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Analysis of the Impact of Cross-sectional Data Discrepancies on the Effectiveness of Radiation Shielding Design Using Monte Carlo Codes

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Abstract The effect of cross-sectional data discrepancies on the effectiveness of radiation shielding design has been investigated in this paper. The MCNP code with cross-sections from ENDF/B-V and ENDF/B-VII has been used to determine the gamma ray dose equivalent, H*(10), behind a lead glass shield enclosing a slow neutron source. It is observed that the radiative capture gamma ray dose behind the shield is higher when ENDF/B-V cross-sections are used compared to that produced by ENDF/B-VII cross-sections. The discrepancy is due to absence of energetic primary gamma rays when ENDF/B-VII is used. The results show that shielding design using ENDF/B-VII cross-sections could underestimate the shield by a fair margin and compromise safety. It is therefore necessary to consider more than one release of ENDF/B when using lead glass for shielding slow neutron capture gamma rays. The discrepancies need to be addressed in the next releases.

Keywords: *lead glass, shielded dose, MCNP, ENDF cross-sections, discrepancies*

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1. Introduction

When a thermal neutron is absorbed by a target nuclide, an excited compound nucleus is formed. This nuclide decays to a lower energy state by emitting γ-rays. These radiative capture gamma rays should be taken into account when shielding any nuclear facility producing neutrons [1]. Shielding design of such facilities can be done experimentally or through calculations. Monte Carlo codes are the most commonly used tools for shielding design. Monte Carlo N particle (MCNP) is one of the Monte Carlo codes used in shielding design. These software utilizes random numbers in conjunction with ENDF evaluated data to simulate the transport and interaction of particles with the nuclides of the shield [2]. Lead is one of the shielding materials used to design shielding for energetic gamma ray sources [3,4]. Recent investigation of the radiative capture reactions in lead using MCNP code and ENDF/B-VII cross-sections revealed a weakness in the radiative capture gamma ray spectrum [5]. Many obvious primary gamma rays which could have arisen from the transition from the neutron separation energy to ground state were conspicuously absent. For example, the energetic primary gamma line of about 7.3 MeV that would be expected from the neutron capture by ^{207}Pb was conspicuously absent in the simulated spectrum [6]. Because different versions of MCNP code could be having different releases of the database, an understanding of the extent to which the different releases will impact on the shielded dose is important. In this study, the shielded gamma ray shielded dose behind Lead glass shield is investigated using the Monte Carlo Code MCNP with two different ENDF/B releases. Lead glass is a composite material commonly used for shielding mixed radiation sources, especially where energetic gamma rays are part [7].

2. Methodology

The Monte Carlo N-Particle code (MCNP) was used in the study. The simulation model consists of a spherical geometry with various shells based on the radial distance from the Centre of the sphere as shown in Figure 1. The F2 tally together with dose conversion coefficients from ICRP 74 [8] were used to estimate the ambient dose equivalent, H*(10) behind the shield. 10 million particles were used as source particle population in each source and the simulation was run on neutron-photon mode. Since we are interested in dose from radiative capture gamma rays, a slow neutron source spectrum (0.001-0.01 MeV) was declared on the source card but only photon dose was declared on the tally cards. The material composition of the lead glass used in the study is also shown in Table 1.

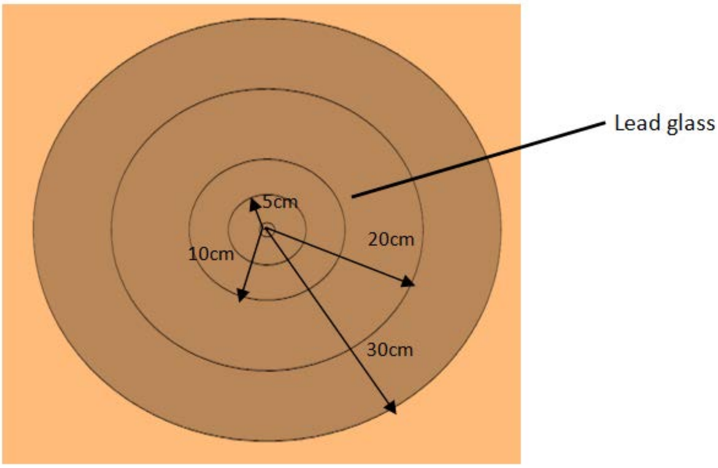

Figure 1. The spherical model used in the simulation

Table 1. Elemental composition in Lead glass

Element	Proportion in lead glass
O	0.156453
Si	0.080866
Ti	0.008092
As	0.002651
Pb	0.751938

3. Results and Discussions

The shielded dose calculated by MCNP at various shield thicknesses is shown in Figure 2. From the figure it is evident that the dose behind the shield is higher when ENDF/B-V cross-sections are used compared to that obtained when ENDF/B-VII cross-section data is used.

The difference in the shielded dose is due to the discrepancies in the gamma ray spectra generated by the two cross-section data as shown in Figure 3 [6]. This result is consistent with our earlier observation that ENDF/B-V produces a more a complete gamma ray spectrum compared to ENDF/B-VII. Since lead has the highest proportion in the composite, the difference in the shielded dose could most be due to the absence of energetic primary gamma rays when ENDF/B-VII is used [5,6]. Depending on the dose limit and radiation protection requirements for the region to be shielded, designing a radiative capture gamma ray lead shield using ENDF/B-VII could underestimate the shield by a reasonable margin. This would in turn highly compromise the safety of personnel to be protected, especially where extrapolation methods are used to estimate the shielding for all potential energies. It could be prudent that shielding experts consider different releases of radiative capture cross-sections when designing a capture gamma ray shield using MCNP code. A quick cross-check of the potential spectra in the cross-section being used in shielding design is also important. Since a number of Monte Carlo codes rely on these evaluated cross-sections to execute calculations, the proposed should also be done when using such codes to ensure the shielding process is effective and efficient. It is also necessary for this weakness in ENDF/B-VII be addressed in subsequent releases considering that many people consider new versions of the evaluated data as the most reliable.

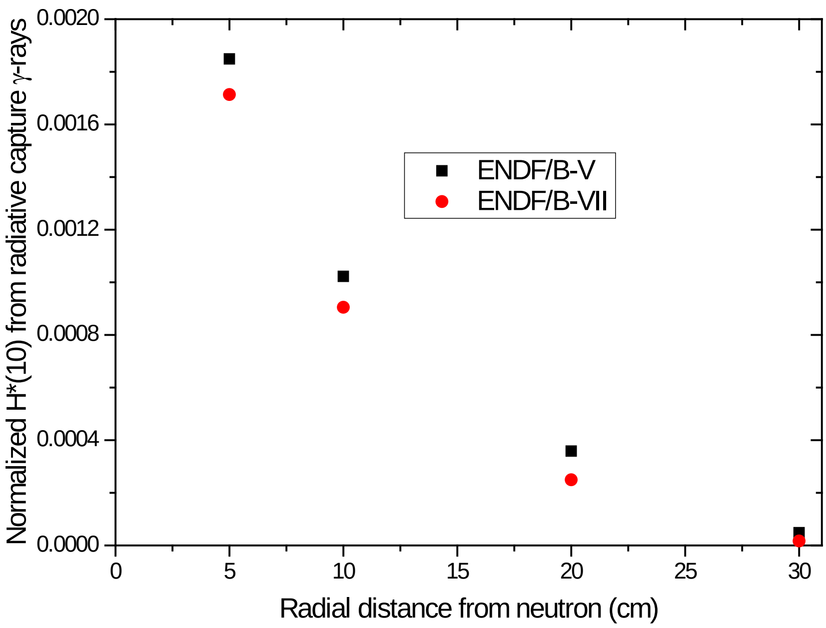

Figure 2. Shielded dose at various shield thickness when two different cross-sections are used

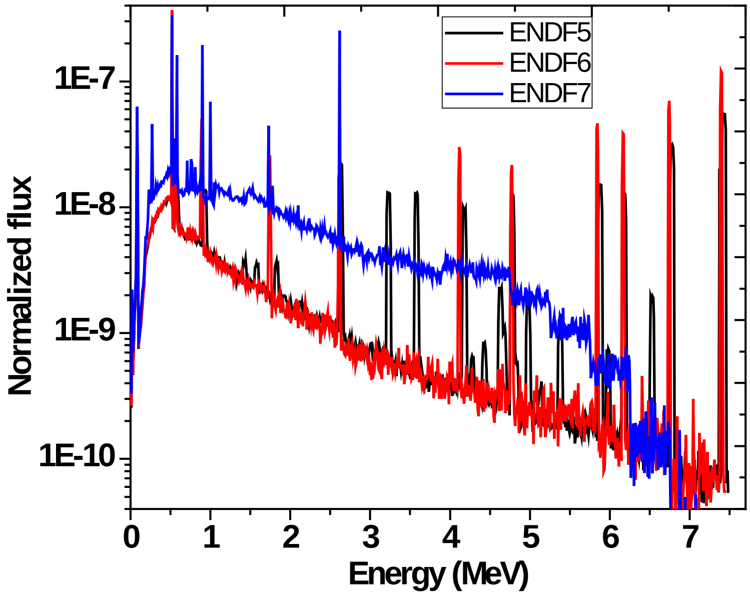

Figure 3. Radiation capture gamma ray spectra simulated in Lead glass using three different ENDF cross-section releases. The results from ENDF 7 reveal a number of missing energetic peaks

4. Conclusion

That radiative capture gamma ray dose behind a lead glass shield has been calculated using the MCNP code and two releases of ENDF/B cross-sections. The shielded dose produced when ENDF/B-V is used is higher than that obtained with ENDF/B-VII. Since the discrepancy is associated with absence of some energetic primary gamma rays when the latter ENDF/B-VII is used, the shield could be underestimated when this cross-sections release is used. It is therefore necessary to cross-check such discrepancies during shielding design to ensure that the proposed shield will have the integrity intended. In addition, subsequent releases should try and address such anomalies.

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