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Estimation of low-level neutron dose-equivalent rate by using extrapolation method for a curie level Am–Be neutron source

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HIGHLIGHTS

- The scope of the affected area for a curie-level Am–Be neutron source was measured.
- The low-level neutron dose-equivalent rates around the source increase exponentially with the increasing count rates when the source is in different shielding state.
- This principle can be used to estimate the low level neutron dose values in the source room which cannot be measured directly by a commercial dosimeter.

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ABSTRACT

Neutron radiation protection is an important research area because of the strong radiation biological effect of neutron field. The radiation dose of neutron is closely related to the neutron energy, and the connected relationship is a complex function of energy. For the low-level neutron radiation field (e.g. the Am–Be source), the commonly used commercial neutron dosimeter cannot always reflect the low-level dose rate, which is restricted by its own sensitivity limit and measuring range. In this paper, the intensity distribution of neutron field caused by a curie level Am–Be neutron source was investigated by measuring the count rates obtained through a ^{3}He proportional counter at different locations around the source. The results indicate that the count rates outside of the source room are negligible compared with the count rates measured in the source room. In the source room, ^{3}He proportional counter and neutron dosimeter were used to measure the count rates and dose rates respectively at different distances to the source. The results indicate that both the count rates and dose rates decrease exponentially with the increasing distance, and the dose rates measured by a commercial dosimeter are in good agreement with the results calculated by the Geant4 simulation within the inherent errors recommended by ICRP and IEC. Further studies presented in this paper indicate that the low-level neutron dose equivalent rates in the source room increase exponentially with the increasing low-energy neutron count rates when the source is lifted from the shield with different radiation intensities. Based on this relationship as well as the count rates measured at larger distance to the source, the dose rates can be calculated approximately by the extrapolation method. This principle can be used to estimate the low level neutron dose values in the source room which cannot be measured directly by a commercial dosimeter.

1. Introduction

Am–Be neutron sources are widely used in scientific research and practical teaching in the laboratories because of their low cost and convenience for operation. Nevertheless, as its strong penetrating power and strong radiation biological effect, people working in/around the Am–Be source room are always worried about its radioactivity in the source room and its adjacent rooms (Ghassoun and Senhou, 2012; Wang et al., 2011). Generally, if the source was properly shielded with low atomic-number materials, then the dose values maintain a relatively lower level. The neutron dose-equivalent rate close to the source can be easily got by using a commercial

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neutron dosimeter. But for a farther distance around the source, the dosimeter cannot always reflect such a low-level dose rate, which is restricted by its own sensitivity limit and measuring range.

Many studies have been done to explore how to measure neutron dose values more accurately, but these studies were mostly focused on the high neutron dose field. Up to now, few studies have been done to estimate the low-level neutron dose-equivalent rate caused by a shielded Am–Be neutron source, and further studies are still essential. This paper aims at investigating the low-level neutron dose-equivalent rate in the working area around the source. As is widely known that the radiation effect of neutron action on human body is closely related to the neutron energy, meanwhile the connected relationship is a complex function of energy (Hunt and Kluge, 1985; Gómez et al., 2010; Hernandez-Davila et al., 2014). But for a shielded neutron source, this relationship can be simplified, because the vast majority of the neutrons escaped from the shield have very low energy (<10 keV).

Consequently, this paper studied the distribution of neutrons by measuring count rates through a ^{3}He gas proportional counter. To further known the dose-equivalent rates at larger distances to the source, two basic instruments including a ^{3}He tube and a commercial dosimeter were used to obtain the internal relationships between count rates and dose-equivalent rates. Then according to the measured corresponding relationship as well as the count rates measured at larger distances to the source, the low-level neutron dose-equivalent rates in the source room can be calculated approximately by the extrapolation method.

To sum up, the present work tentatively put forward a method of estimating the low-level neutron dose-equivalent rates caused by a shielded Am–Be neutron source, which cannot be measured directly by the dosimeter. This method is of great value for low-level neutron radioactivity assessment and radiation protection.

2. Experimental instruments and descriptions

2.1. BH3105 type neutron dose-equivalent meter (Ji et al., 2011)

The neutron dosimeter used in this study is a commercially used BH3105 type neutron dose-equivalent meter, which is designed and manufactured by Beijing Nuclear Instrument Factory of China National Nuclear Corporation. As shown in Fig. 1, a polyethylene sphere of 20 cm in diameter is used as neutron moderator, at the center of which placed a spherical detector made of ^{6}Li glass scintillator. Furthermore, about 100 Cadmium absorption sticks with different lengths are evenly distributed on the surface of the moderator to realize the absorption stick principle method. This method is used for thermal $\sim$14 MeV neutron equal dose-equivalent detection, which gives high neutron sensitivity and wide measurement range of 10 cps/(μSv h^{-1}) and 0.1 μSv h^{-1}–999.9 mSv h^{-1}, respectively. The energy response characteristic of the dosimeter satisfies the ICRP standard. The gamma inhibition coefficient and the deviation of directional response are superior to the international standard.

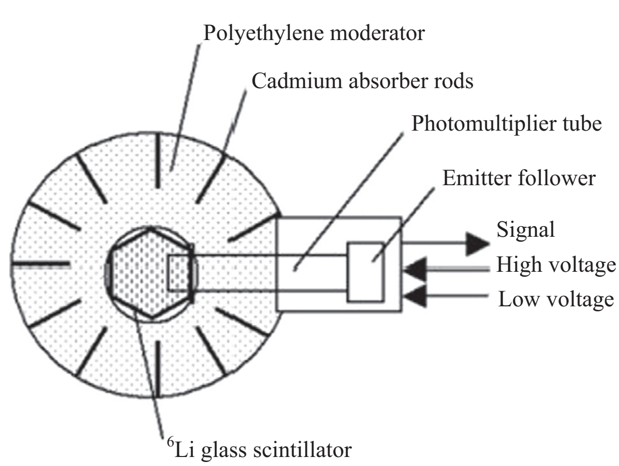

Fig. 1. Schematic diagram of the probe of the BH3105 type neutron dose-equivalent meter.

2.2. ^{3}He proportional countertube

The ^{3}He gas proportional counters are particularly sensitive to detect low-energy neutrons with high cross section of 5330 b for thermal neutron (Falahat et al., 2013), which makes it an ideal candidate for the measurement of neutrons emitted from a shielded source. The cylindrical ^{3}He counter used in this study was manufactured by Centronic Company, which consists of a stainless steel tube that is filled with ^{3}He under a pressure of 6 atm. The neutron sensitivity of the counter with a diameter of 25 mm and an effective length of 127 mm is 35 cps/(n/cm^2 s) (Centronic Company), and the optimum operating voltage based on the experimental measured plateau curve is 1200 V.

2.3. Am–Be neutron source storage configuration

The cylindrical Am–Be neutron source used in this study is manufactured by the China Institute of Atomic Energy. The source is surrounded by three layers of thin stainless steel with the total height and diameter of 36 mm and 30 mm, respectively, and the source activity is 7×10^9 Bq with the neutron emission rate of 4.6×10^6 s^{-1} (Li et al., 2011). The source and its shield are located in the corner of the neutron source room shown in Figs. 2 and 3. Based on Fig. 2, the source is located at the bottom of the PVC tube in normal shielding state, and the PVC tube with an open upper end and a sealed lower end is suspended in the center of the cylindrical steel pail. The steel pail is filled with deionized water and surrounded with dozens of centimeters thickness of paraffin to further slow down the escaped neutrons. In addition, for the purpose of shielding the neutrons emitted from the upper end of the PVC tube, a cylindrical paraffin rod is inserted into the PVC tube as well.

3. Distribution of low-energy neutrons measured by ^{3}He tube

In order to investigate the distribution of the neutron field, several positions in the source room and its adjacent rooms were selected as the measuring points, which were all located on the first floor of the laboratory building. These measuring points were selected at representative positions which were considered to be important. As shown in Fig. 3 with an X–Y coordinate axis, all the measuring points were chosen along the X axis and located in the $Z\approx70$ cm plane. Here, we made the assumption that all the shielding materials (including walls and other objects in the room) along other directions were considered to be similar as the X axis in the X–Y plane. The neutrons emitted from the shield were mostly low-energy neutrons with energy below $\sim$0.01 MeV, and then the emitted neutrons were promptly moderated through elastic scattering and inelastic scattering by walls and other low-atomic-number materials. Therefore, considering the moderating effect of the shield and walls, the count rates outside of the source room are much lower. So in order to reduce the measuring statistical errors, the count rates of point C–O were measured at least 3 times to get its average value with measuring time of 12 h. The measured count rates at different measuring points change with distance are summarized in Table 1.

Table 1 presents the measured neutron count rates at different measuring points around the source. It can be seen that the count