SCALE Capabilities for Molten Salt Reactors

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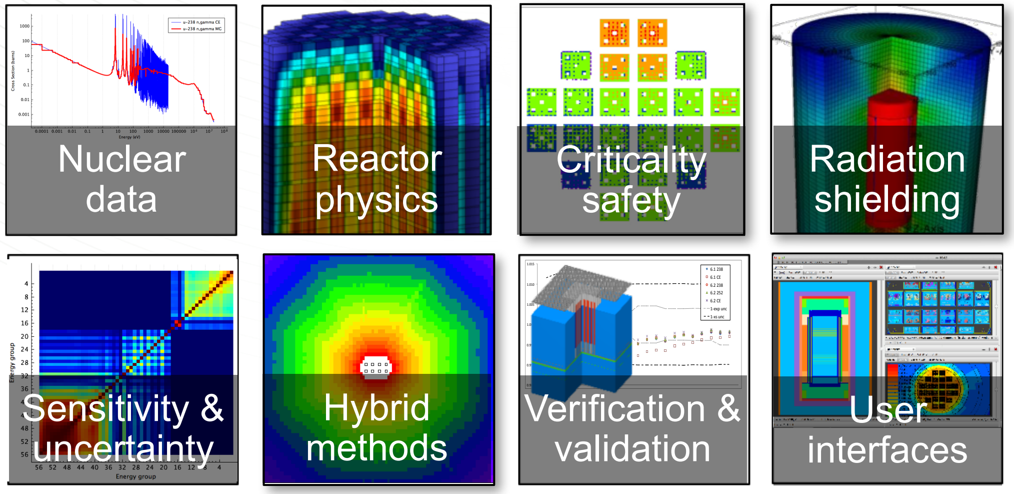
SCALE Code System

Neutronics and Shielding Analysis Enabling Nuclear Technology Advancements – http://scale.ornl.gov

Practical tools relied upon for design, operations and regulation



scale

Global distribution: 8,000 users in 58 nations

Professional training for practicing engineers and regulators

FY17 statistics:
- 10 one-week courses
- 4 conference tutorials
- 150 participants from 15 nations

National Nuclear Security Administration

Primary sponsors

Robust quality assurance program based on multiple standards

OAK RIDGE National Laboratory

SCALE Code System

Analysis enabling nuclear technology advancements

SCALE 6.2 – SCALE 7.0

2016 – present:

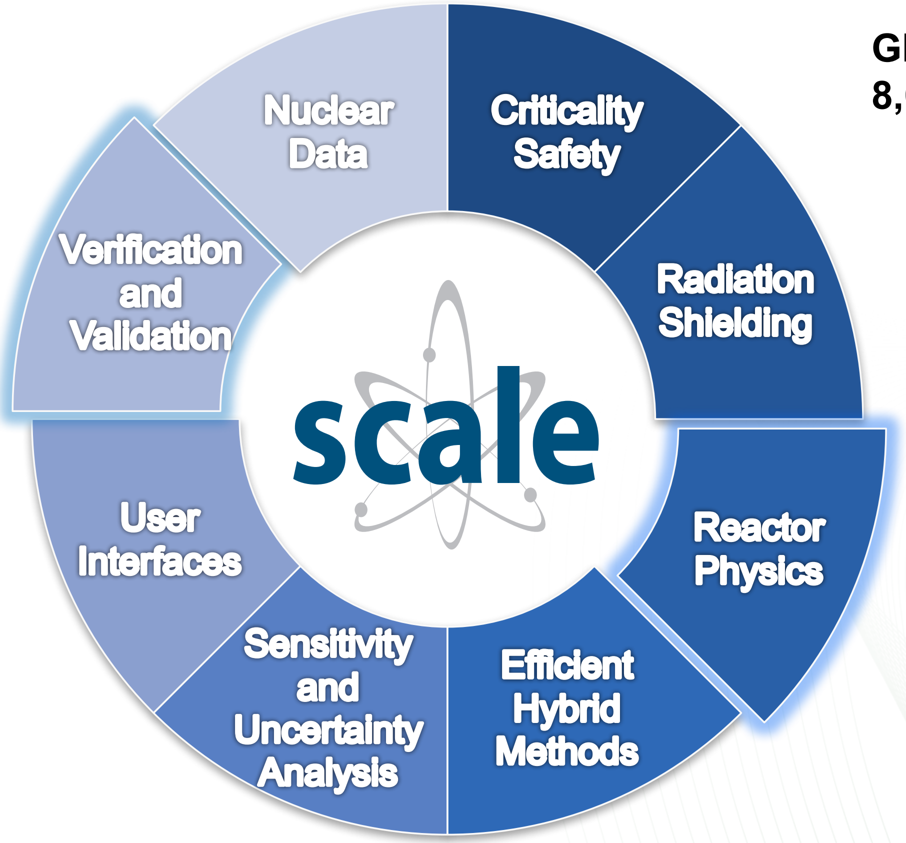
Increased Fidelity, Infrastructure Modernization, Parallelization, Quality Assurance

Solutions for extremely complex systems

High-fidelity shielding, depletion, and sensitivity analysis in continuous energy

Modern, modular software design

Scalable from laptops to massively parallel machines



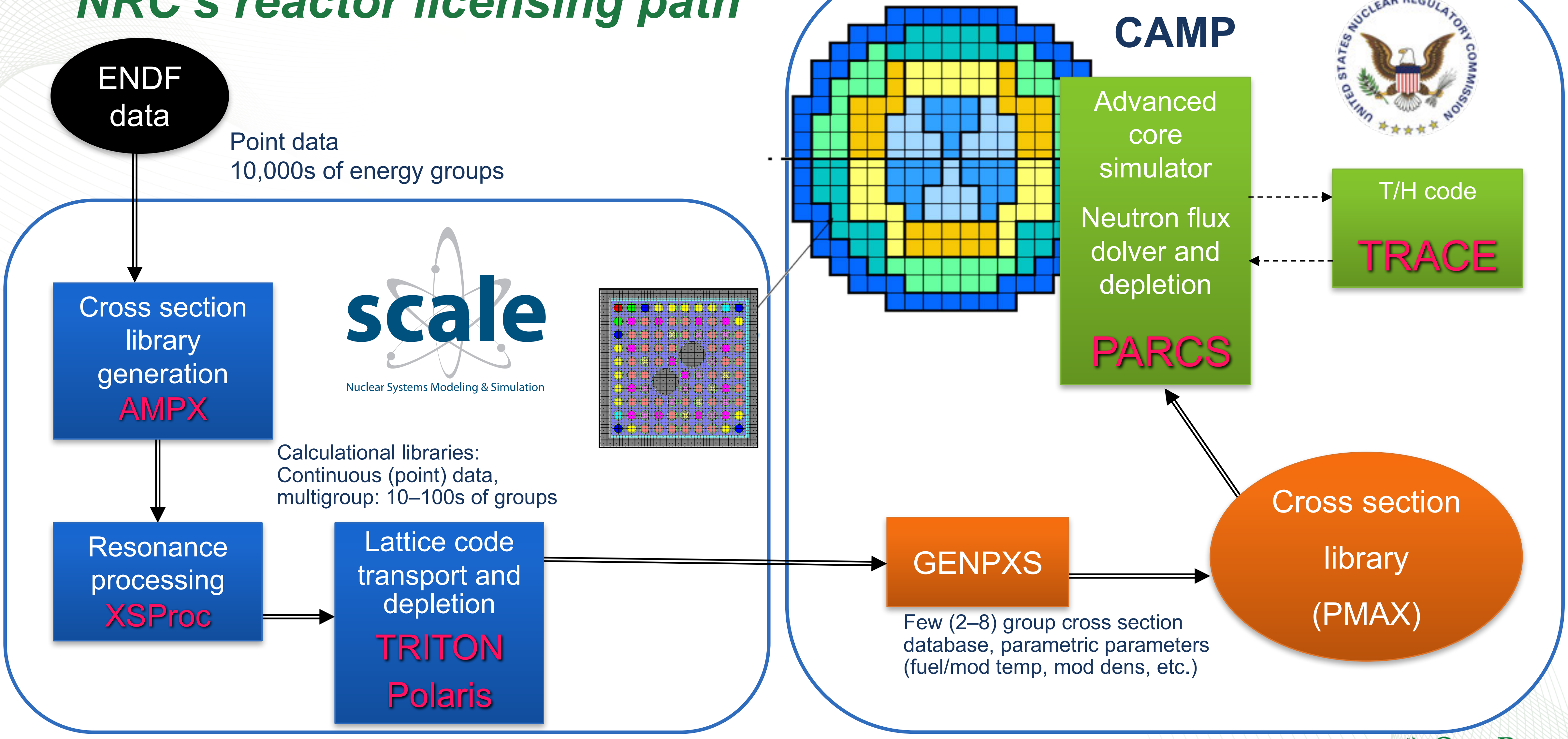
Global Distribution:
8,000 Users in 58 Nations

- Transport
  - Monte Carlo
  - Deterministic
- Point depletion

Oak Ridge National Laboratory

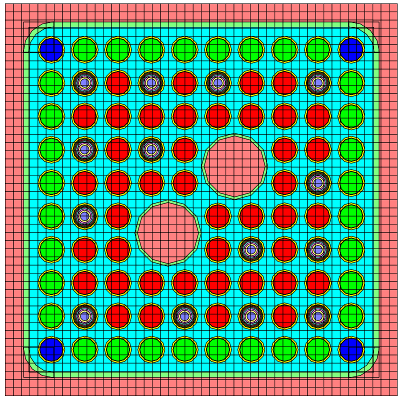
SCALE Code System

NRC's reactor licensing path

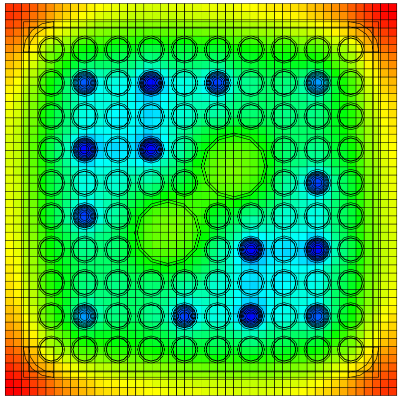


Liquid-Fueled Molten Salt Reactors
Extending methods for solid fuel reactors

- Solid fuel reactor characteristics
  - Fission products and actinides remain with the fuel until reprocessing (if applicable)
  - Excess reactivity control occurs with soluble boron/burnable absorbers



Lattice physics calculation



Burnup-dependent constants

Core simulator (e.g., PARCS)

- Liquid fuel reactor characteristics
  - Fuel flows with carrier material (delayed neutron precursor drift)
  - Includes continuous and batch chemical processes

Motivation

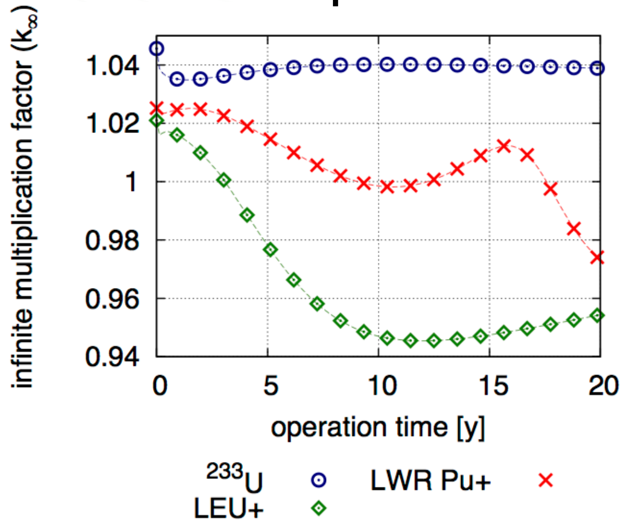
Develop MSR modeling and simulation capabilities in SCALE

- Account for the flowing fuel materials in a liquid-fueled system
  - Model precursor drift and its effect on neutronics and depletion
  - Remove isotopes with specific rates or portions of the fuel salt
- Draw on reactor physics tools within the SCALE code system
  - Neutron transport and depletion
  - Strong quality assurance program
- Provide applicable ORNL modeling and simulation tools to liquid-fueled reactor problems
  - Assessment of MSR impact on fuel cycle outcomes
  - Fuel cycle and core optimization and design

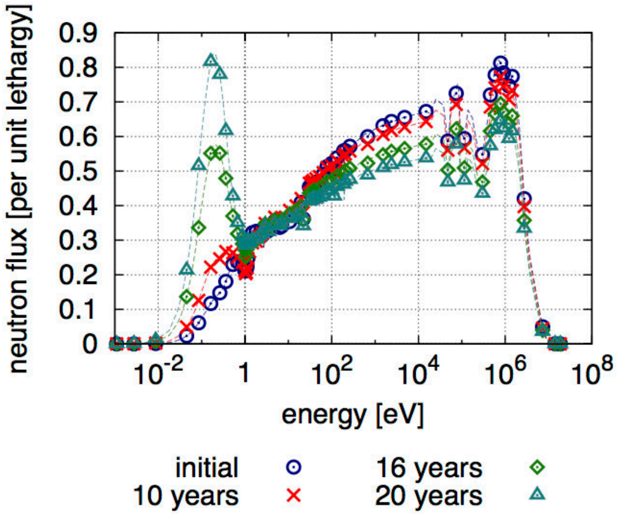
ChemTriton Molten Salt Reactor Analysis

MSR startup fuel cycle analysis

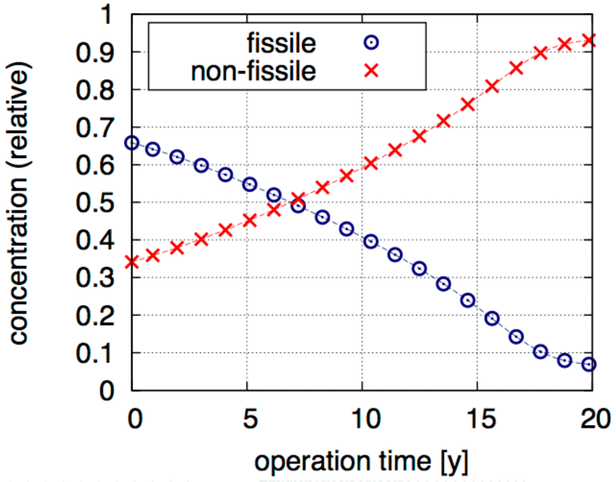
- Analysis of a molten salt breeder reactor (^{233}U/Th fuel, graphite moderated) startup with alternate fissile material without design changes
  - Composition of the initial (startup) fuel salt has a significant effect on operation
  - Non-fissile heavy metals loaded at startup reside in the reactor for long times
  - Neutron spectrum softens during operation



MSBR reactivity with different initial fissile load



Spectral shift in a thorium MSR with plutonium as the initial fissile material

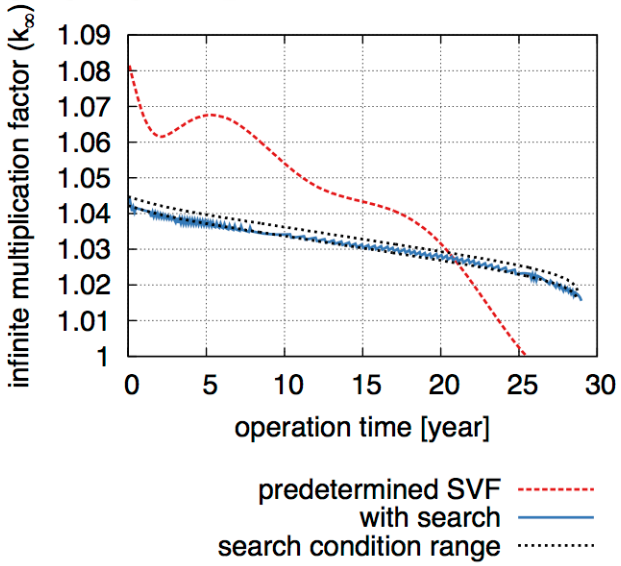


Fissile and non-fissile plutonium concentrations during operation

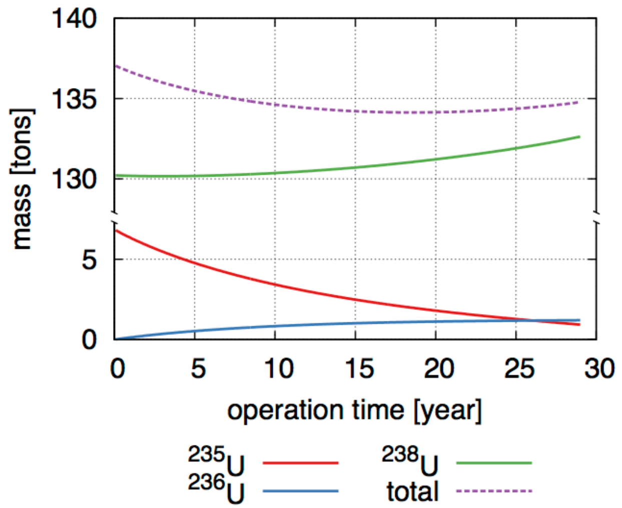
B. R. Betzler et al., “Modeling and Simulation of the Start-Up of a Thorium-Based Molten Salt Reactor,” PHYSOR 2016, Sun Valley, ID, USA, May 1–5 (2016).

ChemTriton Molten Salt Reactor Analysis
Transatomic Power GAIN voucher project

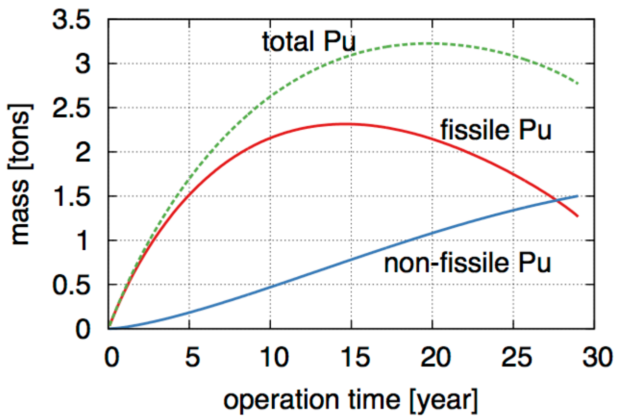
- Two-dimensional analysis of the Transatomic Power (TAP) design
  - Calculations confirm TAP maximum burnup and operation time
  - Critical salt volume fraction (SVF) function implemented into ChemTriton
  - Calculated isotopic content of fuel salt (and plutonium generated) over time



Calculated *k* during operation



Calculated uranium isotopic salt content during operation

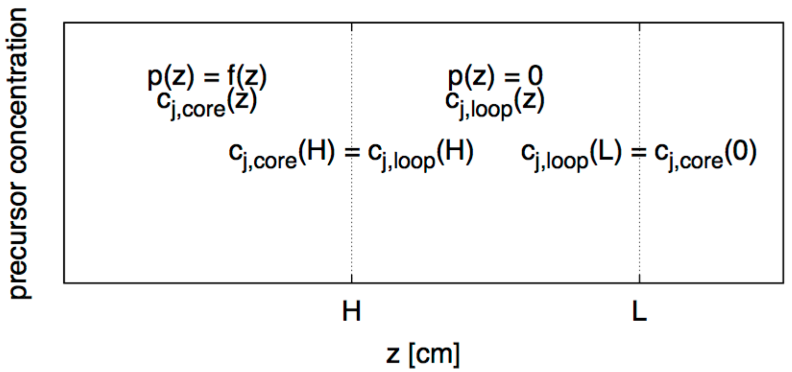


Calculated fissile and non-fissile plutonium salt content during operation

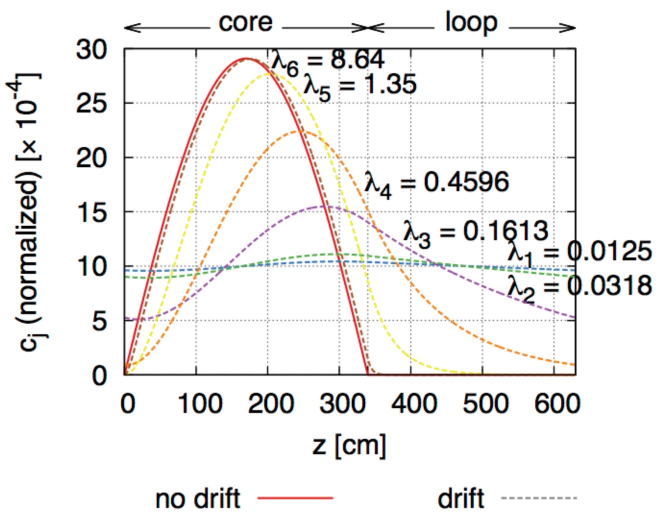
B. R. Betzler et al., "Two-Dimensional Neutronic and Fuel Cycle Analysis of the Transatomic Power Molten Salt Reactor," Oak Ridge National Laboratory Report ORNL/TM-2016/742 (2017).

Molten Salt Reactor Modeling and Simulation Tools
Precursor drift model

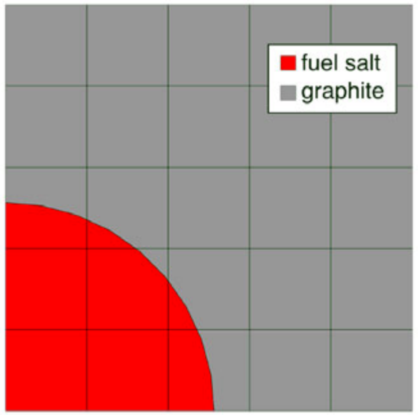
- A 1D precursor drift model has been implemented into SCALE
  - Considers a one-dimensional velocity and power profile
  - Accounts for precursors flowing through the loop before decaying
  - 2D transport model used to generate group constants for a 15 cm region before the outlet of the core



One-dimensional precursor drift problem showing boundary conditions



Delayed neutron precursor concentrations in the primary loop of a liquid-fueled MSR



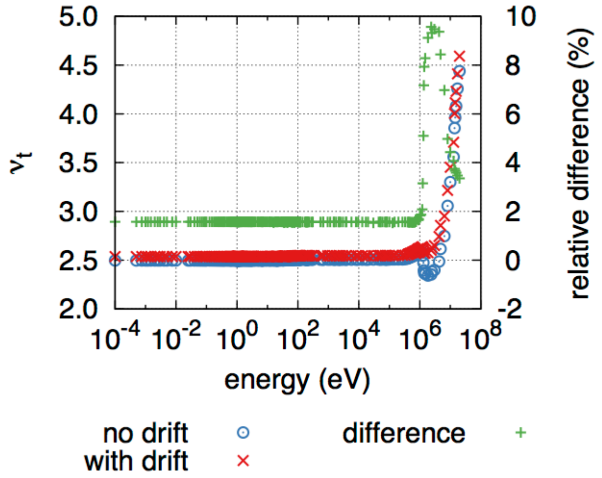
SCALE 2D transport MSBR unit cell

B. R. Betzler et al., “Molten Salt Reactor Neutronics Tools in SCALE,” Proc. M&C 2017, Jeju, Korea, April 16–20 (2017).

Molten Salt Reactor Precursor Drift Analysis

Explore effects on data, criticality, and group constants

- Large effect on the number of neutrons emitted per fission
- More than six times the amount of delayed precursors are generated in the 15 cm region with respect to the solution without precursor drift
- Effect on criticality align with theoretical expectations



Skew in total neutrons emitted per fission due to precursor drift

SCALE-calculated core-averaged parameters using flow-corrected constants

Two-Group Constants	No drift	Middle 15 cm (% difference)	Last 15 cm (% difference)
$(\nu\Sigma_f)_1$	1.243	1.241 (0.19)	1.268 (1.93)
$(\nu\Sigma_f)_2$	7.136	7.125 (0.15)	7.250 (1.57)

B. R. Betzler et al., "Molten Salt Reactor Neutronics Tools in SCALE," Proc. M&C 2017, Jeju, Korea, April 16–20 (2017).

Ongoing Efforts
SCALE continuous isotopic removal and additional capabilities

- Integrating this removal capability with the transport and depletion modules within SCALE
  - Provide the SCALE transport and depletion tool with access to this capability
  - Develop an interface to interact with these tools
  - Develop a method to include removed materials
    - Expand transition rate matrix to include removed elements
    - Enables tracking of waste streams from MSRs
  - Intentional generic implementation to provide a broader application space
- Continuous-energy Monte Carlo nodal data generation capability
- Extension of additional SCALE lattice physics tools for MSR analysis

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  - Fuel Cycles Options Campaign of the Fuel Cycle Technologies initiative of the US Department of Energy Office of Nuclear Energy (DOE-NE)
  - US DOE-NE Gateway for Accelerated Innovation in Nuclear, NE Voucher program
  - US DOE Office of Technology Transitions, Technology Commercialization Fund

Molten Salt Reactor Modeling and Simulation with SCALE
Publications

- Z. G. Skirpan et al., “Fuel Cycle Modeling and Simulation of the Molten Salt Breeder Reactor,” Trans. Am. Nucl. Soc., 117 (accepted).
- C. A. Gentry et al., “Initial Benchmarking of ChemTriton and MPACT MSR Modeling Capabilities,” Trans. Am. Nucl. Soc., 117 (accepted).
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- B. R. Betzler et al., “Fuel Cycle Analysis of Fast and Thermal Molten Salt Reactors,” Proc. GLOBAL 2017, Seoul, Korea, (2017).
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- J. J. Powers et al., “A New Approach for Modeling and Analysis of Molten Salt Reactors Using SCALE,” Proc. M&C 2013, Sun Valley, Idaho (2013).