Advancing Neutron Shielding Evaluation Through LET Measurement and Spectrum Reconstruction with MCNP, FLUKA, and Neural Networks

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Neutron interactions are challenging to characterize due to the particle's neutral charge and indirect ionization. These interactions are commonly quantified using linear energy transfer (LET), a key parameter governing shielding effectiveness and radiation dose potential. Accurate assessment of LET requires knowledge of the incident neutron energy spectrum. Characterization of the spectrum from a source is a computationally complex process, as it represents an underdefined inverse problem.

One method for neutron energy spectra unfolding involves the use of a Bonner Sphere Spectrometer system. This approach requires measurements to be taken for each sphere, making the process time consuming and equipment heavy while still relying on complex unfolding calculations. A potential approach to improve the computationally arduous approach is through machine learning to unfold the measurement data. Machine learning may also be used to perform feature selection on the number of measurements needed to reconstruct the original energy spectrum, saving time in both measurements and computations.

To construct the data set, publicly accessible neutron energy spectra data was rebinned and ran in both a simplified and complex Monte Carlo N-Particle transport (MCNP) code simulation. The simplistic design consisted of the Bonner Spheres, detector, and the associated support structure. The complex geometry was built to replicate the approximate room geometry and neutron generator. The resulting data was then processed to resemble detector responses and was used to evaluate various neural network architectures and hyperparameter configurations.

For measuring LET of the incident neutron, the use of a pixel-based detector, the ADVACAM limepix3, was explored. Pixel-based detectors enable the visualization of radiation-induced interactions, allowing for LET to be measured directly. limepix3 measurement data was analyzed using an ADVACAM specific post-processing tool that provides particle identification and LET values. Experimental data was collected using the neutron generator and AmBe source at Georgia Tech's RSEL.

Key detector parameters, such as detection efficiency and neutron converter thickness, were evaluated using FLUKA due to superior representation of the reaction within the neutron converter. The simplification of the post-processing addresses this issue of whether there is a streamlined method to translate from LET values and dose estimates.