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Investigation of Gamma Ray and Neutron Attenuation Coefficients for Granites Produced in Turkey

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In this study, shielding properties of granites which are produced in Turkey were studied for gamma ray and neutrons. Linear and mass attenuation coefficients for gamma ray were measured at 1.17 MeV, 1.33 MeV and 0.662 MeV by gamma spectrometry system containing NaI(Tl) detector. Pu-Be source was used in measuring linear neutron attenuation coefficients of the granite samples. Measurements were carried out by using narrow beam geometry by using gamma and neutron transmission technique. The gamma transmission results have been compared with winXCOM calculations and a good correspondence has been obtained.

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1. Introduction

Radiation protection is one of the most significant parts of building construction. As shielding is one of the basic methods for radiation protection, besides the physical and mechanical properties of materials used in building construction, the radiation shielding properties should also be known. Granite is widely used as a building and ornamental material because of its polished surface and its availability in a variety of attractive colors. The term ‘granite’ is used to describe all igneous rock types used as building materials in stone market [1].

In radiation physics, measuring the probability of all possible interactions between photon and medium is essential [2]. Linear attenuation coefficient magnitude depends on the atomic number, the density of shielding materials and the incident photon energy [3]. Linear attenuation coefficient of a material for a given specific gamma energy can be determined both experimentally, using narrow beam geometry and theoretically by using winXCOM or XCOM. In literature various natural rocks and building construction materials were studied by many scientists in terms of their gamma shielding properties [2, 4, 5].

In this study different granite samples, which are produced in Turkey were investigated. These are polished granite tiles ready to use in public and commercial buildings. The shielding properties of these granites were studied for gamma ray and neutrons.

2. Experimental details

In this study different granite samples such as Giresun Vizon, Aksaray Pink, Bergama Grey, Çanakkale Grey, Kozak, Aksaray Yaylak, Hisar Yaylak and Balaban Green which are produced in Turkey were investigated. These granites which have form of polished tiles are commonly used in public and commercial buildings. The granite tiles measured 30 cm×30 cm×2 cm and their masses varied from 4 to 6 kg [1].

2.1. Chemical analysis

Theoretical calculations for photon attenuation coefficients require the chemical compositions of the granite samples. Briefly, XRF is an analytical method for determination of the chemical composition of all kinds of materials. X-rays produced by a source, which is generally an X-ray tube, irradiate the sample. The elements in the sample will emit fluorescent X-ray radiation with discrete energies that are characteristic values for elements in the sample. XRF measurements were accomplished at chemical analysis laboratory of Turkish Atomic Energy Authority (CNAEM). Table I shows the chemical compositions of granite samples.

The chemical compositions of granite samples (%). TABLE I

Compound	Giresun Vizon	Pink Aksaray	Aksaray Yaylak	Balaban Green	Bergama Grey	Canakkale Grey	Hisar Yaylak	Kozak
SiO_2	73.87	79.92	79.28	77.33	77.21	76.42	78.47	77.52
Al_2O_3	14.79	15.99	15.87	15.48	15.45	15.29	15.71	15.52
K_2O	6.240	3.240	3.010	2.690	3.340	3.830	2.060	2.790
Fe_2O_3	0.980	0.170	0.004	0.795	0.627	0.660	0.589	0.686
FeO	1.360	0.240	0.006	1.095	0.863	0.910	0.811	0.944
CaO	2.070	0.280	1.560	2.070	2.130	2.410	1.990	2.150
TiO_2	0.200	0.060	0.125	0.268	0.167	0.207	0.122	0.184

2.2. Transmission technique

Penetration of gamma rays through material is the basic of gamma transmission technique [6, 7]. The detector and the gamma source are placed at opposite sides of material on the same axis. Gamma ray intensity comes from the source counted by the detector [8]. The transmittance of gamma radiation can be calculated from the following equation for the narrow beam geometry:

$$I = I_0 \mathrm{e}^{-\mu x}. \quad (1)$$

Here I and I_0 are transmitted and incident gamma radiation intensity, μ is the linear attenuation coefficient

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of the sample at a specific gamma ray energy and x is the thickness of the sample [7]. In radiation shielding, half value layer (HVL) is one of the crucial values. Half value layer depends on the material and the energy of the photons and it can be derived from linear attenuation coefficient by using Eq. 2.

$$HVL = (\ln 2)/\mu, \quad (2)$$

where μ is the linear attenuation coefficient [7]. A general schematic diagram of experimental set up geometry is given in Fig. 1.

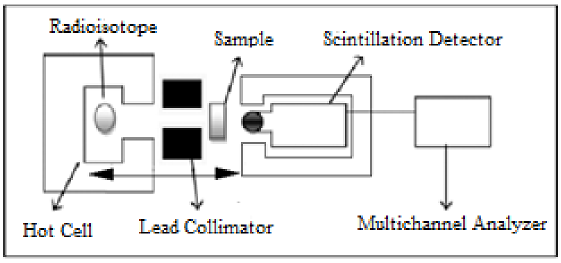

Fig. 1. The schematic diagram of experimental setup [9].

The distance between the source and detector is 100 mm and the holes of collimators are 7 mm. Granite samples were placed at equal distances between the detector and the source. ^{137}Cs and ^{60}Co gamma radioisotopes were used in the experiments where their half lives are 30.1 and 5.23 years, respectively [9–11]. ^{137}Cs radioisotope has single energy peak at 0.662 MeV, ^{60}Co gamma source emits two major energy peaks at 1.17 and 1.33 MeV. $2'' \times 2''$ NaI(Tl) scintillation detector (Canberra) and digital gamma spectrometer were used in the experiments. Digital gamma spectrometer (digiBASE model PMT) has 8.5% resolution for 0.662 MeV of ^{137}Cs. Peak areas in the spectrums were determined by using MAESTRO-32 MCA software program. Counting times was applied as one hour for ^{60}Co and half an hour for ^{137}Cs energy peak. In the experiments, measurements were taken three times for minimizing the errors. Errors were less than 5% for ^{60}Co and ^{137}Cs.

Neutron attenuation coefficients were investigated experimentally by using neutron attenuation setup. A PuBe Neutron Howitzer (NH-3) which was produced by Nuclear Chicago Corporation, was used for neutron source. Pu-Be neutron source has 5 Ci activity, 10^6 n/cm^2 s neutron flux and 5 MeV average neutron energy. Paraffin wax (2.5 cm thick) was used for slowing down the neutrons, to increase the interaction strength of neutrons with materials' atoms. PM1401K model, scintillation detector and Multi Channel Analyzer (MCA), combined system was used to detect gamma rays and He-3 detector was used for neutron counting [10]. At first, the initial intensity I_0 was measured without any material. After then neutron intensities were measured at different thicknesses (I) for all granite materials. Relative intensity I/I_0 values were calculated out for the granites at different thicknesses. Then relative intensity-material thickness graphs were drawn.

TABLE II
The chemical compositions of granite samples (%).

Granite	Phot. En. [keV]	Experimental μ [cm^{-1}]	Experimental Std. Dev.	Experimental μ_{mass} [cm^2/g]	Experimental HVL (cm)	Computational μ [cm^{-1}]	Computational μ_{mass} [cm^2/g]	Computational HVL [cm]
Aksa-	662	0.2146	0.0135	0.0822	3.2299	0.2011	0.0771	4.9724
-ray	1170	0.1542	0.0101	0.0591	4.4951	0.1530	0.0586	6.5370
Pink	1330	0.1320	0.0282	0.0614	5,2511	0.1433	0.0549	6.9784
Gire-	662	0.2230	0.0115	0.0835	3.1083	0.2055	0.0770	4.8661
-sun	1170	0.1682	0.0158	0.0630	5.9459	0.1565	0.0586	6.3901
Vizon	1330	0.1320	0.0024	0.0495	7.5739	0.1466	0.0549	6.8216
Ber-	662	0.1721	0.0102	0.0647	5.8105	0.2048	0.0770	4.8840
-gama	1170	0.1651	0.0050	0.0621	6.0560	0.1559	0.0586	6.4131
Grey	1330	0.1584	0.0151	0.0595	6.3131	0.1461	0.0549	6.8461
Cana-	662	0.3407	0.0094	0.0941	2.9350	0.2048	0.0770	4.8840
-kkale	1170	0.1332	0.0070	0.0501	7.5075	0.1559	0.0586	6.4131
Grey	1330	0.1293	0.0239	0.0486	7.7342	0.1461	0.0549	6.8461
Kozak	662	0.1954	0.0094	0.0737	5.1181	0.2032	0.0767	4.9207
	1170	0.1579	0.0104	0.0596	6.3348	0.1547	0.0584	6.4621
	1330	0.1420	0.0027	0.0536	7.0402	0.1450	0.0547	6.8983
Aksa-	662	0.1729	0.0103	0.0663	5.7846	0.2001	0.0767	4.9980
-ray	1170	0.1489	0.0138	0.0571	6.7181	0.1524	0.0584	6.5636
Yaylak	1330	0.1467	0.0140	0.0562	6.8171	0.1427	0.0547	7.0067
Hisar	662	0.1806	0.0248	0.0684	5.5357	0.2032	0.0770	4.9202
Yaylak	1170	0.1598	0.0159	0.0605	6.2570	0.1548	0.0586	6.4602
	1330	0.1395	0.0033	0.0529	7.1670	0.1450	0.0549	6.8964
Bala-	662	0.1999	0.0372	0.0738	5.0016	0.2086	0.0770	4.7931
-ban	1170	0.1425	0.0184	0.0526	7.0176	0.1589	0.0586	6.2933
Green	1330	0.1414	0.0201	0.0522	7.0736	0.1488	0.0549	6.7183

TABLE III
Experimental results of neutron attenuation coefficients.

Granite	Relative Intensity (I/Io) x	2x	3x	Atten. coeff. [cm^{-1}]	Standard deviation	Mass atten. coeff. [cm^2/g]
Aksaray Pink	0.868	0.762	0.724	0.0720	0.0051	0.0204
Giresun Vizon	0.808	0.710	0.645	0.0679	0.0020	0.0210
Bergama Grey	0.800	0.731	0.669	0.0748	0.0057	0.0154
Canakkale Grey	0.804	0.723	0.673	0.0696	0.0072	0.0177
Kozak	0.843	0.735	0.679	0.0803	0.0083	0.0189
Aksaray Yaylak	0.839	0.726	0.636	0.0799	0.0060	0.0163
Hisar Yaylak	0.811	0.710	0.666	0.0672	0.0063	0.0163
Balaban Green	0.831	0.725	0.676	0.0656	0.0040	0.0196

3. Results and discussion

The linear and mass attenuation coefficients for all granite samples were obtained for gamma energies of 0.662, 1.17 and 1.33 MeV. Table II shows the experimental and computational results for the gamma ray attenuation coefficients. It can be seen from Table II that linear attenuation coefficients decrease with the increasing photon energy because photoelectric absorption is dominant at low energy. Half value layer values which were calculated by using Eq. 2 increase with the increasing photon energy. Linear neutron attenuation coefficients of the granite samples are given in Table III. According to the results, Giresun Vizon has the highest mass attenuation coefficient for neutrons.

The relationship between the relative intensity of neutrons and granite thicknesses can be seen in Fig. 2. This figure shows that relative intensities decrease with increasing thicknesses.

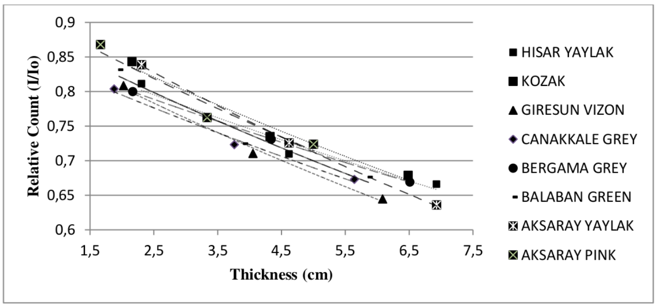

Fig. 2. Relative intensity-thickness graphs for neutrons.

4. Conclusion

In this study radiation shielding properties of the granites produced in Turkey have been evaluated in terms of photon and neutron attenuation coefficients. The highest linear attenuation coefficient was obtained for Canakkale Grey, Giresun Vizon and Aksaray Pink at 662 keV, 1173 keV and 1332 keV respectively. For neutrons, Giresun Vizon has the highest mass attenuation coefficient and Bergama grey has the lowest. The gamma ray attenuation coefficients were also calculated computationally by using XCOM code [12]. It could be said that the experimental results are close to the theoretical results.

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