The SCALE Code System

2007 ANS/ENS International Meeting

Session Organizer: Steve Bowman

Session Chair: Mark Williams

Sponsored by: RPSD, NCSD, and YMG

You are invited to the:

Monte Carlo SCALE Tutorial

Tomorrow morning

8:30 – 11:30

Featured topics:

KENO V.a Criticality Safety

TSUNAMI Sensitivity & Uncertainty

TRITON/KENO Monte Carlo Depletion

Overview of the SCALE Code System

Steve Bowman

SCALE Project Leader

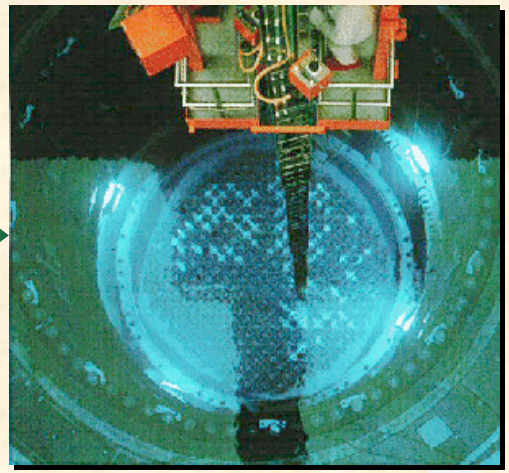
Oak Ridge National Laboratory

Introduction to SCALE

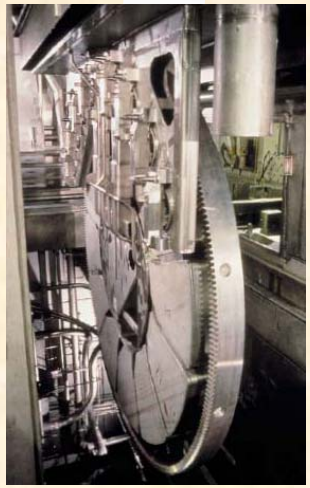
- **Standardized Computer Analyses for Licensing Evaluation**
  - **Modular computer software system for analysis of nuclear facilities and transport/storage packages with fissile and/or radioactive materials**
- **SCALE is a modular code system that uses automated sequences to provide:**
  - **Problem-dependent cross-section processing**
  - **Reactor / lattice physics analysis**
  - **Criticality safety analysis**
  - **Sensitivity/uncertainty analysis**
  - **Radiation shielding analysis**
  - **Spent fuel and HLW characterization**
  - **Advanced 3-D visualization and automated user interface**
- **Distributed and used worldwide for > 25 years**

Material processing and fabrication

Commercial and research reactors

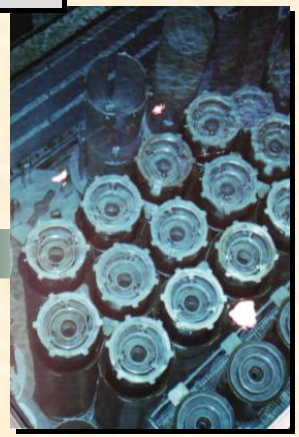


SCALE is used worldwide (~30 nations) by regulators, vendors, utilities, cask designers, R&D labs, safeguard agencies



Recycling

SCALE provides mature and flexible software for nuclear analysis of nearly any application within the nuclear fuel cycle



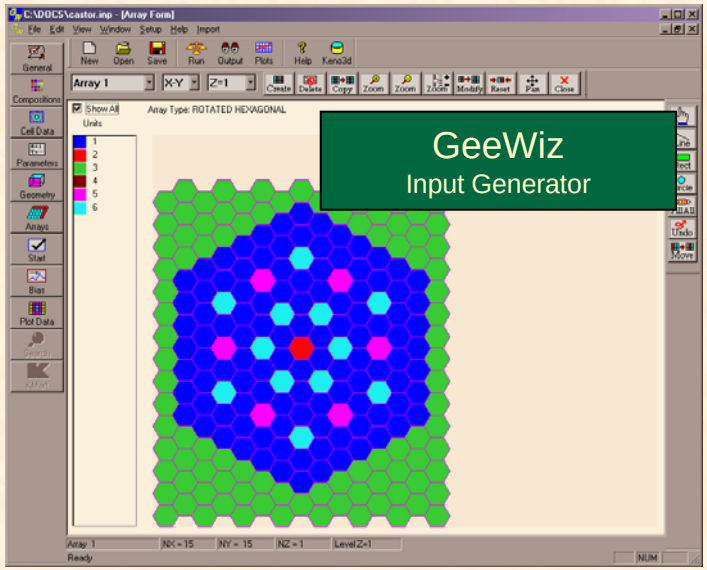
Storage

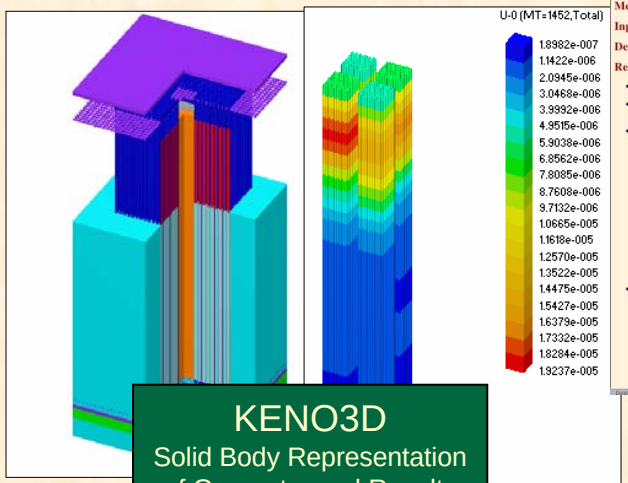
Transport

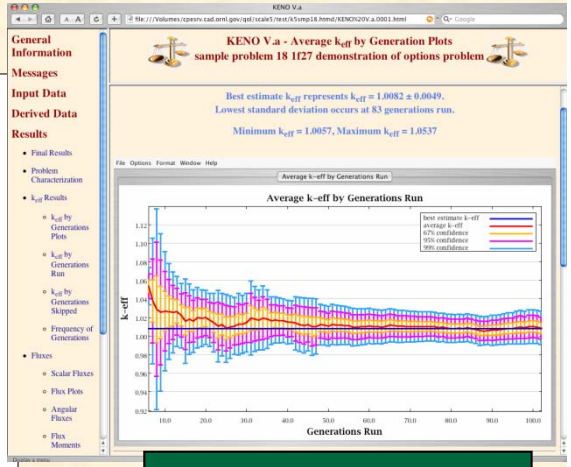
D&D

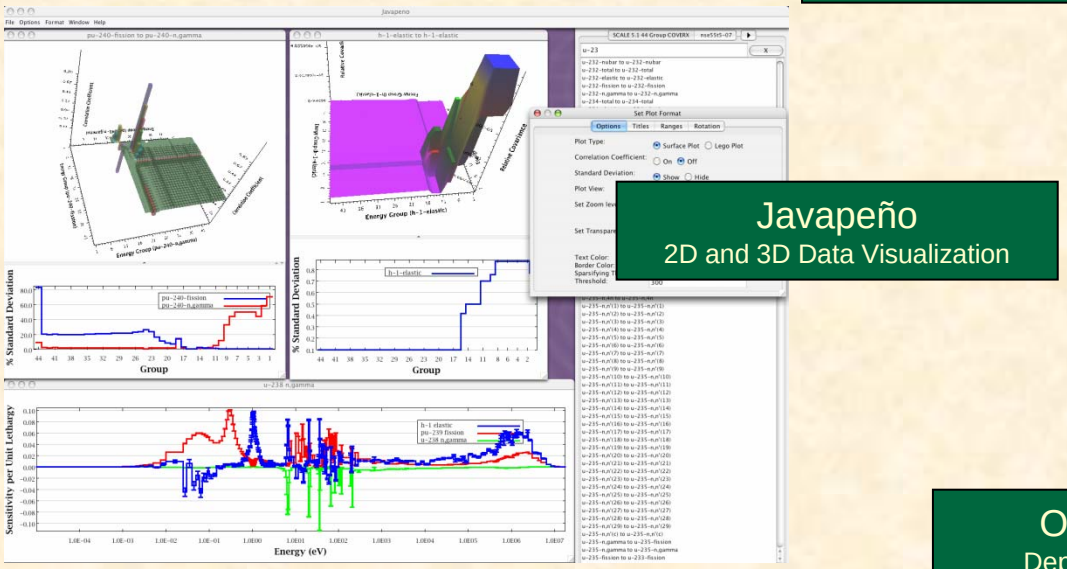
SCALE focuses on:

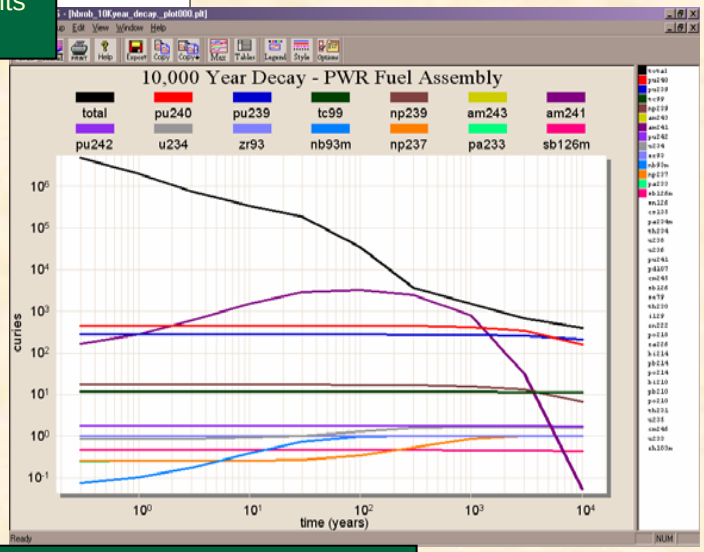
- **Ease of use**
- **State-of-the-art computational methods**









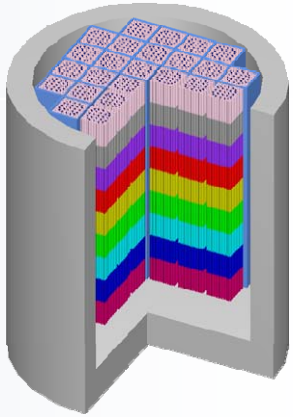


SCALE Is Widely Used and Accepted

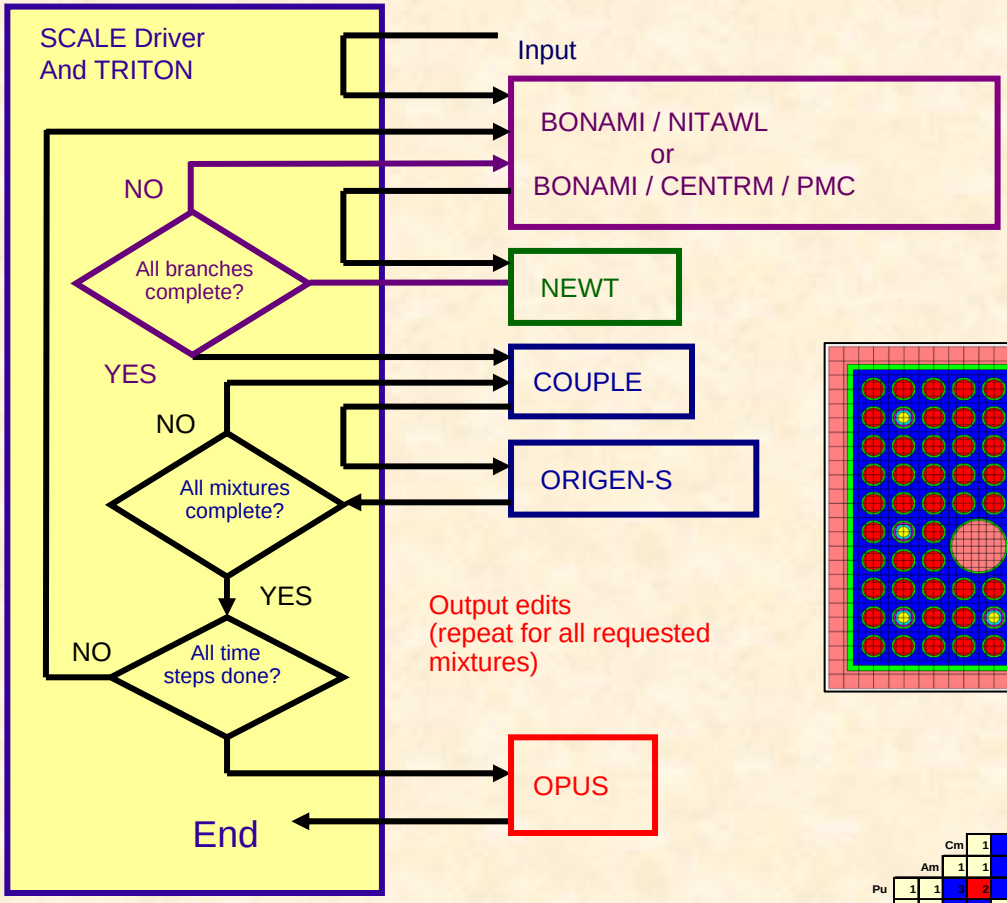
- **Accepted by both domestic and international technical communities**
  - **Users in approximately 30 nations**
- **SCALE training courses in U.S., Canada, Europe, Japan, and Latin America**
  - **Over 800 attendees (one-third foreign nationals from 28 nations) in public courses since 1993**
- **SCALE Newsletter issued twice per year**
  - **Over 1200 members in SCALE E-mail news group**
- **Technical support via email**
  - **Responded to ~ 800 requests in past year**

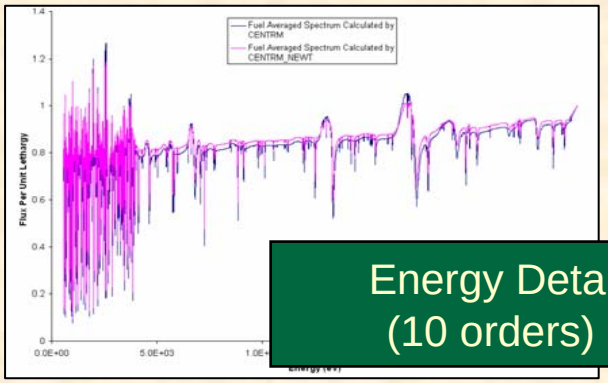
SCALE 5.1 Highlights

Version 5.1 of SCALE code system	
Updates	• ENDF/B-VI cross-section libraries • 3-D Monte Carlo depletion analysis capability • Upgrade of 2-D flexible mesh discrete ordinates module for lattice physics calculations • Enhanced ORIGEN reactor analyses for PWR, BWR, and VVER fuel based on 2-D lattice physics models • New capability to model pebble bed, prismatic, and other complex fuel designs • HTML output including interactive plots for Monte Carlo criticality safety analyses • Enhanced Java plotting program to plot cross-section and covariance data, including 3-D plots
Characteristics	• 90 executable modules • More than 2 GB of nuclear data • 500,000 lines of Fortran-90 programming • 5,200 pages of documentation • Unix, Windows, Linux, and Intel Mac platforms

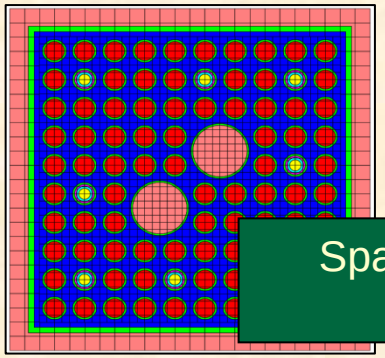


SCALE Is Built on a Modular Design

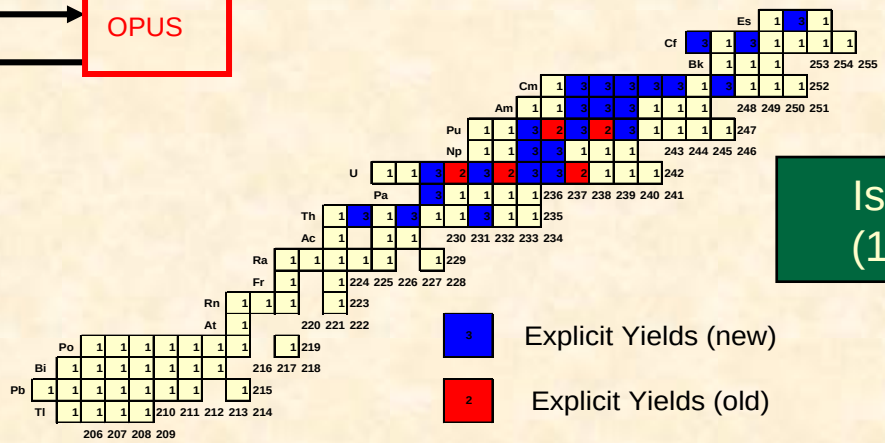




Energy Detail
(10 orders)



Spatial/Angular Detail
(5 orders)



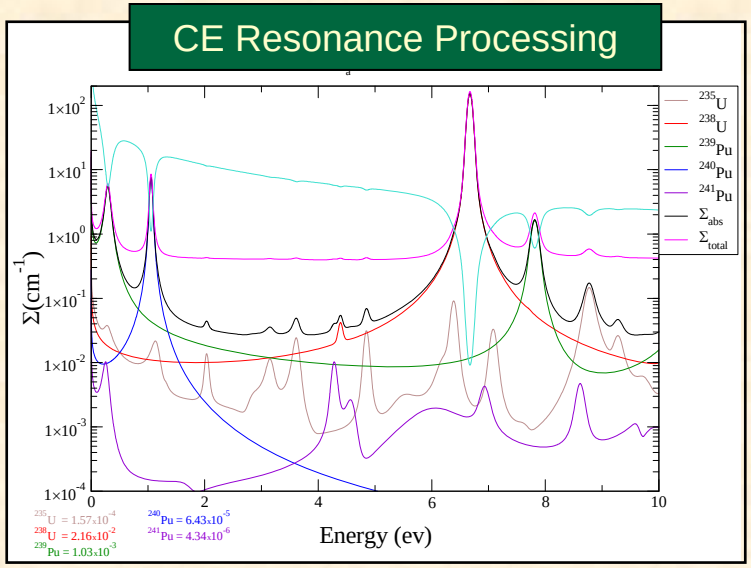
Isotopic Details
(1600 nuclides)

SCALE Automated Sequences

Control Module(s)	Analysis Function(s)	Key Functional Modules
CSAS, CSAS6	3-D Monte Carlo k-eff calculation	KENO V.a, KENO-VI
SMORES	1-D optimization of material distribution for criticality safety	XSDRNPM
STARBUCS	3-D burnup credit analysis	ORIGEN-ARP, KENO
TSUNAMI-1D, -3D	1-D and 3-D sensitivity/uncertainty for criticality safety	XSDRNPM, KENO V.a
SAS1, SAS3, SAS4	1-D discrete ordinates and 3-D Monte Carlo shielding sequences	XSDRNPM, MORSE
QADS	3-D point-kernel gamma-ray shielding analysis	QAD-CGGP
SAS2	1-D depletion w/ discrete ordinates	XSDRNPM, ORIGEN-S
ORIGEN-ARP	Point depletion/decay with reactor-specific xsecs	ARP, ORIGEN
TRITON	2-D or 3-D multi-material depletion w/ discrete ordinates	NEWT or KENO, ORIGEN-S

Note: Cross-section processing modules BONAMI, NITAWL or CENTRM/PMC are also used in all sequences except ORIGEN-ARP

SCALE Capabilities: Resonance Processing of Cross-Section Data



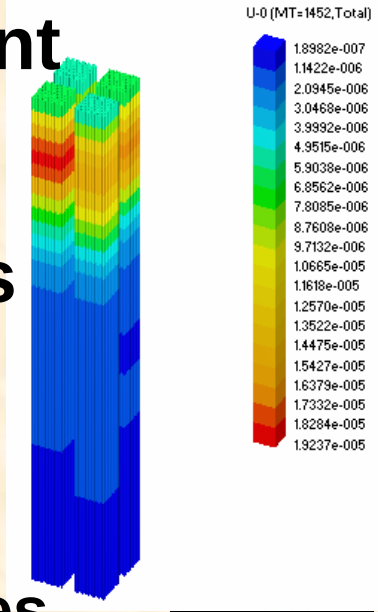
- **New ENDF/B-VI libraries in 5.1**
  - **238-group criticality safety**
  - **Continuous energy**
  - **Expanded covariance library**
- **CENTRM (Continuous Energy Transport Module) calculates 1-D discrete ordinates continuous energy flux spectrum for a unit cell**
- **PMC (Pointwise Multigroup Converter) uses continuous energy flux and cross sections from CENTRM to generate problem-dependent multigroup cross sections**
- **CENTRM/PMC explicitly handles effects from**
  - **overlapping resonances**
  - **fissile material in the fuel and surrounding moderator**
  - **anisotropic scattering**
  - **inelastic level scattering**

Resonance Processing of Cross Sections

- **Unit cell types include**
  - **Lattice cell**
  - **Multiregion**
  - **Infinite homogeneous medium**
  - **Doubly heterogeneous cell**
- **Other resonance processing options**
  - **Efficient 2-region method for "traditional" applications, such as reactor fuel**
  - **Generalized Dancoff approach to treat non-uniform lattices**
    - **Users can input Dancoff factors**
    - **SCALE calculates Dancoff-equivalent unit cell for CENTRM**

SCALE Capabilities: Criticality Safety

- KENO V.a and KENO-VI Monte Carlo codes are widely used to model fissionable systems
- Calculate k_{eff}, angular & group-dependent fluxes, absorptions, fissions, etc.
- KENO V.a has been in use for > 20 years
  - Very fast and easy to use
- KENO-VI was introduced 12 years ago
  - provides more powerful modeling capabilities



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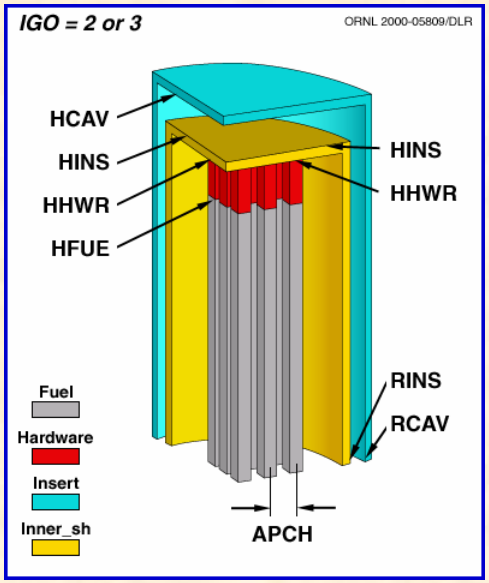
SCALE Capabilities: Radiation Shielding

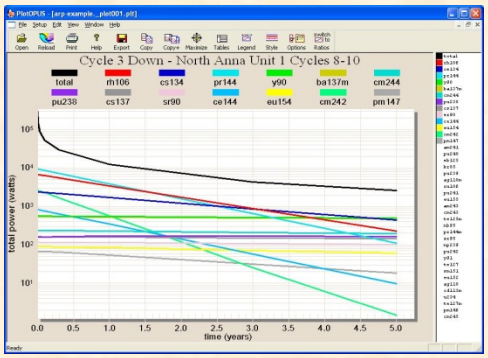


- **SAS1**
  - 1-D analysis with XSDRN
- **SAS4**
  - 3-D Monte Carlo analysis with MORSE
  - Will be replaced in SCALE 6 with MAVRIC/Monaco
- **QADS**
  - 3-D point-kernel analysis using QAD-CGGP
- **MAVRIC/Monaco**
  - SCALE Generalized Geometry Package (SGGP)
  - Automated 3-D variance reduction

SCALE Capabilities: Depletion and Decay

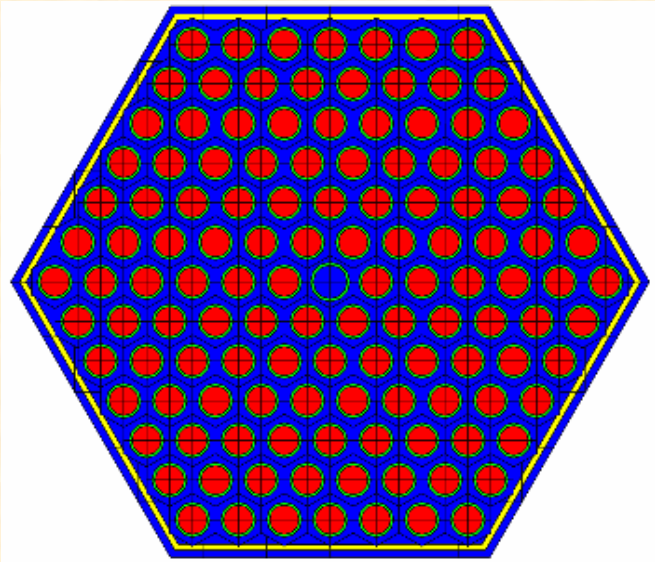
- **ORIGEN (Oak Ridge Isotope Generation) is widely used to predict spent fuel isotopic concentrations and associated radiation sources**

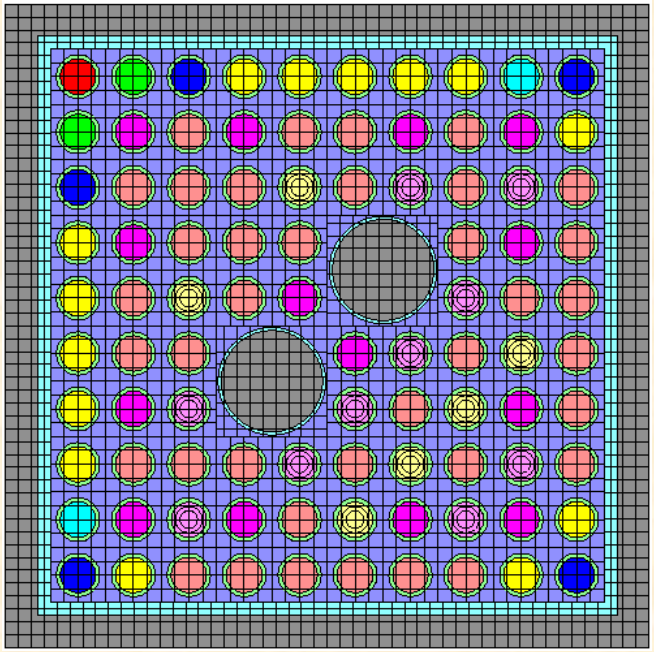
- **ORIGEN-S Code capabilities**
  - **Time-dependent nuclide concentrations during irradiation and/or decay**
  - **Batch and continuous chemical processing options**
  - **Neutron and gamma source spectra**
  - **Decay heat**
  - **Comprehensive isotopic characterization of fuel over time scale of seconds to millennia**
  - **Windows GUI and interactive plotting of results**



SCALE Capabilities: Reactor Physics

- **NEWT 2-D flexible mesh discrete ordinates code**
  - **SCALE Generalized Geometry Package (SGGP) combinatorial input format based on KENO-VI**
  - **easy to move models between codes in SCALE**
- **TRITON control sequence performs depletion analysis by linking NEWT and ORIGEN-S**



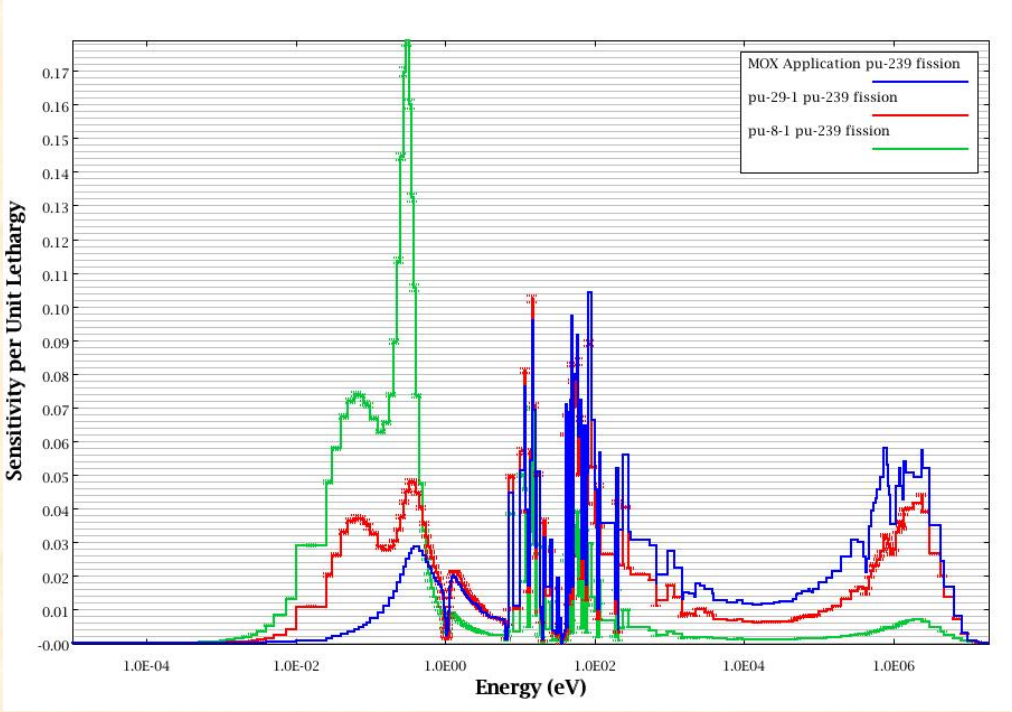


TRITON Monte Carlo Depletion

- KENO V.a or KENO-VI based 3-D depletion
- Couples KENO with ORIGEN-S depletion
- Allows user to perform detailed calculations
  - Axial portions of a fuel rod in 3-D
  - Track isotopic depletion by individual fuel rods
  - Concentric rings in a rod loaded with burnable poison

SCALE Capabilities: Sensitivity/Uncertainty

- **TSUNAMI calculates sensitivity coefficients for k-eff vs. cross section changes**
  - **Runs KENO V.a in forward and adjoint mode**
  - **Sensitivity data for each reaction of each nuclide on energy-dependent basis**
  - **Sensitivity profiles computed for experiments and applications can be compared to determine the degree of similarity**

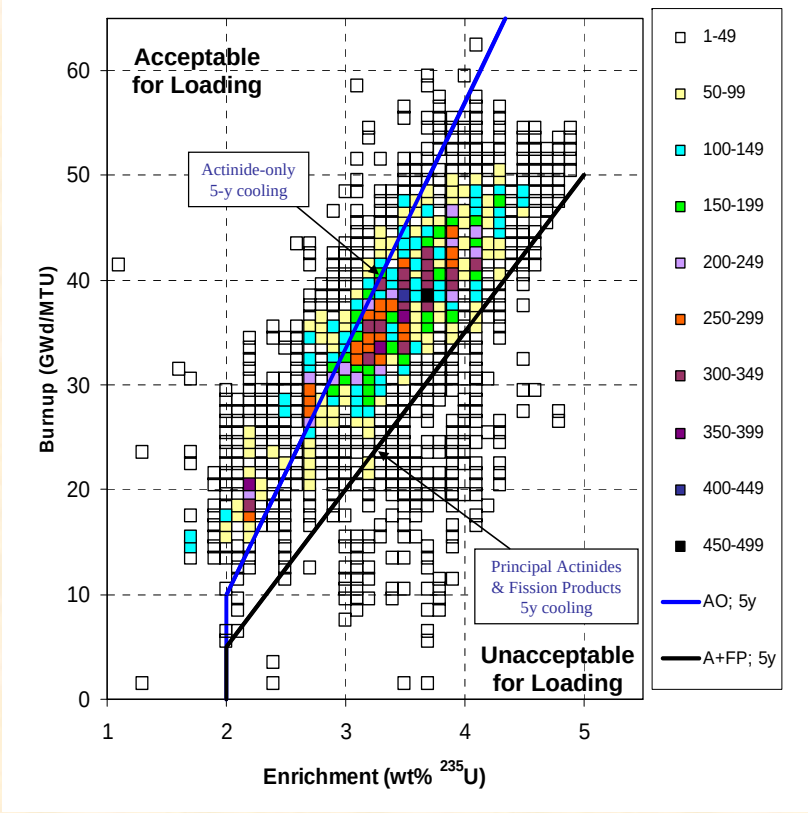


Covariance Data Libraries

- **44GROUPV5COV and 44GROUPV6COV**
  - **Basic sets with only covariance data included in ENDF/B**
  - **Approximately 50 nuclides corresponding to ENDF/B-V and ENDF/B-VI, respectively**
- **44GROUPV5REC and 44GROUPV6REC**
  - **Recommended set with covariance data for nearly every nuclide in the cross-section library**
  - **Contain ENDF/B-V and ENDF/B-VI data plus a large number of nuclides for which covariance information is included based on integral uncertainty data**
- **All 4 libraries in the SCALE 44 neutron-energy group structure**
- **Reactions included: total, elastic, inelastic, (n,2n), fission, chi, (n,gamma), (n,p), (n,d), (n,t), (n,He-3), (n,alpha), and nu-bar**

SCALE Capabilities: Burnup Credit

- **STARBUCS is designed to simulate many of the important burnup credit phenomena identified in ISG-8, e.g.,**
  - **Axial and horizontal burnup variations**
  - **Analyses can be performed for nuclide subgroups, i.e., evaluation of fission product margin**
  - **Isotopic correction factors may be applied**



New Features in SCALE 6 (October 2008 release)

- New general purpose Monte Carlo shielding sequence MAVRIC/Monaco
  - SCALE General Geometry Package (SGGP); same as KENO-VI
  - Automated 3-D variance reduction
  - GeeWiz and KENO3D interface
- ENDF/B-VI multigroup coupled library for radiation shielding
- Continuous-energy capability in KENO V.a and KENO-VI
- HTML Output with KENO-VI
- Automated loading curve search with STARBUCS

New Features in SCALE 6 (October 2008 release)

- **New modules to enhance sensitivity/uncertainty analysis with TSUNAMI**
  - **TSUNAMI-3D with KENO-VI**
  - **S/U data adjustment tool TSURFER**
  - **Reactivity sensitivity analysis tool TSAR**
  - **New USLSTATS (Upper Subcritical Limits STATisticS)**
  - **Javapeno plotting of CENTRM and CE cross section data**
  - **New user interfaces EXSITE and VIBE**
- **TRITON/NEWT Enhancements**
  - **Depletion of doubly heterogeneous fuel (e.g. PBMR)**
  - **2-D S/U analysis (aka TSUNAMI-2D)**
  - **Full support for fixed source calculations**
  - **HTML output**

Training and User Assistance

- **SCALE Web Site (www.ornl.gov/sci/scale)**
  - SCALE Newsletter - current and past issues
  - SCALE Users Notebooks
  - SCALE system overview
  - Validation and benchmark reports
  - Download updates
  - Training course information/registration
- **User help available via e-mail (scalehelp@ornl.gov)**

SCALE Training Course Schedule

Course at OECD/NEA Data Bank

Feb. 25-29 **TSUNAMI Sensitivity/Uncertainty Tools**

Courses at ORNL

March 31-April 4 **ORIGEN-ARP/TRITON**

April 7-11 **KENO-VI Criticality Safety**

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On with the show…

- KENO Monte Carlo Code Capabilities
- Advanced Variance Reduction Strategies for Optimizing Mesh Tallies in MAVRIC
- High-Fidelity Depletion Capabilities Using TRITON
- Overview of ORIGEN-ARP and Its Applications to VVER and RBMK
- TSUNAMI Sensitivity and Uncertainty Analysis Capabilities
- Plans for Future SCALE Development Beyond Version 6.0