The SCALE Code System

Bradley T. Rearden, Ph.D.
Manager, SCALE Code System

scale

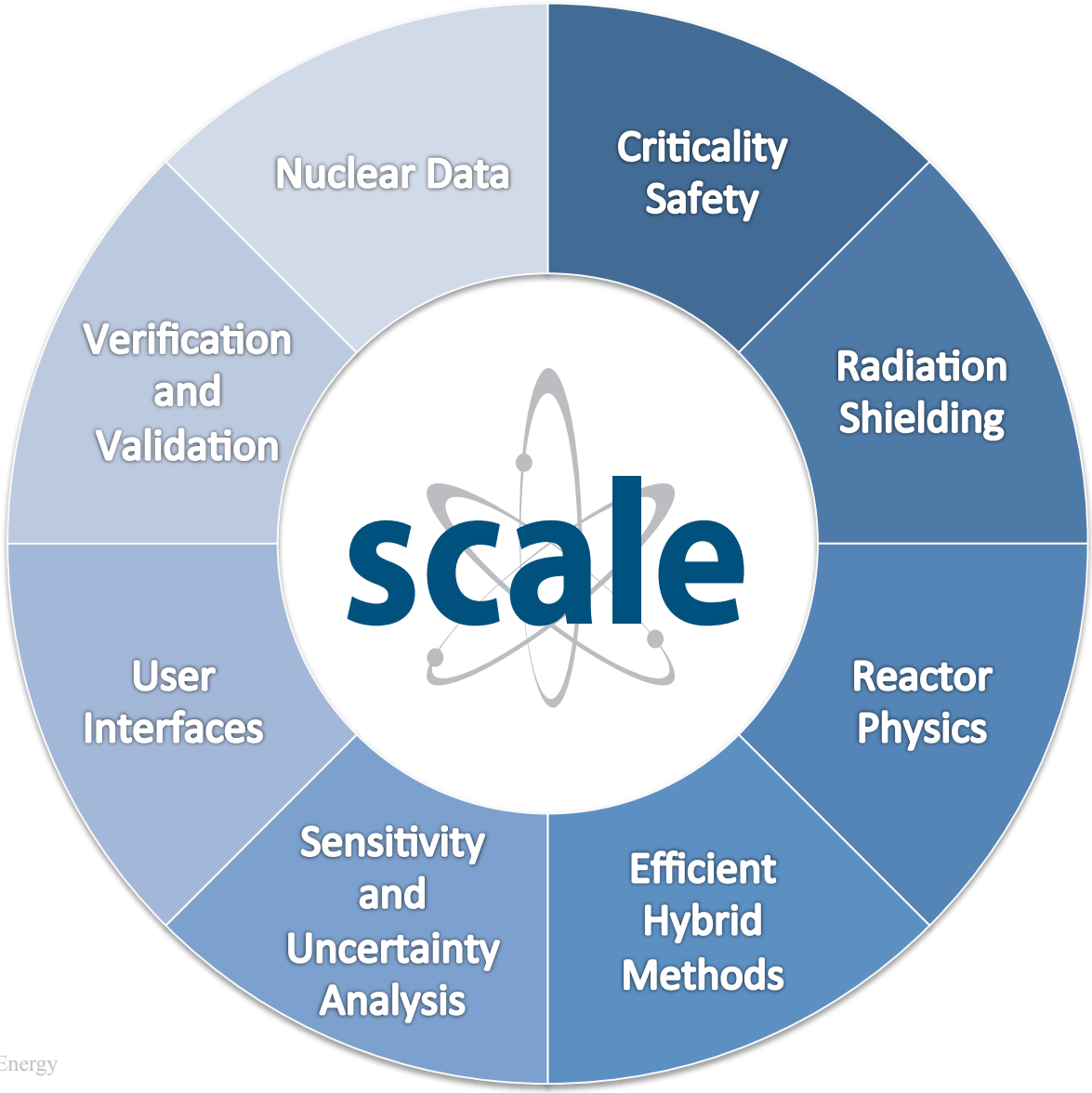
Nuclear Systems Modeling & Simulation

U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

The SCALE Code System

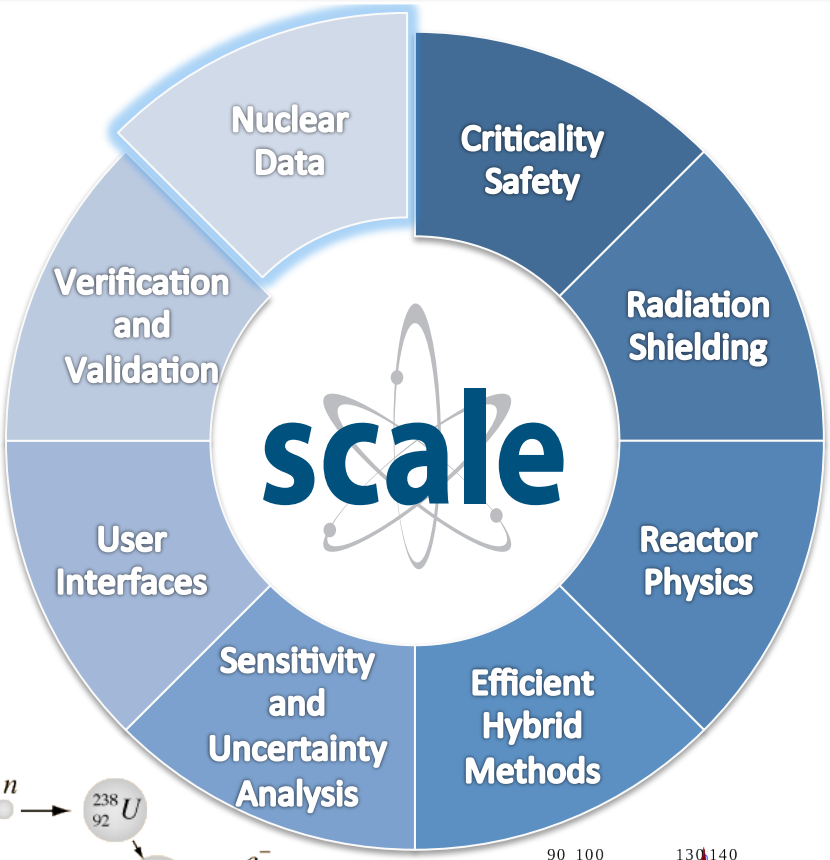
Neutronics and Shielding Analysis For Enabling Nuclear Technology Advancements

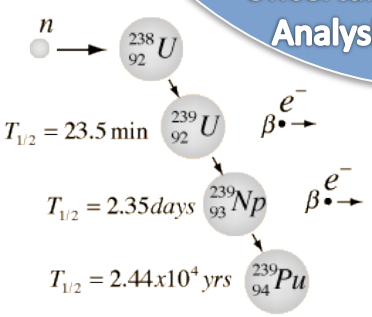


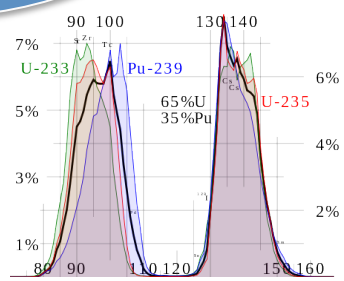
Oak Ridge National Laboratory is managed and operated by UT-Battelle, LLC, for the U.S. Department of Energy under Contract No. DE-AC05-00OR22725. SCALE is sponsored by the U.S. Nuclear Regulatory Commission and the U.S. Department of Energy.

The SCALE Code System

Neutronics and Shielding Analysis For Enabling Nuclear Technology Advancements

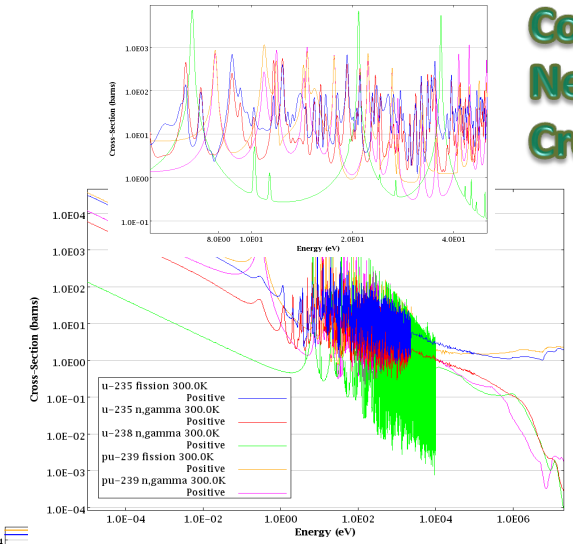






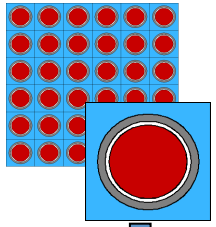
Depletion, Decay, and Activation Data

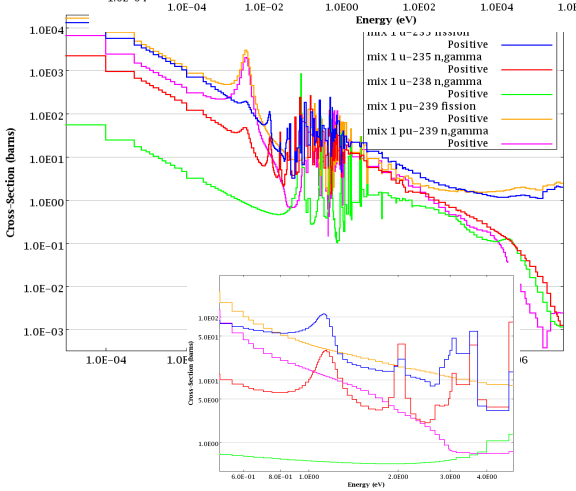
Nuclear Data



Continuous-Energy Neutron and Gamma Cross Sections

Resonance Self-Shielding



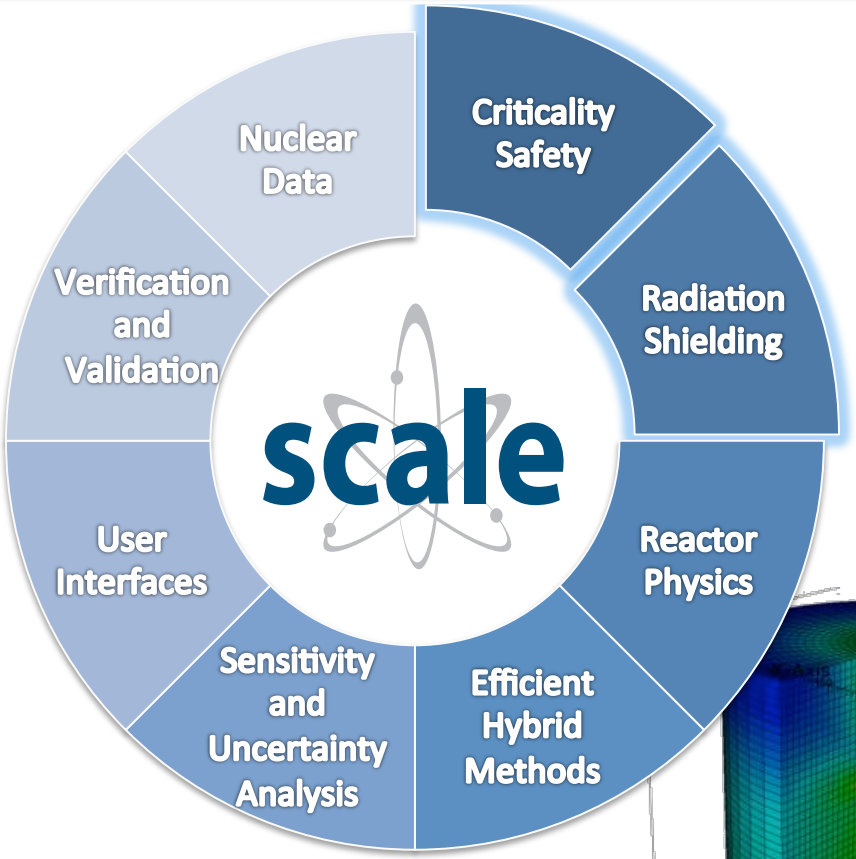


Multigroup Neutron and Gamma Cross Sections

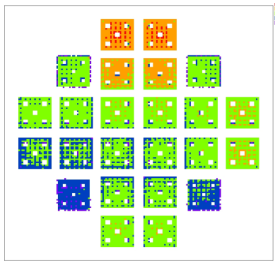
Oak Ridge National Laboratory is managed and operated by UT-Battelle, LLC, for the U.S. Department of Energy under Contract No. DE-AC05-00OR22725. SCALE is sponsored by the U.S. Nuclear Regulatory Commission and the U.S. Department of Energy.

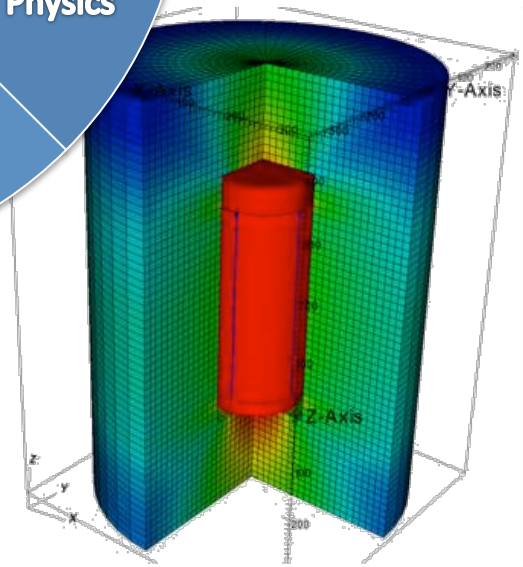
The SCALE Code System

Neutronics and Shielding Analysis For Enabling Nuclear Technology Advancements

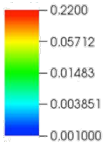


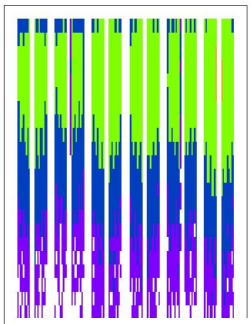
Criticality Safety and Radiation Shielding



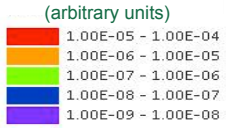


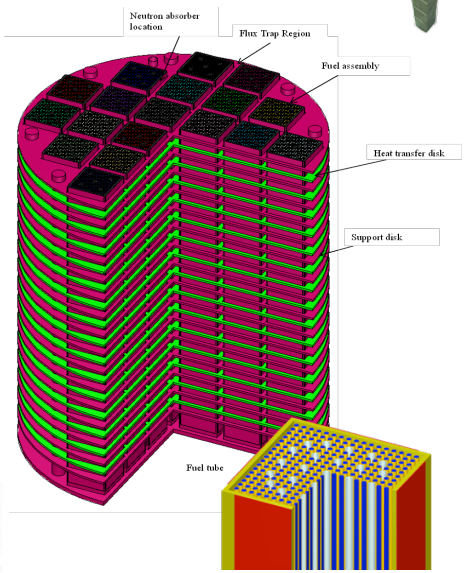
Dose from Used Fuel
(rem/hr)





Fission Distribution in Used Fuel
(arbitrary units)





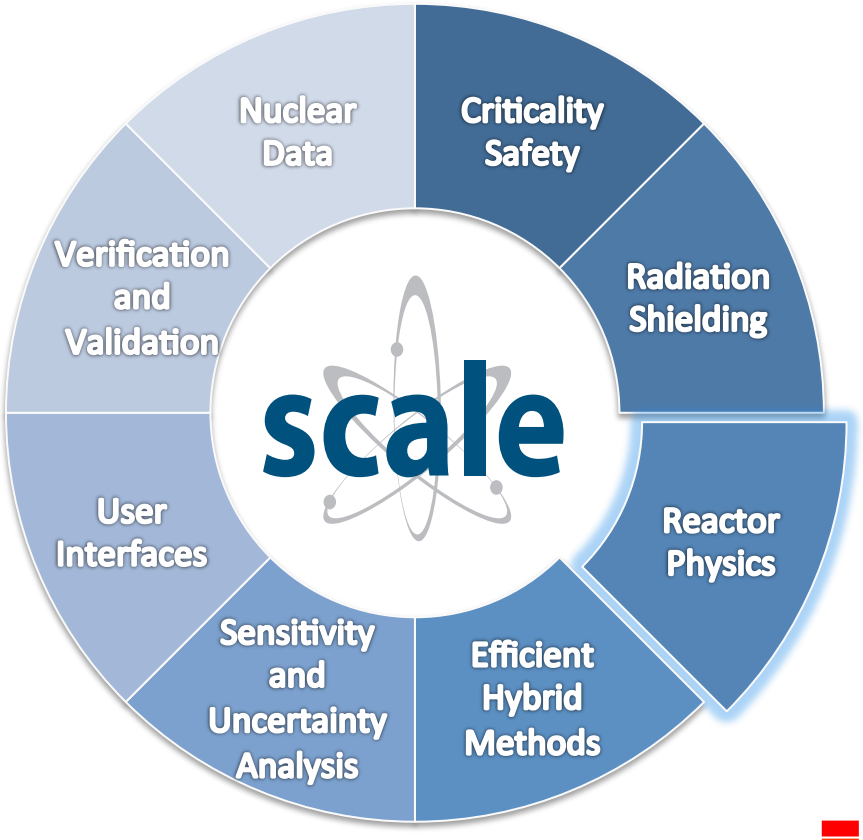
As-loaded used fuel cask

High-Fidelity Monte Carlo Methods

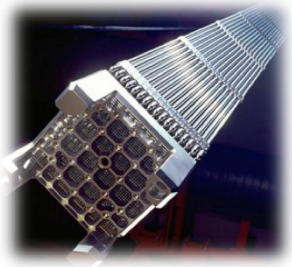
Oak Ridge National Laboratory is managed and operated by UT-Battelle, LLC, for the U.S. Department of Energy under Contract No. DE-AC05-00OR22725. SCALE is sponsored by the U.S. Nuclear Regulatory Commission and the U.S. Department of Energy.

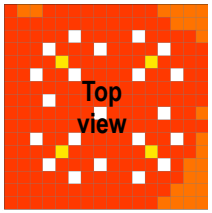
The SCALE Code System

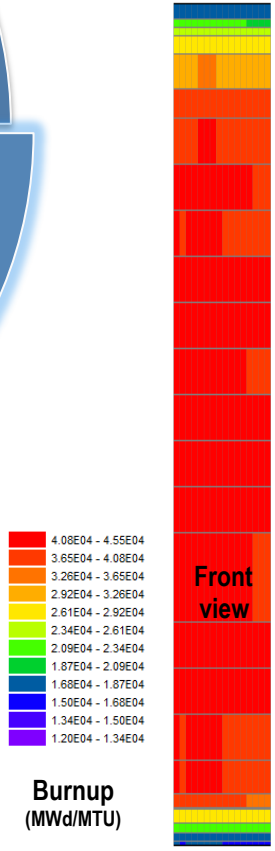
Neutronics and Shielding Analysis For Enabling Nuclear Technology Advancements



Reactor Physics and Used Fuel Characterization

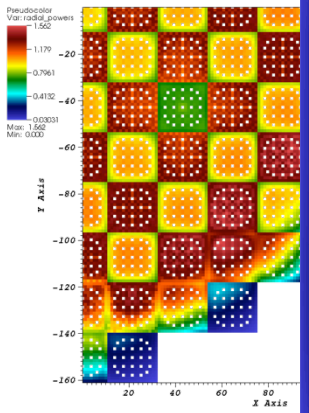


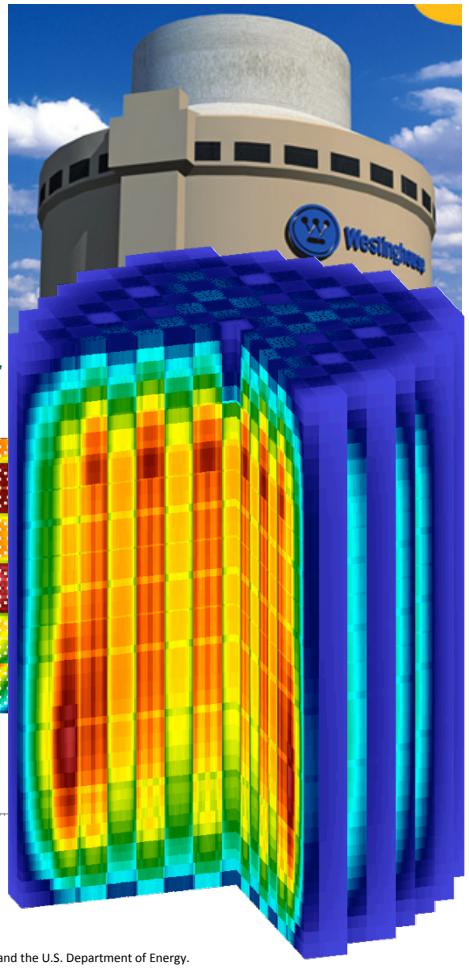




Pin-by-pin burnup of used nuclear fuel

Power distribution for AP-1000 reactor

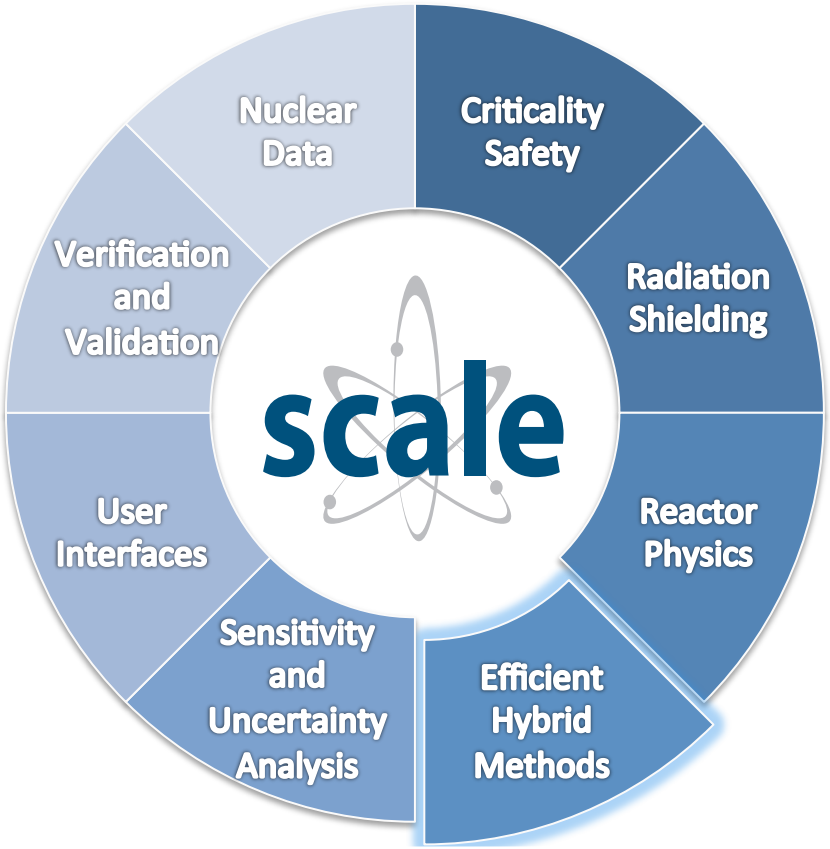




Oak Ridge National Laboratory is managed and operated by UT-Battelle, LLC, for the U.S. Department of Energy under Contract No. DE-AC05-00OR22725. SCALE is sponsored by the U.S. Nuclear Regulatory Commission and the U.S. Department of Energy.

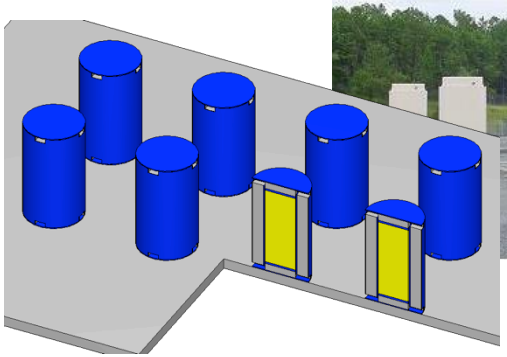
The SCALE Code System

Neutronics and Shielding Analysis For Enabling Nuclear Technology Advancements

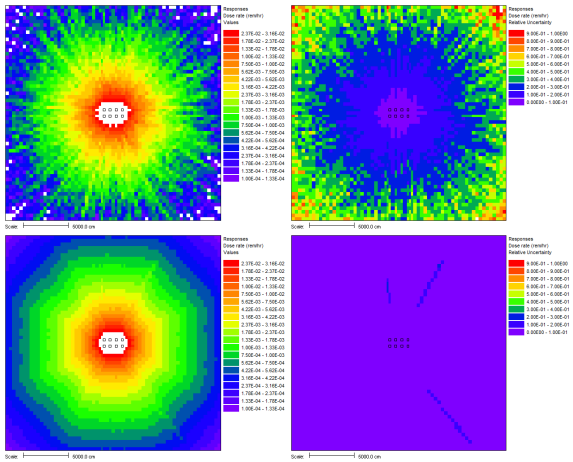


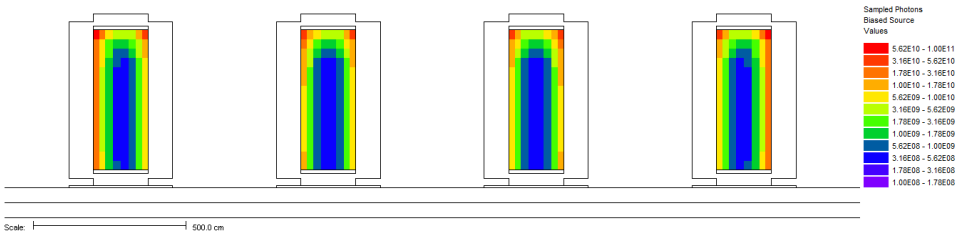
Efficient Hybrid Methods

Dose analysis for used nuclear fuel storage



	Dose Rate (rem/hr)	Relative Uncertainty
Analog		
Hybrid (Same run time)		



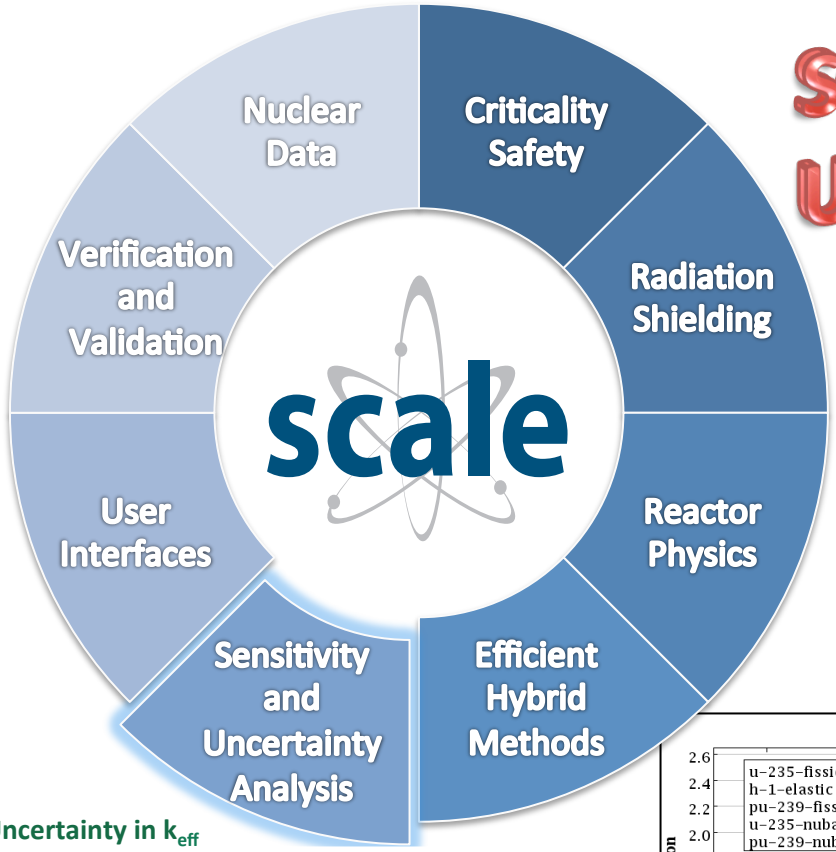


Oak Ridge National Laboratory is managed and operated by UT-Battelle, LLC, for the U.S. Department of Energy under Contract No. DE-AC05-00OR22725. SCALE is sponsored by the U.S. Nuclear Regulatory Commission and the U.S. Department of Energy.

The SCALE Code System

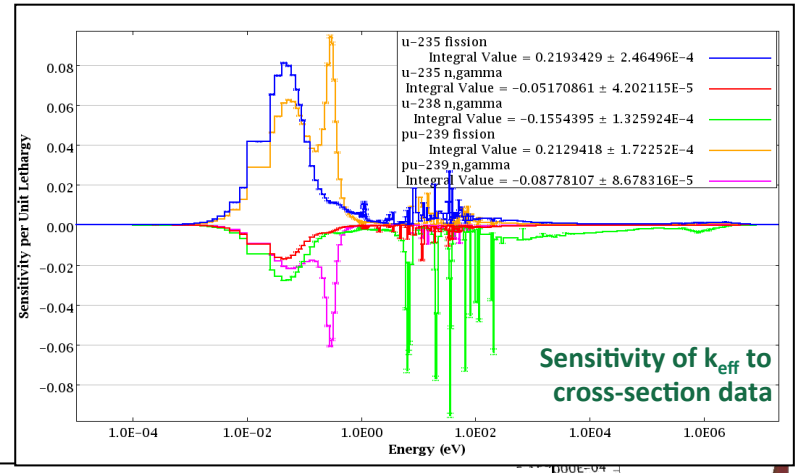
Neutronics and Shielding Analysis For Enabling Nuclear Technology Advancements

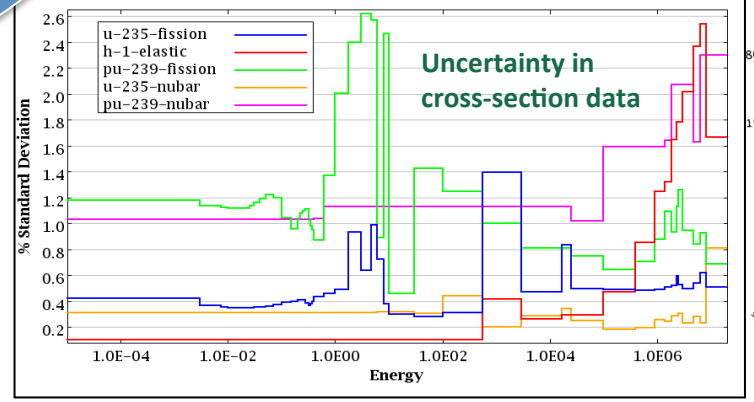
OAK RIDGE National Laboratory

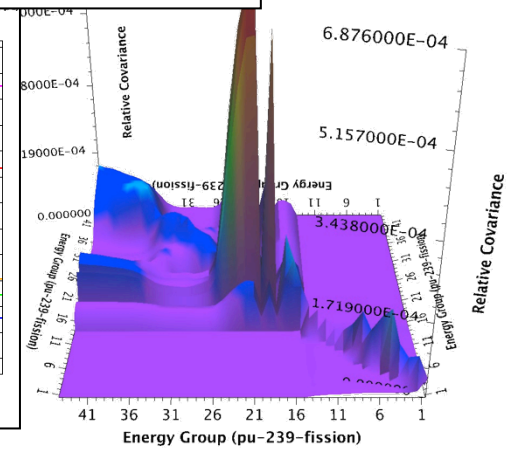


Sensitivity and Uncertainty Analysis

Uncertainty Assessment for Used Nuclear Fuel







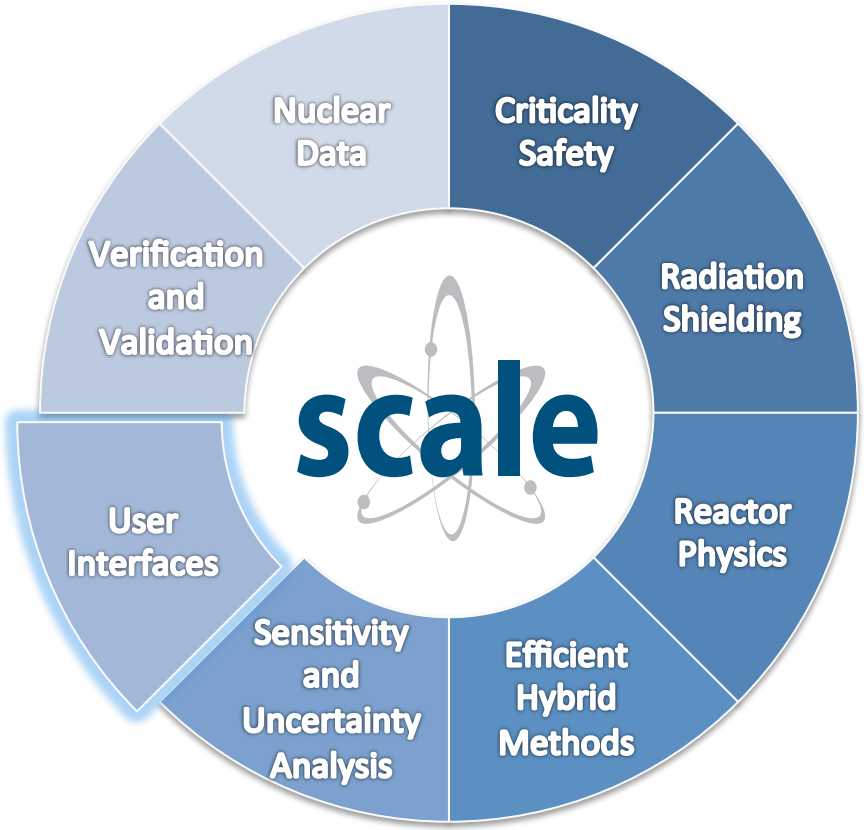
Uncertainty in k_{eff}

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
^{239}Pu fission	^{239}Pu n,gamma	1.2261E-01 ± 4.3564E-06

Oak Ridge National Laboratory is managed and operated by UT-Battelle, LLC, for the U.S. Department of Energy under Contract No. DE-AC05-00OR22725. SCALE is sponsored by the U.S. Nuclear Regulatory Commission and the U.S. Department of Energy.

The SCALE Code System

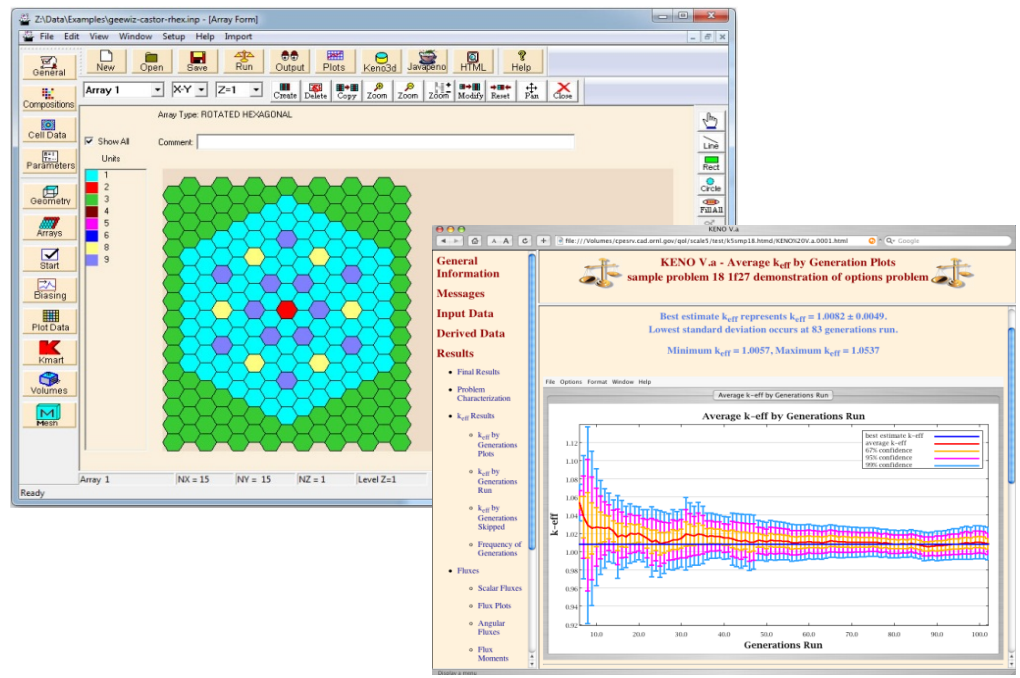
Neutronics and Shielding Analysis For Enabling Nuclear Technology Advancements



User Interfaces

Convenient user interfaces

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

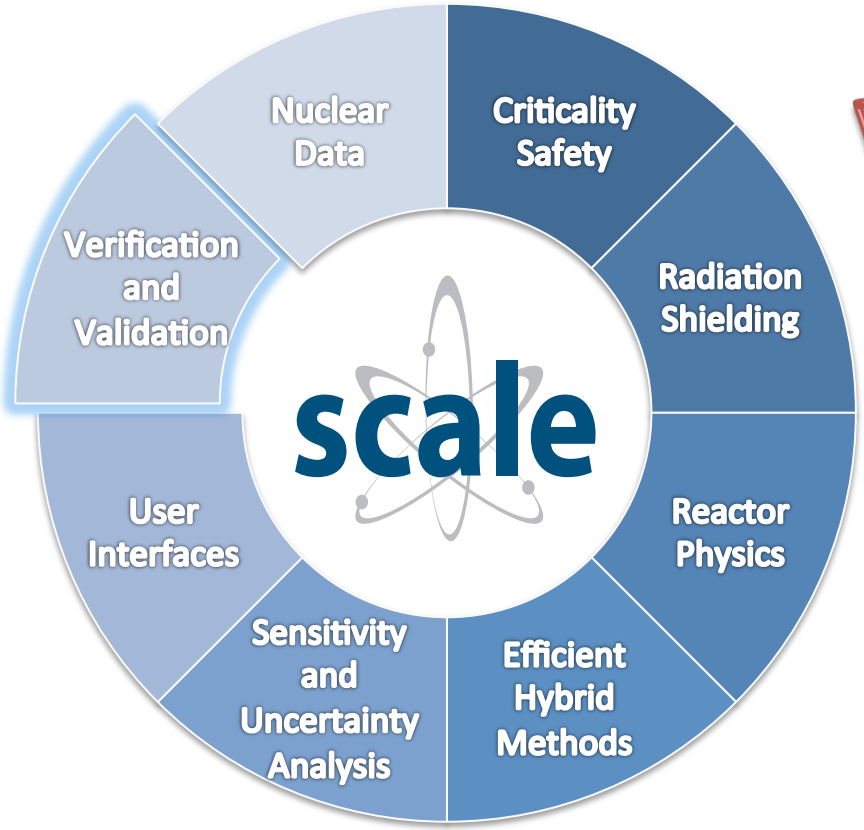


Oak Ridge National Laboratory is managed and operated by UT-Battelle, LLC, for the U.S. Department of Energy under Contract No. DE-AC05-00OR22725. SCALE is sponsored by the U.S. Nuclear Regulatory Commission and the U.S. Department of Energy.

The SCALE Code System

Neutronics and Shielding Analysis For Enabling Nuclear Technology Advancements

OAK RIDGE National Laboratory

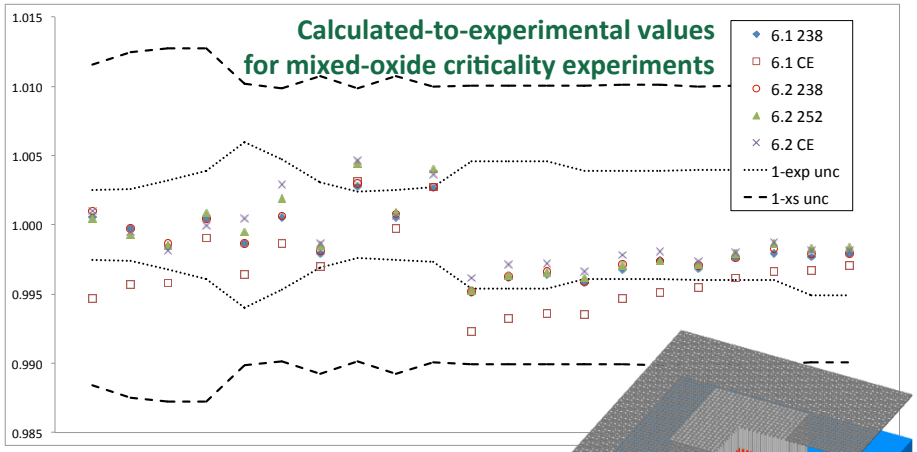


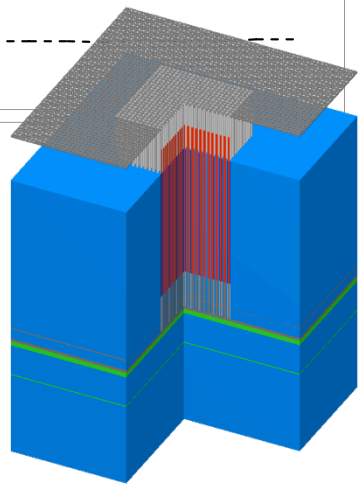
Verification and Validation

Validation

400 criticality and shielding benchmarks

125 isotopic assays samples





MIX-COMP-THERM-004
Critical Experiment

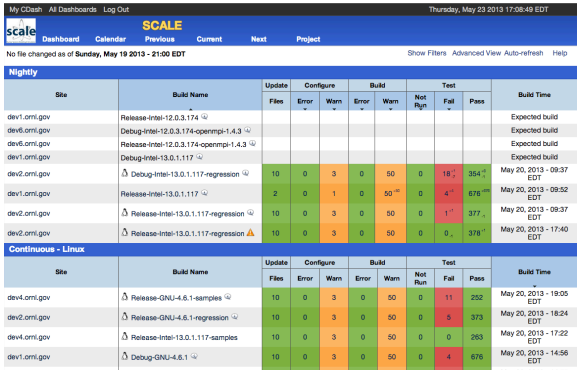
Verification

6300 transmission tests

5000 infinite medium tests

2000 unit/regression tests

70,000 tests/day on multiple platforms



My CDash All Dashboards Log Out — Thursday, May 23 2013 17:08:49 EDT

SCALE — Dashboard Calendar Previous Current Next Project

No file changed as of Sunday, May 19 2013 - 21:00 EDT — Show Filters Advanced View Auto-refresh Help

Nightly

Site	Build Name	Update	Configure		Build		Test			Build Time
		Files	Error	Warn	Error	Warn	Not Run	Fail	Pass	
dev1.ornl.gov	Release-Intel-12.0.3.174									Expected build
dev6.ornl.gov	Debug-Intel-12.0.3.174-openmpi-1.4.3									Expected build
dev6.ornl.gov	Release-Intel-12.0.3.174-openmpi-1.4.3									Expected build
dev1.ornl.gov	Debug-Intel-13.0.1.117									Expected build
dev2.ornl.gov	Debug-Intel-13.0.1.117-regression	10	0	3	0	50	0	18	354	May 20, 2013 - 09:37 EDT
dev1.ornl.gov	Release-Intel-13.0.1.117	2	0	1	0	50	0	4	676	May 20, 2013 - 09:52 EDT
dev2.ornl.gov	Release-Intel-13.0.1.117-regression	10	0	3	0	50	0	1	377	May 20, 2013 - 09:37 EDT
dev2.ornl.gov	Release-Intel-13.0.1.117-regression	10	0	3	0	50	0	0	378	May 20, 2013 - 17:40 EDT

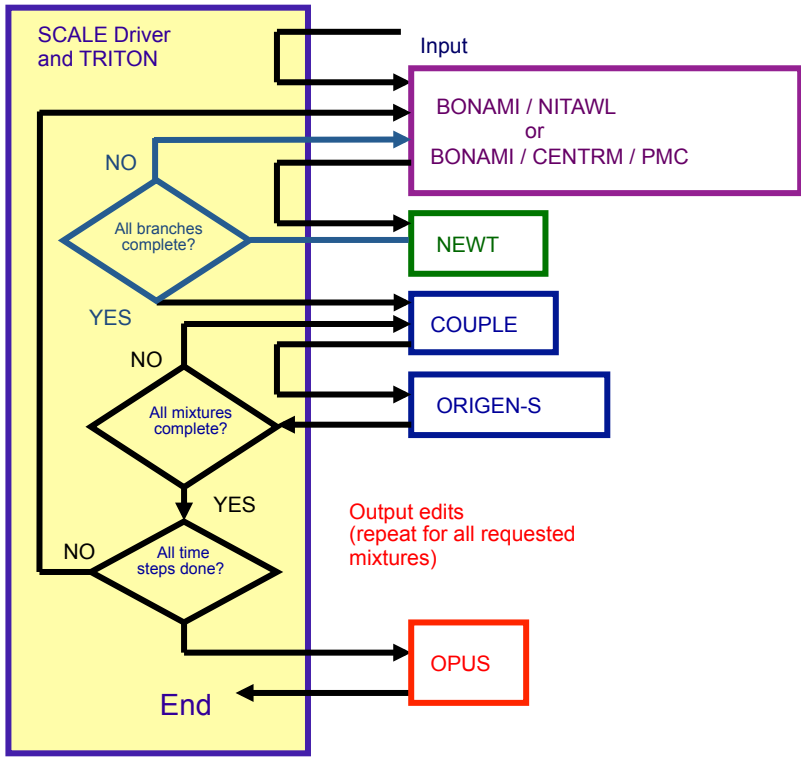
Continuous - Linux

Site	Build Name	Update	Configure		Build		Test			Build Time
		Files	Error	Warn	Error	Warn	Not Run	Fail	Pass	
dev4.ornl.gov	Release-GNU-4.6.1-samples	10	0	3	0	50	0	11	252	May 20, 2013 - 19:05 EDT
dev2.ornl.gov	Release-GNU-4.6.1-regression	10	0	3	0	50	0	5	373	May 20, 2013 - 18:24 EDT
dev4.ornl.gov	Release-Intel-13.0.1.117-samples	10	0	3	0	50	0	0	263	May 20, 2013 - 17:22 EDT
dev1.ornl.gov	Debug-GNU-4.6.1	10	0	3	0	50	0	4	676	May 20, 2013 - 14:56 EDT

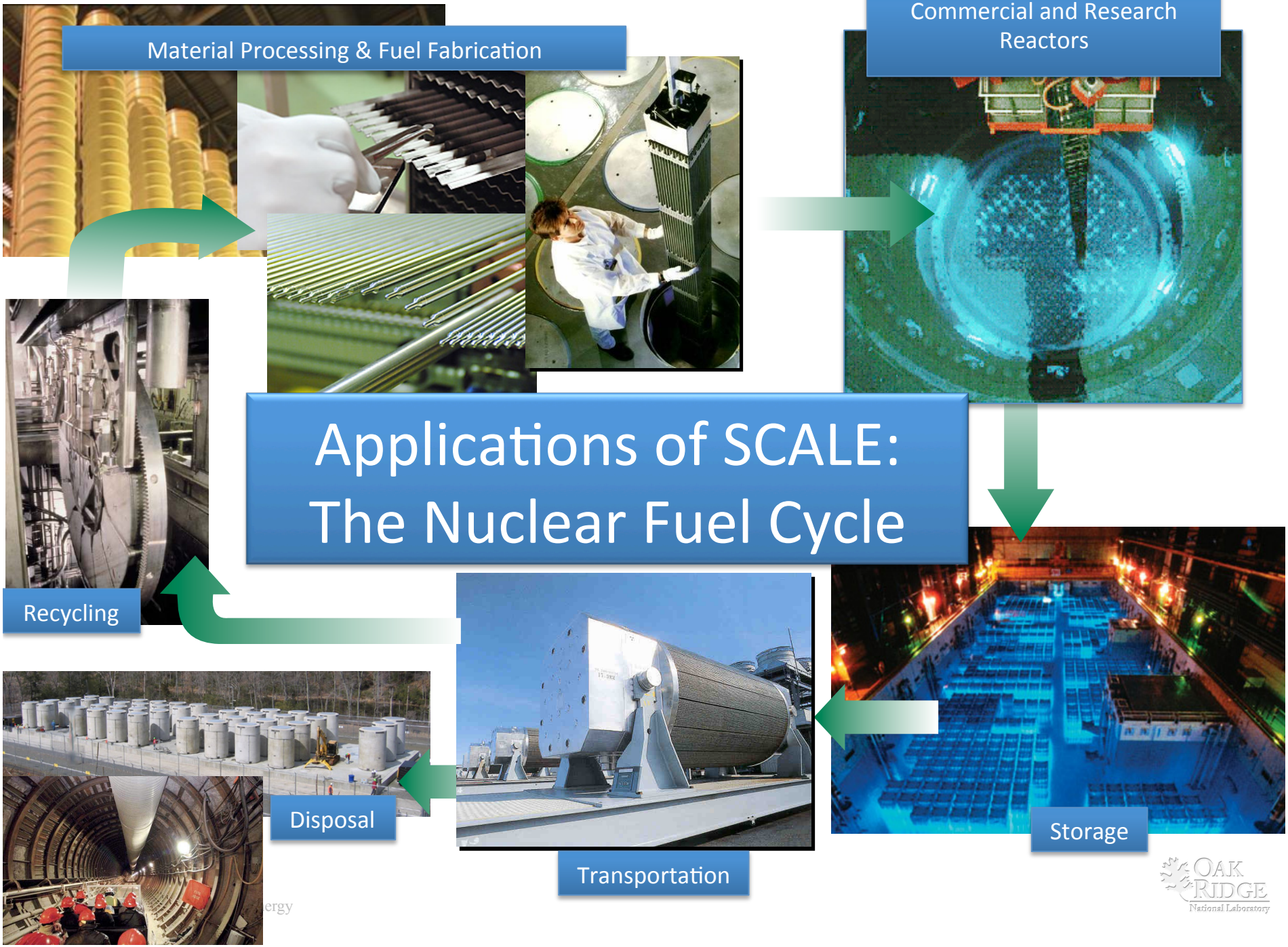
Oak Ridge National Laboratory is managed and operated by UT-Battelle, LLC, for the U.S. Department of Energy under Contract No. DE-AC05-00OR22725. SCALE is sponsored by the U.S. Nuclear Regulatory Commission and the U.S. Department of Energy.

Design of SCALE Code System

- Design focus:
  - Ease of use by novice and occasional users
  - State-of-the-art computational methods
- Modular system of well-established programs and data
- Automated calculational sequences handle data processing and execution of modules
- Engineering input parameters with keywords and GUIs
- System maintained/enhanced under software QA plan



Applications of SCALE: The Nuclear Fuel Cycle



ergy
OAK RIDGE National Laboratory

SCALE 0.0 – SCALE 4.4a

1980 – 2000

Established for Nuclear Regulatory Commission

Provides an independent rigorous nuclear safety analysis capability for out-of-reactor license reviews

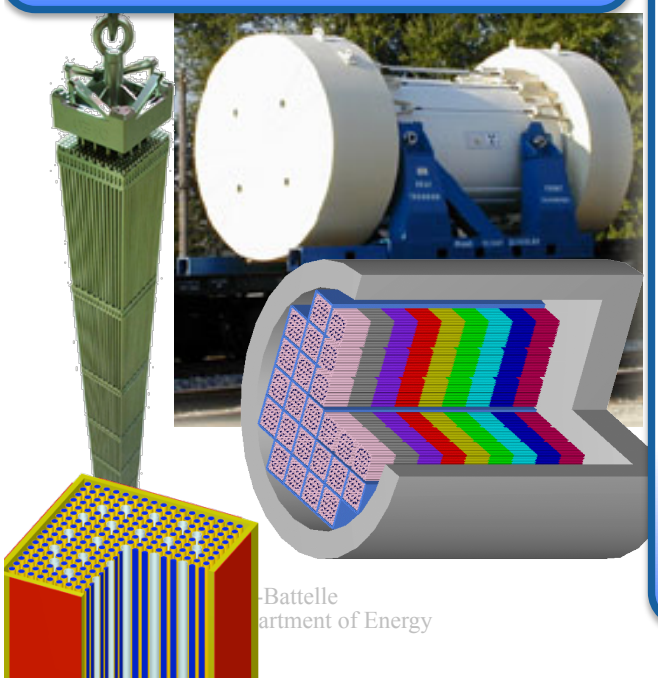
Key Capabilities

Criticality safety

Radiation source term characterization

Radiation shielding

Heat transfer



-Battelle
artment of Energy

scale

Nuclear Systems Modeling & Simulation

SCALE 5.0 – SCALE 6.1

2004 – 2011

Expanded Capabilities to Address a Broader Class of Problems & Sponsors

Reactor physics

Shielding analysis with automated variance reduction

Sensitivity and uncertainty analysis

High-fidelity criticality safety in continuous energy

Graphical user interfaces and visualization tools

Expanding Use

Used in 51 nations by regulators, industry, utilities, and researchers

SCALE 6.2 – SCALE 7.0

2012 –

Increased Fidelity, Infrastructure Modernization, Parallelization

Solutions for extremely complex systems

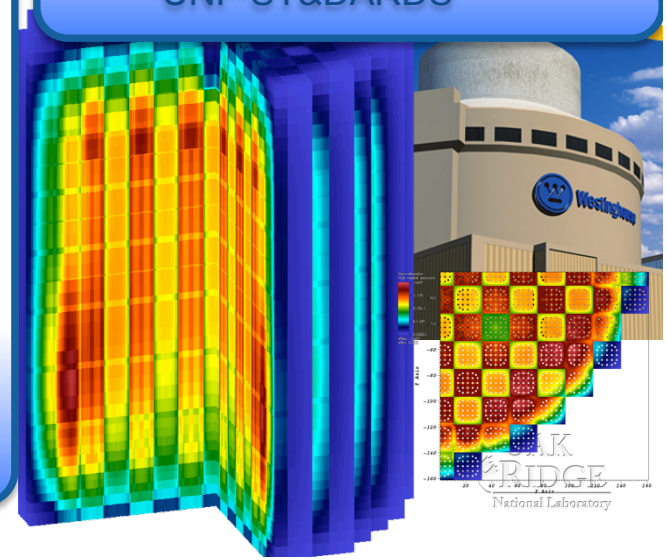
High-fidelity shielding, depletion and sensitivity analysis in continuous energy

Scalable from laptops to massively parallel machines

Integration with other projects:

Consortium for the Advanced Simulation of LWRs (CASL)

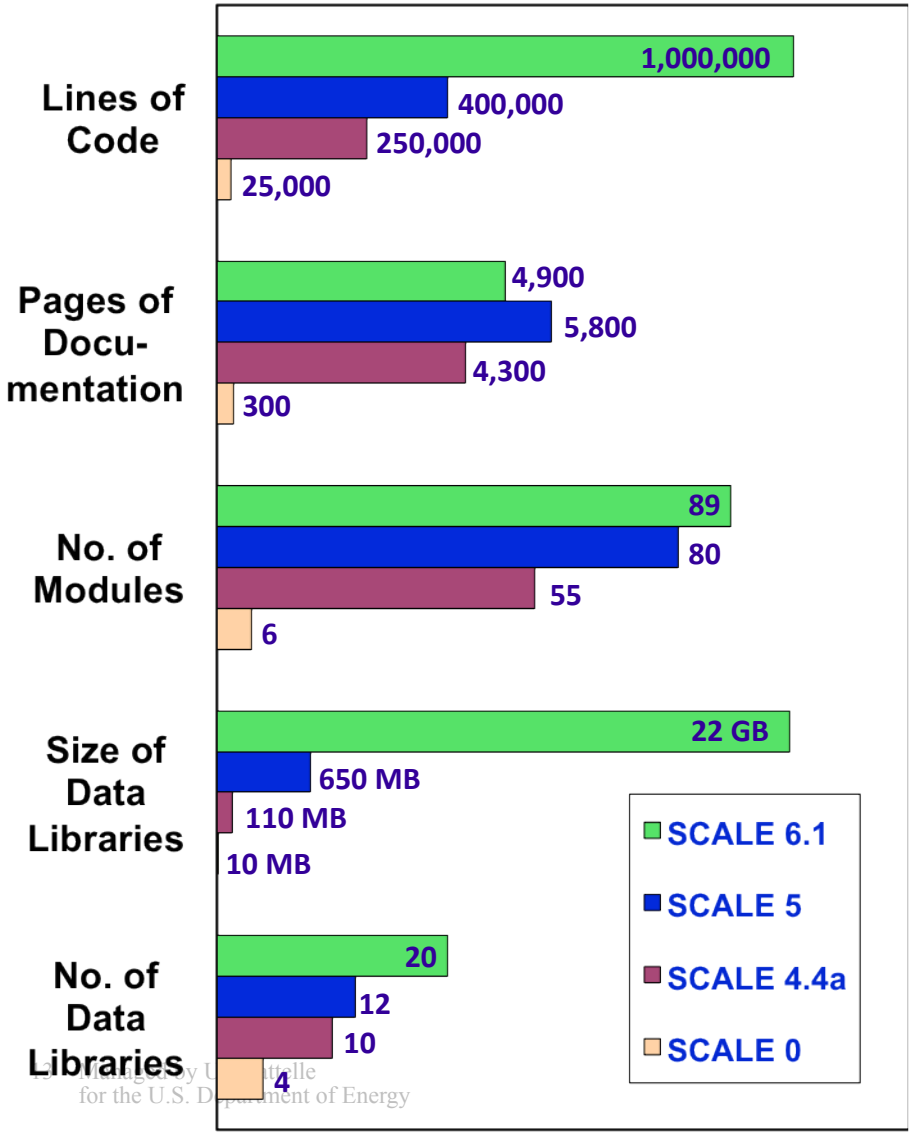
UNF-ST&DARDS

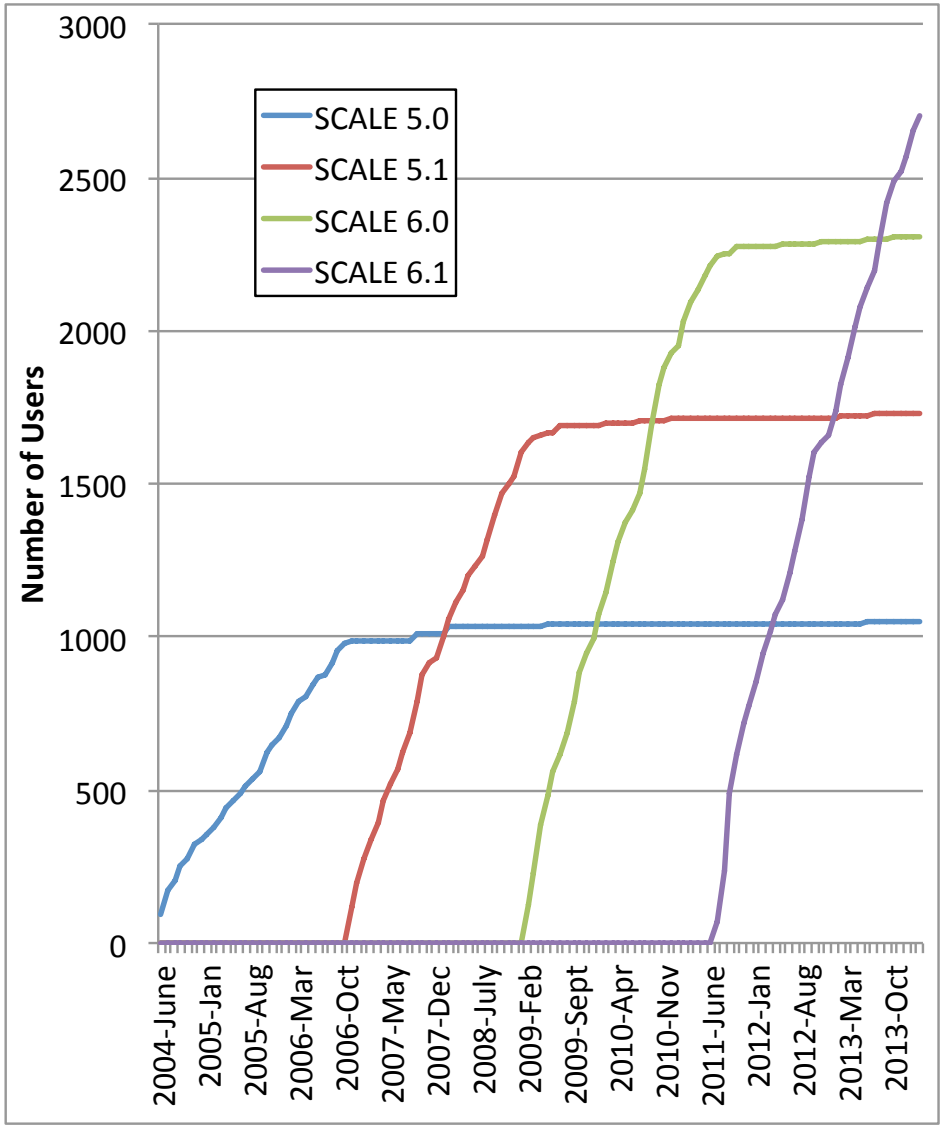


OAK RIDGE National Laboratory

Growth of SCALE

Expanded capabilities, expanded user base





UT-Battelle
Managed by UT-Battelle
for the U.S. Department of Energy

5600+ Users
In 51 Nations

Regulators
Industry
Utilities
Research Laboratories
Government Agencies
Universities

Distributed by RSICC (USA), NEA Data Bank (France) and RIST (Japan)

The SCALE Code System

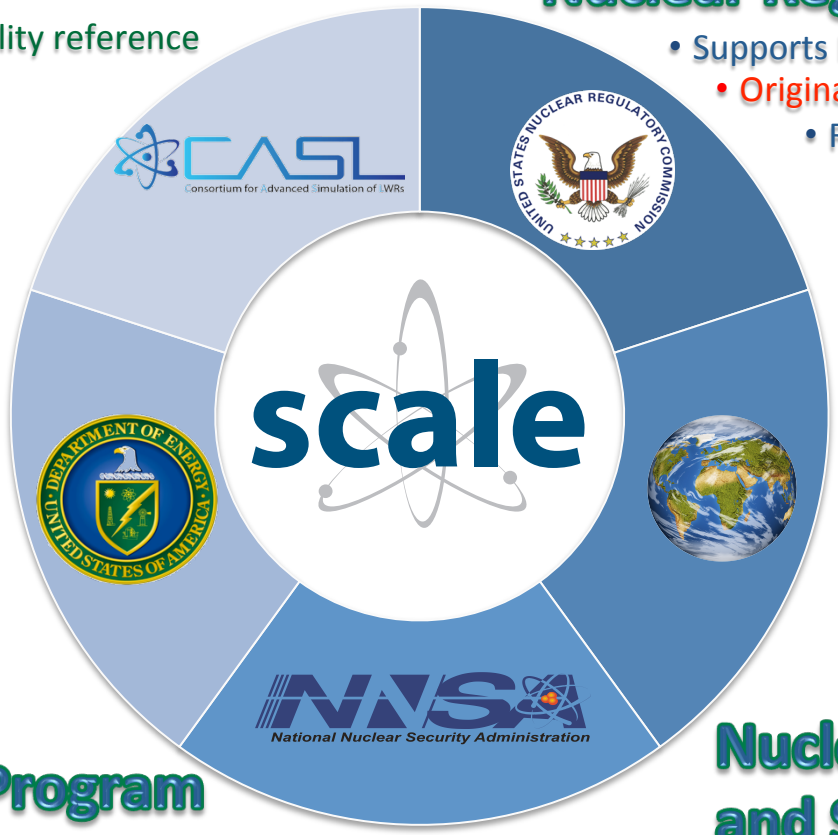
Neutronics and Shielding Analysis For Enabling Nuclear Technology Advancements

CASL

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

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



DOE Used Fuel Disposition

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

Global Distribution

- 5600 users in 51 nations
- Regulators
- Industry
- Research and Development

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 Nonproliferation and Safeguards

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

Oak Ridge National Laboratory is managed and operated by UT-Battelle, LLC, for the U.S. Department of Energy under Contract No. DE-AC05-00OR22725. SCALE is sponsored by the U.S. Nuclear Regulatory Commission and the U.S. Department of Energy.

SCALE 6.2 Team

SCALE Leadership Team

Brad Rearden
Manager, SCALE Code System

Steve Bowman
Group Leader, Reactor Physics

Mike Dunn
Group Leader, Nuclear Data and Criticality Safety

Bob Grove
Group Leader, Radiation Transport

Mark Williams
Distinguished R&D Staff

Matt Jessee
Senior R&D Staff

Douglas Peplow
Senior R&D Staff

Development Team

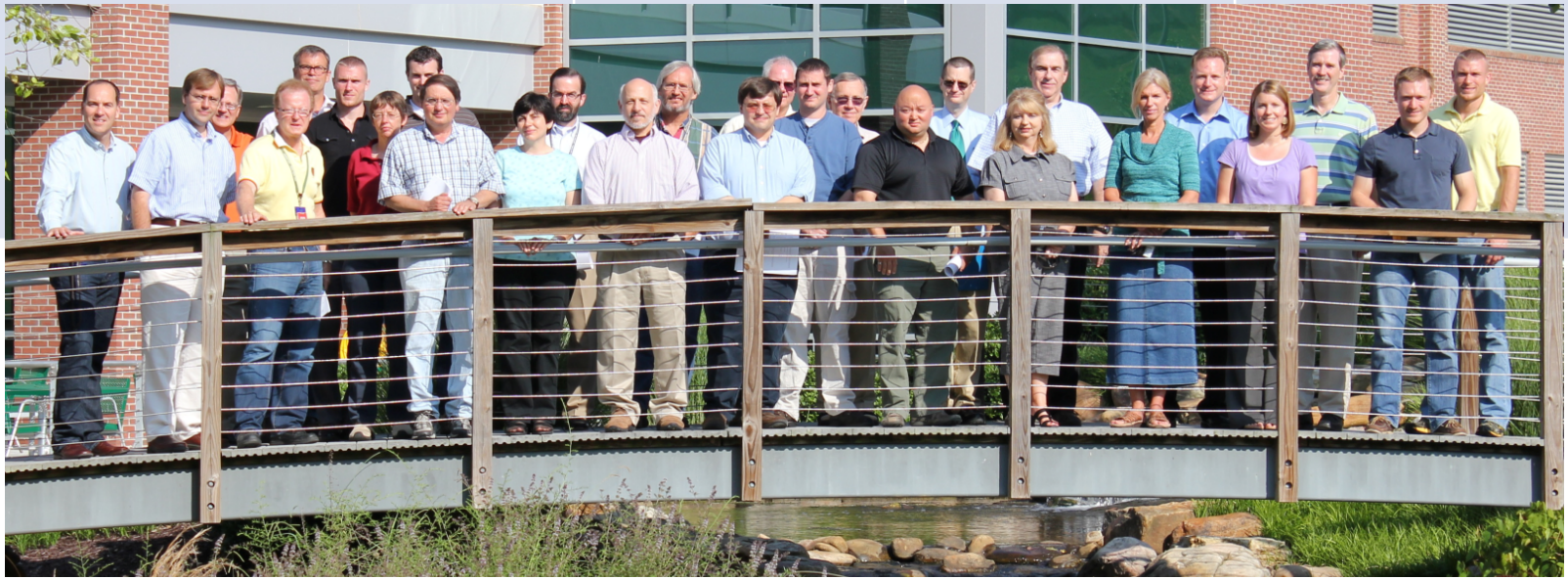
Goran Arbanas
Kursat Bekar
Keith Bledsoe
Cihangir Celik
Kevin Clarno
Greg Davidson
Tom Evans
Ian Gauld
Shane Hart
Ahmad Ibrahim
Matt Jessee
Seth Johnson
Kang-Seog Kim
Jordan Lefebvre
Rob Lefebvre
Ugur Mertyurek
Tara Pandya
Douglas Peplow
Chris Perfetti
Lester Petrie
Marco Pigni
Adam Thompson
Doro Wiarda
Will Wieselquist
Mark Williams

Application Testing/QA Reviewers

Brian Ade
Mark Baird
Kaushik Banerjee
Doug Bowen
Justin Clarity
Charles Daily
Ron Ellis
Matthew Francis
Andrew Godfrey
Jianwei Hu
Dan Ilas
Germina Ilas
B.J. Marshall
Don Mueller
Thomas Miller
Bruce Patton
Josh Peterson
Jeff Powers
Georgeta Radulescu
Joel Risner
John Scaglione
Eva Sunny
Dean Wang
Andy Worrall

Infrastructure / Documentation

Paul Miller
Sandra Poarch
Hannah Turpin
Sheila Walker



Oak Ridge National Laboratory

More Information

- Training courses
  - ~10 weeks/year
- Workshops
  - Presented free of charge at conferences
- SCALE Website (scale.ornl.gov)
  - Publications/Training
  - Validation and benchmark reports
  - Downloads
- SCALE Newsletter
- SCALE Users Group forum
- On-demand assistance
  - scalehelp@ornl.gov
- Facebook page
  - facebook.com/scale.codes

Questions?

Nuclear Systems Modeling & Simulation

Brad Rearden
Manager, SCALE Code System
reardenb@ornl.gov