Document #: SRNL-STI-2024-00022

Title: Investigation of Misuse Potential and Detection for Homogeneous Fluoride Fast Molten Salt Reactors Based on Neutronics Signatures

Authors: Thomas DeGuire[1] and Dr. Jean Ragusa[1]
[1]Texas A&M University

The International Atomic Energy Agency (IAEA) has obligations to apply safeguards to nuclear material and facilities within States subject to IAEA safeguards agreements. As a result of these obligations, safeguards will need to be applied to Generation IV reactors, including liquid fueled molten salt reactors (MSRs), if they are deployed in States with safeguards agreements. Recently, the IAEA has noted that a growing number of Member States are showing interest in MSR technology. This has been accompanied by an increase in short term development and deployment activities relating to MSRs. To ensure MSRs can be safeguarded effectively and efficiently upon possible future deployment, safeguards approaches and techniques need to be investigated now.

To properly develop these approaches, scenarios involving the misuse and diversion of nuclear material associated with these reactors require investigation. This project focuses on researching potential misuse scenarios for employing MSRs in the illicit breeding of fissile nuclear material and detectable signatures of misuse. This work concentrates specifically on homogeneous fluoride fast MSRs. The Molten Salt Fast Reactor (MSFR) described in Idaho National Laboratory's Virtual Test Bed, which is based on the MSFR design created through Euratom's EVOL and ROSATOM's MARS projects, was used as a representative reference design for this family of MSRs. Both reflected and un-reflected models of the core were studied in this work. The Serpent 2 Monte Carlo transport code was used to investigate a variety of illicit breeding scenarios utilizing the 3000 MWth MSFR design with a fuel salt composition of 19.7% ThF_4, 2.8% $U^{233}F_4$, and 77.5% LiF by mole percent.

Breeding scenarios investigated focused on the undeclared production of U^{233} and plutonium both within and external to the reactor core, including the illicit breeding of 1 significant quantity of U^{233} or Pu in a time period of less than one year. For the cases involving illicit breeding within the un-reflected core, initial results showed an average decrease in core reactivity of 1095.27 ± 13.01 pcm compared to a reference case of a core with fresh fuel salt and no undeclared breeding occurring. For cases involving illicit breeding only external to the core, results indicated an average increase in core excess reactivity of 33.16 ± 12.93 pcm. However, two breeding cases resulted in a reactivity difference which could not be differentiated from the reference case when accounting for uncertainty. Comparable results were found for cases using a core with a reflector. Analysis of the neutron flux within 10 cm of the core's vertical midplane has identified variations in the absolute value of the average relative differences of the neutron flux between scenarios involving illicit breeding of a significant quantity of fissile material compared to the fresh core reference cases. For the cases studied, these average relative differences range from approximately 3.54 ± 4.78E-02% to 9.42 ± 4.13E-02%. This work demonstrates that illicit breeding of fissile nuclear material with a MSFR may impact neutronics characteristics of

the reactor and serves as a justification for further investigation into identifying safeguards-relevant signatures for MSRs.

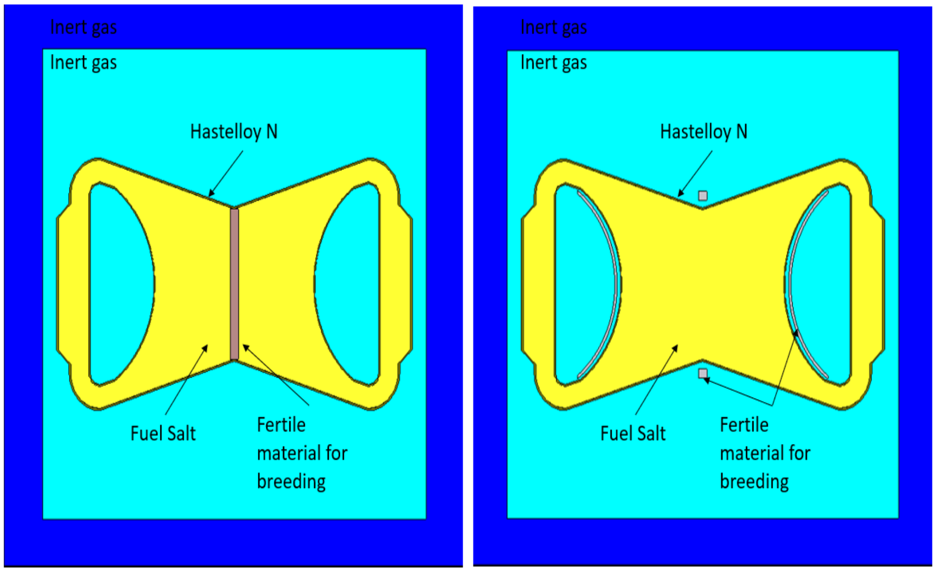

Figure: XZ view of example illicit breeding cases modeled in Serpent 2. The left image depicts an internal breeding scenario, while the right image depicts an external breeding scenario.

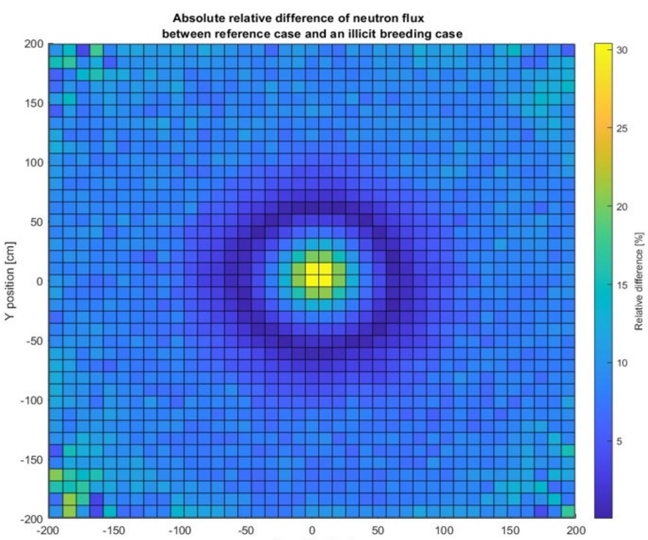

Figure: Absolute relative difference of neutron flux within 10 cm of the core vertical midplane between a reference case and an internal illicit breeding case.

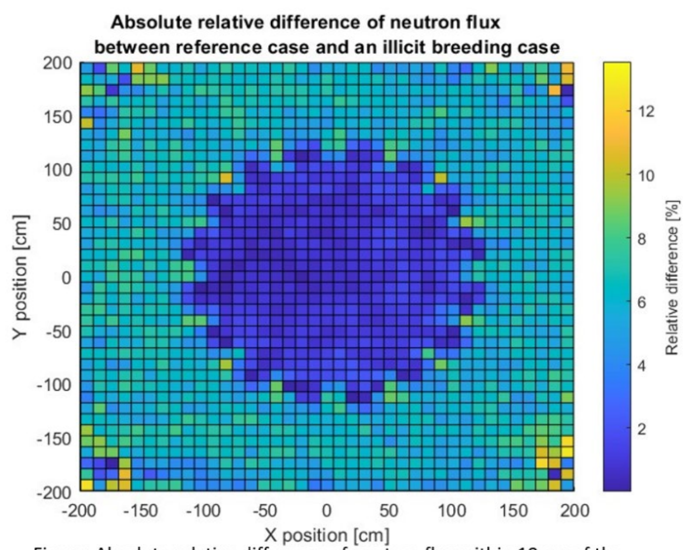

Figure: Absolute relative difference of neutron flux within 10 cm of the core vertical midplane between a reference case and an external illicit breeding case.