AN INVESTIGATION ON SHIELDING PROPERTIES OF DIFFERENT GRANITE SAMPLES USING MCNPX CODE

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In this paper, mass attenuation coefficients of different granite samples are calculated at 662, 1173 and 1332 keV photon energies by using Monte Carlo code MCNPX (version 2.4.0). The obtained numerical results are compared not only with previous experimental and theoretical studies but also with standard theoretical data. The results showed that MCNPX results from generated simulation input agreed well with experimental studies and previous investigations. In addition, numerical deviation values of the mass attenuation coefficients in three photon energies has been obtained minimum between MCNPX andtheoretical data. The comaparative results underlined R-squared value for MCNPX approach out performs compared to both experiemental results and GATE model. Our results showed that, MCNPX is significantly convenient in comparison to GEANT4 for the energy range used. The results obtained from validated simulation input have been used for the calculation of some other important shielding parameter such as half value layer (HVL). It can be concluded that, standard simulation geometry would be useful for scientific community and MCNPX can be used as a powerful tool where no analogous experimental data exist for investigating shielding materials used in nuclear fields, industrial fields and high-energy radiation therapy facilities.

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1. Introduction

Nowadays, the increase in the number of industrial and medical fields based on the use of radiation has made the radiation protection more important. The shielding is one of the important methods to control the personnel exposure right from beginning of radiation sources and inspection methodology that can be used for radiation protection.It is significantly important to know the properties of materials used for radiation shielding materials. Moreover, during the selection of the radiation shielding material, the type of radiation and the energy of the radiation with the usage field also should be known. The term of radiation shielding is result of the radiation interaction with the material. One can say that, amount of the interaction highly depends upon atomic features such as number and density of the shielding material. Therefore, radiation shielding requires investigation on various types of compounds, mixtures and pure materials to

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provide the characteristics for radiation protection from the sources [1].Various types of building materials such as concrete, cement, brick, sand, aggregate, marble, granite, limestone gypsum can be used as radiation shielding due to their interaction properties. Granite is a well-known type of igneous rock and the term granite is used to describe all igneous rock types used as building material [2]. It has been found from the literature that a large number of investigations on shielding properties and radioactivity properties of granite have been studied by different authors. Shielding properties of Indian granites have been studied by Mavi and Akkurt [3]. The linear and mass attenuation coefficients for gamma rays for various types of common use granite samples have been studied by Najam et. al. [4]. Calculation of gamma ray attenuation coefficient of some granite samples at 662, 1173.2 and 1332.5 keV photon energies by using GATE code have been studied by Ozyurt et. al.[5].However, simulation on shielding propeties of granite by using MCNPX Monte Carlo code is not found in literature. On theotherhand, the simulation setup by GATE code of granite showed higher deviation with theoretical Standard WinXcom data. This has encourages us to develop simulation setup using MCNPX code and re-evaluate the obtained results. This study aimed to introduce a novelsimulationtoolgivingtheclosestresultwithstandardWinXcomdataforscientificcommunityforthe purpose of investigations on shielding properties.

2. Materials and method

In this study, shielding properties of different types of granitesamples has been studied by using MCNPX (version 2.4.0) general purpose Monte Carlo code. The investigated samples have been studied experimentally by Ozyurt et al [6]. The commercial names of granite samples are Aksaray Yaylak, Hisar Yaylak, Balaban Green, Giresun Vizon, Bergama Grey, Aksaray Pink, Çanakkale Grey, Kozak (S1, S2, S3, S4, S5, S6, S7, S8) with elemental mass fraction are given in Table 1.

2.1. MCNPX code

Monte Carlo simulation is found an effective method to calculate radiation interaction features in different types of compounds and mixtures for shielding studies. In this study, MCNPX (version 2.4.0) code has been used for investigation of shielding properties of different granite samples.MCNPX is a general purpose Monte Carlo code used for modeling interactions of radiation with defined materials and tracking all particle in different energy values [7]. The high capability of MCNPX Monte Carlo code for investigation of radiation mass attenuation coefficients and other shielding parameters has been found in literature[8-19]. Before the calculations, each MCNPX simulation parameter such as cell card, surface card, material definations and energy values was introduced within the input file. After that, each simulation component was placed by considering the locations of the experimental setup. As it can be seen from Fig.1, isotropic radiation source has been located inside the Pb collimator. Moreover, granite attenuator sample and F4 detection cell have been located, respectively. To obtain absorbed dose amounts in the detection area, average flux tally F4 has been used. This type of tally mash gives the sum of average flux in cell. The radiation source has been defined as a point isotropic source and geometric center of detection area has been defined as axial direction as well. Energy value of the point isotropic sources have been defined at 662, 1173 and 1332 keV photon energies for each calculations, respectively. As the quantity of number of particle (NPS), the initial quantity of gamma ray is set as 10^8 partice.Due to requirements of material definition in MCNPX input code, each granite sample has been defined with their elemental mass fractions in Table 1. The design and screeshot of MCNPX simulation setup can be seen in Fig.2.MCNPX calculations were done by using Intel® Core™ i7 CPU 2.80 GHz computer hardware. At the end of the simulation study, the error rate has been observed less than 0.1% in the output file.

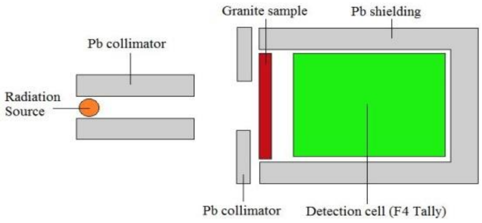

Fig. 1. MCNPX simulation geometry

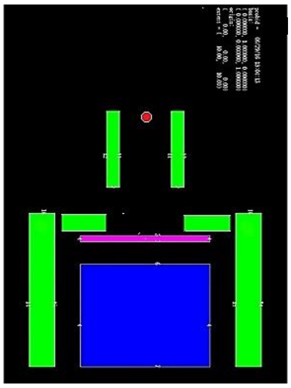

Fig. 2. Cross-sectional screenshot of MCNPX simulation setup

2.2. Definition of granite material samples in MCNPX

In general, computational modeling of radiation interaction problems including radiation shielding and protection all depend upon material definitions. There is several requirements in MCNPX Monte Carlo code for definition of material. The MCNPX material card block ensures the material definition due to shape required by MCNPX Monte Carlo code. The basic material information block contains the elemental mass fraction of the defined material. Therefore, each investigated granite samples have been defined in material card block with their elemental mass fractions. Definition of S1 grainte sample in MCNPX input file shown in below.

m1 8000 0.5077 13000 0.0841 14000 0.3711 19000 0.0250 20000 0.0111 22000 0.0007

Here, m1 is the definition of material number and 8000 is the coding of the atomic number of Oxygen since the atomic number of Oxygen is 8. Finally, the value of 0.5077 is the elemental mass fraction of Oxygen in S1 granite sample. The rest of the M1 encoding can be considered and handled in this way. In addtion, density of the S1 granite sample has been defined in cell card. The definition of density value of the S1 sample has shown in below. In this definition, the number of 3 is cell of the S1 granite sample. Moreover, the number of 1 is the definition of material identification that S1 granite sample is composed from material 1, which has been defined in m1 material definition with elemental mass fraction of S1. Rest of the numbers is geometrical surface numbers of attenuator granite material.

2.3. WinXcom Program

In this study, WinXcom program [20] was also used to calculate the radiation mass attenuation coefficients of the investigated granite samples. WinXcom program is a user friendly calculation program and input parameter specifications are quite flexible and easy to access. In the WinXcom program, each granite sample as shielding material were defined by their elemental fractions which also given in Table 1. Afterwards, the well-known gamma ray energies such as 662, 1173 and 1332 keV have been defined. The attenuation coefficients of the selected granite samples were finally calculated by the WinXcom program.

Table 1. Elemental mass fractions of each granite sample(%)

	S1	S2	S3	S4	S5	S6	S7	S8
SiO2	79.29	78.47	77.33	73.87	77.21	79.92	76.41	77.52
Al2O3	15.87	15.71	15.48	14.79	15.45	15.99	15.30	15.52
K2O	3.01	2.06	2.69	6.24	3.34	3.24	3.83	2.79
CaO	1.56	1.99	2.07	2.07	2.13	0.28	2.41	2.15
FeO	0.01	0.81	1.09	1.36	0.86	0.24	0.91	0.94
Fe2O3	<0.01	0.59	0.80	0.98	0.63	0.17	0.66	0.69
TiO2	0.12	0.12	0.27	0.20	0.17	0.06	0.21	0.18
density (g/cm^3)	2 .62	2 .64	2 .71	2 .67	2.66	2.62	2 .66	2 .65

2.4. Mass attenuation coefficient

In principle, almost all the materials can be used for radiation shielding if they employed in a particular material thicknes. Somehow, the radiation attenuation features of mentioned materials are highly dependent upon the density of the shielding material. It can be said that, intensive shielding material with a higher atomic number has a better shielding features for energetic gamma rays. On the other hand, for monochromatic gamma beams, the intensity reduces as the photon beam propagates through the shielding material according to the Lambert-Beer law by following equation [21].

$$I=I_0 \exp(-\mu t) \quad (1)$$

In this equation, where I_0 is the incident intensity of radiation, t is the path length, and μ is the linear attenuation coefficient of shielding material. This coefficient depends on the elemental or composition chemical of the sample. The linear attenuation coefficient depends on the density. Because of this reason, an information which is independent of the density (μ/ρ) of the substance is needed. This information, which is independent from density is called the mass attenuation coefficient and its unit is cm^2/g. The term of mass attenuation coefficient (μ/ρ) is the one of the important parameter to appraise the shielding features of materials and can be calculated. The mass attenaution coefficient can be obtained by dividing the linear attenuation coefficient (μ) by density (ρ) of studied shielding material. However, the mass attenuation coefficient (μ/ρ) of a mixture or compound material at a specific energy is the sum of the products of the weight fraction and the mass attenuation coefficient of the element i at that energy namely:

$$\mu/\rho = \sum_i w_i (\mu/\rho)_i \quad (2)$$

where w_i and (μ/ρ)i are the fractional weight and the total mass attenuation coefficient of the ith constituent in the mixture shielding material sample.

2.5. Half Value Layer

Half value layer (HVL) is the most frequently used quantity for describing both the penetrating ability of gamma radiations and the penetration through shield materials. HVL is expressed, where the intensity of the incident radiation reduces to one half ofits initial value. Mathematically, it was calculated as the product the reciprocal ofattenuation coefficient by the logarithm of two (HVL=ln2/μ). It increases with increasing thepenetrating ability of a radiation. Therefore, for a better shielding material, a lowHVL value is desired.

3. Results and Discussion

Mass attenuation coefficients of the granite samples was investigaed using MCNPX simulation and the results are shown in Table 2. The results of present investigation were shown along with earlier reported data by using theoretical, experiment and simulation. The comparison of mass attenuation coefficients of investigated granite samples with standard XCOM data is shown in Figs. 3-4. Moreover, the HVL of granite samples at different photon energies (662, 1173 and 1332 keV) is shown in Fig 5. Table 2 shows the mass attenuation of granite samples computation by using MCNPX simulation code and standarised simulation set-up. It is to be noted that the mass attenuation coefficients of the granite samples decreases with increase of photon energy, with largest at 662 keV. The behaviour of variaiton of mass attenuation coefficinets with photon energy can be explained by photon interaction process (photoelectric effect, Compton scattering and pair production) in low, intermedium and high energy photon region using atomic number of elements and photon energy as cited in various literature elsewhere.Also, it is to be oserved that the mass attenuation coefficients of granite sample using exprement (Ozyurt, 2017), GATE simulation (Ozyurt, 2017) and theoretical WinXcom results are found to be comparable with present investigation.It can be clearly seen that the mass attenuation coefficients calculated from XCOM and MCNPX code for three photon energies are almost same for all investigated granite samples, regarding to their similar composition. Similarly, dependence of mass attenuation coefficients to incident photon energyhas been observed strong in low-energy values. This can be due to predominant photoelectic absorbtion in low-energy values. Figure 5 shows variaiton of HVL thickness of granite samples (S1 to S8) with photon energy. It is to be observed that the HVL thickness of granite samples increases with increase in photon energy, i. e. larger photo energy requires very thick material to get desired level of radiaiton outside the material.The coefficient of determination is employed in order to explain how much variability of one factor is expressed in terms of another independent factor. That parameter is heavilybased on the trendanalysis having values between zero and one. The closer the value is to one, the beter the model is fitting, and beter relationship between the two factors. The coefficient of determination is thesquare of the correlation coefficient (R) shows the degree of linear correlation between two variables. Thecorrelation is generallyexpressed as the "goodness of fit." A value of “1” indicates a perfect fit, and therefore it is a veryreliable model forfuturepredictionswhile a value of zeroindicatesthatthe model failstoaccurately model thedata. In order to Express the correlation of theaforementionedmodels, we have employed a comparative study and plotted the regression lines of the model outputs and theircoefficient of determination parameters as given in figure 6, figure 7 and figure 8.The results given in the Figures 6-8 strongly emphasizes that the goodness of fit, the degree of linear correlation of MCNPX approach is quite satisfactory and relatively beter compared to GATE and Experiemental approaches with its almost perfect fitting function and R-squarred value illustrating a very strong relationship between MCNPX and WinXCOM results. In addition, slight difference between experimental and MCNPX mass attenuation coefficient values have been observed. This can be due to deviations from narrow-beam geometry in the source-detector setup, statistical parameters such as counting quantity, gaps in granite material and assessment of detector peak areas in experimental studies.

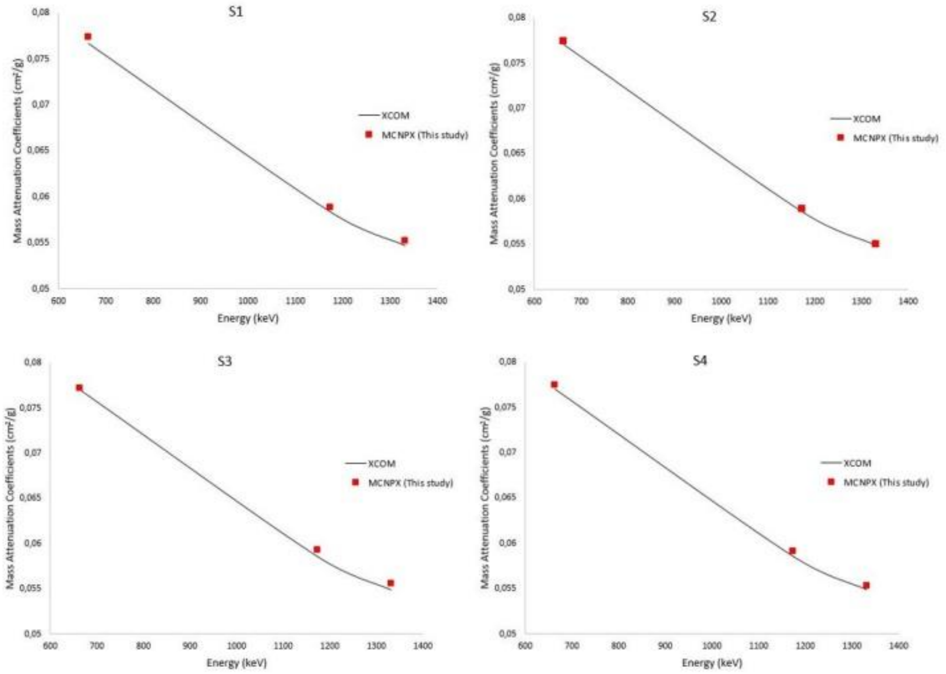

Fig. 3. Mass attenuation coefficients of S1,S2,S3,S4 granite samples using MCNPX and XCOM data

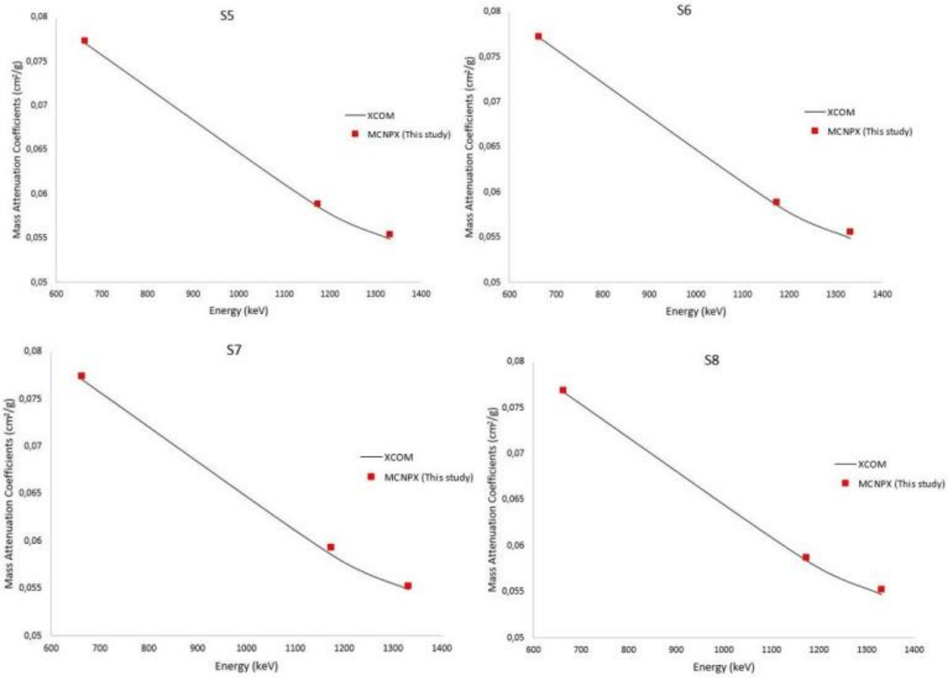

Fig. 4. Mass attenuation coefficients of S5,S6,S7,S8 granite samples using MCNPX and XCOM data

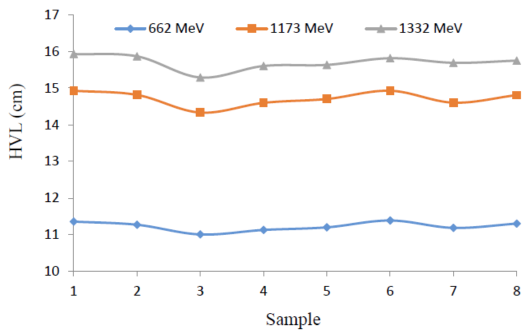

Fig. 5. Half-value layer thickness of Granite Samples

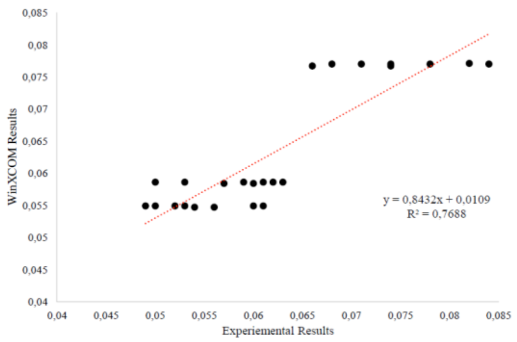

Fig. 6. Regression line and R-squared value for Experimental results and XCOM

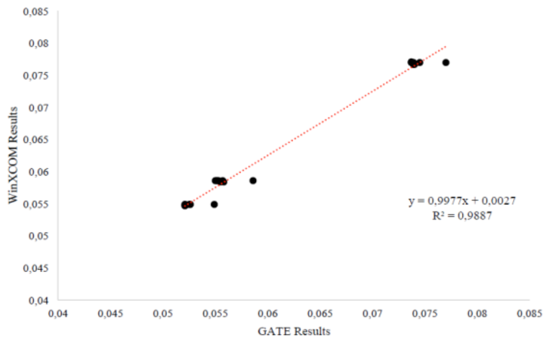

Fig. 7. Regression line and R-squared value for GATE and XCOM

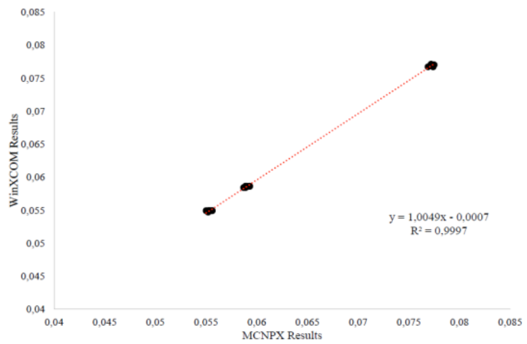

Fig. 8. Regression line and R-squared value for MCNPX and XCOM

Table 2.Results of mass attenuation coefficients for granite samples

Granite Sample	Energy (keV)	Experimental (Ozyurt, 2017)	WinXCOM (Gerward,2004)	GATE (Ozyurt, 2017)	MCNPX (ThisStudy)
S1	662	0.066	0.0767	0.0740	0.0774
	1173	0.057	0.0584	0.0558	0.0589
	1332	0.056	0.0547	0.0521	0.0552
S2	662	0.068	0.0770	0.0770	0.0774
	1173	0.061	0.0586	0.0586	0.0589
	1332	0.053	0.0549	0.0549	0.0550
S3	662	0.074	0.0770	0.0737	0.0772
	1173	0.053	0.0586	0.0551	0.0593
	1332	0.052	0.0549	0.0526	0.0556
S4	662	0.084	0.0770	0.0739	0.0775
	1173	0.063	0.0586	0.0552	0.0591
	1332	0.050	0.0549	0.0526	0.0553
S5	662	0.071	0.0770	0.0739	0.0773
	1173	0.062	0.0586	0.0553	0.0589
	1332	0.060	0.0549	0.0521	0.0554
S6	662	0.082	0.0771	0.0737	0.0772
	1173	0.059	0.0586	0.0550	0.0589
	1332	0.061	0.0549	0.0525	0.0556
S7	662	0.078	0.0770	0.0745	0.0774
	1173	0.050	0.0586	0.0557	0.0593
	1332	0.049	0.0549	0.0521	0.0552
S8	662	0.074	0.0767	0.0739	0.0769
	1173	0.060	0.0584	0.0555	0.0587
	1332	0.054	0.0547	0.0521	0.0552

4. Conclusions

In present study, eight different kind of granite samples were used. MCNPX Monte Carlo code (version 2.4.0) was used to investigate the shielding parameters of different kind of granite samples. The results showed that, attenuation of photons in granite attenuators increased with decreased energy. Moreover, it can be concluded that, results obtained from MCNPX Monte Carlo code has closer results with standard XCOM data compared to GATE. Since GATE code is an application of GEANT4 toolkit, the primary reason of this result can be due to the GEANT4 being designed for high energy physics calculations [22] whereas MCNPX was developed and successfully applied in high- and the low-energy physics calculations. It can be also concluded that modeled standard MCNPX geometry can be useful for scientific community for similar future studies since radiation shielding studies by using new generation materials and different kind of technologies rapidly growing in the field of nuclear sciences and medical applications.

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