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Progress of Shielding Integral Experiments at China Institute of Atomic Energy

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Beryllium, zirconium, and bismuth play crucial roles in nuclear science and technology: beryllium serves as a neutron reflector and moderator, zirconium is widely used in reactor structural materials, and bismuth is essential in accelerator-driven systems and lead-bismuth-cooled reactors. Accurate nuclear data for these materials are critical for shielding, reactor design, and nuclear safety assessments. To assess the reliability of nuclear data libraries, shielding integral experiments were conducted at the China Institute of Atomic Energy (CIAE) using the 400 kV nanosecond pulsed neutron generator. The experiments were performed on three different thicknesses of each material at six measurement angles, providing valuable benchmark data for the evaluation of CENDL-3.2, ENDF/B-VIII.0, JENDL-5, and JEFF-3.3.

To improve the accuracy of shielding integral experiments, several key optimizations were implemented. SiC detectors were introduced for associated particle detection, enabling simultaneous measurement of D-D and D-T neutron yields, which effectively resolved the issue of D-D reactions induced by deuterium deposition on the target. A monitor detector system was deployed at 0° and 90°, and its neutron time-of-flight spectra were analyzed using the MLEM algorithm, achieving a source neutron pulse time distribution precision better than 10-3. To validate the reliability of the experimental platform, polyethylene benchmark experiments were conducted at 47°, 61°, and 79° to examine the consistency of C/E values across different energy regions.

For beryllium, CENDL-3.2 demonstrated reasonable agreement with experimental data in the elastic scattering region, with minor overestimations observed at small angles. However, in the (n,2n) reaction region, significant deviations in spectral shape were present, particularly at larger angles. ENDF/B-VIII.0 and JENDL-5 provided good agreement at small angles but underestimated neutron spectra at larger angles. JEFF-3.3 consistently underestimated experimental results across all angular ranges, highlighting the need for further refinement in the (n,2n) reaction region.

For zirconium, CENDL-3.2 showed increasing C/E values with angle in the (n,el) region, underestimating at small angles and overestimating at large angles, while the other libraries remained stable but consistently overpredicted. In the (n,inl)D region, CENDL-3.2 and JEFF-3.3 overestimated at all angles, while ENDF/B-VIII.0 was notably lower. In the (n,inl)C region, JEFF-3.3 underestimated at large angles with decreasing cross-section values. In the (n,2n) region, CENDL-3.2 and JEFF-3.3 predicted lower neutron spectra than experimental results, with their cross-sections lower than ENDF/B-VIII.0 and JENDL-5.

For bismuth, CENDL-3.2 showed reliable performance across various scattering regions, particularly at intermediate angles. The discrete inelastic scattering region showed that JEFF-3.3 provided better agreement at small angles, whereas JENDL-5 was more accurate at larger angles. The continuous inelastic scattering region indicated that JEFF-3.3 provided the best overall agreement. ENDF/B-VIII.0 provided the closest agreement in the (n,2n) reaction region, while JENDL-5 demonstrated stable performance across multiple energy regions.

These results highlight the importance of continuous experimental validation for improving nuclear data libraries. The study provides valuable benchmark data for neutron transport simulations, shielding analysis, and nuclear reactor applications. Further refinements in nuclear models, particularly in the (n,2n) reaction region, are necessary to enhance the reliability of nuclear data for beryllium, zirconium, and bismuth.

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