Material Accountancy Evaluation of Plutonium Content from Beryllium Fuel Forms using New Nuclear Data Measurements of Be(alpha,n)-driven Be(n,2n) Reactions

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ABSTRACT: This project addresses critical gaps in nuclear data by experimentally measuring neutron interactions within beryllium-bearing molten salt reactor (MSR) systems, focusing on the ^{9}Be(α,n) -driven ^{9}Be(n,2n) reaction channels. These interactions impact reactor reactivity, isotopic inventories, and plutonium (Pu) quantification in material control and accountability (MC&A) for MSRs using FLiBe salt. By refining cross-sections and emission spectra associated with these reactions, this project aims to improve predictive accuracy in burnup and neutron transport models underpinning reactor design, safeguards, and spent nuclear fuel management. Combining simulation, experimental, and theoretical approaches, this project develops intrinsic technologies that support MC&A programs and enable accurate neutron-based measurements of special nuclear material (SNM).

The objectives of this project are to:

- Validate ENDF/B nuclear cross-section data of the ^{9}Be(α,n)-driven ^{9}Be(n,2n) and provide measurement data to improve cross-section data for α energies greater than 5 MeV, including the representation of the emergent neutron spectrum.
- Measure emergent neutron spectra by unfolding the pulse-height distribution of neutron events observed in advanced ^{3}He-alternative detectors (e.g., organic scintillators).
- Conduct experimental code validation of contemporary nuclear reaction simulation codes with related implementation in the SOURCES4C data library.
- Determine the extent to which contaminated ^{9}Be confounds quantification of $^{240}Pu_{effective}$ using nondestructive assay by neutron coincidence counting method for MC&A safeguards, and its impact on accountancy paradigms in MSR fuel salts, spent nuclear fuel (SNF), and waste streams.

Following SCALE characterization of (α,n) operational timepoints in a FLiBe MSR, experiments begin with characterization of radionuclide and generator neutron sources for spectral and angular flux, followed by emission measurements using both a thin Be planchet and Be hemispheres. The planchets allow for nearly full-energy reactions with minimal scattering, enabling precise measurement of (α,n) and (n,2n) cross-sections, while Be hemispheres capture bulk transport effects, secondary interactions, and angular distributions representative of MSR environments. Advanced detectors, including ^{3}He alternatives such as organic glass scintillators, ^{4}He detectors, and the AdvaPIX TPX3, will provide spatial and spectral data, with pulse shape discrimination to separate neutron and gamma events. Time-of-flight measurements will distinguish primary and secondary neutron events, such as those generated from (α,n) and (n,2n) reactions, by measuring the time delay between a known trigger event and neutron detection. Oak Ridge National Laboratory's Active Well Coincidence Counter will measure neutron multiplicity and yield through coincidence counting. Generated data will provide benchmarks for integrating cross-section nuclear data into SOURCES4C, supporting Pu uncertainty evaluation in MCNP and SCALE.

This project will provide the following outcomes, impacts, and deliverables:

- Validated cross-section data for ^{9}Be(α,n) and ^{9}Be(n,2n) reactions, supporting MSR operations, MC&A, and SNF management.
- Nuclear data integration in SOURCES4C and ENDF/B libraries in MSR simulations.
- Enhanced precision in reactor modeling for Pu isotopic accountancy within MSR systems.