

Nuclear power plants — Instrumentation important to safety — Radiation detectors — Characteristics and test methods

ICS 27.120.20

National foreword

This British Standard was published by BSI. It is the UK implementation of IEC 60515:2007. It supersedes BS 5548:1978 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee NCE/8, Reactor instrumentation.

A list of organizations represented on NCE/8 can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 30 April 2007

© BSI 2007

ISBN 978 0 580 50497 6

Amendments issued since publication

Amd. No.	Date	Comments

BS EN 60515:2007

INTERNATIONAL STANDARD

IEC
60515

Second edition
2007-02

**Nuclear power plants –
Instrumentation important to safety –
Radiation detectors –
Characteristics and test methods**



Reference number
CEI/IEC 60515:2007

CONTENTS

FOREWORD.....	4
INTRODUCTION.....	6
1 Scope	8
2 Normative references	8
3 Terms and definitions	9
4 Abbreviations	12
5 Functions of an ex-core detection system.....	12
6 Neutron sensitive materials.....	13
7 Description of different types of detectors	14
7.1 General.....	14
7.2 Neutron sensitive proportional counters	14
7.3 Ionization chambers.....	16
8 More detailed factors which influence the use and testing of neutron detectors	19
8.1 Pulse mode neutron detectors.....	19
8.2 Current mode neutron detectors.....	21
9 General principles for detector operation.....	24
9.1 Detection basis conditions	24
9.2 Detector operating conditions.....	24
9.3 Limits due to the detector	24
9.4 Limits due to the measuring channel.....	25
9.5 Limits due to surrounding gamma radiation	25
10 Connectors and cables	26
11 Characteristics of detectors including their cables and connectors	26
11.1 General.....	26
11.2 Detector mechanical data	26
11.3 Detector electrical and nuclear data	27
11.4 Connector mechanical data.....	28
11.5 Connector electrical characteristics.....	28
11.6 Cable mechanical data	29
11.7 Cable electrical characteristics.....	29
12 Test methods – general	29
13 Factory tests	29
13.1 General.....	29
13.2 List of typical factory tests	30
13.3 Mechanical tests.....	31
13.4 Specific tests for fission counters (see Figure 4).....	31
13.5 Specific tests for proportional counter tubes	33
13.6 Specific tests for compensated ionization chambers (see Figure 3).....	34
13.7 Specific tests for uncompensated neutron sensitive d.c. ionization chambers (see Figure 2).....	37
13.8 Specific tests for d.c. ionization chambers for gamma radiation	39

13.9	Specific test for current fluctuation (Campbelling) fission chambers	39
14	Qualification tests	40
14.1	Principles	40
14.2	Test sequence on a detector	40
14.3	Test for environmental conditions	40
14.4	Seismic tests	40
	Bibliography	41
	Figure 1 – Neutron sensitive proportional counter	15
	Figure 2 – Diagram of an uncompensated ionization chamber	16
	Figure 3 – Diagram of a compensated ionization chamber	17
	Figure 4 – Diagram of a fission counter	18
	Table 1 – Important connector mechanical factors	28

INTERNATIONAL ELECTROTECHNICAL COMMISSION

**NUCLEAR POWER PLANTS –
INSTRUMENTATION IMPORTANT TO SAFETY –
RADIATION DETECTORS –
CHARACTERISTICS AND TEST METHODS**

FOREWORD

- 1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
- 2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
- 3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
- 4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
- 5) IEC provides no marking procedure to indicate its approval and cannot be rendered responsible for any equipment declared to be in conformity with an IEC Publication.
- 6) All users should ensure that they have the latest edition of this publication.
- 7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
- 8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
- 9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

International Standard IEC 60515 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 1975. This edition constitutes a technical revision.

The revision of the standard is intended to accomplish the following:

- To clarify the definitions by including the thermal neutron fluence rate and the total neutron fluence rate.
- To up-date the reference to new standards published since the first issue, including IEC 61513 and IEC 61226.
- To update the units of radiations: nv unit of neutron fluence rate and Gy/h for gamma.

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

FDIS	Report on voting
45A/644/FDIS	45A/647/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 maintenance result 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 neutron detectors used mainly for ex-core instrumentation systems. It describes the principles, the characteristics and the test methods for neutron detectors including: Proportional Counters, Ionization Chambers (compensated and non compensated) and fission chambers or fission counters.

It is organized into clauses giving:

- the definitions;
- description of the different types of neutron detectors;
- analysis of the factors of influence;
- the operational conditions for detectors;
- the factory tests;
- the qualification tests.

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

IEC 60515 is the third level IEC SC 45A document tackling the specific issue of characteristics and test methods related to radiation detectors used 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 this 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 nuclear power plants (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 50-C-QA (now replaced by IAEA 50-C/SG-Q) 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 – RADIATION DETECTORS – CHARACTERISTICS AND TEST METHODS

1 Scope

This International Standard applies to the radiation detectors which are installed external to the core of nuclear reactors and which provide electrical input signals to the reactor's control and instrumentation system. These detectors are usually gas-filled neutron detectors and this standard applies only to that type although many of its principles could be used for others, for example, gas-filled gamma radiation detectors. This standard therefore describes characteristics and tests methods for gas-filled radiation detectors used for the protection of nuclear reactors.

The detectors subject to this standard are:

- boron d.c. ionization chambers,
- fission d.c. ionization chambers or fission pulse ionization chambers (fission counters),
- boron trifluoride proportional pulse counter tubes,
- helium-3 proportional pulse counter tubes.

This standard may be used for d.c. ionization chambers for gamma radiation but the detectors discussed here are not used for personnel dosimetry.

In-core radiation detectors are specifically addressed by IEC 60568 and IEC 61468.

NOTE This list is not restrictive and it is hoped that all types of radiation detectors used in reactor installations will benefit from the present standard. The standard for tests also applies to connecting cables and connectors when they form an integral part of the detector.

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 60050-393:2003, *International Electrotechnical Vocabulary (IEV) – Part 393: Nuclear instrumentation – Physical phenomena and basic concepts*

IEC 60050-394:1995, *International Electrotechnical Vocabulary (IEV) – Chapter 394 Nuclear Instrumentation: instruments*
Amendment 1 (1996)
Amendment 2 (2000)

IEC 60780:1998, *Nuclear power plants – Electrical equipment of the safety system – Qualification*

IEC 60980:1989, *Recommended practices for seismic qualification of electrical equipment of the safety system for nuclear generating stations*

IEC 61226:2005, *Nuclear power plants – Instrumentation and control systems important to safety – Classification of instrumentation and control functions*

IEC 61501:1998, *Nuclear reactor instrumentation – Wide range neutron fluence rate meter – Mean square voltage method.*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-393 and IEC 60050-394, as well as the following, apply.

3.1

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]

3.2

compensation factor <of a compensated ionization chamber>

ratio of the sensitivity to undesired radiation of the compensated ionization chamber, to the sensitivity to the same undesired radiation of the same chamber, if it were not compensated

[IEV 394-18-41]

3.3

compensation ratio <of a compensated ionization chamber>

inverse of the compensation factor, used as an index of performance of a compensated ionization chamber.

[IEV 394-18-42]

3.4

concomitant radiation

radiation which is associated with the radiation to be measured but which is not the object of the measurement, and whose effects on the measurement should preferably be eliminated

NOTE This radiation is also designated as an “undesired” radiation.

3.5

fluence <particles>

ϕ

quotient of dN by da , where dN is the number of particles incident on a sphere of cross sectional area da .

$$\phi = \frac{dN}{da}$$

[IEV 393-14-25]

3.6**particle fluence rate
particle flux density** ϕ

quotient of $d\Phi$ by dt , where $d\Phi$ is the increment of particle fluence in the time interval dt

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

[IEV 393-14-26]

NOTE 1 The Fluence rate is identical with the product of the volume particle density by the average speed of the particles. In the case of neutrons, the fluence rate unit is often expressed as “nv” instead of “number of neutrons /cm²/s”

NOTE 2 This definition applies to all kinds of particles. In the particular case of neutrons, the importance of energy is fundamental and requires a more specific definition especially for thermal neutrons.

3.7**thermal neutron fluence rate
thermal neutron flux**

integral of the neutron fluence rate on the energy of neutrons limited to the thermal part of the spectrum. The thermal spectrum corresponds to neutrons with energy (E) below about 0,625 eV

$$\Phi (\text{thermal}) = \int_0^{0,625 \text{ eV}} \phi(E) dE$$

NOTE 1 This definition allows the prediction of the signal from a detector or the comparison of signals from different detectors.

NOTE 2 The neutron fluence rate is the basic concept used to define the sensitivity of neutron detectors.

3.8**total neutron fluence rate
total neutron flux**

integral of the neutron fluence rate over the whole spectrum

3.9**influenceability**

if the operation of a detector is disturbed by a concomitant radiation, the detector is said to be “influenced” by this undesired radiation. The concomitant radiation is an influence quantity.

The Influenceability of a detector to concomitant radiation is given by:

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

with all other influence quantities held constant at specified values. Other factors such as temperature, pressure, polarizing potential, etc., may also be influence quantities. The influenceability is also defined as the sensitivity of the detector to the concomitant radiation

3.10

perturbed neutron fluence rate (flux)

spatial mean neutron fluence rate at the detector location with the neutron detector present for measurement. The neutron detector itself changes the unperturbed neutron fluence rate. This quantity is equal to the detector signal output divided by its (perturbed) sensitivity and is, in practice, approximated by the neutron fluence rate averaged over the detector surface

3.11

unperturbed neutron fluence rate (flux)

mean neutron fluence rate at the detector location, without the presence of the detector

3.12

sensitive material <of a neutron detector>

material used in certain neutron detectors, for example in a lining or a filling gas, which is intended to produce by nuclear reactions from the neutrons, directly ionizing particles including fission fragments

[IEV 394-10-13]

3.13

sensitivity to radiation <of a detector>

for a given value of the measured radiation, the ratio of the variation of the observed signal to the corresponding variation of the measured radiation

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

The units in which the radiation is measured depend on the radiation: Gy/h for gamma, nv for neutron fluence rate, etc. Neutron sensitivity is usually based on the perturbed fluence rate but is sometimes expressed in unperturbed units.

In many situations, for example in the testing of some new neutron detectors, the detector's signal is linear and negligible for zero input.

Hence, for example:

$$S \text{ (thermal – neutrons)} = \frac{\text{signal (detector response)}}{\text{thermal neutron fluence rate}}$$

This definition is valid provided that influence signals quantities are negligible

[IEV 394-19-07, modified]

3.14

useful life <of a 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, number of produced pulses, etc.

4 Abbreviations

cps: counts per second. The unit for counting rate.

nv: neutron fluence rate unit. Equivalent to the number of neutrons $\text{cm}^{-2} \text{s}^{-1}$.

5 Functions of an ex-core detection system

Reactor safety systems normally require measurements of reactor power on timescales comparable with the fastest possible reactor transient and this is most easily achieved by detecting the fluence rate of leakage neutrons, at the boundary of the core. Appropriate detectors are installed in or near the neutron reflector or, sometimes, in special “Thermal Columns” in the biological shielding. Ex-core detectors based on radiation other than neutrons have been used in this role but have never been able to meet all the system requirements on their own.

The ambient conditions at these detector positions can vary from very hostile, for example with high radiation levels and temperatures up to 550 °C, to relatively benign but they are generally not as harsh as those encountered by in-core instruments. The detector used shall, however, be able to withstand whatever the ambient conditions happen to be and are additionally selected for a variety of reasons. These include:

- Appropriate sensitivity. The system as a whole shall cover the full power range of the reactor and the fluxes at the detector positions vary from very low to moderately high (although still low by in-core standards).
- Ability to contribute towards covering the complete, wide working range – either singly or by complementing other detectors.
- Relatively high level output signals to help the immunity of the system to EMI.
- Different types of output so that the system as a whole has appropriately diverse protection.

In general, only detectors based on gas ionization can fulfill enough of these needs. Self powered detectors are seldom used because of their restricted working ranges and relatively low sensitivities.

Neutrons do not ionize directly and are detected by their interaction with a sensitive material to produce charged and therefore ionizing particles for example alpha particles, fission fragments, etc. In gas filled detectors, these secondary particles generate electrons and positive ions in the gas. The polarizing field separates these and this, in turn, generates the output signal. In some detectors, high local fields are used to enhance the signal by secondary ionization (gas gain).