

Nuclear power plants — In-core instrumentation — Characteristics and test methods of self-powered neutron detectors

ICS 27.120.20

National foreword

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Summary of pages

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**Centrales nucléaires de puissance –
Instrumentation en-cœur –
Caractéristiques et méthodes
d'essais des collecteurs**

**Nuclear power plants –
In-core instrumentation –
Characteristics and test methods
of self-powered neutron detectors**



Commission Electrotechnique Internationale
International Electrotechnical Commission
Международная Электротехническая Комиссия

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

NUCLEAR POWER PLANTS – 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: Reactor instrumentation, of IEC technical committee 45: Nuclear instrumentation.

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

FDIS	Report on voting
45A/369/FDIS	45A/379/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 3.

Annex A is for information only.

The committee has decided that the contents of this publication will remain unchanged until 2004. At this date, the publication will be

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- withdrawn;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

NUCLEAR POWER PLANTS – IN-CORE INSTRUMENTATION – CHARACTERISTICS AND TEST METHODS OF SELF-POWERED NEUTRON DETECTORS

1 Scope and object

This International Standard applies to in-core neutron detectors and instrumentation which are designed for purposes important to safety: protection, control and information. It is restricted to characteristics and test methods for self-powered neutron detectors (SPNDs). Self-powered neutron detectors can be used for neutron fluence rate (flux) measurements and spatial power measurements in nuclear reactors. This standard gives requirements, recommendations and guidance on selection of the type and characteristics of SPNDs for different possible applications of SPNDs.

For the principles of overall plant and I&C system design and the purpose of neutron fluence rate measurements, reference should be made to general principles of nuclear reactor instrumentation according to IAEA Codes and Safety Guides and IEC 61513.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 60050(394):1995, *International Electrotechnical Vocabulary (IEV) Chapter 394: Nuclear Instrumentation: Instruments*

IEC 60515:1975, *Radiation detectors for the instrumentation and protection of nuclear reactors; characteristics and test methods*

IEC 60568:1977, *In-core instrumentation for neutron fluence rate (flux) measurements in power reactors*

IEC 61226:1993, *Nuclear power plants – Instrumentation and control systems important for safety – Classification*

IEC 61513, *Nuclear power plants – Instrumentation and control for systems important to safety – General requirements for systems* ¹⁾

¹⁾ To be published.

3 Definitions and abbreviations

3.1 Definitions

For the purpose of this publication, the following definitions apply:

3.1.1

background or lead-compensation (of a self-powered detector signal)

a method employed to correct the current from a SPND for background contribution. 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 (see figure 3)

3.1.2

beta decay

radioactive decay process in which mass number A remains unchanged but the atomic number Z changes. Processes include electron emission (β^- decay), electron capture, and positron emission (β^+ decay)

3.1.3

burn-up

depletion or reduction of target atoms when exposed to a thermal neutron fluence rate over time, due to conversion to other radioisotopes

3.1.4

burn-up life (of a neutron detector)

estimated fluence of neutrons of a given energy distribution after which the sensitive material will be consumed to such an extent that the detector characteristics exceed the specified tolerances for a specified purpose [IEV 394-18-30]

3.1.5

capture cross-section

measure of the probability of a particular collision or interaction process, stated as the effective area which target particles present to incident particles for that process

3.1.6

Compton effect

ordinary elastic collision in which an incident photon of energy $E_0 = h\nu_0$ strikes a target electron causing the electron to recoil with energy $E = 1/2mv^2$. The photon itself is scattered at an angle Θ and energy $E' = h\nu_0 - E$

3.1.7

cross-section, σ

area within a target nucleus, which if struck by an incident particle will lead to a reaction taking place. The number of particles undergoing interaction (n_r) is equal to the number of incident particles (n_i) times the cross-section (σ) times the total number of target nuclei per target volume (N) times the target thickness (t).

$$n_r = n_i \sigma N t$$

The cross-section is expressed in barns ($1 \text{ b} = 10^{-28} \text{ m}^2$)

3.1.8

decay constant (λ)
disintegration constant
radioisotope decay constant
proportionality constant

for each radioisotope, λ is derived by dividing the natural logarithm of 0,5 by the half-life (in seconds), and expressed in s^{-1}

$$\lambda = (\ln 0,5)/t_{1/2} = 0,693/t_{1/2}$$

3.1.9

delayed response

time delay or lag in signal generation after exposure to a step change in neutron fluence rate. The mean lag time is $(t_{1/2}/\ln 2)$ where $t_{1/2}$ is the half-life of the radioisotope which produces the signal. The signal reaches equilibrium after a period of about five times $t_{1/2}$ following the step change

3.1.10

equilibrium response

for beta-decay self-powered neutron detectors, the response (signal) generated once the rate of neutron capture in the emitter equals the decay rate of radioisotopes in the emitter

3.1.11

half-life ($t_{1/2}$)

time required for the number of atoms or the activity of a radioactive element to decrease from a particular value to half that value

3.1.12

in-core neutron detector

detector, fixed or movable, designed for the measurement of neutron fluence rate (flux) or neutron fluence at a defined point or in a region of a reactor core or primary envelope

3.1.13

integral self-powered neutron detector

self-powered neutron detector assembly 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)

3.1.14

modular self-powered neutron detector

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

3.1.15

photoelectric effect

photon collision in which the energy of the incident photon is absorbed by the target atom, causing an electron to be emitted with energy $E = h\nu - B_e$, where $h\nu$ is the energy of the incident photon and B_e is the binding energy of the emitted electron

3.1.16

prompt response

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

3.1.17

radioisotopes

radioactive isotopes

unstable atomic species which have the atomic number Z of the same element but different mass numbers A ; isotope of an element that undergoes disintegration

3.1.18

self-powered neutron detector (SPND)

neutron-sensitive radiation detector that requires no external power supply and 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 (see figure 1)

3.1.19

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

3.1.20

sensitivity (of a detector)

sensitivity of a detector to the radiation to be measured. This sensitivity is given by:

$$S = \frac{\text{variation of the output quantity (detector response)}}{\text{variation of the input quantity (radiation to be measured)}}$$

In most applications, the detector response is linear and has a negligible output signal for zero input.

Hence

$$\text{sensitivity } S = \frac{\text{output quantity (detector response)}}{\text{input quantity (radiation to be measured)}}$$

3.1.21

thermal neutrons

neutrons with kinetic energy equal to about 0,025 eV at 293 K; neutrons that are approximately in thermal equilibrium with their surroundings

3.1.22

useful life (of a neutron detector)

operational life, under irradiation and environmental conditions restricted within specified limits, after which the detector characteristics exceed the specified tolerances [IEV 394-18-29]

NOTE Useful life can be expressed in incident particle fluence, etc.

3.2 Abbreviations

3.2.1

BWR

boiling water reactor

3.2.2

CANDU

the name given to a Canadian reactor design featuring natural uranium fuel and heavy water moderator and coolant. An acronym for CANada, Deuterium, Uranium

3.2.3

HWR

heavy water reactor – A heavy water (D_2O) cooled and moderated reactor

3.2.4

LWR

light water reactor – A light water cooled and moderated reactor. Commercial types include the pressurized water reactor (PWR) and the boiling water reactor (BWR)

3.2.5

PWR

pressurized water reactor

3.2.6

RBMK

a graphite moderated light water cooled reactor

3.2.7

SIR

an acronym for "straight individually replaceable". An integral type self-powered detector used in HWRs

3.2.8

SPND

self-powered neutron detector

4 Self-powered neutron detectors – General characteristics

In self-powered neutron detectors (SPNDs), the interactions of neutrons and atomic nuclei are used to produce a current which is proportional to the neutron fluence rate (flux). When compared to other types of in-core detectors, they have the following advantages:

- no need of power supply;
- simple and robust structure;
- relatively small mechanical "size" well-suited for in-core installation;
- good stability under temperature and pressure conditions;
- low burn-up (dependent on emitter material).

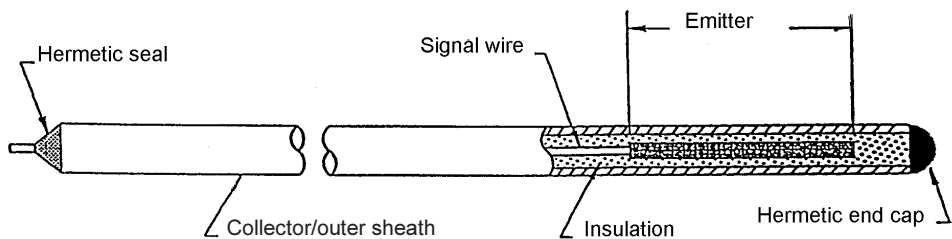
At the same time, they have the following disadvantages:

- limited operating range due to relatively low neutron sensitivity;
- compensation for background noise required (for some emitters);
- delayed signal response (for some emitters).

5 Mechanical structure and characteristics

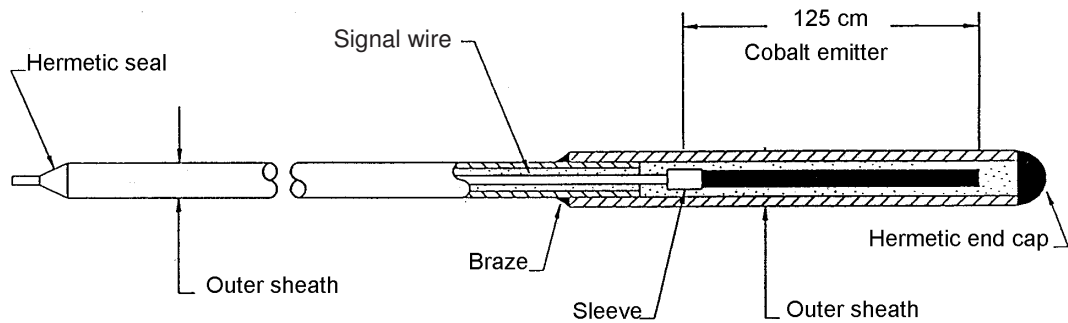
The typical SPND (see figure 1) is a coaxial cable consisting of an inner electrode (the emitter), surrounded by insulation and an outer electrode (the collector).

Preferably, the lead cable and detector sections are integral, i.e. the signal wire of the lead cable mates directly to the emitter; the insulation of both sections is identical and the collector of the detector section is also the outer sheath of the lead cable section. Detectors constructed in this manner are termed Integral SPNDs. SPND assemblies may also be made from separate detector and lead cable sections and are termed modular SPNDs as shown in figure 2.



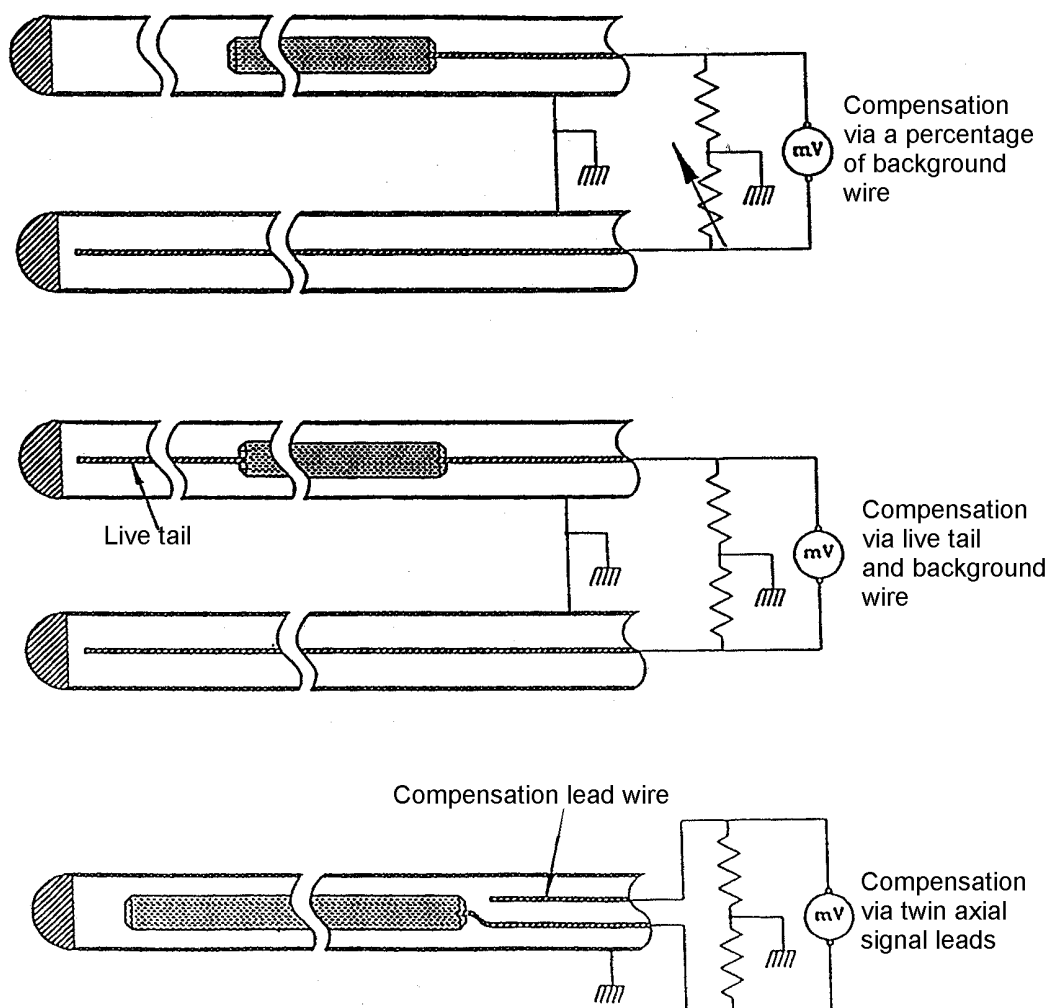
IEC 244/2000

Figure 1 – Typical integral self-powered neutron detector



IEC 245/2000

Figure 2 – Typical modular self-powered neutron detector



IEC 246/2000

Figure 3 – Methods of compensation of a self-powered detector signal

SPNDs may be located in the reactor core as single elements, or more typically, in assemblies of several units grouped around a central tube in which the sensor of a calibration system can be located. Examples are described in A.5, showing typical assembly configurations used in light water and heavy water nuclear power plants.

SPNDs are available in a variety of designs with sensitive lengths ranging from a few centimetres to full core height. The design of an SPND should incorporate proper selection of emitter type and thickness, as well as sheath and insulation material types and dimensions, to optimize the mechanical design for a specific radiation measurement.

The material of the collector and lead cable sections shall be resistant to corrosion effects if in contact with the primary coolant under normal operation and transient conditions. SPNDs may be installed in assemblies in which the SPND elements are not in contact with the primary coolant, to eliminate the effects of corrosion and extend the element lifetime.

The collector may be fabricated from nickel-based alloys, characterized by low manganese content and excellent corrosion resistance. (Low manganese content of less than 1 % is desired because manganese produces interfering beta emissions when exposed to neutrons.)

The insulation should be virtually transparent to neutrons or gamma fluence rate, i.e. it should have an extremely low probability of interaction with neutrons or gamma rays. It should ensure that the detector maintains a resistance between centre conductor and collector in excess of $10^7 \Omega$ in "hot" operating conditions, and in excess of $10^{12} \Omega$ for "cold" nonoperating conditions. Ceramic oxides are the preferred materials because they can withstand the hostile environment inside a nuclear reactor.

Typically, three materials may be used for the insulation in SPNDs employed in power reactor applications, namely, Al_2O_3 , MgO and SiO_2 . Al_2O_3 has been chosen for most applications as it is readily available and, in powder form, is less sensitive than MgO to the effects of humidity. MgO is hygroscopic and is therefore sensitive to cable swelling if moisture penetrates the cable sheath. SiO_2 may be used in some applications because its low density enhances emitter to collector electron transmission and thus maximizes sensitivity characteristics. However SiO_2 has lower insulation resistance at high temperature than MgO or Al_2O_3 .

6 Nuclear and electrical characteristics

For power reactor applications, typical emitter materials used in SPNDs include vanadium, cobalt, rhodium, silver, platinum and hafnia. These materials should be used because they possess relatively high melting temperatures, relatively high cross-sections to thermal neutrons and are compatible with the SPND manufacturing process. Other emitters such as cadmium, gadolinium and erbium may be used in SPNDs for low temperature experimental reactors, but are not practical for power reactor applications.

Table 1 gives an overview of some of the important characteristics of SPND emitters used in power reactor applications.