Turkish Journal of Science & Technology
15(1), 43-48, 2020

Monte Carlo Study of XSO4 (X= Ba, Be, Ca, Mg, and Sr) Response to Common Particles (Proton, Electron, and Neutron): A Shielding Application

Serkan GÜLDAL[1*]
[1] Department of Physics, Faculty of Arts and Sciences, Adiyaman University, Adiyaman, Turkey
*sguldal@adiyaman.edu.tr

(Geliş/Received: 13/02/2020; Kabul/Accepted: 20/02/2020)

Abstract: Subatomic particles are continuously studied by researchers parallel to developing detectors and theories. In experiments, accelerated particles penetrate the considered target and even shielding. Thus, the protection of researchers and equipment from high energy particles is an important problem in the field of high energy physics. Because of the need, researchers are looking for new materials to be used for shielding (besides detectors, dosimeters, and many other applications). In this study, we have tested the interaction of proton, electron, and neutron for various energy levels with XSO_4 (X= Ba, Be, Ca, Mg, and Sr) targets. XSO_4 is in the powder structure, so it is mobile unlike concrete. We show the energy deposition of particles in the defined geometry. The simulation results show $MgSO_4$ is significantly less responsive to proton and neutron beams. Thus, it is less likely a shielding material between the considered molecules. The other important conclusion, the most of the proton beams energy is absorbed by the listed molecules show similar responsiveness as concrete which makes these molecules possible alternatives as a shielding material in the high energy experiments.

Key words: Monte Carlo, SO_4, Shielding, High Energy

XSO4 (X= Ba, Be, Ca, Mg, ve Sr)'ün Bilinen Parçacıklara (Proton, Elektron, ve Nötron)Tepkisinin Monte Carlo Çalışması: Bir Zırh Uygulaması

Öz: Detektörlerdeki ve teorilerdeki gelişmelere paralel olarak atom altı parçacıklar çalışılmaya devam edilmektedir. Deneylerde hızlandırılmış parçacıklar çalışılan hedeflerin ve hatta zırh içine bile nüfuz etmektedir. Bu sebepten dolayı araştırmacıları ve ekipmanları yüksek enerjili parçacıklardan korumak yüksek enerji araştırmalarında önemli bir problemdir. Bu ihtiyaçtan dolayı, araştırmacılar (detektör, dozimetre, ve diğer uygulamaların yanı sıra) zırh olarak kullanılabilecek yeni malzemeler arayışındadır. Bu çalışmada proton, elektron ve nötron ışınlarına maruz bıraktığımız XSO4 (X= Ba, Be, Ca, Mg, ve Sr) moleküllerini çeşitli enerji seviyeleri için inceledik. XSO4 pudra yapısındadır, böylece betonun aksine taşınabilirdir. Tanımlanan geometride enerji dağılımları incelendi. Yapılan analizler gösterdi ki MgSO4 diğer moleküllere kıyasla proton ve nötron ışınımlarına belirgin bir şekilde daha az tepki göstermiştir. Diğer bir önemli sonuç ise proton ışınımın enerjisinin büyük bir kısmı analiz konusu olan moleküller tarafından tutulmuştur, bu davranış referans noktası olarak kullandığımız beton ile benzerlikler göstermesi deney düzeneklerinde bu moleküllerin alternatif zırh malzemesi olarak kullanılabileceğini düşündürmektedir.

Anahtar kelimeler: Monte Carlo, SO_4, Zırh, Yüksek Enerji

1. Introduction

Irradiation of molecules by subatomic particles studied by many researchers [1-3]. Accelerators are propagating high energy particles to a specific target(s) for various reasons such as generate particles which have a short lifetime or to simulate an event at the establishment of the universe [4]. In experimental studies, sensitive and high technology devices are necessary. For example, the latest detectors collect more reliable data in shorter times since information about the short-lived particles could be captured with relatively fast detectors [5]. However, one approach to design better detectors requires that various combinations of elements to be tested. These tests could be done by the well-developed models with an appropriate package program such as FLUKA.

We have used FLUKA Monte Carlo package for our simulations [6, 7]. FLUKA is a comprehensive tool to study interactions of high energy particles with matter [8]. Thus, it has a wide variety of applications that are continuously studied such as shielding, detector design. It is continuously developed and used for simulations of experimental research in CERN (Conseil Européen pour la Recherche)[9]. The experimental researches investigate highly energized dense particles. The particles which have the potential to harm the around of the experimental setup are stoped by shielding [10]. We have investigated the molecules (XSO4 (X= Ba, Be, Ca, Mg, ve Sr)) respect to portland concrete which is a highly utilized shielding material.

---

[*] Corresponding author: sguldal@adiyaman.edu.tr. ORCID Number of authors: [1] 0000-0002-4247-0786

The main objective in this investigation is the show the relational energy deposition of XSO_4 (X= Ba, Be, Ca, Mg, and Sr) targets with Portland concrete for different energy levels of subatomic particles (proton, electron, and neutron) [11].

Simulation details have been explained in Materials and Method section. After Materials and Method section, we summarize results and give a brief discussion of the outputs. Lastly, we conclude this study with the conclusion of the findings with future studies.

2. Materials and Method

Geometry is a combination of a target, environment and black hole (Figure 1). The environment is defined as a vacuum. Outside of the vacuum is surrounded by a black hole. Target is a rectangular prism (40 cm x 40 cm x 100 cm) which is relatively thin for shielding applications, but it is enough big to extract response of the material under the common subatomic particles [12]. Geometry is used in the simplest form possible to obtain the pure response of the targets' molecules. Target materials are made of by the following molecules, XSO_4 (X= Ba, Be, Ca, Mg, and Sr) and concrete Portland (which is made of Hydrogen: 0.01, Carbon: 0.001, Oxygen: 0.529107, Sodium: 0.016, Magnesium: 0.002, Aluminum: 0.033872, Silicon: 0.337021, Potassium: 0.013, Calcium: 0.044, Iron: 0.014).

Beam gun is placed 10 cm away from the target. It is a Gaussian wave and pointed to positive z-direction for all particles. Also, full width at half maximum of beam wave is 1 cm by 1 cm for x and y directions respectively and energy levels change between 1 MeV- 120 MeV. This beam setup allows us to imitate experimental designs.

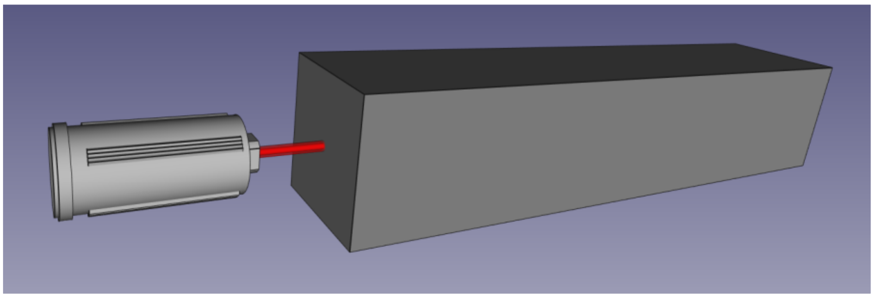

Figure 1. The simulation setup shows the beam and the target prism.

We use FLUKA Monte Carlo package for our simulations. Monte Carlo method randomly generates the beams with the limit of given properties (Shape: Gaussian, Energy: 1MeV- 120MeV, and Particle: e^-, p^+, n). Propagation and focus of Gaussian beam are well known, and a relatively lower diffraction rate are some of the advantages [13]. Utilized energy range corresponds to the energy of traditional laser-plasma accelerators [14, 15]. The well-studied charged and neutral particles are selected for the beam to broaden the effect of the study. Lastly, 5000 primaries produced a smoother distribution of the beam.

Targets are made out of alkaline earth metals with SO_4 for shielding applications. Specifically, $BaSO_4$ had been doped to cement with various concentrations to improve shielding [16, 17]. $BeSO_4$ is been investigated experimentally against high energy irritation to estimate the "age" of cosmic rays by means of ^{10}Be isotopes [18, 19]. $CaSO_4$, also, has been subject to radioactivity studies [20, 21]. $MgSO_4$ is effectively used as a drug component [22]. $SrSO_4$ is a promising candidate for a dosimeter [23, 24].

Structural properties are given in Table 1. The density of the target is an effective parameter for the simulations. The selected molecules highly durable with respect to the high temperatures.

Table 1. Densities of examined molecules are shown [25].

MOLECULE	DENSITY (GR/CM^3)	MELTING POINT (^{O}C)
$BaSO_4$	4.49	1580
$BeSO_4$	2.5	1127
$CaSO_4$	2.96	1460
$MgSO_4$	2.66	1137
$SrSO_4$	3.96	1606

3. Results and Discussion

Five sulfate-based molecules` and concrete Portland’s responses have been measured against three well-studied particles (e^-, p^+, n). The beams send to target from 6 different angles which are between the target surface and incoming beam (Figure 2).

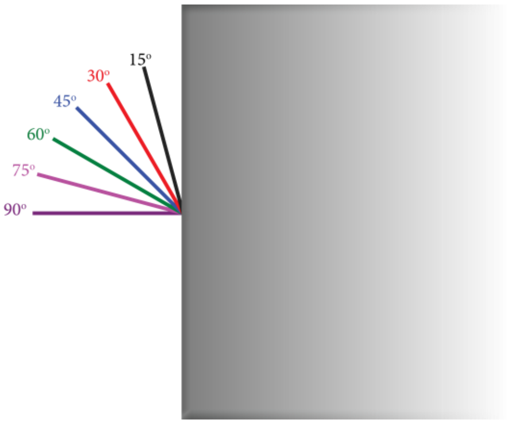

Figure 2. 6 different beam angles used to irritate targets

There is only one study for the considered molecules which is related to the dosimeters [26]. We have collected the information about deposited total energy in the material after every particle hits the specified target. Although, there is no significant difference between the responses of the molecules; $MgSO_4$ shows distinguishable behavior respect for the other molecules. It is described with detail in the following paragraphs.

In Figure 3, $BaSO_4$ target is irritated by e^-, p^+, and n. Electron beams’ energies are stored in the target for relatively higher energies. Low energy beams are bounced from the surface of the target based on the energy decomposition. Proton beams have a linear relation with the beams’ energies regardless of the beam angles. Proton energy residue is lower than electron energy because of the higher mass. Neutron beams behave differently than the other particles. Its energy is the least captured for 40 MeV. For the higher energy levels, angles’ effect becomes more visible.

In Figure 4, $BeSO_4$ target’s responses shown against various energy levels. Electron beams are deposited lesser for 10 MeV since relatively lower energy electrons scattered from the surface. Closer beams’ angles to perpendicular have higher momentum respect to the surface normal caused higher interaction with the target. Neutron beams are less capable of escaping from the target for 10 MeV. However, the neutron beams with higher energies bounce from the surface by leaving 2% of their energies. Moreover, for 90 MeV and higher energies, the effect of the incoming beam angle becomes more visible.

In Figure 5, the response of $MgSO_4$ is presented. $MgSO_4$ stores lesser energy for the higher energized electron beams. For the lower energy, less than 10 MeV, the molecular mass of the molecules plays a crucial role in energy absorption. Diverse characteristics of $MgSO_4$ is also visible for the neutron beams. Beam angle becomes more visible for higher energy beams. The beams that are perpendicular to the surface and closer to the perpendicular angle are captured relatively higher level.

In Figure 6, the energy deposition for $CaSO_4$ target is shown for electron, proton, and neutron beams. The beams that come from lower angles are stored relatively lower. 10 MeV is a pivot point for storing energy in the target. Electron beams reach their highest ratio, but neutron beams reachest their lowest ratio. Additionally, electron beams reach their highest (~100%) for the perpendicular positions.

In Figure 7, $SrSO_4$ target’s responses are presented for the beams which are released from the various angles. Electron is the most stored beam between all three beams. The stored proton beam energies are directly related to the energy of the beams regardless of the angle.

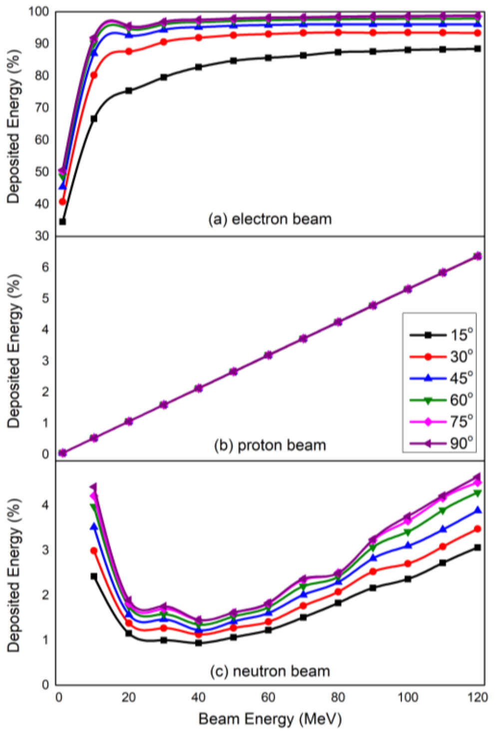

Figure 3. Stored energy ratio of $BaSO_4$ target (a) for an electron beam, (b) for a proton beam, and (c) for a neutron beam

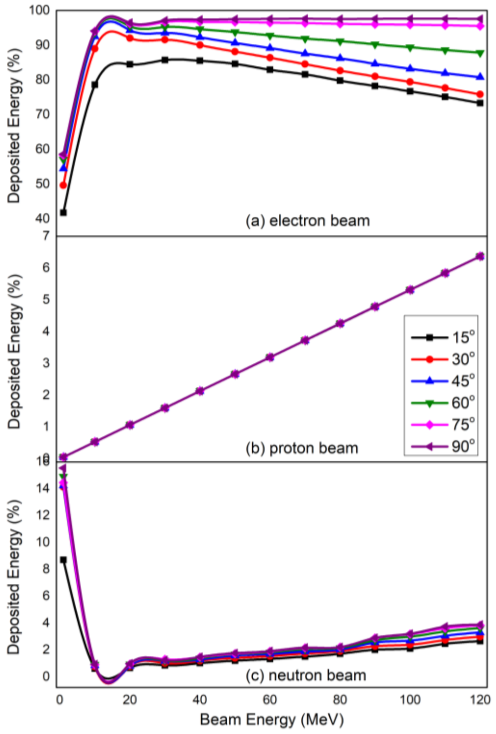

Figure 4. Stored energy ratio of $BeSO_4$ target (a) for an electron beam, (b) for a proton beam, and (c) for a neutron beam

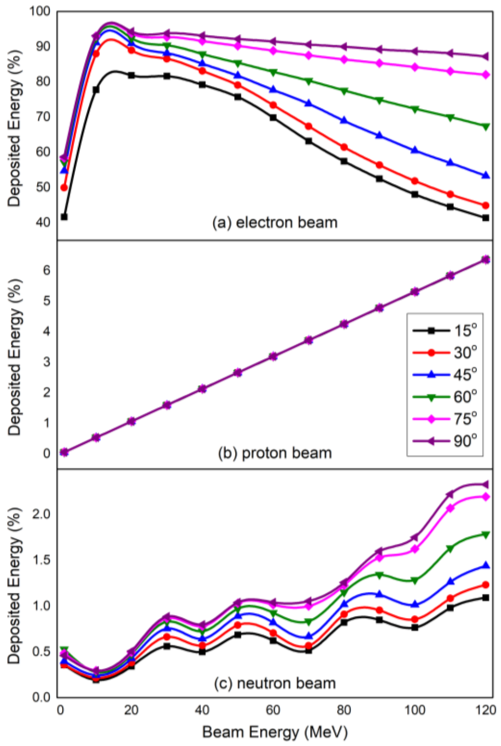

Figure 5. Stored energy ratio of $MgSO_4$ target (a) for an electron beam, (b) for a proton beam, and (c) for a neutron beam

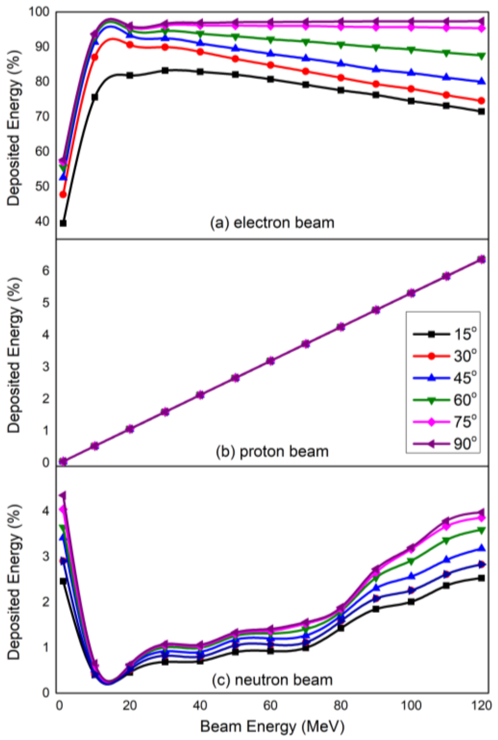

Figure 6. Stored energy ratio of $CaSO_4$ target (a) for an electron beam, (b) for a proton beam, and (c) for a neutron beam

In Figure 8, the Energy deposition behavior of Portland Concrete is shown as the reference point for the rest of the study. The concrete is commonly used as the shielding material. There is no result fully fits with the reference study. Thus, they are not equivalent to the concrete. However, the electron behavior of $BeSO_4$ and $CaSO_4$ resembles better for higher energy beams. The stored proton beams change from ~0% to ~6% for all the targets including the Portland Concrete. The closest neutron beams' depositions are detected in $BeSO_4$.

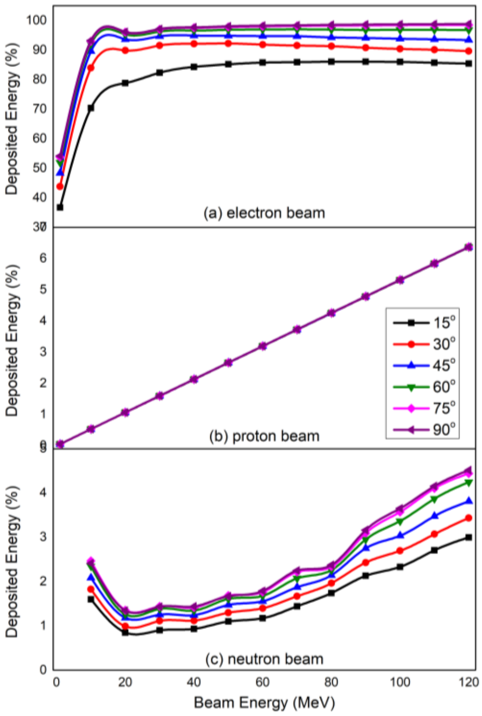

Figure 7. Stored energy ratio of $SrSO_4$ target (a) for an electron beam, (b) for a proton beam, and (c) for a neutron beam

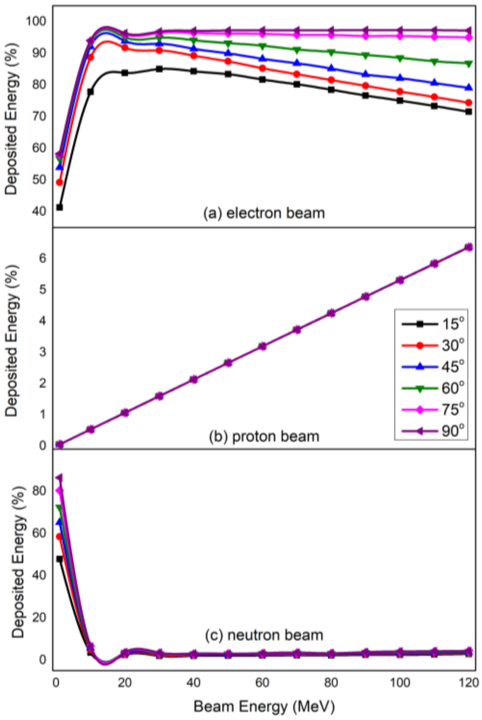

Figure 8. Stored energy ratio of Portland Concrete target (a) for an electron beam, (b) for a proton beam, and (c) for a neutron beam

4. Conclusion

In this work, we have examined the reaction of XSO_4 (X= Ba, Be, Ca, Mg, and Sr) against to e^-, p^+, n beams (1MeV- 120MeV and from 15° to 90°). The deposition of energy shows us how much energy stored in the target. Deposited energy in the targets shows the measurable quantity about the intensity of the interactions. $MgSO_4$ shows distinguishable behavior with respect to the other targets. For the higher energies, the beam angle plays a crucial role by the means of storing energy.

In future studies, we are planning to broaden this study to different particles and ions as the high energy beams. Additionally, we will test more promising molecules to be used in high energy experiments.

References

[1] Korkut H, Korkut T, Kara A, Yiğit M, and Tel E, "Monte Carlo Simulations of 17.9–22.3 MeV Energetic Proton Irradiation Effects on bcc-Zirconium Fusionic Materials," *Journal of Fusion Energy,* 2016; 35(3): 591-596.

[2] P.Limkitjaroenporn, Kaewkhao J, Chewpraditkul W, and Limsuwan P, "Mass Attenuation Coefficient and Effective Atomic Number of Ag/Cu/Zn Alloy at Different Photon Energy by Compton Scattering Technique," *Procedia Engineering*, 2012; 32: 847-854.

[3] Aygün B, Korkut T, Karabulut A, Gencel O, and Karabulut A, "Production and Neutron Irradiation Tests on a New Epoxy/Molybdenum Composite," *International Journal of Polymer Analysis and Characterization* 2015; 20(4): 323-329.

[4] Howell R H, Sterne P A, Hartley J, and Cowan T E, "High energy beam lifetime analysis," *Applied Surface Science,* 1999; 149(1-4): 103-105.

[5] Leach S A *et al.*, "Front-end electronics of the Compact High Energy Camera," presented at the Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 2020/02/01/, 2020.

[6] Böhlen T T *et al.*, "The FLUKA Code: Developments and Challenges for High Energy and Medical Applications," *Nuclear Data Sheets,* 2014; 120: 211-214.

[7] Ferrari A, Sala P R, Fasso` A, and Ranft J, "FLUKA: a multi-particle transport code," *CERN-2005-10,* 2005; INFN/TC_05/11, SLAC-R-773

[8] Hançerlioğullari A, Korkut T, and Madee Y G A, "The Neutron Macroscopic Cross Sections Calculation of Some Minerals by Using FLUKA Monte Carlo Method," *The Online Journal of Science and Technology* 2007; 7(3): 137-143.

[9] Fassò A, Ferrari A, Sala P R, and Ranft J, "FLUKA: Status and Prospects for Hadronic Applications," *Advanced Monte Carlo for Radiation Physics, Particle Transport Simulation and Applications,* (2001); 955-960.

[10] Sarıyer D and Küçer R, "Proton Hızlandırıcılarında Farklı Maddeler İçin Zırh Kalınlıklarının Analitik Yöntemle Belirlenmesi," *Determination of Shielding Thicknesses by Using Analytical Method for Different Materials in Proton Accelerators.,* Article 2013; 8, (1): 100-105.

[11] Callan E J, "Concrete for Radiation Shielding," *Journal Proceedings American Concrete Institute,* 1953; 50(9): 17-44.

[12] Nunomiya T *et al.*, "Measurements of Neutron Attenuation through Iron and Concrete at ISIS," *Journal of Nuclear Science and Technology,* 2014; 37 (1): 158-161.

[13] Shealy D and Hoffnagle J, *Laser beam shaping profiles and propagation*. 2006, pp. 5118-5131.

[14] Malka V, Faure J, Glinec Y, and Lifschitz A F, "Laser-plasma accelerator: status and perspectives," (in English), *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences,* 2006; 364(1840): 601-610.

[15] Glinec Y and Malka V, *High charge (0.5 nC) monoenergetic 170 +/-20 MeV electrons beam generated by 30 fs laser pulses*. 2004.

[16] Chanthima N, Prongsamrong P, Kaewkhao J, and Limsuwan P, "Simulated radiation attenuation properties of cement containing with BaSO4 and PbO," *Procedia Engineering,* 2012; 32: 976-981.

[17] Zezulová A, Staněk T, and Opravil T, "The Influence of Barium Sulphate and Barium Carbonate on the Portland Cement," *Procedia Engineering,* 2016; 151: 42-49.

[18] Moussavi-Zarandi A, "Determination of beryllium by use of photonuclear activation techniques," *Applied Radiation and Isotopes,* 2008; 66 (2): 158-161.

[19] Amin B S, Biswas S, Lal D, and Somayajulu B L K, "Radiochemical measurements of 10Be and 7Be formation cross sections in oxygen by 135 and 550 MeV protons," *Nuclear Physics A,* 1972; 195 (1): 311-320.

[20] Nambi K S V, "Self-dose and fading of CaSO4(Dy/Tm) and CaF2 (natural) TL phosphors in environmental radiation monitoring," *Nuclear Instruments and Methods in Physics Research,* 1982; 197 (2): 453-457.

[21] Bakshi A K, Suryanarayana P, Sharma R K, Maheshwari N K, Joshi V J, and Chougaonkar M P, "Measurement of gamma attenuation for ANR end shield model using CaSO4:Dy phosphor," *Annals of Nuclear Energy,* 2013; 55: 205-210.

[22] Thapa K and Jha R, "Magnesium sulphate: a life saving drug," (in eng), *JNMA; journal of the Nepal Medical Association,* 2008; 47(171): 104-108.

[23] Singh V P, Medhat M E, and Badiger N M, "Photon attenuation coefficients of thermoluminescent dosimetric materials by Geant4 toolkit, XCOM program and experimental data: A comparison study," *Annals of Nuclear Energy,* 2014; 68: 96-100.

[24] Rushdi M A H, Abdel-Fattah A A, and Soliman Y S, "Physico-chemical studies for strontium sulfate radiation dosimeter," *Journal of Radiation Research and Applied Sciences,* 2015; 8 (2): 221-225.

[25] Dongxue L and Liu Y, "Recent progress of dopant-free organic hole-transporting materials in perovskite solar cells," *Journal of Semiconductors,* 2017; 38 (1).

[26] McConn R J, Gesh C J, Pagh R T, Rucker R A, and Williams Iii R, "Compendium of Material Composition Data for Radiation Transport Modeling," United States2011-03-04 2011, Available: https://www.osti.gov/servlets/purl/1023125.