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Modeling and Uncertainty Analysis of MSR Nuclear Material Accounting Methods for Nuclear Safeguards

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ABSTRACT:

Liquid-fueled Molten Salt-fueled Reactor (MSRs) have gained significant interest in the USA and beyond in recent years due to the potential improvements MSRs offer (compared to current light water reactors) in terms of safety margins, fuel utilization, and economics. While MSRs are a promising reactor concept, technical challenges exist, including those challenges facing nuclear material accounting for nuclear safeguards. Specific challenges include developing a nuclear material accounting strategy, particularly in those MSR concepts that include plans for online processing of the molten salt fuel.

The objective of the proposed research is to model and analyze the limits of detection for the diversion of special nuclear materials from an MSR fuel cycle that includes online reprocessing. This goal will be achieved via the identification of reactor observables and other signatures that will be the most effective for the rapid, accurate discovery and quantification of material diversions. To tackle this problem, we propose to work in three main areas: reactor modeling and uncertainty analysis; process and waste stream monitoring; and data integration and analysis.

A liquid fueled, thermal MSR depletion model will be developed using SCALE, with the newly-developed continuous feed/removal capabilities. Output parameters, including overall reactivity, and isotopic composition of the various process streams will be obtained. Isotopic compositions will be obtained for all possible process points where isotopics may change, including off-gas treatment, bulk salt processing, heat exchangers (where fission products may plate out), and the waste salt stream. Sensitivity of the output quantities (or observable reactor performance) will be determined as a function of the amount of fissile material diverted. Uncertainties due to nuclear data (neutron cross-sections, fission product yield and decay data) and other parameters (geometry, initial isotopics, temperature, off-gas removal rate, fission product precipitation/plateout, total reactor power, etc.) will be examined using the Sampler module in SCALE. In order to mitigate with high uncertainties, we also propose a new method to limit uncertainty due to cross-sections by forcing consistency with startup physics measurements.

The reactor modeling will be coupled with an analysis of detection methods that may quantify the spent fuel or process streams. The effect of the changing isotopic compositions due to material diversion will be examined for gamma-ray, neutron, off-gas, and other sensor signatures. Correlations will be sought between these signatures and changes in reactor performance observables, and ultimately to material diversion. Based on this analysis, the type of sensor signatures, and their location within the different process/waste streams will be optimized. This will be accomplished by selecting the sensor/location combinations that have the highest expected signature-change, and the lowest measurement and modeled uncertainty (i.e., those with the highest signal-to-noise ratio). Ultimately, this will inform considerations for reactor safeguards by design and guide directions for future sensor research.