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DETERMINATION RISK OF BREMSSTRAHLUNG RADIATION PRODUCED BY BETA-RAY

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Abstract: When interacting with absorption materials, beta rays, which are emitted by isotopes, are harmful because bremsstrahlung (braking) radiation is produced. Therefore, the efficiency of a shielding material can be improved by considering the bremsstrahlung radiation generated by the material's beta ray absorption. In this study, to determine the risk of bremsstrahlung radiation produced by beta rays, the fractions of beta energy transformed into bremsstrahlung radiation were calculated for beta emitters in the energy ranges of 0.0026–0.1734, 0.205–0.694, and 0.9345–2.640 MeV, using five different absorption materials ($_{13}$Al, $_{26}$Fe, $_{48}$Cd, $_{74}$W, and $_{82}$Pb). The relationship between the fractions of beta energy transformed into bremsstrahlung radiation by the five shielding materials and the maximum energies of some beta emitters was studied to determine the most suitable beta-ray shielding materials to effectively minimize bremsstrahlung radiation. The results showed that the fractions of beta energy transformed into bremsstrahlung radiation increased as the beta energy and the atomic number of the shielding material increased. The fraction of beta energy transformed into bremsstrahlung radiation in $_{13}$Al < $_{26}$Fe < $_{48}$Cd < $_{74}$W < $_{82}$Pb.Therefore, beta ray shields should be made with low atomic number materials to reduce the generation of bremsstrahlung radiation. Practically, beta shields made from materials with atomic numbers greater than 13 are rarely employed; notably, aluminum successfully decreased the production of bremsstrahlung radiation. However, it is also necessary to use materials with medium and high atomic numbers as secondary beta shields to reduce the effect of the bremsstrahlung radiation photons formed by the interaction between beta rays and shielding materials.

Keywords: *beta emitters, beta particles, bremsstrahlung radiation, shielding materials.*

1. Introduction

A beta (β) particle, which has moderate penetration power, is a high-velocity electron or sometimes a positron (the electron's antiparticle) (Duaa et al., 2019). Beta particles are electrons with a negative or positive charge (e^- and e^+). The atomic number (Z) of an element increases by one unit in the case of β^- decay and decreases by one unit in the case of β^+ decay. Some nuclei undergo radioactive change by taking an atomic electron, generally from the K shell, releasing a neutrino, and decreasing in atomic number (James, 2007; Murtadha et al., 2019). Beta particles react with absorber materials in four ways: direct ionization, delta rays from electrons generated by ionization, production of bremsstrahlung radiation, and Cerenkov radioactivity (Michael, 2003). Charged particles (e.g., beta particles) with enough energy can travel at speeds greater than the phase velocity of light through optically transparent media (e.g., water, organic solvents, plastic, glass). When this occurs, the charged particles produce Cherenkov photons at ultraviolet and visible wavelengths (Ahmed et al., 2022). The most significant reactions are bremsstrahlung radiation and direct ionization (Martin, 2006).

Shielding substances, when located between the source of radiation and the receptor, can affect the quantity of radiation that reaches the receptor. This implies that the reduction and absorption of produced radiation occurs in the source itself, in substances employed in the encapsulation of the source, or in a shielding block (Martin, 2006).

Radiation protection blocks people and the environment from the damaging results of ionizing radiation. One major concern in nuclear energy plant construction is radiation exposure. Using powerful (high-activity) radioisotopes in "spin-off" applications, such as medical X-ray diagnostic systems, food protection, particle acceleration, and cancer treatment, can be dangerous for workers involved in these radiation-based services (Thomas et al., 2016).

Many studies have focused on the absorption of beta rays into shielding substances and the resulting bremsstrahlung radiation. For example, Wesley et al. (2007) studied the production of bremsstrahlung photons from shielding materials, such as plastic and lead, in various arrangements to determine the absolute efficiency of plastic and lead alone and the optimal order and positions of plastic and lead together. Amato et al. (2009) established a Monte Carlo simulation in Geant4 to compare the bremsstrahlung radiation produced by various kinds of plastic substances used as shields for beta ray emitters and their attenuation properties. Serkan et al. (2016) estimated the radiation yields from electrons in several absorbing materials, such as water, carbon, aluminum, copper, lead, and uranium, in

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the primary electron energy range from 10 keV to 1 GeV. Moreover, Manjunath (2020) measured the photon and bremsstrahlung yields from β^- particles in the energy range of 0.1668–2.274 MeV for intensive targets with atomic numbers of 13–83. This paper aims to determine the risk of bremsstrahlung radiation produced by beta rays. The fractions of beta energy transformed into bremsstrahlung radiation for some beta emitters in energy ranges of 0.0026–0.1734, 0.205–0.694, and 0.9345–2.640 MeV are calculated using five different absorption materials ($_{13}$Al, $_{26}$Fe, $_{48}$Cd, $_{74}$W, and $_{82}$Pb).

2. Theory

Bremsstrahlung radiation is produced when high-speed charged particles experience a fast transformation in velocity, specifically when they accelerate. Because velocity is a vector quantity that contains both direction and magnitude, a change in path—even if the speed value remains the same—results in a change in speed (Thomas, 2017).

As soon as an electron or beta particle passes near nuclei shielding material, beta particles deviate from their original path due to the influence of the nucleus's electric field. This transformation involves radial acceleration. According to Maxwell's classical theory, beta particles lose energy by emitting electromagnetic radiation that is proportional to the square of its acceleration (Thomas, 2017).

Bremsstrahlung radiation occurs when beta particles (high-speed electrons) pass near the nuclei of the absorbing material (Thomas et al., 2016; Mangiarotti et al., 2017), especially if the material has a high atomic number. Thus, when beta emitters or expedited monoenergetic electrons are used, the fraction of beta energy transformed into bremsstrahlung radiation must be considered to determine the type and design of shielding materials that can be used (Thomas et al., 2016).

It is significant for those who work with radionuclides to understand that bremsstrahlung radiation is not a feature of beta sources and thus cannot be seen in the spectrum of decay. X-rays are an outcome of the reaction of beta particles with neighboring materials, such as flasks or shields (Thomas, 2017).

To estimate the bremsstrahlung risk from beta radiation (Thomas, 2017), the fraction of beta energy transformed into bremsstrahlung rays can be calculated using the following equation (Wesley et al., 2007):

$$F = 3.5 \times 10^{-4}\, E_m\, Z \qquad (1)$$

where F is the fraction of beta energy (MeV) transformed into X-rays, E_m is the maximum energy (MeV) of the beta ray, and Z is the atomic number of the shielding material.

3. Methodology

This study focused on determining the risk of bremsstrahlung radiation, which can be achieved by calculating the fraction of beta energy transformed into bremsstrahlung radiation using Equation 1. These fractions have been calculated for 50 beta sources, which are classified into three energy ranges: low (0.0026–0.1734 MeV), medium (0.205–0.694 MeV), and high (0.9345–2.640 MeV), using five shielding materials ($_{13}$Al, $_{26}$Fe, $_{48}$Cd, $_{74}$W and $_{82}$Pb).

Aluminum is a multipurpose, cheap, and appealing metal substance for its wide scope of use. It can be processed as a smooth, highly flexible packaging foil and can be used in numerous engineering applications. Aluminum has a density of 2.7 g/cm^3, and its surface can be an efficient reflector. It efficiently reflects electromagnetic waves, radiant energy, visible light, and radiant heat (Davis, 2001).

Iron is a cheap but strong structural material that has a relatively high density. It is activated by neutrons. Thus, thicker and heavier shields are required to achieve equivalent attenuation in lead, bismuth, or tungsten. Significantly, the generation of bremsstrahlung radiation in iron is lower than in bismuth or lead (Daniel, 2018).

Cadmium (Cd) is a gray-white, soft, ductile metal (Honey et al., 2015). As a radiation shielding material, its photon-like mass attenuation factor (μ/p) and effective atomic number (Z_{eff}) gradually increase as CdO content increases (Alajerami et al., 2020).

Tungsten exhibits stability at high temperatures, with lower toxicity and attenuation factors than lead or bismuth, but its higher density means that a similar material thickness will achieve the same attenuation (Daniel, 2018). Tungsten also has a lower half-value layer compared to traditional shielding substances, such as lead (Nadin et al., 2020).

Metallic lead is frequently employed as a radiation shielding substance because it has a high atomic number, low cost, and easy processability; specifically, it offers good shielding against breakthrough gamma radiation. (Rajeshwari et al., 2017).

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Malaysian Journal of Science 43(3): 109-118 (September 2024)

4. Results and Discussion

The fractions of the beta energy transformed into bremsstrahlung radiation in the five shielding materials, calculated using Equation 1, are shown in Tables 1, 2, and 3. The relationship between the beta energies and the calculated fractions of the beta energy transformed into bremsstrahlung radiation for each of the five shielding materials was visualized by plotting the fraction of beta energy as a function of total beta energy. A plot was created for each shielding material using the specific low, medium, and high ranges of beta energies (0.0026–0.1734, 0.205–0.694, and 0.9345–2.640) MeV, as shown in Figures 1, 2, and 3, respectively.

Table 1. Fractions of beta energy transformed into bremsstrahlung radiation by shielding material ($_{13}Al$, $_{26}Fe$, $_{48}Cd$, $_{74}W$, and $_{82}Pb$) for beta energies of 0.0026–0.1734 MeV.

Beta sources	Maximum Beta Energy (MeV) (Wang et al., 2012)	Fraction (MeV)*10^{-3}				
		$_{13}Al$	$_{26}Fe$	$_{48}Cd$	$_{74}W$	$_{82}Pb$
Re-187	0.0026	0.0118	0.0236	0.0436	0.0673	0.0746
H-3	0.0186	0.0846	0.1692	0.3124	0.4817	0.5338
Pu-241	0.0208	0.0946	0.18928	0.3494	0.5387	0.5970
Tm-171	0.0297	0.1351	0.2703	0.4990	0.7692	0.8524
Pd-107	0.033	0.1502	0.3003	0.5544	0.8547	0.9471
Ru-106	0.0394	0.1793	0.3585	0.6619	1.0205	1.1308
Sm-151	0.0548	0.2493	0.4987	0.9206	1.4193	1.5728
W-188	0.058	0.2639	0.5278	0.9744	1.5022	1.6646
Ni-63	0.0669	0.3044	0.6088	1.1239	1.7327	1.9200
Sm-151	0.0763	0.3472	0.6943	1.2818	1.9762	2.1898
Tm-171	0.0964	0.4386	0.8772	1.6195	2.4968	2.7667
Bk-249	0.1257	0.5719	1.1439	2.1118	3.2556	3.6076
Se-79	0.1507	0.6857	1.3714	2.5318	3.9031	4.3251
C-14	0.1565	0.7121	1.4242	2.6292	4.0534	4.4916
S-35	0.1668	0.7589	1.5179	2.8022	4.3201	4.7872
Kr-85	0.1734	0.7890	1.5779	2.9131	4.4911	4.9766

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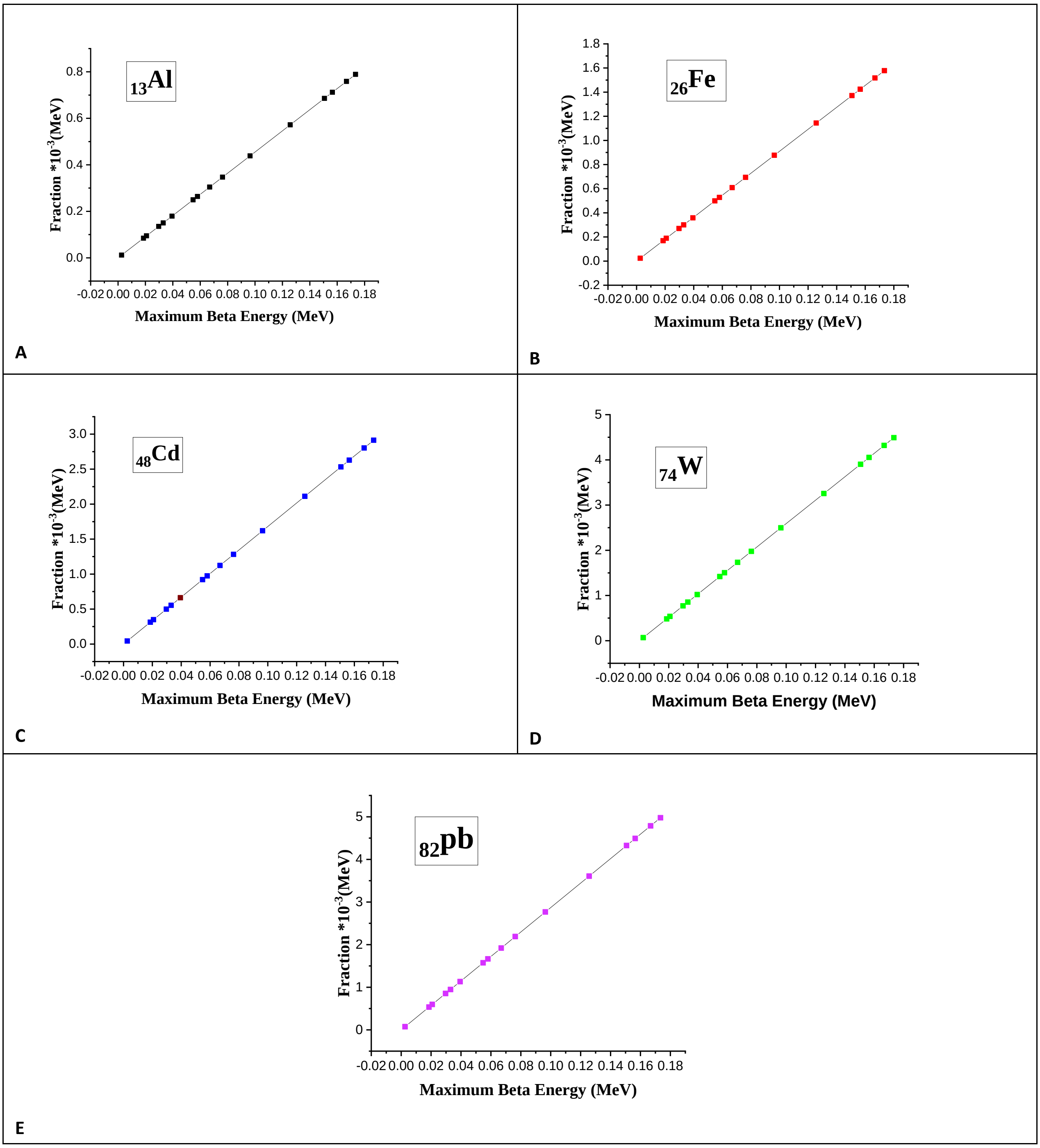

Figure 1. Fractions of beta energy transformed into bremsstrahlung radiation as a function of beta energy for a) $_{13}$Al, b) $_{26}$Fe, c) $_{48}$Cd, d) $_{74}$W, and e) $_{82}$Pb shielding materials for beta energies of 0.0026–0.1734 MeV.

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Malaysian Journal of Science 43(3): 109-118 (September 2024)

Table 2. Fractions of beta energy transformed into bremsstrahlung radiation by shielding material ($_{13}$Al, $_{26}$Fe, $_{48}$Cd, $_{74}$W, and $_{82}$Pb) for beta energies of 0.205–0.694 MeV.

Beta sources	Maximum Energy (MeV) (Wang et al., 2012)	Fraction (MeV)*10^{-3}				
		$_{13}$Al	$_{26}$Fe	$_{48}$Cd	$_{74}$W	$_{82}$Pb
Cs-135	0.205	0.9328	1.8655	3.444	5.3095	5.8835
Pm-147	0.2246	1.0219	2.0439	3.7733	5.8171	6.4460
Si-32	0.225	1.0238	2.0475	3.7800	5.8275	6.4575
Ni-66	0.227	1.0329	2.0657	3.8136	5.8793	6.5149
P-33	0.2485	1.1307	2.2614	4.1748	6.4362	7.1320
Ca-45	0.2568	1.1684	2.3369	4.3142	6.6511	7.3702
Te-127	0.276	1.2558	2.5116	4.6368	7.1484	7.9212
W-188	0.285	1.2968	2.5935	4.7880	7.3815	8.1795
Tc-99	0.2935	1.3354	2.6709	4.9308	7.6017	8.4235
Sn-123	0.314	1.4287	2.8574	5.2752	8.1326	9.0118
Cd-113	0.316	1.4378	2.8756	5.3088	8.1844	9.0692
Y-91	0.3409	1.5511	3.1022	5.7271	8.8293	9.7838
Er-169	0.3425	1.5584	3.1168	5.7540	8.8708	9.8298
W-188	0.349	1.5880	3.1759	5.8632	9.0391	10.0163
Er-169	0.3509	1.5966	3.1932	5.8951	9.0883	10.0708
Sn-121	0.3889	1.7695	3.5390	6.5335	10.0725	11.1614
In-115	0.497	2.2614	4.5227	8.3496	12.8723	14.2639
Sr-90	0.5462	2.4852	4.9704	9.1762	14.1466	15.6759
Be-10	0.5562	2.5307	5.0614	9.3442	14.4056	15.9629
Ar-39	0.565	2.5708	5.1415	9.4920	14.6335	16.2155
Cd-113	0.580	2.6390	5.2780	9.7440	15.0220	16.6460
Ar- 42	0.600	2.7300	5.4600	10.0800	15.5400	17.2200
Pb-209	0.6444	2.9320	5.8640	10.8259	16.6900	18.4943
Kr-85	0.6874	3.12767	6.2553	11.5483	17.8037	19.7284
Te-127	0.694	3.1577	6.3154	11.6592	17.9746	19.9178

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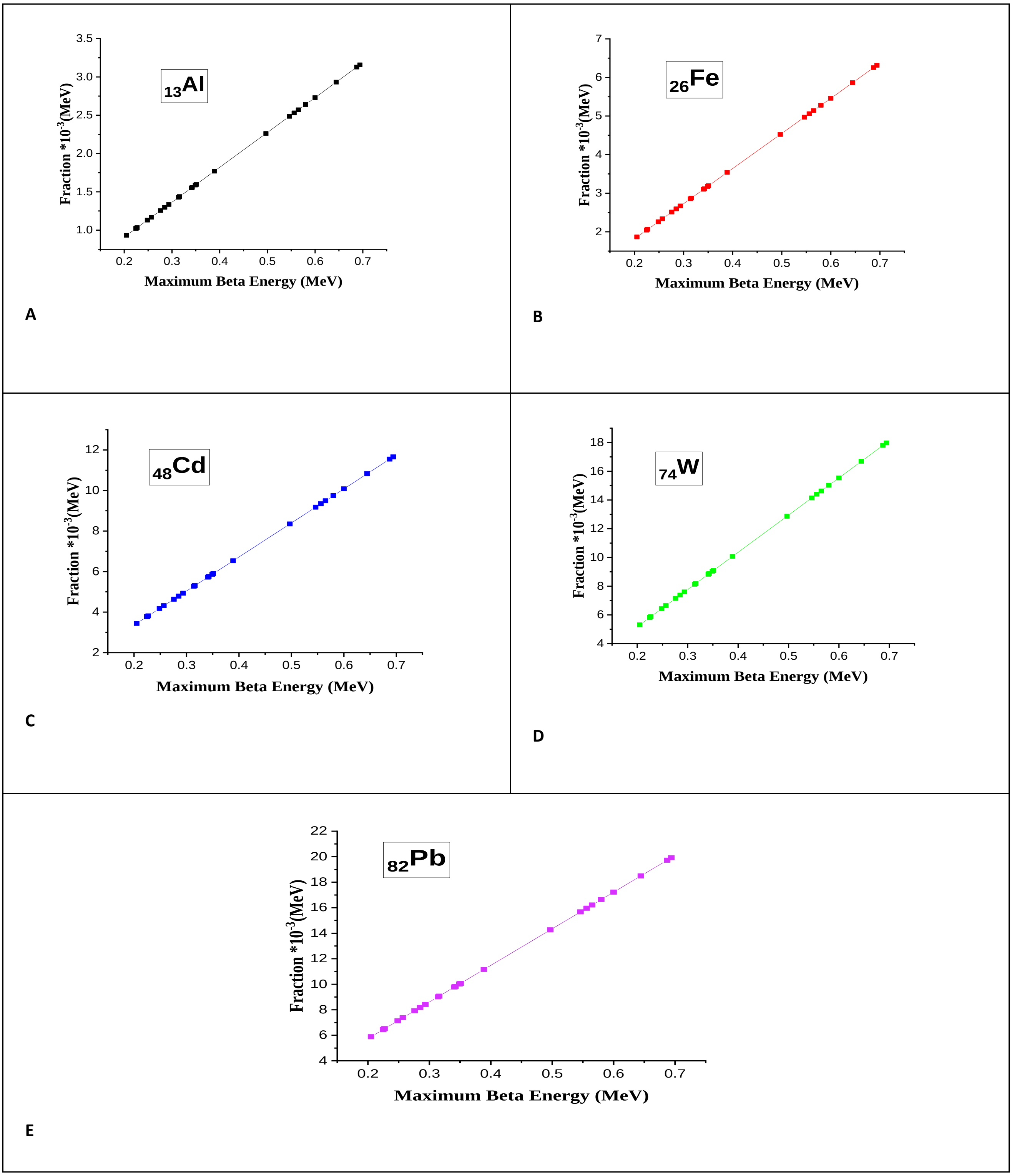

Figure 2. Fractions of beta energy transformed into bremsstrahlung radiation as a function of beta energy for a) $_{13}$Al, b) $_{26}$Fe, c) $_{48}$Cd, d) $_{74}$W, and e) $_{82}$Pb shielding materials for beta energies of 0.205–0.694 MeV.

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Table 3. Fractions of beta energy transformed into bremsstrahlung radiation by shielding material ($_{13}Al$, $_{26}Fe$, $_{48}Cd$, $_{74}W$, and $_{82}Pb$) for beta energies of 0.9345–2.640 MeV

Beta sources	Maximum Energy (MeV) (Wang et al., 2012)	Fraction (MeV)*10^{-3}				
		$_{13}Al$	$_{26}Fe$	$_{48}Cd$	$_{74}W$	$_{82}Pb$
Pr-143	0.9345	4.2520	8.5040	15.6996	24.2036	26.8202
Bi-210	1.1615	5.2848	10.5697	19.5132	30.0829	33.3351
Sn-123	1.403	6.3837	12.7673	23.5704	36.3377	40.2661
Sr-89	1.492	6.7886	13.5772	25.0656	38.6428	42.8204
Y-91	1.5456	7.0325	14.0650	25.9660	40.0310	44.3587
P-32	1.7103	7.7819	15.5637	28.7330	44.2968	49.0856
Pr-145	1.805	8.2128	16.4255	30.3240	46.7495	51.8035
Y-90	2.2814	10.3804	20.7607	38.3275	59.0883	65.4762
Cu-66	2.640	12.0120	24.0240	44.3520	68.3760	75.7680

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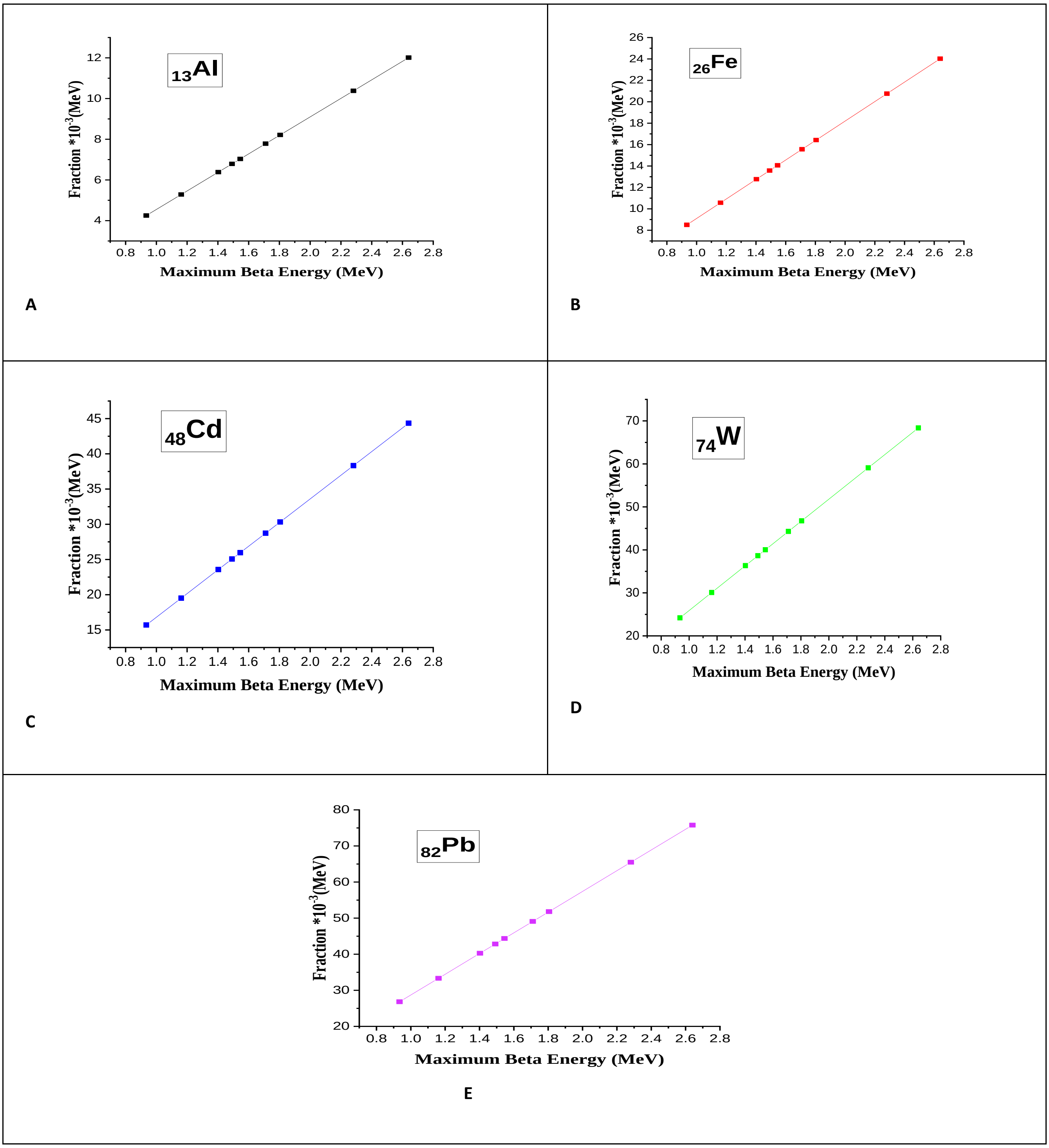

Figure 3. Fractions of beta energy transformed into bremsstrahlung radiation as a function of beta energy for a) ${}_{13}$Al, b) ${}_{26}$Fe, c) ${}_{48}$Cd, d) ${}_{74}$W, and e) ${}_{82}$Pb shielding material for beta energies of 0.9345–2.640 MeV.

For all five shielding materials (${}_{13}$Al, ${}_{26}$Fe, ${}_{48}$Cd, ${}_{74}$W or ${}_{82}$Pb), the fractions of beta energy transformed into bremsstrahlung radiation related to the low beta energy range (0.0026–0.1734 MeV) [(0.01183–0.78897, 0.02366–1.57794, 0.04368–2.91312, 0.06734–4.49106, and 0.07462–4.97658) × 10^{-3} MeV] were significantly lower than the fractions resulting from the medium beta energy range (0.205–0.694 MeV) [(0.93275–3.1577, 1.8655–6.3154, 3.444–11.6592, 5.3095–17.9746, and 5.8835–19.9178) × 10^{-3} MeV] and the high beta energy range (0.9345–2.640 MeV) [(4.251975–12.012, 8.50395–24.024, 15.6996–44.352, 24.20355–68.376, and 26.82015–75.768) × 10^{-3} MeV].

To compare the fractions of beta energy transformed into bremsstrahlung radiation for all shielding materials, the fraction values were plotted as a function of maximum beta energies for the three beta energy ranges, as shown in Figures 4, 5, and 6.

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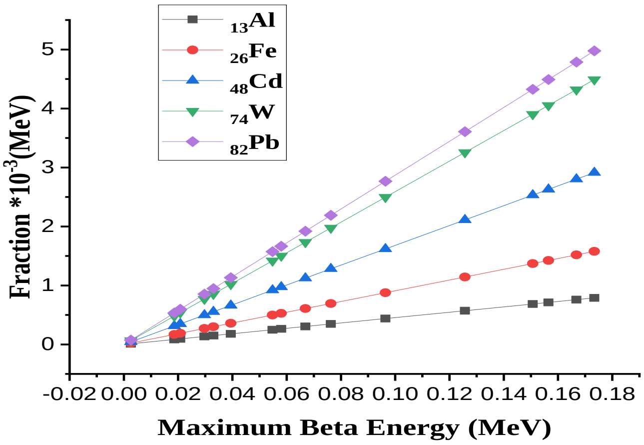

Figure 4. Comparison of the fractions of beta energy transformed into bremsstrahlung radiation for all shielding materials at beta energies of 0.0026–0.1734 MeV.

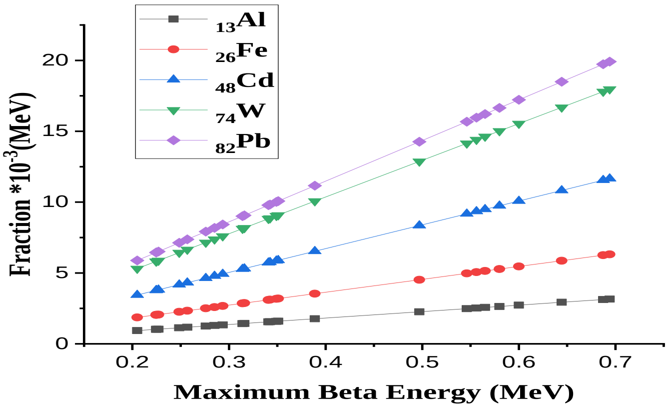

Figure 5. Comparison of the fractions of beta energy transformed into bremsstrahlung radiation for all shielding materials used in this work at beta energies of 0.205–0.694 MeV.

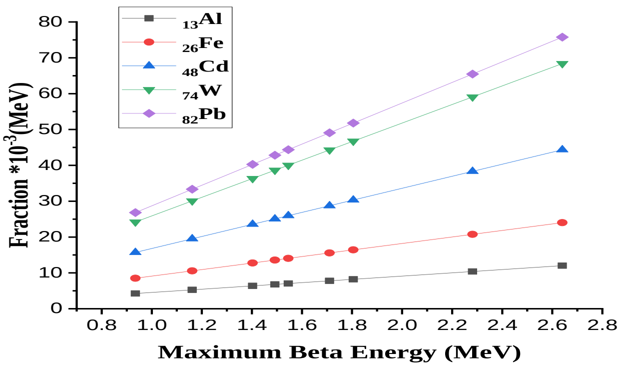

Figure 6. Comparison of the fractions of beta energy transformed into bremsstrahlung radiation for all shielding materials used in this work at beta energies of 0.9345–2.640 MeV.

Figures 4, 5, and 6 show that the fractions of $_{13}$Al (black line) are lower than the fractions of the other shielding materials. The fractions of bremsstrahlung production for the shielding materials, as well as the risk of beta sources, increase as the beta energy and atomic number of the shielding materials increase. This is due to the increased probability of interaction between beta rays and shield materials with increasing beta energies and atomic numbers.

5. Conclusion

This work demonstrated that the fractions of beta rays transformed into bremsstrahlung radiation increases as the beta

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energy and atomic number of the shielding materials increase. Therefore, beta shields should be made from materials with lower atomic numbers to reduce the risk of bremsstrahlung radiation. Practically, beta shields with atomic numbers greater than 13 (e.g., aluminum) are rarely employed; however, shields made from substances of low mass number (e.g., aluminum) yield less bremsstrahlung radiation. It is also necessary to use materials with medium and high atomic numbers as secondary beta shields to reduce the effect of bremsstrahlung photons, which are formed in the interaction between beta rays and shielding material.

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7. References

Ahmed Fadhil Mkhaiber and Naz T. Jarallah. (2022) Study the Relationship between Bremsstrahlung Dose Rate and The Energy of Beta Ray for different Types of Shiels", Malaysian Journal of Science, vol.41, no.2, pp. 47-54.

Alajerami, Y.S., Drabold, D., Mhareb, M.H.A., Cimatu, Katherine Leslee A., Chen, Gang and kurudirek M. (2020), Radiation Shielding Properties of Bismuth Borate Glasses Doped with Different Concentrations of Cadmium Oxides, Ceramics International, vol.46, pp.12718- 12727.

Amato, E. and Lizio, D. (2009), Plastic materials as a radiation shield for β − sources: a comparative study through Monte Carlo calculation, J. Radiol. Prot.,vol.29, no.2, pp.239–250.

A Mangiarotti and M N Martins. (2017), A review of electron–nucleus bremsstrahlung cross sections between 1 and 10 MeV, Radiation Physics and Chemistry,vol.141,pp.312-338.

Daniel R. McAlister. (2018), Gamma Ray Attenuation Properties of Common Shielding Materials, PG Research Foundation, Inc. University Lane Lisle, USA, June 18.

Davis, J.R. (2001), Alloying: Understanding the Basics", ASM International.

Duaa Abed Salim, and Sameera Ahmed Ebrahim. (2019) Measurement of Radon concentration in College of Education, Ibn Al- Haitham buildings using Rad-7 and CR-39 detector, Energy Procedia, vol.157, pp. 918–925.

H.C. Manjunatha. (2020), Empirical formula for beta-particle-induced bremsstrahlung yields, Pramana – J. Phys., vol. 94, no. 1.

James, E, Turner. (2007), Atoms, radiation and radiation protection", WILEY-VCH Verlag GmbH & Co.KGaA, Weinheim.

M. Wang ,G.Audi, A.H. Wapstra, F.G. Kondev, M. MacCormick, X.Xu and B. Pfeiffer. (2012), The Ame2012 atomic mass evaluation,Chinese Physics C,vol. 36, no.12, pp.1603–2014.

Martin J.E. (2006) Physics for Radiation Protection, WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim, 3rd ed.

Michael F. (2003). Handbook of Radioactivity Analysis, (USA), Elsevier Science.

Mirji, Rajeshwari and Lobo, Blaise. (2017), Radiation shielding materials: A brief review on methods, scope and significance, In Proceedings of the National Conference on Advances in VLSI and Microelectronics, Huballi, India, pp.96-100.

Murtadha S Nayyef ., Naz T Jarallah. (2019) Study Mass Parabola and Most Stable Isobar from Some Isobaric Nuclides, AIP Conference Proceedings. 2190, 020007.

Nadin Jamal Abu Al Roos, Azman Mira Natasha, Amin Noor fatin Aida Baharul and Zainona, Rafidah. (2020), Tungsten-based material as promising new lead-free gamma radiation shielding material in nuclear medicine, Physica Medica, vol.78, pp.48-57.

Serkan Akkoyun, Tuncay Bayram, Nihat Yildiz. (2016), Estimations of Radiation Yields for Electrons in Various Absorbing Materials, Science Journal (CSJ), vol. 37, no.2, pp. 59-65.

Sharma, H.,Rawal, N. and Mathew, B. B. (2015), The Characteristics, Toxicity and Effects of Cadmium, International Journal of Nanotechnology and Nano science, vol. 3, pp.1-9.

Thomas E. Johnson. (2017) Introduction to Health Physics, Fifth Edition. McGraw-Hill Education.

Thomas, G. A. and Symonds, P. (2016) Radiation Exposure and Health Effects – is it Time to Reassess the Real Consequences, Clinical Oncology, vol. 28, no. 4, pp. 231–236.

R.Wesley, Pelt, Van and Drzyzga, Michael. (2007), Beta Radiation Shielding with Lead and Plastic Effect on Bremsstrahlung Radiation when Switching the Shielding Order, The Radiation Safety Journal, vol. 92, no.1, pp.13–17.

DOI:https//doi.org/10.22452/mjs.vol43no3.12
Malaysian Journal of Science 43(3): 109-118 (September 2024)