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Design of a Multi-Layer-Type Neutron Monitor for Measuring Dose of Three Energy Groups

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A neutron monitor for measuring dose of three energy groups is being developed. The radiation quality factors that ICRP recommends differ among neutron energies. In order to evaluate neutron dose precisely, it is expected that the neutron fluence of each energy group should be measured. Therefore, we propose a measuring instrument with a three-layer configuration. A liquid scintillator (LS) is arranged at the center, while Li-6 glass scintillators (GS) are arranged in an external layer and interposed layer. Fast neutrons are detected by the LS, and low energy neutrons are measured by the GS of the outer layer. Other middle energy neutrons are measured by the GS of the inner layer. The configuration of external layer and interposed layer was discussed using MCNP. Boron nitride was placed as a neutron absorption material between the external layer and intermediate layer. As a result of this design, the outer and inner GS can measure low energy neutrons in the range of thermal neutrons to 10^{-2} MeV, and middle energy neutrons from 10^{-2} to 1 MeV, respectively.

KEY WORDS: neutron monitor, neutron dose, energy response, glass scintillator, liquid scintillator

I. Introduction

The conversion factor for neutrons from fluence to dose equivalent varies with their energies. REM counters are commonly used. However, these counters exhibit a large error for dose conversion in the intermediate energy range, since the fluence to dose conversion factor differs with the detector response, especially in this energy range[1-4].

Therefore, we proposed an instrument for measuring neutrons in three energy groups--low, intermediate, and fast neutrons--which have multi-layer configurations[5]. This monitor is capable of a threefold detection for neutrons. The first detection layer in the most outer layer is for measuring neutrons of low energy. The second detection layer arranged behind the first layer is set for measuring the intermediate energy of neutrons, while the third detection is conducted using a liquid scintillator in the center of the monitor for measuring fast neutrons. Dose can be evaluated from three data that are obtained in three detection regions. It is expected that the neutron dose can be evaluated more precisely using this instrument, because the response of the three energy groups can be adjusted to a particular energy characteristic in an applied field.

In this study, a design of the first and the second detection layer of this monitor were discussed by means of a calculation with the MCNP.

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II. Model for Calculations

The cross section of the monitor is shown in **Fig. 1**. The monitor is cube-shaped. The response of the monitor was calculated using Monte Carlo calculation code MCNP-4B[6]. The liquid scintillator (LS) which is placed at the center of the monitor is the tertiary detector for measuring fast neutrons. The LS is 76 mm in diameter with a height of 76 mm, within a container of 1 mm thick stainless steel wall. Five sheets of Li-6 enriched lithium glass scintillator (GS) of a thickness of 1 mm and 80 mm square were assembled as a cube surrounding the LS. These 5 GS are the second detection layer for measuring intermediate neutron energy. This cube was encompassed by thick boron nitride (BN) as an absorption material. Furthermore, as the first detection layer, 5 sheets of GS of 1 mm thickness comprised the BN cube on 5 faces. In this calculation, the components of peripheral equipment such as a light guide and photomultiplier were not considered.

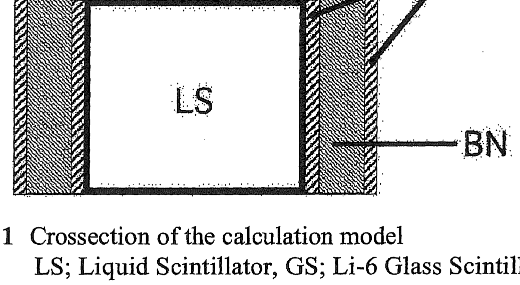

Fig. 1 Crossection of the calculation model
LS; Liquid Scintillator, GS; Li-6 Glass Scintillator, BN; Boron Nitride

The calculation model is shown in Fig.1. The monochrome energy neutrons were injected toward the center of the monitor from a point located 250 mm away from the front surface of the monitor. Neutrons were injected into the surface of the monitor perpendicularly. The incident energies were chosen to be from 10^{-8} to 10 MeV, every one or two columns. The reaction rate of ^{6}Li(n,alpha)T was considered to be the count rate of the GS.

III. Results and Discussions

1. Albedo effect

In this measuring instrument, the albedo from the LS was expected to increase sensitivity to the intermediate neutron energy. This albedo effect can be understood by comparing the results obtained when the LS was turned into a void. The absorption layer was assumed to be voided in this calculation. As shown in **Fig. 2**, with the injection of fast neutrons or intermediate energy neutrons, the count in the 2nd detection layer increased when the LS region was not changed to a void.

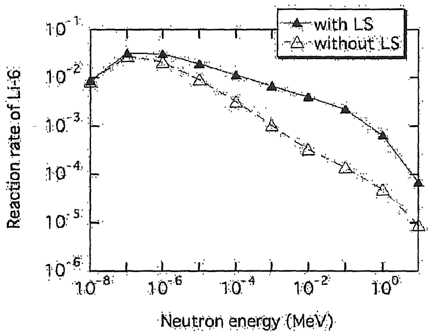

Fig. 2 Energy response of the 2nd detection layer (effect of albedo)

2. Absorption materials

The absorption material, BN, was arranged between the first detection layer and the second layer in order to limit the energy sensitivity of the second layer only to intermediate neutron energy. **Figure 3** shows the response in the 2nd detection layer when the thickness of the BN was gradually changed from 0 mm to 35 mm. The thicker the BN, the higher the bottom energy of the sensitivity, because the BN layer limited the injection of a low energy component.

The appropriate thickness of the BN layer should be selected depending on the energy range to be measured. The energy range of the second layer was set from 10^{-2} MeV to 1 MeV, in which the quality factor of neutrons changes in a large way. One MeV corresponds to the bottom energy for the sensitivity of the LS. As shown by Fig.3, the appropriate thickness of BN layer is 35 mm. In addition, the monitor was covered with polyethylene at a thickness of 10 mm, thus flattening the energy response of the first detection layer. Finally, the energy response of the first detection layer and the second layer were calculated as shown in **Fig. 4**.

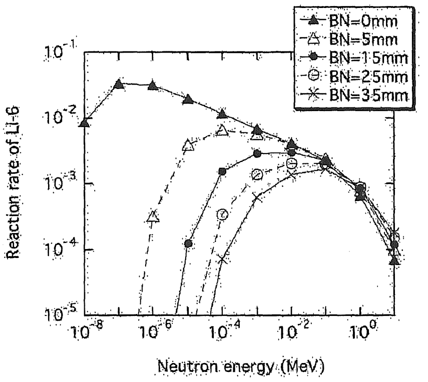

Fig. 3 Energy response of the 2nd detection layer (thickness of the BN layer; 0~35mm)

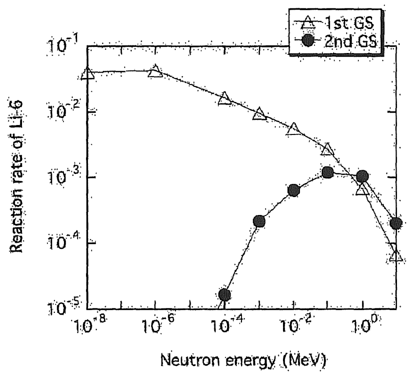

Fig. 4 Energy response of the 1st and 2nd detection layer (BN; 35 mmt, Polyethylene; 10 mmt)

3. Variation of sensitivity with incident angle

In this monitor, it is predicted that the response of the GS varies with incident angle. The direction dependence of this monitor was evaluated by means of calculation. On a plane indicated in **Fig. 5,** the responses were calculated at incident angles of 0, 45, and 90 degrees, respectively.

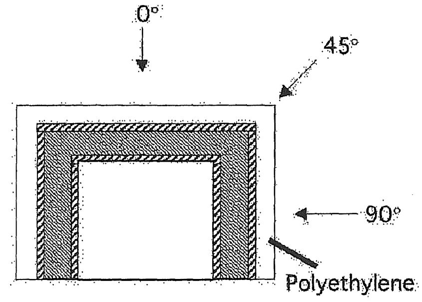

Fig. 5 Arrangement of the monitor and incident angle

Figure 6 shows the response of the GS. Although the count from the GS of each face differs whether the side faces to a neutron source or the side is rear side. However, the difference of count with changes in the incident angle was less than 36% when the counts from five faces of the GS were summed up for the 1st and the 2nd layer, respectively.

When injection of neutrons to the monitor is not uniform, it is predicted that the count will differ among the five faces. An injection direction can be estimated from these differences. It is expected that a more accurate dose can be evaluated using five data obtained from five faces.

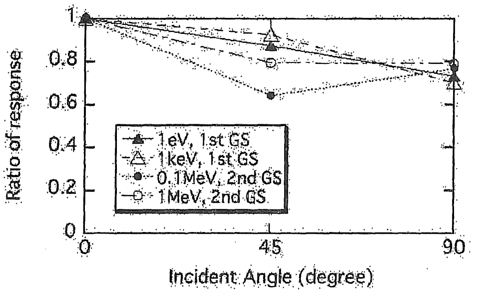

Fig. 6 Variation of the response ratio according to incident angle

IV. Conclusions

We have designed a multi-layer-type neutron monitor for measuring dose of three energy groups. The monitor is composed of three components. The first component is a liquid scintillator in the center of the monitor for measuring fast neutrons. The second component is 5 faces of a detection unit covering the LS in the form of a cube which consists of 2 sets of a lithium glass scintillator 1 mm thick as the 1st and 2nd detection layer, while the BN absorption layer is 35 mm thick. The first detection layer was set for measuring low neutron energy, while the 2nd layer was for measuring intermediate neutron energy. The third component of the monitor is polyethylene layer 10 mm thick surrounding the whole detection unit as a moderator.

The characteristics of this monitor, especially two GS layers, were evaluated using a MCNP calculation. The calculations clarified that by means of the albedo from a liquid scintillator and absorption by BN, the second detection layer showed a high level of sensitivity to the intermediate neutron energy. In addition, the count difference depending on incident angle was less than 36%.

Additional calculations with varing geometry or material are needed in order to have a better performance for evaluating dose precisely.

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