A FULLY ENCAPSULATED DIRECTIONAL SELF-POWERED
GAMMA RAY DETECTOR FOR USE IN IN-CORE
NUCLEAR REACTOR MEASUREMENTS

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Summary

A study of a fully encapsulated directional self-powered gamma ray detector designed for localized in-core measurements in a nuclear reactor was conducted. The detector consisted of a multilayer arrangement of a metal-dielectric-metal-dielectric-metal structure. The dielectric material was made of two plates of unequal thicknesses which were placed on opposite sides of the central metal plate. The direction discrimination exhibited by the detector was attributed to the combined effect of electron ranges, Photo-Compton electron generation rates, and the presence of E-fields in the unequal thicknesses of dielectric material. Results showing the response of the detector when it was placed in a gamma ray field with a known anisotropic component are presented.

Introduction

As part of in-core reactor monitoring systems, self-powered detectors are being used in an increasing number of reactors. Since these radiation monitors are operated without any applied voltage they tend to be reliable and resistant to radiation damage. Even though they can be constructed in several configurations, they are normally coaxial in design with the emitter as the central electrode. The collector in the coaxial configuration is the sheath, and the two are electrically separated by a mineral insulating material. The choice of emitter material (typically Rh, V, Co, and Pt) determines the type of radiation to which these devices are most sensitive. If the emitter is constructed using Rh, V, or Co, the detector will be primarily sensitive to neutrons. In the case of an emitter which makes use of Pt, the detector will be neutron and gamma sensitive. A coaxial gamma sensitive self-powered detector must have an emitter composed of a material which has a low neutron capture cross section, large atomic number and high density.

In this paper a different kind of gamma sensitive self-powered detector (SPD) is discussed. The central electrode in the present detector design acts both as an emitter and collector of electrons. The insulation of the detector reported on in this report is an integral part of the design and, together with the sheath and collector, makes up an SPD that is gamma sensitive with directional characteristics. The current-producing mechanism and the directional characteristics will be discussed and experimental results presented showing the relative directional discrimination of the detector when exposed to an asymmetrical gamma field.

Discussion of Design and Operation of the Detector

Both calculations^{1,2} and experimental³ results have demonstrated that when a metal-insulator-metal multilayer structure is placed in a gamma radiation field the measured electrical response is strongly dependent on the geometry of the structure, the existence or non-existence of an applied bias, E-fields developed at interfaces, the relative resistance of the multilayer structure and the energy spectrum of the incident gamma rays. Making use of the geometrical influence

on the measured response of such a system, a metal-insulator-metal-insulator-metal slab (plate) arrangement can be found that exhibits directional sensitivity. A schematic drawing of a multilayer metal and insulator system is shown in Fig. 1. The thicknesses of each of the components of the detector used in the experimental measurements are shown in Fig. 1. The BeO, nickel, and stainless steel plates surrounding the structural elements of the detector were all ~ 6.5 cm² in cross-sectional area.

Figure 1. Schematic of one directional gamma ray detector using BeO insulators.

In order to simulate an evacuated encapsulated detector, this system was placed in a vacuum where vacuum pressure of <10 millitorr could be maintained throughout the experimental measurements.

The thickness of the insulator slabs and the collector were chosen on the basis of the known energy distribution of fission gamma rays and the corresponding average energy distribution of photoelectric and Compton electrons produced by photon interactions in the sheath, the dielectric, and the collector.

Operation of the Detector

The thickness of the nickel central electrode is chosen such that it is essentially transparent to incident photons with an energy greater than 80 KeV and electrons with an energy greater than 50 KeV. Hence, the nickel electrode is most effective as a collector of low energy electrons and as an emitter of electrons when subject to low energy gamma rays.

The net difference in the number of electrons produced in the central electrode and the number that come

to rest in it determines the polarity of the output current from the central electrode. Electrons arriving at the central electrode are emitted by the stainless steel sheath or one of the insulator slabs. Thus, depending on the relative thicknesses of the two slabs of insulator materials, the detector can be made to be more sensitive to electrons produced by photons incident on the detector from the 180° orientation than from the 0° orientation, thereby giving the device directional sensitivity.

Experimental measurements for two detectors identical in every respect except in the choice of insulator materials are presented below.

Experimental Measurements

In the experimental measurements, the dimensions of the various slabs were as given in Fig. 1. Several measurements were made in which the BeO was replaced by lucite slabs of equal thicknesses. During these tests the detector package was housed in a dynamically pumped vacuum tube. The detector was positioned in a graphite pit near the leakage face of the Argonne Thermal Source Reactor (ATSR) along with a 155 gm ^{235}U strip whose purpose was to provide an intense anisotropic gamma ray flux at the detector. This known gamma ray source was superimposed on the gamma ray background in the pit due to the ATSR. The enriched ^{235}U strip was traversed in front of the detector within the graphite pit of the ATSR as indicated in Fig. 2. At the traverse center

Figure 2. Schematic showing the locations of the uranium strip fission gamma source and detector in the graphite pit of the Argonne Thermal Source Reactor (ATSR)

the ^{235}U strip is directly in front of the detector and 9.0 cm distant from its center, while at the traverse extremes, where the uranium strip is displaced by ± 14 cm, the angular displacement of the strip with respect to the detector is $\sim 60^\circ$. The experiments were conducted with the ATSR operating at 3 kW. The thermal neutron flux at the ^{235}U strip was $\sim 6.0 \times 10^9 \text{ n/cm}^2\cdot\text{s}$ and $1.5 \times 10^{10} \text{ } \gamma/\text{cm}^2\cdot\text{s}$.

A second detector which utilized lucite as insulation material was also placed inside the vacuum tube. The central electrodes of both devices were connected to separate current measuring electrometers. Cable currents were measured by a third coaxial cable which was exposed to the same radiation environment as the detector signal cables.

A measurement in which the uranium strip is moved in front of the detector is referred to as a traverse measurement. During a traverse measurement the detector is held stationary in one of two fixed angular positions. These two positions shall be referred to as the 0° and 180° positions. The 0° and 180° positions corresponded to the source (at traverse center) facing the thick and thin dielectric side of the detector, respectively (see Fig. 1).

The results of traverse measurement for the BeO insulated detector are shown in Fig. 3. The data in Fig. 3 are corrected for cable currents which were small and essentially independent of the position of the source. The data, however, were not corrected for linear drift of the signal with time, as is evident from the results in Fig. 3. The drift is presumably due to polarization effects in the insulators.

Figure 3. Response of the multilayer gamma ray detector using BeO as the insulating material to a traverse of the uranium strip source across the graphite pit.

The positive polarity of the current from the central electrode implies that in both 0° and 180° orientations the number of electrons knocked off the central electrode exceeds the number absorbed by it. In the 180° orientation the detector shows a strong response to the traverse of the source across the graphite pit, while in the 0° orientation the response is relatively weak. The maximum response occurs when the source is at closest approach to the detector.

Figure 4 shows the results obtained when the lucite insulated detector was exposed to the fission gamma source. While the overall response of the lucite detector is similar to that obtained with the BeO insulators, the 180° orientation output current is negative in polarity, reflecting an increased number of electrons diffusing through the thin dielectric and coming to rest in the central electrode. The lucite insulated detector's results are similar to that obtained by Pigneret and Stroback⁴ for a multilayer detector exposed to a pulsed x-ray source. In their experiment, the thin and thick insulators are made of polyethylene. When the source is replaced with a lead strip of the same height and width, and a thickness calculated to have the same gamma absorption as the uranium strip, some anisotropy remains. The difference in the current levels observed in the 0° and 180° orientations with the lead strip in place is attributed to an anisotropy in the gamma flux in the graphite pit.

Figure 4. Response of the multilayer gamma ray detector using lucite as the insulating material to a traverse of the uranium strip source across the graphite pit of the Argonne Thermal Source Reactor (ATSR).

The dynamic character of the BeO insulated monitor was estimated by increasing the ATSR's power level at different rates up to power levels of 1.0 and 3.0 kW, and then scrambling the system once the desired power level was reached. Time constants of between 5 and 10 seconds were measured, with the fastest response time occurring after the reactor was scrambled while at a power level of 3 kW. Since the time constant of the detector is roughly given by the ratio of the dielectric constant to the conductivity (i.e., ϵ/σ), which decreases with increasing radiation intensity, one can expect the response of the detector to be much faster in a more intense gamma flux. By extrapolating to large power reactors, time constants of the order of milliseconds or less are estimated for a detector of the present design, assuming a flux of $\sim 10^{13}$ n/cm²/sec.

Conclusions

These results suggest that a directional detector with solid dielectric material can be constructed which would enhance the sensitivity of an in-core detector to information emanating from selected regions of a reactor's core. Measurements indicate that the degree of directional discrimination is a function of: (a) the relative thickness of the dielectric material on the opposite sides of the central electrode and (b) the incident gamma energy spectrum. The dynamic characteristics of the BeO insulated detector were examined in the ATSR's graphite pit. The response of the detector to a reactor scram after the output had stabilized at 1 or 3 kW demonstrated the dependence of the system's time constant on the level of radiation intensity at the detector.

It is clear that more research is required concerning the relationship between dielectric slab thicknesses and density, the thickness of the central electrode and the effect of the atomic number of the sheath and central electrode on the directional sensitivity of the detector.

References

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