IEC 62651

Edition 1.0 2013-04

# INTERNATIONAL STANDARD

# NORME INTERNATIONALE



**Nuclear power plants – Instrumentation important to safety – Thermocouples: characteristics and test methods**

**Centrales nucléaires de puissance – Instrumentation importante pour la sûreté – Thermocouples: caractéristiques et méthodes d'essai**



IEC 62651:2013

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

COMMISSION ELECTROTECHNIQUE INTERNATIONALE

PRICE CODE
CODE PRIX **V**

ICS 27.120.20

ISBN 978-2-83220-754-3

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# NUCLEAR POWER PLANTS – INSTRUMENTATION IMPORTANT TO SAFETY – THERMOCOUPLES: CHARACTERISTICS AND TEST METHODS

## FOREWORD

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International Standard IEC 62651 has been prepared by subcommittee 45A: Instrumentation and control of nuclear facilities, of IEC technical committee 45: Nuclear instrumentation.

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

| FDIS | Report on voting |
|---|---|
| 45A/904/FDIS | 45A/920/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- withdrawn,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 IEC standard specifically focuses on thermocouple characteristics and test methods.It is intended that the Standard be used by operators of NPPs (utilities), systems evaluators, designers and by licensors.

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

IEC 62651 is the third level SC 45A document tackling the generic issue of design and qualification of thermocouples. It provides the technical background to the nature and use of thermocouples. It provides information on the choice of thermocouple type in relation to the nuclear power applications of concern. It describes the method of use of thermocouples in nuclear reactors. It gives detailed type test and manufacturing test requirements.

IEC 62651 is to be read in association with IEC 60737 which is the appropriate IEC SC 45A document which provides guidance on temperature sensors for reactor applications in general, and with IEC 60780 for equipment qualification. Other IEC standards of general application to thermocouples are given in the normative references of clause 2, and IAEA documents and background information are referenced in the bibliography.

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 the Standard

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



Aspects for which special recommendations have been provided in this Standard are:

- the types of thermocouple suitable for nuclear reactor applications;
- the normal mounting arrangements;
- the use of hot or cold reference junctions and of compensating cable;
- the mechanical and metallurgical aspects to be considered;
- the use and types of cold-end seals;
- installation;
- testing.

To ensure that the Standard will continue to be relevant in future years, the emphasis has been placed on issues of principle, rather than 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.

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. Regarding nuclear safety, it provides the interpretation of the general requirements of IEC 61508-1, IEC 61508-2 and IEC 61508-4, for the nuclear application sector, regarding nuclear safety. 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 and IAEA GS-G-3.1 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 IAEA Safety Standard SSR 2/1, 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.



NOTE 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, that are based on the requirements of a Standard such as IEC 61508.

# NUCLEAR POWER PLANTS – INSTRUMENTATION IMPORTANT TO SAFETY – THERMOCOUPLES: CHARACTERISTICS AND TEST METHODS

## 1 Scope

This International Standard describes the requirements for thermocouples suitable for nuclear power plant (NPP) applications. Thermocouples are widely used in NPPs with other temperature measurement devices such as Resistance Temperature Detectors (RTDs). They are simple and robust and have some specific characteristics (range of measurement and maximum temperature) which make them uniquely suitable for some measurements.

The requirements given in this standard for thermocouples include design, materials, manufacturing, testing, calibration, procurement, and inspection.

The scope of this standard does not cover the design, material selection, and construction of the thermowell, the guide tube, the extension cable, and the temperature transmitter or bridge which may be associated with the thermocouple.

## 2 Normative references



The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.



IEC 60584-1:1995, *Thermocouples – Part 1: Reference tables*

IEC 60584-2:1982, *Thermocouples – Part 2: Tolerances*
Amendment 1:1989

IEC 60584-3:2007, *Thermocouples – Part 3: Extension and compensating cables – Tolerances and identification system*

IEC 60737:2010, *Nuclear power plants – Instrumentation important to safety – Temperature sensors (in-core and primary coolant circuit) – Characteristics and test methods*

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

IEC 61515:1995, *Mineral insulated thermocouple cables and thermocouples*

## 3 Terms and definitions

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

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

Note 1 to entry: "Accuracy" is a qualitative concept.

Note 2 to entry: The term precision should not be used for "accuracy".

[SOURCE: IEC 60050-394:2007, 394-40-35]

**3.2**
**calibration**
set of operations that establish, under specified conditions, the relationship between values of quantities indicated by measuring instrument or measuring system, or values represented by a material measure or a reference material, and the corresponding values realized by standards

[SOURCE: IEC 60050-394:2007, 394-40-43]

**3.3**
**reference junction**
junction of the thermocouple which is at a known (reference) temperature to which the measuring temperature is compared

Note 1 to entry: The reference junction is also called the cold junction.



[SOURCE: IEC 60584-1:1995, definition 2.4]



**3.4**
**drift**
variation in sensor or instrument channel output that may occur between calibrations that cannot be related to changes in the process variable or environmental conditions

[SOURCE: IEC 62385:2007, definition 3.7]

**3.5**
**measurement junction**
the metal-to-metal junction of the thermocouple located where the temperature is measured. The second junction is located at a reference temperature

Note 1 to entry: The measurement junction is also called the hot junction.

**3.6**
**performance monitoring**
process of demonstrating that an installed instrument channel continues to perform its intended function of monitoring the process variable with the expected accuracy, response time, and stability

[SOURCE: IEC 62385:2007, definition 3.13]

**3.7**
**response time**
the period of time necessary for a component to achieve a specified output state from the time that it receives a signal requiring it to assume that output state

[SOURCE: IAEA Safety Glossary, edition 2007]

**3.8**
**extension and compensating cables**
cables used for the electrical connection between the open ends of a thermocouple and the reference junction in those installations where the conductors of the thermocouple are not directly connected to the reference junction. The thermoelectric properties of extension and compensating cables must be close to the properties of the corresponding thermocouple

[SOURCE: IEC 60584-3:2007, definition 3.1]

**3.9**
**extension cables**
cables manufactured from conductors having the same nominal composition as those of the corresponding thermocouple. They are designated by the letter "X" following the designation of the thermocouple, for example "JX"

[SOURCE: IEC 60584-3:2007, definition 3.1.1]

**3.10**
**compensating cables**
cables manufactured from conductors having a composition different from the corresponding thermocouple. They are designated by the letter "C" following the designation of the thermocouple, for example "KC". In some cases different tolerances apply for the same thermocouple type over different temperature ranges. These are distinguished by additional letters such as, for example, KCA and KCB



[SOURCE: IEC 60584-3:2007, definition 3.1.2]



**3.11**
**thermocouple**
pair of conductors of dissimilar materials joined at one end and forming part of an arrangement using the thermoelectric effect for temperature measurement

[SOURCE: IEC 60584-2:1982, definition 2.2]

**3.12**
**thermocouple assembly**
an assembly used for temperature measurement, comprising a double set of junctions (hot and cold junctions), cables, connections and an electronic system measuring very low voltages

**3.13**
**thermowell**
protective jacket for RTDs, thermocouples and other temperature sensors. The thermowell is also used to facilitate replacement of the temperature sensor

[SOURCE: IEC 62385:2007, definition 3.19]

**3.14**
**time constant**
in the case of a first order system, the time required for the output signal of a system to reach 63,2 % of its final variation after a step change of its input signal. If the system is not a first order system, the term "time constant" is not appropriate. For a system of a higher order, the term "response time" should be used

[SOURCE: IEC 62385:2007, definition 3.20]

**3.15**
**thermoelectric (Seebeck) effect**
the thermoelectric effect is the production of an electromotive force EMF due to the difference of temperature between two junctions of different metals or alloys forming part of the same circuit

[SOURCE: IEC 60584-2, definition 2.1]

## 4 List of abbreviations

| | |
|---|---|
| EMF | Electromotive Force |
| HELB | High Energy Line Break |
| LOCA | Lost Of Coolant Accident |
| NPP | Nuclear Power Plant |
| QA | Quality Assurance |
| RTD | Resistance Temperature Detector |

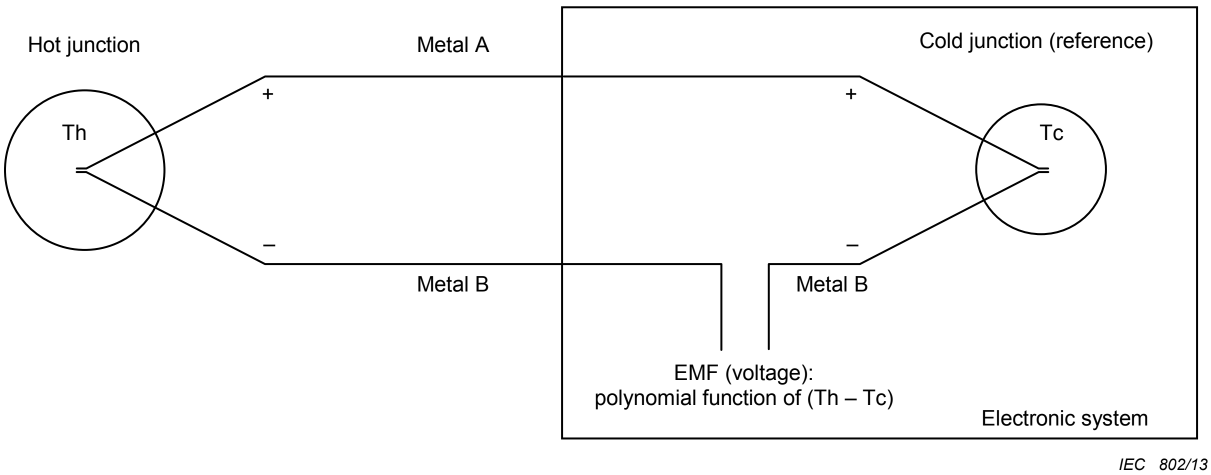
## 5 Principle of a thermocouple

### 5.1 General

When two wires made from dissimilar metals are joined together (by welding or at terminals) at both ends, a small voltage appears on the loop depending on the temperature difference between the two ends as shown on Figure 1. This phenomenon is known as the Seebeck effect. It is the basic principle of a thermocouple used for temperature measurement.



The metal forming one wire is electrically positive compared to the other.




**Key**

Th temperature of hot junction

Tc temperature of cold junction

**Figure 1 – Schematic diagram of a thermocouple**

The measuring end is called the hot junction and the other end at a reference temperature is called the cold junction. An electronic system measures the voltage and converts it to give the temperature by comparison with the reference temperature measured by another principle. The relationship between the thermocouple EMF signal and the process temperature is a polynomial combination whose coefficients are given by Table 1 of IEC 60584-1:1995. The typical voltage generated by type K thermocouple is about 40 $\mu$V/°C from a source with the impedance of the loop resistance of the metals.

The EMF, and therefore the sensitivity and the range of measurement, depend on the nature of the metals. Although many combinations of metals are possible, only specific ones are selected, defining a limited range of types of thermocouple. Each type of thermocouple is defined according to three tolerance classes: Class 1, 2 or 3. Each class corresponds to a tolerance and an associated range where the tolerance is valid.

IEC 60584-2 gives detailed requirements about the classes of tolerance.

IEC 61515 gives general requirements regarding mineral insulated thermocouples and cables.

The environmental conditions in an NPP imply that only some types of thermocouples are recommended.

Table 1 gives the most common thermocouple types. The given temperature range corresponds to the superposition of the three classes of tolerances as described in IEC 60584-2.

**Table 1 – List of thermocouples and their use in an NPP**

| Type | Positive Metal/Alloy | Negative Metal/Alloy | Typical temperature range °C | Example of application |
|---|---|---|---|---|
| **K** | Nickel – Chromium | Nickel – Aluminium | –200 to +1 150 | Primary circuit PWR |
| **T** | Copper | Copper – Nickel | –200 to +350 | Not in neutron flux |
| **J** | Iron | Copper – Nickel | –40 to +750 | Not in neutron flux |
| **N** | Nickel – Chromium- Silicon | Nickel – Silicon | –200 to +1 200 | Fuel temperature |
| **E** | Nickel – Chromium | Copper – Nickel | –200 to +750 | Not in neutron flux |
| **C** | Tungsten – Rhenium (5 %) | Tungsten – Rhenium (26 %) | 0 to +2 300 | Not in neutron flux |
| **R** | Platinum – Rhodium (13 %) | Platinum | 0 to +1 700 | Not in neutron flux |
| **S** | Platinum – Rhodium (10 %) | Platinum | 0 to +1 700 | Not in neutron flux |
| **B** | Platinum – Rhodium (30 %) | Platinum Rhodium (6 %) | +600 to +1 820 | Not in neutron flux |



Some other types of thermocouples based on Molybdenum – Niobium (MoNb) or their alloys may be considered for high performance applications.

The categories (T, J, E, C, R, S, B ) are described in 5.2 for information only.

Only K, N and E types are generally used for nuclear applications, in accordance with the limitations on exposure to neutron flux of Table 1.

## 5.2 Types of thermocouples for nuclear applications

### 5.2.1 General

For nuclear applications, and specifically for measurement on and in the primary coolant circuit of reactors, thermocouples with a robust design and a high quality shall be used. They are protected within a metal sheath and insulated with a mineral material.

Thermocouples are used on water reactors for measurement of fuel channel outlet temperature, which is particularly important in beyond design basis conditions. They may be used in travelling fuel channel probes on water-cooled reactors, often for calibration purposes. They are used on gas cooled reactors for measurements of fuel temperature, and fuel channel outlet temperature, which are needed for reactor protection and for control, and are also used for measurement of moderator and core support structural temperature.

More details are given in IEC 60737.

### 5.2.2 Type K

Type K thermocouple is the most widely used thermocouple. Its voltage output signal curve is virtually linear against the temperature and has a good sensitivity. Type K thermocouples can be used in temperatures up to 1 150 °C and, for short periods, up to 1 250 °C depending on sheath material and diameter.

### 5.2.3 Type T



This thermocouple is not very commonly used. Its temperature range is limited to –200 °C up to +350 °C. It is used in moist or negative temperature conditions because of its resistance to corrosion and the greater homogeneity of the component wires that reduce errors due to temperature gradients.



### 5.2.4 Type J

Type J Thermocouple has a limited temperature range: –40 °C to +750 °C. Its sensitivity increases up to 55 µV/°C and its output signal can be changed by the contamination of the iron. It is not recommended for nuclear applications.

### 5.2.5 Type N

This thermocouple has a good thermoelectric stability. It has an excellent oxidation resistance at high temperature. It is well adapted for accurate measurements in air, up to 1 200 °C. In vacuum or controlled atmosphere, it can withstand 1 300 °C depending on sheath materials and diameter

N thermocouples are more stable than noble metal thermocouples (S or B) under radiation conditions, but they are less stable at high temperature without radiation. Their drift depends on the sheath material and the temperature. Under certains conditions Type K are more stable than type N.

### 5.2.6 Type E

Thanks to its high sensitivity, the type E thermocouple is mainly used for cryogenic measurements. As it is non-magnetic, it can be preferred for some specific applications.

### 5.2.7 Type C

The type C thermocouple is mainly used for high temperature measurements, specifically for nuclear applications not subject to neutron flux.