Annals of Nuclear Energy 37 (2010) 991–995

Contents lists available at ScienceDirect

Annals of Nuclear Energy

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

Radiation shielding of concretes containing different lime/silica ratios

A.M. El-Khayatt *

Reactor Physics Department, Nuclear Research Centre, Atomic Energy Authority, P.O. 13759, Cairo, Egypt

ARTICLE INFO

Article history:
Received 13 December 2009
Received in revised form 28 February 2010
Accepted 14 March 2010
Available online 13 April 2010

Keywords:
Concrete
Lime/silica ratio
Removal cross-section
Photon attenuation
Shielding

ABSTRACT

The shielding of γ-rays and fast neutrons by concrete has been studied for concretes containing different lime/silica ratios. Calculations were carried out for six different concrete samples. The total mass attenuation coefficients (μ/ρ, $cm^2\,g^{-1}$) have been computed at photon energies of 1 keV to 100 GeV using the personal computer software package WinXCom. Also the macroscopic effective fast neutron removal cross-sections (Σ_R, cm^{-1}) have been calculated using MERCSF-N program and the removal cross-section database for all required elements. The obtained results showed that the lime/silica ratio of concrete has significant and insignificant effects on μ/ρ and Σ_R values, respectively.

1. Introduction

Concrete which contains water, cement and aggregate, is widely used in building construction such as nuclear power stations, particle accelerators and medical hospitals. The knowledge of the lime/silica ratio is very important for durability of the concrete structures. The influence of this ratio on the shielding properties (gamma and fast neutrons) has not been evaluated. The reported data of concrete mixtures composition and elemental composition for six concrete samples with different lime/silica ratios (Naqvi et al., 2005) were used for shielding calculations.

The linear attenuation coefficient (μ, cm^{-1}), which is defined as the probability of a radiation interacting with a material per unit path length, is the most important quantity characterizing the penetration and diffusion of γ-rays in a medium. Its magnitude depends on the incident photon energy, the atomic number and the density (ρ) of the shielding materials (Wood, 1982). The density does not have a unique value but depends on the physical state of the material, for example, in the case of concrete, on its moisture content. To obviate the effects of variations in the density of the material, the linear attenuation coefficient is, for reference purposes, expressed as a mass attenuation coefficient (μ/ρ, $cm^2\,g^{-1}$) which is the linear attenuation coefficient per unit mass of the material (Kaplan, 1989).

Several works have been performed to obtain linear attenuation coefficients (μ) and mass attenuation coefficients (μ/ρ) theoretically and experimentally for different elements, compounds and mixtures (Hubbell, 1982), for different building materials (Akkurt et al., 2004; Türkmen et al., 2008; Murat et al., 2009) for concretes (Akkurt et al., 2006) and for some aqueous solutions (Singh et al., 2001).

For neutron shielding calculations, the elastic and inelastic scattering reactions, and neutron-capture interaction process, are of most importance. Attenuation, which is exactly exponential, is characteristic of absorption processes alone. In case of hydrogenous shields, a large fraction of the interactions are equal to absorption. As a result, the effect of the sample can be described by an equivalent absorption cross-section called an effective removal cross-section (Σ_R) (Blizard and Abbott, 1962). Here the "attenuation" or "removal" means removal from the fast group. The macroscopic effective fast neutrons removal cross-section, for simplicity removal cross-section, Σ_R (cm^{-1}), is the probability that a fast or fission-energy neutron undergoes a first collision, which removes it from the group of penetrating, uncollided neutrons (Blizard and Abbott, 1962). The total neutron cross-section Σ_T is the sum of the cross-sections for all the neutron-interaction processes. Not all process leads to remove the neutron from the penetrating beam thus usually Σ_R is less than Σ_T.

In this paper, the mass attenuation coefficients (μ/ρ, $cm^2\,g^{-1}$) were calculated using personal computer software package WinXCom (Gerward et al., 2004). Also the MERCSF-N program (El-Khayatt and El-Sayed Abdo, 2009) was used to calculate the mass removal cross-sections (Σ_R/ρ, $cm^2\,g^{-1}$) and removal cross-sections (Σ_R, cm^{-1}) for these concrete samples. The results can be used for explaining the influence of lime/silica ratios of these samples on their shielding properties.

* Tel.: +20 5 06951775; fax: +20 2 4620778.
E-mail address: ahmed_el_khayatt@yahoo.com

0306-4549/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.anucene.2010.03.001

Table 1
Composition of the six concrete mixtures.

Mixture #	Portland cement (kg)	Coarse-aggregate (kg)	Fine-aggregate (kg)	Water (kg)	ρ (g/cm^3)
1	370.00	680.40	1110.00	197.60	2.358
2	370.00	555.00	680.40	197.60	1.803
3	370.00	1110.00	1020.60	197.60	2.698
4	185.00	1110.00	680.40	197.60	2.173
5	370.00	1110.00	680.40	197.60	2.358
6	370.00	1110.00	340.20	197.60	2.018

Table 2
Elemental compositions, as fraction by weight, of the six concrete samples.

Element (wt.%)	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
H	0.945	1.237	0.827	1.026	0.946	1.106
C	3.574	3.728	4.899	5.976	5.509	6.325
O	51.713	51.768	51.114	52.190	50.910	50.638
Na	0.078	0.070	0.068	0.058	0.060	0.048
Mg	0.318	0.359	0.315	0.276	0.338	0.368
Al	0.762	0.811	0.658	0.494	0.646	0.629
Si	22.331	18.881	18.429	15.306	14.921	10.228
S	0.230	0.271	0.225	0.187	0.245	0.273
K	0.213	0.187	0.186	0.162	0.161	0.127
Ca	19.279	22.059	22.775	23.932	25.740	29.707
Ti	0.028	0.027	0.028	0.027	0.028	0.027
Fe	0.529	0.600	0.477	0.364	0.498	0.524
Lime/silica	0.496	0.679	0.694	0.855	0.969	1.634

2. Theoretical methods

2.1. The total mass attenuation coefficients of γ-ray (μ/ρ)

The interaction coefficients (fractions by weight or partial densities) and total attenuation coefficients for any chemical compound or homogeneous mixture of shielding materials are obtained as weighted sums over the corresponding coefficients for elements. The mass attenuation coefficients (μ/ρ) can be given by the following weighted summation (Seltzer, 1993; Kaplan, 1989; Wood, 1982):

$$\mu/\rho = \sum_i w_i(\mu/\rho)_i, \tag{1}$$

where ρ is the mass density of the sample and w_i and $(\mu/\rho)_i$ are the fraction by weight and mass attenuation coefficient of ith constituent, respectively. For a chemical compound, the fraction by weight is given by:

$$w_i = \frac{a_i A_i}{\sum_j a_j A_j}, \tag{2}$$

where a_i and A_i are, respectively, the number of formula units and the atomic weight of the ith element. Hence the liner attenuation coefficients are given by:

Table 3
Total mass attenuation coefficients μ/ρ for the six concrete samples.

(Required) Photon energy (MeV)	Total mass attenuation coefficients μ/ρ in cm^2/g, with coherent scattering of the concrete samples					
	1	2	3	4	5	6
1.000E−03	3.82E+03	3.91E+03	3.92E+03	3.99E+03	3.70E+03	4.14E+03
1.183E−03	2.46E+03	2.52E+03	2.52E+03	2.56E+03	2.38E+03	2.67E+03
1.305E−03	1.91E+03	1.96E+03	1.96E+03	1.99E+03	1.85E+03	2.07E+03
1.500E−03	1.32E+03	1.35E+03	1.35E+03	1.37E+03	1.28E+03	1.43E+03
1.560E−03	1.19E+03	1.22E+03	1.22E+03	1.24E+03	1.15E+03	1.29E+03
1.560E−03	1.21E+03	1.25E+03	1.24E+03	1.25E+03	1.17E+03	1.31E+03
1.694E−03	9.70E+02	9.97E+02	9.93E+02	1.00E+03	9.38E+02	1.05E+03
1.839E−03	7.75E+02	7.97E+02	7.93E+02	8.00E+02	7.49E+02	8.39E+02
1.839E−03	1.42E+03	1.34E+03	1.32E+03	1.24E+03	1.15E+03	1.13E+03
2.000E−03	1.18E+03	1.11E+03	1.10E+03	1.02E+03	9.43E+02	9.25E+02
3.607E−03	2.43E+02	2.28E+02	2.24E+02	2.07E+02	1.92E+02	1.86E+02
4.038E−03	1.78E+02	1.67E+02	1.64E+02	1.52E+02	1.40E+02	1.36E+02
6.000E−03	1.22E+02	1.28E+02	1.29E+02	1.29E+02	1.25E+02	1.43E+02
1.000E−02	3.02E+01	3.18E+01	3.20E+01	3.19E+01	3.10E+01	3.58E+01
4.000E−02	6.85E−01	7.17E−01	7.20E−01	7.19E−01	7.19E−01	7.93E−01
8.000E−02	2.23E−01	2.27E−01	2.27E−01	2.27E−01	2.37E−01	2.36E−01
8.000E−01	7.15E−02	7.17E−02	7.15E−02	7.16E−02	7.70E−02	7.17E−02
1.000E+00	6.43E−02	6.45E−02	6.42E−02	6.43E−02	6.92E−02	6.44E−02
1.022E+00	6.36E−02	6.38E−02	6.35E−02	6.37E−02	6.84E−02	6.37E−02
2.000E+00	4.51E−02	4.53E−02	4.51E−02	4.52E−02	4.85E−02	4.53E−02
2.044E+00	4.46E−02	4.48E−02	4.46E−02	4.47E−02	4.80E−02	4.47E−02
3.000E+00	3.68E−02	3.69E−02	3.68E−02	3.69E−02	3.94E−02	3.69E−02
1.000E+01	2.33E−02	2.35E−02	2.34E−02	2.34E−02	2.42E−02	2.36E−02
1.300E+01	2.22E−02	2.23E−02	2.23E−02	2.22E−02	2.28E−02	2.25E−02
1.800E+01	2.14E−02	2.15E−02	2.15E−02	2.14E−02	2.17E−02	2.18E−02
2.200E+01	2.12E−02	2.14E−02	2.14E−02	2.13E−02	2.14E−02	2.17E−02
2.400E+01	2.12E−02	2.14E−02	2.13E−02	2.12E−02	2.13E−02	2.17E−02
2.600E+01	2.12E−02	2.14E−02	2.14E−02	2.13E−02	2.13E−02	2.17E−02
2.800E+01	2.13E−02	2.14E−02	2.14E−02	2.13E−02	2.13E−02	2.18E−02
3.000E+01	2.13E−02	2.15E−02	2.15E−02	2.13E−02	2.13E−02	2.18E−02
4.000E+01	2.17E−02	2.18E−02	2.18E−02	2.17E−02	2.15E−02	2.22E−02
5.000E+01	2.21E−02	2.23E−02	2.23E−02	2.22E−02	2.18E−02	2.27E−02
6.000E+01	2.25E−02	2.27E−02	2.27E−02	2.26E−02	2.22E−02	2.32E−02
8.000E+01	2.33E−02	2.35E−02	2.35E−02	2.33E−02	2.28E−02	2.40E−02
1.000E+02	2.39E−02	2.41E−02	2.41E−02	2.40E−02	2.34E−02	2.46E−02
2.000E+02	2.58E−02	2.61E−02	2.61E−02	2.59E−02	2.51E−02	2.66E−02
4.000E+02	2.74E−02	2.76E−02	2.77E−02	2.75E−02	2.66E−02	2.83E−02
6.000E+02	2.81E−02	2.84E−02	2.84E−02	2.82E−02	2.73E−02	2.90E−02
8.000E+02	2.85E−02	2.88E−02	2.88E−02	2.86E−02	2.77E−02	2.94E−02
1.000E+03	2.88E−02	2.91E−02	2.91E−02	2.89E−02	2.80E−02	2.97E−02