STUDY THE RELATIONSHIP BETWEEN BREMSSTRAHLUNG DOSE RATE AND THE ENERGY OF BETA RAY FOR DIFFERENT TYPES OF SHIELD

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ABSTRACT Selection of optimal materials to protect workers from high energy beta ray exposure requires calculation of relevant dose rates. In this study, dose rates were computed for bremsstrahlung radiation from beta particles with energies of 1.710 MeV and 2.28 MeV (from beta-emitters ^{32}P and ^{90}Y) using six different shielding materials. A two-part shielding design was adopted, with a 1 mm thickness of polyethylene, wood, aluminium, iron, tungsten or lead as the first shield, closest to the beta source. A second shield (of polyethylene, aluminium or lead), with a thickness of 1, 2 or 4 mm, was placed at fixed distance of 1 cm from the beta source. Dose rates were calculated using Rad Pro Calculator (version 3.26) and plotted as a function of first shield atomic number (Z), second shield thickness, and beta energy. Results clearly demonstrate that bremsstrahlung dose rates increase with increasing beta particle energy and increasing atomic number of the second shield material. Dose rates decrease with increasing shield thickness.

Keywords: Dose rate; bremsstrahlung radiation; beta sources.

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1. INTRODUCTION

Among many sources of radiation, beta radiation sources are commonly used in manufacturing, medical and therapeutic fields. Beta particles lose energy during transit through matter by deceleration due to interaction with molecules in their pathway. The 'lost' energy of the positron or electron may be emitted as a form of secondary radiation termed bremsstrahlung (Martin, 2006).

There are two kinds of beta decay, β^- and β^+, which produce electrons and positrons, respectively. As the nucleus consists of protons and neutrons, and electrons cannot exist inside the nucleus, in β^- decay a neutron must be converted into a proton at the time of β^- emission. Thus, in this process, the charge of the decaying nucleus (and its atomic number) increases by one. In β^+ decay, a proton is converted into a neutron. In electron capture, a proton is similarly converted into a neutron, and hence electron capture can also be considered a form of beta decay. The type of beta decay is determined by the masses of the primary (parent) and final (daughter) nuclei, which are isobaric (Jan, 2013).

Isobars are nuclides (atoms) of different elements with the same mass number (A) but different numbers of protons (Z) and neutrons (N) (Murtadha et al., 2019). Beta particles interact with matter through the following processes:

(i) Ionisation.
(ii) Electron orbital excitation, leading to dissipation of beta particle kinetic energy.
(iii) Bremsstrahlung (Michael, 2003).
(iv) Cherenkov radiation. Charged particles (e.g. beta particles) with sufficient energy can travel at speeds greater than the phase velocity of light through optically transparent media (e.g. water, organic solvents, plastic or glass). When this happens, the charged particles yield Cherenkov photons in ultraviolet and visible wavelengths (Michael, 2003; Alexander et al., 2019).

The probability of any specific type of interaction occurring, and hence the penetrating power of the primary or secondary radiation, depends on:

(a) the radiation type and energy;
(b) the nature of the absorbing medium (Nesreen, 2014).

Bremsstrahlung Radiation

Bremsstrahlung emissions should be considered when using sources of high-energy beta particles, such as yttrium-90 (^{90}Y) which emits maximum beta radiation energy (Eβmax) of 2.28 MeV (Taisuke et al., 2014). The probability of bremsstrahlung creation increases with increasing beta energy and with increasing atomic number of the absorber (Herman & Thomas, 2005). Additionally, the quantity of bremsstrahlung generated depends strongly on the material involved, with more secondary radiation produced from materials with high atomic numbers than from those with low atomic numbers (Van & Drzyzga, 2007).

The ease with which beta sources may be shielded sometimes leads to the erroneous impression that they are less dangerous than gamma or neutron sources, and that large beta emitters may be handled directly. This is an extremely dangerous practice as, for example, the absorbed dose rate from a 1 MBq beta source at a distance of 3 mm is about 1 Gy/h. A significant problem in shielding against beta radiation is the emission of secondary X-rays, resulting from rapid particle deceleration. This secondary radiation, known as bremsstrahlung, may have greater penetrative power than the beta particles themselves. Hence beta shields should be constructed of materials with low mass numbers (e.g. aluminium or Perspex) to minimise bremsstrahlung emissions (Alan et al., 2012).

2. RESEARCH METHODOLOGY

In this study, bremsstrahlung dose rates were assessed for a dual-shield system. The first shield component (polyethylene, wood, aluminium, iron, tungsten and lead) had a thickness of 1 mm and was placed closest to the beta source. The second shield component (polyethylene, aluminium and lead) was placed at a fixed distance of 1 cm from the beta source. The second shield was tested with thicknesses of 1, 2 and 4 mm. Our measurements were made using phosphorus-32 (^{32}P) and yttrium-90 (^{90}Y) beta sources with energies of 1.710 MeV and 2.28 MeV, respectively.

Bremsstrahlung dose rates were obtained for several contrasting materials using Rad Pro Calculator software (version 3.26). This program allows the researcher to choose the radioactive source, units of dose rate, activity and distance. Next, the first shield material and thickness units are selected. Then, source activity, distance between source and shield, and shield thickness are entered. At this point, the dose rate can be calculated. Finally, the thickness and material of the second shield are selected to calculate the bremsstrahlung exposure dose rate.

3. RESULTS AND DISCUSSION

Estimated dose rates (in units of rad/h) for the different beta sources, shield materials and thicknesses are shown in Tables 1 and 2. Bremsstrahlung dose rates (rad/h) are plotted as a function of first shield atomic number (Z), second shield material, and second shield thickness for beta energies of 1.710 MeV and 2.28 MeV in Figures 1 and 2, respectively

Table 1. Dose rates (rad/h) for an E_β = 1.710 MeV source (^{32}P) for the different shield materials thicknesses described in Section 2.

		Second shield thickness (x=1mm)			**second shield thickness (x=2mm)**			**second shield thickness (x=4mm)**		
First shield material	**(Z)**	**Dose rate (R/hr) Polyethylene**	**Dose rate (R/hr) Aluminum**	**Dose rate (R/hr) Lead**	**Dose rate (R/hr) Polyethylene**	**Dose rate (R/hr) Aluminum**	**Dose rate (R/hr) Lead**	**Dose rate (R/hr) Polyethylene**	**Dose rate (R/hr) Aluminum**	**Dose rate (R/hr) Lead**
Poly-ethylene	4.74	0.4786	0.9703	3.4129	0.4415	0.8952	3.1486	0.3758	0.7619	2.6799
Wood	6.34	0.4972	1.008	3.5454	0.4765	0.9660	3.3978	0.4376	0.8873	3.1209
Aluminum	13	0.4254	0.8625	3.0338	0.3489	0.7073	2.4880	0.5641	1.1437	4.0227
Iron	26	0.5343	1.0833	3.8102	0.444	0.9003	3.1666	0.2244	0.4550	1.6004
Tungstun	74	0.1796	0.3641	1.2807	0.0354	0.0717	0.2524	0.001	0.0021	0.0075
Lead	82	0.2372	0.4809	1.6917	0.0892	0.1810	0.6366	0.0115	0.0235	0.0826

Table 2. Dose rates (rad/h) for an E_β = 2.28 MeV source (^{90}Y) for the different shield materials thicknesses described in Section 2.

		Second shield thickness (x=1mm)			**second shield thickness (x=2mm)**			**second shield thickness (x=4mm)**		
First shield material	**(Z)**	**Dose rate (R/hr) Polyethylene**	**Dose rate (R/hr) Aluminum**	**Dose rate (R/hr) Lead**	**Dose rate (R/hr) Polyethylene**	**Dose rate (R/hr) Aluminum**	**Dose rate (R/hr) Lead**	**Dose rate (R/hr) Polyethylene**	**Dose rate (R/hr) Aluminum**	**Dose rate (R/hr) Lead**
Poly-ethylene	4.74	1.0670	2.1974	13.9079	0.9948	2.0487	12.9669	0.8648	1.7809	11.2716
Wood	6.34	1.1029	2.2714	14.3760	1.0629	2.1890	13.8545	0.9872	2.0330	12.8676
Aluminum	13	0.9634	1.9841	12.5578	0.8111	1.6703	10.5716	1.3537	2.7878	17.6446
Iron	26	0.6997	1.4409	9.1198	1.2538	2.5820	16.3422	0.7143	1.4710	9.3106
Tungstun	74	0.6069	1.2499	7.9109	0.2244	0.4621	2.9252	0.018	0.0371	0.2352
Lead	82	0.9667	1.9908	12.6005	0.4778	0.9839	6.2277	0.0921	0.1896	1.2005

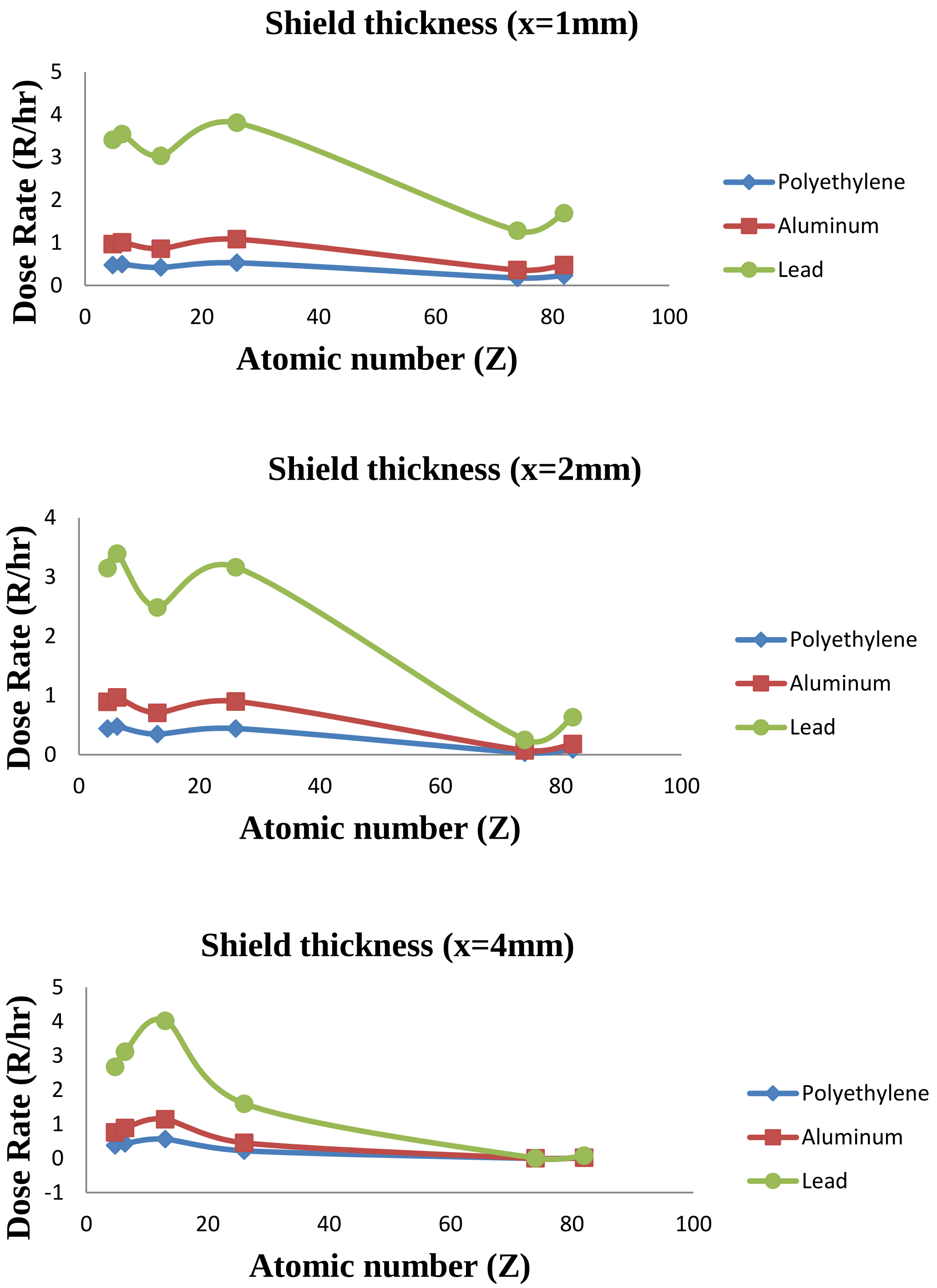

Figure 1. Dose rate for beta source $E_\beta = 1.710$ MeV as a function of atomic number (Z) by first shield material for each second shield thickness.

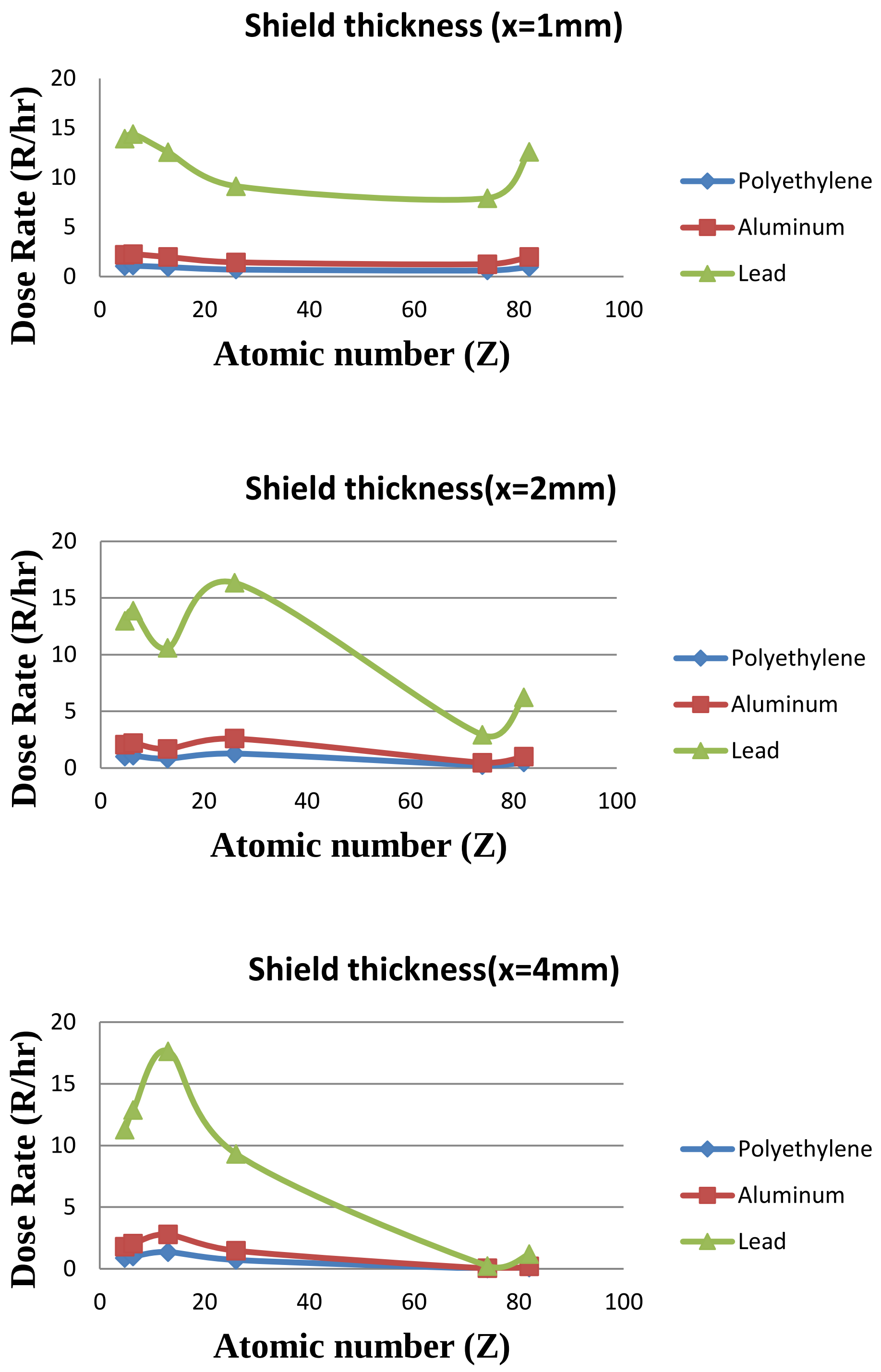

Figure 2. Dose rate for beta source E_{β} = 2.28 MeV as a function of atomic number (Z) by first shield material for each second shield thickness.

It is clear from Figures 1 and 2 that the bremsstrahlung dose rate increases with increasing second shield atomic number for both energies of beta ray. Therefore, beta radiation shields should be produced from materials with the minimum feasible atomic number.

For all shielding materials, dose rates associated with the 2.28 MeV beta source (14–11.5 rad/h) are significantly greater than those resulting from the 1.710 MeV source (3.5–2.5 rad/h). This behaviour can be explained by the increased probability of particle interaction with shield materials with increased beta ray energy.

The effect of second shield thickness on dose rate for different beta ray energies can also be seen in Figures 1 and 2: dose rates decrease with increasing width of the second shield. This is due to the increased probability of particle interaction for a longer pathway through the material.

4. CONCLUSIONS

This investigation demonstrates that shielding materials with low atomic numbers (Z) and low beta energy levels are the key factors controlling safe human exposure to beta radiation. Materials with high atomic numbers might result in unwanted exposure to additional secondary radiation (bremsstrahlung), as discussed in Section 3. The phenomenon of bremsstrahlung production is higher for materials of high atomic numbers and for high particle energies. Beta energy dose rates decrease with increasing width or thickness of the shielding material.

5. ACKNOWLEDGMENTS

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