Development of an MC&A toolbox for liquid-fueled molten salt reactors with online reprocessing

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ABSTRACT:

A critical barrier to the deployment of MSRs is the absence of a well-defined nuclear material control and accounting (MC&A) approach, a vital prerequisite to meet NRC licensing requirements as well as facilitating future international exports. Liquid-fueled MSR variants (especially those incorporating online refueling or reprocessing) present a unique set of challenges to traditional nuclear material control and accountancy. Unlike solid-fueled light-water reactors, traditional item-counting methods cannot be applied as an accountancy strategy. Rather, MC&A approaches to MSR variants (including both uranium and thorium fueled designs) are more analogous to bulk material handling facilities (e.g., enrichment and reprocessing); yet further complicating matters is the fact that fuel medium is also highly radioactive. Meanwhile, the space of MSRs covers a broad range of design parameters, including thermal and fast spectra designs; operation in actinide breeder or burner modes, choice of actinide fuel used (e.g., ^{235}U, ^{232}Th / ^{233}U, denatured ^{233}U, etc.), pool or loop-type configuration, and even different salt chemistry. Each of these design choices introduce significant challenges to MC&A approaches within MSR facilities.

We propose to bridge this gap for liquid-fueled MSRs by developing a modular, component-based test framework for evaluating viable process monitoring and MC&A techniques specifically suited to liquid-fueled MSR system variants employing online refueling or reprocessing. This test platform will consist of a toolbox of independent process modules representing discrete physical units (such as the reactor core, off-gas processing, decay tanks, and actinide separation units), each with its own self-contained physics responsive to the input mass flow, along with appropriate measurement models that can be coupled to key flow points. These dynamic physical signatures thus afford the ability to test the viability and efficacy of potential accountancy techniques under the full range of reactor operating conditions. As process modules are connected via mass flows, the result is a reconfigurable, generic MSR mass flow model capable of serving as an MC&A test platform for a broad spectrum of possible MSR configurations.

The resulting MSR MC&A toolbox will enable robust assessment of accountancy strategies for this unique facility type, including analysis of physical feedbacks arising both from depletion of the fuel over time as well as from potential off-normal events, including those introduced by equipment failures (e.g., a pump failure) as well as by malicious action (i.e., attempts to divert material). The proposed toolbox both addresses a critical needs area for the MPACT analysis toolkit while leveraging existing MPACT-sponsored tools, especially with respect to simulation of measurement and accountancy techniques for advanced fuel cycle facilities. Beyond enabling new analysis capabilities for MSR systems, the design of this toolbox will be to such to maximize compatibility with existing MPACT tools such to enhance existing facility MC&A analysis capabilities.