Progress in Nuclear Energy 85 (2015) 391–403

Contents lists available at ScienceDirect

Progress in Nuclear Energy

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

Investigation of gamma radiation shielding properties of various ores

Berna Oto [a], Nergiz Yıldız [a], Fatma Akdemir [b], Esra Kavaz [b,*]

[a] Yüzüncü Yıl University, Faculty of Science, Department of Physics, 65080, Van, Turkey
[b] Atatürk University, Faculty of Sciences, Department of Physics, 25240, Erzurum, Turkey

ARTICLE INFO

Article history:
Received 16 February 2015
Received in revised form
22 July 2015
Accepted 23 July 2015
Available online xxx

Keywords:
Gamma ray
Mass attenuation coefficients
Effective atomic number
Buildup factor
Radiation shielding

ABSTRACT

Mass attenuation coefficients (μ/ρ, cm^2/g) for some pellet samples produced using barite, magnetite, limonite, hematite and serpentine ores at 81, 276, 302, 356, 383 keV photons emitted from ^{133}Ba and 121, 244, 344, 444, 778 keV photons emitted from ^{152}Eu have been determined by using HPGe detector. Effective atomic numbers (Z_{eff}) and electron densities (N_e) of the ores calculated in the selected energies. . The agreement of measured values of μ/ρ, Z_{eff} and N_e with theoretical calculations is quite satisfactory. Mass attenuation coefficients were found to be highest for barite. The Z_{eff} and N_e values for barite are maximum, for serpentine are minimum. Gamma ray energy absorption (EABF) and exposure buildup factors (EBF) were computed for ore samples using the five-parameter Geometric Progression (G-P) fitting method in the energy range 0.015–15 MeV for penetration depths up to 40 mean free path. Variations of EABF and EBF with incident photon energy and penetration depth were also investigated. It has been observed that among the selected ore samples, barite has lowest values for EABF and EBF in the intermediate energy region. Buildup of photons is more for serpentine. Exposure buildup factors (EBF) of given ores were compared with lead, steel-magnetite concrete (SM), concrete and bismuth borosilicate glass (BBS) with %20 mol Bi_2O_3. Barite is superior in terms of shielding properties among the other ore samples. The present study may be useful for radiation shielding applications.

1. Introduction

In order to preserve both human and their surroundings from harmful effects of radiation different shielding materials have been produced. Barite ($BaSO_4$) is the naturally occurring form of barium sulphate and is a common mineral in nature. High density and chemical compound of barite ore, make it an ideal material for many applications such as industrial, medical and manufacturing. Magnetite (Fe_3O_4) is an oxide of iron which is strongly magnetic. It is one of the most widely used types of heavy aggregate for high-density radiation shielding concrete. Hematite (Fe_2O_3) is an oxide of iron, and the pure mineral. The low cost and high density of hematite also makes it useful for shielding of gamma and X-ray radiations. Limonite ($2Fe_2O_3\cdot 3H_2O$) is basically hydrated iron oxide, deposits of which are found mainly in low-lying areas. Serpentine ($3MgO.2SiO_2\cdot 2H_2O$) is one of the basic ores for asbestos and consists mainly of hydrated magnesium silicate. Because of limonite and serpentine ores' high water level, they are used in concrete for nuclear power plants as neutron shields (Kaplan, 1989).

The interactions of photons with material are characterized by mass attenuation coefficient μ/ρ which is the probability of a photon interacting per unit thickness (g/cm^2) (Hubbell, 1969). The initial photon interactions within material are characterized by mass attenuation coefficient (μ/ρ) which is the probability of a photon interacting per unit thickness (g/cm^2) (Hubbell, 1969). This probability depends on: (i) the incident photon energy; E (MeV), (ii) the material density, ρ (g/cm^3); and (iii) the atomic number (Z) of the material. Hubbell (1977) has determined the mass attenuation coefficients for H, C, N, O, Ar and seven mixtures energy range from 0.1 keV to 20 MeV. Then Hubbell (1982) advanced these studies on different compounds as well as on different elements. Berger et al. (1987) developed XCom for calculating μ_ρ or photon interaction cross-sections for any element, compound or mixture at energies from 1 keV to 100 GeV. Windows version of XCom is being called WinXCom (Gerward et al., 2004).

The attenuation (the scattering and the absorption) of photons is related to the density and atomic number of an element. For

* Corresponding author.
E-mail address: esrakvz@gmail.com (E. Kavaz).

http://dx.doi.org/10.1016/j.pnucene.2015.07.016
0149-1970/

Table 1
Properties of ore samples.

Sample	Mass (g)	Pellet mass (g)	Pellet thickness	Pellet diameter (cm)	Pellet density (g/cm^3)
Barite	10.2	10.166	0.55	3.7	1.72
Magnetite	10.2	10.144	0.59	3.7	1.60
Limonite	10.2	10.123	0.60	3.7	1.57
Hematite	10.2	10.127	0.62	3.7	1.52
Serpentine	10.2	10.128	0.65	3.7	1.45

Table 2
The chemical content of the ores.

Compound	Barite(%)	Magnetite(%)	Limonite(%)	Hematite(%)	Serpentine(%)
SiO_2	2.06	8.41	0.001	38.81	37.6
CaO	0.84	1.15	5.73	0.060	4.82
MgO	0.51	0.50	2.08	7.33	38.40
Al_2O_3	0.36	1.26	1.90	11.0	3.42
Fe_2O_3	0.05	–	70.94	27.0	5.10
NaCl	0.10	–	–	–	–
$CaCO_3$	1.98	–	–	–	–
K_2O	0.03	–	0.77	0.12	–
MnO	0.09	0.44	0.08	0.11	–
$BaSO_4$	93.1	–	–	–	–
SrO	0.88	–	0.005	–	–
FeO	–	85.74	–	–	2.04
Na_2O	–	0.195	2.94	0.014	1.17
CuO	–	0.013	0.03	0.14	–
BaO	–	2.24	–	–	–
P_2O_5	–	–	0.34	0.1	–
TiO_2	–	–	0.30	0.90	–
Cr_2O_3	–	–	–	0.22	–
SO_3	–	–	–	0.98	–
H_2O	–	–	13.7	–	10.26

composite materials such as concrete, alloy, glass system, it is related to effective atomic number (Z_{eff}), and Z_{eff} values change with energy. Many works of effective atomic number for compound materials have been reported by several authors (Akkurt and El-Khayatt, 2013; Elmahroug et al., 2015; Baltaş et al., 2007). Buildup factors, which are important data in nuclear radiation shielding and absorbed dose calculations, have been widely studied by various researchers (Küçük, 2010; Kavaz et al., 2015; Manahora et al., 2010; Singh and Badiger, 2014). There are two types of buildup factor:

- the energy absorption buildup factor that is the buildup factor in which the quantity of interest is the absorbed or deposited energy in the interacting material and the detector response function is that of absorption in the interacting material;
- the exposure buildup factor is the buildup factor in which the quantity of interest is the exposure and the detector response function is that of absorption in air (Singh et al., 2008).

There are various methods for calculating buildup factors such as G.P. fitting method (Harima et al., 1986), invariant embedding method (Shimizu, 2002), iterative method (Suteau and Chiron, 2005) and Monte Carlo method (Sardari et al., 2011). American National Standards ANSI/ANS 6.4.3 (1991) has presented the buildup factor data for 23 elements, one compound and two mixtures (i.e. air and water) and concrete at energies in the range 0.015–15 MeV up to penetration depths of 40 mean free path by using the G-P method (Singh et al., 2008).

In the present work, the shielding parameters of five ores (barite, magnetite, hematite, limonite and serpentine) were investigated. The mass attenuation coefficients, effective atomic numbers and electron densities of the ores were determined at 81, 276, 302, 356 and 383 keV photons from ^{133}Ba point source and 121, 244, 344, 444 and 778 keV photons from ^{152}Eupoint source. Besides, we report the energy absorption and exposure buildup factors by using the G-P fitting method for the ores in the energy region 0.015–15 MeV up to penetration depths of 40 mfp. The effect of some parameters such as photon energy and penetration depth on both the two buildup factors, EABF and EBF, have been

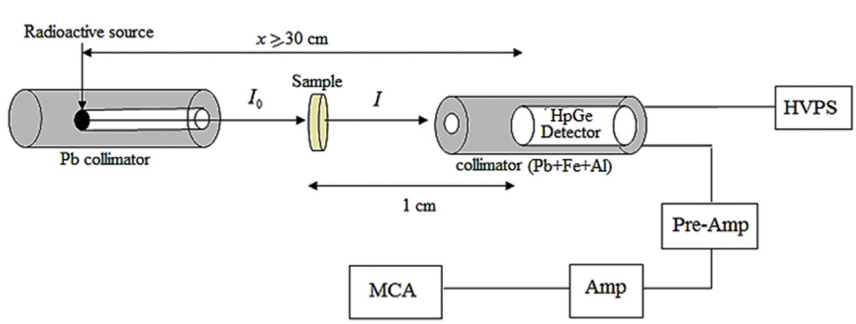

Fig. 1. Experimental set up.