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INTERNATIONAL STANDARD

colour inside

Nuclear power plants – Instrumentation and control important to safety – Electrical equipment condition monitoring methods – Part 1: General

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NUCLEAR POWER PLANTS – INSTRUMENTATION AND CONTROL IMPORTANT TO SAFETY – ELECTRICAL EQUIPMENT CONDITION MONITORING METHODS –

Part 1: General

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 document(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.

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6) All users should ensure that they have the latest edition of this publication.

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This redline version of the official IEC Standard allows the user to identify the changes made to the previous edition IEC/IEEE 62582-1:2011. A vertical bar appears in the margin wherever a change has been made. Additions are in green text, deletions are in strikethrough red text.

IEC/IEEE 62582-1 was prepared by subcommittee 45A: Instrumentation and control of nuclear facilities, of IEC technical committee 45: Nuclear instrumentation, in cooperation with Nuclear Power Engineering Committee of the IEEE Power & Energy Society[1], under the IEC/IEEE Dual Logo Agreement between IEC and IEEE. It is an International Standard.

This document is published as an IEC/IEEE Dual Logo standard.

This second edition cancels and replaces the first edition published in 2011. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) Integration of experience from the work with IAEA-TECDOC-1825:2017 "Benchmark analysis for condition monitoring test techniques of low voltage cables in nuclear power plants. Final results of a Coordinated Research Project".
b) Referral to IEC/IEEE 60780-323 instead of IEC 60780 and IEEE 323.

The text of this International Standard is based on the following IEC documents:

Draft	Report on voting
45A/1510/CDV	45A/1537/RVC

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

The language used for the development of this International Standard is English.

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

A list of all parts of IEC/IEEE 62582 series, under the general title *Nuclear power plants – Instrumentation and control important to safety – Electrical equipment condition monitoring methods*, can be found on the IEC website.

The IEC Technical Committee and IEEE Technical Committee have decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn, or
- revised.

IMPORTANT – The "colour inside" logo on the cover page of this document 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.

[1] A list of IEEE participants can be found at the following URL: http://standards.ieee.org/downloads/62582-1/62582-1-2011/62582-1-2011_wg-participants.pdf.

INTRODUCTION

a) Technical background, main issues and organisation of this document

This part of this IEC/IEEE 62582 series focuses on methods for condition monitoring for management of ageing of electrical equipment installed in nuclear power plants and for application of the concept of qualified condition.

IEC/IEEE 6258-1 is the first part of the IEC/IEEE 62582 series of standards, containing background and guidelines for the application of methods for condition monitoring of electrical equipment important to safety of nuclear power plants. The detailed descriptions of the methods are given in the other parts, one part for each method. This document also includes some elements which are common to all methods.

IEC/IEEE 62582 series is issued with a joint logo which makes it applicable to the management of ageing of electrical equipment qualified to IEEE as well as IEC Standards.

Condition monitoring is a developing field and more methods will be added to the IEC/IEEE 62582 series when they are considered widely applied and a good reproducibility of the condition monitoring method can be demonstrated.

~~Historically, IEEE Std 323-2003 introduced the concept and role that conditionbased qualification could be used in equipment qualification, as an adjunct to qualified life. In equipment qualification, the condition of the equipment for which acceptable performance was demonstrated is the qualified condition. The qualified condition is the condition of equipment, prior to the start of a design basis event, for which the equipment was demonstrated to meet the design requirements for the specified service conditions.~~

IEC/IEEE 60780-323 defined condition-based qualification which is an adjunct to type testing. The qualified condition is established by condition indicator(s) prior to the start of accident conditions for which the equipment was demonstrated to meet the design requirements for the specified service conditions. IEC/IEEE 60780-323 defined condition indicator.

Significant research has been performed on condition monitoring techniques and the use of these techniques in equipment qualification as noted in NUREG/CR-6704, Vol. 2 (BNL -NUREG-52610) [1],[2] JNES-SS-0903, 2009 [2] and IAEA-TECDOC-1825:2017 [3].

It is intended that this IEC/IEEE document be used by operators of nuclear power plants, systems evaluators and by licensors.

b) Situation of the current standard in the structure of the IEC SC 45A standard series

IEC/IEEE 62582-1 is the third level IEC SC 45A document tackling the issue of application of condition monitoring in equipment qualification and management of ageing of electrical I&C equipment in nuclear power plants.

IEC/IEEE 62582-1 is to be read in association with IEC/IEEE 60780-323, which provides general requirements for qualification of I&C systems and equipment that are used to perform functions important to safety in NPPs and nuclear facilities.

For more details on the structure of the IEC SC 45A standard series, see item d) of this introduction.

2 Numbers in square brackets refer to the Bibliography.

c) Recommendations and limitations regarding the application of this document

It is important to note that this document establishes no additional functional requirements for safety systems.

This document discusses the general measurement technique for current condition monitoring methods and is not meant to cover any specific technologies.

d) Description of the structure of the IEC SC 45A standard series and relationships with other IEC documents and other bodies documents (IAEA, ISO)

~~The top-level document of the IEC SC 45A standard series is IEC 61513. It provides general requirements for I&C systems and equipment that are used to perform functions important to safety in NPPs. IEC 61513 structures the IEC SC 45A standard series.~~

~~IEC 61513 refers directly to other IEC SC 45A standards for general topics related to categorization of functions and classification of systems, qualification, separation of systems, defence against common cause failure, software aspects of computer-based systems, hardware aspects of computer-based systems, and control room design. The standards referenced directly at this second level should be considered together with IEC 61513 as a consistent document set.~~

The IEC SC 45A standard series comprises a hierarchy of four levels. The top-level documents of the IEC SC 45A standard series are IEC 61513 and IEC 63046.

IEC 61513 provides general requirements for instrumentation and control (I&C) systems and equipment that are used to perform functions important to safety in nuclear power plants (NPPs). IEC 63046 provides general requirements for electrical power systems of NPPs; it covers power supply systems including the supply systems of the I&C systems.

IEC 61513 and IEC 63046 are to be considered in conjunction and at the same level. IEC 61513 and IEC 63046 structure the IEC SC 45A standard series and shape a complete framework establishing general requirements for instrumentation, control and electrical power systems for nuclear power plants.

IEC 61513 and IEC 63046 refer directly to other IEC SC 45A standards for general requirements for specific topics, such as categorization of functions and classification of systems, qualification, separation, defence against common cause failure, control room design, electromagnetic compatibility, human factors engineering, cybersecurity, software and hardware aspects for programmable digital systems, coordination of safety and security requirements and management of ageing. The standards referenced directly at this second level should be considered together with IEC 61513 and IEC 63046 as a consistent document set.

At a third level, IEC SC 45A standards not directly referenced by IEC 61513 or by IEC 63046 are standards related to specific requirements for specific equipment, technical methods, or ~~specific~~ activities. Usually these documents, which make reference to second-level documents for general ~~topics~~ requirements, can be used on their own.

A fourth level extending the IEC SC 45 standard series, corresponds to the Technical Reports which are not normative.

~~IEC 61513 has adopted a presentation format similar to the basic safety publication IEC 61508 with an overall safety life-cycle framework and a system life-cycle framework and provides an interpretation of the general requirements of IEC 61508-1, IEC 61508-2 and IEC 61508-4, for the nuclear application sector. Compliance with IEC 61513 will facilitate consistency with the requirements of IEC 61508 as they have been interpreted for the nuclear industry. In this framework IEC 60880 and IEC 62138 correspond to IEC 61508-3 for the nuclear application sector.~~

~~IEC 61513 refers to ISO as well as to IAEA 50-C-QA (now replaced by IAEA GS-R-3) for topics related to quality assurance (QA).~~

~~The IEC SC 45A standards series consistently implements and details the principles and basic safety aspects provided in the IAEA code on the safety of NPPs and in the IAEA safety series, in particular the Requirements NS-R-1, establishing safety requirements related to the design of Nuclear Power Plants, and the Safety Guide NS-G-1.3 dealing with instrumentation and control systems important to safety in Nuclear Power Plants. The terminology and definitions used by SC 45A standards are consistent with those used by the IAEA.~~

The IEC SC 45A standards series consistently implements and details the safety and security principles and basic aspects provided in the relevant IAEA safety standards and in the relevant documents of the IAEA nuclear security series (NSS). In particular this includes the IAEA requirements SSR-2/1 , establishing safety requirements related to the design of nuclear power plants (NPPs), the IAEA safety guide SSG-30 dealing with the safety classification of structures, systems and components in NPPs, the IAEA safety guide SSG-39 dealing with the design of instrumentation and control systems for NPPs, the IAEA safety guide SSG-34 dealing with the design of electrical power systems for NPPs, the IAEA safety guide SSG-51 dealing with human factors engineering in the design of NPPs and the implementing guide NSS42-G for computer security at nuclear facilities. The safety and security terminology and definitions used by the SC 45A standards are consistent with those used by the IAEA.

IEC 61513 and IEC 63046 have adopted a presentation format similar to the basic safety publication IEC 61508 with an overall life-cycle framework and a system life-cycle framework. Regarding nuclear safety, IEC 61513 and IEC 63046 provide the interpretation of the general requirements of IEC 61508-1, IEC 61508-2 and IEC 61508-4, for the nuclear application sector. In this framework, IEC 60880, IEC 62138 and IEC 62566 correspond to IEC 61508-3 for the nuclear application sector.

IEC 61513 and IEC 63046 refer to ISO 9001 as well as to IAEA GSR part 2 and IAEA GS-G-3.1 and IAEA GS-G-3.5 for topics related to quality assurance (QA).

At level 2, regarding nuclear security, IEC 62645 is the entry document for the IEC/SC 45A security standards. It builds upon the valid high level principles and main concepts of the generic security standards, in particular ISO/IEC 27001 and ISO/IEC 27002; it adapts them and completes them to fit the nuclear context and coordinates with the IEC 62443 series. At level 2, IEC 60964 is the entry document for the IEC SC 45A control rooms standards, IEC 63351 is the entry document for the human factors engineering standards and IEC 62342 is the entry document for the ageing management standards.

NOTE 1 It is assumed that for the design of I&C systems in NPPs that implement conventional safety functions (e.g. to address worker safety, asset protection, chemical hazards, process energy hazards) international or national standards would be applied.

NOTE 2 IEC TR 63400 provides a more comprehensive description of the overall structure of the IEC SC 45A standards series and of its relationship with other standards bodies and standards.

NUCLEAR POWER PLANTS – INSTRUMENTATION AND CONTROL IMPORTANT TO SAFETY – ELECTRICAL EQUIPMENT CONDITION MONITORING METHODS –

Part 1: General

1 Scope ~~and object~~

This part of the IEC/IEEE 62582 series contains requirements for application of the other parts of IEC/IEEE 62582 related to specific methods for condition monitoring in electrical equipment important to safety of nuclear power plants. It also includes requirements which are common to all methods. The procedures defined in IEC/IEEE 62582 are intended for detailed condition monitoring.

IEC/IEEE 62582 specifies condition monitoring methods in sufficient detail to enhance the accuracy and repeatability, and provide standard formats for reporting the results. The methods specified are applicable to electrical equipment containing ~~organic or~~ polymeric materials. Some methods are especially designed for the measurement of condition of a limited range of equipment whilst others can be applied to all types of equipment for which the ~~organic~~ polymeric parts are accessible.

Although the scope of IEC/IEEE 62582 is limited to the application of instrumentation and control systems important to safety, the condition monitoring methods ~~may~~ can also be applicable to other components which include ~~organic or~~ polymeric materials.

The different parts of IEC/IEEE 62582 are measurement standards, primarily for use in the management of ageing in initial qualification and after installation. For the technical background of condition monitoring methods, reference is made to other IEC standards, e.g. IEC 60544-5 [1]. Information on the role of condition monitoring in qualification of electrical equipment important to safety is found in IEC/IEEE ~~Std~~ 60780-323. General information on management of ageing can be found in IEC 62342 [5] and IEEE 1205 [6].

NOTE ~~The procedures defined in the IEC/IEEE 62582 are intended for detailed condition monitoring.~~ A simplified version of the procedures ~~may~~ can be appropriate for preliminary assessment of the need for detailed measurements.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

~~IEEE Std 323:2003, IEEE *Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations*~~

IEC/IEEE 60780-323, *Nuclear facilities – Electrical equipment important to safety – Qualification*

IEC/IEEE 62582 (all parts), *Nuclear power plants – Instrumentation and control important to safety – Electrical equipment condition monitoring methods*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp
- IEEE Standards Dictionary Online: available at http://dictionary.ieee.org

3.1
condition indicator
characteristic of a structure, system or component that can be observed, measured or trended to infer or directly indicate the current and future ability of the structure, system or component to function within acceptance criteria

[SOURCE: IAEA Nuclear Safety and Security Glossary, ~~2007~~2022 (Interim) Edition]

3.2
condition monitoring
continuous or periodic tests, inspections, measurement or trending of the performance or physical characteristics of structures, systems and components to indicate current or future performance and the potential for failure

[SOURCE: IAEA Safety Glossary, ~~2007~~2018 Edition, modified – note removed.]

3.3
equipment qualification
generation and maintenance of evidence to ensure that equipment will operate on demand, under specified service conditions, to meet system performance requirements

[SOURCE: IAEA Nuclear Safety and Security Glossary, ~~2007~~2022 (Interim) Edition, modified – notes not included.]

3.4
~~**item important to safety**~~
~~item that is part of a safety group and/or whose malfunction or failure could lead to radiation exposure of the site personnel or members of the public~~

~~[IAEA Safety Glossary, 2007 Edition]~~

equipment important to safety
equipment that is part of a safety group and/or whose malfunction or failure could lead to undue radiation exposure of the site personnel or members of the public. Equipment including:

- those structures, systems and components that prevent anticipated operational occurrences from leading to accident conditions;
- those features that are provided to mitigate the consequences of malfunction or failure of structures, systems and components.

Note 1 to entry:

a) For usage consistent with IEC 61226 [11], equipment important to safety are as follows:
   1) all I&C equipment performing Category A to Category C functions (in accordance with the IEC 61226 [11] categorisation scheme);
   2) all electrical equipment necessary to ensure emergency energy supply to this equipment in case of a loss of normal power supply;

3) all electrical equipment necessary to ensure ultimate energy supply in case of total loss of on-site power (if selected as design extension condition to be mitigated).

b) For usage consistent with other IEEE documents and a Class 1E categorization; for equipment important to safety, qualification is essential to the following:

1) electric equipment and systems that are essential to emergency reactor shutdown, containment isolation, reactor core cooling, and containment and reactor heat removal, or;

2) electric equipment that are otherwise essential in preventing significant release of radioactive material to the environment.

Note 2 to entry: Users of this document are advised that Class 1E is a functional term. Equipment and systems are to be classified Class 1E only if they fulfil the functions listed in the definition. Identification of systems or equipment as Class 1E based on anything other than their function is an improper use of the term and should be avoided.

[SOURCE: IEC/IEEE 60780-323:2016, 3.12]

3.5
tactile observation
qualitative assessment of a polymer's condition through the physical examination of the exterior of a material as observed by a knowledgeable person who, via experience or training, can deduce degradation based on the hardness or softness of the material by lightly bending or pressing a fingernail into the surface and via their knowledge and experience, or training can deduce degradation based on the observed condition to assess if quantitative assessments are warranted

3.6
visual observation
qualitative assessment of a polymer's condition through the visible examination of the exterior of material as observed by a knowledgeable person who, via experience or training, can deduce degradation based on the observed condition to assess if quantitative assessments are warranted

3.7
qualified condition
condition of an equipment, prior to the start of a design basis event, for which the equipment was demonstrated to meet the design requirements for the specified service conditions. This could include certain post accident cooling and monitoring systems that are expected to remain operational

[SOURCE: IEC/IEEE 60780-323:2016, 3.19]

3.8
qualified life
period for which a structure, system or component has been demonstrated, through testing, analysis or experience, to be capable of functioning within acceptance criteria during specific operating conditions while retaining the ability to perform its safety functions in accident conditions for a design basis accident or a design basis earthquake

[SOURCE: IAEA Nuclear Safety and Security Glossary, ~~2007~~2022 (Interim) Edition]

3.9
service life
period from initial operation to final withdrawal from service of a structure, system or component

[SOURCE: IAEA Nuclear Safety and Security Glossary, ~~2007~~2022 (Interim) Edition]

3.10
design basis events
postulated events used in the design to establish the acceptable performance requirements for the structures, systems, and components

[SOURCE: IEEE Standards Dictionary Online]

3.11
service conditions
actual physical states or influences during the service life of equipment, including normal operating conditions, abnormal operating conditions, design basis event conditions and conditions following a design basis event and design extension conditions

[SOURCE: IAEA Safety Glossary, 2007, modified, addition of "design extension conditions" and use of term "equipment instead of "structure, system or component"]

3.12
ageing
general process in which characteristics of a system or component gradually change with time or use

[SOURCE: IEC/IEEE 60780-323:2016, 3.2]

3.13
accelerated ageing
method of equipment testing in which the ageing associated with longer term service conditions is simulated in a short time

Note 1 to entry: Usually, accelerated ageing attempts to simulate natural ageing effects by application of stressors representing pre-service and service conditions, but with differences in intensity, duration and the manner of application.

[SOURCE: IAEA Nuclear Safety and Security Glossary, 2022 (interim) Edition]

4 Condition indicators

4.1 General

~~Condition monitoring should only be applied if there is a known relationship between the ageing degradation of the component monitored and the degradation of the equipment's safety function. This relationship should be established during equipment qualification. The relationship should take into account any diffusion limited rate effects that occur during accelerated ageing with high acceleration factors.~~

The condition indicator shall be measurable, change monotonically with time, be linked to the functional degradation of the qualified equipment, and have a consistent trend from unaged through the limit of the qualified pre-accident condition, and applied according to IEC/IEEE 60780-323.

This trend should be established during the pre-ageing part of the equipment qualification. When establishing the trend of condition indicators with ageing time, it is important that acceleration factors (both thermal and radiation) are kept as small as practical. See Annex A for additional information on diffusion limited oxidation (DLO).

Condition monitoring programs rely on measurable indicators that provide insight into the overall degradation of the materials. To perform measurements of the condition of naturally aged components, a sample shall either be taken destructively or the measurements shall be made on the material in the field in a non-destructive way. The latter methods are preferred since they allow the material to be studied without interrupting operation; however, it is often difficult to perform these types of measurements directly in the field with the required degree of repeatability and accuracy.

In ~~organic~~ polymeric materials, ageing occurs that ~~may~~ can adversely impact the important safety function through a range of chemical reactions, including chain scission and cross-linking, which alter the polymeric structure. For condition monitoring programs, it becomes imperative to find methods that, either directly or indirectly, follow the progress of these reactions. A large number of methods exist to perform this task, which makes it difficult to provide an overview of each individual technique. Instead, this document will focus on general groups of methods. The overall description of these groups is provided in 4.2 through 4.6.

4.2 Chemical indicators

As mentioned above, the degradation mechanism for ~~organic~~ polymeric materials follows from a series of chemical reactions in which the chemical structure of the polymer is altered. The progressive change in the chemistry of the material provides an opportunity to monitor the degradation throughout its ageing. Numerous techniques exist to perform this task, some which monitor the polymer chain degradation itself and others which monitor side reactions which are related to the degradation.

4.3 Physical indicators

Another key family of indicators includes techniques which monitor the material's physical properties. The degradation of ~~organic~~ polymeric materials manifests itself in changes to these physical properties (i.e. tensile strength, elongation, and hardness). By measuring these physical characteristics, it is possible to create a correlation with the aged condition of the material.

4.4 Electrical indicators

A third category of techniques involves measuring electrical properties of the materials. Many of these techniques were developed for polymeric materials used in electrical insulation. Within this family there are two basic subsets of methods. The first subset involves measuring the dielectric properties of the materials.

A second subset of methods monitors the electrical response of systems under normal operation. In these cases, a signal is passed through the electrical system and any changes from baseline are detected. These changes could be signs of degradation, whether through ageing or through physical damage.

4.5 ~~Miscellaneous~~Other indicators

As new technologies are developed and implemented, it becomes necessary to develop condition monitoring methods to keep pace. ~~As such, some methods are developed specifically for certain types of materials.~~

4.6 Visual and tactile observation

Visual and tactile testing methods are non-intrusive testing techniques for accessible components. The purpose of this physical inspection method is to identify cracks, discolouration, visible contamination of the components, the presence of chemicals or oils, and other local damage such as swelling or deformation, to provide a qualitative assessment of the condition of for example a cable's jacket material that could indicate problems with the insulation.

Visual and tactile methods may be used as a screening tool for ageing assessment and indicate that further evaluation is necessary by applying other methods in accordance with the different parts of IEC/IEEE 62582.

5 Applicability of condition indicators to different types of ~~organic~~ polymeric materials

There is currently no single condition monitoring method which is suitable for all ~~organic or~~ polymeric materials. A basic requirement for inclusion in a part of the IEC/IEEE 62582 series is that the condition indicators are sensitive to the effects of ageing. An important characteristic of a useful condition indicator is that it shows a trend that changes monotonically with degradation and can be correlated with the safety related performance. An indicator that does not change for a long time and then suddenly undergoes drastic changes is not useful for prognostic applications. This can be the case with mechanical condition monitoring on semi-crystalline materials, e.g. cross-linked polyethylene and thermosetting resins, dependent on the formulation.

Information on the applicability of various condition indicators to different polymeric materials used in instrument and control equipment in nuclear power plants can be found in ~~NUREG/CR-7000 and in IAEA-TECDOC-1188, see Bibliography~~ IAEA-TECDOC-1188 [12], IAEA-TECDOC-1825 [3] and in EPRI 1022969 [14].

6 Destructive and non-destructive condition monitoring

A condition monitoring method ~~may~~ can be considered destructive or non-destructive, depending on whether the measurement or the sampling of material used for the measurement will affect operability or future ageing. Non-destructive use of condition monitoring is preferable in field measurements but with presently available methods it is limited to a few types of equipment, mainly cables, where the parts of the equipment of interest are accessible in the field. In other cases, deposited samples or samples which can be replaced are ~~needed~~ necessary to allow condition monitoring.

If deposited samples are available or where components can be replaced, a broader range of condition monitoring methods can be considered, including destructive methods. In this case, condition monitoring can be applied to all types of equipment where the ageing material – normally ~~organic~~ polymeric materials used for electrical insulation, sealing, etc. can be accessed.

7 Application of condition monitoring in equipment qualification and management of ageing

7.1 General

Condition monitoring as part of qualification and management of ageing of electrical equipment in nuclear power plants can have one or a combination of the following aims:

- determination of acceleration factors for the establishment of qualified life from artificial laboratory ageing;
- extension of qualified life;
- establishment of qualified condition;
- periodic assessment of equipment condition after installation for comparison with qualified condition.

Condition monitoring can also be used for determining whether the degradation of age sensitive materials in equipment is within specific limits. These limits are those for which it has been established that the effects on operability in specified service conditions and design basis events are negligible.

7.2 Use of condition monitoring in the establishment of qualified life

7.2.1 Establishment of qualified life

The qualified life of an equipment is generally established by accelerated ageing of samples in a laboratory, followed by verification of their capability to function within acceptance criteria during a simulated design basis event. The acceleration factor is the ratio between the rate of degradation under the laboratory simulation and in normal operating conditions in the field. Condition monitoring is used to establish activation energies for calculation of the acceleration factor in accelerated thermal ageing.

7.2.2 Determination of the acceleration factor in accelerated thermal ageing

The acceleration factor F in accelerated thermal ageing is normally calculated by application of the Arrhenius equation as follows:

$$F = \frac{t_1}{t_2} = e^{-\frac{E}{k}\left[\frac{1}{T_2} - \frac{1}{T_1}\right]} \quad (1)$$

where

t_1 and t_2 are the times to reach a certain level of degradation at the temperatures T_1 and T_2 (in K);

E is the activation energy, and

k is the Boltzmann constant.

NOTE 1 The Arrhenius equation $r = Ae^{-E/kT}$ is a formula for the temperature dependence of the rate r of a chemical reaction. A is a pre-factor (in case of first order reactions called the frequency factor with the unit s–1), E is the activation energy (here with the unit eV), k is the Boltzmann constant (0,861 7 × 10^{-4} eV × K – 1) and T is the temperature (in K). The activation energy is defined as the energy that ~~must~~ has to be overcome in order for a chemical reaction to occur.

The activation energy of a material is normally calculated from the results of measurements of a condition indicator as a function of time at different temperatures. The pairs of values of temperature and time to reach a certain level of degradation are plotted in an Arrhenius diagram, where the inverse of temperatures (in K) are plotted on a linear scale on the abscissa and the time t is plotted on a logarithmic scale on the ordinate. An example is shown in Figure 1.

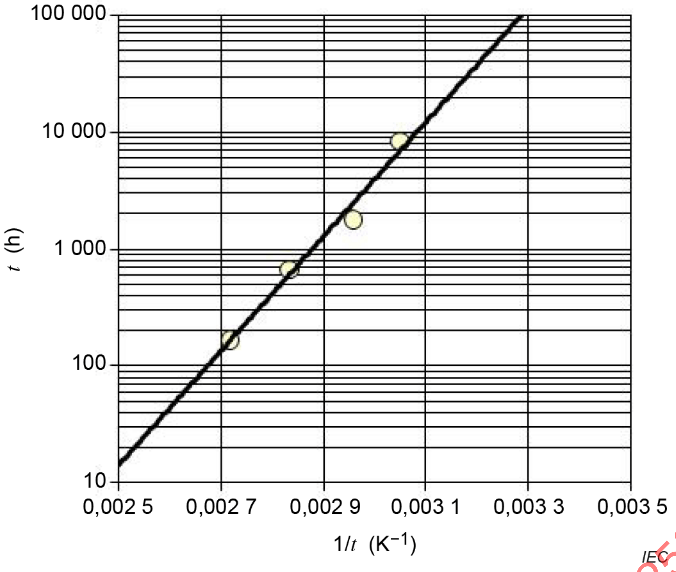

Figure 1 – Example of an Arrhenius diagram

A straight line between three or more points with a high correlation indicates that there is an Arrhenius behaviour of the dependency between rate of degradation and temperature. The activation energy E (in eV) is calculated from the slope of the line.

NOTE 2 Application far outside the range where the measurement points have been acquired can result in significant errors.

The activation energy could vary widely for the same generic type of material for various reasons, e.g. different detailed formulations and manufacturing methods.

The acceleration factor and, consequently, the qualified life is sensitive to the value of the activation energy. Inaccuracy in determination of the activation energy has a very significant influence on the acceleration factor and consequently on the qualified life based on tests including ~~artificial~~ accelerated thermal ageing. This is illustrated in Figure 2.

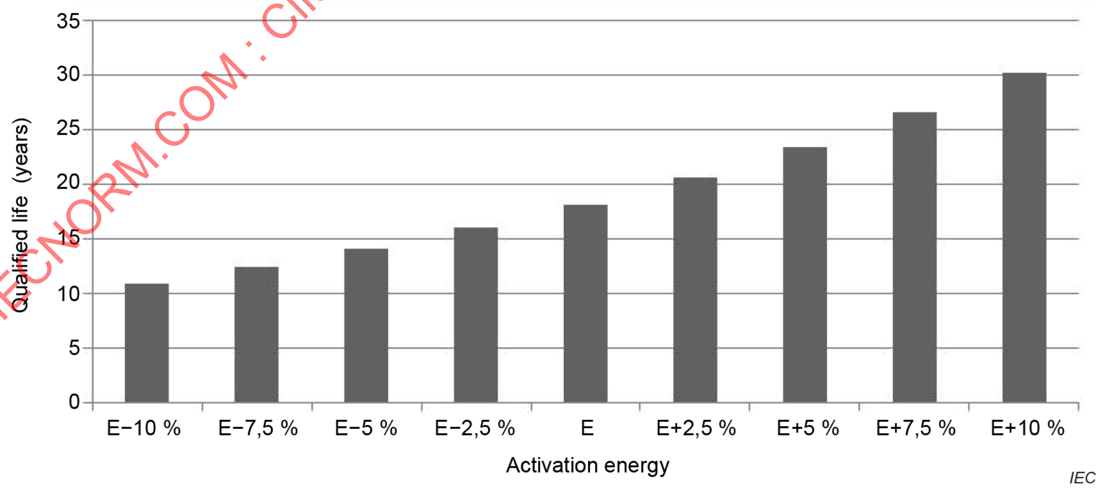

Figure 2 – Influence of activation energy on qualified life, determined from ~~artificial~~ accelerated thermal ageing for 42 days at 110 °C, followed by a simulated design basis event

NOTE 3 The normal service temperature is 50 °C. E = 0,9 eV.

The example illustrates the necessity for high accuracy and repeatability of the condition monitoring methods used in measurements for the determination of activation energies.

7.3 Use of condition monitoring in the extension of qualified life

A high degree of conservatism is normally used in the establishment of qualified life during initial qualification testing. The conservatism takes into account uncertainties in the prediction of the field environmental conditions, uncertainties in the acceleration factors used for determination of the qualified life from simulated laboratory ageing, uncertainties in demonstrating satisfactory performance, normal variations in commercial production, and uncertainties in measurement and test equipment. Most of the equipment will normally see quite lower values regarding, for example, temperature and radiation than the equipment that have the harshest service condition. Different service conditions will give the possibility to have different service life on the equipment depending on the position where the equipment is used. Due to the conservatism and limitation of time available, combined with use of moderate acceleration factors in simulated laboratory ageing, initial qualification can result in an established qualified life which ~~may~~ can be far from the service life that can be tolerated before a design basis event. Methods for extension of qualified life usually include monitoring of the condition of representative samples of installed equipment.

7.4 Use of condition monitoring in the establishment and assessment of qualified condition

~~Condition-based qualification is included in IEEE 323-2003 as a complement or alternative to qualified life.~~

~~Condition based qualification is based on establishment of the values of appropriate condition indicators at the end of ageing prior to design basis event testing. These values represent the qualified condition. The benefit of using condition based qualification as a complement or alternative to qualified life is considerably enhanced if the trends (variation with time) of the values of the condition indicators are established during ageing, e.g. by performing the artificial ageing incrementally and measuring the values of the condition indicators at each increment.~~

Condition-based qualification is an adjunct to type testing.

Condition-based qualification is based on establishment of how the values of appropriate condition indicators change with ageing. This is normally established during artificial pre-ageing by performing the ageing incrementally and measuring the values of the condition indicators at each increment. The values at the end of the pre-ageing prior to successful design basis event testing represent the qualified condition.

NOTE Pre-ageing does not include accident radiation dose.

After installation, identical measurements of the condition of representative samples are carried out periodically and compared with the qualified condition. The principle is illustrated schematically in Figure 3. The rate of change of the condition indicator over time is different for varying levels of severity.

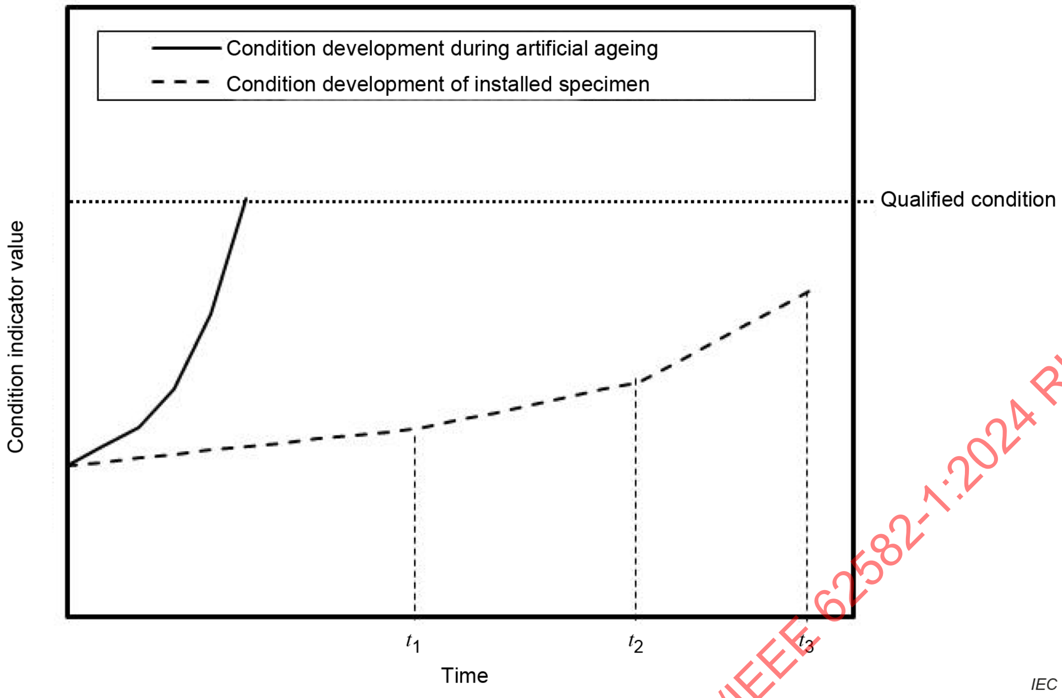

Figure 3 – Illustration of the principle of condition-based qualification

The qualified condition can be established as part of the initial qualification testing. If the initial qualification has been performed with the target to establish a qualified life only and no condition monitoring has been included, it ~~may~~ can be possible to establish the qualified condition afterwards without repeating the design basis event testing. If identical samples of equipment are available which are new or have been stored in environmentally controlled conditions, the qualified condition can be established by repeating the ageing used in the original initial qualification testing and determining the values of appropriate condition indicators (during and) at the end of this ageing.

The measurements after installation may be made by other personnel, instrumentation and in other laboratories than those used when the qualified condition was established. This puts a high demand on the specification of the condition monitoring methods used and the documentation and repeatability of the measurements. It is important that quite small changes in the value of the condition indicator can be detected. This requires a high degree of accuracy in the condition monitoring method.

The acceptance criteria for measurement in the plant shall allow for sufficient time for equipment to be replaced before the qualified condition is exceeded.

7.5 Use of baseline data

Condition monitoring can be useful for evaluating the limits of degradation, below which the functionality in service conditions and simulated design basis events is generally known not to be significantly affected.

The general usefulness of available data on values of condition indicators, for which operability in simulated design basis events has been demonstrated, depends on the repeatability and accuracy of the methods used and how well the condition monitoring has been defined and reported.

Annex A
(informative)

Diffusion limited oxidation (DLO)

A.1 General

Exposure of polymeric components to environments containing oxygen during ageing can often result in heterogeneously oxidised samples. This diffusion limited oxidation (DLO) can occur whenever the rate of oxygen consumption in a material is greater than the rate at which the oxygen can be resupplied to the interior of the material by diffusion processes from the surrounding atmosphere. DLO will lead to a heterogeneity in the oxidation through the sample thickness and a resultant change in physical properties through the thickness. This document focusses on thermal ageing, however, caution should also apply during radiation ageing.

A.2 Importance of DLO in thermal ageing

The importance of DLO in any ageing environment depends on a number of factors:

- sample geometry;
- oxygen consumption rate;
- oxygen permeability in the polymer;
- oxygen partial pressure surrounding the sample.

The oxygen consumption rate is the most important factor in determining the degree of DLO observed, since it is determined by the stress level applied, e.g. temperature. For this reason, DLO becomes much more significant when high acceleration factors are used during accelerated ageing. In thicker samples, e.g. cables and large cross-section seals, DLO will be of more importance than in thin samples for the same ageing conditions.

DLO can occur during thermal ageing of polymeric materials. Two examples are shown below. Figure A.1 illustrates the changes in indenter modulus through the thickness of an ethylene propylene diene monomer (EPDM) seal which has been thermally aged at 170 °C and 110 °C, respectively. Ageing at the lower temperature shows a reasonably uniform degree of ageing through the thickness of the seal, but at the higher temperature, the surface layers are much more degraded than the internal part of the seal.

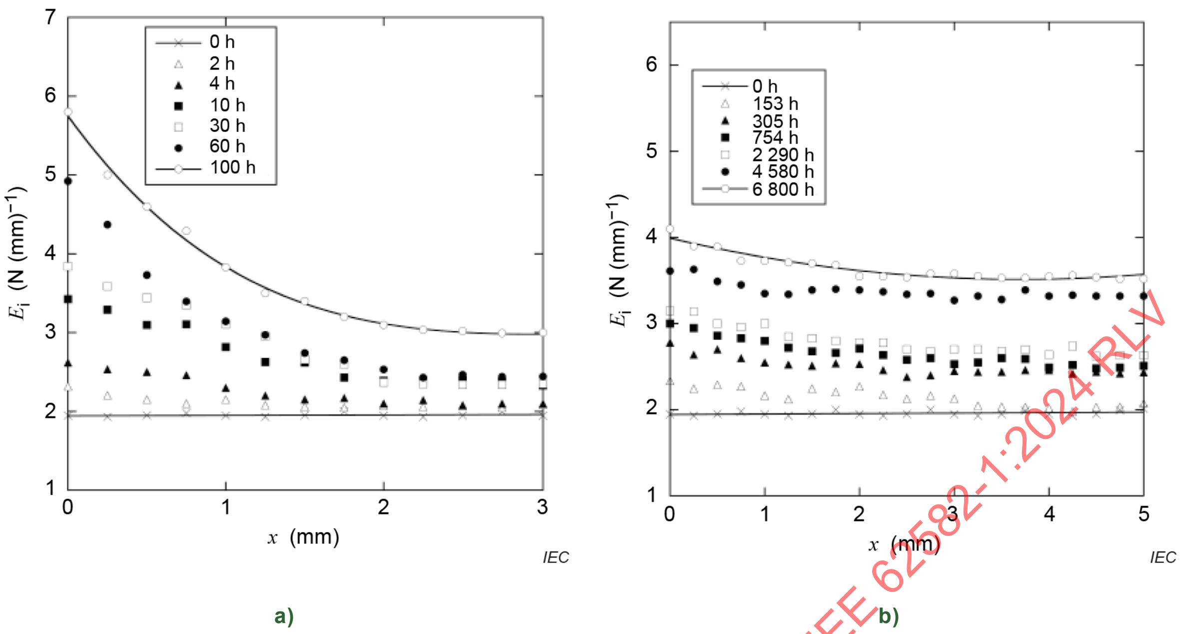

Figure A.1 – Indenter modulus profiles for EPDM seal aged at 170 °C (left) and 110 °C (right) [1]

A.3 Methods for profiling DLO effects

The importance of understanding DLO effects during ageing of polymeric components has required the development of methods for measuring the oxidation profiles in such materials. There are a number of methods available, some of which are described in more detail in IEC TS 61244-1 [13]. The main methods in use are:

- infrared spectroscopy;
- density profiling;
- chemiluminescence;
- modulus profiling;
- X-ray microanalysis (XMA);
- nuclear magnetic resonance (NMR).

Most of these methods require that multiple thin sections are cut from the sample (infrared, density, chemiluminescence) or exposing a cross-section through the thickness (modulus, XMA). A more recent development (NMR) has the potential to be used non-destructively and could represent a practical routine measurement tool [1].

A.4 Theoretical approach to DLO

Theoretical modelling of DLO combines diffusion equations with the kinetics of oxidation. This approach is described in detail in Clause 3 of IEC TS 61244-1:2014 [13]. The shapes of the oxidation curves through the thickness of the material are determined by the balance between the diffusion equations and the kinetics. These shapes can vary from a smooth change through the thickness to an abrupt step change in oxidation at a specific depth. Comparison of experimental profiling data with theoretical curves has shown that this modelling approach is a valid way of approaching DLO.

The theoretical approach to DLO enables an estimate to be made of the maximum sample thickness required to avoid DLO effects. The critical thickness L_c, below which the oxidation across the sample will be > 90 % of a homogenously oxidised sample, is given by:

$$L_c = [2\, p\, P_{ox} / R_0]^{0,5}$$

where

p is the oxygen partial pressure,

P_{ox} is the oxygen permeation rate (equal to diffusion rate times solubility),

R_0 is the equilibrium oxygen consumption rate.

This formula does not take into account different curve shapes, but is a reasonable general expression for estimating L_c, regardless of the precise details of the underlying oxidation kinetics. Values for the parameters P_{ox} and R_0 can be found in the literature for many polymers to enable these estimates to be made.

For a specific polymer compound the values in literature can be different.

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INTERNATIONAL STANDARD

Nuclear power plants – Instrumentation and control important to safety – Electrical equipment condition monitoring methods – Part 1: General

IEC/IEEE 62582-1:2024-09(en-fr)

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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NUCLEAR POWER PLANTS – INSTRUMENTATION AND CONTROL IMPORTANT TO SAFETY – ELECTRICAL EQUIPMENT CONDITION MONITORING METHODS –

Part 1: General

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 document(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.

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2) The formal decisions 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. The formal decisions of IEEE on technical matters, once consensus within IEEE Societies and Standards Coordinating Committees has been reached, is determined by a balanced ballot of materially interested parties who indicate interest in reviewing the proposed standard. Final approval of the IEEE standards document is given by the IEEE Standards Association (IEEE SA) Standards Board.

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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 implementation of this IEC/IEEE Publication may require use of material covered by patent rights. By publication of this standard, no position is taken with respect to the existence or validity of any patent rights in connection therewith. IEC or IEEE shall not be held responsible for identifying Essential Patent Claims for which a license may be required, for conducting inquiries into the legal validity or scope of Patent Claims or determining whether any licensing terms or conditions provided in connection with submission of a Letter of Assurance, if any, or in any licensing agreements are reasonable or non-discriminatory. Users of this standard are expressly advised that determination of the validity of any patent rights, and the risk of infringement of such rights, is entirely their own responsibility.

IEC/IEEE 62582-1 was prepared by subcommittee 45A: Instrumentation and control of nuclear facilities, of IEC technical committee 45: Nuclear instrumentation, in cooperation with Nuclear Power Engineering Committee of the IEEE Power & Energy Society[1], under the IEC/IEEE Dual Logo Agreement between IEC and IEEE. It is an International Standard.

This document is published as an IEC/IEEE Dual Logo standard.

This second edition cancels and replaces the first edition published in 2011. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) Integration of experience from the work with IAEA-TECDOC-1825:2017 “Benchmark analysis for condition monitoring test techniques of low voltage cables in nuclear power plants. Final results of a Coordinated Research Project”.
b) Referral to IEC/IEEE 60780-323 instead of IEC 60780 and IEEE 323.

The text of this International Standard is based on the following IEC documents:

Draft	Report on voting
45A/1510/CDV	45A/1537/RVC

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

The language used for the development of this International Standard is English.

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

A list of all parts of IEC/IEEE 62582 series, under the general title *Nuclear power plants – Instrumentation and control important to safety – Electrical equipment condition monitoring methods*, can be found on the IEC website.

The IEC Technical Committee and IEEE Technical Committee have decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn, or
- revised.

1 A list of IEEE participants can be found at the following URL: http://standards.ieee.org/downloads/62582-1/62582-1-2011/62582-1-2011_wg-participants.pdf.

INTRODUCTION

a) Technical background, main issues and organisation of this document

This part of this IEC/IEEE 62582 series focuses on methods for condition monitoring for management of ageing of electrical equipment installed in nuclear power plants and for application of the concept of qualified condition.

IEC/IEEE 6258-1 is the first part of the IEC/IEEE 62582 series of standards, containing background and guidelines for the application of methods for condition monitoring of electrical equipment important to safety of nuclear power plants. The detailed descriptions of the methods are given in the other parts, one part for each method. This document also includes some elements which are common to all methods.

IEC/IEEE 62582 series is issued with a joint logo which makes it applicable to the management of ageing of electrical equipment qualified to IEEE as well as IEC Standards.

Condition monitoring is a developing field and more methods will be added to the IEC/IEEE 62582 series when they are considered widely applied and a good reproducibility of the condition monitoring method can be demonstrated.

IEC/IEEE 60780-323 defined condition-based qualification which is an adjunct to type testing. The qualified condition is established by condition indicator(s) prior to the start of accident conditions for which the equipment was demonstrated to meet the design requirements for the specified service conditions. IEC/IEEE 60780-323 defined condition indicator.

Significant research has been performed on condition monitoring techniques and the use of these techniques in equipment qualification as noted in NUREG/CR-6704, Vol. 2 (BNL -NUREG-52610) [1],[2] JNES-SS-0903, 2009 [2] and IAEA-TECDOC-1825:2017 [3].

It is intended that this IEC/IEEE document be used by operators of nuclear power plants, systems evaluators and by licensors.

b) Situation of the current standard in the structure of the IEC SC 45A standard series

IEC/IEEE 62582-1 is the third level IEC SC 45A document tackling the issue of application of condition monitoring in equipment qualification and management of ageing of electrical I&C equipment in nuclear power plants.

IEC/IEEE 62582-1 is to be read in association with IEC/IEEE 60780-323, which provides general requirements for qualification of I&C systems and equipment that are used to perform functions important to safety in NPPs and nuclear facilities.

For more details on the structure of the IEC SC 45A standard series, see item d) of this introduction.

c) Recommendations and limitations regarding the application of this document

It is important to note that this document establishes no additional functional requirements for safety systems.

This document discusses the general measurement technique for current condition monitoring methods and is not meant to cover any specific technologies.

2 Numbers in square brackets refer to the Bibliography.

d) Description of the structure of the IEC SC 45A standard series and relationships with other IEC documents and other bodies documents (IAEA, ISO)

The IEC SC 45A standard series comprises a hierarchy of four levels. The top-level documents of the IEC SC 45A standard series are IEC 61513 and IEC 63046.

IEC 61513 provides general requirements for instrumentation and control (I&C) systems and equipment that are used to perform functions important to safety in nuclear power plants (NPPs). IEC 63046 provides general requirements for electrical power systems of NPPs; it covers power supply systems including the supply systems of the I&C systems.

IEC 61513 and IEC 63046 are to be considered in conjunction and at the same level. IEC 61513 and IEC 63046 structure the IEC SC 45A standard series and shape a complete framework establishing general requirements for instrumentation, control and electrical power systems for nuclear power plants.

IEC 61513 and IEC 63046 refer directly to other IEC SC 45A standards for general requirements for specific topics, such as categorization of functions and classification of systems, qualification, separation, defence against common cause failure, control room design, electromagnetic compatibility, human factors engineering, cybersecurity, software and hardware aspects for programmable digital systems, coordination of safety and security requirements and management of ageing. The standards referenced directly at this second level should be considered together with IEC 61513 and IEC 63046 as a consistent document set.

At a third level, IEC SC 45A standards not directly referenced by IEC 61513 or by IEC 63046 are standards related to specific requirements for specific equipment, technical methods, or activities. Usually these documents, which make reference to second-level documents for general requirements, can be used on their own.

A fourth level extending the IEC SC 45 standard series, corresponds to the Technical Reports which are not normative.

The IEC SC 45A standards series consistently implements and details the safety and security principles and basic aspects provided in the relevant IAEA safety standards and in the relevant documents of the IAEA nuclear security series (NSS). In particular this includes the IAEA requirements SSR-2/1 , establishing safety requirements related to the design of nuclear power plants (NPPs), the IAEA safety guide SSG-30 dealing with the safety classification of structures, systems and components in NPPs, the IAEA safety guide SSG-39 dealing with the design of instrumentation and control systems for NPPs, the IAEA safety guide SSG-34 dealing with the design of electrical power systems for NPPs, the IAEA safety guide SSG-51 dealing with human factors engineering in the design of NPPs and the implementing guide NSS42-G for computer security at nuclear facilities. The safety and security terminology and definitions used by the SC 45A standards are consistent with those used by the IAEA.

IEC 61513 and IEC 63046 have adopted a presentation format similar to the basic safety publication IEC 61508 with an overall life-cycle framework and a system life-cycle framework. Regarding nuclear safety, IEC 61513 and IEC 63046 provide the interpretation of the general requirements of IEC 61508-1, IEC 61508-2 and IEC 61508-4, for the nuclear application sector. In this framework, IEC 60880, IEC 62138 and IEC 62566 correspond to IEC 61508-3 for the nuclear application sector.

IEC 61513 and IEC 63046 refer to ISO 9001 as well as to IAEA GSR part 2 and IAEA GS-G-3.1 and IAEA GS-G-3.5 for topics related to quality assurance (QA).

At level 2, regarding nuclear security, IEC 62645 is the entry document for the IEC/SC 45A security standards. It builds upon the valid high level principles and main concepts of the generic security standards, in particular ISO/IEC 27001 and ISO/IEC 27002; it adapts them and completes them to fit the nuclear context and coordinates with the IEC 62443 series. At level 2, IEC 60964 is the entry document for the IEC SC 45A control rooms standards, IEC 63351 is the entry document for the human factors engineering standards and IEC 62342 is the entry document for the ageing management standards.

NOTE 1 It is assumed that for the design of I&C systems in NPPs that implement conventional safety functions (e.g. to address worker safety, asset protection, chemical hazards, process energy hazards) international or national standards would be applied.

NOTE 2 IEC TR 63400 provides a more comprehensive description of the overall structure of the IEC SC 45A standards series and of its relationship with other standards bodies and standards.

NUCLEAR POWER PLANTS – INSTRUMENTATION AND CONTROL IMPORTANT TO SAFETY – ELECTRICAL EQUIPMENT CONDITION MONITORING METHODS –

Part 1: General

1 Scope

This part of the IEC/IEEE 62582 series contains requirements for application of the other parts of IEC/IEEE 62582 related to specific methods for condition monitoring in electrical equipment important to safety of nuclear power plants. It also includes requirements which are common to all methods. The procedures defined in IEC/IEEE 62582 are intended for detailed condition monitoring.

IEC/IEEE 62582 specifies condition monitoring methods in sufficient detail to enhance the accuracy and repeatability, and provide standard formats for reporting the results. The methods specified are applicable to electrical equipment containing polymeric materials. Some methods are especially designed for the measurement of condition of a limited range of equipment whilst others can be applied to all types of equipment for which the polymeric parts are accessible.

Although the scope of IEC/IEEE 62582 is limited to the application of instrumentation and control systems important to safety, the condition monitoring methods can also be applicable to other components which include polymeric materials.

The different parts of IEC/IEEE 62582 are measurement standards, primarily for use in the management of ageing in initial qualification and after installation. For the technical background of condition monitoring methods, reference is made to other IEC standards, e.g. IEC 60544-5 [1]. Information on the role of condition monitoring in qualification of electrical equipment important to safety is found in IEC/IEEE 60780-323. General information on management of ageing can be found in IEC 62342 [5] and IEEE 1205 [6].

NOTE A simplified version of the procedures can be appropriate for preliminary assessment of the need for detailed measurements.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC/IEEE 60780-323, *Nuclear facilities – Electrical equipment important to safety – Qualification*

IEC/IEEE 62582 (all parts), *Nuclear power plants – Instrumentation and control important to safety – Electrical equipment condition monitoring methods*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp
- IEEE Standards Dictionary Online: available at http://dictionary.ieee.org

3.1
condition indicator
characteristic of a structure, system or component that can be observed, measured or trended to infer or directly indicate the current and future ability of the structure, system or component to function within acceptance criteria

[SOURCE: IAEA Nuclear Safety and Security Glossary, 2022 (Interim) Edition]

3.2
condition monitoring
continuous or periodic tests, inspections, measurement or trending of the performance or physical characteristics of structures, systems and components to indicate current or future performance and the potential for failure

[SOURCE: IAEA Safety Glossary, 2018 Edition, modified – note removed.]

3.3
equipment qualification
generation and maintenance of evidence to ensure that equipment will operate on demand, under specified service conditions, to meet system performance requirements

[SOURCE: IAEA Nuclear Safety and Security Glossary, 2022 (Interim) Edition, modified – notes not included.]

3.4
equipment important to safety
equipment that is part of a safety group and/or whose malfunction or failure could lead to undue radiation exposure of the site personnel or members of the public. Equipment including:

- those structures, systems and components that prevent anticipated operational occurrences from leading to accident conditions;
- those features that are provided to mitigate the consequences of malfunction or failure of structures, systems and components.

Note 1 to entry:

a) For usage consistent with IEC 61226 [11], equipment important to safety are as follows:
   1) all I&C equipment performing Category A to Category C functions (in accordance with the IEC 61226 [11] categorisation scheme);
   2) all electrical equipment necessary to ensure emergency energy supply to this equipment in case of a loss of normal power supply;
   3) all electrical equipment necessary to ensure ultimate energy supply in case of total loss of on-site power (if selected as design extension condition to be mitigated).

b) For usage consistent with other IEEE documents and a Class 1E categorization; for equipment important to safety, qualification is essential to the following:

1) electric equipment and systems that are essential to emergency reactor shutdown, containment isolation, reactor core cooling, and containment and reactor heat removal, or;

2) electric equipment that are otherwise essential in preventing significant release of radioactive material to the environment.

Note 2 to entry: Users of this document are advised that Class 1E is a functional term. Equipment and systems are to be classified Class 1E only if they fulfil the functions listed in the definition. Identification of systems or equipment as Class 1E based on anything other than their function is an improper use of the term and should be avoided.

[SOURCE: IEC/IEEE 60780-323:2016, 3.12]

3.5
tactile observation
qualitative assessment of a polymer's condition through the physical examination of the exterior of a material as observed by a knowledgeable person who, via experience or training, can deduce degradation based on the hardness or softness of the material by lightly bending or pressing a fingernail into the surface and via their knowledge and experience, or training can deduce degradation based on the observed condition to assess if quantitative assessments are warranted

3.6
visual observation
qualitative assessment of a polymer's condition through the visible examination of the exterior of material as observed by a knowledgeable person who, via experience or training, can deduce degradation based on the observed condition to assess if quantitative assessments are warranted

3.7
qualified condition
condition of an equipment, prior to the start of a design basis event, for which the equipment was demonstrated to meet the design requirements for the specified service conditions. This could include certain post accident cooling and monitoring systems that are expected to remain operational

[SOURCE: IEC/IEEE 60780-323:2016, 3.19]

3.8
qualified life
period for which a structure, system or component has been demonstrated, through testing, analysis or experience, to be capable of functioning within acceptance criteria during specific operating conditions while retaining the ability to perform its safety functions in accident conditions for a design basis accident or a design basis earthquake

[SOURCE: IAEA Nuclear Safety and Security Glossary, 2022 (Interim) Edition]

3.9
service life
period from initial operation to final withdrawal from service of a structure, system or component

[SOURCE: IAEA Nuclear Safety and Security Glossary, 2022 (Interim) Edition]

3.10
design basis events
postulated events used in the design to establish the acceptable performance requirements for the structures, systems, and components

[SOURCE: IEEE Standards Dictionary Online]

3.11
service conditions
actual physical states or influences during the service life of equipment, including normal operating conditions, abnormal operating conditions, design basis event conditions and conditions following a design basis event and design extension conditions

[SOURCE: IAEA Safety Glossary, 2007, modified, addition of “design extension conditions” and use of term “equipment instead of “structure, system or component”]

3.12
ageing
general process in which characteristics of a system or component gradually change with time or use

[SOURCE: IEC/IEEE 60780-323:2016, 3.2]

3.13
accelerated ageing
method of equipment testing in which the ageing associated with longer term service conditions is simulated in a short time

Note 1 to entry: Usually, accelerated ageing attempts to simulate natural ageing effects by application of stressors representing pre-service and service conditions, but with differences in intensity, duration and the manner of application.

[SOURCE: IAEA Nuclear Safety and Security Glossary, 2022 (interim) Edition]

4 Condition indicators

4.1 General

The condition indicator shall be measurable, change monotonically with time, be linked to the functional degradation of the qualified equipment, and have a consistent trend from unaged through the limit of the qualified pre-accident condition, and applied according to IEC/IEEE 60780-323.

This trend should be established during the pre-ageing part of the equipment qualification. When establishing the trend of condition indicators with ageing time, it is important that acceleration factors (both thermal and radiation) are kept as small as practical. See Annex A for additional information on diffusion limited oxidation (DLO).

Condition monitoring programs rely on measurable indicators that provide insight into the overall degradation of the materials. To perform measurements of the condition of naturally aged components, a sample shall either be taken destructively or the measurements shall be made on the material in the field in a non-destructive way. The latter methods are preferred since they allow the material to be studied without interrupting operation; however, it is often difficult to perform these types of measurements directly in the field with the required degree of repeatability and accuracy.

In polymeric materials, ageing occurs that can adversely impact the important safety function through a range of chemical reactions, including chain scission and cross-linking, which alter the polymeric structure. For condition monitoring programs, it becomes imperative to find methods that, either directly or indirectly, follow the progress of these reactions. A large number of methods exist to perform this task, which makes it difficult to provide an overview of each individual technique. Instead, this document will focus on general groups of methods. The overall description of these groups is provided in 4.2 through 4.6.

4.2 Chemical indicators

As mentioned above, the degradation mechanism for polymeric materials follows from a series of chemical reactions in which the chemical structure of the polymer is altered. The progressive change in the chemistry of the material provides an opportunity to monitor the degradation throughout its ageing. Numerous techniques exist to perform this task, some which monitor the polymer chain degradation itself and others which monitor side reactions which are related to the degradation.

4.3 Physical indicators

Another key family of indicators includes techniques which monitor the material's physical properties. The degradation of polymeric materials manifests itself in changes to these physical properties (i.e. tensile strength, elongation, and hardness). By measuring these physical characteristics, it is possible to create a correlation with the aged condition of the material.

4.4 Electrical indicators

A third category of techniques involves measuring electrical properties of the materials. Many of these techniques were developed for polymeric materials used in electrical insulation. Within this family there are two basic subsets of methods. The first subset involves measuring the dielectric properties of the materials.

A second subset of methods monitors the electrical response of systems under normal operation. In these cases, a signal is passed through the electrical system and any changes from baseline are detected. These changes could be signs of degradation, whether through ageing or through physical damage.

4.5 Other indicators

As new technologies are developed and implemented, it becomes necessary to develop condition monitoring methods to keep pace.

4.6 Visual and tactile observation

Visual and tactile testing methods are non-intrusive testing techniques for accessible components. The purpose of this physical inspection method is to identify cracks, discolouration, visible contamination of the components, the presence of chemicals or oils, and other local damage such as swelling or deformation, to provide a qualitative assessment of the condition of for example a cable's jacket material that could indicate problems with the insulation.

Visual and tactile methods may be used as a screening tool for ageing assessment and indicate that further evaluation is necessary by applying other methods in accordance with the different parts of IEC/IEEE 62582.

5 Applicability of condition indicators to different types of polymeric materials

There is currently no single condition monitoring method which is suitable for all polymeric materials. A basic requirement for inclusion in a part of the IEC/IEEE 62582 series is that the condition indicators are sensitive to the effects of ageing. An important characteristic of a useful condition indicator is that it shows a trend that changes monotonically with degradation and can be correlated with the safety related performance. An indicator that does not change for a long time and then suddenly undergoes drastic changes is not useful for prognostic applications. This can be the case with mechanical condition monitoring on semi-crystalline materials, e.g. cross-linked polyethylene and thermosetting resins, dependent on the formulation.

Information on the applicability of various condition indicators to different polymeric materials used in instrument and control equipment in nuclear power plants can be found in IAEA-TECDOC-1188 [12], IAEA-TECDOC-1825 [3] and in EPRI 1022969 [14].

6 Destructive and non-destructive condition monitoring

A condition monitoring method can be considered destructive or non-destructive, depending on whether the measurement or the sampling of material used for the measurement will affect operability or future ageing. Non-destructive use of condition monitoring is preferable in field measurements but with presently available methods it is limited to a few types of equipment, mainly cables, where the parts of the equipment of interest are accessible in the field. In other cases, deposited samples or samples which can be replaced are necessary to allow condition monitoring.

If deposited samples are available or where components can be replaced, a broader range of condition monitoring methods can be considered, including destructive methods. In this case, condition monitoring can be applied to all types of equipment where the ageing material – normally polymeric materials used for electrical insulation, sealing, etc. can be accessed.

7 Application of condition monitoring in equipment qualification and management of ageing

7.1 General

Condition monitoring as part of qualification and management of ageing of electrical equipment in nuclear power plants can have one or a combination of the following aims:

- determination of acceleration factors for the establishment of qualified life from artificial laboratory ageing;
- extension of qualified life;
- establishment of qualified condition;
- periodic assessment of equipment condition after installation for comparison with qualified condition.

Condition monitoring can also be used for determining whether the degradation of age sensitive materials in equipment is within specific limits. These limits are those for which it has been established that the effects on operability in specified service conditions and design basis events are negligible.

7.2 Use of condition monitoring in the establishment of qualified life

7.2.1 Establishment of qualified life

The qualified life of an equipment is generally established by accelerated ageing of samples in a laboratory, followed by verification of their capability to function within acceptance criteria during a simulated design basis event. The acceleration factor is the ratio between the rate of degradation under the laboratory simulation and in normal operating conditions in the field. Condition monitoring is used to establish activation energies for calculation of the acceleration factor in accelerated thermal ageing.

7.2.2 Determination of the acceleration factor in accelerated thermal ageing

The acceleration factor F in accelerated thermal ageing is normally calculated by application of the Arrhenius equation as follows:

$$F = \frac{t_1}{t_2} = e^{-\frac{E}{k}\left[\frac{1}{T_2} - \frac{1}{T_1}\right]} \qquad (1)$$

where

t_1 and t_2 are the times to reach a certain level of degradation at the temperatures T_1 and T_2 (in K);

E is the activation energy, and

k is the Boltzmann constant.

NOTE 1 The Arrhenius equation $r = Ae^{-E/kT}$ is a formula for the temperature dependence of the rate r of a chemical reaction. A is a pre-factor (in case of first order reactions called the frequency factor with the unit s–1), E is the activation energy (here with the unit eV), k is the Boltzmann constant (0,861 7 × 10^{-4} eV × K – 1) and T is the temperature (in K). The activation energy is defined as the energy that has to be overcome in order for a chemical reaction to occur.

The activation energy of a material is normally calculated from the results of measurements of a condition indicator as a function of time at different temperatures. The pairs of values of temperature and time to reach a certain level of degradation are plotted in an Arrhenius diagram, where the inverse of temperatures (in K) are plotted on a linear scale on the abscissa and the time t is plotted on a logarithmic scale on the ordinate. An example is shown in Figure 1.

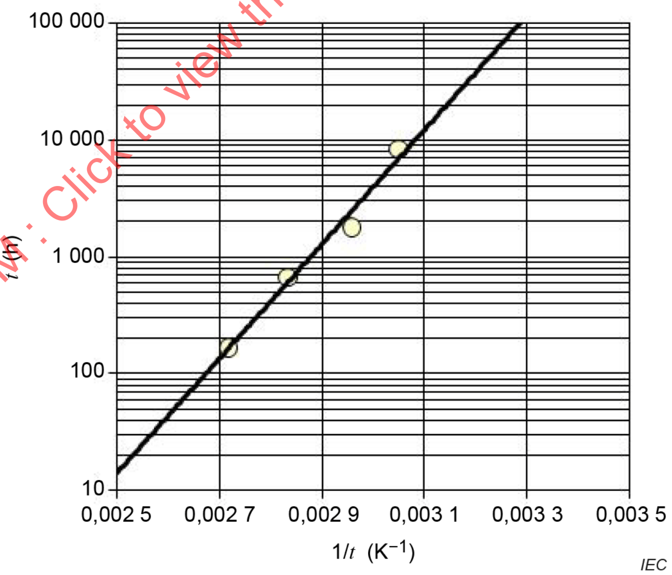

Figure 1 – Example of an Arrhenius diagram

A straight line between three or more points with a high correlation indicates that there is an Arrhenius behaviour of the dependency between rate of degradation and temperature. The activation energy E (in eV) is calculated from the slope of the line.

NOTE 2 Application far outside the range where the measurement points have been acquired can result in significant errors.