Annals of Nuclear Energy 75 (2015) 189–192

Contents lists available at ScienceDirect

Annals of Nuclear Energy

journal homepage: www.elsevier.com/locate/anucene

Technical Note

Neutron kerma coefficients of compounds for shielding and dosimetry

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ARTICLE INFO

Article history:
Received 27 May 2014
Received in revised form 28 July 2014
Accepted 31 July 2014

Keywords:
Neutron
Kerma
Coefficients
Compounds
Dosimetry
Shielding

ABSTRACT

Alloys, concretes, glasses, neutron shielding material, polymers, nuclear track detectors, are being used for shielding and dosimetry applications. The neutron kerma coefficients of eighteen compounds have been calculated for neutrons energy less than 30 MeV; these compounds are used as shielding and dosimetric materials. The kerma coefficients are found lowest for all the compounds in intermediate energy (10 eV < E < 10 keV). The neutron kerma coefficients are higher for the compounds containing large weight fraction of low-Z elements. A resonance in neutron kerma coefficient is observed for the large amount of oxygen containing compounds. It is found that at high energies kerma coefficients are approximately same, but very large differences for energy less than 100 eV.

1. Introduction

Neutrons are used for medical, shielding and material research, requiring detailed investigation of interaction parameters for transport, radiation effects and transmutation. The neutron has a larger linear energy transfer, and is considered a dangerous radiation in comparison with gamma-rays. In reactors and accelerators facilities concretes and low-atomic number compounds, like plastics, polymers and boron containing compounds, are being used as shielding and dosimetry materials (Singh et al., 2014a; Yilmaz et al., 2011).

Kerma is the acronym of kinetic energy released per unit mass; it is defined as the initial kinetic energy of all secondary charged particles liberated per unit mass at a point of interest by uncharged radiation. Kerma coefficients are of practical importance in radiation dosimetry for therapy and protection purposes (Liu and Chen, 2008; Karimi-Shahri et al., 2013). Also, have been used to determine the nuclear heating (Beynon and Taylor, 1976; Zhang and Abdou, 1997), and to test cross section libraries (Kondo et al., 2008).

When a body is irradiated with charged particles, like electrons, protons or ions, the energy released per unit mass is deposited through the ionization induced along the incoming particle track. When uncharged particles, like photons or neutrons, are used the energy is released through the transfer of the kinetic energy from the incident uncharged particles to the charged particles within the volume, thus these secondary charged particles deposit energy along their tracks. Electrons are mainly the secondary charged particles when photons are used; on the other hand protons, deuterons, alpha particles and heavier ions are the secondary particles when the incoming primary particles are neutrons (Blomgren and Olsson, 2003).

It has been shown that differences between the elemental composition of a variety of tumor samples result in approximately 6 to 7% less average neutron kerma than those for average soft tissue for neutrons with energies beyond 1 MeV (Maughan et al., 1997). For neutrons with E > 1 keV the difference between the kerma coefficients of tumor and muscle are minor (Paredes et al., 2010). Tissue equivalent materials to be used as substitutes for human organs in dosimetry for diagnostic radiology have been investigated. Some of these materials are Nylon, polymethylmethacrylate (PMMA), waxes, paraffin, and water (Ferreira et al., 2010; Singh et al., 2014a). Beside the similarity to human tissue studies have been carried out analyzing the phantom geometry (El-Kolaly et al., 1999). Features like attenuation and kerma coefficients of materials used in radiation dosimetry have been investigated with the aim to determine the response in radiation fields (Singh et al., 2014b; Demir and Tursucu, 2012; Hugthenburg et al., 2012).

Neutron kerma is vital parameter for biological, shielding, dosimetric and other materials used in neutron shielding and dosimet-

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http://dx.doi.org/10.1016/j.anucene.2014.07.047
0306-4549/

ric applications. The neutron kerma coefficients for human body organs have been reported in ICRU, 1989. Recently, neutron kerma factors of 24 tissue-substitutes have been investigating (Singh et al., 2014c).

The aim of this work was to calculate the neutron kerma coefficients of 18 compounds used for neutron shielding and dosimetry.

2. Materials and methods

The Kerma is defined as the quotient of dE_{tr} by dm, where dE_{tr} is the sum of the initial kinetic energies of all the charged ionizing particle liberated by uncharged ionizing particles in a material of mass dm. Elemental kerma coefficients, $k(E)$, were used to calculate the kerma coefficients of the shielding and dosimetric compounds, $k_T(E)$, using the compound element weight fraction, w, as is shown in Eq. (1).

$$k_T(E) = \sum_i w_i k(E)_i \tag{1}$$

here, w_i is the weight fraction of ith element in the selected compound, and $k(E)_i$ is the neutron kerma factor of ith element in the compound or mixture (Caswell et al., 1982). Table 1 gives the compound materials and elemental compositions used to calculate the neutron kerma coefficients for shielding and dosimetry studies. Calculations were carried out using the Kerma program whose performance has been tested for elements, water, normal body tissues and selected tumors (Vega-Carrillo et al., 2007). The Kerma program results for tissue substitutes have been compared with ICRU, 1989, and are published recently in the literature (Singh et al., 2014c).

3. Results and discussion

The neutron kerma coefficients of the selected compounds, alloy, SSNTDs, concretes, building materials, glasses, plastic/polymers and neutron absorbers for energy less than 30 MeV are shown in Fig. 1.

Neutron kerma coefficients in the neutron dosimeter and, plastic and polymers groups, B_4C as well as in the Ilmenite concrete (CIl) vary from 10^{-12} up to 10^{-8} cGy-cm^2. For other materials except B_2O_3 neutron kerma coefficients ranges from 10^{-14} up to 10^{-8} cGy-cm^2 approximately.

Regardless the material, the kerma coefficients has the same tendency decreasing from 10^{-8} to approximately 10^{-4} MeV, reaching a minimum in the range of 10^{-5} to 10^{-3} MeV, then above 10^{-3} MeV the kerma coefficients increase as the neutron energy rises. The minimum is shifted from approximately 8×10^{-3} to 5×10^{-2} MeV for Ilemenite concrete (CIl). In the case of brick, cement (Ceme), and Pyrex (Pyre) and soda glass (Soda) a resonance (in 10^{-4} to 10^{-3} MeV) is noticed probably caused by the oxygen concentration. Another resonance, between 10^{-3} and 10^{-2} MeV, is noticed in B_2O_3 (BO) where the minimum appears at 10^{-5} MeV neutrons. Although the PET and the ordinary concrete (COrd) have a large amount of oxygen, the resonance in PET is absent and is very small for the COrd; this is probably because these materials have a large amount of hydrogen, where neutron have a large probability of lose all its energy in a single collision.

The kerma coefficients of the selected compounds can be divided in two energy regions, low energy ($\leqslant$100 eV) and high energy (>100 eV).The neutron kerma coefficients were found higher for neutron dosimeters, polymers and neutron absorbers in the selected energy range. The lowest kerma coefficient (in range of 10^{-15} cGy-cm^2) was noted for B_2O_3 around neutron energy of 10 eV, this is probably due the high absorption cross section in ^{10}B which is approximately 19% in natural boron. Nevertheless B_4C has a larger amount of boron than B_2O_3 this material has its minimum kerma coefficient for 10^{-3} MeV, while B_2O_3 has it for 10^{-5} being approximately 3 orders of magnitude less probably due the moderation caused by C. The minima kerma coefficient for B_4C shifts toward high energy.

The neutron kerma coefficients are found of order of 2.83×10^{-13}, 5.59×10^{-11} to 7.14×10^{-11}, 7.57×10^{-14} to 3.62×10^{-11}, 2.79×10^{-13} to 1.44×10^{-12}, 2.28×10^{-13} to 2.75×10^{-13}, 4.54×10^{-11} to 8.49×10^{-11}, 7.90×10^{-15} to 1.94×10^{-11} cGy-cm^2 for carbon steel, neutron dosimeters, concretes, building materials, glasses, plastic/polymers, and neutron absorbers, respectively at neutron energy of 2 eV.

Table 1
Features of shielding and dosimetric materials.

Type	Description (ID)	Density (g cm^{-3})	Composition
Alloy	Carbon steel (CSt)	8.10	C(0.31); Si(0.19); P(0.01); S(0.01); Mn(0.98); Fe(98.39)
SSNTD	Amber (Amb)	1.1	H(11.18); C(79.95); O(8.87)
	Makrofol (Mak)	1.20	H(5.55); C(75.58); O(18.88)
	PET	1.44	H(4.19); C(62.50); O(33.30)
Concrete	Ordinary (COrd)	2.30	H(0.94); C(0.09); O(53.66); Na(0.46); Mg(0.12); Al(1.32); Si(36.74); S(0.08); K(0.31); Ca(5.65); Fe(0.63)
	Ilmenite (CIl)	3.50	H(0.57); O(35.93); Na(0.06); Mg(1.31); Al(0.61); Si(2.40); S(0.07); Cl(0.02); K(0.03); Ca(3.88); Ti(19.64); Fe(34.78)
	Steel–magnetite (CSM)	5.11	H(0.51); O(15.70); Mg(0.58); Al(0.66); Si(2.68); P(0.08); S(0.06); Ca(3.95); Mn(0.07); Fe(75.73)
Building material	Brick	1.35	O(54.60); Na(0.10); Mg(0.10); Al(4.94); Si(5.95); Ca(34.0); Fe(0.303)
	Lime stone (LimeS)	2.55	C(0.30); O(29.20); Mg(0.40); Si(0.20); Ca(69.90)
	Cement (Ceme)	2.3	O(37.00); Mg(0.40); Al(20.90); Si(2.10); Ca(27.90); Fe(11.70)
Glass	Quartz (Qua)	2.66	O(53.2); Si(46.7)
	Pyrex (Pyre)	2.23	B(4.0064); O(53.9562); Na(2.8191); Al(1.1644); Si(37.722); K(0.3321)
	Soda lime (Soda)	2.52	O(46.8); Na(9.6); Mg(0.1); Al(0.7); Si(34.5); S(8×10^{-2}); K(0.3); Ca(7.5); Ti(6×10^{-2}); Fe(0.3)
Plastic and Polymer	Air-equivalent Plastic (C-552) (AirE)	1.76	H(2.47); C(50.17); O(0.46); F(46.53); Si(0.40)
	Polyethylene terephthalate (Mylar) (Mayl)	1.38	H(4.20); C(62.51); O(33.31)
	Polymethyl methacrylate (PMMA)	1.19	H(8.06); C(59.99); O(31.97)
Neutron absorber	B_4C (BC)	2.52	B(78.26); C(21.74)
	B_2O_3 (BO)	2.46	B(31.05); O(68.95)