ARTICLE IN PRESS

Radiation Physics and Chemistry xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Radiation Physics and Chemistry

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

Determination of gamma ray shielding parameters of rocks and concrete

Shamsan S. Obaid, Dhammajyot K. Gaikwad*, Pravina P. Pawar

Department of Physics, Dr. Babasaheb Ambedkar Marathwada University, Aurangabad 431004, India

A R T I C L E I N F O

Keywords:
Rocks
Concrete
Mass attenuation coefficient
Effective atomic number

A B S T R A C T

Gamma shielding parameters such as mass attenuation coefficient (μ/ρ), effective atomic number (Z_{eff}) and electron density (N_{eff}) have been measured and calculated for rocks and concrete in the energy range 122–1330 keV. The measurements have been carried out at 122, 356, 511, 662, 1170, 1275, 1330 keV gamma ray energies using a gamma spectrometer includes a NaI(Tl) scintillation detector and MCA card. The atomic and electronic cross sections have also been investigated. Experimental and calculated (WinXCom) values were compared, and good agreement has been observed within the experimental error. The obtained results showed that feldspathic basalt, compact basalt, volcanic rock, dolerite and pink granite are more efficient than the sandstone and concrete for gamma ray shielding applications.

1. Introduction

Study of the interaction of gamma radiations with matter is an important subject in the field of nuclear medicine, diagnostics, radiation protection and radiation physics and chemistry. The probability of radiation interacting with a material per unit path length is called the linear attenuation coefficient (μ), and is of great importance in radiation shielding. The mass attenuation coefficient (μ/ρ), which is defined as the μ per unit mass of the material, is the basic physical quantity characterizing the diffusion and penetration gamma radiations in the materials. Scattering and absorption of gamma radiations are related to the density and atomic numbers of the material, therefore knowledge of (μ/ρ), atomic cross section (σ_t), electronic cross section (σ_{el}), Z_{eff} and N_{eff} are of prime importance. The glass, concrete and rock are used in the radiation shielding technology because of its high attenuation cross-section for X-rays, Gamma ray photons and neutrons (Abdo, 2002; Singh et al., 2008). Typical applications of these materials are in the construction of hospitals (X-ray unit and therapy room), nuclear research laboratories, power stations, particle accelerators and radioactive waste disposal units.

Investigation of the physical parameters such as (μ/ρ), σ_t, σ_{el}, Z_{eff} and N_{eff} of rocks and concretes is useful for understanding their physical properties. A comparison of predicted and experimental values of attenuation coefficients provides a check on the validity of physical parameters such as X-ray emission rates, fluorescence yields and jump ratio (Sitamahalakshmi et al., 2015). In composite materials, a single number cannot represent the atomic number uniquely in the entire energy region for photon interactions. This unique number for complex materials is called Z_{eff}, which is varying with energy. The effective atomic number is a convenient parameter for understanding the attenuation of X-rays and gamma photons in composites (Manohara et al., 2007). The accurate value of Z_{eff} is very useful for medical radiation dosimetry, imaging and technological applications.

Nowadays, radiations and radioisotopes are used in many diverse fields such as medical diagnosis, medicine, nuclear and food industry, scientific research. Therefore gamma ray shielding investigation of various material gains great attention. Tabulations of (μ/ρ) and the mass energy absorption coefficients for 40 elements and 45 mixtures and some compounds over the energy range from 1 keV to 20 MeV have been reported by Hubbell (1982). Chantler published tabulations of scattering cross-sections and quantities related to (μ/ρ). A computer program XCOM was developed by the Berger and Hubbell (1987), which calculates attenuation coefficients and photon cross sections for elements compounds and mixtures in the energy range 1 keV to 100 GeV. This widely used program transformed to windows platform called WinXCOM (Gerward, 2001). Using XCOM and WinXCOM, many attempts have been made to calculate attenuation coefficients for different elements, compounds and mixtures. Kaewkhao et al. (2010) determined the (μ/ρ) experimentally and theoretically for borate-bismuth glass system. Un and Demir (2013) calculated (μ/ρ), Z_{eff} and N_{eff} of heavy-weight and normal-weight concrete, and observed that iron, barium and calcium concentration of the concretes is more capable for X- or gamma radiation shielding. Demir and Keles (2006) performed a narrow beam transmission experiment using Am-241 and Ba-133 for concrete containing boron waste, and found out that (μ/ρ) is increased with increasing boron concentration in the concrete. Medhat (2009)

* Corresponding author.
E-mail addresses: shamsan_abed2012@hotmail.com (S.S. Obaid), dhammajyotg26@gmail.com (D.K. Gaikwad), pravinapawar4@gmail.com (P.P. Pawar).

http://dx.doi.org/10.1016/j.radphyschem.2017.09.022
Received 23 January 2017; Received in revised form 21 August 2017; Accepted 19 September 2017

Please cite this article as: Obaid, S.S., Radiation Physics and Chemistry (2017), http://dx.doi.org/10.1016/j.radphyschem.2017.09.022

Table 1
Chemical composition as weight fraction in percentage (*w*%) of rocks and concrete.

Sample	O (*w*%)	Na (*w*%)	Mg (*w*%)	Al (*w*%)	Si (*w*%)	P (*w*%)	K (*w*%)	Ca (*w*%)	Ti (*w*%)	Mn (*w*%)	Fe (*w*%)	S (*w*%)	H (w%)	C (w%)
Feldspathic basalt	0.44352	0.02923	0.02404	0.06711	0.23944	0.00172	0.00769	0.07866	0.01408	0.00132	0.09321	–	–	–
Compact basalt	0.44537	0.03282	0.02058	0.06329	0.24496	0.00238	0.00833	0.06438	0.01699	0.0013	0.0996	–	–	–
Volcanic rock	0.434257	0.038852	0.02455	0.061466	0.222114	0.00372	0.01166	0.08656	0.021733	0.002072	0.093016	–	–	–
Pink granite	0.487639	0.03831	0.000019	0.054954	0.358348	0.000249	0.041024	0.004965	0.00103	0.000242	0.01322	–	–	–
Sandstone	0.526674	0.000108	0.000021	0.028128	0.437027	0.000169	0.000043	0.00218	0.000702	0.000064	0.004883	–	–	–
Dolerite	0.43996	0.02976	0.02287	0.06466	0.22981	0.00152	0.00259	0.07076	0.02251	0.00167	0.1139	–	–	–
Concrete	0.45558	0.04176	0.02967	0.04176	0.12205	–	0.01934	0.24957	0.00024	–	0.01602	0.00215	0.0087	0.0256

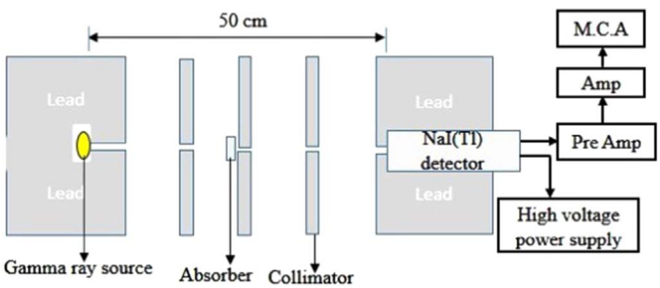

Fig. 1. Schematic view of experimental setup.

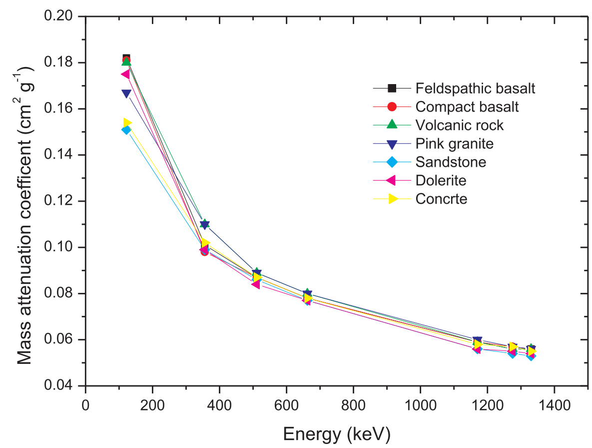

Fig. 2. The measured mass attenuation coefficients at 122–1330 keV.

determined the (μ/ρ) for the building materials using a high-resolution HPGe spectrometer detector, and showed that a brick covered with cement can shield about 49–67% more radiations than brick itself. In recent years, A great number of researchers reported (μ/ρ), Z_{eff} and N_{eff} in different materials such as concretes (Akkurt et al., 2012; Medhat, 2012; Oto et al., 2015, 2016), alloys (Singh et al., 2014; Kaewkhaoa et al., 2008), compound and mixtures (Awasarmol et al., 2017a, 2017b; Bhosale et al., 2016a, 2016b; Gaikwad et al., 2016; Pawar and Bichile, 2013; Un and Sahin, 2011) and glasses (Matori et al., 2017; Singh et al., 2014). Oto et al. (2016) calculated Z_{eff} and effective removal cross-sections of magnetite concrete for gamma and fast neutron shielding.

In this paper, mass attenuation coefficients (μ/ρ) of some rocks and a concrete have been measured in the energy range 122–1330 keV and calculated using the computer code WinXCom. Then atomic and electronic cross sections, effective atomic number and electron density have been determined using (μ/ρ) for same energies. This work also includes a comparison of attenuation coefficients of rocks with concrete. Present results could be very useful in radiation shielding applications for construction of nuclear power plants, X-ray and radiotherapy units.

2. Experimental details

Concrete has been produced using the ordinary Portland cement (PC 42.5) and normal sand. A constant water (w) to cement (c) ratio (w/c = 50%) and 25% normal sand concentration was selected for concrete preparation. Rocks and produced concrete samples were ground separately and sieved with 400 mesh. These samples were heated (at 60 °C)

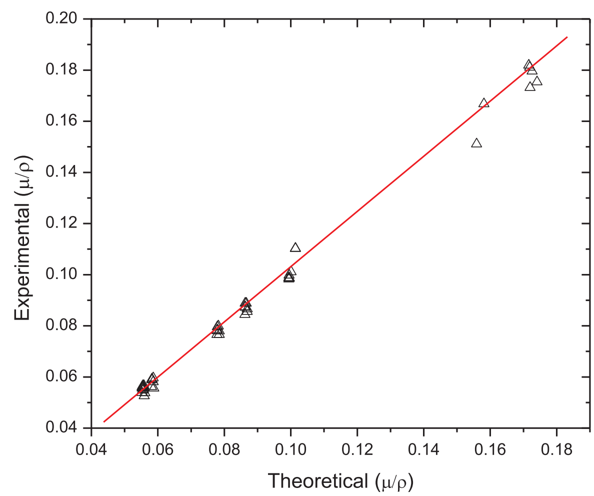

Fig. 3. Experimental (μ/ρ) versus theoretical (μ/ρ).

Table 2
Mass attenuation coefficients (cm^2/g) of rocks and concrete samples.

Energy (keV)	Feldspathic basalt		Compact basalt		Volcanic rock		Pink granite		Sandstone		Dolerite		Concrete	
	μ/ρ exp.	μ/ρ theo.	μ/ρ exp.	μ/ρ theo.	μ/ρ exp.	μ/ρ theo.	μ/ρ exp.	μ/ρ theo.	μ/ρ exp.	μ/ρ theo.	μ/ρ exp.	μ/ρ theo.	μ/ρ exp.	μ/ρ theo.
122	0.182	0.172	0.181	0.172	0.180	0.173	0.167	0.158	0.151	0.156	0.175	0.174	0.154	0.153
356	0.101	0.100	0.098	0.099	0.110	0.101	0.110	0.101	0.099	0.010	0.099	0.099	0.102	0.100
511	0.087	0.086	0.087	0.086	0.089	0.086	0.089	0.087	0.086	0.087	0.084	0.086	0.087	0.086
662	0.078	0.078	0.078	0.078	0.080	0.078	0.080	0.078	0.077	0.079	0.077	0.078	0.078	0.077
1170	0.059	0.058	0.059	0.058	0.059	0.058	0.060	0.059	0.056	0.059	0.056	0.058	0.058	0.059
1275	0.056	0.056	0.057	0.056	0.056	0.056	0.057	0.056	0.054	0.056	0.055	0.055	0.057	0.057
1330	0.056	0.055	0.056	0.055	0.056	0.055	0.056	0.056	0.053	0.056	0.054	0.055	0.055	0.055