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Study of Radiation Shielding Properties of Lead, Concrete, and Water using Different Radionuclide Sources

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Abstract
Radiation protection for people and environment from the harmful radiation is a prime issue all over the world. Shielding is one of the basic principles of radiation protection in the existing radiation situation. Radiation interacts with the matter, and its interaction depends upon the various factor.Based on the interaction, the shielding material is selected. In the present, we have chosen the three different shielding materials namely: lead, concrete, and water. Our aim is to select the proper shielding material among these materials based on their performances. In the virtual lab work, three different types of radionuclide sources such as Co-60, Cs-137, and Am-241 of activity 1µCi have been used and results show that lead has strong shielding performance rather than concrete and water.

Keywords: radiation shielding, ionizing radiation, activity, radionuclide, and radiation protection

Introduction
The International Commission of Radiation Protection (ICRP) recommended an appropriate level of protection for people and the environment from the harmful effect of ionizing radiation because it has capable of causing a deterministic or stochastic effect on the biological tissues(Domenech, 2016).Hence, the understanding of the health effect of ionizing radiation is the prime issue of radiation protection. There are three fundamental principles of radiation protection: distance, time, and shielding. If anyone is in an existing radiation

situation, exposure can be reduced by actions taken on the exposure pathways using the fundamental principle of radiation shielding. When the gamma radiation passes through matter, due to its interaction with matter, its intensity exponentially with thickness of the matter. As a result, such material is used as a shielding material to protect personnel and sensitive electronic equipment (Özavci & Çetin, 2016). It is one of the key protection methods rather than minimizing operation time and maximizing distance(ArifSazali et al., 2019). Basically, effectiveness of shielding depends upon the thickness, type of shielding material and energy of the incident radiation. Moreover, material with high atomic number and density are more effective for radiation shielding.

One of the effective shielding materials for gamma radiation is metallic lead (Pb)dueto its low cost, ease processability, high atomic number (Z), and high density. However, it is known for its extremely low level of neutron absorption, environmental pollution, and toxicity(Mirji & Lobo, 2017). In addition to lead, other materials such as concrete and water are also used as shielding materials for gamma radiation nuclear facilities such as in nuclear power plant and research reactor.

Here, we are going to discuss the three different types of sources namely: Cobalt-60, Caesium-137, and Americium-241.Cobalt-60 (a half-life of 5.27 years) is a beta-emitting radioactive isotope along with gamma radiation. It has wide variety of industrial and medical applications, such as in thickness gauges,leveling devices, and radiotherapy in hospitals and industries.One use for it is in a medical gadget that treats brain tumors and blood vessel abnormalities precisely when they would otherwise be incurable. Large cobalt-60 sources are increasingly used for the sterilization of foods and spices. It kills bacteria and other pathogens, without damaging the product and remains non-radioactive after sterilization. The isotope Co-59 is intentionally activated with neutrons to form cobalt-60 and undergoes to produce nickel-60, a stable isotope. Since the activated nickel nucleus releases two gamma rays with energy of 1.17 and 1.33 MeV as shown in Figure 1, and the overall nuclear reaction is given in eq (1).

$$ {}^{59}_{27}Co + n \rightarrow {}^{60m}_{27}Co \rightarrow {}^{60}_{28}Ni + e^{-} + \gamma \quad \ldots\ldots(1) $$

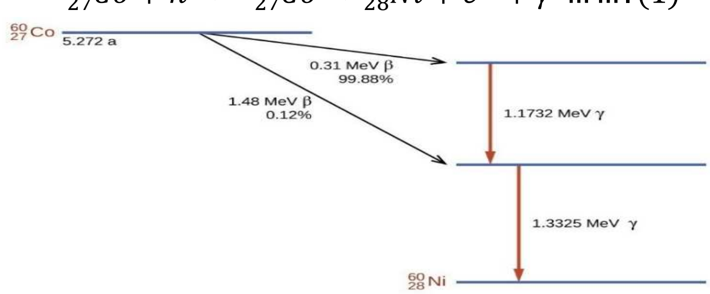

Figure1: Decay scheme of Co-60(Ahmad, 2022)

Caesium-137 undergoes β-decay by a neutron decaying into a proton, releasing an electron.The decay mode of Cs-137 is shown in Figure 2 and overall reaction is given by eq. (2).

$$^{137}_{55}Cs \rightarrow {}^{137}_{56}Ba + e^{-} + \gamma \;\; \dots \dots (2)$$

Americium-241 is a man-made radioactive metal of half-life 432 years. It is mostly alpha emitter andexists in a solid state under normal condition.The radionuclideis created when plutonium absorbs neutrons in nuclear weapons tests andnuclear reactors. It is employed as a radiation source in industry, research, and medical diagnostic equipment.It is frequently utilized as an ionization source in smoke detectors in trace levels.The first decay product of americium-241 is neptunium-237,and it is presented in Figure 3 as given by eq. (3).It also decays and forms other daughter radionuclides and finally a stable bismuth is formed. The radiation from the decay of americium-241 and its daughters is in the form of alpha particles, beta particles, and gamma rays.

$$^{241}_{95}Am \rightarrow {}^{237}_{93}Np + {}^{4}_{2}He + \gamma \dots \dots (3)$$

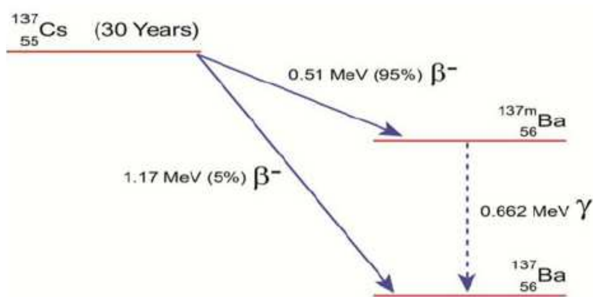

Figure2: Decay scheme of Caesium-137(Goodier et al., 1975)

Lambert's law

When the ionizing radiation passes through the matter, a part of the radiation is absorbed by matter. If a sheet of any substance is interposed in the path of ionizing radiation, its intensity decreases. Let I_0 be the intensity of the incident radiation and I be the intensity of the radiation after it has traversed a thickness dx of the matter. Then the decrease in intensity dI is observed to follow the equation$dI = -\mu I dx$. Where μ is called the linear absorption coefficient and depends upon the frequency of the radiation and nature of the medium. Solving, we get(Cherkasov et al., 2019)

$$I = I_0 e^{-\mu x}$$

This equation is known as Lambert's law

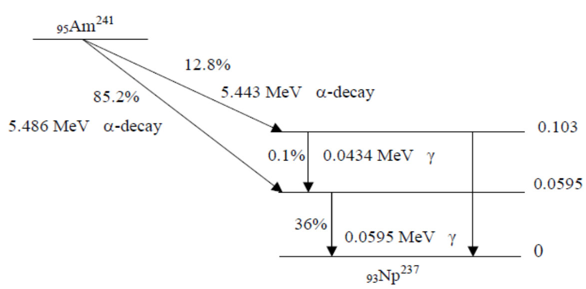

Figure3: Decay scheme of Am-241(Beling et al.,1952)

Literature Review

Azeez et al. (2013a) performed the radiation shielding properties for concrete with different aggregate granule sizes and result showed that linear absorption coefficient is inversely proportional to the thickness of the shielding material.Kim (2021) also conducted a work about the shielding materials that can replace the lead. He observed the effects of the particle size of shielding materials in shielding performance. Particle structure and performance were observed for every shielding sheet, which were fabricated by mixing micro particles and nanoparticles with a polymer material using the same process. Result showed that nanoparticle shielding sheets resulted in a 5% increase in shielding efficiency in high-energy regions, and the difference between microparticles and nanoparticles was almost equivalent in the production of low-energy shielding.Azeez et al. (2013b) conducted the study of linear attenuation coefficient of concrete and result showed that concrete containing 30% iron filling has highest linear attenuation coefficient. Al-Khawalny& Khan(2018) conducted linear and mass absorption coefficient of various soil samples in India using various gamma sources that helps to study the soil properties.

To carry out such work, it needs sophisticated radiation laboratory with gamma spectrometer. Moreover, each sample should pass through the homogeneity test to get the consistent result. It is a kind of tedious laboratory work however it can be carried out anywhere without laboratory procedure in virtual lab because it is interactive, digital simulations of activities of real phenomena. While virtual lab provides unique opportunities for interactive learning and self-paced education, they also pose challenges related to technical requirementsand the potential reduction of hands-on experience(De Vries & May, 2019). The main aim of the work is to study the radiation shielding properties of lead, concrete, and water using different sources of radiation using virtual lab.

Materials and Methods

It is a virtual experiment in which three different types of sources such as Co-60, Cs-137 and Am-241 of activity of1 μCi have been used.The experimental setup for the radiation shielding calculation has been shown in Figure4. The distance between the source and absorbing material (d_1) is adjusted at 10 cm and distance$(d_3) = 0$. For the exposure calculation, three different type of shielding materials such as lead, concrete and water have been used. To calculate the exposure with the radial distance between the shielding material $(d_2) = 0$ and detector, the thickness of the shielding is adjusted at 0.5cm for all. The shielding

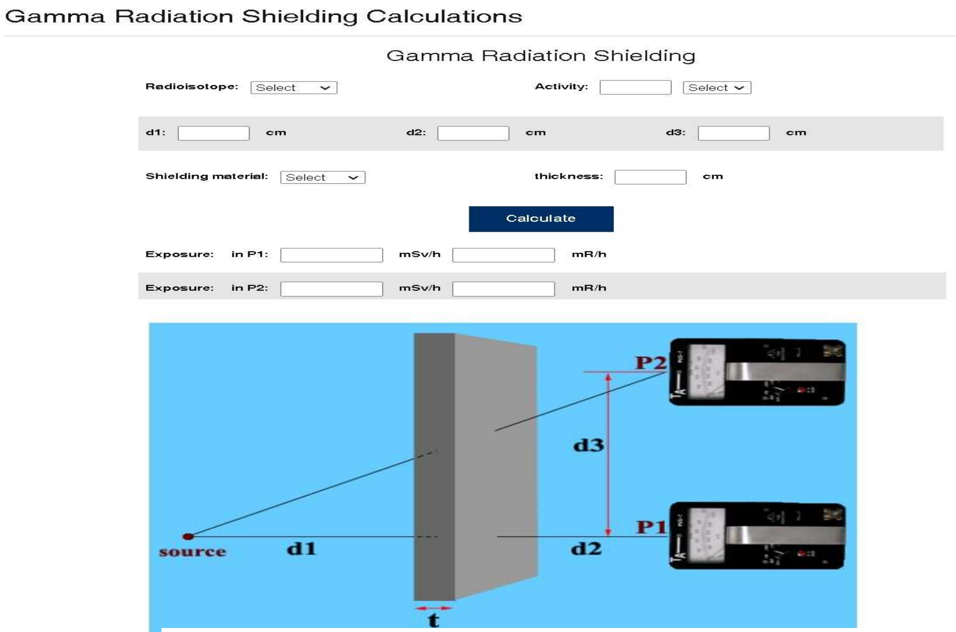

Figure4: Experimental setup for radiation shielding calculation

material is always adjusted perpendicular to the direction of incident radiation.

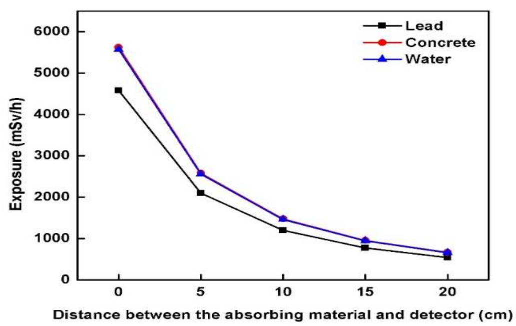

Figure5: Variation of the exposure with the radial distancebetween shieldingmaterial and detector for Co-60

Results and Discussion

When the source of radioisotopes (Co-60), its activity (1µCi) and the thickness of the shielding materials (0.5 cm) are adjusted and the exposure is observed with the change of distance between the shielding material and detector, the variation of the exposure has been observed as shown in Figure 5.

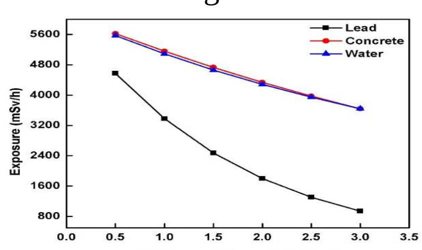

Figure 6: Variation of exposure with the thickness of the shielding material for Co-60

As the distance of the detector is increased from the shielding materials, its intensity gradually decreases due to the scattering of the materials. Same result was also obtained when the source of Cs-137 and Am-241were kept away from the source. It indicates that changing the distance of source or detector from shielding material does not alter the result. Again, the exposure rate was relatively higher in concrete and water rather thanlead. The least exposure has been observed on passing through the lead.

The exposure of the ionizing radiation with the thickness of the shielding material for different source of radioisotopes also have been studied keeping distance d_1=0,d_3=0 and d_2=10 cm.Figure6 shows how effective is the lead to block the ionizing radiation from exposure.

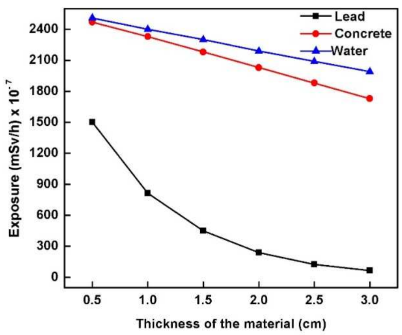

Figure7: Variation of exposure with the thickness of the shielding material for Cs-137

In all cases, the intensity of the ionizing radiation in term of exposure decreases as the thickness of the shielding material increases. However, lead shows the dramatic decreases in intensity of radiation that passes through theshielding material. It may be due to the higher density of the lead. Comparing the shielding materials water and concrete for Co-60 radioisotopes, water shows relatively higher absorbing properties of radiation. Hence, least absorbing properties has been observed in the concrete.

The shielding property of the radioisotope Cs-137 also has been studied under the same condition as mentioned in Co-60. The change of radiation exposure with thickness of the shielding material is also shown in Figure 7. Three different shielding materials such as lead, concrete and water were used for that purpose. Data showed that on changing the thickness of shielding material from 0.5 to 3.0 cm, the radiation exposure decreases from 15.0×10^{-5} to 0.65×10^{-5} mSv/h in lead, from 24.7×10^{-5} to 17.3×10^{-5}mSv/h in concrete, and from 25.1×10^{-5} to 19.9×10^{-5}mSv/h in water. In this case also, lead shows the strong radiation absorbing material rather than water and concrete. For radioisotope Cs-137, concrete has less exposure than water in all thickness of the shielding material. Probably, it is due to the low value of gamma radiation of Cs-137. As we know, Am-241 is the alpha source with gamma energy around 0.06MeV. Alpha particle is a heavier particle that can easily blocked by the thin layer of paper. On passing the radiation from the Am-241 through lead, it is found that the intensity of radiation was dramatically reduced, and it was not possible to represent in the graph, so it is absent in the Figure8. This figure only shows the variation of the intensity of radiation with thickness of shielding material concrete and water only. Result indicates that concrete is the good shielding material rather than water.

It is due to the higher density of concrete. The material having higher density can easily block the path of the alpha particle due to the interaction with radiation as a result, they are easily absorbed.

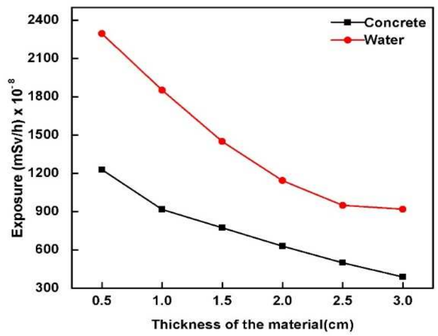

Figure 8: Variation of exposure with the thickness of the shielding material for Am-241

Conclusion

Lower exposure has been detected on passing through the lead and it strongly suggests that lead is the good shielding material for gamma, beta and alpha particle. For alpha source, concrete is far better than water for radiation shielding purpose.

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