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Study of Radiation Shielding Materials based on Scattering

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Abstract
The aim of this work is to study the Klien-Nishina (KN) cross section on the basis of scattering. To study the KN cross section we developed and scattering model and select the material made up of carbon, tungsten, bismuth, tungsten carbide and bismuth carbide. The study found that bismuth and bismuth carbide material have high KN cross section than other, due high cross section bismuth and its carbide is best for radiation shielding. This is because high cross section means high region of scattering and high region of scattering means interacting of protect and target is high. The interaction reduces the energy of ejected electron and redirect projected particle. In this way, the energy of project particles/radiation get reduced and protect the hazard. Therefore, bismuth and its carbide among the considered material is best than other. In addition, the KN cross section of consider materials found decreases with increased in projected energy. Therefore, on the basis of scattering one can select the radiation shielding material for different uses like in therapy, imaging, ore and mines, Power plants etc.

1. Introduction

Radiation is energy in the form of waves or streams of particles. There are many kinds of radiation all around us. When people hear the word radiation, they often think of atomic energy, nuclear power, and radioactivity, but radiation has many other forms. Sound and visible light are familiar forms of radiation; other types include ultraviolet radiation, infrared radiation, and radio and television signals. Uncontrolled use of man-made radiation carries a potential risk to the health and safety of workers and the public. Canadian Nuclear Safety Commission (CNSC) regulates the use of nuclear energy and materials to protect the health, safety, and security of Canadians and the environment from the effects of radiation. The transmission of directly and indirectly ionizing radiation through matter and its interaction with matter are fundamental to radiation shielding design and analysis. In analysis, the shielding material is specified, and the task is to determine the dose, given the source intensity, or the latter, given the former. Radiation is conceptualized as particles – photons, electrons, neutrons, and so on. Characterization of the radiation field, for any one type of radiation particle, requires a determination of the spatial variation of the joint distribution of the particle's energy and direction. In certain cases, such as those encountered in neutron scattering experiments, properties such as spin may be required for full characterization **[1].**

Almost any material can act as a shield from gamma or x-rays if used in sufficient amounts. Different types of ionizing radiation interact in different ways with shielding material. The effectiveness of shielding is dependent on stopping power, which varies with the type and energy of radiation and the shielding material used. Different shielding techniques are therefore used depending on the application and the type and energy of the radiation. Shielding reduces the intensity of radiation, increasing with thickness.

The effectiveness of a shielding material in general increases with its atomic number, called Z, except for neutron shielding, which is more readily shielded by the likes of neutron absorbers and moderators such as compounds of boron like boric acid, cadmium, carbon, and hydrogen. Compared to single-material shielding, the same mass of graded-Z shielding has been shown to reduce electron penetration by over 60%. In a typical graded-Z shield, the high-Z layer effectively scatters protons and electrons. It also absorbs gamma rays, which produce X-ray fluorescence. Each subsequent layer absorbs the X-ray fluorescence of the previous material, eventually reducing the energy to a suitable level. Each decrease in energy produces bremsstrahlung and Auger electrons, which are below the detector's energy threshold. The effectiveness of a material as a biological shield is related to its cross-section for scattering and absorption, and a first approximation is proportional to the total mass of material per unit area interposed along the line of sight between the radiation source and the region to be protected. Hence, shielding strength or thickness is conventionally measured in units of g/cm^2.

Personal Protection Equipment (PPE) includes all clothing and accessories which can be worn to prevent severe illness and injury as a result of exposure to radioactive material. These include an SR100 (protection for 1hr), and SR200 (protection for 2 hours). Because radiation can affect humans through internal and external contamination, various protection strategies have been developed to protect humans from the harmful effects of radiation exposure from a spectrum of sources. A few of these strategies were developed to shield from internal, external, and high-energy radiation. A very high level of radiation exposure delivered over a short period can cause symptoms such as nausea and vomiting within hours and can sometimes result in death over the following days or weeks. This is known as acute radiation syndrome, commonly known as radiation sickness. It takes a very high radiation exposure to cause acute radiation syndrome—more than 0.75 gray (75 grays idn a short period (minutes to hours). This level of radiation would be like getting the radiation from 18,000 chest x-rays distributed over your entire body in this short period. Acute radiation syndrome is rare and comes from extreme events like a nuclear explosion or accidental handling or rupture of a highly radioactive source.

Ionizing radiation has sufficient energy to affect the atoms in living cells and thereby damage their genetic material (DNA). Fortunately, the cells in our bodies are extremely efficient at repairing this damage. However, if the damage is not repaired correctly, a cell may die or eventually become cancerous. Exposure to very high levels of radiation, such as being close to an atomic blast, can cause acute health effects such as skin burns and acute radiation syndrome radiation sickness. It can also result in long-term health effects such as cancer and cardiovascular disease. Exposure to low levels of radiation encountered in the environment does not cause immediate health effects but is a minor contributor to our overall cancer risk. The heavy metals most commonly associated with the poisoning of humans are lead, mercury, arsenic, and cadmium. Heavy metal poisoning may occur as a result of industrial exposure, air or water pollution, foods, medicines, improperly coated food containers, or the ingestion of lead-based paints. Unlike other metals such as lead and mercury, silver is not toxic to humans and is not known to cause cancer, reproductive or neurological damage, or other chronic adverse effects.

The study of Lennard-Jone's Potential (LJP) of carbon-carbon, carbon-oxygen, oxygen-oxygen, water-water molecule, silver-silver, gold-silver, gold-carbon, and silver-carbon interactions potential shows the silver-silver interaction potential has a maximum at a distance 3.5 Å and carbon-carbon minimum potential at the same distance, at 300K. The understanding of the interaction potential between the considered atom and other atoms has various applications in molecular physics, computational chemistry, molecular models, and material science: radiation shielding and other, etc **[2].** Also, the differential cross-section in the presence of a weak laser field (visible and UV) in the case of inelastic scattering. The differential cross-section initially decreases to a minimum and finally takes a maximum value, when the target emits the energy of 5 eV, 10 eV,13 eV, 16 eV, 20 eV, 25 eV, and 30 eV **[3].**
The total cross-section of electrons, atoms, and molecules in iron oxides was studied in radiation field or energy 0 MeV to 10MeV. The studies show at low energy, the total cross-section of electrons, atoms, and molecules is large, indicating that scattering is significant. High scattering indicates photon divergence and material protection behind the target, implying radiation shielding **[4].** The attenuation coefficient of tissue, bone, gold, copper oxygen, water, and its mixture was studied. The study shows the mixture of gold, copper, and oxygen sample has a medium attenuation coefficient which means the emitted electron has the best preformation to kill the cancer cell with low energy. The energy electrons emitted by Au are greater and it may affect the tissue and bone while the energy emitted from Cu and O has less energy and can't kill the larger amount of cancer cells. Therefore, if the mixture of chemo-material of gold, copper, and oxygen is better and safer than the individual element to load the tumor for radiotherapy and this technique is applicable for radiation shielding materials also because the principle is the same **[5].**
The study of radionuclide cross-section, two nuclear reactions (p,n) and (d, 2n) of Rh and Pd shows the cross-sectional area of (d, 2n) is higher than (p, n)during the reaction. Therefore, the (d,2n) reaction is best for a radiation shield than (p, n) because the (d, 2n) reaction scattered radiation and preserved the penetration of radiation and species formed from such reaction **[6].** The study of the electronic and atomic cross-sectional area for low atomic masses (Carbon, Aluminum, Iron, and Zinc) using the Klien-Nishina differential equation shows an atomic cross-section with incidence photon found on the order of Carbon< Aluminum <Iron< Zinc **[7].**

2. Methodology

2.1 Shielding Materials

Shielding of X-ray generators was recognized within months of Roentgen's 1895 discovery, but dose limitation by time, distance, and shielding was at the discretion of the individual practitioner until about 1913. In 1913, the German Radiological Society on X-Ray Protection Measures issued recommendations that 2 mm of lead shielding was needed, regardless of generator voltage, workload, or filtration. Only organized professional efforts to establish guides for radiation protection, and not until about 1925 were their instruments available to quantify radiation exposure. In a survey of organizations for radiation protection, Taylor in 1979 begins with British and German efforts at establishing guidance for X-ray shielding.

In Britain, the Roentgen Society addressed radiation protection, stressing operator protection, the need for beam collimation, and the importance of scattered X-rays. No explicit recommendations on shielding requirements were issued. In 1921, the British X-Ray and Radium Protection Committee issued broad guidelines, both physical and administrative, on radiation protection in x-ray facilities. For diagnostic examinations, 2 mm of lead screening was recommended for the operator, as well as gloves with effectively 0.5 mm of lead shielding. For superficial therapy (up to 100 kV X-rays), 2 mm of lead shielding was recommended. For deep therapy (more than 100 kV X-rays) 3 mm of lead shielding was recommended. Again, filtration and workload were not addressed. The radiation doses from 50 to 700 millisieverts, if gets to expose on the human body for one hour daily then the health effect might get is changes in blood chemistry, nausea, fatigue, vomiting, etc. Hair loss, diarrhea, and hemorrhage might get happen in the human body if continuously get exposed to the 750 to 1000 millisieverts radiation doses within 2-3 weeks. If radiation doses exceed 4000 millisieverts, there could be possible death within 2 months.

2.2 Impact of Radiation

Daily, healthcare workers (HCWs) are exposed to occupational contact with various diagnostic and therapeutic radiology interventions **[8].** The HCWs' exposure to various radiology waves results in acute complications (dermatitis, mucositis, and hair loss) as well as long-term complications (cataracts, skin problems, genetic problems, and cancer) through impairment in normal DNA functioning **[9]**. Specifically, the HCWs exposed to radiation develop cancer by approximately more than 40% compared to patients and other groups **[10]**. To prevent the side effects of radiation, the International Radiation Protection Association (IRPA) has designed some guidelines to limit the dose received by the HCWs, and it is periodically reviewed **[11]**. The most important method of proper radiation protection principal implementation is education **[12]**.

Today, with the increase in the number of radiology procedures, all healthcare workers exposed to radiology waves should know how these procedures are performed and how they can better protect themselves **[13]**. The extent of awareness of the healthcare workforce about radiation protection has a considerable impact on the proper attitude and performance regarding protection against radiology waves **[14]**. Current evidence suggests different results regarding the level of awareness, attitude, and performance of healthcare workers about radiation protection across different countries **[15]**. Further, many studies have shown that HCWs with good knowledge may lack a good attitude toward radiation protection **[16]**. Also, many individual studies have found poor knowledge about radiation protection. Precise determination of awareness, attitude, and performance of HCWs about radiation protection across different fields can help healthcare policymakers in the better management and improvement of awareness, attitude modification, and performance. To the best of our knowledge, so far, no study has been performed in this regard and with this scope. Accordingly, this systematic review study was conducted to determine the knowledge, attitude, and practice (KAP) of healthcare workers toward radiation protection.

High atomic number (Z) materials/ elements can effectively replace the poisonous Pb, and these alternative elements/ salts/ compounds can be reinforced within a polymer matrix **[17]**. Some of the high Z constituents used for radiation shielding applications are tungsten, dysprosium, gadolinium **[18]**, and tin. These materials are known for their non-toxicity and environmentally friendly nature when compared to Pb **[19]**. They are having major advantages over lead compounds (like lead nitrate) and are considered to be the least toxic among heavy metals. A third component in the form of a binder can be added along with the high Z constituents and the polymer matrix, so that the physical, radiological and electrical properties of the resulting composite are improved. Some of these materials have found application in radiology and dosimetry.

2.3 Product characterization

The products (biomass biochar and hybrid biochar) recovered from the process were characterized to ascertain some of their properties using a Scanning Electron Microscope with Energy Dispersive X-ray Spectroscopy (SEM-EDS), Fourier Transform Infra-Red Spectroscopy (FTIR) and Brunauer-Emmet-Teller (BET) analysis. Scanning Electron Microscopy (SEM, Phenom ProX, Phenom-World BV, Netherlands) was used to study the surface morphology of the particles of the biochar. A double adhesive was placed on a sample stub. The sample was sprinkled on the sample stub and subsequently taken to a sputter coater (quorum-Q150R Plus E) and coated with 5 nm of gold. The sample was placed on a charge reduction sample holder and introduced into the column of the SEM machine. It was first viewed with a NavCam before being sent to SEM mode. The acceleration voltage of the microscope was set to 15 kV and magnification at 1000 – 1500×. FTIR (Shimadzu, FTIR-8400S, Japan) was used to determine the functional groups and complexes present in both biochar samples. The surface area, pore volume, and size of the chars were measured. The surface properties of the char samples were studied using a Multipoint BET surface area and the DR (Dubinin–Radushkevic) method for the pore volume and width (diameter). The chars were characterized by N_2 adsorption test at 77 K. 100 ml/min of dry nitrogen was introduced into the sample tube to prevent contamination of the clean surface, then the sample tube was removed and the sample weighed. The sample tube was fixed to the volumetric apparatus, and then the sample was evacuated to 2 Pa pressure. Adsorbate was introduced to give the lowest desired relative pressure, and then the volume adsorbed was measured.

2.3 Theory

The generalized Klein-Nishina differential formula for Compton scattering with a finite train of pulses is also applicable to classical Thomson scattering. The number of scattering photons generated into a given solid angle dΩ is

$$\frac{dN_{scat}}{d\Omega} = \int_{-\infty}^{\infty} \frac{\epsilon_0 c|E_x(\omega)|^2}{2\pi\hbar|\omega|} \frac{d\sigma}{d\Omega} d\omega \qquad \textbf{Eqn. 1}$$

And because the scattered photon has energy $\hbar\omega'$, the total scattered energy is:

$$\frac{dU_r}{d\Omega} = \int_{\infty}^{\infty} \frac{\epsilon_0 c|E_x(\omega)|^2}{2\pi} \frac{\omega'}{\omega} \frac{d\sigma}{d\Omega} d\omega \qquad \textbf{Eqn. 2}$$

The dominant scattering process for 511 Kev photons is Compton scattering, where the incident gamma-ray strikes an atomic electron producing atomic ionization. The incident photon will scatter through an angle θ determined by the Klein-Nishina differential cross section equation,

$$\left(\frac{d\sigma}{d\Omega}\right)_a = \frac{Zr_e^2}{2}\left(\frac{1}{1+\alpha(1-cos\theta)}\right)^2 \left((1+\cos^2\theta) + \frac{\alpha^2(1-cos\theta)^2}{[1+\alpha(1-cos\theta)]}\right) \qquad \textbf{Eqn. 3}$$

This equation is a differential atomic cross-sectional area equation for K-N. Also, the total K-N cross section per atom can be written as:

$$\sigma_a = 2\pi \int_0^{\pi} \left(\frac{d\sigma}{d\Omega}\right)_a sin\theta d\theta \qquad \textbf{Eqn. 4}$$

Where θ is scattering angle overall photons. Now from **Eqn. 3** and **Eqn. 4**, we get:

$$\sigma_a = 2\pi \int_0^{\pi} \frac{Zr_e^2}{2}\left(\frac{1}{1+\alpha(1-cos\theta)}\right)^2 \left((1+\cos^2\theta) + \frac{\alpha^2(1-cos\theta)^2}{[1+\alpha(1-cos\theta)]}\right) sin\theta d\theta \qquad \textbf{Eqn. 5}$$

On solving the total KN cross section per atom is obtained as:

$$\sigma_a = Z2\pi r_e^2 \left\{\frac{1+\alpha}{\alpha^2}\left[\frac{2(1+\alpha)}{1+2\alpha} - \frac{\ln(1+2\alpha)}{\alpha}\right] + \frac{\ln(1+2\alpha)}{2\alpha} - \frac{1+3\alpha}{(1+2\alpha)^2}\right\} \qquad \textbf{Eqn. 6}$$

Since Klein-Nishina atomic cross-sections are obtained by multiplying electronic cross-sections with charge number Z of each element that is $\sigma_a = Z.\sigma_e$, therefore, from equation **Eqn. 5**, the electronic cross-sectional area for KN is:

$$\sigma_e = 2\pi r_e^2 \left\{\frac{1+\alpha}{\alpha^2}\left[\frac{2(1+\alpha)}{1+2\alpha} - \frac{\ln(1+2\alpha)}{\alpha}\right] + \frac{\ln(1+2\alpha)}{2\alpha} - \frac{1+3\alpha}{(1+2\alpha)^2}\right\} \quad \textbf{Eqn. 7}$$

where $r_e = 2.818\,fm$ is the classical electron radius, Z is the nuclear charge of the target molecule and $\alpha = \frac{E}{m_e c^2} = \frac{hf}{0.511 MeV}$ by Knoll in 1989. On putting the value of σ_e in $\frac{\mu}{\rho} = \frac{\sigma_e Z N_A}{A}$ we get:

$$\frac{\mu}{\rho} = 2\pi r_e^2 \left(\frac{ZN_A}{A}\right)\left\{\frac{1+\alpha}{\alpha^2}\left[\frac{2(1+\alpha)}{1+2\alpha} - \frac{\ln(1+2\alpha)}{\alpha}\right] + \frac{\ln(1+2\alpha)}{2\alpha} - \frac{1+3\alpha}{(1+2\alpha)^2}\right\} \quad \textbf{Eqn. 8}$$

Therefore, this equation gives mass attenuation coefficient in term of KN parameters and known as Compton mass attenuation coefficient. Where N_A is Avogadro's number (6.02×10^{23} $atom/\,mol$), Z is the atomic number, and A is the material atomic mass **[20]**.

3. Results and Discussion

3.1 Mass attenuation coefficient of Tungsten, Bismuth and Carbon

The study of the cross-section area of atom and molecules for the protection of health workers and patients from radiation is important during diagnosis, treatment, and therapy. For our study carbon, bismuth, and tungsten material are considered because the properties of such materials are flexibility, lighter weight, mechanical strength, etc. Also, this element has very fewer hazards and easily available with cost-effectiveness. The MAC of pure carbon, tungsten, and bismuth is shown in figure 1.

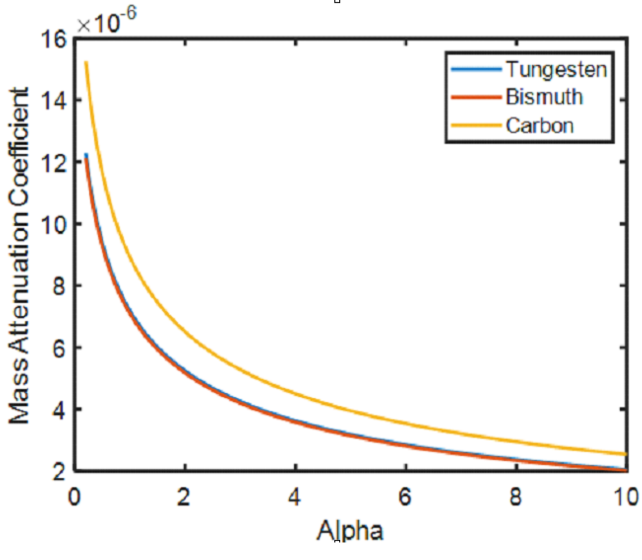

Figure 1. Mass Attenuation Coefficient with Alpha

Figure 1 represents the MAC of Tungsten, Bismuth, and carbon. The nature of the MAC decreases with an increase in the incidence energy of photon, asymptotically. The MAC is high below 2MeV and then decreases slowly, below 2MeV the value is high due to the coherent scattering of outer kick electrons and beyond 4MeV the MAC is constant. Therefore, the best energy range for Tungsten, Bismuth, and carbon is up to 4MeV for coherent scattering. The incidence energy of photons kicking the electron from orbit of Tungsten, Bismuth, and carbon plays an important role in molecular cross-section and by controlling the incidence energy one can control the molecular cross-section area during scattering. The kick out electron carry kinetic energy to penetrated the material by losing the energy and hence apron with shielding material blocks the harmful radiation entering our body. The energy of the free electrons is also determined by the incidence of photon energy. Therefore, on the basis of scattering with incidence energy one can determine the cross section (reaction of particles) and energy of ejected electron to protect from radiation hazarding.

3.2 KIein-Nishina cross-section area for consider element and compound

The Klein Nishina Cross section of considering element is shown in **Figure 2**. On the basis of cross section bismuth and interacting energetic particles has high cross section than other. The higher cross section means projected particles get diverted from longer distance of nucleus/target. The penetration of the particles is lower so the higher KN cross-section scattering is better for radiation shielding. Therefore, on the basis of cross section bismuth is better for radiation shielding than carbon and tungsten because scattered region is higher meaning the projected particles and target distance separation is higher. Hence, the energetic projected particles diverted and the materials behind the shielding material get protect. The KN Cross section of considering carbine is shown in Figure 3.

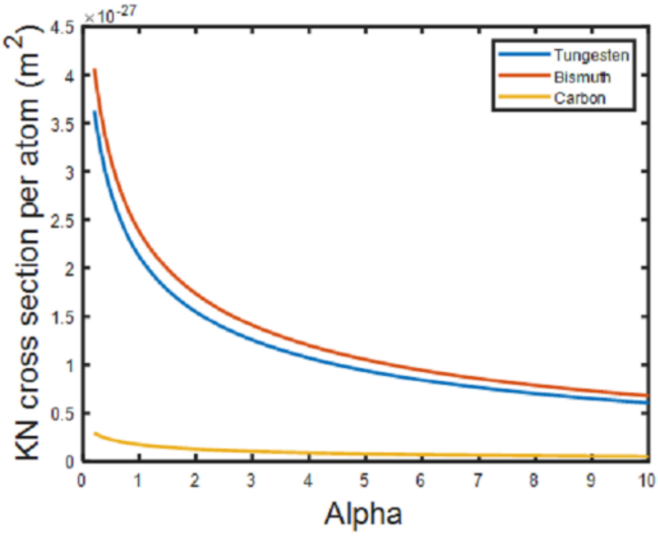

Figure 2. KN Cross-Section Per Atom with Alpha

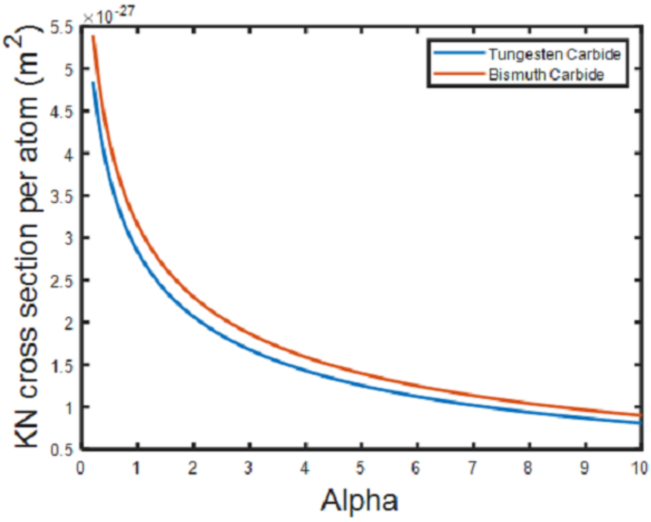

Figure 3. KN Cross-Section Per Compound with Alpha

KN cross-section decrease with increasing the energy of incidence photon, the KN cross section of bismuth carbide is found greater than tungsten carbide. Therefore, bismuth carbide is the best shielding materials than tungsten carbide because scattering of photon is higher from bismuth carbide while penetration of photon is higher for tungsten carbide. In lower region scattering is higher because cross section is high for both carbide with increasing the energy of incidence photon cross section goes asymptotic decreasing.

Conclusion

KN cross section area decrease with increases the energy of incidence photon and vice versa with asymptotic nature. The energy for this research is considered in between 0.200 MeV to 10 MeV and this energy of photon also goes to Photoelectric effect and Compton Effect. The protective equipment for health workers who are exposed to radiation must have materials which goes under Photoelectric and Compton Effect. This is because such material reduces the energy of incidence photon and protects the health worker from radiation. In our research, on the basis of scattering bismuth and its carbide is best because the KN cross section are is higher. Therefore, if health workers wear protective equipment or clothes made up of Bismuth and its carbide, they get more protected than carbon and tungsten. The KN cross section of consider material was found in increasing order carbon<tungsten<bismuth. Roos et al. study tungsten carbide is best gamma radiation (0.160 MeV to 0.779 MeV) and concluded that tungsten carbide has high potential to replace lead as new lead-free radiation shielding material in nuclear medicine [21]. In this way on the basis of scattering this bismuth carbide is better for shielding in radiation. The study of scattering theory elaborated for searching of radiation shielding materials by doping, mixing, computed formation, thickness, etc. The beneficial of this theory is that it reduces the material cost because nano layer of high KN cross section material shield the radiation by redirecting and absorbing. By using the proper shielding, workers and the public direct radiation exposure from the use of irradiation facilities should be reduced to the lowest possible limits. The radiation chamber shield is frequently built from concrete, although it can also be made from other materials such earth fill, steel, and lead. Since larger cross section equals higher scattering, which equals redirected projection and ejection of particles with lesser energy, the selected material for radiation protection should have a high KN cross section.

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References

[1] J. K. Shultis and R. E. Faw, *"Department of Mechanical and Nuclear Engineering,"* Kansas State University, Manhattan, KS, USA, 2015.

[2] B. Koirala, S.H. Dhobi, P. Subedi, M. Gurung, N.K. Teemilsina, "Study of Lennard-Jones Potential at 300K between Carbon, Silver, Gold and Oxygen Atom", *International Journal of Scientific Research in Physics and Applied Sciences*, 10 (2022) 8-14.

[3] S.H. Dhobi, K. Yadav, S.P. Gupta, J.J. Nakarmi, B. Koirala, "Differential Cross-Section in the Presence of a Weak Laser Field for Inelastic Scattering," *Ukrainian Journal of Physics*, 67 (2022) 227-228.

[4] B. Koirala, S. H. Dhobi, D. Khadka, K. Yadav, J.J. Nakarmi, K. Poudyal, "Study the Radiation Shielding Material of Iron Oxides onthe basis of Total Cross Section," *IOSR Journal of Applied Physics* 13(2021) 19-25.

[5] B. Koirala, S.H. Dhobi, K. Yadav, J.J. Nakarmi, K. Poudyal, "Cancer Radiotherapy Based on Attenuation Coefficient," *International Journal of Research and Innovation in Applied Science*, VI (2021), 21-22.

[6] S.H. Dhobi, "Selection of Anti-Cancer Agent based on Radionuclide Cross Sectional Area used in Nuclear Therapy Technology," *International Journal of Scientific Research in Physics and Applied Sciences*, 8 (2020) 1-5.

[7] S.H. Dhobi, S.K. Das, K. Yadav, "Klein Nishina Differential Equation for the Selection of Radiation Shielding Material (C, Al, Fe, and Zn) on the Basis of Attenuation and Cross sectional Area," *European Journal of Applied Physics,* 3 (2021) 30-31.

[8] F. Ilyas, B. Burbridge, P. Babyn, "Health care–associated infections and the radiology department," *Journal of Medicine Imagine Radiation Science*, 50 (2019) 596–606

[9] S.J. Alqahtani, R. Welbourn, J.R. Meakin, R.M. Palfrey, S.J. Rimes, K. Thomson, et al., "Increased radiation dose and projected radiation-related lifetime cancer risk in patients with obesity due to projection radiography," J Radiol Prot 2018;39:38.

[10] E. Pukkala, J. I. Martinsen, E. Lynge, H. K. Gunnarsdottir, P. Sparen, L. Tryggvadottir, et al., Occupation and cancer–follow-up of 15 million people in five Nordic countries, Acta Oncol 2009;48: 646–790.

[11] M. Seidenbusch, V. Rösenberger and K. Schneider, "Radiation risk and radiation protection in paediatric radiology, Imaging practice and radiation protection in pediatric radiology. Berlin, Germany: Springer; 2019. 3–8 pp.

[12] S.H. Tajmir and T. K. Alkasab, "Toward augmented radiologists: changes in radiology education in the era of machine learning and artificial intelligence," *Acadmic Radiology,* 25 (2018) 747–750

[13] N.G.S. Eldeen and S.A. Farouk, "Assessment of awareness and practice of ionizing radiation protection procedures among exposed health care workers," *Egyptian Journal of Occupational Medicine*, 44 (2020) 529–544.

[14] C. Khamtuikrua and S. Suksompong, "Awareness about radiation hazards and knowledge about radiation protection among healthcare personnel: a quaternary care academic center–based study," *SAGE Open Med,* 8 (2020) 5-6.

[15] S. S. Alavi, S. T. Dabbagh, M. Abbasi and R. Mehrdad, "Medical radiation workers' knowledge, attitude, and practice to protect themselves against ionizing radiation in Tehran Province," *Iranian Journal of Educational Health Promotion,* 6 (2017) 1-5.

[16] H. Söylemez, A. A. Sancaktutar, M. S. Silay, N. Penbegül, Y. Bozkurt, M. Atar, et al., "Knowledge and attitude of European urology residents about ionizing radiation," *Urology,* 81 (2013) 30–36.

[17] S. El-Fiki, S. U. El Kameercy, D. E. El Nashar, M. A. Abou-Leila, M. K. El-Mansy and M. Ahmad, "Influence of the Bismuth content on the mechanical and gamma ray attenuation properties of silicon rubber composites," *International Journal of Advanced Research,* 3 (2015) 1035-1039

[18] V.P. Singh, N. M. Badiger, S. Kothan, S. Kaewjaeng, T. Korkut, H.J. Kim and J. Kaewkhao, "Gamma- ray and neutron shielding efficiency of Pb-free gadolinium based glasses," *Journal of Nuclear Science and Techniques,* 27 (2016) 103-106.

[19] Y. Yao, X. Zhang, M. Li, R. Yang, T. Jiang and J. Lv, "Investigation of gamma ray shielding efficiency and mechanical performances of concrete shields containing bismuth oxide as environmentally friendly additive," *Radiation Physics and Chemistry*, 127 (2016) 188-193.
[20] S. H. Dhobi, S. K. Das and K. Yadav, "Klein Nishina Differential Equation for the Selection of Radiation Shielding Material (C, AL, Fe, and Zn) on the Basis of Attenuation and Cross sectional Area," *European Journal of Applied Physics*, 3 (2021) 30-34.
[21] N. J. A. Roosa, M. N. Azmana, N. A. B. Amina, R. Zainona, "Tungsten-based material as promising new lead-free gamma radiationshielding material in nuclear medicine," *Physica Medica*, 78 (2020) 48–57.