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Calculating the ambient dose equivalent of fast neutrons using elemental composition of human body

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ABSTRACT

The sphere of International Commission on Radiation Units and Measurements (ICRU) consists of 4-elemental compositions of 76.2% oxygen (O), 11.1% carbon (C), 10.1% hydrogen (H), and 2.6% nitrogen (N) whereas there are 26 elemental compositions in the human body. In this work, human body elemental composition has been used to calculate the ambient dose equivalent rate of fast neutrons. ^{241}Am–Be of 185 GBq (5 Ci) was utilized as neutron source. In addition, the conversion coefficients in International Commission on Radiological Protection publication 116 (ICRP 116) was used to verify from the results of using elemental compositions in the human body. The calculated results have been compared to those measured by a neutron monitor. The mean values of discrepancies from the measured values were within ∼8%. Moreover, systematic comparisons have been carried out with values published in literature. This work concluded that the elemental compositions in the human body could be used to design a phantom that has the same elemental composition of human body.

1. Introduction

The ambient dose equivalent, H∗(10), at a point in a radiation field, is the dose equivalent, which would be produced by the corresponding expanded and aligned field in the sphere of International Commission on Radiation Units and Measurements (ICRU) at a depth of 10 mm on the radius opposing the direction of the field. ICRU sphere is the sphere that is 30 cm in diameter and its density equals to 1 g/cm^3. This sphere consists of 4-elemental compositions (percentage by mass) of 76.2% oxygen (O), 11.1% carbon (C), 10.1% hydrogen (H), and 2.6% nitrogen (N). This sphere phantom nearly approximates the human body [1] . In contrast, from the anatomy of human body, there are twenty-six different chemical elements normally are present in the human body. Four elements are called the major elements, whereas 8 other elements are called the lesser elements, and 14 other are called trace elements. The major elements constitute about 96% of the body's mass: 65% oxygen (O), 18.5% carbon (C), 9.5% hydrogen (H), and 3.2% nitrogen (N). The lesser elements are calcium, phosphorus (P), potassium (K), sulfur (S), sodium (Na), chlorine (Cl), magnesium (Mg), and iron (Fe). The trace elements are aluminum (Al), boron (B), chromium (Cr), cobalt (Co), copper (Cu), fluorine (F), iodine (I), manganese (Mn), molybdenum (Mo), selenium (Se), silicon (Si), tin (Sn), vanadium (V), and zinc (Zn). The lesser elements and trace elements constitute 4% of the body's mass [2,3]. Therefore, there are differences in elemental compositions between ICRU sphere and human body.

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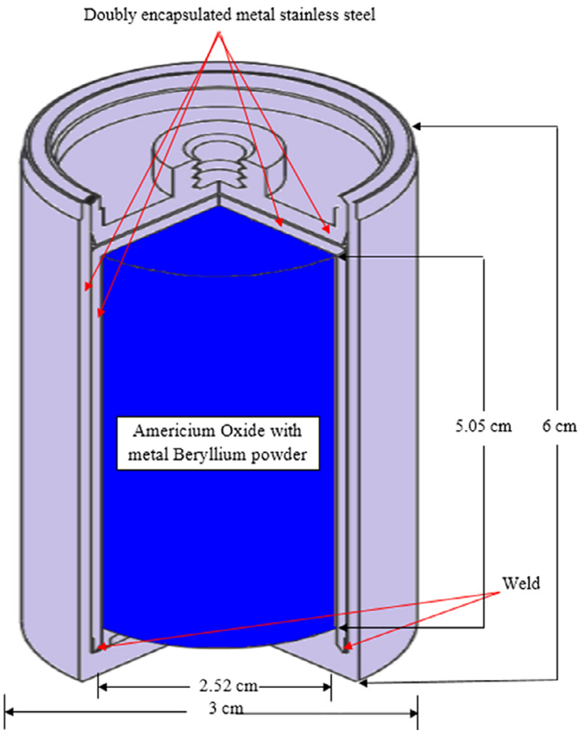

Fig. 1. Capsule of the ^{241}Am–Be neutron source - X.14 (code AMN.24), assembly.

Neutrons are uncharged particles, they can travel appreciable distances in matter without undergoing interactions. When neutrons fall into tissues, they may collide with atoms by an elastic or inelastic reaction. In the elastic reaction, the total kinetic energy of the incoming particle is conserved whereas, in the inelastic collision, the nucleus absorbs some neutron's energy and it is left in an excited state [4]. Threshold neutron energy to differentiate between elastic and inelastic collisions depends on target nucleus. It varies from infinity for atoms of hydrogen to about 6 MeV for atom of oxygen to $\leq$ 1 MeV for uranium [5]. In general, the inelastic scattering cross section is small. It is approximately $\leq$ 1 barn for low-energy fast neutrons. Between 100 MeV and 25 MeV, the neutron inelastic cross section increases rapidly with decreasing energy. However, the neutron inelastic cross section decreases rapidly with decreasing energy when energy is less than 25 MeV [4].

The absorbed dose from a beam of neutrons can be computed by considering the absorbed energy by each of the tissue elements that react with the neutrons. The type of reaction depends on the neutron's energy. For fast neutrons with energy up to about 20 MeV, the dominant mechanism to transfer energy is elastic collision and the radiation dose absorbed locally in first collision dose. It is estimated by the primary neutron flux, and by neglecting the scattered neutrons after this primary interaction [5].

This study aimed to calculate the ambient dose equivalent rate $\dot{H}^*(10)$ of fast neutron using the elemental compositions of human body. ^{241}Am–Be has been considered as a neutron source because it has been used as a calibrating source for most of the neutron surveying instruments [5]. In addition, the ambient dose equivalent rates produced by an ^{241}Am–Be neutron source at various source-to-detector distances have been studied in literature [6–8].

In this present work, the neutron flux has been calculated analytically at different source-to-detector separations from ^{241}Am–Be neutron source. Then, the ambient dose equivalent rate has been estimated with two different approaches. In the first approach, the dose rates were calculated using, the neutron cross-section, σ and elemental composition of human body tissue and the radiation-weighting factor of neutrons have been used from ICRP 103 [9]. The second approach is based on calculating the effective dose per fluence value as in ICRP 116 [1] Moreover, a comparison between the calculated ambient dose equivalent and the measured ones by neutron monitor NM2 (Nuclear Enterprise, UK NM2), as well as with the published data in literature has been carried out.

2. Experimental work

2.1. ^{241}Am–Be neutron source

One hundred and eighty five GBq (5 Ci) ^{241}Am-Be neutron source in the form of capsule X.14 (code AMN.24), has been supplied by Amersham International PLC., Buckinghamshire, England to the Nuclear Physics Lab, Faculty of Science, King Abdulaziz University, Jeddah, Saudi Arabia. It has been corrected for the decay at the time of measurement. The capsule is a cylinder of 3 cm base diameter and 6 cm height. The schematic diagram of the ^{241}Am–Be source configuration is shown in Fig. 1. The neutron