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INTERNATIONAL STANDARD

NORME INTERNATIONALE

Nuclear power plants – Instrumentation and control important to safety – Electrical equipment condition monitoring methods – Part 4: Oxidation induction techniques

Centrales nucléaires de puissance – Instrumentation et contrôle-commande importants pour la sûreté – Méthodes de surveillance de l'état des matériels électriques – Partie 4: Techniques d'induction à l'oxydation

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International Standard IEC/IEEE 62582-4 has been prepared by subcommittee 45A: Instrumentation and control of nuclear facilities, of IEC technical committee 45: Nuclear instrumentation, in cooperation with the Nuclear Power Engineering Committee of the Power & Energy Society of the IEEE[1], under the IEC/IEEE Dual Logo Agreement between IEC and IEEE.

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

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

FDIS	Report on voting
45A/842/FDIS	45A/851/RVD

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

International standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

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

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- withdrawn,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

1 A list of IEEE participants can be found at the following URL: http://standards.ieee.org/downloads/62582-4/62582-4-2011/62582-4-2011_wg-participants.pdf.

INTRODUCTION

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

This part of this IEC/IEEE standard specifically focuses on oxidation induction methods for condition monitoring for the management of ageing of electrical equipment installed in nuclear power plants. The methods are primarily suited to samples taken from materials that are polyolefin-based, but they can also be used for some materials based on ethylene-propylene polymers and for some ethylene vinyl acetate materials.

This part of IEC/IEEE 62582 is the fourth part of the IEC/IEEE 62582 series. It contains detailed descriptions of condition monitoring based on oxidation induction measurements.

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.

Historically, IEEE Std 323-2003 introduced the concept and role that condition based 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.

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).

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

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

Part 4 of IEC/IEEE 62582 is the third level IEC SC 45A document tackling the specific issue of application and performance of oxidation induction measurements in the management of ageing of electrical instrument and control equipment in nuclear power plants.

Part 4 of IEC/IEEE 62582 is to be read in association with part 1 of IEC/IEEE 62582, which provides background and guidelines for the application of methods for condition monitoring of electrical equipment important to safety of nuclear power plants.

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 standard

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

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 categorisation 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.

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

A fourth level extending the IEC SC 45A 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.

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

Part 4: Oxidation induction techniques

1 Scope and object

This part of IEC/IEEE 62582 specifies methods for condition monitoring of organic and polymeric materials in instrumentation and control systems using oxidation induction techniques in the detail necessary to produce accurate and reproducible measurements. It includes the requirements for sample preparation, the measurement system and conditions, and the reporting of the measurement results.

The different parts of IEC/IEEE 62582 are measurement standards, primarily for use in the management of ageing in initial qualification and after installation. Part 1 of IEC/IEEE 62582 includes requirements for the application of the other parts of IEC/IEEE 62582 and some elements which are common to all methods. Information on the role of condition monitoring in the qualification of equipment important to safety is found in IEEE Std 323.

2 Terms and definitions

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

2.1
Oxidation Induction Time (OIT)
relative measure of a stabilised material's resistance to oxidative decomposition, determined by the calorimetric measurement of the time interval to the onset of exothermic oxidation of the material at a specified temperature in an oxygen atmosphere, under atmospheric pressure

NOTE OIT is expressed in minutes (min).

2.2
Oxidation Induction Temperature (OITP)
calorimetric measurement of the temperature of the onset of exothermic oxidation of the material when subjected to a specified heating rate in an oxygen atmosphere, under atmospheric pressure

NOTE OITP is expressed in degrees Celsius (°C).

3 Abbreviations and acronyms

CSPE chlorosulphonated polyethylene

DSC differential scanning calorimeter

EPDM ethylene propylene diene monomer

EPR ethylene propylene rubber

EVA ethylene vinyl acetate

OIT oxidation induction time

OITP oxidation induction temperature

PE polyethylene

PEEK poly ether ether ketone

PVC poly vinyl chloride

XLPE cross-linked polyethylene

4 General description

Oxidation induction methods are based on the detection of the oxidation exotherm that occurs when a sample is heated in the presence of oxygen. This exotherm is sensitive to the level of degradation in some organic and polymeric materials and can be used as an indicator of ageing. There are two oxidation induction methods available, based on the time required to reach the onset of oxidation at a constant temperature (oxidation induction time – OIT) or based on the temperature at the onset of oxidation during a constant temperature ramp rate (oxidation induction temperature – OITP). The two methods are complementary, in that OITP is often effective in those materials where OIT is difficult to determine. OIT and OITP decrease with increasing degradation. The methods are related to the amount of antioxidants present in the material. As degradation proceeds, these antioxidants are depleted.

5 Applicability and reproducibility

The oxidation induction method is primarily suited to samples taken from materials (such as cable jackets or insulation) that are polyolefin-based (e.g. polyethylene PE, cross-linked polyethylene XLPE). It can also be used for some materials based on ethylene-propylene polymers (e.g. ethylene propylene rubber EPR, ethylene propylene diene EPDM) and for some ethylene vinyl acetate EVA materials. It is not applicable to high temperature polymers, such as poly ether ether ketone (PEEK).

The method is generally not suitable for chlorinated polymers (e.g. polyvinyl chloride PVC, chlorosulphonated polyethylene CSPE) because of the corrosive degradation products evolved during the measurements, which can damage the instrument. For these materials, smaller sample masses (1 mg to 2 mg) may enable the method to be used with care.

The method is not suitable for field use in the nuclear power plant but uses samples taken from the plant, which are then measured in the laboratory. Each OIT measurement in the laboratory can take up to 90 min to complete for unaged samples, decreasing for heavily aged samples, whereas OITP measurements typically take 30 min to 40 min.

Measurements of OIT typically have a standard deviation of 5 % to 10 % of the mean value whereas measurements of OITP typically have a standard deviation of 1 % to 3 % of the mean value, both within the same laboratory and between different laboratories. Some of this variation arises from inhomogeneity of the sample materials, which becomes significant when making condition measurements on samples whose mass is very low. OITP measurements are usually more reproducible than OIT measurements but require baseline data for interpretation of the changes.

6 Measurement procedure

6.1 Stabilisation of the polymeric materials

An appropriate time period shall be allowed for the polymeric materials in recently manufactured equipments to stabilise before any condition monitoring or accelerated ageing

programmes are carried out. The time period over which the polymeric materials stabilise is normally dependent on the processing additives and polymer composition. If manufacturers' stabilisation time data are not available, a period of 6 months shall be allowed.

6.2 Sampling

6.2.1 General

Measurements of OIT or OITP provide information on the status of the equipment only at the specific location which has been sampled. The selection of the sample locations for condition monitoring shall be made based on the environmental conditions in representative areas during plant operation. It is important that these locations represent as wide a range of ageing conditions as possible with special consideration given to locations where ageing conditions could be severe, e.g. hotspots. The location of the sampling and available information about the environmental time history at the sample location selected shall be documented.

6.2.2 Sample requirements

To enable up to 5 measurements to be made on one specific sample, a minimum of 50 mg of material is needed. The material to be sampled shall be cleaned of surface debris. No solvents shall be used to clean the surface. Samples typically may take the form of slivers or scrapings of material taken from the surface of a cable jacket or a thin slice through insulation at a termination. The location of the sampling position shall be noted, including its radial distribution (i.e. whether it is a surface sample or a through thickness slice).

Sampling and measurement procedures shall comply with local instructions, taking into account the safety of personnel and equipment.

Care shall be taken to avoid unsuitable conditions in storage during the time period between sampling and measurements. It is recommended that samples be stored in the dark at temperatures not exceeding 25 °C and at humidity conditions within 45 % and 75 %.

6.2.3 Precautions

When taking samples for OIT/OITP in the field, the equipment shall be visually inspected before and after the sampling in order to document that the equipment is not damaged.

If samples are to be taken from operational equipment in plant, the impact of such sampling on future operational use and qualification of such equipment shall be evaluated prior to sampling.

NOTE Where removal of material from operational equipment is considered detrimental to qualification or future use, the equipment should be removed from service or repaired according to the utility's local procedures to ensure that qualification is maintained.

6.3 Sample preparation

Samples for each OIT or OITP measurement shall be in the range 10 mg ± 2 mg in weight. Each sample shall be chopped into pieces with max dimensions of 1 mm. It is recommended that the chopped sample should be screened with a mesh to provide a particle size not greater than 0,85 mm as consistent sample preparation is important to enable reproducible oxidation of the sample during measurement. The chopped sample shall be placed into a sample pan appropriate to the instrument being used.

The sample pans shall be of aluminium and be open or have lids with holes or mesh to allow free access for oxygen during the measurement. A minimum of three samples shall be measured.

NOTE 1 If smaller sample weights need to be used, e.g. for chlorinated materials, this should be noted in the measurement report.

NOTE 2 If the results of measurements on three samples have a standard deviation >10 % of the mean value for OIT or >3 % of the mean value for OITP, an additional two samples should be measured.

6.4 Instrumentation

The instrument used for oxidation induction measurements shall be capable of determining exotherms in the sub-milliwatt range, e.g. a differential scanning calorimeter (DSC). It shall be capable of maintaining an isothermal stability of ± 0,3 °C over the duration of the measurement, typically up to 90 min. The temperature ramp rate shall be programmable.

The instrument shall allow purging of the sample chamber with specific gases at a controllable rate. The distance between the gas-switching point and the instrument cell needs to be kept as short as possible, with a dead time of less than 1 min, to minimise the switching volume. Accordingly, for a flow rate of 75 ml·min^{-1}, the dead volume shall be less than 75 ml.

For analysis purposes, the difference in heat flow between a reference pan and the sample pan as a function of time (for OIT measurements) or temperature (for OITP measurements) shall be measured.

6.5 Calibration

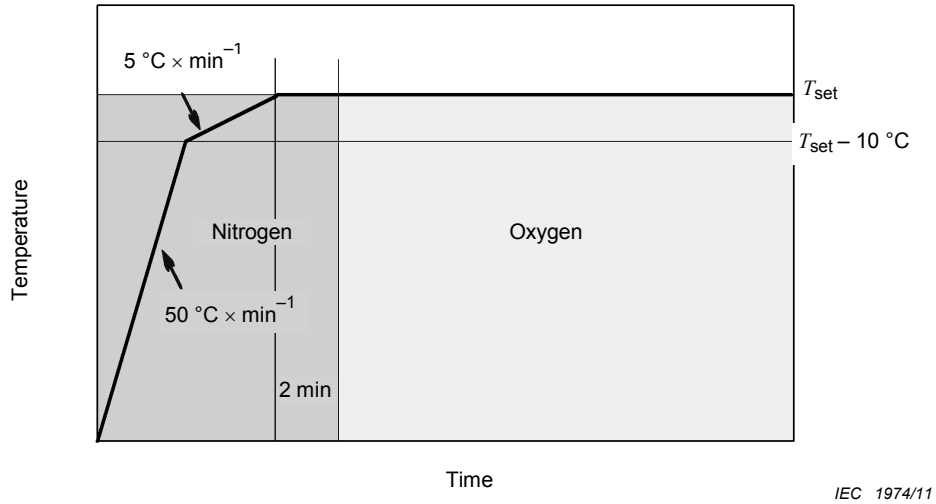
The instrument shall be calibrated according to the manufacturer's recommendations and the relevant QA (quality assurance) procedure, using a suitable calibration standard for the temperature ranges being used (e.g. lead/indium/tin). Measurement of a reference sample shall be carried out prior to each batch of OIT or OITP measurements to verify this calibration.

6.6 OIT measurement method

6.6.1 Measurement procedure

The measurement procedure is illustrated in Figure 1. It includes the following steps.

- The sample is heated in nitrogen at a rate of temperature rise of 50 °C·min^{-1} until 10 °C below the set temperature T_{set}. The ramp rate is then reduced to 5 °C·min^{-1} to reach the set temperature.
- The sample is then held for 2 min at the set temperature in nitrogen after which the atmosphere in the instrument is switched to oxygen.
- The oxidation exotherm is detected by a rapid increase in heat flow.
- The time from switching the atmosphere to oxygen until the sample starts oxidising is determined. This time is the oxidation induction time.



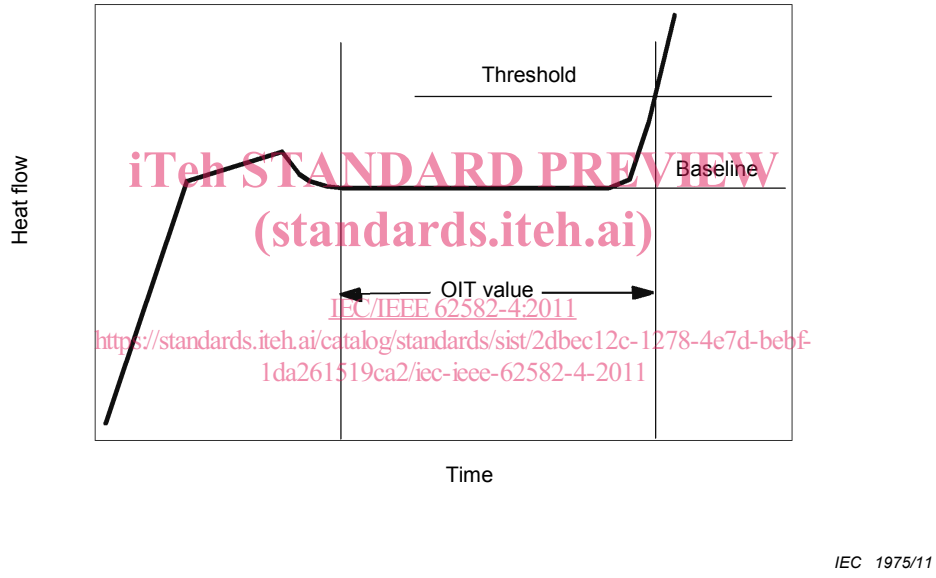


Figure 1 – OIT measurement – Schematic of temperature and gas profile and corresponding heat flow

6.6.2 Temperature profile

The reproducibility of OIT measurements is dependent on using a standardised thermal history. T_{set} for OIT measurements shall be 210 °C, provided that the oxidation induction time for unaged material is at least 30 min. The OIT value is highly dependent on T_{set} selected, see example in Annex C. If the OIT is less than 30 min for unaged material, then T_{set} shall be reduced in 10 °C increments until the OIT is $>$ 30 min. If the OIT is $>$ 90 min for unaged material, then T_{set} shall be increased in 10 °C increments until the OIT is $<$ 90 min. Once the value of T_{set} has been selected for a specific material, the same value shall be used for all subsequent measurements on that material.

NOTE OIT $>$ 90 min for unaged material is acceptable provided that the heat flow observed during the oxidation exotherm is sufficient to exceed the required threshold value (see 6.6.4.2).

6.6.3 Gas flow

The flow rate for oxygen during OIT tests shall be 75 ml·min^{-1} ± 25 ml·min^{-1}. The flow rate for nitrogen during the initial phase of OIT tests is not critical but it is recommended that 75 ml·min^{-1} ± 25 ml·min^{-1} be used.

NOTE Oxidation induction measurements can be affected by the oxygen flow rate used during the tests. For low flow rates (<50 ml·min^{-1}), this can result in increased induction times in OIT tests. For the range of flow rates from 50 ml·min^{-1} to 100 ml·min^{-1}, oxidation induction times are not strongly dependent on the oxygen flow rate.

6.6.4 Determining the value of oxidation onset

6.6.4.1 Definition of the baseline

The threshold for oxidation induction is measured relative to a baseline, as shown in Figure 2. There will usually be a period of constant heat flow prior to the onset of oxidation; this is used as the baseline. In some materials, there is a linear change in heat flow before the onset of oxidation. This can also be used as a baseline and is referred to as a sloping baseline.

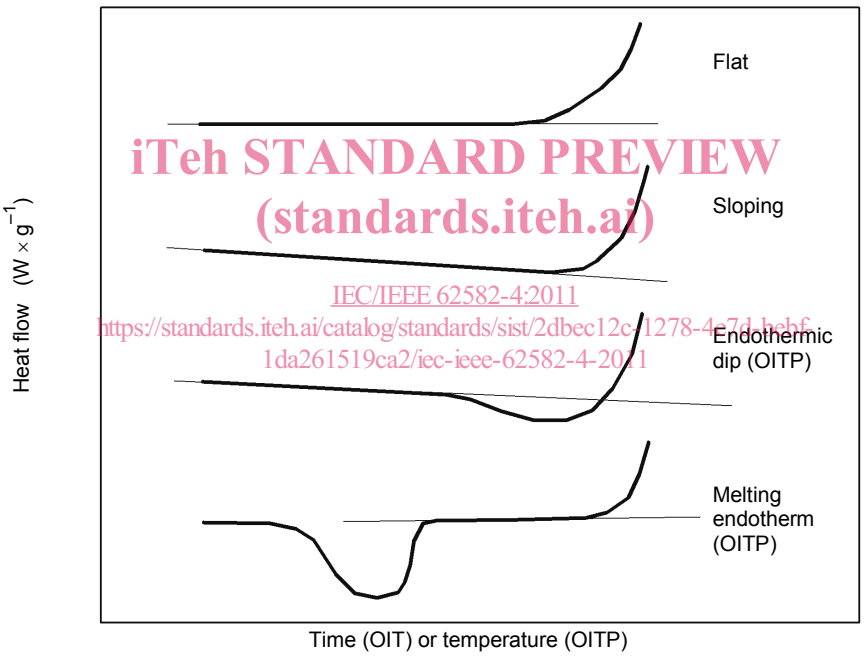


Figure 2 – Schematic showing the types of baselines (flat, sloping, endothermic dip, melting endotherm) observed for OIT and OITP measurements

6.6.4.2 Definition of the threshold and onset time

The threshold shall be defined at 0,1 W·g^{-1} relative to the baseline. The onset time is defined by the intersection of the test curve with the threshold relative to the baseline, as shown in Figure 3.