

Specification for

Radiation detectors for the instrumentation and protection of nuclear reactors: characteristics and test methods

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The Nuclear Engineering Standards Committee, under whose direction this British Standard was prepared, consists of representatives from the following scientific and industrial organizations:

- Association of Consulting Engineers*
- British Electrical and Allied Manufacturers' Association (BEAMA)
- British Insurance (Atomic Energy) Committee
- Electricity Supply Industry in England and Wales*
- Health and Safety Executive*
- Hevac Association
- Institution of Mechanical Engineers
- Lloyd's Register of Shipping
- National Radiological Protection Board*
- Scientific Instrument Manufacturers' Association*
- The Institution of Nuclear Engineers*
- United Kingdom Atomic Energy Authority*
- Water-tube Boilermakers' Association

The organizations marked with an asterisk in the above list, together with the following, were directly represented on the committee entrusted with the preparation of this British Standard:

- Association of University Protection Officers
- British Industrial Measuring and Control Apparatus Manufacturers' Association
- British Institute of Radiology
- British Nuclear Design and Construction Limited
- British Nuclear Forum
- British Steel Industry
- Business Equipment Trade Association
- Control and Automation Manufacturers' Association (BEAMA)
- Electronic Engineering Association
- Hospital Physicists' Association
- Ministry of Defence
- Society for Radiological Protection
- Individual companies

This British Standard, having been prepared under the direction of the Nuclear Engineering Standards Committee, was published under the authority of the Executive Board on 30 June 1978

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National foreword

This British Standard is identical with IEC 515:1975 “*Radiation detectors for the instrumentation and protection of nuclear reactors: characteristics and test methods*” published by the International Electrotechnical Commission (IEC).

The formal decisions or agreements of IEC on technical matters, prepared by technical committees on which all the national committees having a special interest therein are represented, express, as nearly as possible, an international consensus of opinion on the subjects dealt with.

They have the form of recommendations for international use and they are accepted by the national committees in that sense.

This British Standard has been prepared under the direction of the Nuclear Engineering Standards Committee, and the United Kingdom took part in the work of the IEC Technical Committee No. 45, Nuclear Instrumentation.

Terminology. The text of the International Standard has been accepted as suitable for publication, without deviation, as a British Standard. Some terminology is not identical with that used in British Standards; attention is especially drawn to the following.

Wherever the word “standard” appears, referring to this publication, it should be interpreted as “British Standard”.

Cross-reference. For the following International Standard, referred to in the text, there is a corresponding British Standard; this is given below:

International Standard	Corresponding British Standard
IEC 231:1967	BS 4877:1972 <i>Recommendations for general principles of nuclear reactor instrumentation</i> (Technically equivalent)

NOTE The references to the remainder of the International Standards relate to informative matter only and not to mandatory requirements; in fact IEC intends to withdraw IEC 232 and to incorporate parts of it into the impending revision of IEC 231.

Additional information. The text of the International Standard uses the Röntgen (symbol: **R**) as the unit of exposure. While the use of this unit is expected to continue for some time, it is intended that it will eventually disappear in favour of the SI unit of exposure, the coulomb per kilogram (symbol: C/kg). The conversion equation is: **1 R = 258 µC/kg**.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 18, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

Section 1. Introduction

1 Scope

The aim of this publication is to establish a standard concerning the characteristics and test methods of gas-filled radiation detectors used for the instrumentation and protection of nuclear reactors.

These detectors function as electrical transducers and are used particularly in:

- assemblies for measuring power and rate of change of power by means of neutron fluence rate (flux);
- periodmeters or reactivity meters;
- reactor warning and safety monitoring assemblies;
- assemblies for measuring power by means of gamma radiation.

The detectors examined in this standard are not used for personnel dosimetry purposes.

In so far as they do not conflict with the present standard, IEC Publication 231, General Principles of Nuclear Reactor Instrumentation, and IEC Publication 232, General Characteristics of Nuclear Reactor Instrumentation, should be followed, as well as general recommendations and safety standards for electrical equipment which have already been issued.

The detectors subject to this standard are:

- boron current ionization chambers;
- fission current ionization chambers or pulse ionization chambers;
- ionization chambers for gamma radiation;
- boron trifluoride proportional counter tubes;
- boron-lined proportional counter tubes;
- helium-3 proportional counter tubes.

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 Definitions

Preliminary note

Definitions given in Sub-clauses **2.1**, **2.2** and **2.4** to **2.9** are taken from or based on IEC Publication 50(391), Detection and Measurement of Ionizing Radiation by Electric Means. The other definitions are still under consideration and given here to facilitate understanding of this standard.

2.1

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

2.2

sensitivity (of a measuring assembly)

for a given value of the measured quantity, the ratio of the increase of the observed variable to the corresponding increase of the measured quantity

$$S = \frac{\text{variation of output quantity (detector response)}}{\text{variation of input quantity (radiation to be measured)}} \quad 1)$$

2.3

influenceability

if the operation of a detector is disturbed by a concomitant radiation, the detector is said to be "influenceable" by this other radiation. The concomitant radiation is an influence quantity

¹⁾ In many applications where the detector has a linear characteristic and negligible output for zero input

$$S = \frac{\text{output quantity}}{\text{input quantity}}$$

the influenceability of a detector to concomitant radiation is given by:

$$S = \frac{\text{variation of the output quantity (detector response)}^2}{\text{variation of the input quantity (concomitant radiation)}}$$

with all other influence quantities held constant at specified values. Other factors such as temperature, pressure, polarizing potential, etc., may also be influence quantities

2.4

compensation factor (of a compensated ionization chamber)

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

2.5

compensation ratio (of a compensated ionization chamber)

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

2.6

sensitive material (of a neutron detector)

the material used in certain neutron detectors either, for example, in a lining or a filling gas, which is intended to produce *directly ionizing* particles from the neutrons by nuclear reaction

NOTE The word “particle” is used here in a general sense including *fission fragments*.

2.7

burn-up life (of a neutron detector)

an 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

2.8

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. Useful life can be expressed in incident particle *fluence*, number of produced pulses, etc.

2.9

(particle) fluence rate (particle flux density)

increment of fluence $\Delta \Phi$ during a suitably small interval of time Δt divided by that interval of time

Symbol: φ

$$\varphi = \frac{\Delta \Phi}{\Delta t}$$

NOTE Fluence rate is identical with the product of the volume particle density and the average speed.

2.10

unperturbed neutron fluence rate (flux)

mean neutron fluence rate in a position without the neutron detector placed in the same position

2.11

perturbed neutron fluence rate (flux)

spatial mean neutron fluence rate in a position with the neutron detector placed in the same position for measurement. This quantity is equal to the detector output divided by its sensitivity and is, in practice, approximated by the neutron fluence rate averaged over the detector surface

²⁾ In many applications where the detector has a linear characteristic and negligible output for zero input

$$S = \frac{\text{output quantity}}{\text{input quantity}}$$

3 Interpretation of this standard

The verbs listed below have the following implications in this standard:

Mandatory: “shall” or “must”.

Recommendation: “should”.

Permissible: “may”.

Section 2. Preliminary

4 General

Although each category of detector and each type of apparatus has its own particular conditions of use and range of application, it is possible to define general principles of use which depend essentially on the following:

- a) the intrinsic characteristics of each type of detector;
- b) the limitations resulting indirectly from the quantity measured, e.g. activation of the materials by neutrons;
- c) the measuring sub-assembly used, the characteristics of which must be suited to those of the detector;
- d) the characteristics of the medium surrounding the detector and particularly the influence quantities.

The mode of use of the ionization produced must be defined: the pulse mode, the direct current mode and the mean square or variance current mode are examples.

If detectors are operated in more than one mode, their characteristics shall be given for each mode.

5 Types of radiation to be measured

The two principal types of radiation to be measured are neutrons and photons. They are represented by neutron fluence rate (flux) in the first case and by either the absorbed dose rate or the exposure rate in the second case.

Each detector is preferably constructed to measure one single kind of radiation but it is almost always influenced by other radiations which surround it. This means:

- the superposition on the measurement of a background which impairs accuracy and can reduce the range of measurement;
- if the influence of the concomitant radiation becomes significant, the radiation to be measured may be obscured. In particular, residual gamma radiation often impairs the measurement of neutrons.

All radiation in the detector environment has to be considered in the conditions of use. The characteristics may be altered by activation of the detector materials by neutrons, the release of heat by the absorption of radiation and therefore changes in material properties, or by other changes to the filling gas.

6 Detector operating conditions

Detectors placed in or near the core of reactors are subject to very stringent design regulations, particularly with reference to the materials used.

The variables which impose a limitation on the use of detectors should be specified together with their limits for each type of detector.

The significant variables, in general, are neutron fluence rate (flux) and spectrum, environmental temperature, pressure, humidity, etc.

7 Conditions of detector measurement

Measuring conditions are characterized mainly by the following:

- a large range of measurement (often of the order of six to ten decades);
- the severity of the ambient conditions due to high-flux values, a high intensity of concomitant radiation and high pressures and temperatures;
- the activation of materials, often resulting in replacement difficulties even when the reactor is shut down.

7.1 Limits due to the detector

For an ionization chamber, the upper limit of the measuring range is set by the rate of recombination of ions causing deviation from proportionality between the neutron fluence rate (flux) and the output signal. This upper limit of the measuring range may be determined by a specified deviation from proportionality for a given polarization voltage or by the output current at which a given ratio or difference between $U_{1.1}$ and $U_{0.9}$ is obtained (see Sub-clause 16.4.1).

For pulse detectors, an absolute upper limit to the measuring range is set by the resolving time of the detector together with its associated measuring assembly.

The intrinsic lower limit of the measuring range is determined by the output signal in the absence of the primary ionizing radiation under given ambient conditions.

It is desirable not to exceed a given value of the neutron fluence rate (flux) beyond which activation of materials would produce a gamma or beta background large enough to make subsequent low-level measurements difficult.

An important case is that of highly sensitive detectors used for reactor start-up (in particular boron trifluoride or boron-lined counter tubes) where the activity of materials may be prejudicial to immediate re-use.

7.2 Limits due to the measuring sub-assembly

The limits due to the measuring sub-assembly are determined essentially by the resolving time, bandwidth, noise level and input impedance in the case of pulse measuring systems, and by the current sensitivity, drift, zero offset and input impedance in the case of current measuring sub-assemblies.

7.3 Limits due to surrounding gamma radiation

Frequently, the surrounding gamma radiation imposes a lower limit in the use of detectors. Gamma radiation generates spurious ionization current in current ionization chambers and modifies the counting plateau to give false counts in ionization pulse chambers. This limit can be lowered in neutron current ionization chambers by compensation, and in pulse fission chambers by reduction of the chamber and amplifier assembly resolving time. Improvements can also be made by suitably shielding the detector against gamma radiation.

In the particular case of boron current ionization chambers, the lower limit imposed by gamma radiation is relatively high. When the chambers are compensated, the lower limit of practical use can be calculated with the following relation:

$$\varphi_{\min} = \frac{f}{e} \frac{S_{\gamma}}{S_n} X$$

in which:

- $\varphi_{\min}$ = minimum neutron fluence rate (flux) measurable with the required accuracy
- e = required maximum ratio of the gamma current to neutron current expressed as a percentage (%)
- f = compensation factor expressed as a percentage (%)
- S_n = sensitivity of the chamber to neutron radiation in amperes per unit of neutron flux density ($A \cdot n^{-1} \cdot cm^2 \cdot s$)
- S_{γ} = influenceability of the chamber to gamma radiation without compensation, in amperes per unit of exposure rate ($A \cdot R^{-1} \cdot h$)
- X = exposure rate ($R \cdot h^{-1}$)

In some designs, the compensation factor can be changed, for example by adjusting the compensation voltage.

The compensation factor can depend on the intensity of the radiation γ and its energy spectrum. The compensation should therefore allow for variation in conditions with respect to the gamma radiation source and the source to detector geometry.