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# Development of an inconel self powered neutron detector for in-core reactor monitoring

M. Alex*, M.D. Ghodgaonkar

*Electronics Division, BARC, Mumbai, India*

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**Abstract**

The paper describes the development and testing of an Inconel600 (2 mm diameter × 21 cm long) self-powered neutron detector for in-core neutron monitoring. The detector has 3.5 mm overall diameter and 22 cm length and is integrally coupled to a 12 m long mineral insulated cable. The performance of the detector was compared with cobalt and platinum detectors of similar dimensions. Gamma sensitivity measurements performed at the $^{60}Co$ irradiation facility in 14 MR/h gamma field showed values of $-4.4\times10^{-18}$ A/R/h/cm ($-9.3\times10^{-24}$ A/$\gamma$/cm$^2$-s/cm), $-5.2\times10^{-18}$ A/R/h/cm ($-1.133\times10^{-23}$ A/$\gamma$/cm$^2$-s/cm) and $34\times10^{-18}$ A/R/h/cm ($7.14\times10^{-23}$ A/$\gamma$/cm$^2$-s/cm) for the Inconel, Co and Pt detectors, respectively. The detectors together with a miniature gamma ion chamber and fission chamber were tested in the in-core Apsara Swimming Pool type reactor. The ion chambers were used to estimate the neutron and gamma fields. With an effective neutron cross-section of 4b, the Inconel detector has a total sensitivity of $6\times10^{-23}$ A/nv/cm while the corresponding sensitivities for the platinum and cobalt detectors were $1.69\times10^{-22}$ and $2.64\times10^{-22}$ A/nv/cm. The linearity of the detector responses at power levels ranging from 100 to 200 kW was within $\pm5\%$. The response of the detectors to reactor scram showed that the prompt response of the Inconel detector was 0.95 while it was 0.7 and 0.95 for the platinum and cobalt self-powered detectors, respectively. The detector was also installed in the horizontal flux unit of 540 MW Pressurised Heavy Water Reactor (PHWR). The neutron flux at the detector location was calculated by Triveni code. The detector response was measured from 0.02% to 0.07% of full power and showed good correlation between power level and detector signals. Long-term tests and the dynamic response of the detector to shut down in PHWR are in progress.


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## 1. Introduction

The safe and economic operation of a large power reactor with a distributed core configuration requires the continuous on line measurement of neutron flux levels at various locations within the core [1]. For a large reactor like the 540 MW Pressurised Heavy Water Reactor (PHWR) local power perturbations may result due to xenon induced local power oscillations. These may not be detected by an out-of-core ion chamber since out-of-core ion chambers detect only the leakage fluxes, emerging out of the reflector zones and not the integrated power profile within the core, which is the true representation of neutron thermal power produced in the core. To assess the reactor core power based on in core measurements, self-powered neutron detectors (SPDs) are used. They are simple, rugged and relatively inexpensive devices ideally suited for in-core neutron flux measurement [2,3].

The sensing material in a self-powered detector is an emitter from which electrons are emitted when exposed to radiation. These electrons penetrate the thin insulation around the emitter and reach the outer sheath without polarising voltage. Some electrons are emitted from the insulator and sheath also. The net flow of electrons from the emitter gives rise to a DC signal in an external circuit

*Corresponding author. Tel.: +91 22 2559 5060.
*E-mail address:* maryalex@barc.gov.in (M. Alex).

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between the emitter and sheath, which is proportional to the incident neutron flux. Rh and V SPDs work on the basis of (n, $\beta$) reaction and are used for flux mapping while Co and Pt SPDs work on the basis of (n, $\gamma$–e) prompt reaction and are used for reactor control and safety. However, the build-up of the $^{60}$Co and $^{61}$Co gives rise to background signal in the cobalt detector thereby reducing the useful life [4]. In the case of the platinum detector, the detector responds to both reactor neutrons via (n, $\gamma$, e) interaction and reactor gamma rays via ($\gamma$, e) interaction. Since the neutron sensitivity varies with irradiation as a result of burn up while the gamma sensitivity remains the same, the dynamic response of a mixed response detector varies with time. This mixed and time-dependent response of platinum SPD gives rise to anomalous behaviour in some situations [5,6]. Development of SPDs with Inconel emitters as alternative to Co and Pt prompt SPDs has been reported in literature [7]. The present paper describes the design, development and performance of an Inconel self powered neutron detector.

## 2. Detector design

The detector (Fig. 1) consists of a 2 mm diameter × 21 cm long Inconel 600 emitter wire surrounded by a high purity alumina ceramic tube (2.2 mmID × 2.8 mm OD). The assembly is enclosed in a 3 mmID × 3.5 mm OD Inconel600 tube.

One end of the emitter is coupled to the conductor of a 2 mm diameter × 12 m long twin core mineral insulated (MI) cable while the detector sheath is laser welded to the MI cable sheath. The detector is integrally coupled to the MI cable and the cold end of the cable is sealed by a twin core ceramic-to-metal seal over which a Lemo connector is fitted. For comparing the performance of the Inconel detector, cobalt detector of similar dimensions and platinum detector of smaller length were developed. The specifications of the detectors are given in Table 1.

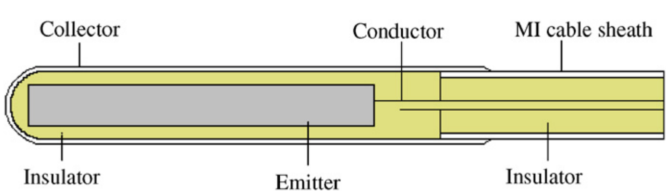


Fig. 1. Schematic diagram of self powered neutron detector.

## 3. Performance tests

### 3.1. Measurement of gamma sensitivity of SPNDs

The gamma sensitivity of the detectors was measured in pure gamma field using $^{60}$Co source facility. The detectors were placed at a distance of 1 m from the source for better source to detector geometry and 1 m above the ground to minimise background from scattered rays.

To estimate the gamma field at the detector location, a miniature gamma ion chamber (6 mm diameter and 25 mm long) developed by M/s ECIL, Hyderabad was used. The chamber was initially calibrated at the HIRUP $^{60}$Co Gamma Cell in gamma field of 0.125 MR/h. The accuracy of the gamma field measured by Fricke Dosimeter by the Radiation Safety Systems Division, of BARC was within ±5%. The chamber was installed in the Gamma Cell and the cold end of the chamber cable assembly was connected to variable (0–100 V) power supply. The signal was measured using Keithley 614 electrometer amplifier. The voltage was varied from 10 to 100 V and the $V/I$ characteristics of the chamber were measured. Fig. 2 shows the saturation characteristics of the chamber.

The gamma current at 100 V was measured to be 3.1 nA. The gamma sensitivity ($S_\gamma$) of the miniature gamma ion chamber was calculated using the formula

$$S_\gamma = I_\gamma/\varphi_\gamma. \quad (1)$$

Here $I_\gamma$ is the saturated current measured to be 3.1 nA and $\varphi_\gamma$ is the gamma field $= 0.125 \times 10^6$ R/h, hence

$$S_\gamma = 3.1 \times 10^{-9}/0.125 \times 10^6 = 24.8\,\text{fA/R/h}.$$

This value of gamma sensitivity was used to determine the gamma field at the self-powered neutron detector location. The three SPNDs were tested together with the miniature gamma chamber in a 200 kCi $^{60}$Co source facility. Each of the detectors was coupled to the Keithley614 electrometer amplifier and the signal was measured. For the ion chamber, $V/I$ characteristics was measured (Fig. 3) and the ion chamber measured 0.35 μA at saturation voltage of 100 V.

Using the gamma sensitivity value of 24.8 fA/R/h established for the gamma chamber, the gamma field ($\varphi_\gamma$) was calculated to be 0.35 μA/24.8 fA/R/h = 14 MR/h. The signal ($I_\gamma$) for the various detectors in the presence of 200 kCi $^{60}$Co source at a distance of 1 m from the

Table 1
Main specifications of the detectors

| Detector | Emitter dimensions | Outer housing | Coaxial MI cable |
|---|---|---|---|
| Inconel SPD | Inconel600<br>2 mm diameter × 21 cm | Inconel600<br>3.5 mm diameter × 22 cm L | Twin core<br>2 mm diameter × 12 m L |
| Cobalt SPD | Cobalt<br>2 mm diameter × 21 cm | | |
| Platinum SPD | Platinum<br>2 mm diameter × 5 cm | Inconel600<br>3.5 mm diameter × 6 cm L | |