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Technical Note

A REVIEW OF NEUTRON SCATTERING CORRECTION FOR THE CALIBRATION OF NEUTRON SURVEY METERS USING THE SHADOW CONE METHOD

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ABSTRACT

The calibration methods of neutron-measuring devices such as the neutron survey meter have advantages and disadvantages. To compare the calibration factors obtained by the shadow cone method and semi-empirical method, 10 neutron survey meters of five different types were used in this study. This experiment was performed at the Korea Atomic Energy Research Institute (KAERI; Daejeon, South Korea), and the calibration neutron fields were constructed using a ^{252}Californium (^{252}Cf) neutron source, which was positioned in the center of the neutron irradiation room. The neutron spectra of the calibration neutron fields were measured by a europium-activated lithium iodide scintillator in combination with KAERI's Bonner sphere system. When the shadow cone method was used, 10 single moderator-based survey meters exhibited a smaller calibration factor by as much as 3.1–9.3% than that of the semi-empirical method. This finding indicates that neutron survey meters underestimated the scattered neutrons and attenuated neutrons (i.e., the total scatter corrections). This underestimation of the calibration factor was attributed to the fact that single moderator-based survey meters have an under-ambient dose equivalent response in the thermal or thermal-dominant neutron field. As a result, when the shadow cone method is used for a single moderator-based survey meter, an additional correction and the International Organization for Standardization standard 8529-2 for room-scattered neutrons should be considered.

1. Introduction

The calibration factor or dose equivalent response of a neutron-measuring device (e.g., a neutron survey meter) is a unique property of the type of device, and may depend on the ambient dose equivalent rate, the neutron source spectrum, or the angle of incidence of the neutrons; however, it should not be a function of the characteristics of the calibration facility or the experimental techniques employed. All calibrations should refer to the free field (i.e., with no contribution

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from neutrons scattered by the air and room) and the influence of scattered neutrons on the reading of the device should be corrected [1,2]. However, most laboratories engaged in routine calibration generally perform the calibration measurement in a calibration room, not in a free-field space. When neutron survey meters are calibrated with a radionuclide neutron source in a calibration room, the reading should be corrected for all extraneous neutron scattering effects because the neutron survey meter responds to the scattered neutrons and the direct neutrons from the neutron source. The neutron survey meter is placed in a neutron calibration field of a known free-field fluence rate, and the instrument reading is recorded. The reading should be corrected for all extraneous neutron scattering effects such as neutron scattering by the air, walls, floor, and ceiling of the calibration room. In general, the scattering of neutrons may occur by the following scattering effects: neutrons scattered by the floor and walls of the laboratory room (i.e., room scatter); neutrons attenuated by nuclear reactions with the air (i.e., air outscatter); neutrons scattered by the air from outside the direct source-to-detector path (i.e., air inscatter); and neutrons scattered from support structures.

The International Organization for Standardization (ISO) recommends three different approaches to quantify the scattering of neutrons. The three methods—denoted as the "shadow cone method," the "generalized fit method," and the "semi-empirical method"—usually involve an initial set of careful measurements as a function of the distance between the neutron source and the detector. However, these measurements need not be repeated each time an identical device is calibrated [3,4]. In general, the calibration factors obtained from different methods have similar values. However, we found that the calibration factors obtained by the two methods have different values. In this study, the calibration factors of several neutron survey meters were obtained by the shadow cone method and semi-empirical method.

2. Neutron scatter correction for the calibration methods for a neutron survey meter

The accuracy of the shadow cone method depends strongly on the design of the shadow cone and on its position relative to the source detector geometry. If $M_S(l)$ and $M_T(l)$ are the detector readings measured with a shadow cone (which is placed between the source and the detector) and without a shadow cone, then Eq. (1) holds [3,4]:

$$F_A(l)\cdot[M_T(l)-M_S(l)] = F_A(l)\cdot M_T(l)\cdot\left[1-\frac{M_S(l)}{M_T(l)}\right] = R_\phi\cdot\varphi,\quad \varphi=\frac{B\cdot F(\theta)}{4\pi\, l^2} \tag{1}$$

in which l is the distance from the center of the source [a ^{252}Californium (^{252}Cf) source was used in this study] to the point of the test, and $F_A(l)$ is the measured reading corrected for all extraneous effects and appropriate air attenuation (i.e., air outscatter) factor [5,6]. The variable R_ϕ is the free-field fluence response and φ is the free-field fluence rate. The value B is the neutron source strength (i.e., the total neutron-emission rate into 4π sr) and $F(\theta)$ is the anisotropy function of the radionuclide neutron source [4,7]. The variable $M_T(l)$ is the survey meter's reading resulting from the total radiation field (i.e., the source neutrons plus the scattered neutrons) and $M_S(l)$ is the scattered neutrons. Hence, the value of $M_T(l)-M_S(l)$ is the source neutrons. A schematic diagram illustrating the arrangement and structure of the shadow cone used in the present study is shown in Fig. 1. It consists of two parts: the front end, which is 20 cm long and composed entirely of stainless steel, and the rear section, which is 30 cm long and composed of borated polyethylene. In the present study, all neutron survey meters were positioned 100 cm from the center of the neutron source.

The semi-empirical method is based on the assumption that a fraction of the instrument's reading resulting from scattered neutrons can be deduced from a deviation of the reading from the inverse-square law [1,2,7]. The various contributions are characterized by a component that is independent of l because of room-return neutrons and by a component that decreases linearly with the separation

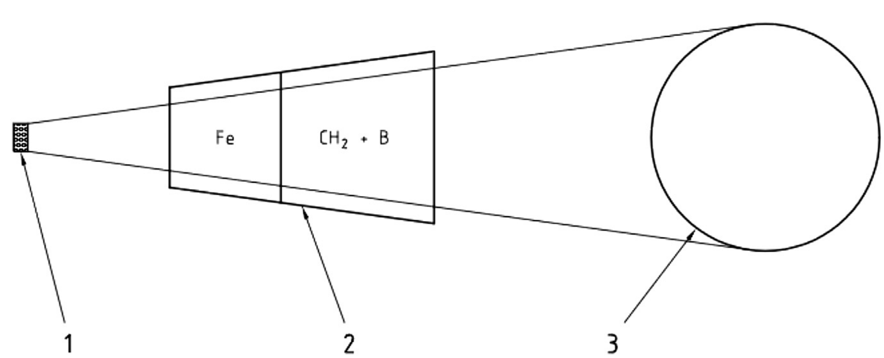

Fig. 1 – The schematic diagram illustrates the arrangement of neutron source (1), shadow cone (2), and neutron-measuring device (3). The shadow cone consists of two parts: a front end, which is 20 cm long and composed entirely of stainless steel (Fe), and a rear section, which is 30 cm long and composed of borated polyethylene (CH_2 + B). The shadow is placed 5 cm from the center of the ^{252}Californium (^{252}Cf) neutron source.