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Development of a gamma compensated boron lined ionisation chamber for reactor safety and control applications

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Abstract

Boron lined ionisation chambers with an overall diameter of 85 mm and maximum length of 165 mm have been developed and tested. The chamber consists of 34 numbers of parallel plate aluminium electrodes spaced at a distance of 2 mm and mounted on SS rods and radiation resistant polyetheretherketone (PEEK) spacers. One surface of the signal electrode and both the surfaces of the +HT electrodes are dip coated with boron. It is filled with nitrogen gas at a pressure of 128 cm of Hg. Tests at the ^{60}Co source facility at gamma fields ranging from 200 R/h to 830 kR/h showed that the chamber required 500 V to obtain 90% of the saturation current at 830 kR/h. The gamma compensation factor was measured as 0.12–7% for various gamma fields for polarising voltages of +400 and −350 V. Neutron measurements at the Apsara Thermal Column showed that the linearity of the chamber response as a function of reactor power was within 2%. The neutron sensitivity was measured as 3.9 fA/nv.

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1. Introduction

Ionisation chambers with their electrodes coated with enriched ^{10}B isotope are used in out-of-core reactor location to monitor neutron flux and provide on-line information of reactor power for the control and safety of reactors [1–3]. These detectors respond to both neutrons and gamma rays. Most of the gamma radiation is proportional to the instantaneous reactor power. However, radiation due to long-lived fission products, radioactive neutron capture that leads to the formation of long-lived activation products is not indicative of the prompt neutron flux. This delayed component of the signal generated by gamma rays does not represent reactor power. Thus, to derive signals proportional to the neutron flux and eliminate gamma-induced currents, gamma compensation is employed.

A gamma compensated boron lined neutron chamber consists of three cylindrical aluminium electrodes mounted coaxially on a central support rod (Fig. 1). The inner diameter of the +HT electrode and outer diameter of the signal electrode are coated with enriched ^{10}B, which detects thermal neutrons by means of the ^{10}B(n,α) reaction. The sensitive volume between the +HT electrode and the signal electrode is neutron sensitive as well as gamma sensitive while the sensitive volume between the signal electrode and the −HT electrode is gamma sensitive. When the chamber is exposed to pure gamma radiation, currents are generated in the outer and inner volumes. By applying voltages of opposite polarity to the two sections of the chamber the unwanted gamma signal is cancelled out. The volumes in the two sections are adjusted very carefully to achieve compensation of the order of 95–97% and to avoid overcompensation. Gamma compensation factor is defined as $(I_{n\gamma}-I_{\gamma\gamma})/I_{n\gamma}$, where $I_{n\gamma}$ and $I_{\gamma\gamma}$ are the gamma currents generated in the outer and inner volumes, respectively. For a well-designed detector, this factor should remain unchanged up to gamma exposure rates of the order of 1000 R/h.

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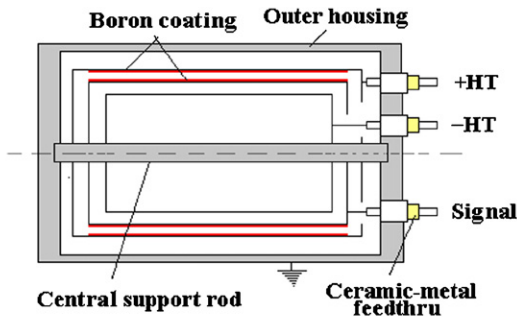

Fig. 1. Schematic diagram of gamma compensated boron lined ion chamber.

Electronics Division, BARC, has been carrying out development of these devices. Presently, these devices for reactor instrumentation are being developed using cylindrical electrodes and polyetheretherketone (PEEK) spacers [4]. To enhance the neutron sensitivity without significantly altering the chamber dimensions, a gamma compensated ^{10}B lined ion chamber with parallel plate electrode geometry and PEEK spacers was developed. The paper describes the design, mechanical construction and tests performed on the gamma compensated neutron detector.

2. Design

In boron-coated ionisation chambers, the current output range is limited by lack of saturation at high currents and by the gamma radiation background at the lower neutron flux levels. The chamber design was oriented toward good saturation characteristics and optimisation of neutron to gamma sensitivity ratio and was based on the following considerations. Since the chamber is used to measure neutron flux from 10^4 to 10^9 nv, it should have adequate neutron sensitivity at lower levels and should saturate at the highest level of neutron flux. Neutron sensitivity depends on the number of boron atoms while the saturation characteristics of the ion chamber depend on the electrode spacing. The current I in an ionisation chamber is given by

$$I = \frac{eN\sigma\varphi fE}{w}. \tag{1}$$

Here e is the charge of an electron, N is the number of boron atoms, σ is the neutron cross-section, φ is the neutron flux, f is the efficiency of the reaction, E is the energy of the reaction products and w is the energy required to produce an ion pair. The overall detector dimensions are chosen to suit the maximum space available at the reactor location. The diameter and length of the ion chamber was chosen as 85 and 165 mm, respectively. Since the current in an ionisation chamber depends on the number of boron atoms and hence the coated area, to achieve maximum neutron sensitivity within the dimensions of the chamber, the maximum diameter of the electrodes and the sensitive length of the electrodes was chosen as 50 and 110 mm, respectively. The range of alpha and lithium particles emitted in the ^{10}B(n,α) reaction is 7mm and 4.3 mm, respectively, in standard air. Hence in an ion chamber containing standard air with boron on the wall, all the ionisation must occur within 7 mm of the wall. Since not all of the reaction products emerge from the surface of the boron coating, maintaining smaller electrode spacing is advantageous as it generates a smaller gamma current and requires lower voltage to saturate. It has been reported in literature that if the electrode spacing were only half of 7 mm, the loss of ionisation would be limited to 10% [5]. In the present design, an electrode spacing of 2 mm and a fill gas pressure of 128 cm of Hg is chosen to achieve maximum discrimination against gamma background, to obtain complete ionisation (saturation) at the maximum neutron flux with minimum voltage and maximum signal from the reaction products.

3. Expected gamma and neutron sensitivity

From the definition of Roentgen, 1 cm^3 of air or 0.001293 g of air at normal temperature and atmospheric pressure when exposed to 1 R/h of gamma radiation produces a current of 10^{-13} A. Hence, for the ion chamber having a sensitive volume of 80 cm^3 at a pressure of 128 cm of Hg of nitrogen gas, the expected uncompensated gamma sensitivity is calculated as $I_\gamma = (10^{-13} \times 80 \times 128)/76 = 13.5$ pA/R/h. Similarly, substituting the values of e (1.6×10^{-19} C), N (2.5×10^{22}), σ (1555×10^{-24} cm^2), φ (1 nv), f (0.04), E (1.47×10^6 eV) and w (33 eV) in Eq. (1), the neutron sensitivity workout to be 11 fA/nv.

4. Mechanical construction and assembly

The detector consists of 34 aluminium circular parallel plates of 40 and 50 mm diameter mounted on nine 4-mm diameter stainless steel rods. The rods are supported at either end by suitably machined PEEK spacers, which insulate the electrode assembly from the end plates and also eliminate the extra-cameral volume at the ends of the electrodes. The smaller diameter plates are used as the signal electrodes while the larger diameter plates are the +HT and −HT electrodes. One side of the signal electrode and both the sides of the +HT electrodes are dip coated with boron. Fig. 2 shows the sequence pattern of the discs and the photograph of the assembly is shown in Fig. 3. The entire assembly is placed in an aluminium enclosure and filled with nitrogen gas. The main specifications of the chamber are given in Table 1.

5. Performance tests

5.1. Gamma sensitivity and gamma compensation factor measurements

To assess the gamma sensitivity and gamma compensation factor the ion chamber was tested at the ^{60}Co