[Document reference]

NEW WORK ITEM PROPOSAL

Proposer Sweden	Date of proposal
TC/SC	Secretariat
Date of circulation	Closing date for voting

A proposal for a new work item within the scope of an existing technical committee or subcommittee shall be submitted to the Central Office. The proposal will be distributed to the P-members of the technical committee or subcommittee for voting, and to the O-members for information. The proposer may be a National Committee of the IEC, the secretariat itself, another technical committee or subcommittee, an organization in liaison, the Standardization Management Board or one of the advisory committees, or the General Secretary. Guidelines for proposing and justifying a new work item are given in ISO/IEC Directives, Part 1, Annex C (see extract overleaf). **This form is not to be used for amendments or revisions to existing publications.**

The proposal (to be completed by the proposer)

Title of proposal
Methods for condition monitoring of electrical equipment of safety system for nuclear power plants.

☒ Standard	☐ Technical Specification	☐ Publicly Available Specification

Scope (as defined in ISO/IEC Directives, Part 2, 6.2.1)
Standardization of methods used for monitoring the conditions of electrical equipment. The Standard should include description of the methods, control of parameters of importance for the measurement results and format for reporting of measurement results.

Purpose and justification, including the market relevance and relationship to Safety (Guide 104), EMC (Guide 107), Environmental aspects (Guide 109) and Quality assurance (Guide 102) . (attach a separate page as annex, if necessary)
The importance of management of ageing of electrical components important to safety is recognized. Condition measurements are essential in determination of parameters used for estimation of qualified life from artificial ageing as well as in management of ageing after installation. There is an urgent need for an international Standard for ascertaining quality, reproducibility and comparability of results of condition measurements. See further Annex A

Target date	for first CD	for IS ....
Estimated number of meetings	Frequency of meetings: per year	Date and place of first meeting: Stockholm, Sweden
Proposed working methods	☐ E-mail	☐ ftp

Relevant documents to be considered
IEC 60780 (1998), IEC 60544-5, IEC 60216-1, IEC 1244-1, IEC 167, IEC TS 61244-3,
IEEE 323 (2003)

Relationship of project to activities of other international bodies

Liaison organizations IEEE SC-2.1	**Need for coordination within ISO or IEC** IEC TC112

Preparatory work
Ensure that all copyright issues are identified. Check one of the two following boxes

☐ A draft is attached for comment ☒ An outline is attached

We nominate a project leader as follows in accordance with ISO/IEC Directives, Part 1, 2.3.4 (name, address, fax and e-mail): Kjell Spång,Strandskärsvägen 9,SE-42658 V.Frölunda,Sweden,e-mail kjell.spang@swipnet.se

Concerns known patented items (see ISO/IEC Directives, Part 2) ☐ yes If yes, provide full information as an annex ☒ no	**Name and/or signature of the proposer**
Comments and recommendations from the TC/SC officers	
1) Work allocation ☐ Project team ☐ New working group ☐ Existing working group no:	
2) Draft suitable for direct submission as ☐ CD ☐ CDV ☐ Publication as a PAS	
3) General quality of the draft (conformity to ISO/IEC Directives, Part 2) ☐ Little redrafting needed ☐ Substantial redrafting needed ☐ no draft (outline only)	
4) Relationship with other activities In IEC In other organizations	
Remarks from the TC/SC officers	

Elements to be clarified when proposing a new work item

Title

Indicate the subject matter of the proposed new standard.

Indicate whether it is intended to prepare a standard, a technical report or an amendment to an existing standard.

Scope

Give a clear indication of the coverage of the proposed new work item and, if necessary for clarity, exclusions.

Indicate whether the subject proposed relates to one or more of the fields of safety, EMC, the environment or quality assurance.

Purpose and justification

Give details based on a critical study of the following elements wherever practicable.

a) The specific aims and reason for the standardization activity, with particular emphasis on the aspects of standardization to be covered, the problems it is expected to solve or the difficulties it is intended to overcome.

b) The main interests that might benefit from or be affected by the activity, such as industry, consumers, trade, governments, distributors.

c) Feasibility of the activity: Are there factors that could hinder the successful establishment or general application of the standard?

d) Timeliness of the standard to be produced: Is the technology reasonably stabilized? If not, how much time is likely to be available before advances in technology may render the proposed standard outdated? Is the proposed standard required as a basis for the future development of the technology in question?

e) Urgency of the activity, considering the needs of the market (industry, consumers, trade, governments etc.) as well as other fields or organizations. Indicate target date and, when a series of standards is proposed, suggest priorities.

f) The benefits to be gained by the implementation of the proposed standard; alternatively, the loss or disadvantage(s) if no standard is established within a reasonable time. Data such as product volume of value of trade should be included and quantified.

g) If the standardization activity is, or is likely to be, the subject of regulations or to require the harmonization of existing regulations, this should be indicated.

If a series of new work items is proposed, the purpose and justification of which is common, a common proposal may be drafted including all elements to be clarified and enumerating the titles and scopes of each individual item.

Relevant documents

List any known relevant documents (such as standards and regulations), regardless of their source. When the proposer considers that an existing well-established document may be acceptable as a standard (with or without amendments), indicate this with appropriate justification and attach a copy to the proposal.

Cooperation and liaison

List relevant organizations or bodies with which cooperation and liaison should exist.

Preparatory work

Indicate the name of the project leader nominated by the proposer.

Annex A

NWIP. Methods for condition monitoring of electrical equipment of safety system for nuclear power plants. Purpose and justification.

1. Purpose

The purpose of this NWIP is to standardize the most commonly used condition monitoring methods – mechanical condition indicators (e.g. elongation, indenter modulus) dielectric condition indicators (e.g. insulation resistance, dielectric loss factor), and chemical condition indicators (e.g. DSC-OIT, OITP). The aims are to identify and carefully define the parameters of primary importance for the results of condition measurements and to standardize the format for reporting of condition measurement results. The requirements on the performance of the condition measurements have to be prescribed in sufficient detail to ensure a degree of accuracy and reproducibility of the results that makes them acceptable for management of ageing of electrical equipment in safety systems of nuclear power plants.

2. Justification for a specific standard on condition monitoring

Existing IEC Standards as well as IEEE Standards and other national Standards on qualification of electrical equipment in safety systems of nuclear power plants refer to condition monitoring as an important tool in management of ageing. Measurement of condition indicators are used in determination of activation energies for calculation of qualified life and in verification after installation that the equipment maintains a status for which it has been demonstrated that it meets the design requirements for the specified service conditions. Methods for condition monitoring are described in various international and national standards. A specific standard satisfying what is needed for application to the management of ageing of electrical equipment in safety systems of nuclear power plants is, however, missing.

There are many benefits of a generally accepted Standard for condition measurement designed for application to the management of ageing of electrical equipment of nuclear power plants: comparability of measurement results from different origins, facilitation of exchange of experiences, usefulness of databases on long term environmental effects on degradation of electrical equipment and components, broad acceptance of qualification results, etc.

3. Relationship to IEEE

It is proposed that the standard is developed within IEC SC45A (WGA10) in close cooperation with members of IEEE SC-2.1– responsible for the preparation and revision of IEEE 323 – with the target that it will ultimately be subjected to a joint logo procedure. The board of IEEE SC-2.1 has expressed that they support this. A joint logo IEC/IEEE standard would widen the use of identical condition measurements to the majority of nuclear power applications, which would very significantly increase the general benefit of the results.

4. Needs for high accuracy and repeatability

In order for the results of the condition measurements to be useful for its purposes the methods must be characterised by a high degree of reproducibility and repeatability.
In 1996-97, an IAEA expert group initiated round robin measurements of conditions of identical unaged and aged cable samples. The measurements were made by a number of laboratories in various countries. The results showed substantial variations between the laboratories. An analysis of the reasons showed that a number of test parameters of importance for the results were not adequately specified and the tradition of use of the methods varied between the laboratories. The following statement was made by the expert group, reported in IEAE TECDOC 1188: “The main conclusion that has come out of this series of round-robin tests has been the need for more detailed specification of the test procedures for condition monitoring methods”.

Annex A

Use of Arrhenius or similar formulas for calculation of acceleration factors in artificial ageing requires knowledge of activation energies of organic materials. The calculation of acceleration factors and qualified life is very sensitive to the values of activation energies as illustrated in the example in Figure 1.

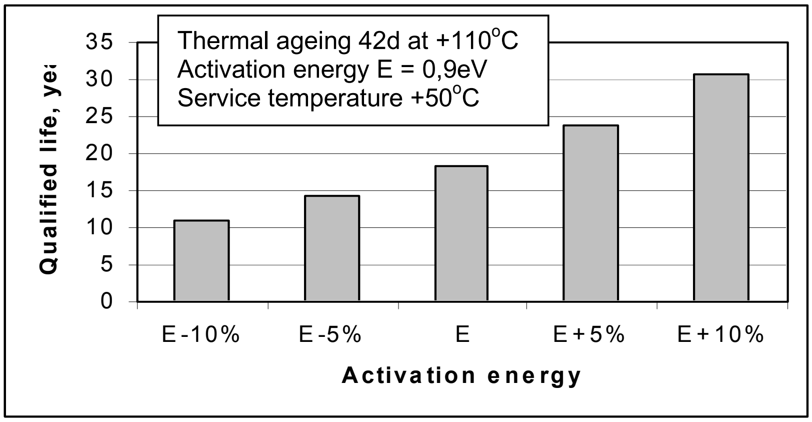

Figure 1. Example of calculated qualified life from artificial thermal ageing

As shown in Figure 1, a small deviation in the activation energy results in a large deviation in the qualified life calculated. Determination of relevant activation energies are normally based on tests which include use of condition monitoring. The relevance of the activation energy determined is related to a number of factors. The quality and repeatability of the condition monitoring technique used is one of the most important factors. Activation energies are commonly referred to in specification of qualified life of components important to safety. The values used are either conservative (low) values based on available data for the relevant organic materials or values based on measurement in laboratory of degradation in terms of changes of a selected condition indicator at different combinations of temperature and exposure time. Use of very well defined and accurate standard methods for condition measurements improves significantly the credibility and general applicability of activation energies based on laboratory measurements and consequently the credibility of estimated qualified life.

Due to the uncertainties in determination of qualified life from laboratory testing it has become more common to include regular follow-up activities after installation as a compliment to the initial qualification of components important to safety. Condition monitoring is used for ascertaining operability as well as for extension of qualified life. IEEE-323 (2003) has also included qualified condition as an alternative or compliment to qualified life. In order to be applicable to management of ageing after installation and use of the concept of qualified condition, the condition indicator values must be determined within tolerances and with a repeatability that makes it possible to compare the condition of the equipment at different measurement occasions with a high degree of accuracy. The problem that arises with non-accurate or non-identical measurements is illustrated by Figure 2, reproducing data from the IAEA round robin measurements. The oxygen induction temperature (OITD) was measured by two different laboratories on identical samples of new and artificially aged cable insulations. Laboratory A presented values on the aged cable samples which were even higher than the values of the un-aged cable samples presented by laboratory B. It is obvious that more well defined, accurate and standardised measurements are needed for application to management of ageing and use of the concept of qualified condition.

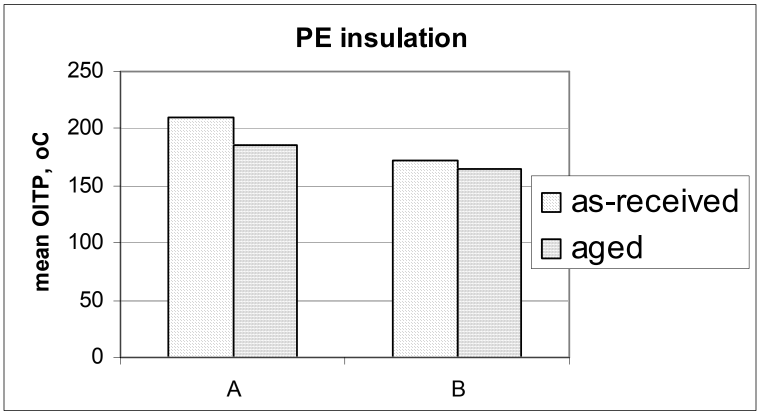

Figure 2. Results of OITP measurements in two different laboratories on identical cable insulation samples

Annex B

NWIP. Methods for condition monitoring of electrical equipment of safety system for nuclear power plants. Outline.

The text provided below is intended as a suggestion of the structure of the Standard and of what kind of information that should be worked out and included. A suggestion of a standard procedure for indenter measurements is given as an illustration of the details needed for achievement of the repeatability and accuracy required in management of ageing.

The discussion of the benefits of including condition monitoring as a tool for management of ageing and the concept of condition based qualification should be left to the generic standard 60780. This standard should be restricted to a discussion of the accuracy needed when applying Condition monitoring for various purposes and a description and standardisation of the methods in such detail that the accuracy needed can be met.

Foreword

In case this standard is developed as a joint effort between IEC and IEEE this should be indicated in the foreword.

Introduction

1 Scope

This International Standard specifies methods for condition monitoring of electrical equipment of safety system for nuclear power plants. Condition monitoring is an important tool for management and control of ageing after installation, including application of the concept of qualified condition. It is also a tool for determination of values (e.g. activation energies) used in determination of qualified life in initial qualification.

2 Normative references

3 Definitions and abbreviations

3.1 Condition monitoring

Measurement of a physical property of equipment, its part or materials, that changes with time.

3.2 Qualified condition (from IEEE 323-2003)

The condition of equipment, prior to start of a design basis event, for which the equipment was demonstrated to meet the design requirements for the specified service conditions.

Further definitions to be given

4 Requirements on accuracy and repeatability of condition monitoring methods when used as a tool in management of ageing

4.1 General

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

- Determination of activation energies for use in Arrhenius and similar formulas for establishment of qualified life from artificial laboratory thermal ageing, followed by demonstration that the equipment meets the design requirements for the specified service conditions.
- Establishment of qualified condition as an alternative or complement to qualified life.
- Management of ageing after installation based on following the change of the value of a condition indicator and observing when it approaches the qualified condition.

Condition monitoring can also be used for determination if the degradation of the age sensitive materials included in the equipment is within values at which it is well established that the ageing effects on operability in specified service conditions are negligible.

4.2 Use of condition monitoring in determination of activation energies

The most common way to determine activation energies for use in establishment of qualified life from accelerated thermal ageing includes use of condition monitoring. Basically, the activation energy is calculated from results of measurement of the change of a certain condition (degradation) indicator as 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 absolute temperatures (*1/T*) are indicated in a linear scale on the abscissa and the time *t* is indicated in a logarithmic scale on the ordinate. An example is shown in Figure 1.

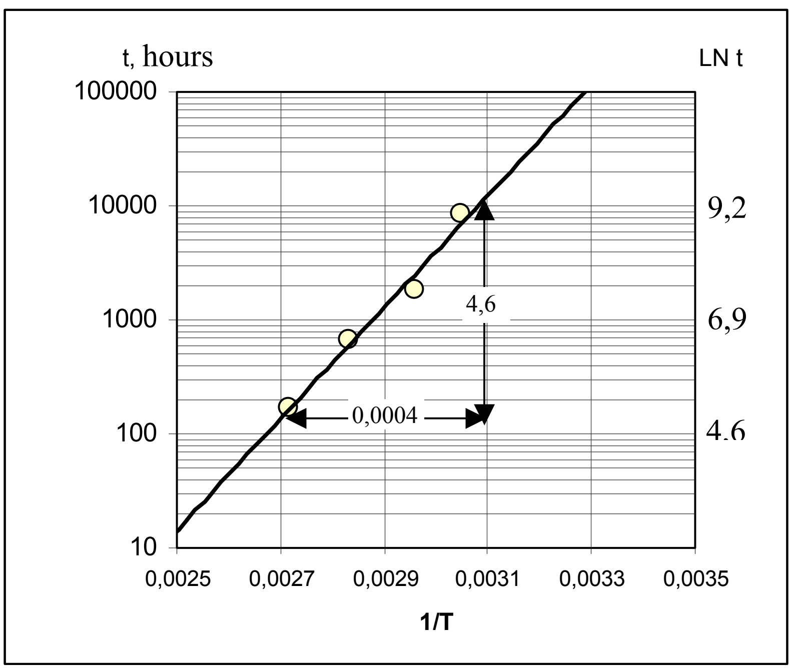

Figure 1. Example of an Arrhenius diagram

A straight line between the points 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

E = *S***k*, where *S* is the slope of the line ($\Delta t/\Delta(1/T)$) and *k* is the Bolzman constant ($0{,}8617 \cdot 10^{-4}$ eV/K).

In the example above $E = \frac{4{,}6}{0{,}0004} \cdot 0{,}8617 \cdot 10^{-4} = 0{,}99eV$

and determined by the Arrhenius formula is very sensitive to the value of the activation energy. The dependency is shown in Figure 2.

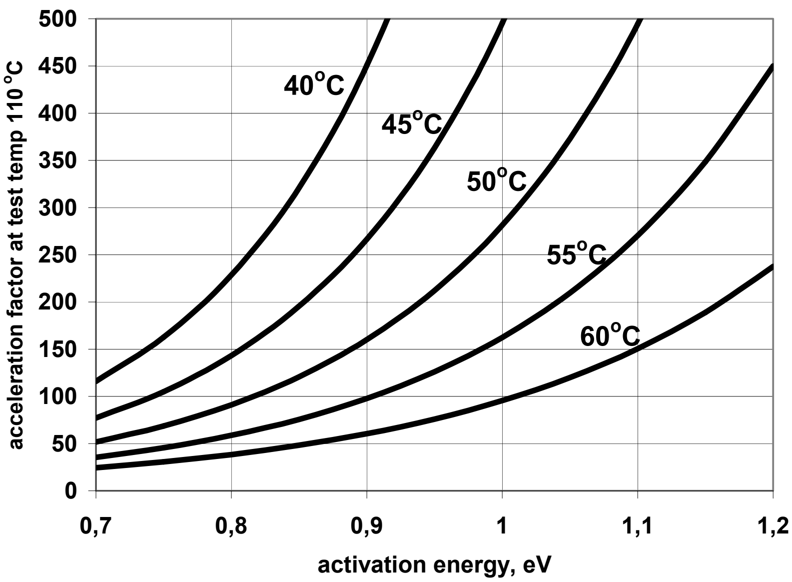

Figure 2. Thermal ageing at temperature 110°C. Acceleration factor as function of service temperature and activation energy.

When applying the Arrhenius formula in accelerated artificial ageing at elevated temperature, the acceleration factor is determined as

$$\text{acceleration factor} = \frac{t_1}{t_2} = e^{\frac{E}{k \cdot (1/T_2 - 1/T_1)}}$$

Where t_1 and t_2 are the times to reach a certain degradation at temperatures T_1 and T_2.

Figure 3 illustrates the sensitivity of qualified life to the choice of activation energy.

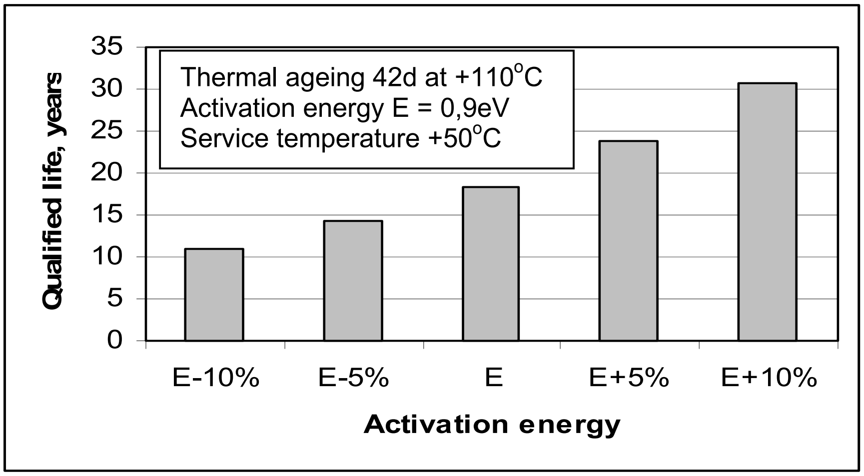

Figure 3. Example of qualified life determined from artificial thermal ageing for 42 days at +110°C, followed by a successful functionality test under specified service conditions (e.g. LOCA). The normal service temperature is +50°C.

In the case illustrated in Figure 1, the acceleration factor is just above 150 at an activation energy of 0,9 eV. A 10% overestimation of the activation energy results in an assumption of an acceleration factor above 250 and an overestimation of qualified life by 67%. The diagram shows that inaccuracy in determination of the activation energy has a large influence on the acceleration factor and consequently on the qualified life based on tests including artificial accelerated thermal ageing. High accuracy and repeatability of the condition monitoring method used in measurements for determination of activation energies is required.

4.3 Use of condition monitoring in management of ageing after installation and in application of the concept of qualified condition

4.3.1 General

The benefits and application of use of condition monitoring as a tool for management of ageing after installation are described in IEC 60780. The concept of condition based qualification is included in IEEE 323*) as a complement or alternative to qualified life.

*) If qualified condition is included in the revision of IEC 60780 we can refer to this.

A basic requirement for applicability to management of ageing is that the condition indicators are sensitive to effects of ageing and that the values measured are well correlated to exposure time.

4.3.2 Establishment of qualified condition

The use of condition based qualification requires as a minimum establishment of the values of appropriate condition indicators at the end of an age conditioning prior to the test (e.g. DBE testing) for demonstration that the equipment meets the design requirements for the specified service conditions. These values represent the qualified condition. The benefit of using condition based qualification as 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 the age conditioning, e.g. by performing the age conditioning incrementally and measuring the values of the condition indicators at each increment.

The qualified condition can be established as part of the initial qualification testing before installation. If the initial qualification has been performed with the target to establish a qualified life only and no condition measurements have been included it may be possible to establish the qualified condition afterwards without repeating the demonstration (e.g. DBE test) that the equipment meets the design requirements for the specified service condition. 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 age conditioning used in the establishment of the qualified life and determination of the values of appropriate condition indicators (during and) at the end of the conditioning.

Application of the concept of qualified condition is built on comparing values of certain condition indicators measured at the end of artificial ageing (or incrementally) in laboratory and at different times in field. The measurements several years after installation may be made by other personnel, instrumentation and in other laboratories than 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. In most cases it must be possible to detect rather small changes in the value of the condition indicator used. This requires a high degree of accuracy.

4.3.3 Management and follow-up of ageing of installed equipment

The degradation due to ageing of installed equipment can be followed by condition monitoring at certain time intervals. If the equipment qualification is condition based and the end condition to which it is qualified for operation under specified service conditions, the condition measured is compared with the qualified condition.

Depending on the condition indicators used and the acceptable influence of the measurement on the equipment, the condition measurement can be non-destructive or destructive. If the equipment is accessible and does not have to be removed for condition measurement and the method used is non-destructive, the condition measurement can be made on-site. If the equipment is not accessible for condition measurement or the method used is destructive, the condition measurements have to be made on equipments which are either removed and substituted by identical equipments or on spare samples which have been stored in representative positions (equally or more severe than the conditions of installed equipments).

4.4 Baseline data from condition monitoring

Knowledge of limits of degradation due to ageing, below which the operability of equipments in specified service conditions is not significantly affected, can be very useful in application of condition based qualification or in complimentary control of life based qualification. An example used extensively for elastomeric materials is elongation-at-break, defined either as the minimum limit of elongation-at-break or as the ratio between elongation-at-break for the aged material and for the unaged material.

The general usefulness of data on values of condition indicators after ageing, for which operability in DBE has been demonstrated, depends on how well the condition measurement have been defined and reported. They can only be used for comparison with values attained from identical measurements.

5 Condition indicators

5.1 General

There are a large number of condition monitoring methods and condition indicators used for assessment of degradation from ageing. This international Standard is limited to the most commonly used indicators. From the point of view of usefulness they can be subdivided in

- Non-destructive
- Destructive

Non-destructive methods are often preferable since the degradation of the equipment can be followed without demounting and substitution of installed equipment or use of equipment deposits. On the other hand it may be difficult to make measurements in field with the required degree of repeatability and accuracy.

There exist a large number of methods. Only those which are most commonly used are indicated below. The selection and number of methods to be included in the standard has to be discussed by the group. Examples of methods not included below are Luminiscence, MDSC (modulated differential scanning calorimetry, can be used for more exact determination of activation energy), MTGA (modulated thermo gravimetry, similar to the classical TGA method), DMA (dynamic mechanical analyser, using deformation under cyclic load), IR spectroscopy and near-IR spectroscopy, torsion (used rather extensively in Japan), Ultrasound (expensive and not very reliable).

5.2 Mechanical indicators

The most commonly used indicators of degradation of mechanical properties are

- Tensile, often indicated by elongation-at-break
- Indenter modulus

Tensile measurements are generally destructive.
Indenter modulus measurements are generally regarded as non-destructive. Normally, the intrusion of the anvil into the material does not affect the operability or further ageing of the equipment.

To be discussed: Shall we also include Microhardness? It is similar to indenter measurements (using a standard Vickers or Knoop anvil). It can be used on geometries where the present indenter instruments are difficult to use.

5.3 Chemical indicators

The most commonly used indicators of degradation of chemical properties are

- Oxidation induction time (OIT). Two alternative methods – DSC-OIT (differential scanning) and TGA-OIT (thermogravimetric analysis). The most commonly used method is DSC-OIT
- Oxidation induction temperature (OITP)
- …

To be discussed: Shall we include Microcalorimetry? It is an advanced method requiring expensive equipment but it is also the only method where the measurement of activation energy can be made close to the normal field temperature of the specimen.

Only a few mg of the material is needed for these measurements. Samples can normally be collected from the material without affecting the operability or further ageing of the equipment.

5.4 Dielectric indicators

The most commonly used indicators of dielectric properties are

- Dielectric spectroscopy (dielectric loss factor)
- Insulation resistance
- …

(destructive/non-destructive?)

5.5 Electrical indicators

The most commonly used electrical indicators of defects in cables are

- TDR
- …

(it is questionable if the methods presently available are sensitive enough to be regarded as tools for management of ageing. A new method invented by the Halden organization – LIRA – could also be considered since it may be more suitable than TDR for detecting the degree of global ageing)

6 Applicability, reproducibility, complexity and pros and cons

In this chapter a discussion should be made of the general reproducibility and complexity of each of the methods included in the standard. Pros and cons of the methods for various applications should be discussed. This chapter may be substituted by an informative annex which instead is referred to.

Illustration by example of discussion for the indenter method:

Reproducibility. The indenter modulus can have substantially local variations due to variation in thickness of the specimen. This is typically the case for measurement on cables where the measurement point may be situated above a cavity beneath the jacket surface. The local variation is taken care of by measuring the modulus in a number of points and using the mean value after deleting the highest and lowest values.

Complexity. The measurements are easy to make on free cables. Measurements on o-rings are also rather easy but require the o-rings to be cut and bent out or a special fixture to be used. Measurements on other polymeric parts of equipment can be difficult and require development of special fixtures. The degree of complexity in field measurements on cables depends on accessibility.

Pros. The method can normally be regarded as non-destructive. Instruments which can be easily used exist. The method can be used in field on cables if they are accessible. Measurements in a rather large number of points can be made in a short time. The results are achieved directly and can be easily stored.

Cons. The method is primarily useful for measurements on cables (jackets or lead insulation) and o-rings. Use on other types of components can need development of special mounting fixtures. Like elongation at break, indenter modulus is not suitable for measurements on cross-linked materials or irradiated PVC. Non-destructive measurements on cables in field can only be made on the jacket. The relationships between the condition of the jacket and of the lead insulation may need to be established in laboratory in order to make the results useful.

7 Measurement procedures

7.1 General

In this clause the most common methods for the condition monitoring are described in detail. For each method, the items of importance for the measurement results are identified and specified.

One example – indenter measurements – is outlined below illustrating the extent of details and recommendations that may need to be given for each condition indicator included in this standard in order to reach the goal of sufficiently accurate and repeatable measurements.

For other indicators only examples of items which need to be covered in addition to a description of the measurement method are given below. The examples are not exhaustive – experts in the preparation group will probably find further items that need to be covered in order to define accurate and repeatable measurements or may decide to delete details which are not significant. An important task for the expert group will be to find the best compromise between the demand for accurate and repeatable measurements and the complexity of the measurement procedure. The illustration of the possible significance of temperature and humidity influence on measured indenter modulus values is included in the example in 6.2.3 and in the informative annex in order to exemplify the kind of matters which may have to be taken into consideration by the group when deciding what needs to be included in their draft.

7.2 Indenter measurements

Text included as an illustration, not as a final proposal. Only the elements of importance for the accuracy and repeatability are dealt with. The final text also has to include description of the method etc.

7.2.1 Description of the measurement method

…

7.2.2 Instrumentation

…

7.2.3 Calibration and tolerances

The indenter and the measurement system shall be calibrated before each series of measurements in accordance with the manufacturer's instructions. The calibration shall include calibration of force and probe speed. The total error of force measurement shall be less than …% of the upper limit of the force range, including instrumentation tolerances as well as reading precision. The probe speed shall be close to constant regardless of the penetration depth and the total error of measurement of the average speed shall be less than …%. If weights are used in calibration of the force, the variation of gravity with geographical position shall be taken into account.

7.2.4 Conditions for measurement of indenter modulus

The surface of the specimen shall be free from debris and deposits. Solvents shall not be used for cleaning of the surface.

The indenter modulus varies with the temperature and content of humidity of the specimen as shown in Annex ….

In case of measurements in laboratory, e.g. after accelerated thermal ageing, measurements shall be made in standard atmospheric conditions for testing defined IEC 60068-1 (1988). Before start of measurements the specimen shall be allowed time to attain temperature equilibrium with the surrounding.

NOTE. It should be noted that the specimen can be extremely dry after long term exposure to high temperature in an oven. The effect of this can be that the modulus measured is higher than if the specimen is in humidity equilibrium with the laboratory atmosphere which is the case for measurements before age conditioning. This can have an influence on the determination of activation energy. The effect of the moisture content of the material at the time of indenter measurement can also have an influence on the comparison of values at certain times after installation with the value on which the qualified condition is based. It is therefore recommended that time is allowed for the specimen to get reasonably close to the laboratory condition of humidity when measuring the end value of the indenter modulus after artificial thermal ageing before subjection of the specimen to a DBE test. This is especially important for testing of hygroscopic insulation material.

It may not be possible to make field measurement in standard atmospheric conditions. In such cases it is important to report the temperature under which the measurements are made. Annex … shows a method for transformation of a measured indenter modulus to a corresponding modulus at a different temperature. In addition to reporting of the temperature at which the value has been measured, it is recommended to calculate and report the corresponding value at +20°C.

7.2.5 Selection of measurement points

The indenter modulus can vary significantly in different points on the specimen. Cable insulation is often of different thickness around the circumference as well as in different cross-sections. Measurements shall therefore be made in several points and the mean value and standard deviation shall be reported. For measurements on cables three points around the circumference in three cross-sections shall be used. In case of measurements on test samples of cables which have been subjected to accelerated laboratory ageing, no measurement point shall be closer than 10 cm from the cable ends.

7.2.6 Selection of probe speed and maximum force

The probe speed can have a significant influence on the indenter modulus measured. A probe speed of 5 mm/min is recommended. If another speed is used, this shall be reported and justified.

The maximum force is a compromise between the need for a rise time which is long enough to achieve reasonable resolution in the time scale axis and a total travel distance short enough to result in an anvil intrusion that can be accepted for a non-destructive measurement. For most insulation materials, a maximum force of 10 N is recommended. This will normally result in a probe penetration depth below 1 mm (for unaged material, smaller for aged material). For some rather soft insulation materials, e.g. Sir, a lower value has to be used in order to avoid deep penetration.

7.2.7 Clamping of object

The indenter modulus can be significantly dependent on the force by which the specimen is clamped in the mounting fixture. In order to minimize the effect of the clamping, the specimen shall be mounted in the fixture using the minimum clamping force needed for the specimen to be fixed.

7.2.8 Determination of the value of the indenter modulus

The indenter modulus M is determined by the slope of the force-penetration depth curve and expressed in N/mm.

$$M = \frac{F_2 - F_1}{d_2 - d_1}$$

where F_i is the corresponding force values at penetration depth d_i

d_i is the penetration depth $= \frac{5}{60} \cdot t_i$ if the travel speed is 5 mm/s; t_i is the travel time

In cases where the force-penetration depth curve is not linear, the indenter modulus shall be determined by using the values $F_1 = 1N$ och $F_2 = 4N$.

7.2.9 Reporting

The measurement report shall as a minimum include the following information:
Measurements made in laboratory:

a) Identification and description of the specimen
b) Pre-history (unaged, artificially aged, naturally aged)
c) Locality of the measurement (laboratory, on-site)
d) For laboratory measurement of thermally artificially aged specimen: time allowed for attaining temperature equilibrium with laboratory before performing the measurements (time interval between removing of the specimen from the heat chamber until start of measurement)
e) Measurement temperature; if outside 18-23^{o}C also the calculated value at 20^{o}C.
f) In case of hygroscopic materials, a margin to apply to the indenter modulus in case the modulus value given represents a value measured soon after removal from a dry heat chamber.
g) Measurement instrumentation and calibration
h) Mounting of the specimen for measurements (clamping)
i) Measurement points
j) Probe speed
k) Maximum force
l) Indenter modulus value, mean value and standard deviation, in N/mm together with information on the force interval for which it has been determined (normally 1N-4N). It is recommended to enclose a diagram showing a typical force versus penetration depth curve.
m) Any other information of importance in interpretation of the measurement results in relation to the purposes of the measurements.

7.3 Tensile tests

Requirements on the test machine used
Calibration procedure
Method of gripping samples and type of grip face
Test temperature
Cross-head speed
Method of measuring elongation
Content of measurement report

7.4 OIT and OITP tests

Requirements on instrument used
Method of calibration
Sample weight and preparation method
Type of sample pan (open or closed)
Oxygen flow rate used
Temperature profile used to reach oxidation temperature (OIT tests) or temperature ramp rate and starting temperature (OITP tests)
Method of establishing baseline (data plot)
Method of establishing oxidation onset

7.5 TGA tests

Requirements on instrument used
Method of calibration

Sample weight and preparation method
Type of sample pan (open or closed)
Oxygen flow rate used
Temperature ramp rate and starting temperature
Method of establishing oxidation onset
Content of measurement report

7.6 Insulation resistance

To be stated

7.7 Dielectric loss factor

To be stated

…

8 Bibliography

ANNEX…(informative)

Examples illustrating the influence on the indenter modulus value of restoration after artificial thermal ageing

Examples of temperature dependence

The examples come from a study of the temperature dependence of the indenter values of three types of thermally aged cables.

Lipalon – jacket and lead insulation materials CSPE
Rockbestos – jacket material CSPE, Lead insulation material XLPE
Dätwyler – jacket and lead insulation materials EPDM

The measurements were made in 9 (3*3) points on the jacket and the indenter modulus values were attained from the slope of the force-distance curve between 1 and 3 N. All cables had been thermally aged at +120°C for 48 days. The measurements were made after temperature stabilization at +12°C, +21°C, +35°C and +50°C.

Figure A1 shows the results in terms of mean values and standard deviation of the indenter modulus.

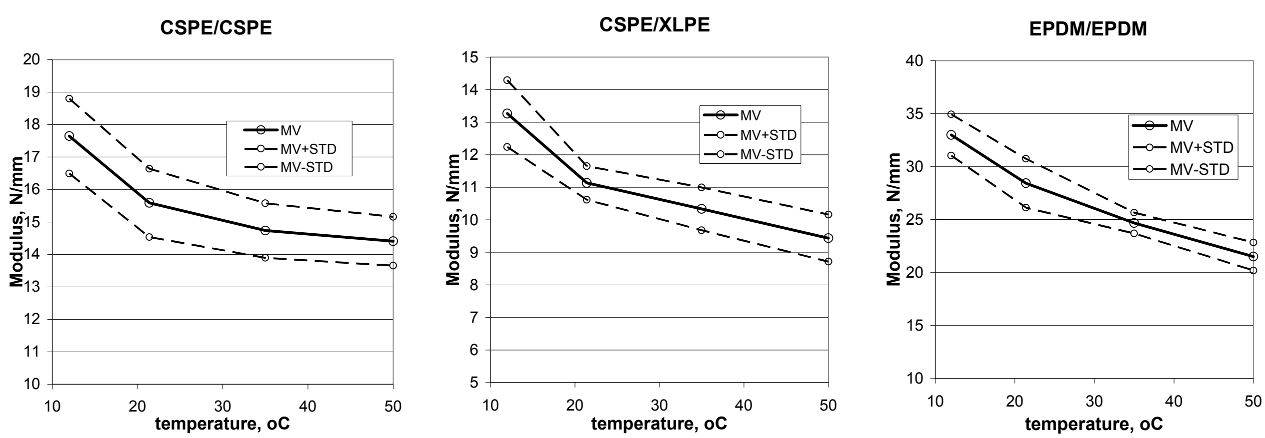

Figure A1. Indenter values measured at different temperatures

The results illustrate the needs to allow time for the specimen to attain temperature equilibrium close to standard temperature for testing (+20°C) before indenter measurements are performed.

In case indenter measurements are made at temperatures which differ substantially from standard temperature for testing (+20°C), e.g. on site, a normalisation to a value M_0 *at* +20°C can be made by use of the following formula

$$M_0 = [1 + A \cdot (t - t_0)/(t_2 - t_1)] \cdot M \qquad \text{(A.1)}$$

where $A = \frac{2 \cdot (M_2 - M_1)}{(M_2 + M_1)}$ (A.2)

M_1 och M_2 are the modulus measured at two different temperatures t_1 and t_2 ; $t_2 > t_1$.

Figure A2 shows the values in Figure 1 normalised according to (A.1)

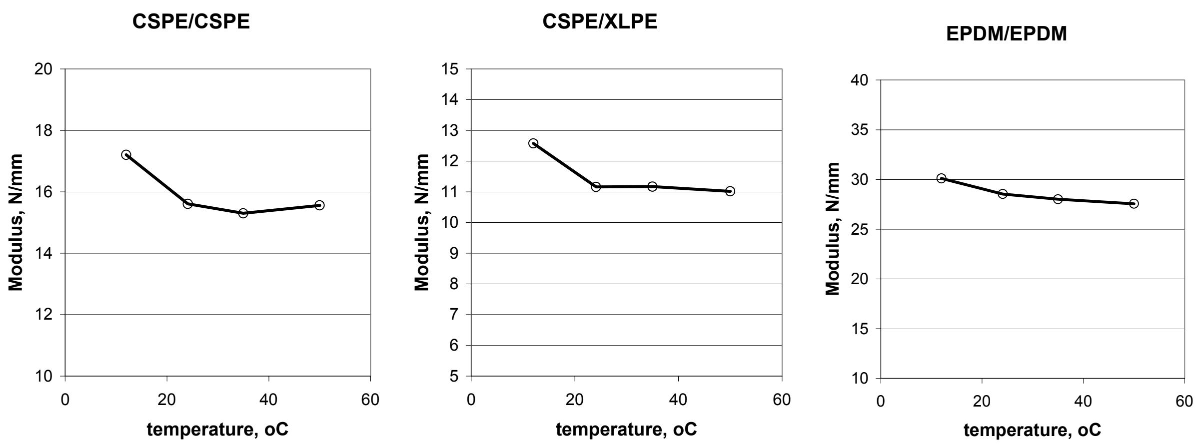

Figure A2. Normalised indenter values

The normalisation works well in the measurement temperature interval +20°C to +50°C. If the measurements are made at low temperatures (substantially below +20°C), and the value of *A* in the formula is determined from measurements at laboratory temperature and a higher temperature, application of the formula results in values measured at higher temperature (e.g. on site) than standard laboratory temperature results in values close to what would have been measured at +20°C.

To summarize, the recommendation is

- If practicable, to measure the indenter modulus after stabilisation to standard laboratory temperature close to +20°C.
- If it is foreseen that measurements will be made on site at significantly higher temperature than standard laboratory temperature, e.g. for comparison with qualified condition, it is recommended to determine and report the relevant value of *A* by measurements at two temperatures (laboratory temperature and one elevated temperature, close to what can be expected in site measurements) after the artificial laboratory ageing forming part of the initial qualification testing.

Examples of influence of moisture content

The influence of the moisture content of the material on indenter modulus is only significant if the material is hygroscopic. This is to some extent the case with one of the cable types which was used for determination of the effect of temperature on modulus – the Lipalon cable. This is still a material which is only slightly hygroscopic.

The example given shows the influence on the indenter modulus of letting the specimen being conditioned for a longer period in laboratory with standard atmospheric conditions after removal from the dry heat chamber used for artificial ageing at +120°C during 46 days. Figure A3 shows how the indenter modulus values change with the time of conditioning in laboratory after removal from the dry heat test chamber.

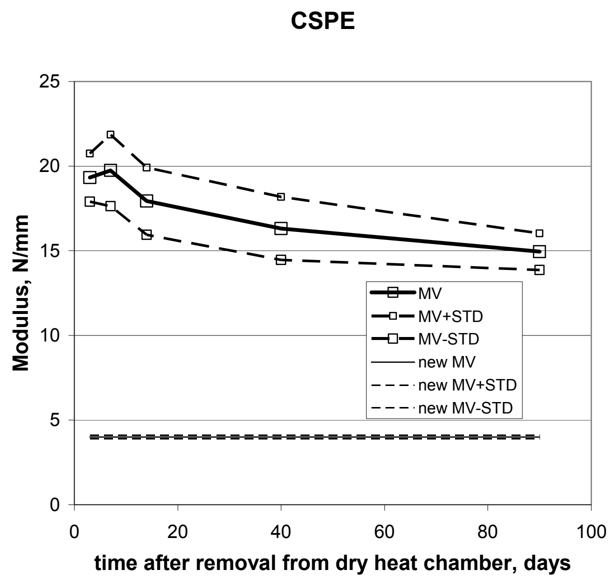

Figure A3. Example of change of indenter modulus after conditioning in laboratory conditions for restoration of initial moisture content

For application of indenter measurements on artificially aged significantly hygroscopic specimen it is recommended either to measure the indenter modulus after conditioning in laboratory for at least one month after removal from the dry heat chamber or using a margin on the modulus when compared by ageing in field in case the measurements are made shortly after the removal.