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Nuclear Instruments and Methods in Physics Research B 262 (2007) 65–68

NIM B
Beam Interactions with Materials & Atoms

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Flux measurements in a nuclear research reactor by using an aluminum nitride detector

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Received 7 February 2007; received in revised form 24 April 2007
Available online 8 May 2007

Abstract

A small polycrystalline aluminium nitride detector with a thickness of 381 μm was used to measure a 200,000 Ci Co^{60} source and to measure the flux in a research reactor where the neutron flux is about $10^{14}/cm^2$ s, which is nearly the same order as in the commercial power plant. If the applied voltage is greater than or equal to 2000 V and if the measurements are done in a short period of time so that the heat energy does not build up in the aluminium nitride, then the measured electric current is linearly proportional to the input flux. It is assumed of course that the energy spectrum of the input flux remains constant. This linearity relation is illustrated by the results of a measurement in which the reactor power has been controlled so that the flux becomes a step function.

PACS: 83.85.Hf; 87.50.Gi; 87.52.−g

Keywords: Flux detector; Aluminum nitride; Research reactor; Irradiation facility; Flux measurement; EGS4 calculations

1. Introduction

There have been many studies on solid state neutron detectors based on natural diamond [1,2], silicon wafers [3], cadmium–zinc–telluride, and scintillators such as BGO. The neutron sensitivity or the gamma sensitivity of the particular solid state detectors has been studied. Ndoye et al. [4] studied a detector using 0.15 mm thick LiF as the depletion layer for the neutrons of energies in the range 0.5 eV to 500 keV to show that a threshold energy higher than 600 keV and lower than 2.05 MeV is necessary for the rejection of the gamma sensitivity. For better estimates of nuclear power in a reactor it is desirable that the detector rejects as many of the pulses due to the gamma particles as possible since the response of the gamma particles to the power change is much slower than that of the neutrons.

In our earlier study [5], we performed MCNP4B and EGS4 calculations to determine the range of an optimal thickness for the aluminum nitride so that the number of gamma pulses is relatively small compared with the number of neutron pulses. If the thickness is below 250 μm then the ratio of the pulses would be less than 1%, assuming that only pulses of height greater than 750 keV are taken. As the aluminium nitride is made thinner the cut-off energy level can be reduced to keep this ratio below 1%. For example, if a thickness of 100 μm is used instead of 250 μm, then the ratio can be kept below 1% with the energy level reduced to 350 keV. A thickness of 250 μm or less, however, is not practical due to its lack of mechanical strength.

In a previous study [6] we used aluminium nitride detectors of size 3 mm × 3 mm × 0.635 mm to measure the neutron flux at a beam port (IR port) of the Hanaro reactor where the neutron flux is about $10^9/cm^2$ s. We counted

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doi:10.1016/j.nimb.2007.04.285

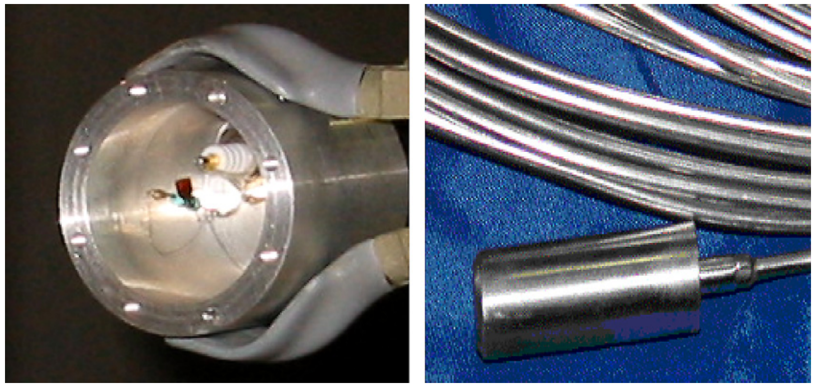

Fig. 1. AlN in a holder (Left) and encapsulated (Right).

about 960 pulses/s on average. Considering that the neutron flux in commercial nuclear power plant ranges up to $10^{15}/\mathrm{cm}^2\,\mathrm{s}$, this result indicates that the aluminum nitride detectors can be used to measure the ex-core power level of the PWR nuclear power plant when the power is in the range of about 0.001% of the rated power.

In this paper, we study the linearity of the relation between the electric current measured by an aluminum nitride detector with a thickness 381 μm and the input neutron or gamma flux. We started with measurements of the 187 Ci Co^{60} source at the Korea Atomic Energy Research Institute (KAERI). This gamma source is chosen since the flux can be controlled easily, i.e. changed in a stepwise programmed fashion. Then we measured the highest gamma flux using the 200,000 Ci Co^{60} source at another irradiation facility to see how the linearity extends to a large flux. Finally, we measured the full range of the neutron flux with gamma radiation included inside the cold neutron source hole (CNS hole) of the Hanrao research reactor [7] at KAERI where the neutron flux is about $0.6 \times 10^{15}/\mathrm{cm}^2\,\mathrm{s}$ during its full power operation. The reactor power was increased in a stepwise manner and the electric current generated by the aluminum nitride detector shown in the right side picture of Fig. 1 was measured.

2. High gamma flux measurements and linearity

The aluminum nitride sensor shown in the middle of the left picture in Fig. 1 was repeatedly cleaned in an ultrasonic cleaner with 2-PROPANOL (purity 99.5%), baked in a vacuum oven for over 24 h, and molded by epoxy resin to reduce the surface current. Then, we installed a 10 MΩ resistance to the sensor to protect it from the electric shock when a high voltage is applied to it, and put the sensor into a holder as shown in the left picture of Fig. 1. The insulation resistance of the sensor was measured to be about 10^{15} Ω. Hence, when the surface current or the leakage current is measured with 1000 V applied, we obtain about 1 pA as the average current with the standard deviation of 0.35 pA as shown in Fig. 2. The detector shown in the right picture of Fig. 1 was used for in-core flux measurements.

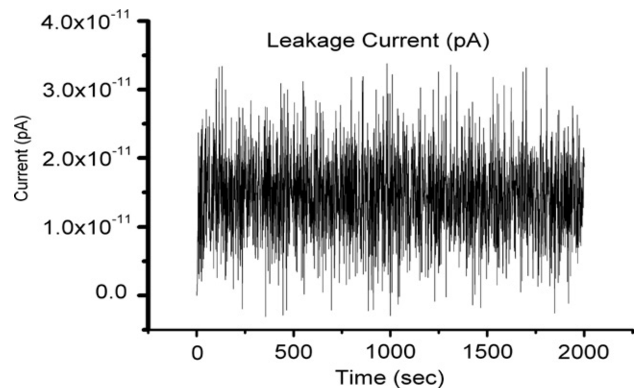

Fig. 2. Leakage current of the sensor with 1000 V applied.

To check the linearity of the sensor response to the flux increase, we measured the gamma flux from a 187 Ci Co^{60} source where the pencil-shaped source could be programmed to move up and down automatically. Table 1 shows a summary of the measured values at 6 different dose rates while Fig. 3 shows the results in a graphic form, along

Table 1
Linearity of the aluminum nitride sensor response

Rad/h	1200	2400	4800	0.78×10^5	1.45×10^5	3.10×10^5
Current (nA)	2.1	4.4	9.1	104	162	255

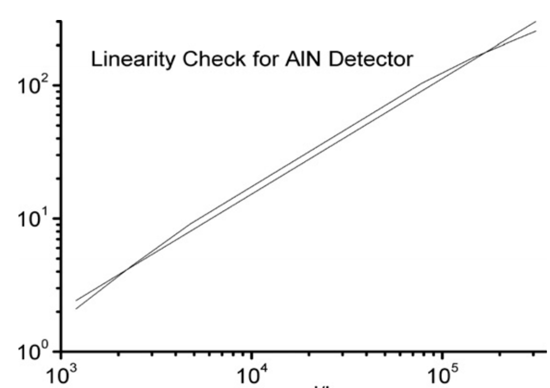

Fig. 3. Measured current versus a linear fit for Co^{60} flux measurement.