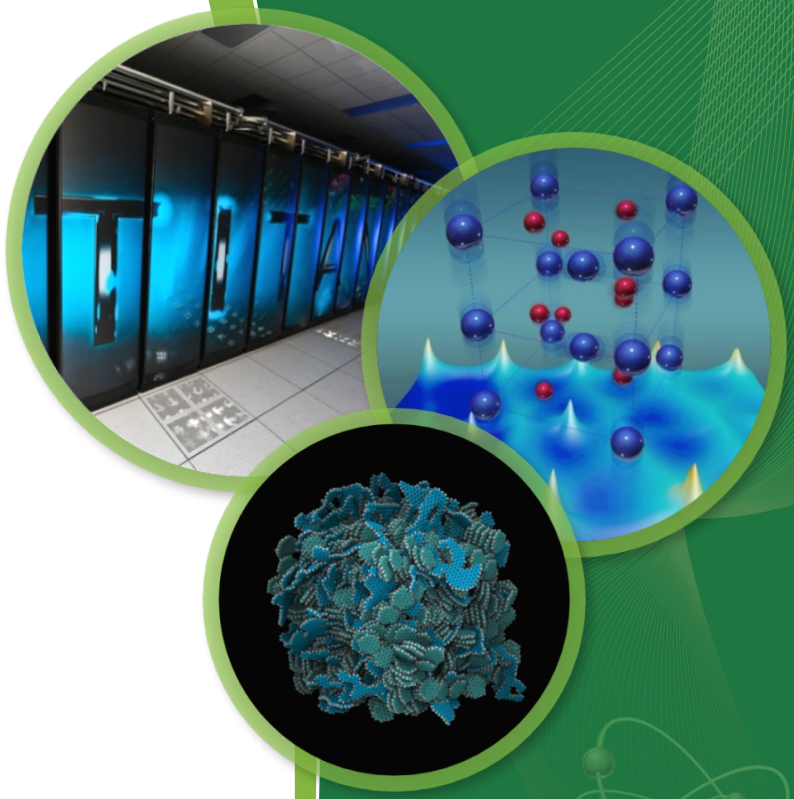
Introduction to the SCALE Code System



Presented to:

SCALE Users' Group Workshop
September 26–28, 2017

Bradley T. Rearden, PhD
Leader, Modeling and Simulation Integration
Manager, SCALE Code System
Reactor and Nuclear Systems Division

ORNL is managed by UT-Battelle
for the US Department of Energy

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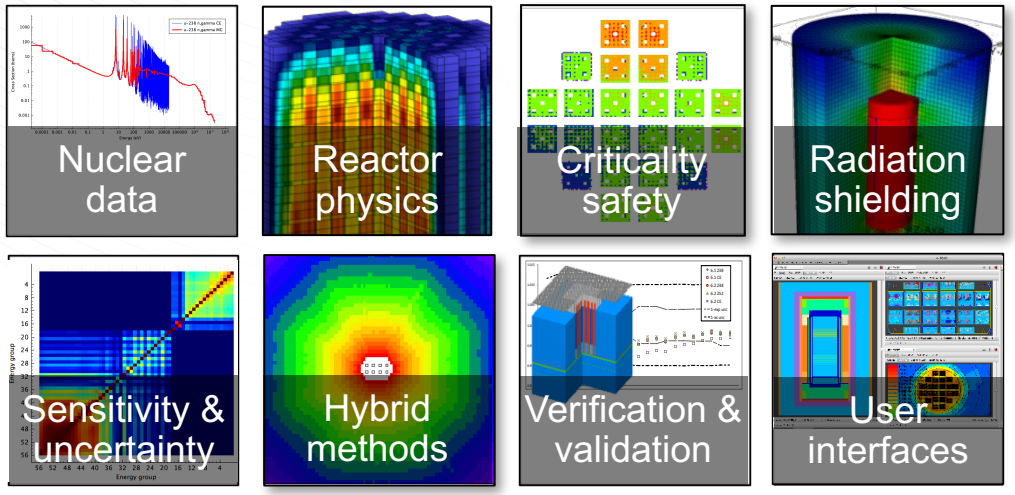
SCALE Code System:

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

Primary sponsors

UNITED STATES NUCLEAR REGULATORY COMMISSION

National Nuclear Security Administration

DEPARTMENT OF ENERGY

Robust quality assurance program based on multiple standards

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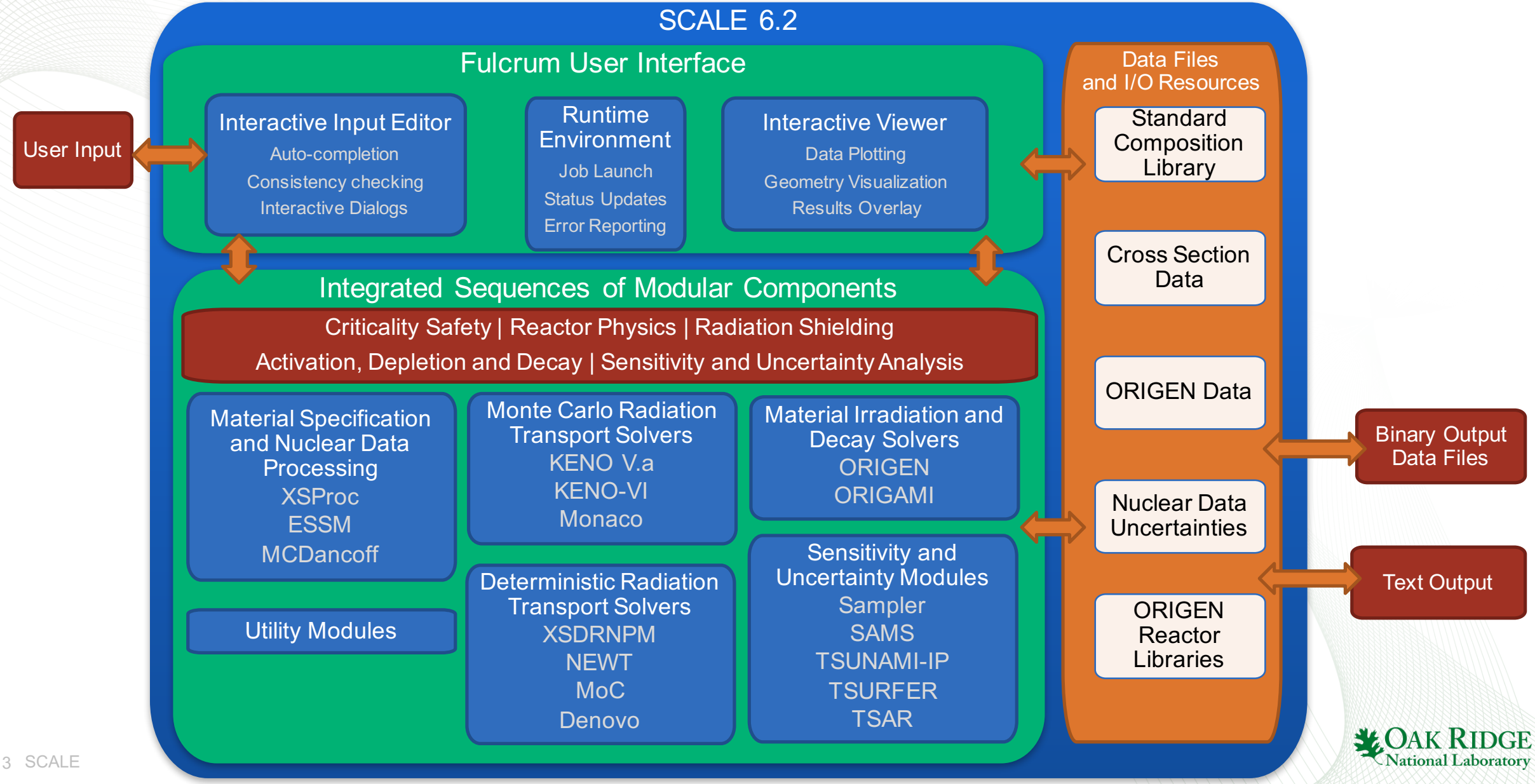
SCALE is an integrated system with many features



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SCALE 6.2 – April 2016

Innovative

- Modernized architecture for efficiency and quality
- Enhanced sensitivity and uncertainty analysis
- Problem-dependent temperature treatments for continuous-energy Monte Carlo
- Reference continuous-energy depletion
- AMPX tools for cross section library generation

Efficient

- Accelerated lattice physics capabilities
- Reduced memory requirements
- Parallel calculations
- Rapid radioactive source term generation

Accurate

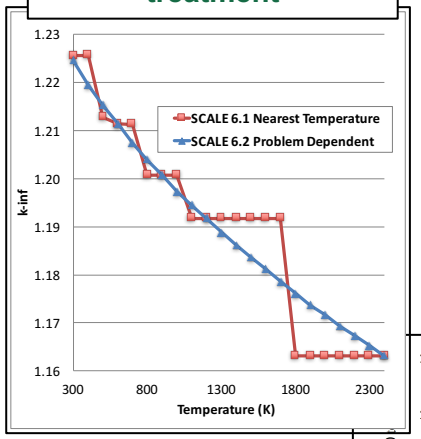
- Code and data enhancements to minimize historical biases
- Greatly expanded test suites for validation and verification

Easy to Use

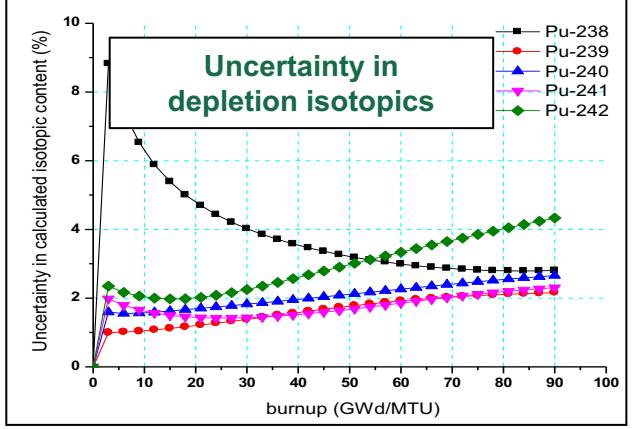
- Integrated user interface
- Simplified input

2,840 licenses issued through August 2017

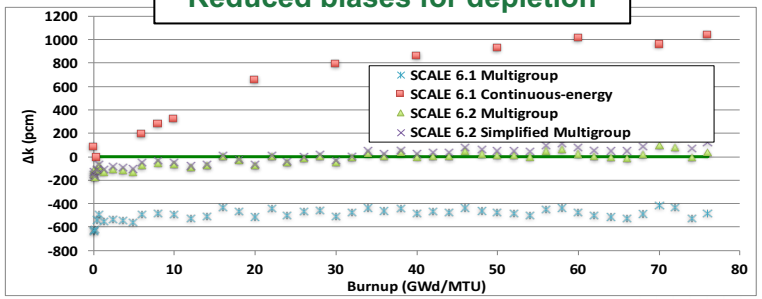
Impact of temperature treatment



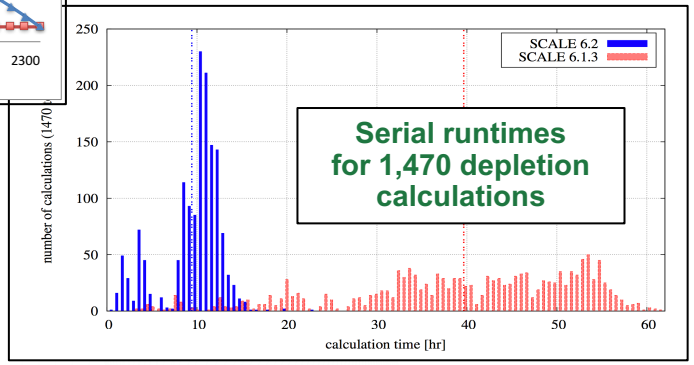
Uncertainty in depletion isotopics



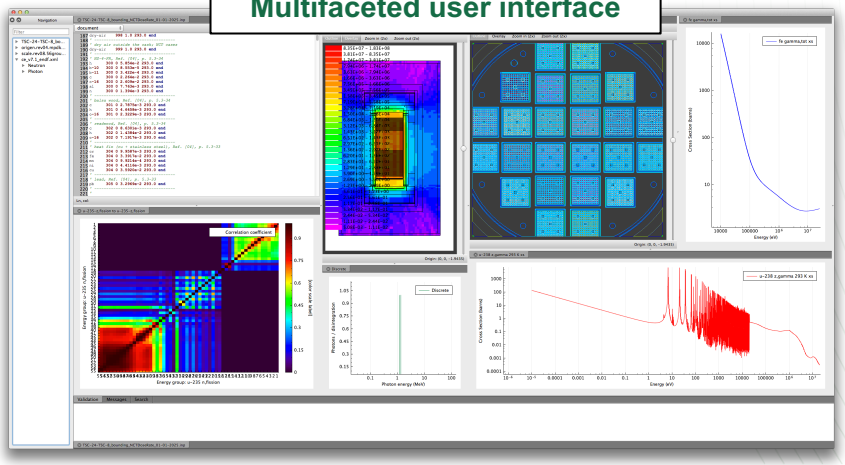
Reduced biases for depletion



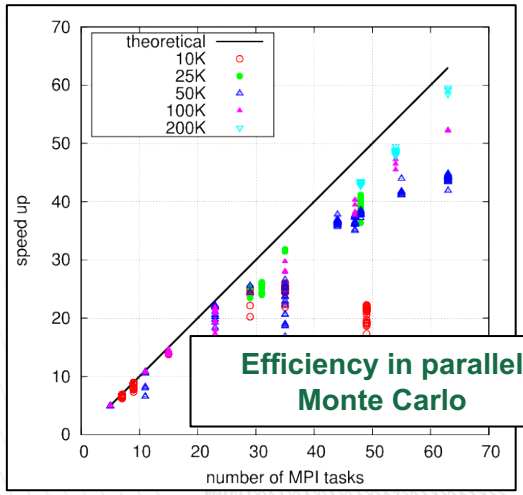
Serial runtimes for 1,470 depletion calculations



Multifaceted user interface



Efficiency in parallel Monte Carlo



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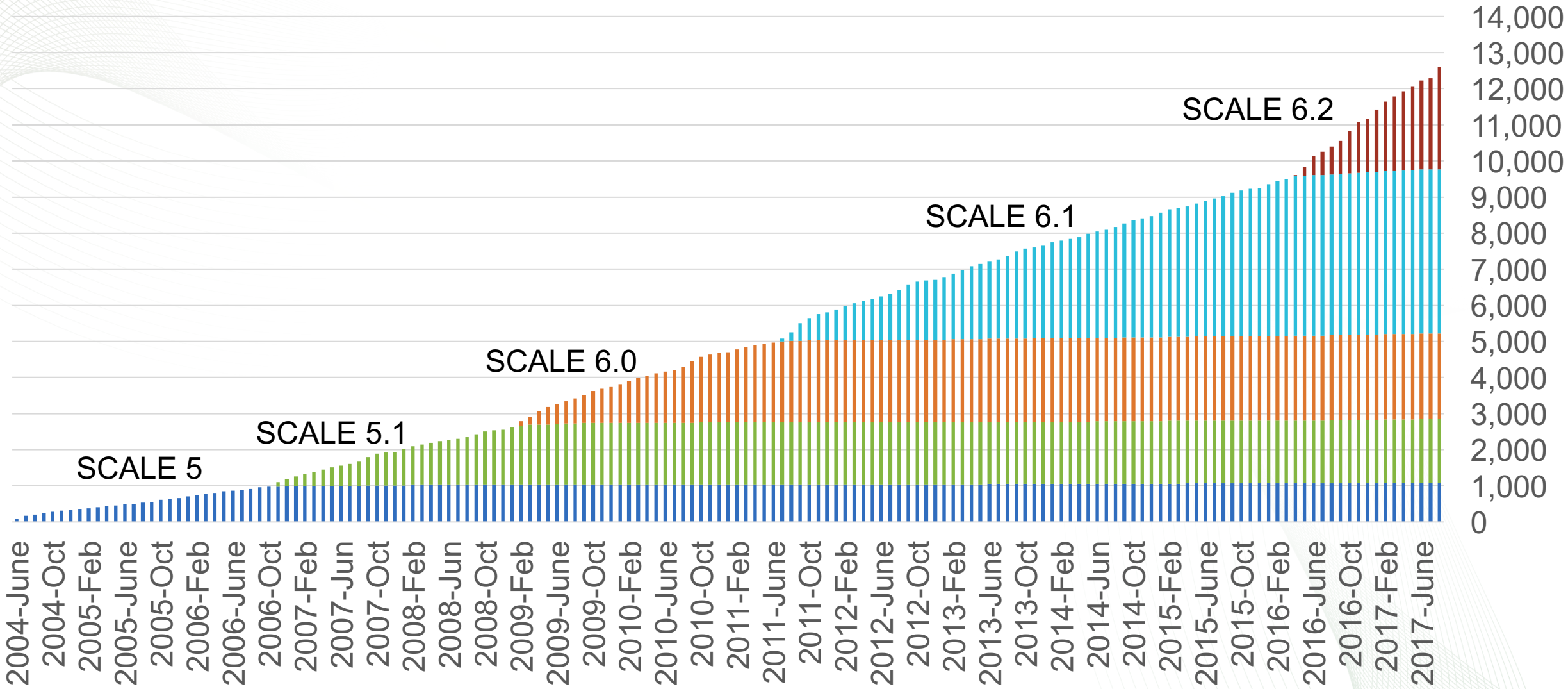
SCALE licenses by version



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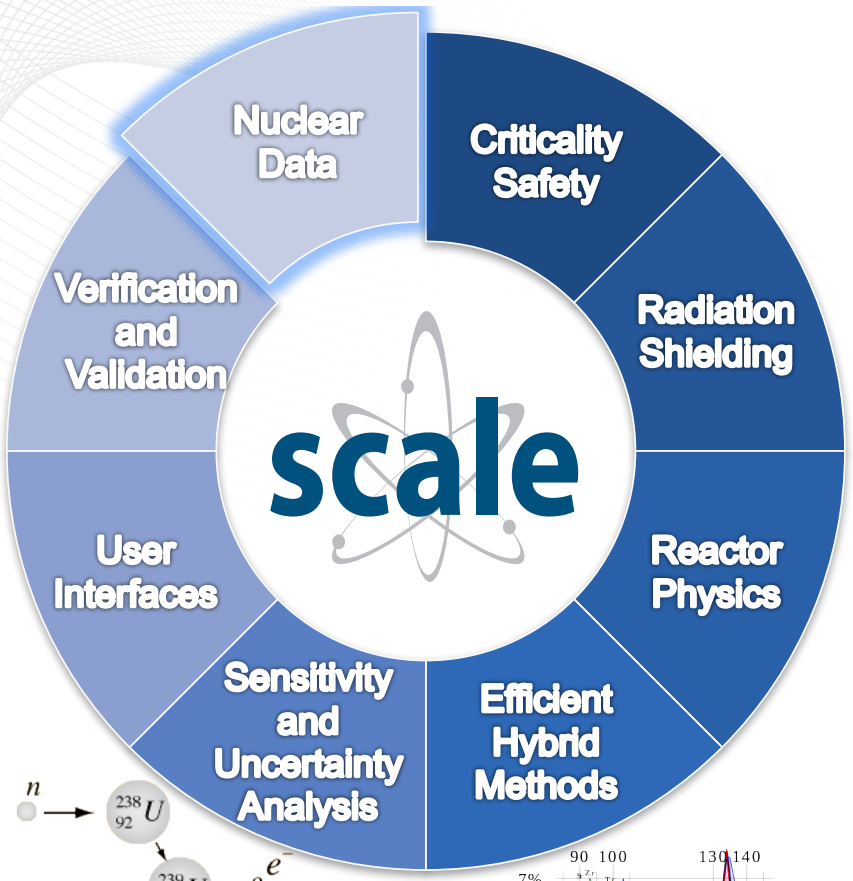
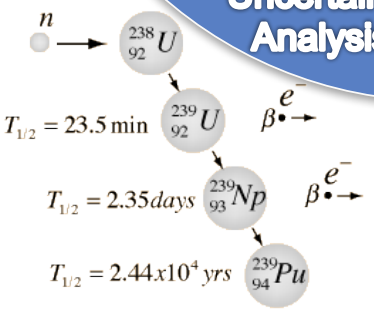
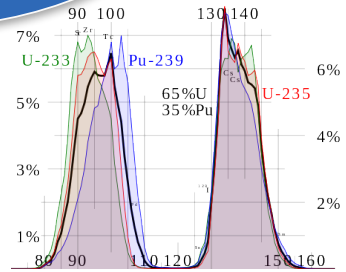
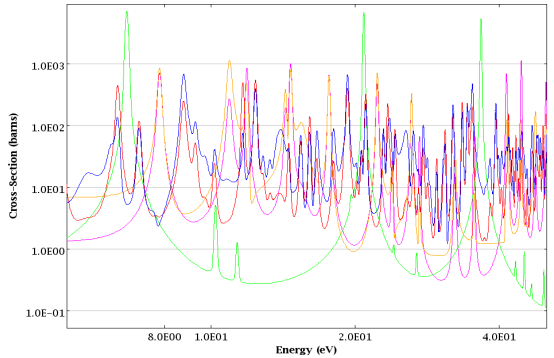
Nuclear data from ORNL AMPX tools



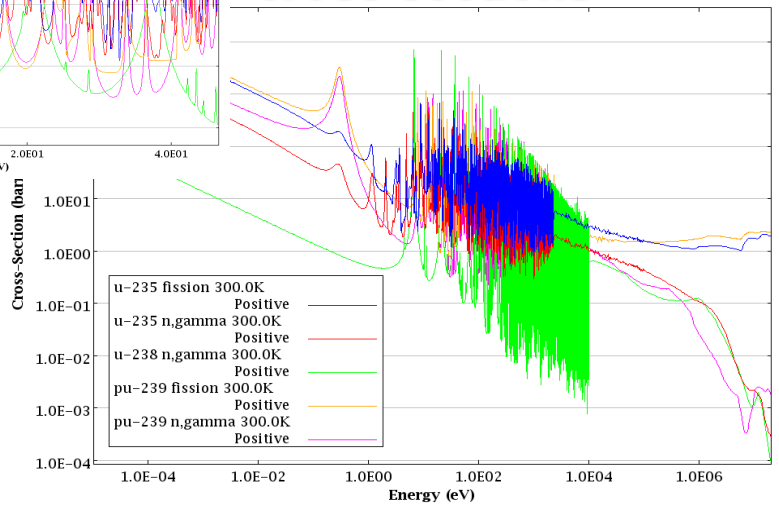




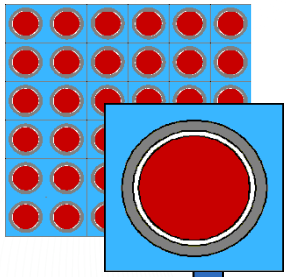
Depletion, decay, and activation data

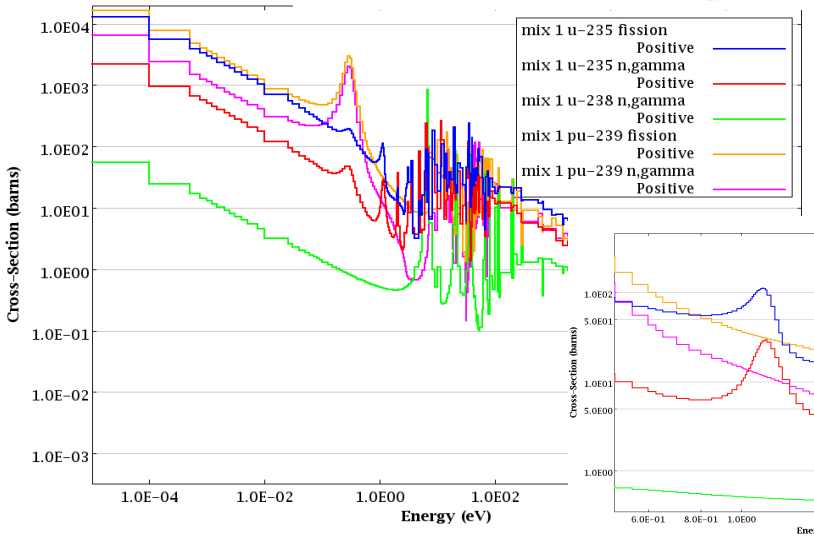


Continuous-energy neutron and gamma cross sections



Resonance self-shielding





Multigroup neutron and gamma cross sections

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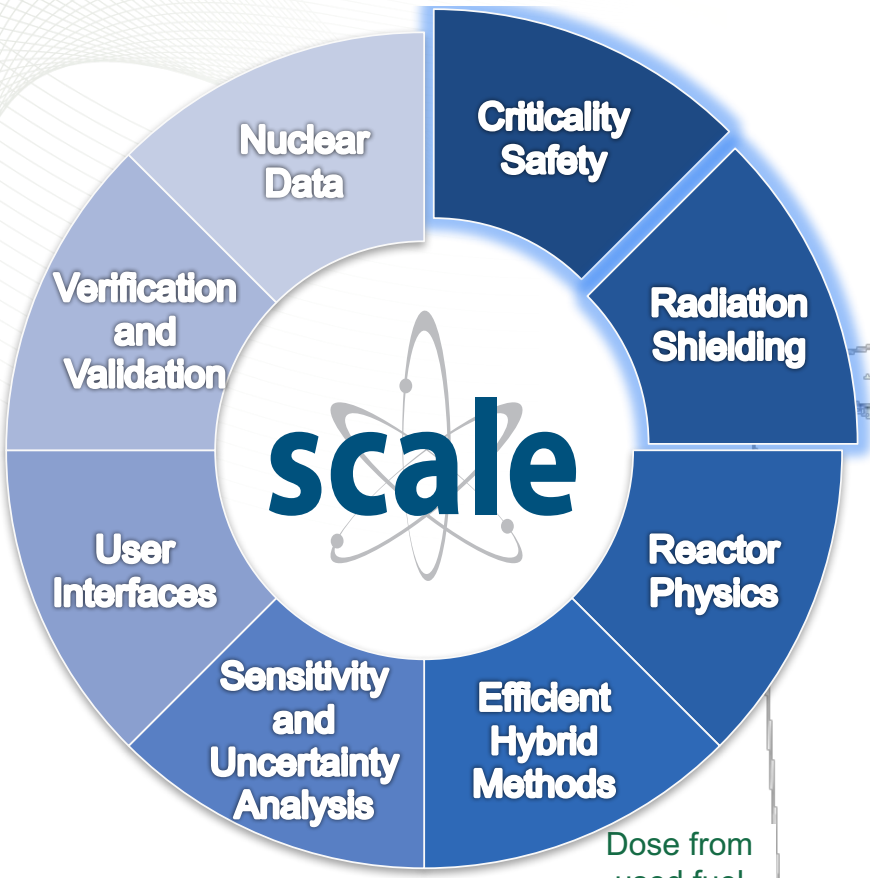
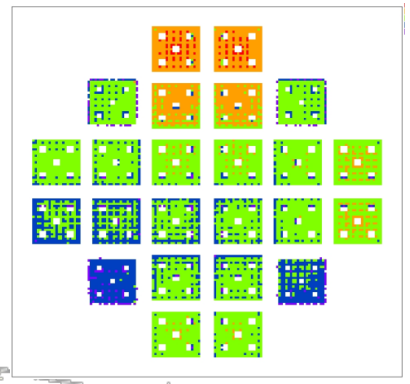
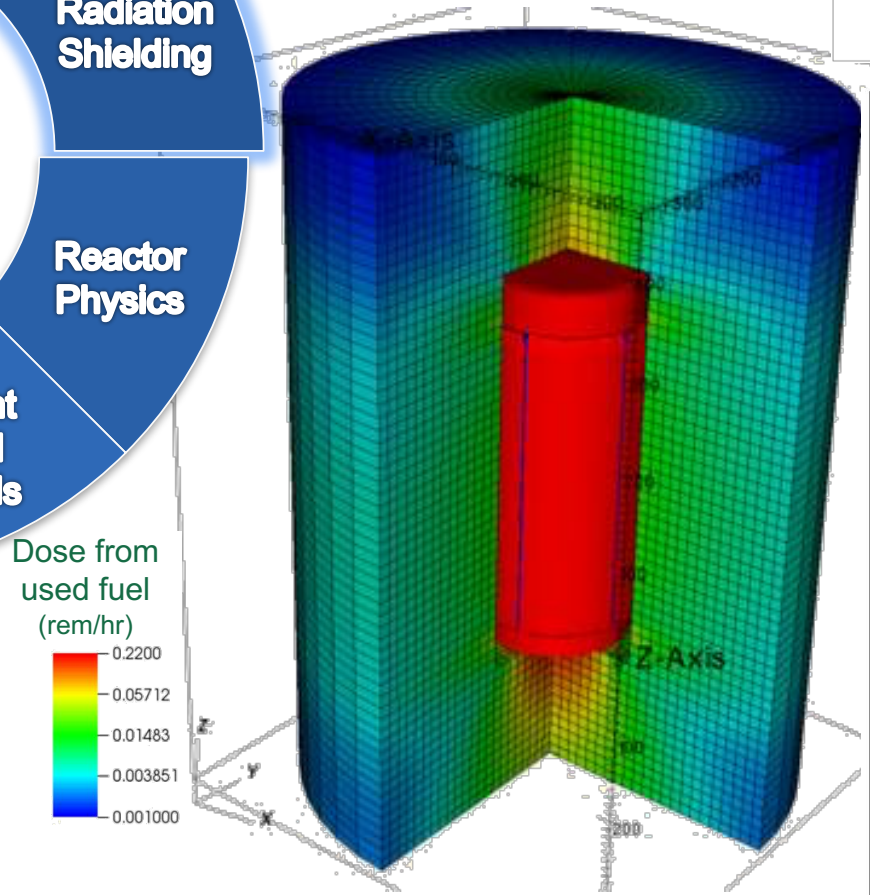
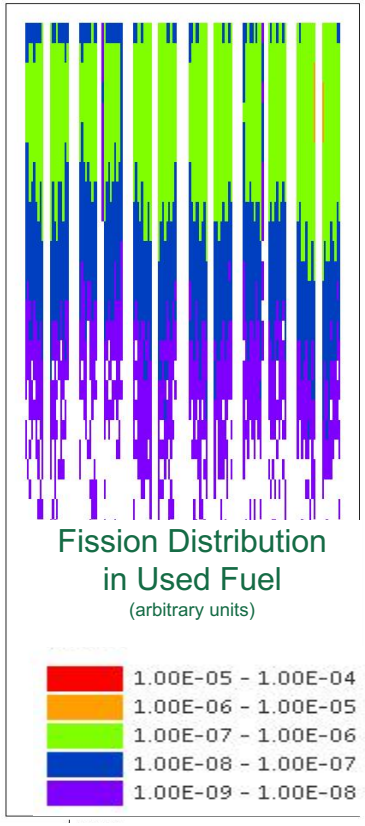
Criticality safety and radiation shielding

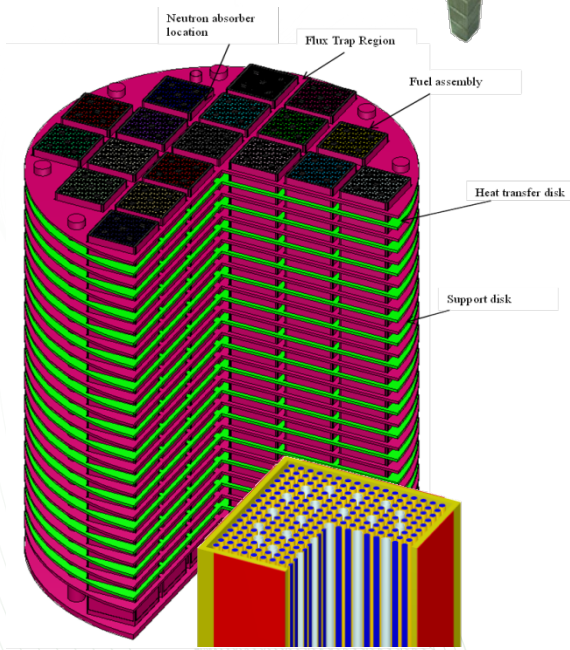


High-fidelity Monte Carlo methods









As-loaded used fuel cask

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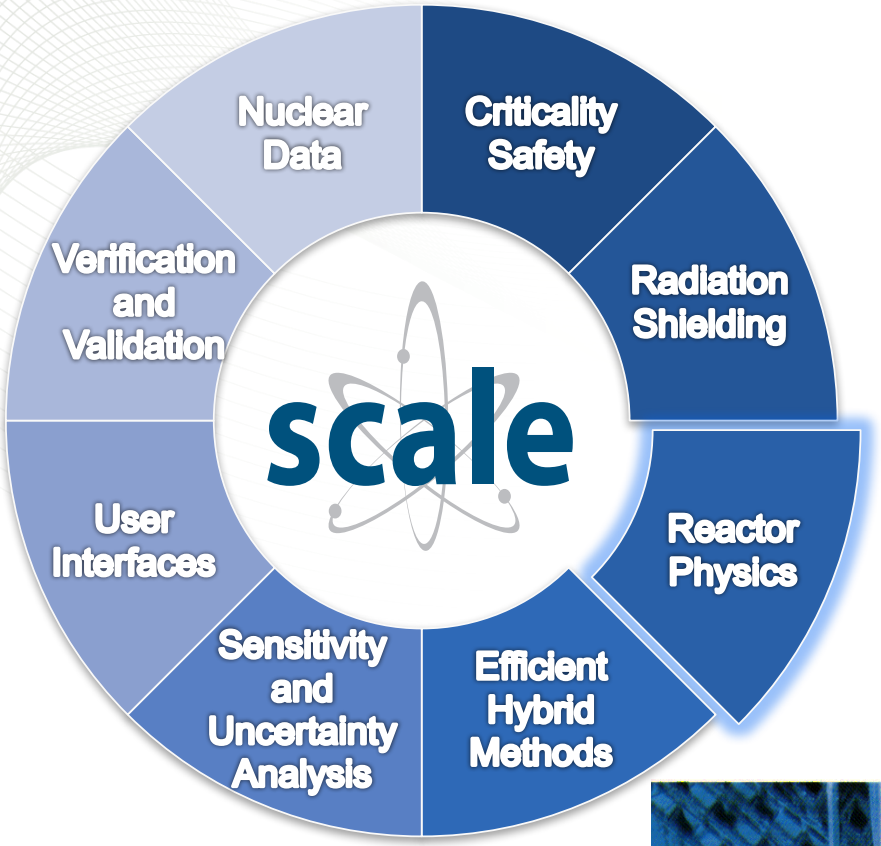
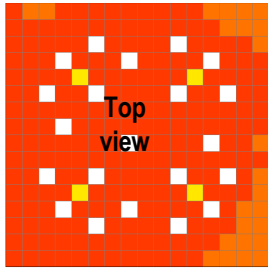
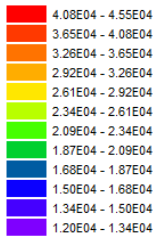
Reactor physics and used fuel characterization

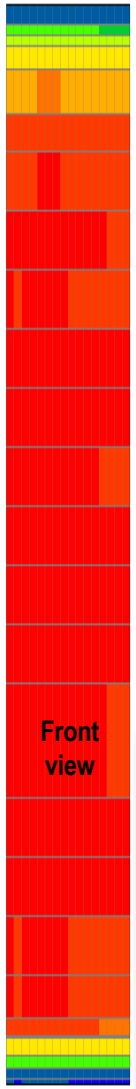


Pin-by-pin burnup and radioactive source terms

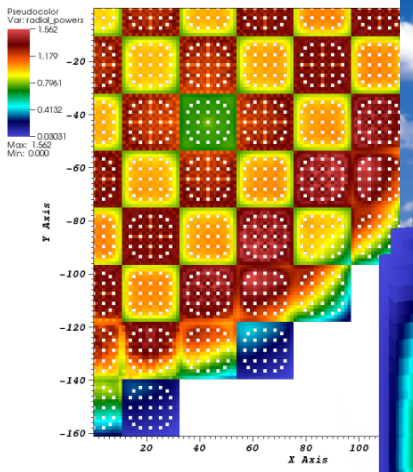


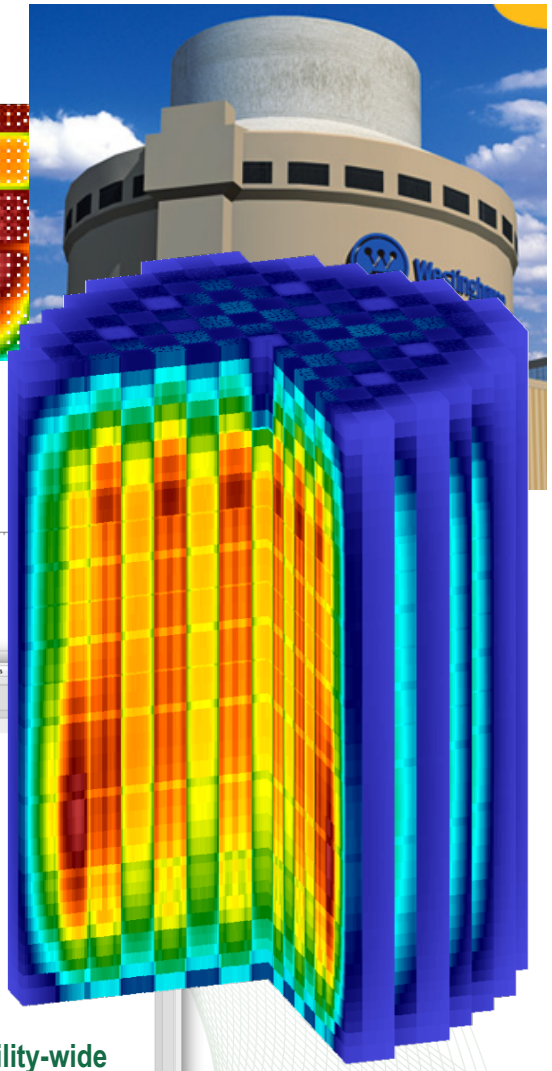
Burnup (MWd/MTU)

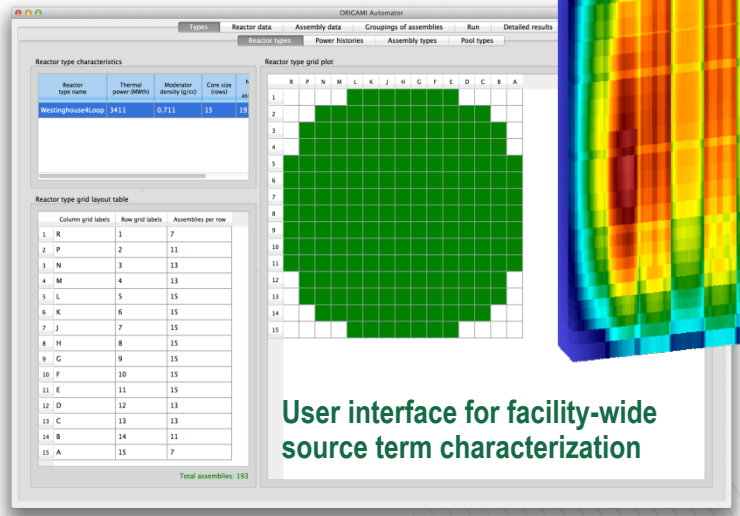




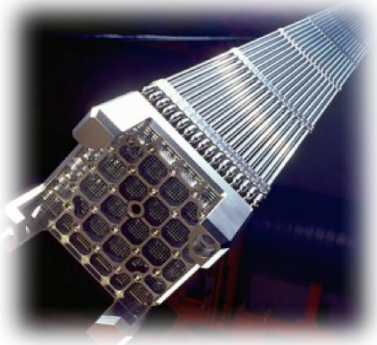
Power distribution for AP-1000 reactor

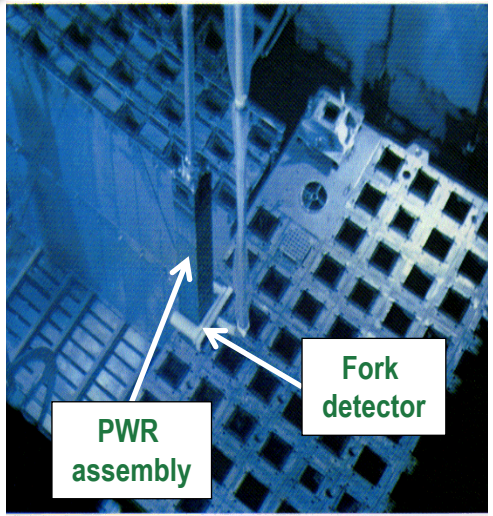






User interface for facility-wide source term characterization





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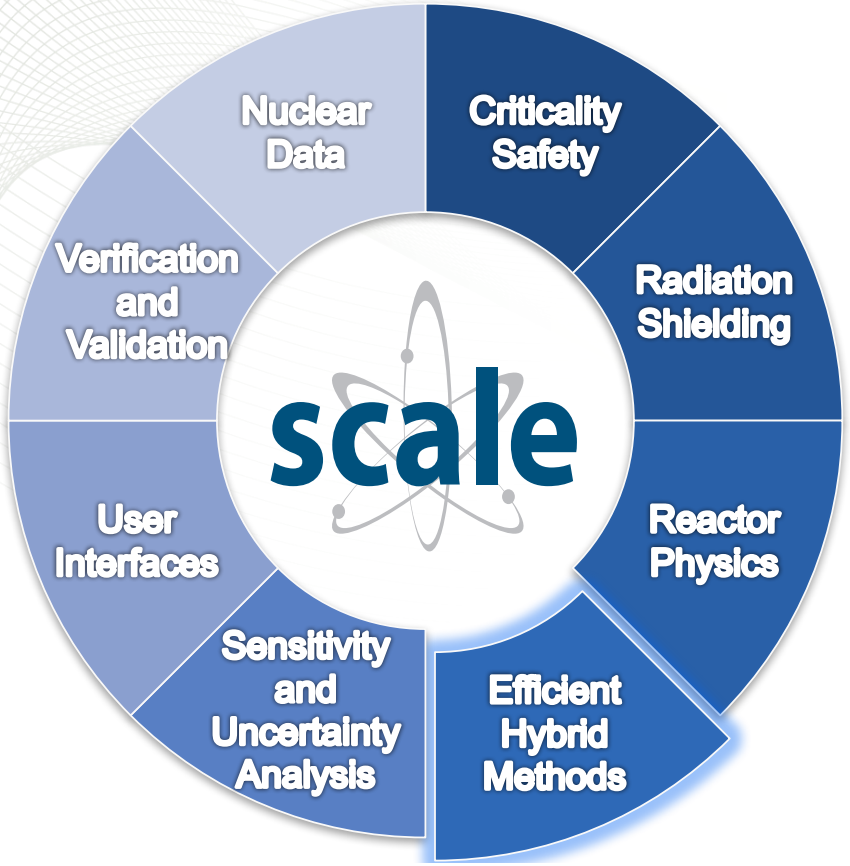
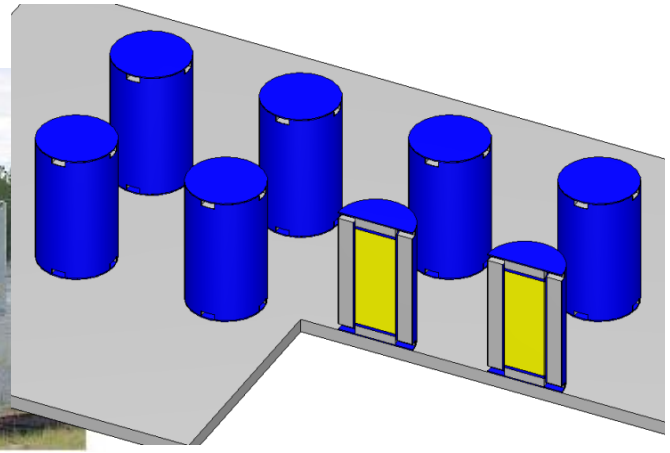
Efficient hybrid methods



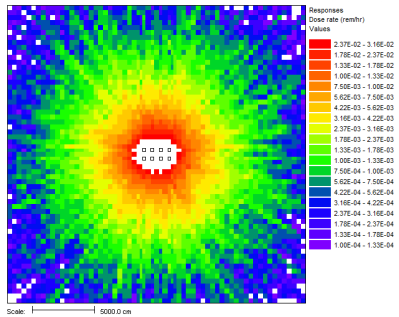


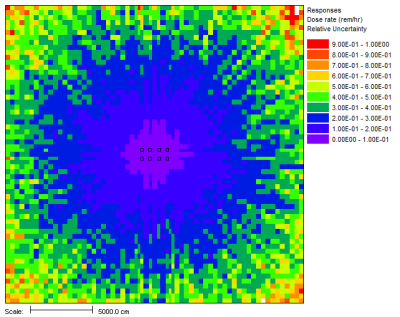
Dose analysis for used nuclear fuel storage

Dose rate (rem/hr)

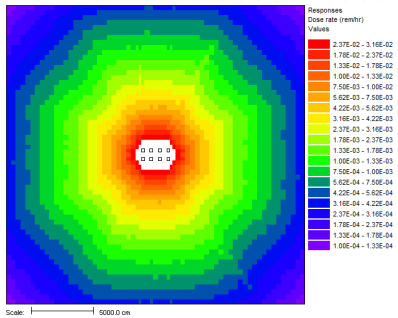
Relative uncertainty

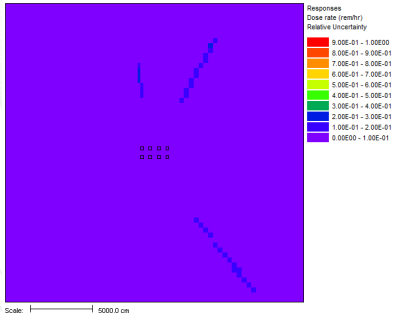
Analog

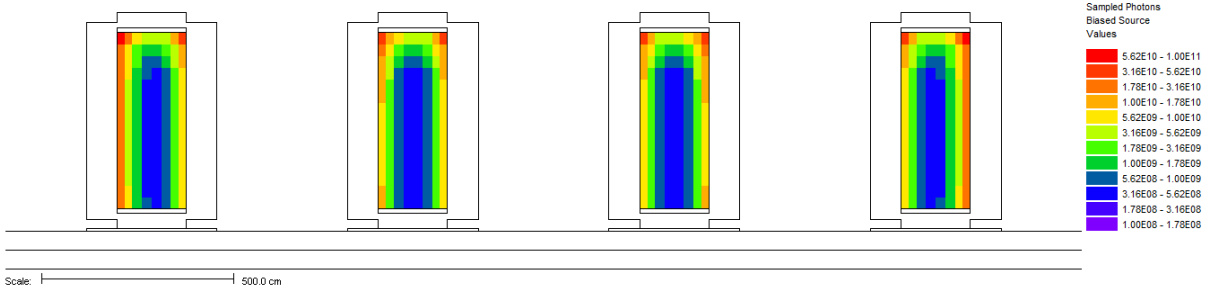




Hybrid
(Same run time)







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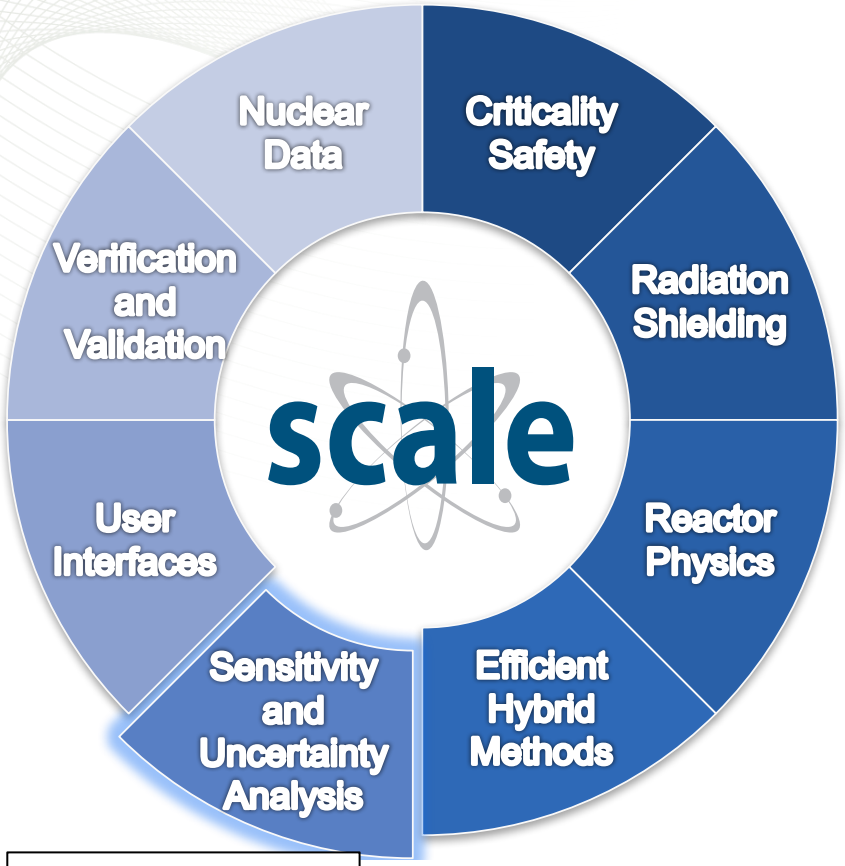
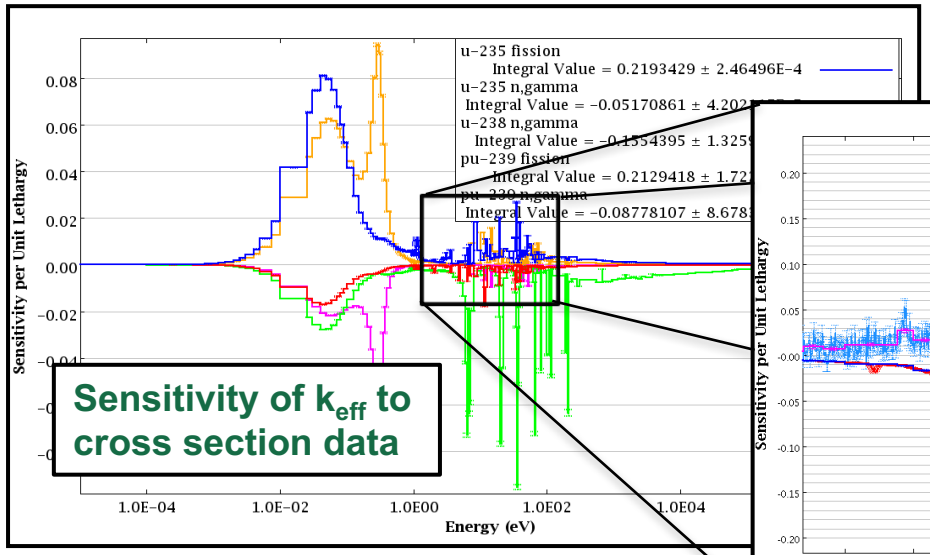
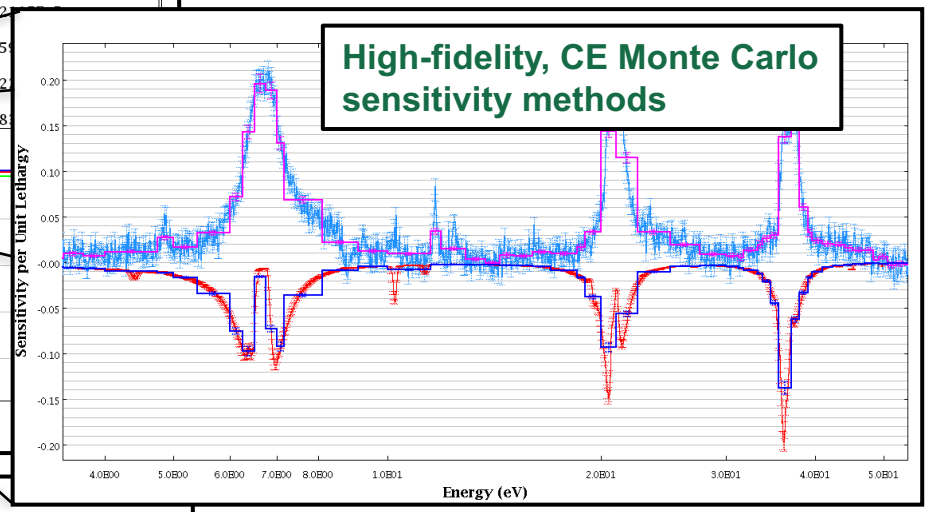
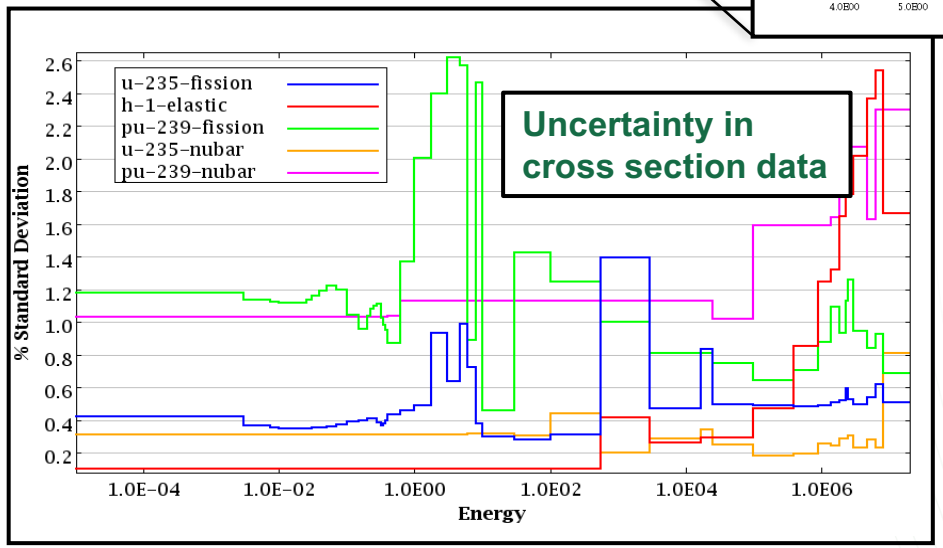
Sensitivity and uncertainty analysis

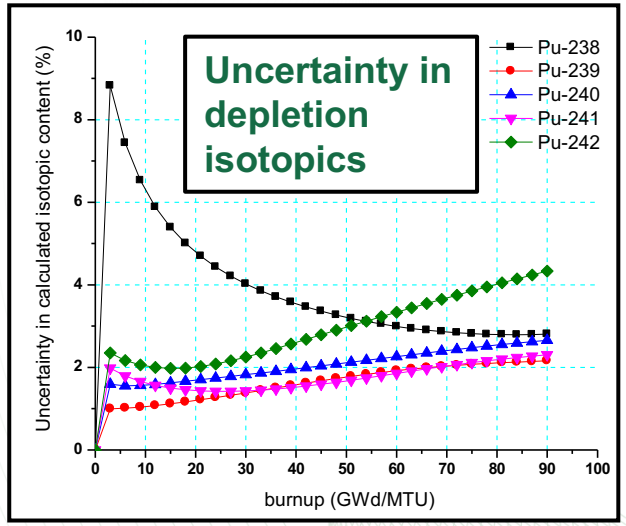
$$S_{k,\Sigma} = \frac{\delta k/k}{\delta \Sigma/\Sigma}$$







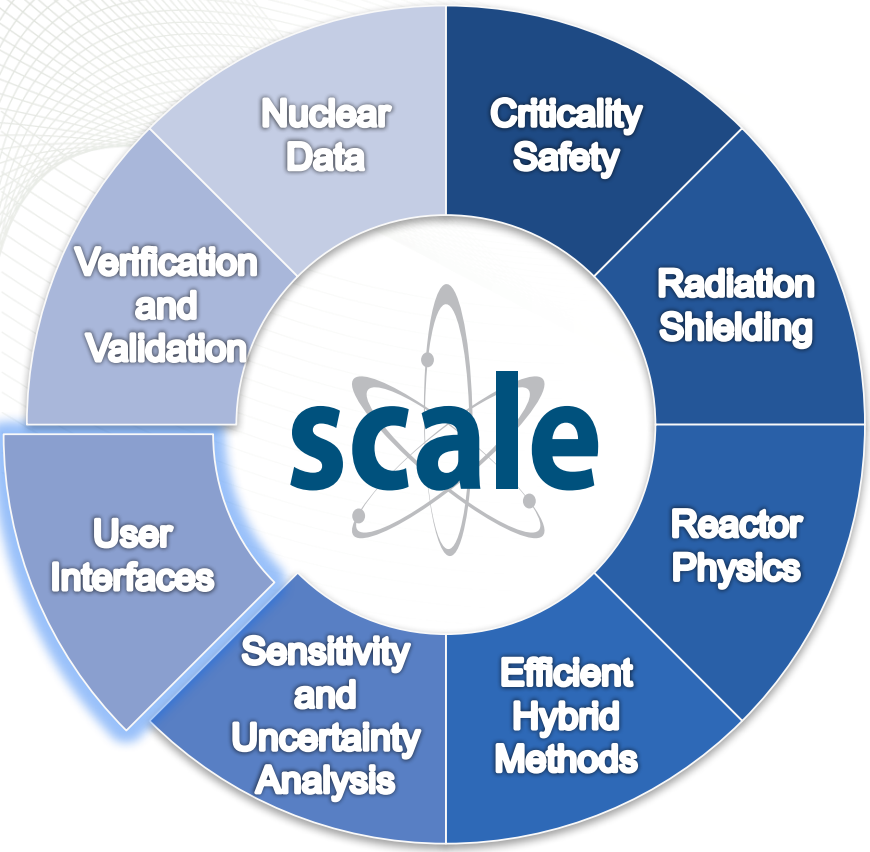


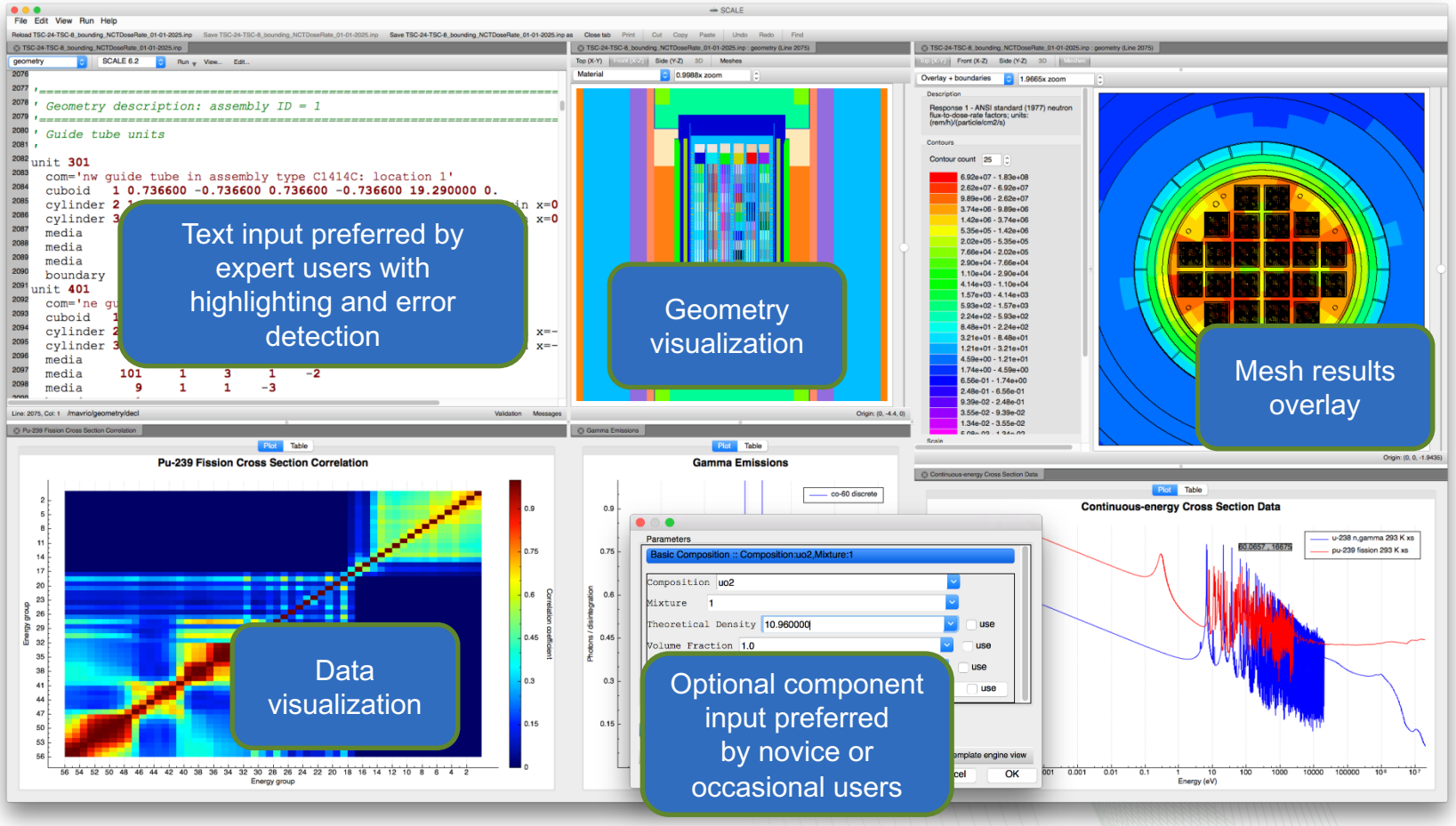


Uncertainty in k_{eff}

Covariance Matrix		Unc. in % dk/k
Nuclide-Reaction	Nuclide-Reaction	Due to this Matrix
^{239}Pu nubar	^{239}Pu nubar	4.0032E-01 ± 2.5625E-06
^{238}U n,gamma	^{238}U n,gamma	1.9457E-01 ± 1.2387E-05
^{239}Pu fission	^{239}Pu fission	1.5501E-01 ± 1.0838E-05
^{235}U nubar	^{235}U nubar	1.3981E-01 ± 5.0038E-07

User interfaces

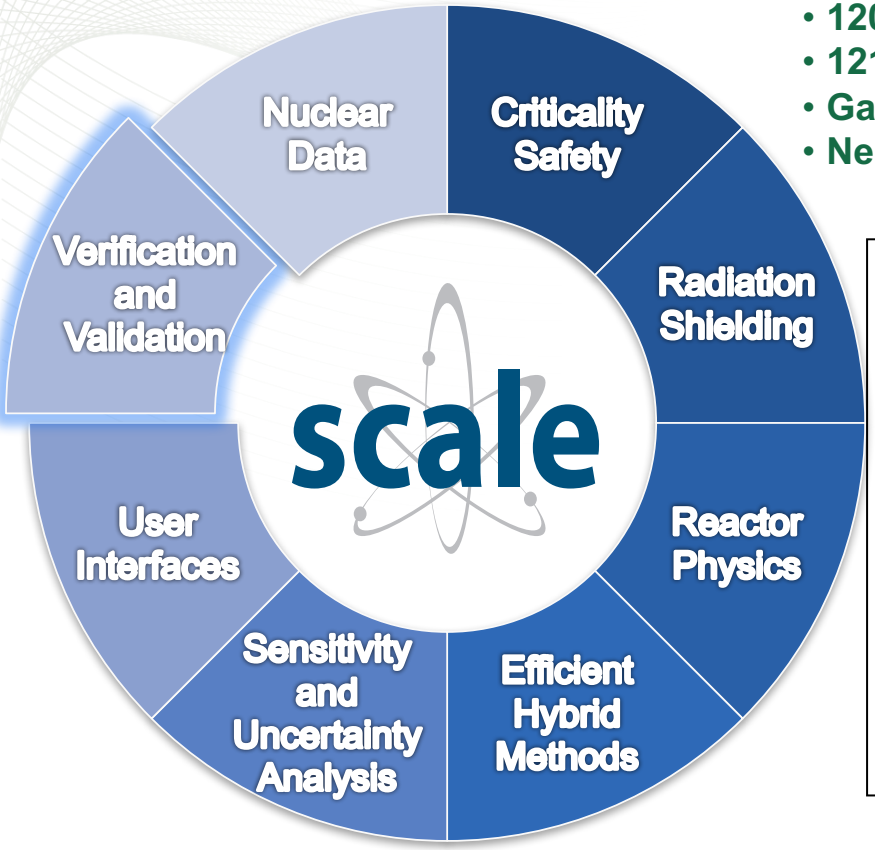




Fulcrum - Integrated user interface

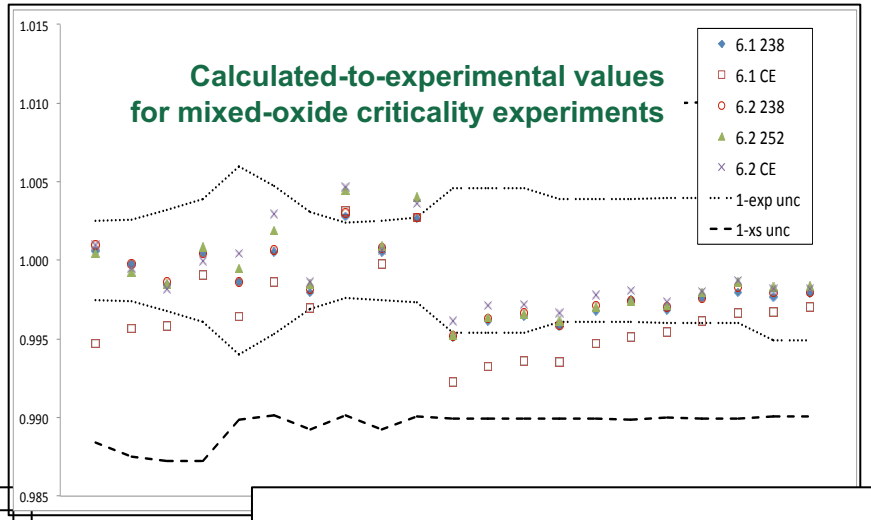
- Input generation
- Model visualization
- Nuclear data plotting
- Job execution
- Results review

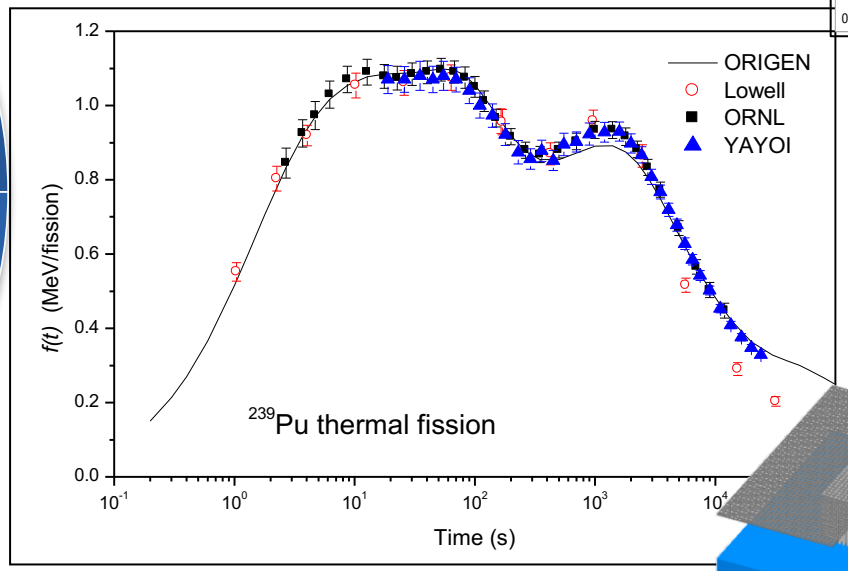
Verification and validation

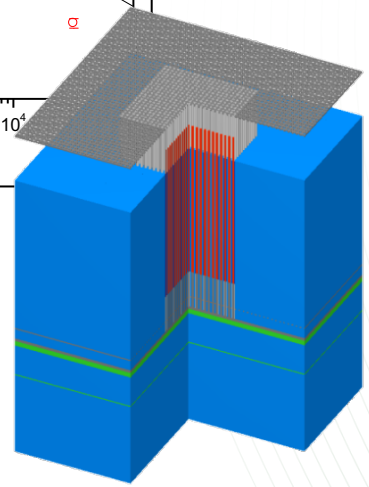


Validation

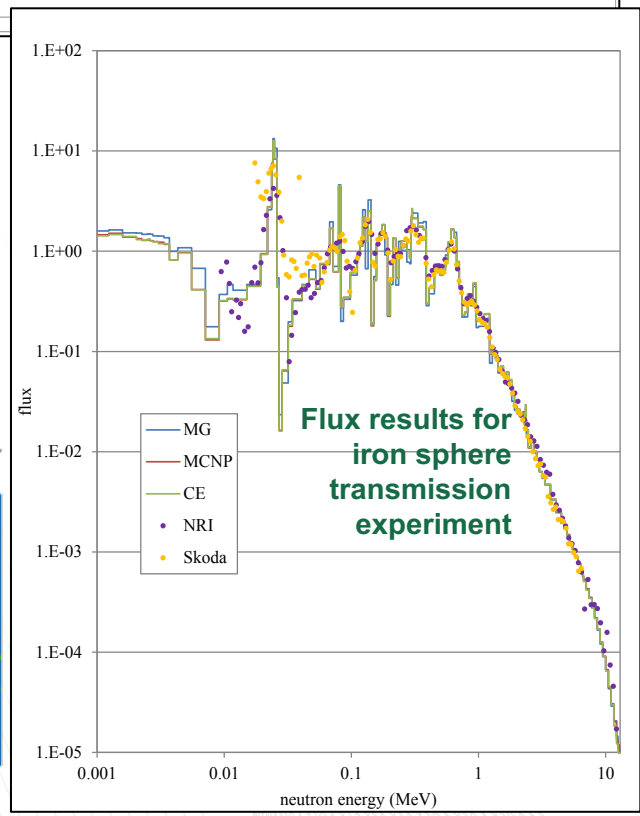
- 400 criticality and shielding benchmarks
- 120 isotopic assays samples
- 121 decay heat measurements
- Gamma spectra – burst fission
- Neutron spectra – spent fuel and (α,n) sources







MIX-COMP-THERM-004
Critical Experiment



Verification

- >7,000 fixed-source transmission tests for neutron/gamma spectral data
- Every nuclide/element at multiple energies
- >5,000 infinite medium k_{inf} tests

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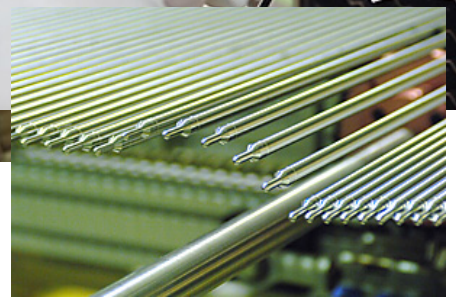
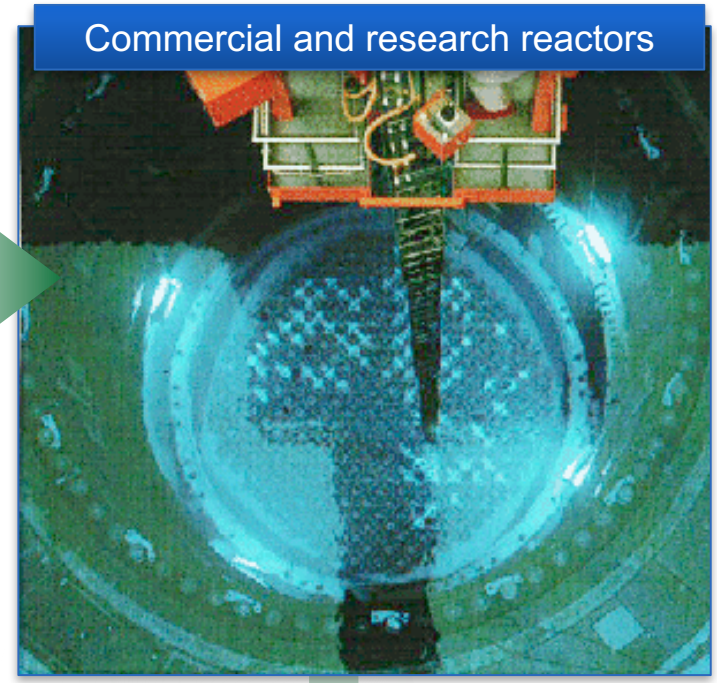
Applications of SCALE: The Nuclear Fuel Cycle

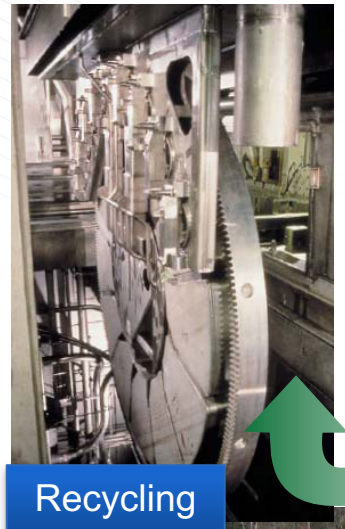





Material processing and fuel fabrication



Commercial and research reactors



Recycling

Disposal

Transportation

Storage, safeguards, and security

The SCALE Code System

Neutronics and Shielding Analysis for Enabling Nuclear Technology Advancements

CASL / NEAMS

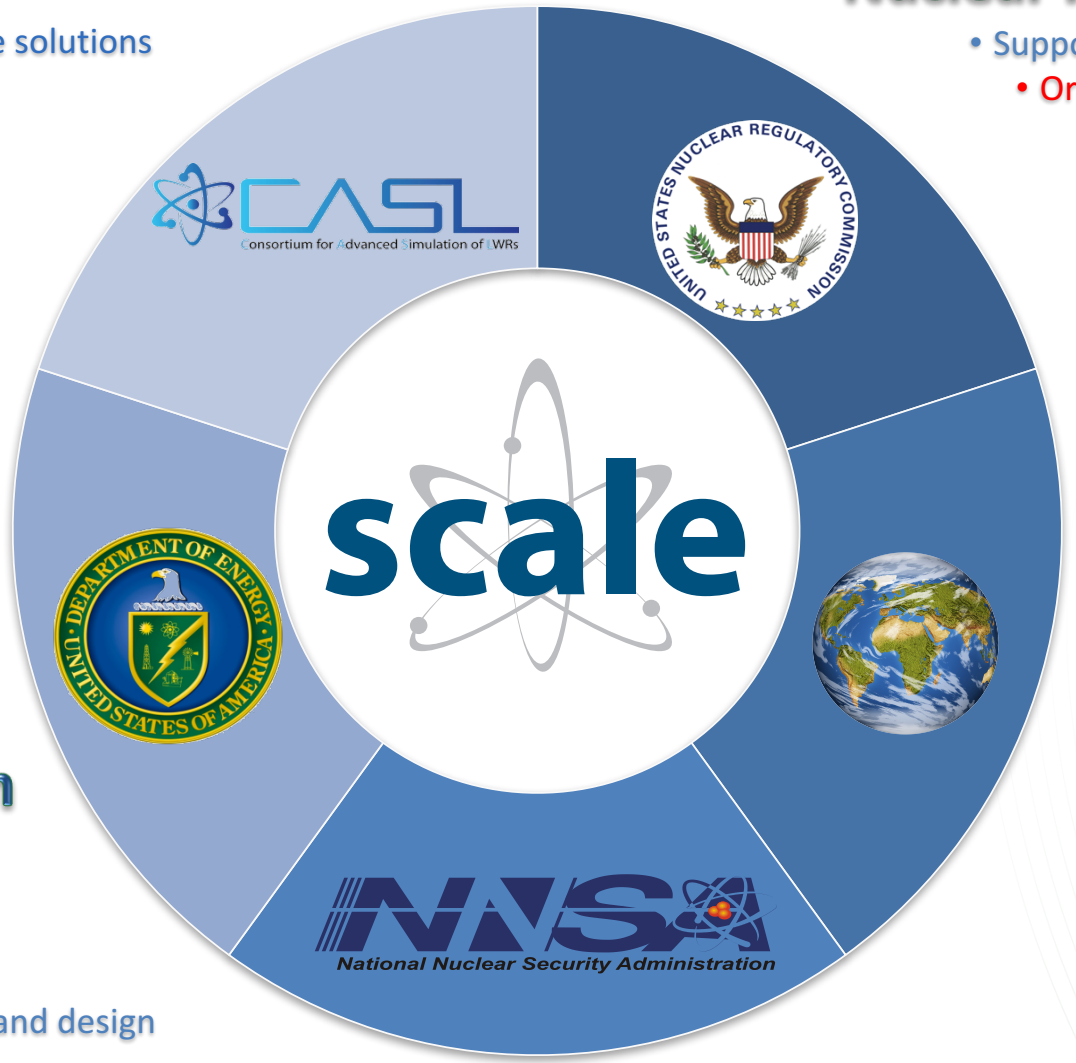
- Continuous-energy, high-fidelity reference solutions for reactor physics
- Cross section data libraries
- Reactor fuel depletion
- Uncertainty quantification

DOE Used Fuel Disposition

- Radiation shielding
- Nuclear fuel depletion
- Used fuel source terms
- Criticality safety analysis
- Uncertainty quantification

DOE Nuclear Criticality Safety Program

- Criticality safety assessments
- Sensitivity and uncertainty analysis
- Advanced validation methods
- Experiment design
- Criticality accident alarm system analysis and design



Nuclear Regulatory Commission

- Supports licensing and regulatory research
- Original sponsors of SCALE – since 1976
- Reactor physics and source terms
- Criticality safety and shielding
- Cross section data libraries

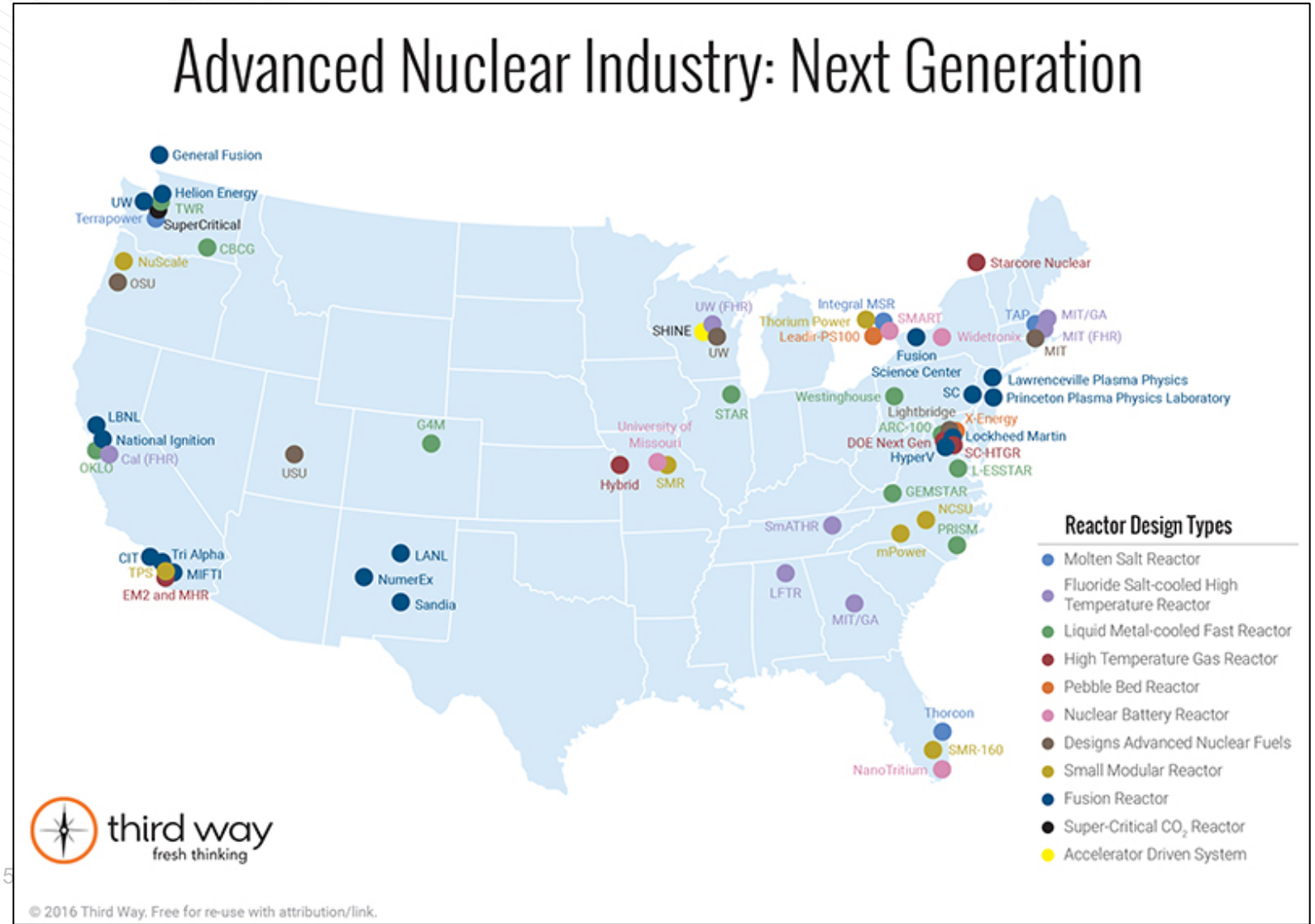
Global Distribution

- 8,000 users in 58 nations
- Regulators
- Industry
- Research and Development

Nuclear Nonproliferation and Safeguards

- Used fuel and radionuclide source terms
- Reactor depletion analysis
- Radiation transport
- Nuclear forensics

A number of private US companies are pursuing conceptual and technological development of advanced reactors



AREVA

HITACHI

Westinghouse

X energy

TerraPower

TERRESTRIAL ENERGY

Kairos Power

TRANSATOMIC

ARC
ADVANCED REACTOR CONCEPTS, LLC

GENERAL ATOMICS
AND AFFILIATED COMPANIES

SOUTHERN NUCLEAR
A SOUTHERN COMPANY

OAK RIDGE National Laboratory

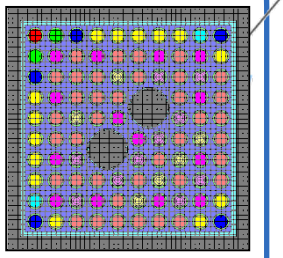
SCALE is a part of the NRC's reactor licensing path

ENDF data

Point data
10,000s of energy groups

Cross section library generation
AMPX

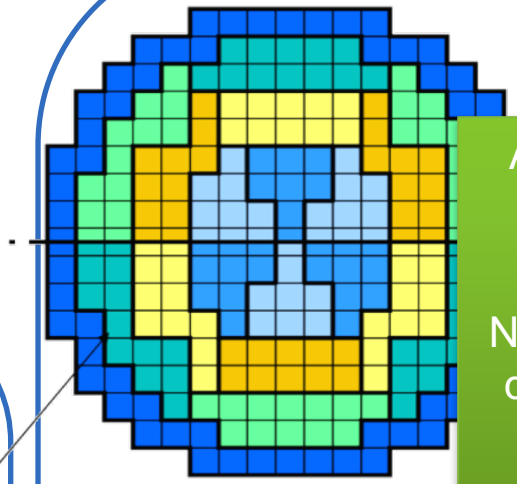
scale
Nuclear Systems Modeling & Simulation



Calculational libraries:
Continuous (point) data,
multigroup: 10–100s of groups

Resonance processing
XSProc

Lattice code transport and depletion
TRITON
Polaris



CAMP

Advanced core simulator
Neutron flux dolver and depletion
PARCS

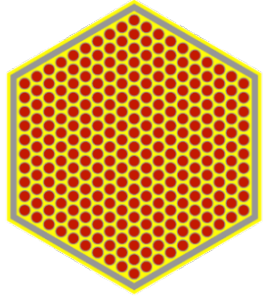
T/H code
TRACE

GENPXS

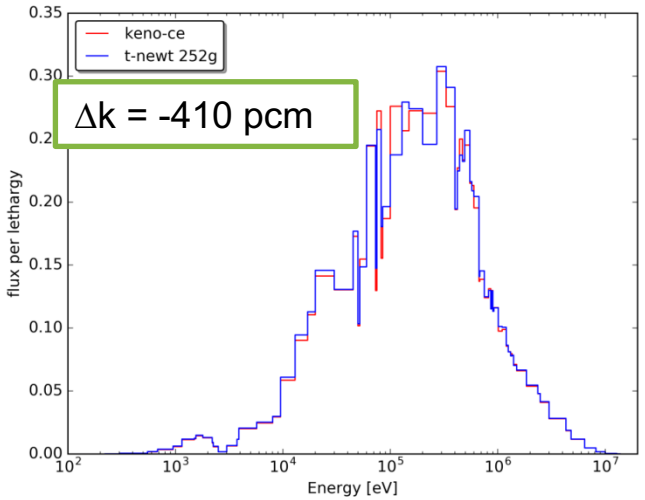
Few (2–8) group cross section database, parametric parameters (fuel/mod temp, mod dens, etc.)

Cross section library
(PMAX)

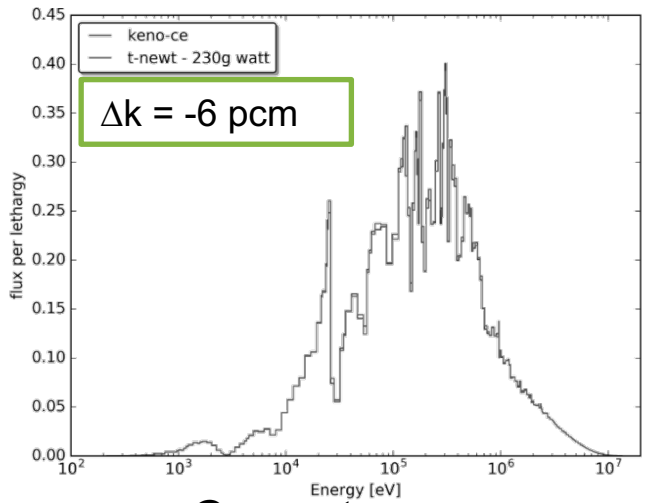
Generation of multigroup libraries and covariance data for advanced reactors – studies in collaboration with GRS



- Continuous-energy data serve as reference solution to confirm multigroup approximations
- SCALE 6.2 includes multigroup neutronics libraries that are optimized for LWRs
- Multigroup cross sections can be generated for any type of system—LWR, HTGR, MSR, FHR, SFR, etc.—with appropriate energy group structure and weighting spectrum
- Uncertainties in cross sections (covariance data) quantify confidence in deployed data libraries
- Example for SFR:



Incorrect group structure/weighting



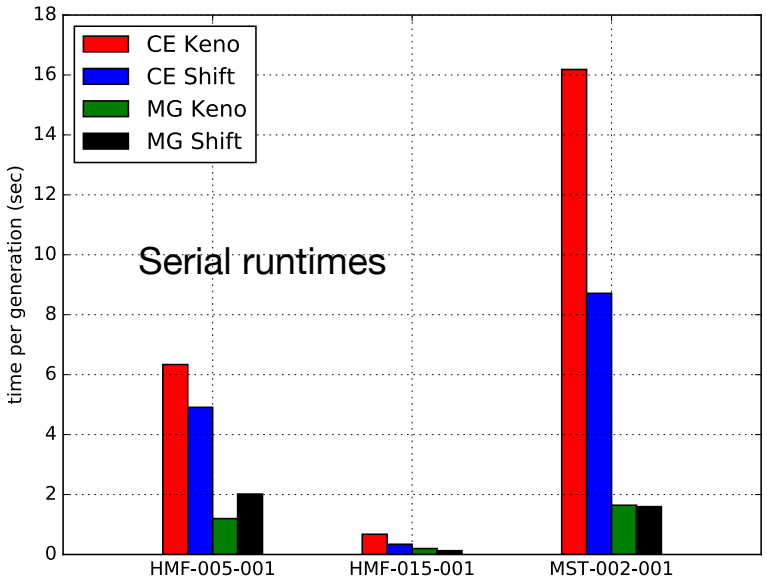
Correct group structure/weighting

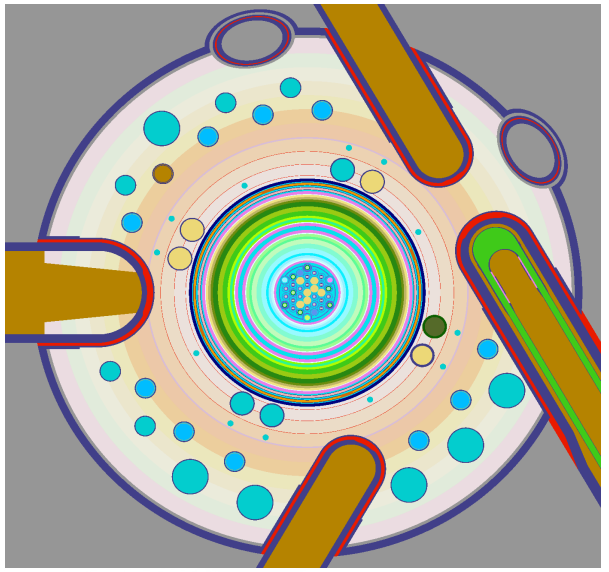
Uncertainty in k_{eff} due to nuclear data uncertainties: 1,435 pcm!

Covariance matrix nuclide-reaction		with nuclide-reaction		% Δk/k due to this matrix
^{238}U	n,n'	^{238}U	n,n'	1.2053(9)
^{23}Na	elastic	^{23}Na	elastic	0.3242(2)
^{56}Fe	elastic	^{56}Fe	elastic	0.2590(3)
^{238}U	n,gamma	^{238}U	n,gamma	0.2435(1)
^{56}Fe	n,n'	^{56}Fe	n,n'	0.2388(1)

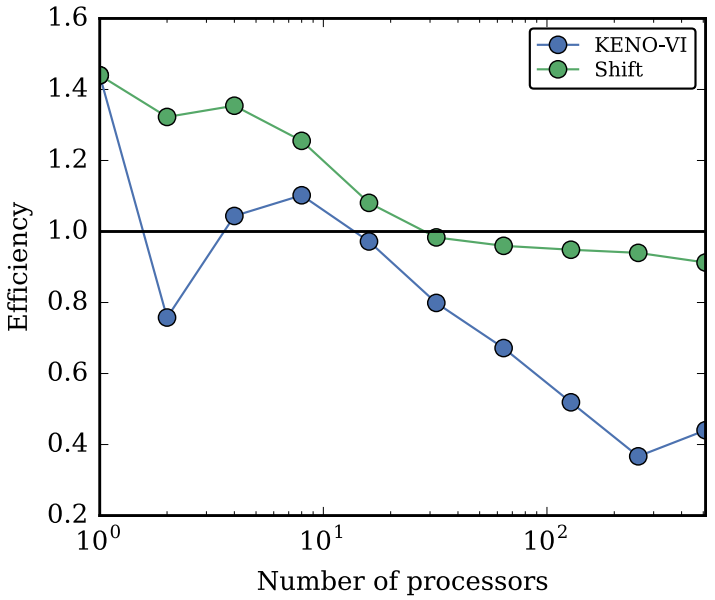
Advanced reactor Monte Carlo analysis with Shift

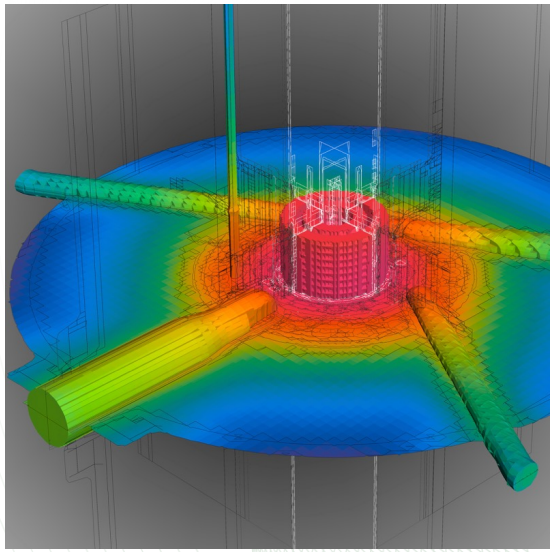
- Flexible, high-performance Monte Carlo radiation transport *framework*
- Shift is physics agnostic
  - SCALE CE physics
  - SCALE MG physics
- Shift is geometry agnostic
  - SCALE geometry
  - Exnihilo RTK geometry
  - MCNP geometry
  - DagMC-CUBIT CAD geometry
- Shift provides fixed-source and eigenvalue solvers
- Shift is integrated with Denovo for hybrid methods
- Shift has multiple parallel decompositions and concurrency models
- Shift is designed to scale from supercomputers to laptops





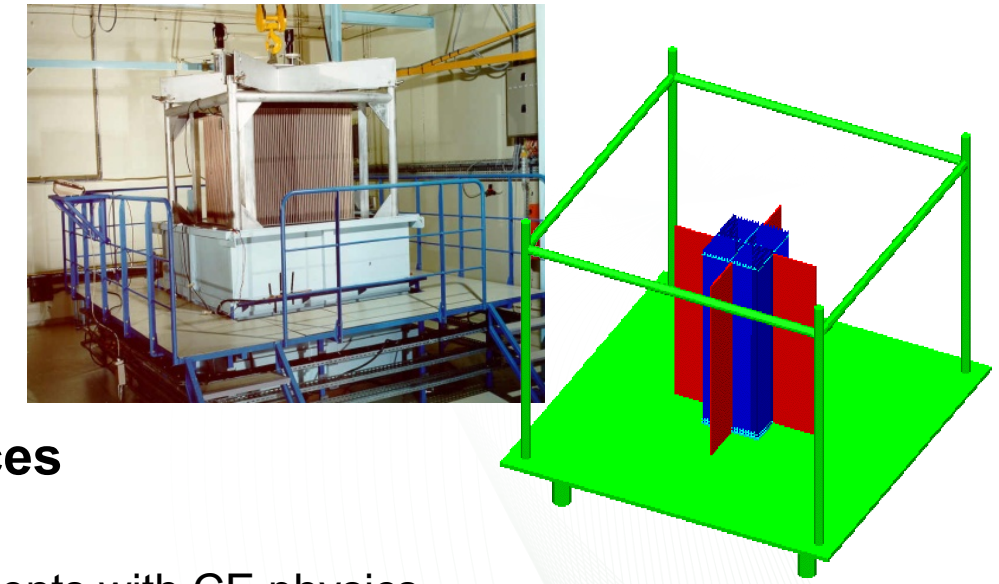
HFIR flux





Shift / SCALE integration

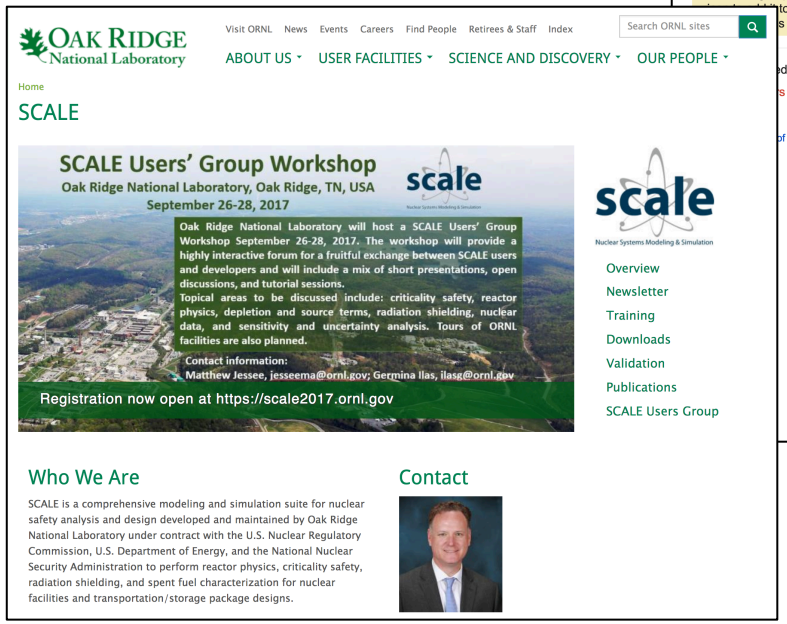
- **Integrated in CSAS criticality sequence**
  - Eigenvalue mode for criticality safety
  - KENO V.a and KENO-VI geometry
  - Uses standard SCALE geometry, material, and control specifications
  - Validated with over 400 benchmark experiments
- **Integration in TRITON depletion sequence**
  - Currently in development
  - Flux-solver
  - Depletion
  - Multigroup cross section generation for nodal codes
  - Randomized geometry for TRISO and pebble bed

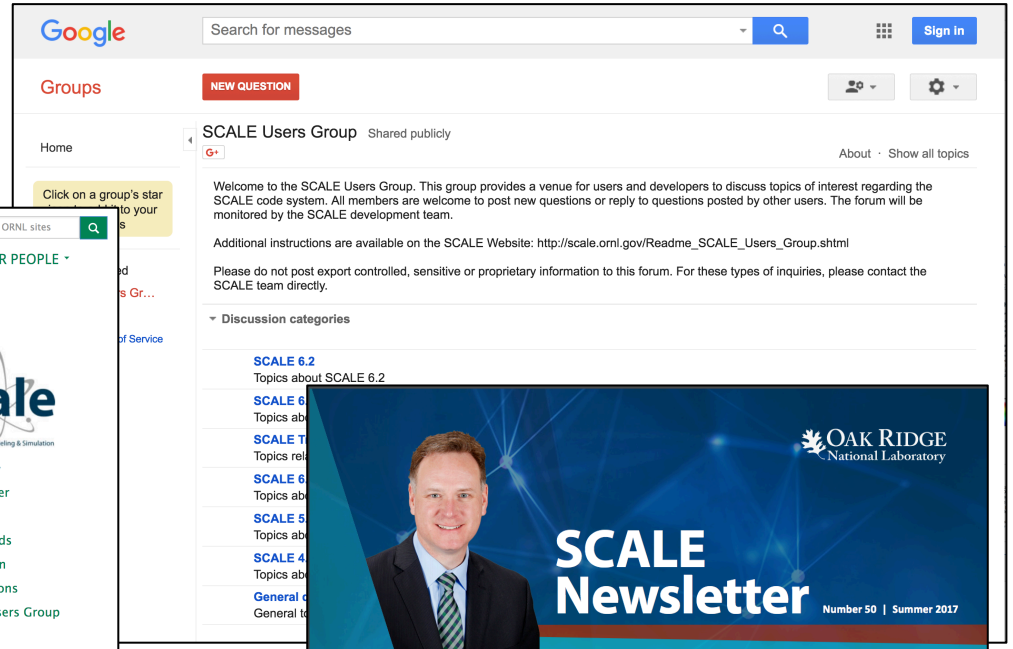


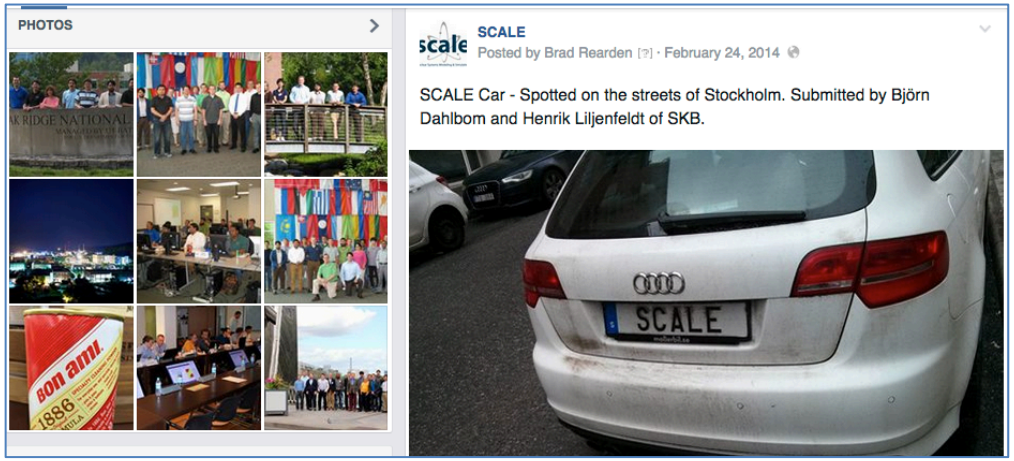
- **Integration in TSUNAMI sensitivity/uncertainty sequences**
  - Capability demonstrated
  - Eigenvalue and generalized perturbation theory sensitivity coefficients with CE physics
- **Planned integration in MAVRIC shielding sequence**
  - Fixed-source shielding problems using hybrid methods, especially for large facility and site modeling
  - Planned for future development

External communication

- SCALE website (ornl.gov/scale)
  - Publications and training information
  - Validation and benchmark reports
  - Downloads
- SCALE Newsletter
- SCALE Users Group Forum
- On-demand assistance (scalehelp@ornl.gov)
- Facebook page facebook.com/SCALE.codes/







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Updated SCALE website: http://scale.ornl.gov

Training course schedule and registration links


SCALE

Upcoming Training Courses

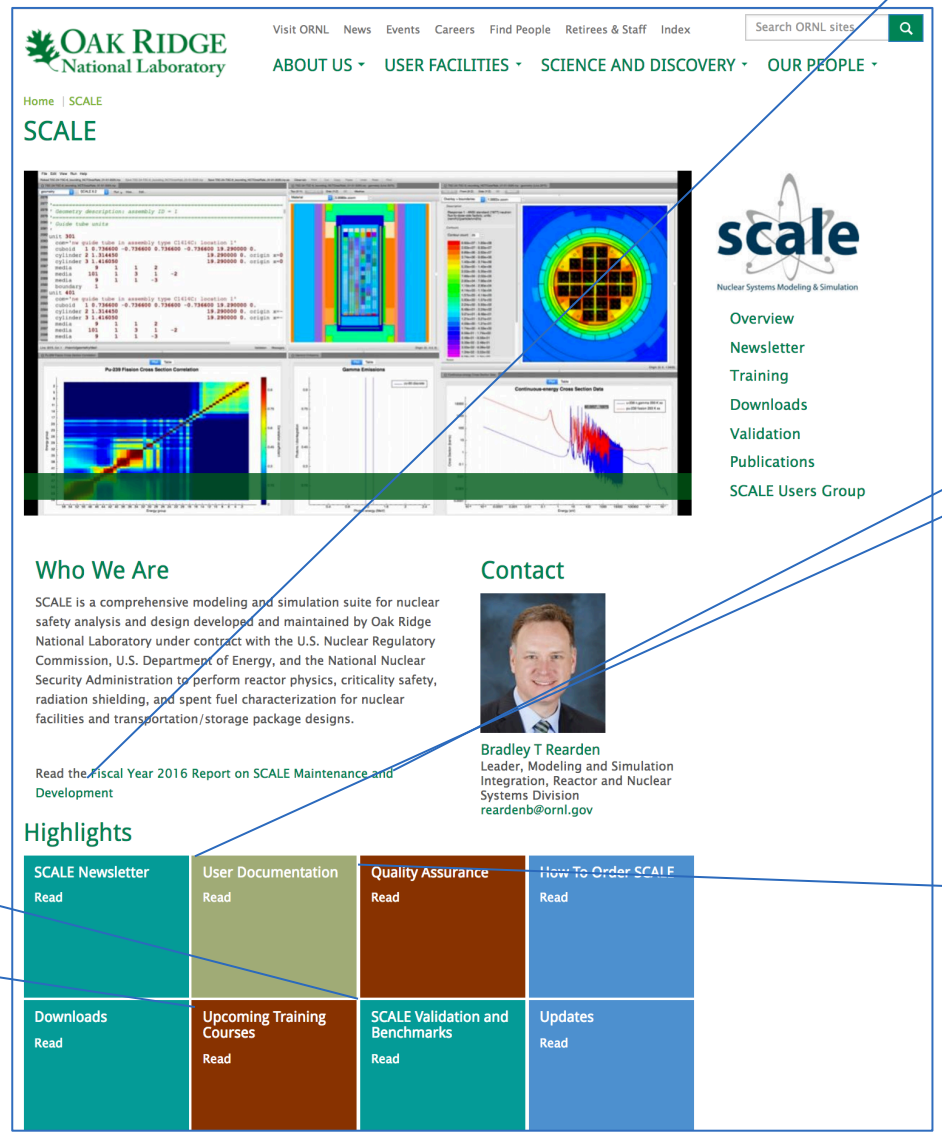
Training is provided by developers and expert users from the SCALE team. Courses provide a review of theory, description of capabilities and limitations of the software, and hands-on experience running problems of varying levels of complexity.

All attendees must be licensed users of SCALE 6.2, which is available from ORNL/RSICC, the OECD/NEA Data Bank in France, and the RIST/NUCIS in Japan. All currently scheduled SCALE Courses are described below.

Course Dates and Descriptions

October 2-6, 2017
SCALE/TRITON Lattice Physics and Depletion Course ($2000*)
Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA
Register Here

SCALE supports a wide range of reactor physics analysis capabilities. SCALE reactor physics calculations couple neutron transport calculations with ORIGEN to simulate the time-dependent transmutation of various materials of interest. TRITON is SCALE's modular reactor physics sequence for a wide variety of system types. Attendees of this course will learn how to use TRITON for depletion analysis. The TRITON training material is centered around using the NEWT 2-D transport module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SCALE

scale
Nuclear Systems Modeling & Simulation

- Overview
- Newsletter
- Training
- Downloads
- Validation
- Publications
- SCALE Users Group

Who We Are

SCALE is a comprehensive modeling and simulation suite for nuclear safety analysis and design developed and maintained by Oak Ridge National Laboratory under contract with the U.S. Nuclear Regulatory Commission, U.S. Department of Energy, and the National Nuclear Security Administration to perform reactor physics, criticality safety, radiation shielding, and spent fuel characterization for nuclear facilities and transportation/storage package designs.

Read the Fiscal Year 2016 Report on SCALE Maintenance and Development

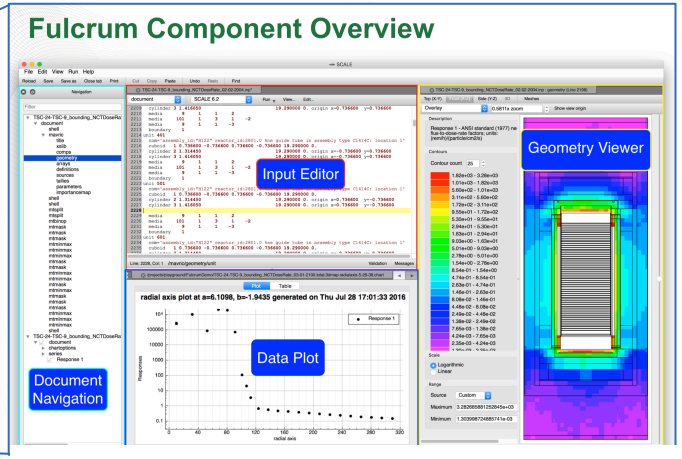
Contact

Bradley T Rearden
Leader, Modeling and Simulation Integration, Reactor and Nuclear Systems Division
reardenb@ornl.gov

Highlights

SCALE Newsletter Read	User Documentation Read	Quality Assurance Read	How To Order SCALE Read
Downloads Read	Upcoming Training Courses Read	SCALE Validation and Benchmarks Read	Updates Read

FY16 Annual Report



User documentation
Fulcrum user interface tutorial

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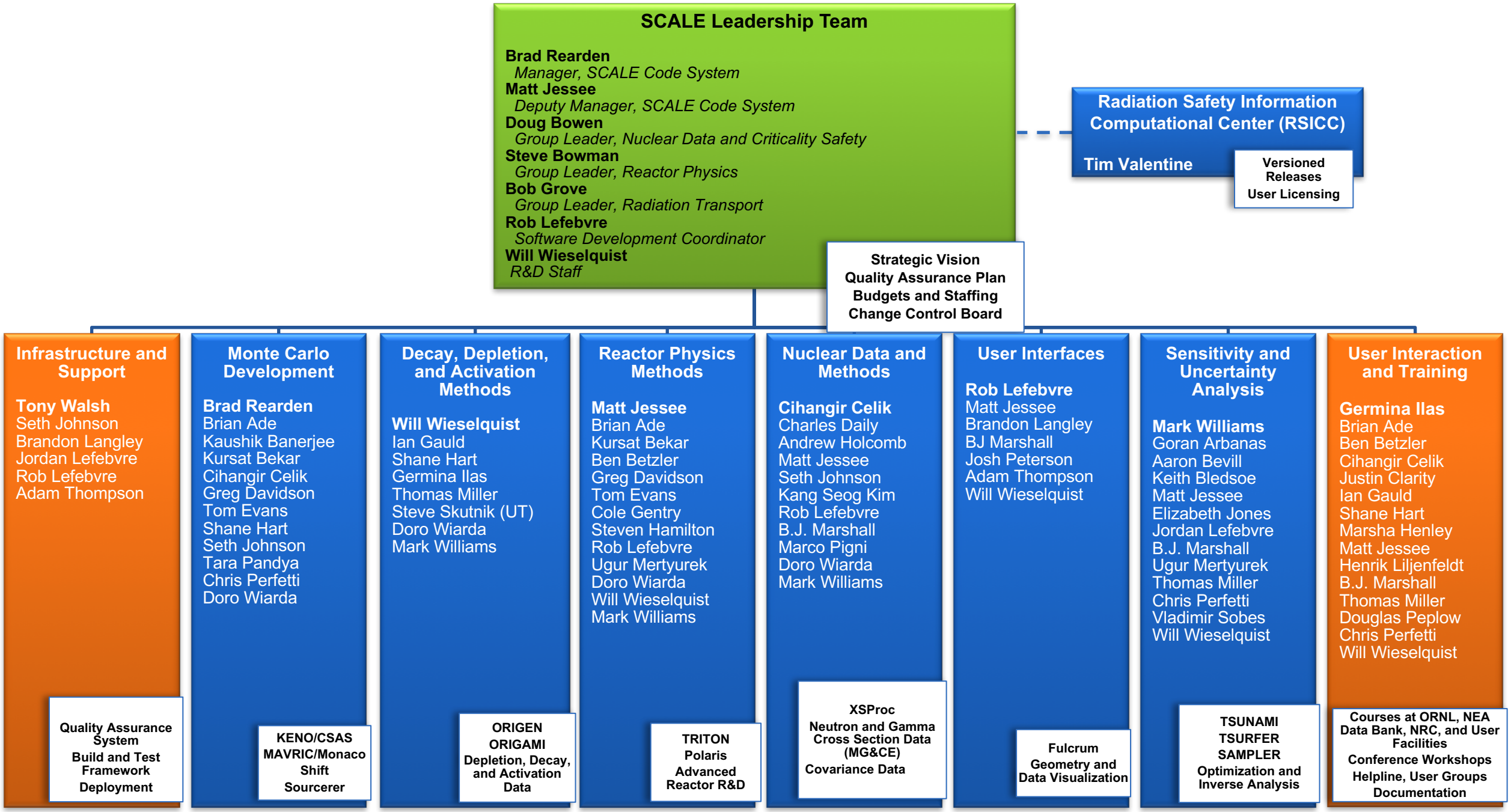
SCALE Leadership Team
Brad Rearden
Manager, SCALE Code System
Matt Jessee
Deputy Manager, SCALE Code System
Doug Bowen
Group Leader, Nuclear Data and Criticality Safety
Steve Bowman
Group Leader, Reactor Physics
Bob Grove
Group Leader, Radiation Transport
Rob Lefebvre
Software Development Coordinator
Will Wieselquist
R&D Staff
Radiation Safety Information Computational Center (RSICC)
Tim Valentine
Versioned Releases
User Licensing
Strategic Vision
Quality Assurance Plan
Budgets and Staffing
Change Control Board
Infrastructure and Support
Tony Walsh
Seth Johnson
Brandon Langley
Jordan Lefebvre
Rob Lefebvre
Adam Thompson
Quality Assurance System
Build and Test Framework
Deployment
Monte Carlo Development
Brad Rearden
Brian Ade
Kaushik Banerjee
Kursat Bekar
Cihangir Celik
Greg Davidson
Tom Evans
Shane Hart
Seth Johnson
Tara Pandya
Chris Perfetti
Doro Wiarda
KENO/CSAS
MAVRIC/Monaco
Shift
Sourcerer
Decay, Depletion, and Activation Methods
Will Wieselquist
Ian Gauld
Shane Hart
Germina Ilas
Thomas Miller
Steve Skutnik (UT)
Doro Wiarda
Mark Williams
ORIGEN
ORIGAMI
Depletion, Decay, and Activation Data
Reactor Physics Methods
Matt Jessee
Brian Ade
Kursat Bekar
Ben Betzler
Greg Davidson
Tom Evans
Cole Gentry
Steven Hamilton
Rob Lefebvre
Ugur Mertyurek
Doro Wiarda
Will Wieselquist
Mark Williams
TRITON
Polaris
Advanced Reactor R&D
Nuclear Data and Methods
Cihangir Celik
Charles Daily
Andrew Holcomb
Matt Jessee
Seth Johnson
Kang Seog Kim
Rob Lefebvre
B.J. Marshall
Marco Pigni
Doro Wiarda
Mark Williams
XSProc
Neutron and Gamma Cross Section Data (MG&CE)
Covariance Data
User Interfaces
Rob Lefebvre
Matt Jessee
Brandon Langley
BJ Marshall
Josh Peterson
Adam Thompson
Will Wieselquist
Fulcrum
Geometry and Data Visualization
Sensitivity and Uncertainty Analysis
Mark Williams
Goran Arbanas
Aaron Bevill
Keith Bledsoe
Matt Jessee
Elizabeth Jones
Jordan Lefebvre
B.J. Marshall
Ugur Mertyurek
Thomas Miller
Chris Perfetti
Vladimir Sobes
Will Wieselquist
TSUNAMI
TSURFER
SAMPLER
Optimization and Inverse Analysis
User Interaction and Training
Germina Ilas
Brian Ade
Ben Betzler
Cihangir Celik
Justin Clarity
Ian Gauld
Shane Hart
Marsha Henley
Matt Jessee
Henrik Liljenfeldt
B.J. Marshall
Thomas Miller
Douglas Peplow
Chris Perfetti
Will Wieselquist
Courses at ORNL, NEA Data Bank, NRC, and User Facilities
Conference Workshops
Helpline, User Groups
Documentation

SCALE 6.2 Team – May 2016

Left to right: Ahmed Ibrahim, Germina Ilas, Brandon Langley, Andrew Holcomb, Shane Hart, Cihangir Celik, Seth Johnson, Matt Jessee, Kevin Clarno, Adam Thompson, Bob Grove, Rob Lefebvre, Greg Davidson, Charles Daily, Alan Icenhour, Barbara Snow, Brian Ade, Brad Rearden, Ben Betzler, B. J. Marshall, Kursat Bekar, Will Wieselquist, Mark Baird, Mark Williams, Georgeta Radulescu, Ron Ellis, Thomas Miller, Dan Ilas, Elizabeth Jones, Cecil Parks, Sheila Walker, Teresa Moore, Marsha Henley, Sandra Poarch, Lester Petrie