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A new approach for discriminative measurements of different components of external ionizing radiation

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ABSTRACT

For discriminative measurements of the different components of external ionizing radiation by passive dosimeters, a new monitoring post consisting of a 3-layer lead chamber and 4 sets of passive dosimeters was designed in this study. Based on the theoretical studies, the thicknesses of the lead layers were determined and the algorithm for quantifying the different components of external ionizing radiation was derived. To testify the design, *in-situ* measurements were carried out at two different sites throughout a year. The results indicated that the monitoring post could accurately measure the hard and soft components of secondary cosmic rays and the terrestrial gamma radiation. Furthermore, it was also confirmed that by adding a passive radon monitor in the monitoring site, the artificial gamma radiation around the monitoring site could also be quantified by the monitoring post.

1. Introduction

The public exposure to ionizing radiation from natural sources is continuing and inevitable. It is known that the natural external radiation mainly consists of secondary cosmic rays, terrestrial gamma radiation, and gamma radiation originating from airborne radon and its progeny, *etc*. (UNSCEAR, 2000). As the energies of the secondary cosmic rays are quite different from those of gamma radiations, it is considered that the discriminative measurements are necessary for a more accurate assessment of the public external exposure. On the other hand, with the rapid development and applications of nuclear energy and nuclear techniques, it is also desired to discriminate the low-level artificial gamma radiation from the natural external radiations.

For discriminative measurements of the natural and artificial external radiations by using passive dosimeters, Akhmad et al. proposed a prototype of monitoring post in the early 1990s (Akhmad et al., 1994). However, the contributions of the soft component secondary cosmic rays (SCR) and the terrestrial gamma radiation for each dosimeter inside the lead chamber were not discussed. Moreover, the different responses of thermoluminescent dosimeter (TLD) among the hard component secondary cosmic rays (HCR), the SCR and the terrestrial gamma radiation were not considered in the measurements either, which have been proved to be not negligible (O'Brien, 1978; Jensen and Thompson, 1995). On the other hand, several new types of passive dosimeters, such as the radiophotoluminescent glass dosimeters (RPLGDs) and optical stimulated luminescent dosimeters (OSLs), have been proved to be more promising for environmental monitoring in recent decades (Lee et al., 2009). Therefore, it is necessary to systematically review the monitoring approach.

In this study, based on the theoretical studies on the attenuation characteristics for different components of the external radiation in different thicknesses of the lead, an optimal configuration of monitoring post was designed to discriminate the different components of external ionizing radiation. To testify its performance, *in-situ* measurements were carried out at **two** different sites throughout a year. It is expected that the new approach could be used for more accurate monitoring of different components of external ionizing radiation.

2. Materials and methods

2.1. Monitoring principle

Based on the previous method for discriminative measurements

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of the different components of external ionizing radiation (Akhmad et al., 1994), a new configuration of the monitoring post was proposed in this study. As shown in Fig. 1, it consists of a 3-layer lead chamber and 4 sets of passive dosimeters. By considering the HCR can hardly attenuate within 10 cm of the lead, the absorbed doses measured by the dosimeters set at different layers can be expressed as followings,

$$D_{up} = D_{HCR} + D_{SCR} + D_{SS} + D_{RN} + D_{SD} + D_{PB} \quad (1)$$

$$D_{in1} = D_{HCR} + k_{11}D_{SCR} + k_{12}D_{SS} + k_{13}D_{RN} + D_{SD} + 2D_{PB} \quad (2)$$

$$D_{in2} = D_{HCR} + k_{21}D_{SCR} + k_{22}D_{SS} + k_{23}D_{RN} + D_{SD} + 2D_{PB} \quad (3)$$

$$D_{down} = D_{HCR} + k_{31}D_{SCR} + k_{32}D_{SS} + k_{33}D_{RN} + D_{SD} + D_{PB} + D_{TER} \quad (4)$$

where, D_{HCR} and D_{SCR} are the doses caused by the hard and soft components of secondary cosmic rays, respectively; D_{SS} is the sky-shine radiation scattered from terrestrial gamma which was supposed to be 10% of the terrestrial gamma radiation in the field (Nagaoka et al., 1981); D_{RN} is the dose due to airborne ^{222}Rn and its progeny; D_{SD} is the self-dose of the dosimeter; D_{PB} is the dose caused by inherent radioactive isotopes in the lead; D_{TER} is the dose contributed from the terrestrial gamma radiation; k_{ij} are the remaining fractions of different external radiation components except the HCR after the shielding of lead at each position.

2.2. Monte Carlo simulations

For obtaining the coefficients of k_{ij} and further determining the optimal configuration of the monitoring post, Monte Carlo simulations were carried out to study the shielding effects of lead on different components of external ionizing radiation except the HCR. Fig. 2 shows the conceptional diagram of the environmental external radiation and its detection. The air *kerma* caused by different components of ionizing radiation penetrating through different thicknesses of the lead were calculated by using the software Geant4 (version 9.6) (Geant4 Collaboration, 2012). The energy deposited in air was recorded in every 1 cm and then the corresponding air *kerma* was computed. In each simulation, a total of 1×10^8 particles were generated, it was found that the computational errors could be controlled within 3%.

In the simulations, the Cosmic-ray Shower Generator (CRY) was

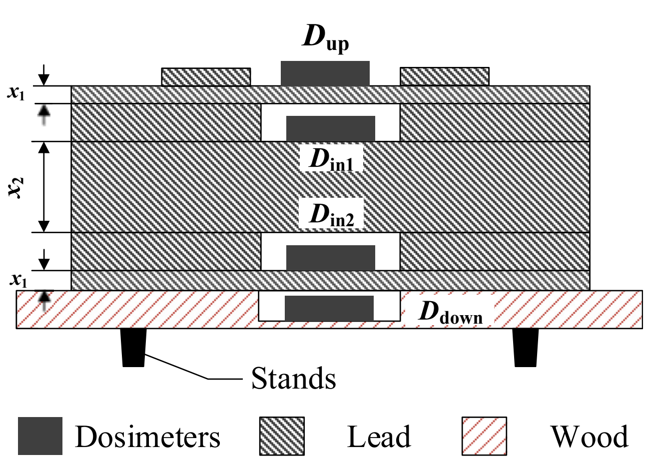

Fig. 1. Schematic of the new monitoring post.

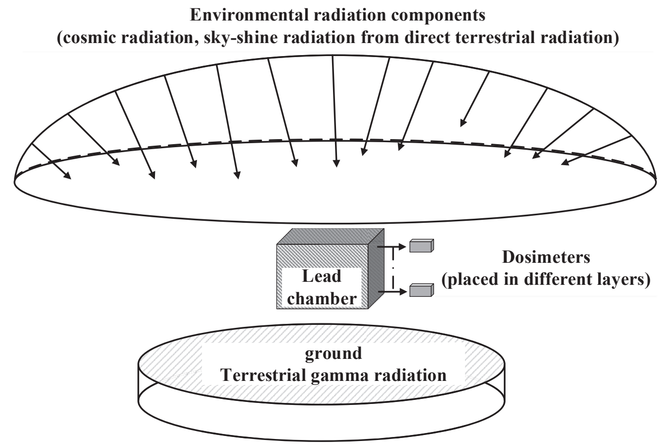

Fig. 2. The conceptional diagram of environmental external radiation and its detection.

used to generate the ionizing component of secondary cosmic rays at the sea level, including the gammas, the negatrons, the positrons and the muons (Hagmann et al., 2007). In general, the muons are categorized into the HCR, and the gammas, the negatrons and the positrons are categorized into the SCR (Dorman, 2013). For terrestrial gamma radiation, it originates from the gamma-emitting radionuclides of ^{238}U-, ^{232}Th-series and ^{40}K. The radionuclides were supposed to be uniformly distributed in the soil and reach their radioactive equilibria. The energies and the branching ratios of gamma rays decaying from the radionuclides were cited from the Table of Radioactive Isotopes (Browne and Firestone, 1986). The energy spectra of sky-shine radiation from terrestrial radiation were obtained from the simulation of scattered terrestrial radiation in air (Sandness et al., 2009).

2.3. Test experiments

To test the performance of the monitoring post designed in this study, *in-situ* measurements with the RPLGDs were carried out at two sites throughout a year with an interval of about 90 days. Both of the two sites were in a large open area in our campus. For Site A, the monitoring posts were set at two points within 20 m above a lawn. For Site B, a monitoring post was set above a basketball court, and it was about 50 m apart from Site A. As shown in Fig. 3, the dosimeters were placed at four positions of the lead chamber. In each position, 10 pieces of the RPLGDs were put inside of an airtight plastic box.

In this study, as the lead blocks were made more than 60 years ago, the D_{PB} was negligible; the D_{SD} was taken to be 1.10 nGy h^{-1} for the RPLGDs (Burgkhardt et al., 1996), and the D_{RN} was estimated from the ^{222}Rn concentration (C_{RN}, in Bq·m^{-3}) measured at the site by the formula below (Akhmad et al., 1994).

$$D_{RN} = 0.8 \times 0.4 \times C_{RN} \left(\mathrm{nGy \cdot h^{-1}}\right) \quad (5)$$

2.4. Monitoring of the artificial gamma radiation

Theoretically, the monitoring post can also discriminate the artificial gamma radiation (D_{MM}) provided the D_{RN} could be quantified, as illustrated in Eq. (6),