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STUDY OF MATERIAL CHOICE IN BEAM DUMPS FOR ENERGETIC ELECTRON BEAMS

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Abstract

Lead is typically used as the initial target in a design for beam dumps for high energy electron beams (>20 MeV). Electron beams with energies above 20 MeV are usually built within concrete bunkers and therefore the design of any beam dump would just be a lead block (very cost effective) as close to the electron source as possible, after a vacuum flange of some sort. In a study of a hypothetical 100 MeV electron beam inside a concrete bunker with an extremely low dose rate constraint outside the bunker, the thickness of lead required would have been too restrictive for a compact design. In this study we investigate the potential benefits of designs that incorporate low Z materials like graphite as the primary target material in vacuum followed by progressively higher Z materials up to lead. The results show the more diffuse elastic scattering from the primary target reduces the back scattered photons and reduces the overall neutron generation. The effect was a more compact design for the beam dump to meet the same dose rate constraint.

THE AUSTRALIAN SYNCHROTRON 100 MeV LINAC

The Australian Synchrotron Light Source (ASLS) uses a full energy injector system comprising of a 100 MeV linac and 3 GeV booster synchrotron to inject beam into its 3 GeV storage ring. The linear accelerator (or linac) accelerates the electron beam to an energy of 100 MeV over about 10 metres. The linac operates in either long-pulse mode, in which up to 4 nC is generated in a bunch train of up to 150 ns with repetition rate 1 Hz, or in 1 ns short-pulse mode, in which a single bunch of up to 0.5 nC is delivered [1]. The linac is distributed inside the linac tunnel. During machine study time, the 100 MeV electron beam can be extracted for radiological study.

THE FLUKA SIMULATION CODE

In this research, the FLUKA code is used to simulate the radiological environment in the linac tunnel. FLUKA is a Monte Carlo code for calculations of particle transport and interactions with matter, covering an extended range of applications spanning from proton and electron accelerator shielding to target design, calorimetry, activation, dosimetry, detector design, accelerator driven systems, cosmic rays, neutrino physics, radiotherapy etc. [2, 3]. It has the best physics models in terms of completeness and precision, through a microscopic approach where each step has sound physics bases. FLAIR acts as an intermediate layer between the user and FLUKA. The integration of FLUKA with FLAIR provides an advanced user-friendly interface.

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ELECTRON BEAM INTERACTION WITH LEAD AND GRAPHITE

A geometry was created in FLUKA for the simulation of electron beam interacting with different shielding materials. The linac bunker dimensions and concrete wall thicknesses are the same as in the linac tunnel, but the target and the local shielding differs significantly. The bunker is with 100 cm thickness for the walls and 50cm thickness for the roof. The type of concrete used was Portland mixture which has a density of 2.34 g/cm^3. To change the units from ‘per electron’ to ‘per hour’ the number of electrons expected to be emitted by the electron source in one hour of constant operation is required. The number of electrons emitted by the 100MeV, 4 nC per pulse, 1 Hz repetition rate election source is 2.5×10^{10} electrons per hour. In the simulation coordinate system, X is the inboard-outboard horizontal direction, Y is the vertical direction, Z is the beam direction.

First, the penetration of electron in lead and graphite is compared. The target is a 50cm×50cm×50cm cubic block placed approximately 10 cm downstream of primary electron emitted position. The target material is lead and graphite respectively.

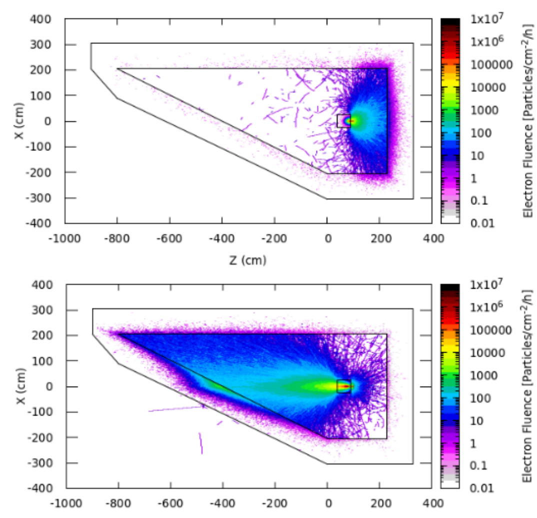

Figure 1: Electron fluence from different target, lead(top) and graphite (bottom).

Figures 1-4 provide electron fluence (track-length density), photon fluence, neutron fluence, and effective dose rate equivalent maps on horizontal cross section of the tunnel at beam height. In each figure, the top one is for lead target and bottom one is for graphite target.

From the simulation results as showing in Fig. 1, electron beam can easily penetrate through the graphite block, but the lead will stop electron after about 25 cm

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penetration. When the electron bombing on the lead surface, it will produce large back scattering electrons and photons. It is well suited to back scattering x-rays and gamma-rays. The high dose rate region is mainly focused on the back scattering area. Lead can effectively attenuate certain kinds of radiation because of its high density and high atomic number; principally, it is effective at stopping gamma rays and x-rays.

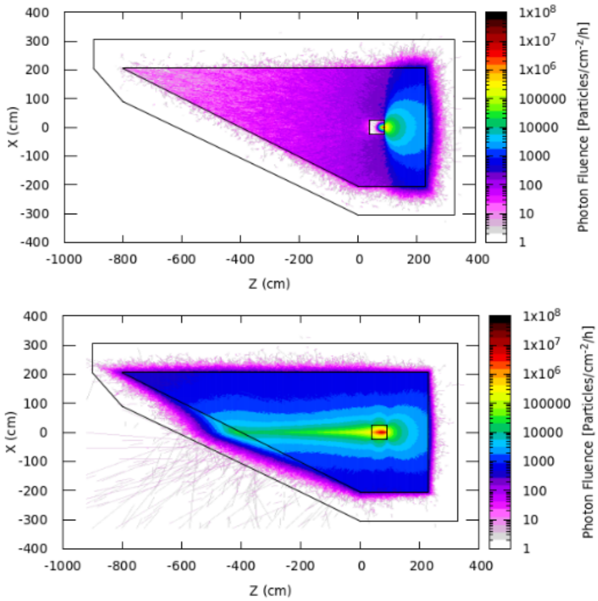

Figure 2: Photon fluence from different target, lead(top) and graphite (bottom).

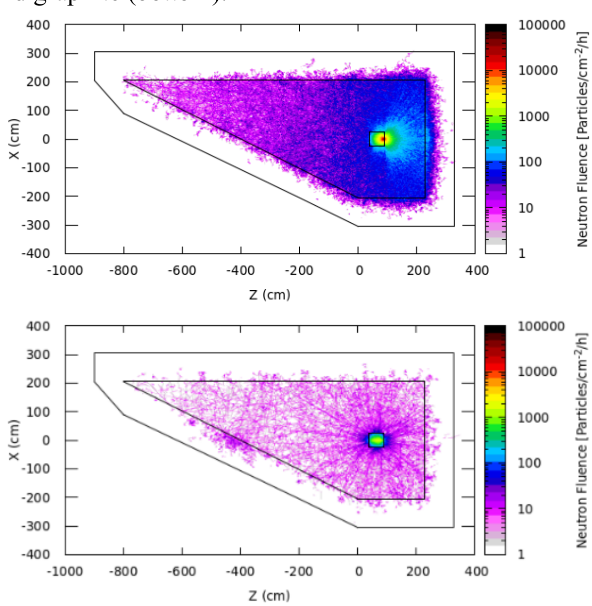

Figure 3: Neutron fluence from different target, lead(top) and graphite (bottom).

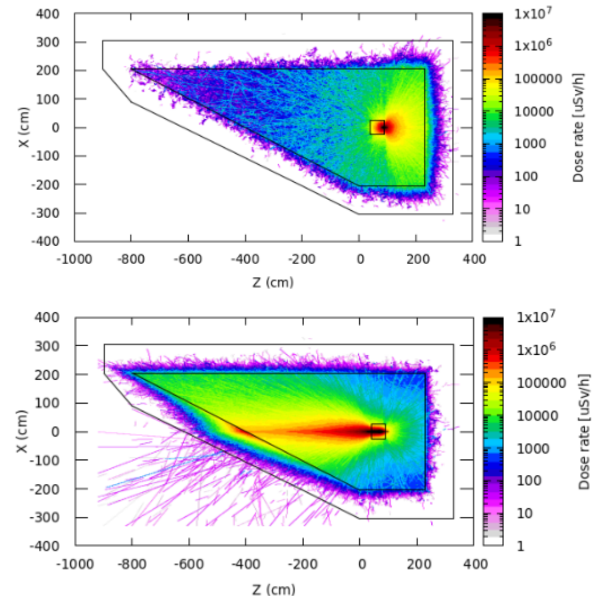

Figure 4: Total effective dose equivalent maps from different target, lead(top) and graphite (bottom).

For graphite target, because of the longer distance interaction between electron and graphite, neutron can be produced and absorbed in the graphite. Its total effective dose rate is spreading in all the bunker because the electron beam can easily go through it.

COMBINED STRUCTURE WITH LEAD AND GRAPHITE

To take advantages of both lead and graphite shielding, two types of combined structure for the target are proposed. As shown in Fig. 5, the left picture for the target is separating the cubic of 50 cm thickness to two cuboids with thickness 30 cm lead and 20 cm graphite. Electron beam will go through the graphite and then to the lead. The second geometry the target is a graphite cylinder embedded inside a lead cylinder. The lead cylinder is 50 cm in length and 60 cm in diameter. The graphite core insert is a 15 cm long cylinder with a 20 cm diameter. It is recessed 5 cm into the lead.

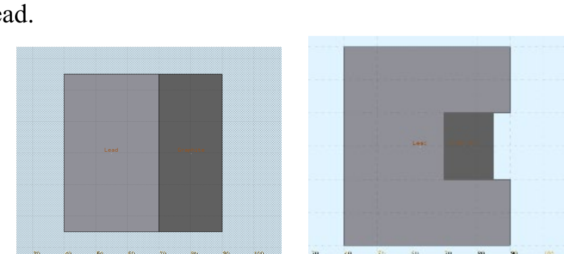

Figure 5: Two types of combined structure for the target.

Figures 6-9 provide another set of electron fluence, photon fluence, neutron fluence, and effective dose rate equivalent maps on horizontal cross section of the tunnel at beam height. In each figure, the top graph is from the left target in Fig.5. The bottom graph is from the right target in Fig.5.

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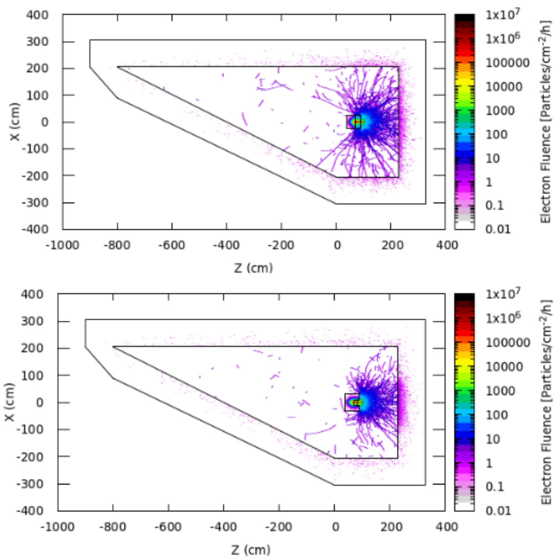

Figure 6: Electron fluence from combined structures.

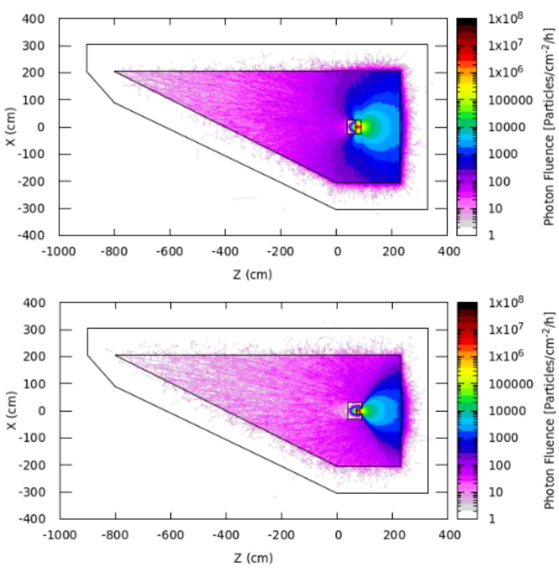

Figure 7: Photon fluence from combined structures.

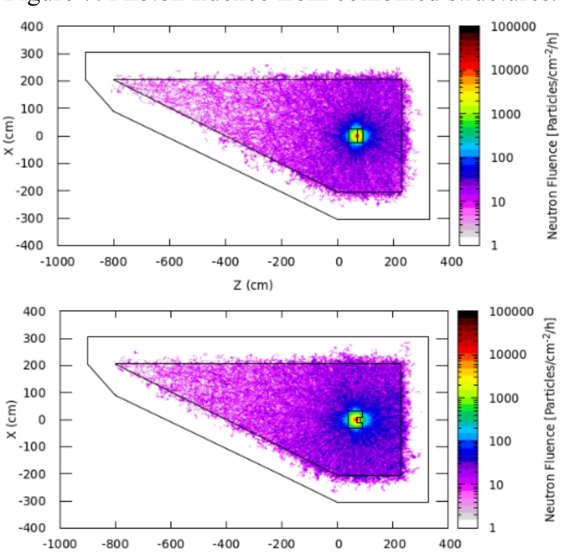

Figure 8: Neutron fluence from combined structures.

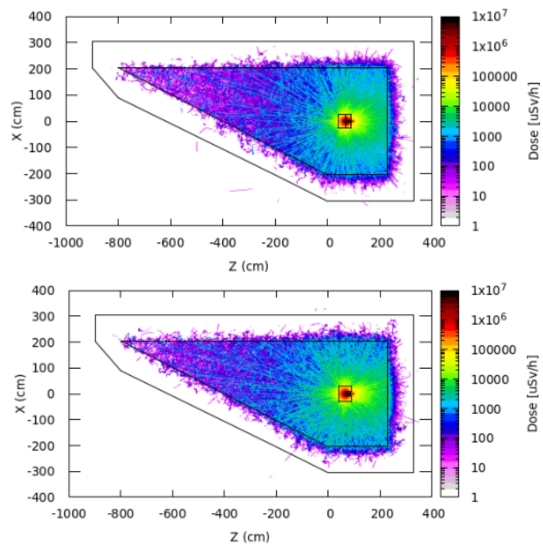

Figure 9: Total effective dose equivalent maps from combined structures.

Comparison between Figs. 1 and 6, there are significant reduction of electron fluence under each combined structure. That's because the primary electron interacting with graphite first, enlarging the interaction distance and decreasing electron back scattering intensity. From Figs. 2 and 7, the back scattering photon fluence is decreasing with combined structures. Also, the back scattering photon angle is confined by the special lead-graphite cone structure. Figures 3 and 8 show the neutron can easily deposit in lead and graphite. But electron longer travel distance in graphite can produce more neutron. Also, the back scattering neutron from lead can be absorbed in graphite. Overall, the total effective dose rate in the bunker is significantly reduced as comparing Figs. 4 and 9.

CONCLUSION

The interaction characteristic of 100 MeV electron beam injected in lead and graphite is studied. The lead can effectively scatter protons and electrons. It also absorbs gamma rays. From radiation shielding view, the lead can effectively reflect radiation backward. The electron beam can travel in graphite with longer distance, produce more neutron and absorb it. For efficient radiation shielding, a well-designed electron beam collector is required. It combines lead and graphite and use graphite as the primary beam collector. This combined structure will largely decrease radiation level in the linac tunnel with less shielding material cost.

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