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Nuclear power plants – Instrumentation systems important to safety – In-core instrumentation: Characteristics and test methods of self-powered neutron detectors

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IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

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NUCLEAR POWER PLANTS – INSTRUMENTATION SYSTEMS IMPORTANT TO SAFETY – IN-CORE INSTRUMENTATION: CHARACTERISTICS AND TEST METHODS OF SELF-POWERED NEUTRON DETECTORS

FOREWORD

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International Standard IEC 61468 has been prepared by subcommittee 45A: Instrumentation, control and electrical power systems of nuclear facilities, of IEC technical committee 45: Nuclear instrumentation.

This second edition cancels and replaces the first edition, published in 2000, and its Amendment 1, published in 2003. This edition constitutes a technical revision.

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

a) Title modified.
b) Justify the requirements for SPND characteristics in terms of influencing factors.
c) Align the terminology with the current state of the regulatory framework.

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

FDIS	Report on voting
45A/1381/FDIS	45A/1383/RVD

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

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

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

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

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- withdrawn,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

INTRODUCTION

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

This International Standard focuses on self-powered neutron detectors (SPNDs).

It is intended that this document be used by operators of NPPs (utilities), systems evaluators and by licensors.

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

IEC 61468 is a third level IEC/SC 45A document.

IEC 61468 is to be read in conjunction with IEC 61513 which establishes general requirements for I&C systems and with IEC 60568 which establishes general requirements for in-core instrumentation for neutron fluence rate (flux) measurements in power reactors.

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

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 documents of the IEC SC 45A standard series are IEC 61513 and IEC 63046. IEC 61513 provides general requirements for I&C systems and equipment that are used to perform functions important to safety in NPPs. IEC 63046 provides general requirements for electrical power systems of NPPs; it covers power supply systems including the supply systems of the I&C systems. IEC 61513 and IEC 63046 are to be considered in conjunction and at the same level. IEC 61513 and IEC 63046 structure the IEC SC 45A standard series and shape a complete framework establishing general requirements for instrumentation, control and electrical systems for nuclear power plants.

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

At a third level, IEC SC 45A standards not directly referenced by IEC 61513 or by IEC 63046 are standards related to specific 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.

The IEC SC 45A standards series consistently implements and details the safety and security principles and basic aspects provided in the relevant IAEA safety standards and in the relevant documents of the IAEA nuclear security series (NSS). In particular this includes the IAEA requirements SSR-2/1, establishing safety requirements related to the design of nuclear power plants (NPPs), the IAEA safety guide SSG-30 dealing with the safety classification of structures, systems and components in NPPs, the IAEA safety guide SSG-39 dealing with the design of instrumentation and control systems for NPPs, the IAEA safety guide SSG-34 dealing with the design of electrical power systems for NPPs and the implementing guide NSS17 for computer security at nuclear facilities. The safety and security terminology and definitions used by SC 45A standards are consistent with those used by the IAEA.

IEC 61513 and IEC 63046 have adopted a presentation format similar to the basic safety publication IEC 61508 with an overall life-cycle framework and a system life-cycle framework. Regarding nuclear safety, IEC 61513 and IEC 63046 provide the interpretation of the general requirements of IEC 61508-1, IEC 61508-2 and IEC 61508-4, for the nuclear application sector. In this framework IEC 60880, IEC 62138 and IEC 62566 correspond to IEC 61508-3 for the nuclear application sector. IEC 61513 and IEC 63046 refer to ISO as well as to IAEA GS-R part 2 and IAEA GS-G-3.1 and IAEA GS-G-3.5 for topics related to quality assurance (QA). At level 2, regarding nuclear security, IEC 62645 is the entry document for the IEC/SC 45A security standards. It builds upon the valid high level principles and main concepts of the generic security standards, in particular ISO/IEC 27001 and ISO/IEC 27002; it adapts them and completes them to fit the nuclear context and coordinates with the IEC 62443 series. At level 2, IEC 60964 is the entry document for the IEC/SC 45A control rooms standards and IEC 62342 is the entry document for the ageing management standards.

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.

NUCLEAR POWER PLANTS – INSTRUMENTATION SYSTEMS IMPORTANT TO SAFETY – IN-CORE INSTRUMENTATION: CHARACTERISTICS AND TEST METHODS OF SELF-POWERED NEUTRON DETECTORS

1 Scope

This document applies to in-core neutron detectors, viz. self-powered neutron detectors (SPNDs), which are intended for application in systems important for nuclear reactor safety: protection, instrumentation and control. This document contains SPND characteristics and test methods. In this document, the main sources of errors, and the possibilities for their minimization are also considered.

Self-powered neutron detectors can be used for measurement of neutron fluence rate and associated parameters in nuclear reactors. Most popular for the indicated applications are detectors with rhodium emitters.

In this document dynamic characteristics, emitter burn-up, identity and other factors influencing operational characteristics of detectors are considered.

Besides SPNDs with rhodium emitters, SPNDs with emitters from other materials and their main characteristics are also considered in this document.

This document contains requirements, recommendations and instructions concerning selection of SPND type and characteristics for various possible applications. This document about SPNDs uses the basic requirements of IEC 61513 and IEC 60568 and complements them with more specific provisions in compliance with IAEA Safety Guides.

2 Normative references

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

IEC 60515:2007, *Nuclear power plants – Instrumentation important to safety – Radiation detectors – Characteristics and test methods*

IEC 60568:2006, *Nuclear power plants – Instrumentation important to safety – In-core instrumentation for neutron fluence rate (flux) measurements in power reactors*

IEC/IEEE 60780-323:2016, *Nuclear facilities – Electrical equipment important to safety – Qualification*

IEC 61226, *Nuclear power plants – Instrumentation, control and electrical power systems important to safety – Categorisation of functions and classification of systems*

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

3 Terms and definitions

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

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

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1
background-compensation <of a self-powered neutron detector signal>
method employed for compensation of background contribution to the self-powered neutron detector current

Note 1 to entry: This is usually accomplished by placing an "emitterless" background detector in the in-core assembly, or by using detectors with an internal compensating lead wire.

Note 2 to entry: An equivalent term is “lead-compensation”.

3.2
beta decay
radioactive decay process in which mass number A remains unchanged, but the atomic number Z changes

Note 1 to entry: Processes include electron emission (b– decay), electron capture, and positron emission (b+ decay).

3.3
burn-up
depletion or reduction of target atoms when exposed to a thermal neutron flux density over time, due to conversion to other radioisotopes

3.4
burn-up life
time after which, at a given value of the neutron fluence rate of given energy distribution, the amount of emitter sensitive material will decrease to such an extent that the characteristics of the detector go beyond the tolerance established for their given application

3.5
Compton effect
effect which occurs when an incident high-energy photon is deflected from its original path by an interaction with an electron

Note 1 to entry: The electron is ejected from its orbital position and the x-ray photon loses energy because of the interaction but continues to travel through the material along an altered path. Energy and momentum are conserved in this process. The energy shift depends on the angle of scattering and not on the nature of the scattering medium. Since the scattered photon has less energy, it has a longer wavelength than the incident photon.

Note 2 to entry: An equivalent term is “Compton scattering”.

[SOURCE: IEC 60050-395:2014, 395-02-07]

3.6
cross-section
σ
measure of the probability of a nuclear reaction of a specific type, stated as the effective area which targets particles present to incident particles for that process

Note 1 to entry: The standard unit for measuring a nuclear cross-section is the barn, which is equal to 10−28 m^{2} or 10−24 cm^{2}.

Note 2 to entry: A microscopic cross-section can be measured for each process of nuclear reaction (capture, fission, n-n′, n-2n, n-g,etc.).

Note 3 to entry: The macroscopic cross-section allows the calculation of the number of interactions for a given nuclear reaction in a given material; this value is the produce between the corresponding cross-section and the number of particles in volume of this material; it is expressed in m^{-1} or cm^{-1}.

[SOURCE: IEC 60050-395:2014, 395-01-23]

3.7
decay constant
λ
number of disintegrations per unit time dN/dt for an atomic nucleus divided by the number of nuclei N existing at the same time t

$$\lambda = -\frac{1}{N} \times \frac{dN}{dt}$$

Note 1 to entry: The decay constant is expressed in reciprocal seconds (s^{-1}).

Note 2 to entry: The decay constant may be considered the total probability of radioactive decay (disintegration and/or nuclear transition).

[SOURCE: IEC 60050-395:2014, 395-01-11]

3.8
fluence rate
φ
quotient of $d\Phi$ by dt where $d\Phi$ is the increment of particle fluence in the time interval dt:

$$\phi = \frac{d\Phi}{dt}$$

[SOURCE: IEC 60050-881:1983, 881-04-19]

3.9
in-core neutron detector
detector, fixed or movable, designed for the measurement of neutron fluence rate at a defined region of a reactor core

3.10
integral self-powered neutron detector
self-powered neutron detector in which the lead cable section is an extension of the detector section, i.e. the emitter is directly attached to the core/signal wire; both sections share common insulation, and the collector of the detector section is also the outer sheath of the lead cable section (see Figure 1)

Note 1 to entry: An equivalent term is "cable-type self-powered neutron detector".

3.11
modular self-powered neutron detector
self-powered neutron detector made by mechanically joining, welding or brazing a detector (emitter, insulator, collector) to a lead cable (core/signal wire, insulator, outer sheath) (see Figure 2)

Note 1 to entry: An equivalent term is "prefabricated self-powered neutron detector".

3.12
isotope
variants of a chemical element that differ by atomic mass, having the same number of protons and differing in the number of neutrons in the nucleus

EXAMPLE 13C refers to a carbon atom that has an atomic mass of 13.

Note 1 to entry: Radionuclides or nuclides with a non-natural isotopic ratio are shown in the structural representation with the nuclide number displayed. Natural abundance isotopes are represented by an elemental symbol without a nuclide number.

[SOURCE: ISO 11238: 2018, 3.37]

3.13
photoelectric effect
complete absorption of a photon by an atom with the emission of an orbital electron

[SOURCE: IEC 60050-395:2014, 395-02-08]

3.14
prompt response
signal generation from a self-powered neutron detector based on the (n, γ, e) reaction

3.15
radioactive half-life
time required for the activity of a radioisotope to decrease to half of its initial value

Note 1 to entry: The radioactive half-life is related to the decay constant λ by the expression: $T_{1/2} = \ln 2/\lambda \approx 0{,}693/\lambda$. This quantity is expressed in seconds (s).

[SOURCE: IEC 60050-395:2014, 395-01-12]

3.16
radioisotope
isotope of an element with the property of spontaneously emitting particles or gamma radiation or of emitting X-radiation

[SOURCE: ISO 5576:1997, 2.104]

3.17
self-powered neutron detector
neutron-sensitive radiation detector that requires no external power supply, consists of three basic elements: an emitter that interacts with neutrons to emit electrons; a collector that collects these electrons and an insulator that isolates the emitter from the collector and converts the neutron fluence rate into electrical signal

Note 1 to entry: See Figure 1 and Figure 2.

3.18
self-shielding
self-absorption which occurs in the emitter: as emitter diameter increases, the escape probability of an electron born in the interior of the emitter decreases, and current-producing efficiency drops

3.19
in-core detector assembly
mechanical arrangement for positioning different detectors inside the core of a nuclear reactor. In-core detector assembly may contain both single-type detectors as well as detectors for various purposes and designs, for example, SPND and thermoelectric converters

3.20
sensitivity <of a detector>
characteristic measure of the signal of a detector to radiation. If in a given range of radiation quantity, the response of the detector depends linearly on the applied radiation, then in this range the sensitivity is given by the ratio: