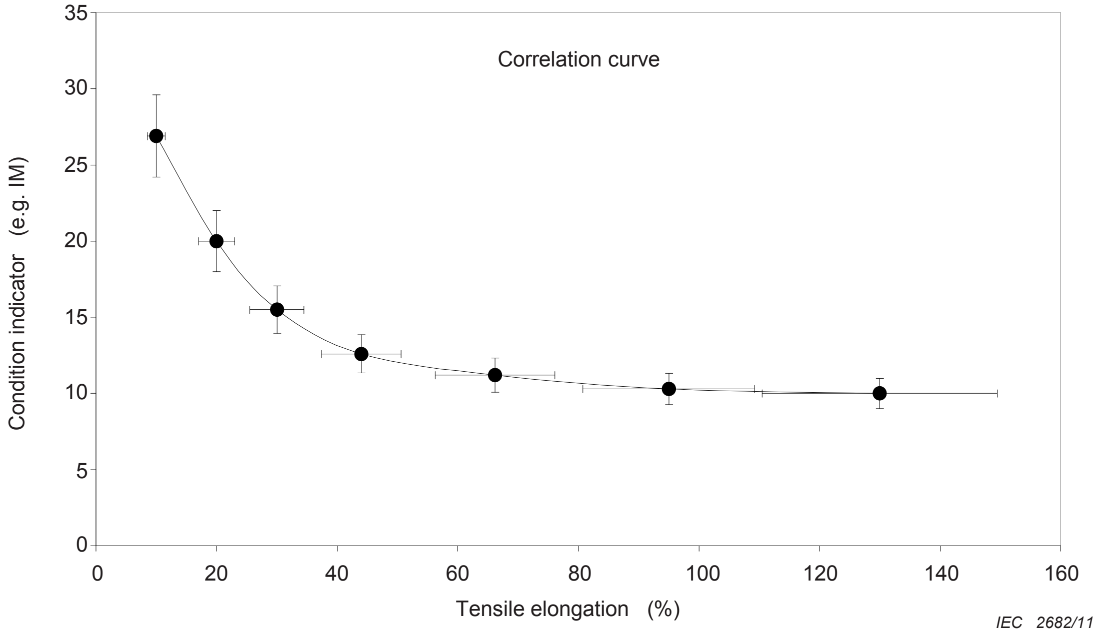


Figure 2 – Correlation curve derived from data in Figure 1 – Schematic

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.

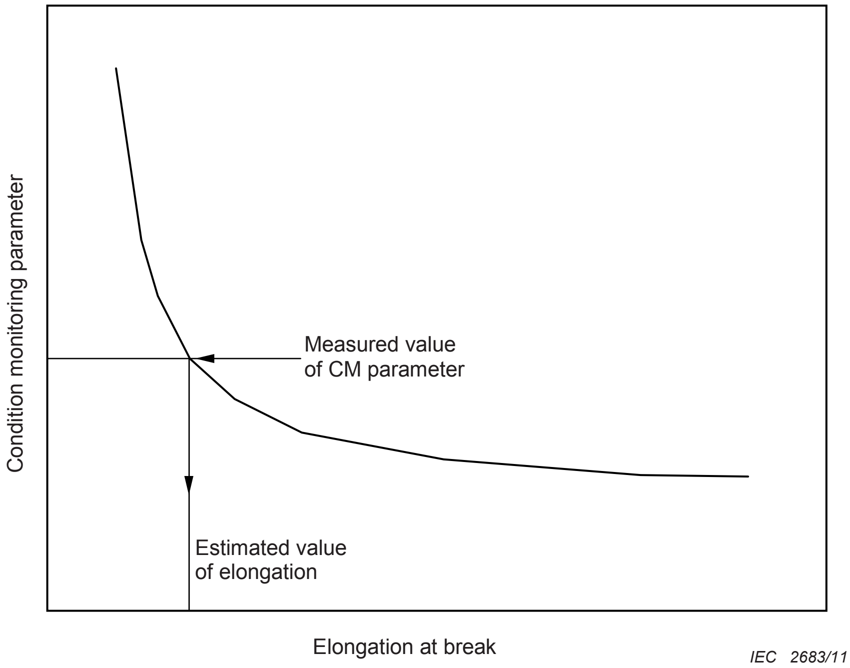


Figure 3 – Estimation of elongation from a correlation curve

8 Predictive modelling

Data obtained during laboratory accelerated ageing tests can be used to generate model parameters for predictive ageing models, such as those described in IEC 61244-2. These models can be used to predict the degradation of specific materials under various ageing conditions of temperature and radiation dose rate. By using the data obtained from environmental monitoring of the actual temperatures and dose rates in the plant, the degradation expected to occur in real-time ageing can be assessed.

This approach can also be used to estimate the effect of changes in the environmental conditions, e.g. a short-term increase in temperature arising from damage to thermal insulation on a nearby steam pipe.

The detailed accelerated ageing tests required to obtain the model parameters are most likely to be carried out on materials for use in new plant. The use of such models combined with design data on environmental conditions can be used during the design phase of new plant to identify potential problem areas where re-siting of equipment would be appropriate, e.g. re-routing of a cable run to avoid a localized hotspot.

Three predictive models which make use of a matrix of accelerated ageing data are described in detail in IEC 61244-2, together with the limitations and data requirements for use of these models:

- a power law model that has proved useful for materials exposed to radiation environments where thermal ageing is negligible;
- a time dependent superposition model which can model combined thermal and radiation ageing for those materials with a single dominant ageing mechanism;
- a dose dependent superposition model which is particularly useful in the low dose rate radiation ageing range where thermal ageing is important, and for materials with complex ageing behaviour.

9 Sample deposit

9.1 General

The testing of materials from a sample 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 and/or CM as part of an ageing management programme.

Assessment of the long-term properties of components using a sample deposit has advantages over accelerated ageing programmes. Its use means that the components age under real plant conditions but can, nevertheless, be checked and monitored without impairing plant operation. Such deposits are often installed in an area of the plant which has a relatively severe environment compared with most other areas where such materials are used. In this case, the sample in the deposit will age more rapidly and therefore will have a lead time over the bulk of the material in the plant.

Most deposits are primarily used for evaluation of cables and small electrical components and are mainly set up in a plant which has been in operation for less than 5 years. However, a deposit can also be of use in an older plant, provided that the samples are pre-aged using accelerated ageing before installation in the deposit. Samples in deposits are particularly useful for on-going qualification programmes.

9.2 Requirements of a deposit

A major prerequisite for the implementation of a sample deposit is a good knowledge of the radiation dose and temperature distribution at the deposit position and at positions in the plant where the material being tested is in routine use.

Environmental monitoring can be used to select a position in the plant that is exposed to a higher dose than most of the real positions. It may even be possible to find a location where the temperature is also similar to the maximum design temperature. Experience has shown that the loop line between the reactor pressure vessel and the steam generator is suitable for this purpose in pressurized water reactors (PWRs) and the reactor water clean-up system in boiling water reactors (BWRs). In VVER type reactors, the main circulation pipe, either hot or cold leg, is also a suitable location for a deposit.

In selecting a position for the deposit, care shall be taken to ensure that the environmental conditions at the deposit will produce degradation which simulates real conditions. In particular, care shall be taken in exposing some XLPE and EPR based components to radiation ageing at elevated temperature if their normal use is at lower temperatures. These materials can show a reverse temperature effect [15,16,17], with degradation occurring more rapidly at the lower temperatures. For XLPE materials, the deposit shall be at the lowest ambient temperature normally seen in plant operations.

9.3 Pre-ageing samples for a deposit

When a deposit is set up in a NPP which has been in operation for more than 5 years, it will be necessary to pre-age the samples to be placed in the deposit to a level equivalent to the actual age of the plant. The accelerated ageing used to pre-age the samples shall use low acceleration factors. The temperature and dose rate being simulated shall be based on the actual values in the plant, as determined from environmental monitoring (see 6.3).

9.4 Installation of an sample deposit

The deposit shall be arranged so that the samples are exposed to a reasonably uniform radiation field (e.g. if using the loop line in a PWR as the radiation source, they are kept at a constant distance from the loop). This can be readily done by using cable trays strapped to the circumference of the loop line. The specific design of the deposit can easily be adapted to the local conditions in the plant. Samples shall be placed in a single layer to avoid self-shielding.

The deposit needs to be equipped with a representative selection of the materials (e.g. cable samples, small electrical components) used in radiation environments. The number and type of samples required needs to be sufficient to ensure that enough material is available for the scheduled removal of samples over the required period of up to 60 years (for a deposit in a new plant). It is prudent to include extra samples to allow for future improvements in CM methods. Annex B illustrates the type of samples usually included in a deposit.

In assessing the number and type of samples required, the intervals at which samples are to be removed and the tests those are to be performed need to be established. For example, for cables, samples of about 0,3 m to 0,5 m in length are quite satisfactory for measurements of tensile elongation at break. Most of the CM methods currently available are non-destructive or need only small amounts of material; however, electrical tests will need longer lengths. If samples are required for a DBE test with electrical measurements, a minimum length of 3 m is required. Any whole cable samples included in a deposit shall have their ends sealed.

The deposit shall be fitted with dosimeters to record the profile of the radiation dose within the deposit and temperature monitoring is also required. This environmental monitoring shall be continued over at least two years to get a representative picture of the long-term environmental conditions within the deposit. Care shall be taken to ensure that there is a free flow of air into the deposit. Suitable contamination protection is desirable but shall not restrict air access.

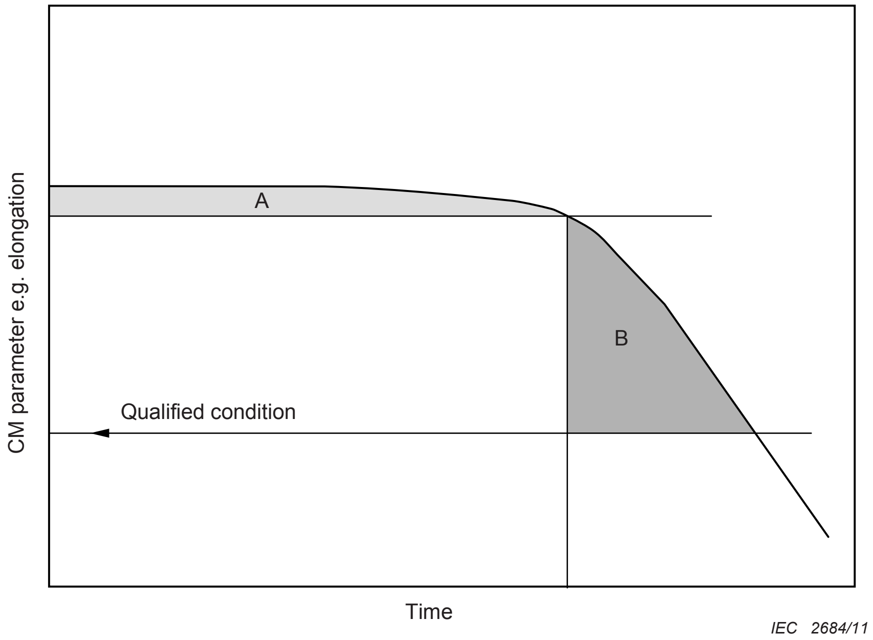
9.5 Testing of samples from the deposit

Initially, baseline data for all of the materials installed in the deposit shall be determined using unaged material. This baseline data shall utilize all of the CM tests which will be used on the materials in the deposit.

At regular intervals, samples will be removed for destructive tests (e.g. tensile elongation measurements) or subjected to CM tests. The test intervals will generally be limited by the accessibility of the sample deposit. In most plants, the deposit will only be available for access when the plant is shut down. The type of testing schedule required is illustrated in Annex B.

9.6 Determination of sampling intervals

For the cable types currently in use, it is reasonable to remove the first samples from the deposit 5 years after the start of plant operation, since the type and qualification tests that have already been performed provide an acceptable confidence interval for at least this period. The recommended interval between tests for a deposit in a new plant is 5 to 8 years. This interval shall be decreased if the materials are showing signs of more rapid degradation than expected. Once degradation starts to be observed the sampling interval shall be reduced, as indicated in Figure 4. A revised sampling interval of 1 to 2 years is then recommended. The precise boundaries of zones A and B illustrated schematically in Figure 4 shall be defined by the degradation curve for the specific material and by the qualified condition for that material.



NOTE In zone A, samples are taken at 5 to 8 year intervals; in zone B, the interval is decreased to 1-2 years.

Figure 4 – Modification of sampling interval dependent on values of the CM indicator

9.7 Real time aged materials

The deposit method is primarily suitable for new plants where unaged samples are readily available for the material types that are to be included in the deposit. For older plants, where unaged samples are not available for use in a deposit, an alternative is to evaluate the actual long-term ageing behaviour by removing samples from the plant. The disadvantages of this sampling procedure are that it constitutes an intervention into the plant and that the samples have to be replaced with suitably qualified materials. However, it may be necessary to use this method if, for special reasons, validated results have to be available within a short time (e.g. for older plants without existing EQ).

If there are data available on environmental conditions within the plant, a position can be selected where the material has been exposed to the worst case condition. For cable materials, such positions are usually in the direct vicinity of the loop lines (PWR) or in the reactor water cleanup system (BWR). Cable samples from real positions are normally irradiated quite inhomogeneously, e.g. a cable run converging on the loop line. Before removing the cable sample, the dose distribution shall be determined and the cable location identified clearly in a reproducible manner to allow the test results to be interpreted correctly.

CM methods that are non-destructive or use only micro-samples can be used to evaluate ageing degradation where sample removal for destructive testing is not practical. Baseline data are still required.

Annex A
(informative)

Example of a CM correlation curve

An example of a correlation curve in Figure A.1 for a CSPE cable material, shows the correlation between indenter measurements and changes in the tensile elongation at break obtained during an accelerated ageing programme [18]. A good correlation has been obtained for both radiation and thermal ageing of this CSPE material. This correlation curve also illustrates the degree of scatter that is likely to be observed in real data.

In-plant CM measurements on this material using the indenter can be compared with the predicted degradation that allows residual life to be estimated. The predicted degradation is obtained from use of ageing models (such as those described in IEC 61244-2), combined with knowledge of the environmental conditions in the plant. Alternatively, the condition can be compared to a qualified condition determined during EQ.

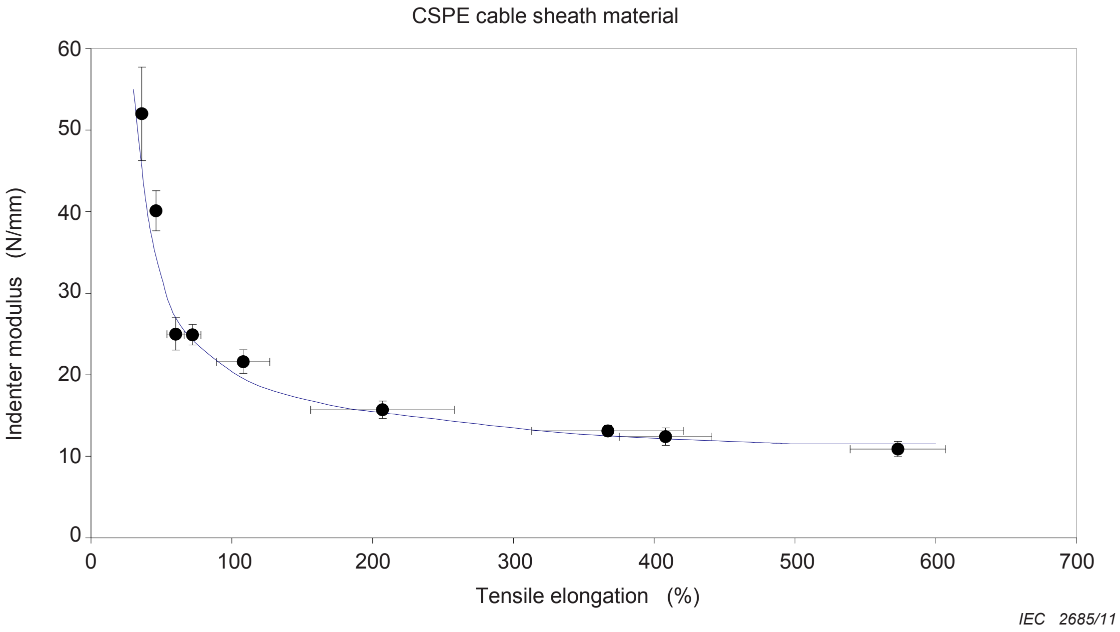


Figure A.1 – Correlation curve for indenter modulus against tensile elongation for a CSPE cable jacket material [18]

Annex B
(informative)

Use of a deposit

B.1 Typical sample in a deposit

A number of sample deposits have been installed in NPPs, mainly for cable materials. The detail of what is included in the deposits will vary from plant to plant but some typical examples are illustrated below.

A typical cable deposit might include the following types of samples:

- batches of pre-prepared dumb-bell samples for elongation tests;
- short sections of whole cable (typically 0,3 m to 0,5 m in length) for indenter and other CM measurements (these samples can also be used for preparation of dumb-bell samples after ageing);
- longer sections of whole cable (typically 1 m to 2 m in length) for periodic electrical tests;
- whole cable (typically 3 m in length) for future DBE testing.

Alternatively, longer lengths of cable can be utilized in a deposit and short lengths cut off for elongation tests and other CM tests at intervals.

B.2 Typical testing schedule for a deposit

For a plant cable deposit, the testing schedule could take the following form:

- Samples are removed for CM measurements on each component type. Initially these CM tests should be non-destructive (e.g. indenter or other CM techniques, as appropriate to the component type) or require only small samples (e.g. OIT tests), to preserve the material in the deposit.

The amount of material available in a deposit is often very limited, it is therefore important to conserve material as much as possible in the early stages of its use.

- If the non-destructive or micro-sample tests indicate that degradation is starting to occur, samples for elongation at break tests should be removed and tested.
- The values of the CM parameters are compared with the baseline data for that component. If significant degradation has occurred, additional tests may be carried out e.g. a DBE test.

It is important that the CM measurements are carried out using the methods specifically recommended for ageing management programmes, e.g. see [8].

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