IEC 60737

Edition 2.0 2010-06

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Nuclear power plants – Instrumentation important to safety – Temperature sensors (in-core and primary coolant circuit) – Characteristics and test methods

Centrales nucléaires de puissance – Instrumentation importante pour la sûreté – Capteurs de température (dans le cœur et le circuit primaire) – Caractéristiques et méthodes d'essai

IEC 60737:2010

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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

COMMISSION
ELECTROTECHNIQUE
INTERNATIONALE

PRICE CODE
CODE PRIX **U**

ICS 27.120.20
ISBN 978-2-88912-020-8

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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NUCLEAR POWER PLANTS – INSTRUMENTATION IMPORTANT TO SAFETY – TEMPERATURE SENSORS (IN-CORE AND PRIMARY COOLANT CIRCUIT) – CHARACTERISTICS AND TEST METHODS

FOREWORD

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International Standard IEC 60737 has been prepared by subcommittee 45A: Instrumentation and control of nuclear facilities, of IEC technical committee 45: Nuclear instrumentation.

This second edition cancels and replaces the first edition published in 1982. This edition constitutes a technical revision.

The main changes with respect to the previous edition are listed below:

- to up-date the references to standards published or revised since the issue of the first edition of the current standard, including IEC 61513 and IEC 61226;
- to include descriptions of the comparative performance of thermocouples and resistance temperature detectors;
- to include a discussion of the temperature measuring system requirements for reactors;
- to adapt the definitions;

- to update the format to align with the current ISO/IEC Directives on style of standards.

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

FDIS	Report on voting
45A/800/FDIS	45A/806/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.

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

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

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- withdrawn,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

INTRODUCTION

a) Technical background, main issues and organisation of the Standard

This International Standard addresses the issues specific to temperature detectors used mainly for in-core and primary coolant circuit instrumentation systems. It describes the principles, the characteristics and the test methods for temperature detectors including: RTDs and thermocouples.

It is organized into clauses giving:

- the definitions;
- description of the different types of temperature sensors;
- system design;
- analysis of the factors of influence;
- the operational conditions for sensors;
- the factory tests;
- the qualification tests.

It is intended that the Standard be used by operators of NPPs (utilities), nuclear plant designers and constructors, systems evaluators and by licensors.

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

IEC 60737 is the third level IEC SC 45A document tackling the specific issue of characteristics and test methods related to temperature detectors used in power reactors.

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

c) Recommendations and limitations regarding the application of the Standard

There are no special recommendations or limitations regarding the application of this standard.

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.

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 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 IMPORTANT TO SAFETY – TEMPERATURE SENSORS (IN-CORE AND PRIMARY COOLANT CIRCUIT) – CHARACTERISTICS AND TEST METHODS

1 Scope

This International Standard is applicable to general aspects of system and component design, manufacturing and test methods for temperature sensors used in-core and for the primary coolant circuit in nuclear power reactors.

These sensors include thermocouples and RTDs (Resistance Temperature Detector–RTD). Emphasis is placed on the features specific to the nuclear application and recommendations concerning components and sensors are made only when they relate to the containment of such components within the reactor primary envelope and/or in high radiation fields.

The conditions imposed by reactor use are often different from those which occur in non-nuclear applications. Parts of the in-core system may be located in very severe environments.

Exposure to high neutron and gamma radiations is liable to cause error due to nuclear transformations, heating and structural changes, and to affect the mechanical and electrical properties of the equipment so that extra care has to be taken in the standards adopted for installations and in the choice of materials.

Furthermore, design consideration needs to be given to the effects of high environmental pressure, high temperature, temperature gradients and temperature cycling as well as to the way in which the temperature measuring system could influence the safety or economic performance of the reactor.

The consequences of nuclear conditions for temperature sensors lead to strong requirements regarding qualification.

This standard deals with specific requirements for nuclear applications of temperature sensors. It has two purposes:

a) to provide a guide which will help to ensure that the reactor conditions do not damage the temperature sensors;
b) to ensure that the in-core temperature measuring system and the sensor installation do not prejudice the safe operation and the availability of the reactor.

Statements of general applicability are made but detailed consideration is restricted to thermocouples and RTDs.

2 Normative references

The following referenced documents are indispensable for the application 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 60584-1, *Thermocouples – Part 1: Reference tables*

IEC 60584-2, *Thermocouples – Part 2: Tolerances*

IEC 60584-3, *Thermocouples – Part 3: Extension and compensating cables – Tolerances and identification system*

IEC 60709, *Nuclear power plants – Instrumentation and control systems important to safety – Separation*

IEC 60751, *Industrial platinum resistance thermometers and platinum temperature sensors*

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

IEC 60980, *Recommended practices for seismic qualification of electrical equipment of the safety system for nuclear generating stations*

IEC 61226, *Nuclear power plants – Instrumentation and control important to safety – Classification of instrumentation and control functions*

IEC 61513, *Nuclear power plants – Instrumentation and control for systems important to safety – General requirements for systems*

IEC 61515, *Mineral insulated thermocouple cables and thermocouples*

IEC 62342, *Nuclear power plants – Instrumentation and control systems important to safety – Management of ageing*

IEC 62385, *Nuclear power plants – Instrumentation and control important to safety – Methods for assessing the performance of safety system instrument channels*

IEC 62397, *Nuclear power plants – Instrumentation and control important to safety – Resistance temperature detectors*

IEC 62460, *Temperature – Electromotive force (EMF) tables for pure-element thermocouple combinations*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IAEA Safety Glossary edition 2007, IEC 60050-393 and IEC 60050-394 apply as well as the following:

3.1
accuracy of measurement
closeness of the agreement between the result of a measurement and the conventionally true value of the measurand

[IEV 394-40-35]

NOTE 1 “Accuracy” is a qualitative concept.

NOTE 2 The term “precision” should not be used for “accuracy”.

3.2
electrical shunting
effect of the shunting of the source impedance of the sensing device by the input impedance of the measuring device and the earth leakage impedance of the sensor

3.3
post-accident temperature sensor
temperature sensor designed to withstand and measure very high temperatures, which may be above 1 100 °C, that can occur if the fuel elements are not sufficiently cooled

3.4
resistance temperature detector (RTD)
detector generally made up of a stainless steel cylindrical barrel protecting a platinum resistor whose resistance varies with temperature. This detector is placed in the piping containing the fluid whose temperature is measured in this way. It can be directly immersed in the fluid or protected by an intermediate casing called the thermowell

NOTE 1 Mounting means or connection heads may be included. The temperature-sensing resistor can be made of platinum, nickel tungsten, copper, or other metals. However, a platinum sensor is commonly used in the RTD in an NPP; therefore, a platinum resistance thermometer is referred to in this standard.

NOTE 2 In this standard, the term “sensor” describes the RTD unit with all its associated protection, for example, barrel or thermowell. For most applications of measuring process fluid temperature in an NPP, the platinum resistor sensor is installed inside a stainless steel thermowell. For air temperature measurement, a direct sensor may be used.

[IEC 62397, 3.5]

3.5
sensitivity
for a given value of the measured quantity, ratio of the variation of the observed variable to the corresponding variation of the measured quantity

[IEV 394-39-07, modified]

3.6
service life
the period from initial operation to final withdrawal from service of a structure, system or component

[IAEA Safety Glossary, edition 2007]

NOTE The service life for a sensor corresponds to the operational life under irradiation and environmental conditions restricted within specified limits, after which the sensor characteristics exceed specified tolerances. It can be expressed in terms of incident particle fluence, time of operation, etc.

3.7
sheathed thermocouple
thermocouple embedded in a mineral insulation within a gas-tight, metal protecting tube as a sheath, with the two leads brought out for measurement through a moisture-proof seal

3.8
temperature measuring sensor
device, fixed or movable, designed to provide a signal for the measurement of temperature at a defined point in the core of the reactor or on the primary coolant circuit

NOTE Examples are Resistance Temperature Detectors and thermocouples such as sheathed thermocouples, insulated junction thermocouples and non-insulated junction thermocouples.

3.9
temperature measuring system
system, using in-core temperature measuring sensors, designed for the measurement of primary coolant, fuel, moderator and reactor structure temperatures

NOTE This system may be either independent of or a part of the general in-core monitoring system which provides the information necessary for normal reactor operation. A temperature measurement system includes all the components necessary to produce information or a signal representing the temperature at the sensor location. The components are: the temperature sensor itself, the thermowell, the cables, the connectors, the electronic system.

3.10
thermocouple
temperature measuring device based on the use of two conductors of different metals welded together at their two ends to form two junctions

NOTE One junction is at the temperature site of interest, the other at a reference stable cold temperature. The signal of a thermocouple arises from the Seebeck effect which generates a voltage that varies with the temperature difference between the junctions.

3.11
thermowell
protective jacket for RTDs, thermocouples, and other temperature sensors. The thermowell is also used to facilitate replacement of the temperature sensor

[IEC 62385, 3.19]

4 General considerations

4.1 Requirements for temperature measurements

Temperature is a fundamental parameter related to the nuclear process in a reactor. It can be measured with specific sensors to perform the following main safety functions:

– to monitor the temperature of the cooling system and to follow the operating conditions with regard to the design parameters;
– to measure the thermal power of the reactor when the temperature measurement is combined with the coolant flow rate measurement;
– to monitor the temperature of the fuel elements in order to avoid a boiling incident or melting of the fuel element itself.

Temperature measurements are required from the fuel, moderator, coolant or structural members supporting the core. They are used for control purposes, for the protection system, for shut-down and accident monitoring or for the provision of more general information about the reactor or its components.

In a power reactor with a core which has large physical dimensions, it may be important to monitor not only mean temperatures but also spatial temperature distributions. Measurements at particular positions may be used for the control of specific parts of the reactor core to ensure adequate safety margins for protection system parameters or to provide for optimum fuel utilization.

Some in-core measurements may also be necessary for reasons such as protecting the fuel from damage caused by local disturbances in coolant flow or by transients in local power density. In most cases, temperature sensors are used to measure temperature directly, but applications do arise in which information is derived from fluctuations in temperature. An example of the latter is the derivation of coolant flow by correlation of the fluctuations obtained from a spaced pair of sensors.

The measurement of in-core temperature for water reactors is important for reactor efficiency and fuel burn up, and may be achieved through probes inserted into specific channels of the reactor, or by permanently installed detectors. The measurements of these sensors are normally taken at routine intervals, followed by calculations to assess the conditions at each monitored fuel channel.

In all these applications, the environment is demanding and the performance of the temperature measurement system is either important to safety or to operation.

The temperature signals may be measured in a continuous or discontinuous manner depending on the application. This will not usually affect the design of the in-core installation.

4.2 Safety applications

Temperature sensors used in a system performing safety functions classified according to IEC 61226 shall follow the associated safety requirements determined by the safety class of the functions. If the measurements are important to safety, the cable routes shall also satisfy separation requirements to meet relevant single failure criteria and to avoid common cause failures, see IEC 60709.

After an accident, the cooling of fuel elements may decrease and the temperature inside the fuel may increase dramatically. A fuel element melt may occur and, when the coolant is water, a chemical reaction between the cladding and water produces a large quantity of hydrogen. The post accident conditions should be monitored by using temperature measurements capable of withstanding very high temperatures (for example, higher than 1 100 °C for light water reactors). The maximum temperature to be measured and the locations of the temperature sensors shall be specified by the designer of the reactor.

4.3 Nuclear conditions

The nuclear conditions related to the coolant circuit or inside the reactor vessel are very specific and different from general industry conditions. These conditions are characterized by the following:

– High radiation dose rates induced by gamma and neutrons, noting that:
  - high gamma dose rates damage organic materials by changing the molecular links;
  - fast neutrons damage organic and mineral materials by changing the atomic structure. This phenomenon can cause a change in characteristics;
  - thermal neutrons induce activation.

– Because the sensors are usually not easily accessible, they shall have a very high reliability, and the electronic components should be located far away from the radioactive zone.

– A reactor operates continuously with harsh conditions for a long time.

A temperature sensor specific for nuclear applications differs from normal industrial sensors by the following:

– qualification to normal conditions and nuclear conditions;

– quality assurance in accordance with nuclear standards, depending on the requirements.

5 Temperature sensors

5.1 Resistance temperature detector

A resistance temperature detector (RTD) is a temperature sensor whose resistance increases with temperature. An RTD consists of a wired coil or deposited film of pure metal. RTDs can be made of different metals (Pt, Cu, Ni..) and have different resistances, but the most common RTD is platinum and has a nominal resistance of 100 Ω at 0 °C. For nuclear applications on water cooled reactors the use of only one type of RTD gives better consistency of the measurement and easier maintenance.

The following two standards give some clarification on RTDs:

- IEC 60751:2008;
- IEC 62397:2007.

The relationship between the resistance and the temperature is given by the Callendar-Van Dusen formula:

$$R = R_0\left(1 + AT + BT^2\right)$$

where

$T =$ is the temperature in °C – in the range 0 °C to 1300 °C;

$R =$ is the resistance (Ω) at temperature T;

$R_0 =$ is the resistance at 0 °C (reference);

A and B are coefficients.

The coefficient B is relatively small (about 6×10^{-7} °C^{-2}) so that the resistance varies almost linearly with temperature, and it is taken to be linear for the rest of this standard.

RTDs can be difficult to measure because they have a relatively low resistance that changes only slightly with temperature (less than 0,4 Ω/°C). To measure these small changes in resistance accurately, special connection configurations should be used that minimize errors from lead wire resistance.

Typically, an RTD can be used with three different wiring configurations: 2, 3 or 4 wires. The wiring configuration has a direct impact on accuracy. The 4 wires configuration offers the best accuracy.

The sensitive element of an RTD is a metallic wire or a metallic coating on an insulating material. Due to the principle of measurement, the sensitive element shall be protected in a sheath filled with a mineral insulating material.

Because an RTD is a passive resistive device, a current has to be passed through the sensitive element to produce a measurable voltage. This current causes the RTD to internally heat, which appears as an error. Self heating is typically specified as the amount of power that will raise the RTD temperature by 1 °C, usually expressed in mW/°C.

The self heating can be minimized by using the smallest possible excitation current. The amount of self heating also depends on the medium in which the RTD is immersed.

RTDs are constructed in a number of forms and offer greater stability, accuracy and repeatability in some cases than thermocouples.

RTDs have a resistance varying linearly with temperature. They are characterized by

- an excellent accuracy;
- a wide range of operation, up to 600 °C;
- a low drift.

IEC 60751 defines two performance classes for RTDs, Class A and Class B. These performance classes define tolerances on ice point and temperature accuracy.

- Class A: highest RTD element tolerance and accuracy;
- Class B: most common RTD element tolerance and accuracy.

RTDs require the same precautions that apply to thermocouples, including using shields and twisted-pair wire, proper sheathing, avoiding mechanical stress and steep temperature gradients, and using large diameter extension wire.