ScienceDirect

Radiation Physics and Chemistry

Volume 148, July 2018, Pages 86-94

Attenuation coefficients and exposure buildup factor of some rocks for gamma ray shielding applications

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https://doi.org/10.1016/j.radphyschem.2018.02.026

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Highlights

- Measurement of gamma ray shielding properties of some rocks.
- Experimental results are compared with Xcom and MCNP.
- Exposure buildup factor has been determined to understand the shielding capability of rocks.
- Rocks are good candidates for shielding against ionizing radiation than concretes.
- Pink marble is efficient gamma ray shielding material.

Abstract

In the present work, the mass attenuation coefficient μ/ρ is investigated experimentally and theoretically for seven rocks (olivine basalt, green marble, jet black granite, telphone black granite, cuddapah limestone, white marble and pink marble). The rock samples were collected from different places of India. The mass attenuation coefficients of the samples were measured experimentally at photon energies of radioisotopes Co^{57} (122 keV), Ba^{133} (356 keV), ^{22}Na (511 and 1275 keV), Cs^{137} (662 keV), Mn^{54} (840 keV), and Co^{60} (1330 keV). Theoretically, the simulation results of μ/ρ using both XCOM and MCNP5 codes were compared with experimental results and a satisfactory agreement was observed. Total atomic cross sections ($\sigma_{t.a}$) electronic cross sections ($\sigma_{t.e}$), effective atomic number (Z_{eff}), electron density (N_e) and half value layer (HVL) were evaluated using the obtained μ/ρ values for investigated rocks. The HVL values for the selected rocks were compared with some common shielding concretes. Moreover, by Geometric Progression method (G-P) exposure buildup factor (EBF) and energy absorption buildup factor (EABF) values were calculated for incident photon energy 0.015–15 MeV up to penetration depths of 40 mean free paths. The results show that among the studied rocks pink marble possesses superior shielding properties for γ-ray. This work was carried out to explore the advantage of utilizing the selected rocks in engineering structures and building construction to shield gamma-rays.

Introduction

Human beings are exposed to many types of radiation, some existing in the soil, water and plants; while others are man-made, such as x-ray, medical equipment and factory waste. For this reason, it is important to determine the buildup factors to make corrections for effective energy deposition in different shielding materials. Nowadays, radioactive isotopes are used widely in tomography, medicine gamma-ray fluorescence studies, radiation biophysics, nuclear power plant, agriculture, industry and research, this brings serious shielding problems as X-rays, gamma photons and neutrons are hazardous to human health. Concretes with aggregates of different rocks are used widely in the construction of medical hospitals (X-ray unit and Gamma chamber), nuclear power plant, accelerators, etc. Homogeneous and high density rocks are essential for effective radiation protection; these rocks would be a good choice in building construction to protect against hazardous radiations (Akkurt et al., 2007a, Akkurt et al., 2007b). Using rocks in building construction is reasonable as plenty of rocks reservoir available worldwide. Some rocks contain a high attenuation coefficient of gamma rays, and the appropriate type of rocks for shielding can be selected in buildings as a protection against various radiations by calculating the buildup factors. The buildup factor is defined as the ratio of the total value of a specified radiation quantity at any point to the contribution to that value from radiation reaching the point without having undergone a collision. Buildup factors exist into two types: (1) the absorbed buildup factor or deposited energy in the interesting materials and detector response function is that of absorption in the interacting medium, (2) the exposure buildup factor (EBF) in which quality of interest is the exposure and a detector response function is that of absorption in the air (Kurudirek and Topcuoglu, 2011, Mann et al., 2012a, Mann et al., 2012b, Mann et al., 2012c, Sayyed and Elhouichet, 2017, Lakshminarayana et al., 2017, Singh et al., 2008a, Singh et al., 2008b, Singh and Badiger, 2014, Manjunatha and Rudraswamy, 2012).

High energy photons penetration and diffusion in the medium can be characterized by linear and mass attenuation coefficients. The linear attenuation coefficient is the probability of a radiation interacting with a matter per unit path length, depends on the intensity of the incident photons, atomic number and density of absorber. A computer program XCOM was developed by 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. Gerward et al. (2001) transformed this program to windows platform called WinXCOM. In recent years, many researchers have been studied extensively attenuation coefficients and buildup factor using XCOM and WinXCOM of various materials such as bricks (Sayyed et al., 2017a), ores (Oto et al., 2015), glasses (Sayyed, 2016a, Sayyed, 2017, Dong et al., 2017a, Matori et al., 2017, Singh et al., 2014a, Singh et al., 2014b, Singh et al., 2014c, Brow, 2000, Sayyed et al., 2017b), organic compounds (Gaikwad et al., 2016, Gaikwad et al., 2017, Pawar and Bichile, 2013, Awasarmol et al., 2017a), minerals (Han et al., 2009, Han et al., 2011), soil (Al-Masri et al., 2013, Alam et al., 2001, Appoloni and Rios, 1994), rocks (Akkurt et al., 2007a, Akkurt et al., 2007b, Karabul et al., 2015; Obaid et al., 2018), concretes (Akkurt et al., 2012, Ali et al., 2016, Oto et al., 2016, Demir and Keleş, 2006) and building materials (Medhat, 2009; Singh et al., 2004; Salinas et al., 2006; Awadallah and Imran, 2007; Mann et al., 2012a, Mann et al., 2012b,Mann et al., 2012c, Mann et al., 2013). Variety of rocks and concretes 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., 2008a, Singh et al., 2008b).

However, recent works have investigated the gamma-ray shielding properties of different concretes and rocks. For example, Akkurt et al., 2007a, Akkurt et al., 2007b have been reported gamma radiation shielding properties of granite, granodiorite, andesite (black) and andesite a type of igneous rock.Karabul et al. (2015) have studied Exposure and absorption buildup factors of three basalt rocks collected from different parts of Van city, Turkey. Akkurt et al. (2012) have reported radiation shielding properties of concrete and stated that the radiation shielding parameters are decreased with the increasing exposed time of concrete in the chemical media. This demonstrates that additional works are necessary for better understanding of the gamma-ray shielding capability of the other types of rocks. Besides, the rocks are abundantly available in all parts of the world, cheap and can be shaped into any desired form.

In general, rocks are frequently utilized as building and architectural covering stones in different schools, hospitals, houses and engineering constructions, therefore it is important to examine their response to radiation. Hence, some shielding parameters such as mass attenuation coefficients should be evaluated by testing the materials for radiation shielding. It is important in radiation protection since it measures the probability of the interaction that occurs between gamma radiation and atomic medium of the rock sample. Therefore, in the present work, experimental values of mass attenuation coefficients (μ/ρ), atomic cross section, electronic cross sections, effective atomic numbers, effective electron densities and half value layer have been determined for seven rocks (olivine basalt, green marble, jet black granite, telephone black granite, cuddapah limestone, white marble and pink marble) at the energies 122, 356, 662, 840, 1170, 1275 and 1330 keV. The μ/ρ values were also calculated theoretically using the MCNP5 code and XCOM program. In addition to that, we have calculated the exposure buildup factors (EBF) using G-P fitting method for incident photon energy 0.015–15 MeV up to penetration depths of 40 mean free path (mfp), where the mean free path is the average distance between two successive interactions of photons which results in decreasing the intensity of incident photon beam by the factor of 1/*e*. This work also includes a comparison of attenuation coefficients of the selected rocks with different concretes.

The various rock samples used in this study were collected from different places of India. To our best knowledge, theoretical and experimental investigations of the different shielding parameters for present rocks are not available in the literature. Besides, the results of this investigation can simulate theoretical and experimental research for other rocks.

Section snippets

Sample preparation

Seven rock samples were collected carefully from various places in India. Special attention, on the availability, compactness, physical formation and uniform composition, was given in selecting the rocks. The rock samples were crushed and ground. Each sample was crushed into small pieces by using a crushing machine and then sieve to 200 meshes with grinding machine. The fine powder of rocks was dried in a muffle furnace at 110 °C for each sample. Then, the rock analysis was obtained by X-ray…

Results and discussion

The mass attenuation coefficient, μ/ρ for the rocks (olivine basalt, green marble, jet black granite, telphone black granite, cuddapah limestone, white marble and pink marble) were measured at 122, 356, 511, 662, 840, 1170, 1275 and 1330 keV. In order to test the validity of our results, the μ/ρ values for the investigated rocks were carried out by the XCOM and MCNP5 code. Simulated geometry was the same as used by Dong et al. (2017a). The results of the present calculations are listed in Table …

Conclusion

The present study aimed to obtain some information on the μ/ρ and related parameters such as μ, $\sigma_{t.a}$, $\sigma_{t.e}$, Z_{eff}, N_e and HVL for different rocks. The experimental values of μ/ρ were verified by XCOM and MCNP5 code at different energies. In addition, the G-P fitting method was used to evaluate the EBF and EABF values of the investigated rocks. Also, the selected rocks were compared in terms of HVL with different concretes. It is found that the μ, $\sigma_{t.a}$, $\sigma_{t.e}$, Z_{eff} and N_e, values of pink marble…

Acknowledgement

One of the authors DKG would like to thank UGC New Delhi for Providing RGNF....

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