Nuclear Data Needs for Space Radiation Transport Calculations

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The determination of risks to crew and electronics in space missions from exposure to galactic cosmic rays (GCR), trapped belt radiation, and solar energetic particles (SEP) depends on accurate model predictions of the transport of those environments through shielding and other materials. Many of these models are also used for the design of mission architectures, including spacecraft and habitat designs, where optimization of the mass used for shielding has a significant impact on mission cost. Advanced Monte Carlo codes such as MCNP6, Geant-4, FLUKA, PHITS, and others are used along with NASA models such as HZETRN for design and risk assessment. These models have been compared with data taken in space and at accelerator facilities that produce beams with ions and energies that are present in the space radiation environment. The comparisons of model to data, and the comparison of models to each other are used to determine the uncertainties associated with model calculations of GCR and SEP transport. Those comparisons indicate the need for additional experimental data to help resolve the differences between model calculations and to improve the accuracy of those calculations

Norbury et al. [1] has reported on the current state of experimental, accelerator-based data that can be used for model comparison. The lack of intermediate and high-energy He data (data above ~100 MeV/nucleon up through several GeV/nucleon), along with the fact that He makes up about 9% of the GCR fluence, calls for additional data on He-induced interactions across a wide range of targets. Although there are more data for heavier ions that exist in the GCR fluence, such as carbon, neon, silicon, and iron, to name a few, gaps still exist for specific beam ions, beam energies, and target materials.

In addition to gaps in incident beam ions, energies and targets, gaps exist in the double-differential data on secondary particles created in those interactions. A study by Slaba et al. [2] investigated the dose and dose equivalent resulting from GCR transport through aluminum shielding and through polyethylene shielding, using a number of transport codes. Figure 1 is from reference [2] and shows that as shielding thickness increases, the differences between model calculations become significant, especially for aluminum shielding. The largest source of those differences is in the prediction of light ions – protons, deuterons, tritons, ^{3}He, ^{4}He, and neutrons. As shown in Ref. [1], there is also a lack of data on double-differential secondary light ion production from heavy ion systems.

An overview of the current state of data relevant to space radiation transport will be presented along with recommendations for additional data needed to reduce the uncertainty and improve the accuracy of model predictions.

[1] Norbury J. W., Battistoni G., Besuglow J., Bocchini L., Boscolo D., Botvina A., Clowdsley M., de Wet W., Durante M., Giraudo M., Haberer T., Heilbronn L., Horst F., Krämer M., La Tessa C., Luoni F., Mairani A., Muraro S., Norman R. B., Patera V., Santin G., Schuy C., Sihver L., Slaba T. C., Sobolevsky N., Topi A., Weber U., Werneth C. M., Zeitlin C., "Are Further Cross Section Measurements Necessary for Space Radiation Protection or Ion Therapy Applications? Helium Projectiles", Frontiers in Physics 8, (2020) DOI:10.3389/fphy.2020.565954

[2] Slaba, T. C., Bahadori, A. A., Reddell, B. D., Singleterry, R. C., Clowdsley, M. S., and Blattnig, S. R., "Optimal shielding thickness for galactic cosmic ray environments", Life Sci. Space Res. **12**, 1-15 (2017)

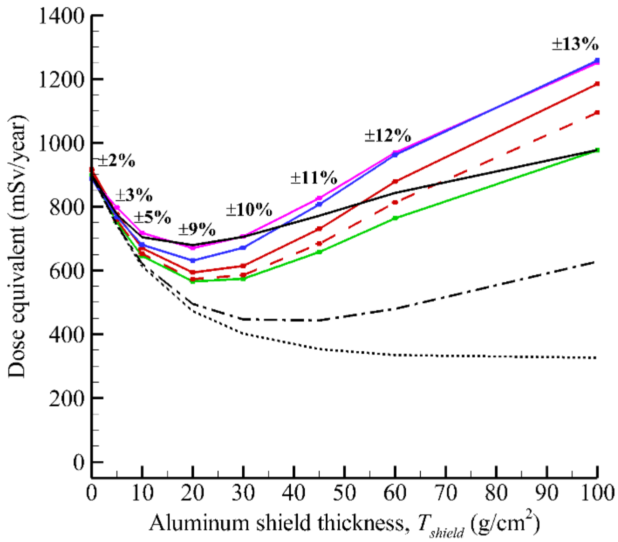

Figure 1. Calculated dose equivalents behind various thicknesses of aluminum (left plot) and polyethylene (right plot) in a GCR environment, using several Monte Carlo transport codes and three different versions of the deterministic transport code HZETRN. Figure courtesy [2] Fig. 13 page 9.