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FOR IN-CORE FUEL MOTION MONITORING

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DEVELOPMENT OF A DIRECTIONAL GAMMA RAY DETECTOR FOR IN-CORE FUEL MOTION MONITORING*

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Summary

In-core detectors should have wide application in the reactor safety program. A detector development program has been underway at Argonne National Laboratory to provide in-core detectors which are either neutron or gamma sensitive. The present paper describes one of the detectors under consideration for in-core fuel motion monitoring. It is gamma sensitive and has been tested in the core region of the Argonne Research Reactor (CP-5). The detector performed well over a 5-week period and yielded a directional discrimination factor, front to back, of 10 to 1, in good agreement with earlier tests conducted using a low power reactor and a radium source.

Introduction

In a number of experiments in the national reactor safety program it is planned to study the dynamics of fuel meltdown. It is essential that the fuel motion which occurs during these tests be monitored in order to extrapolate from the experimental tests to an actual meltdown in a full size core. Various types of detection methods have been proposed, both ex-core and in-core. The detector described in this paper is an in-core gamma detector with directional sensitivity and with the capability of rejecting the low energy component of the gamma spectrum. The directional sensitivity is highly desirable since the test section containing the fuel to be melted down is placed in the core of a nuclear reactor. As a result the detector must be capable of observing changes in the gamma flux from the test section in the presence of a large background flux from the reactor core. The discrimination against the low energy component is necessary because the very low energy gamma rays and x-rays do not contain the same degree of directional information as the high energy gamma rays.

Detector Description

The effort to date has been concerned with investigating the characteristics of a detector with a flat plate electrode consisting of a plate of graphite with a thin layer of lead on one side. The electrode is contained in an evacuated tube which itself is surrounded by a thin layer of lead. The principle of operation of the detector is based on the experimental observation that the production of electrons by gamma rays incident on a material is more strongly peaked in the direction of the incident gamma ray for low atomic number materials than for high atomic number materials.^{1,2} Figure 1 shows an example of this effect for 1 MeV gamma rays incident on carbon and lead. The interaction of the gamma rays with the carbon and lead produces a current of secondary electrons from each material. The arrows attached to the slabs of carbon and lead give the relative intensity of the electrons emitted in the direction of the incident gamma ray and in the direction opposite to the direction of the incident gamma ray. The ratio of this forward to backward electron emission is much

Fig. 1. Schematic showing the relative intensity of forward and backward secondary electron emission induced by the passage of 1 MeV gamma rays through thin slabs of carbon and lead.

greater for carbon than for lead. An electrode made up of a layer of lead bonded to a layer of graphite would exhibit a directional asymmetry in its detection efficiency, with the total electrode current reaching a maximum when the gamma rays were incident normally on the lead face of the electrode. Lead and graphite were chosen as the two materials because they are not only very high and very low atomic number materials, but also have low activation cross sections for thermal neutrons.

ATSR Measurements

The majority of measurements were carried out in the graphite pit of the Argonne Thermal Source Reactor (ATSR). The detector was placed near the wall of the pit closest to the reactor core, near the center line, and centered with respect to the width of the pit. In order to provide a movable source of gamma rays, a metallic strip of enriched uranium 1 in. wide and 12 in. high was placed against the wall adjacent to the detector. The vertical strip of uranium served as a line source of gamma rays and, as such, was a good simulation of a vertical fuel bundle in the proposed meltdown experiments. In one type of measurement to simulate fuel motion, the detector was kept fixed in angular position and centered with respect to the width of the graphite pit, and the uranium strip was moved back and forth across the width of the pit. These are referred to as traverse measurements. A schematic of the top view of the graphite pit is given in Fig. 2. The dashed line shows the traverse path of the uranium strip. The detector was positioned approximately 7 cm from the traverse line. With the geometry shown the uranium strip covered the angular range of the detector from approximately -60 deg to +60 deg when the strip was moved from 17 cm to the left of the detector to 17 cm to the right of the detector. Figure 3 gives the results of two such measurements, one labeled 180 deg for which the

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Fig. 2. Top view of the graphite pit of the Argonne Thermal Source Reactor showing locations of the detector and converter strip.

Fig. 3. Typical results of a traverse measurement in the graphite pit of the Argonne Thermal Source Reactor.

lead side of the electrode faces toward the traverse line of the uranium strip, and one labeled 0 deg for which the lead side faces away from the traverse line. It is apparent from the figure that the response to fuel motion in the 180 deg orientation is much greater than the response in the 0 deg orientation. The background has been subtracted in Fig. 3. The background is defined as that signal the detector would measure if the uranium strip were removed. The remaining signal is about half of the background signal.

Since the ATSR provides a mixed flux of neutrons and gamma rays, the detector response was also measured using a radium source facility. The detector was placed approximately 2.75 in. from a 1 in. diameter radium source and measurements were made with the detector at various angles from 0 to 180 deg. The best results were obtained with 0.20 in. of lead

bonded to 0.125 in. of graphite as shown in Fig. 4. The background has not been subtracted for the data in Fig. 4. The front to back ratio of the detector

Fig. 4. Typical results of a rotation measurement using a 1 curie radium source.

was approximately 20 to 1 with the response beyond 90 deg in either rotation essentially constant at 5 to 10% of the response at 180 deg. The source used was actually a radium-beryllium source, but since there were approximately 30,000 gamma rays to every neutron the neutron effect on the detector was negligible. A measure of the detector sensitivity is that the signal induced in the lead graphite electrode by the 1 curie radium source was 0.4 picoamperes. The electrode dimensions were 1.27 cm wide by 5 cm long. The radiation field had a strength of approximately 100. roentgens/hour; so the detector sensitivity with the electrode described above is approximately 0.4×10^{-14} amperes/r/hr.

CP-5 Measurements

With the design parameters determined from the ATSR and radium source measurements, a detector was fabricated for tests in the core region of the Argonne Research Reactor (CP-5). A schematic of the core region of the CP-5 reactor is given in Fig. 5.

Fig. 5. Top view of the core region of the Argonne Research Reactor (CP-5).

The location chosen for the tests was at the core center line and a few inches outside the outer ring of fuel elements. At this location the total neutron flux was approximately 5×10^{13} neut/sec/cm². Because of the impracticality of continuous pumping on the detector, the detector was baked out and sealed with an activated charcoal getter inside to maintain a good vacuum. The design which was used is shown in Fig. 6. The graphite pieces bridging the space

Fig. 6. Cross section of one of the detectors used in the CP-5 tests.

between the central electrode and the outside containment tube were necessary to carry away the gamma heat produced in the central electrode. The detectors were inserted into vertical thimbles which extended into the heavy water surrounding the fuel elements. The outside of the detectors were forced air cooled. Thermocouples were attached to the detectors to monitor the temperature. A sufficient flow of air was maintained so that the temperature of the outside vacuum wall of the detectors did not exceed 104 deg centigrade. After an initial burning in period of less than one day the detector current stabilized and remained essentially constant for any given angular position for the duration of the tests. The results of a rotation measurement in CP-5 are given in Fig. 7. The front to back ratio is approximately 10 to 1, which is in good agreement with the

Fig. 7. Typical results of a rotation measurement with detector just outside the fuel element region of the CP-5 reactor.

results of the radium source measurement when consideration is given to the fact that the background has not been subtracted from the CP-5 data. The angular response of the gamma detector was measured repeatedly over a 5-week period and showed no deterioration during this period.

Conclusions

A detector has been developed for use as an in-core fuel motion monitor, which has the desired directional discrimination and energy discrimination characteristics. Measurements in the ATSR have demonstrated the directional discrimination of the detector, as well as its sensitivity to fuel motion. Tests were made in the CP-5 research reactor to demonstrate that the detector retained the same performance characteristics in a high radiation environment as in the relatively low radiation environment of the ATSR. The detector performed as expected over a 5-week period in-core in CP-5 with no deterioration in performance during this time.

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