

Nuclear Simulation @ ORNL

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**Reactor Analysis Group
Nuclear Science & Technology Division**

**OAK RIDGE NATIONAL LABORATORY
U. S. DEPARTMENT OF ENERGY**

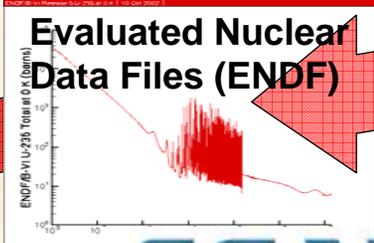
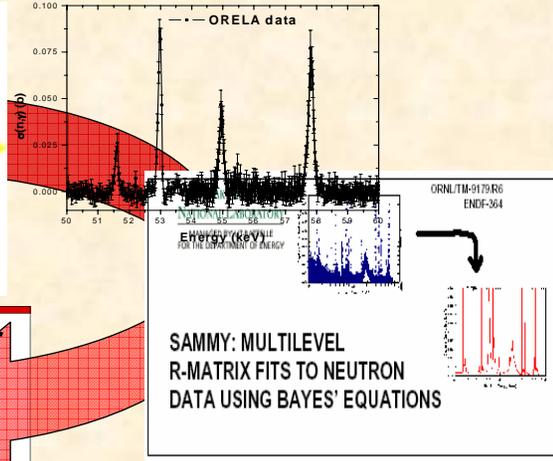
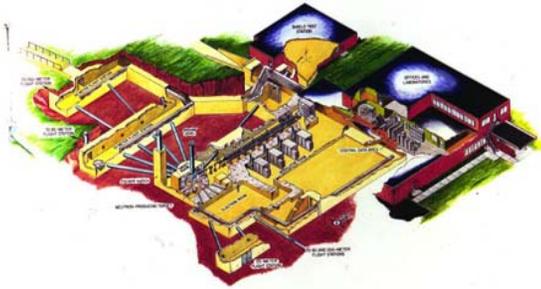


Nuclear @ ORNL

- **Nuclear Science & Technology Division**
 - ✦ All things nuclear
- **Space Nuclear Power Program**
 - ✦ Electricity generation, propulsion, shielding, materials
- **Fusion Engineering Division**
 - ✦ Teamed with Princeton as the US lead for ITER
- **Spallation Neutron Source**
 - ✦ Neutron and atomic physics
- **Research Reactor (HFIR)**
 - ✦ Materials testing, irradiation research, and isotope production
- **Radiation biology, medical physics, astrophysics, etc.**

SCALE @ ORNL: Science to Applications

science



computational modeling

AMPX

SCALE

Interface **science** (the basic physics of cross-section measurements), **computational modeling (SCALE)**, and **applications** expertise to support evaluation and resolution of nuclear engineering and safety issues.

- Cross-section processing
- Criticality safety
- Radiation protection and shielding
- Reactor physics
- SNF/waste characterization (e.g., inventory, decay heat, radiation source and spectra)

applications



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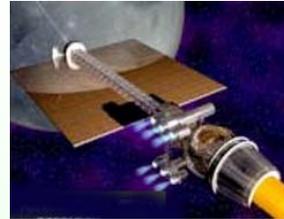
Nuclear Science and Technology Division

NUCLEAR SECURITY TECHNOLOGIES



- Material protection, control, and accounting
- Safeguards
- Arms control assessments
- Export control
- Nuclear threat reduction
- Radiation detection
- Radiation transport
- Transportation technologies
- Fissile material detection
- Fissile material disposition
- Instrumentation

NUCLEAR SYSTEMS ANALYSIS, DESIGN, AND SAFETY



- Nuclear data and codes
- Criticality safety
- Reactor physics
- Radiation shielding
- Advanced/Space reactors
- Thermal hydraulics
- Material and fuel irradiation
- Information/Systems analysis
- Facility safety
- Risk assessment
- Regulatory support
- System instrumentation and controls
- Enrichment technology

FUELS, ISOTOPES, AND NUCLEAR MATERIALS



- Nuclear fuels
- Heavy element production
- Stable/radioactive isotopes
- Medical isotope development
- Separations science and technology
- Nuclear process and equipment design
- Robotics
- Remote handling
- Chemical engineering

There are many codes within SCALE

Input & Visualization

GeeWiz

KENO-3D

JAVAPENO

PLOTOPUS

Multi-Group Cross Sections

BONAMI

NITAWL

CENTRM

PMC

GEMINEWTRN

Radiation Transport

KENO-CE

KENO

MONACO

TORT

NEWT

XSDRN-PM

Feedback & Coupling

ORIGEN-S

STARBUCS

OPUS

KMART

Drivers to Simplify

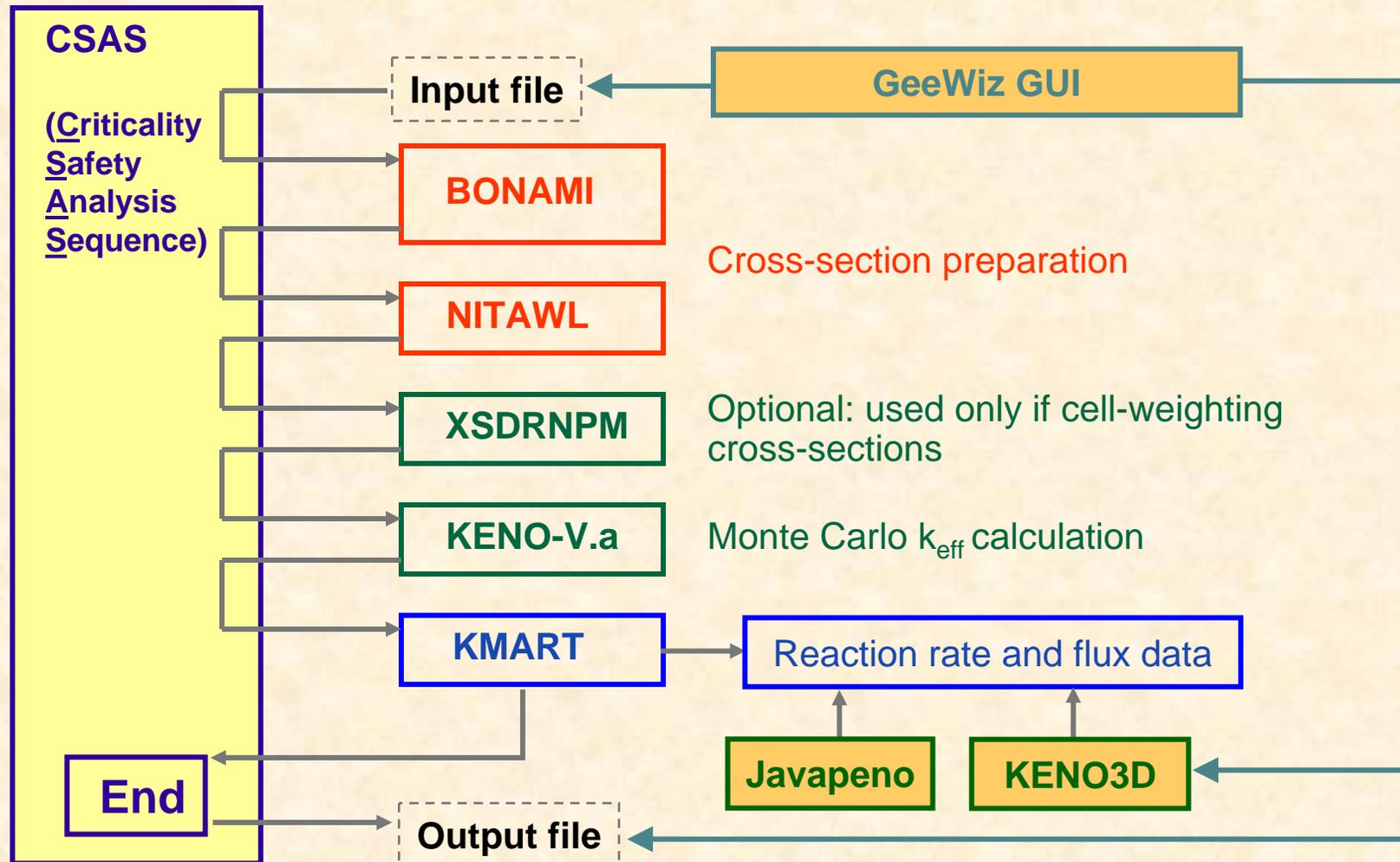
TRITON

CSAS

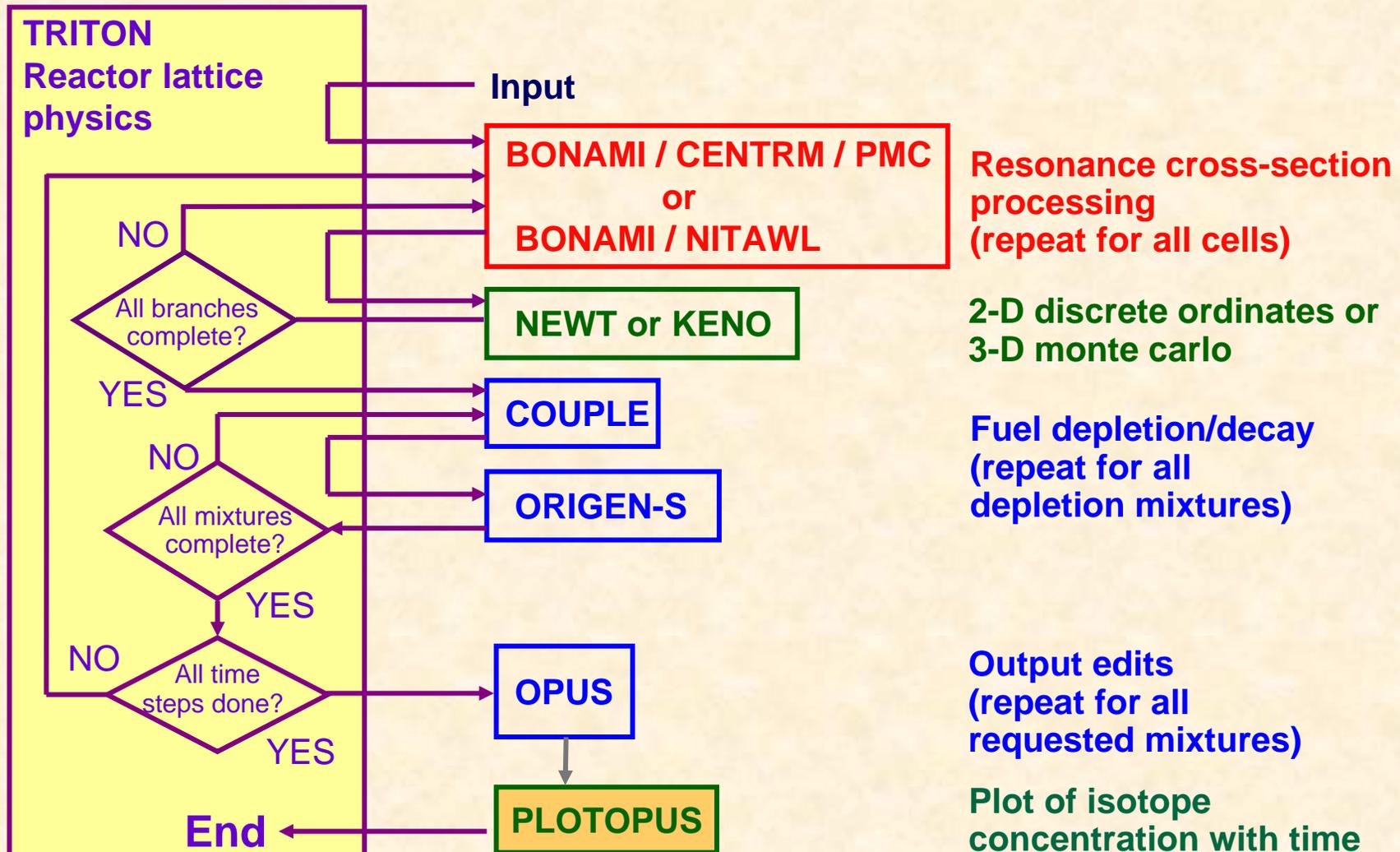
SAS

TSUNAMI

SCALE is built on a Modular Concept



Some drivers make many decisions



From Data to Cross Sections: Resonance Self-Shielding

➤ BONAMI: **Bondarenko Method**

- ✦ *Tabulated correction factor for temperature & concentration of an isotope*
- ✦ *Generally used in the unresolved energy range only*

➤ NITAWL: **Nordheim Integral Treatment**

- ✦ *Every resonance is treated independently*
- ✦ *Approximates problem-dependent geometry & material affects*
- ✦ *Fast, good accuracy with few high concentration isotopes (< ENDF/B-VI)*

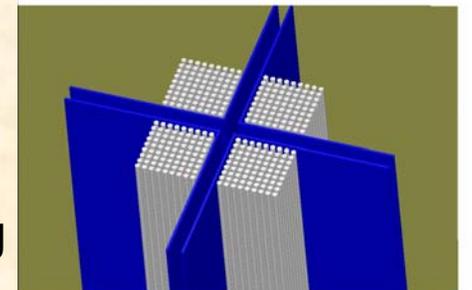
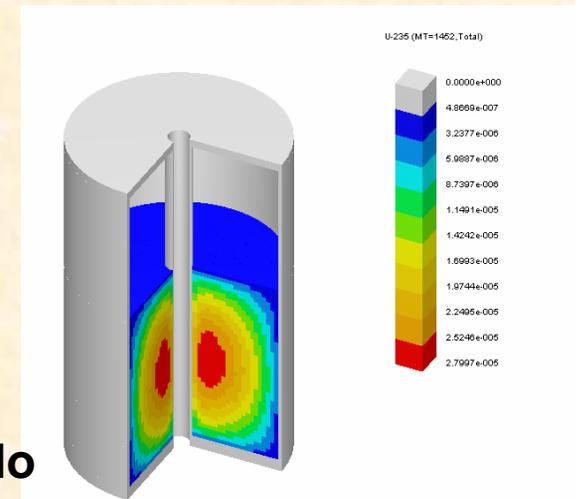
➤ CENTRM: **C**ontinuous **EN**ergy **TR**ansport **M**odule

for resolved resonance range (all libraries: ENDF/B-VI)

- ✦ **Performs 1-D S_n calculation for continuous-energy neutron spectra using with Point-Wise nuclear data**
- ✦ **Processes problem-dependent multigroup XS's using Point-Wise nuclear data and flux spectrum**

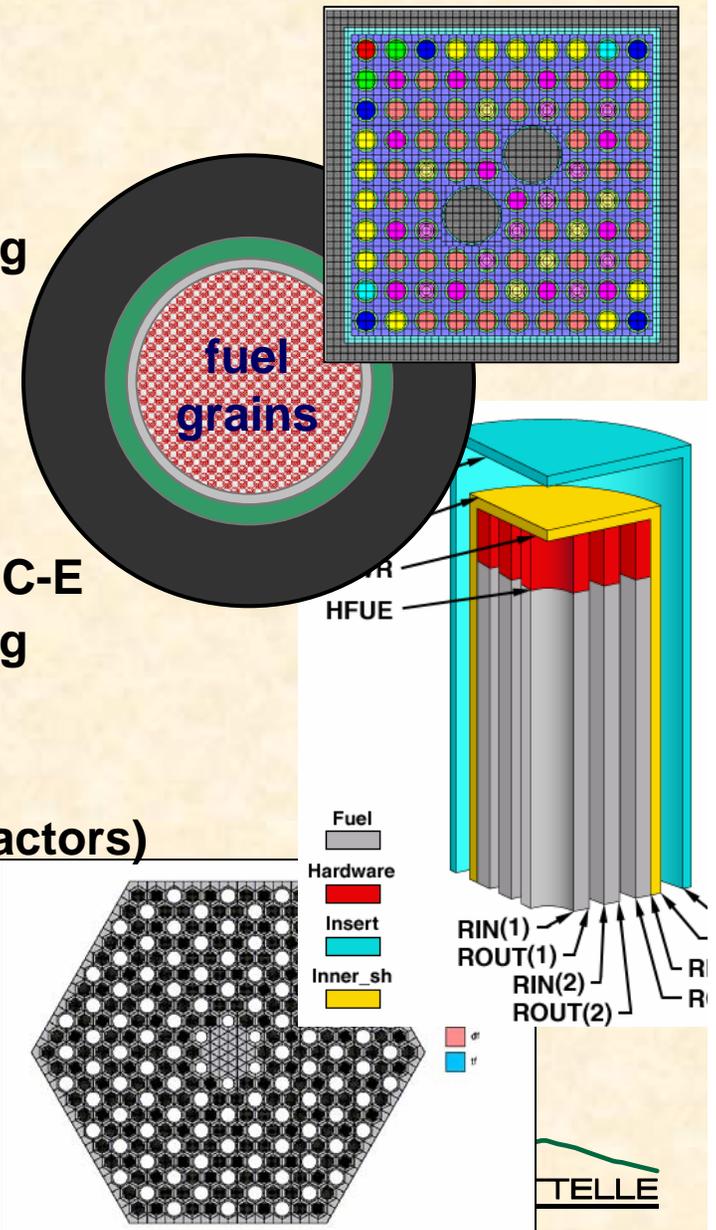
SCALE Stochastic Transport Methods

- **KENO-5 and KENO-VI multi-group Monte Carlo codes**
 - ✦ Developed for criticality safety applications
 - ✦ Much faster than continuous energy
 - ✦ Now integrated with TRITON for depletion
- **Continuous Energy KENO**
 - ✦ Currently under development
 - ✦ Provides the rigor of continuous energy Monte Carlo
- **MORSE/MONACO Monte Carlo Shielding**
 - ✦ Advanced variance reduction
- **A Single Consistent Geometry**
 - ✦ SCALE Generalized Geometry Package (SGGP) being adopted for all ORNL codes
 - ✦ Easily switch from NEWT to KENO-VI to CE-KENO



SCALE Deterministic Transport Methods

- **CENTRM**
 - ✦ 1-D, source-driven, continuous-energy
 - ✦ For problem-dependent resonance processing
- **XSDRN-PM**
 - ✦ 1-D, WDD, multi-group
 - ✦ Forward/adjoint with a host of uses
- **GEMINEWTRN**
 - ✦ 2-D arbitrary polygonal mesh, source-driven, C-E
 - ✦ For problem-dependent resonance processing
- **NEWT**
 - ✦ 2-D arbitrary polygonal mesh, multi-group
 - ✦ Forward/adjoint solutions for all analyses (reactors)
- **TORT**
 - ✦ 3-D orthogonal mesh, multi-group
 - ✦ For all analyses, widely-used in shielding



ORIGEN-S: Irradiation and decay simulation code

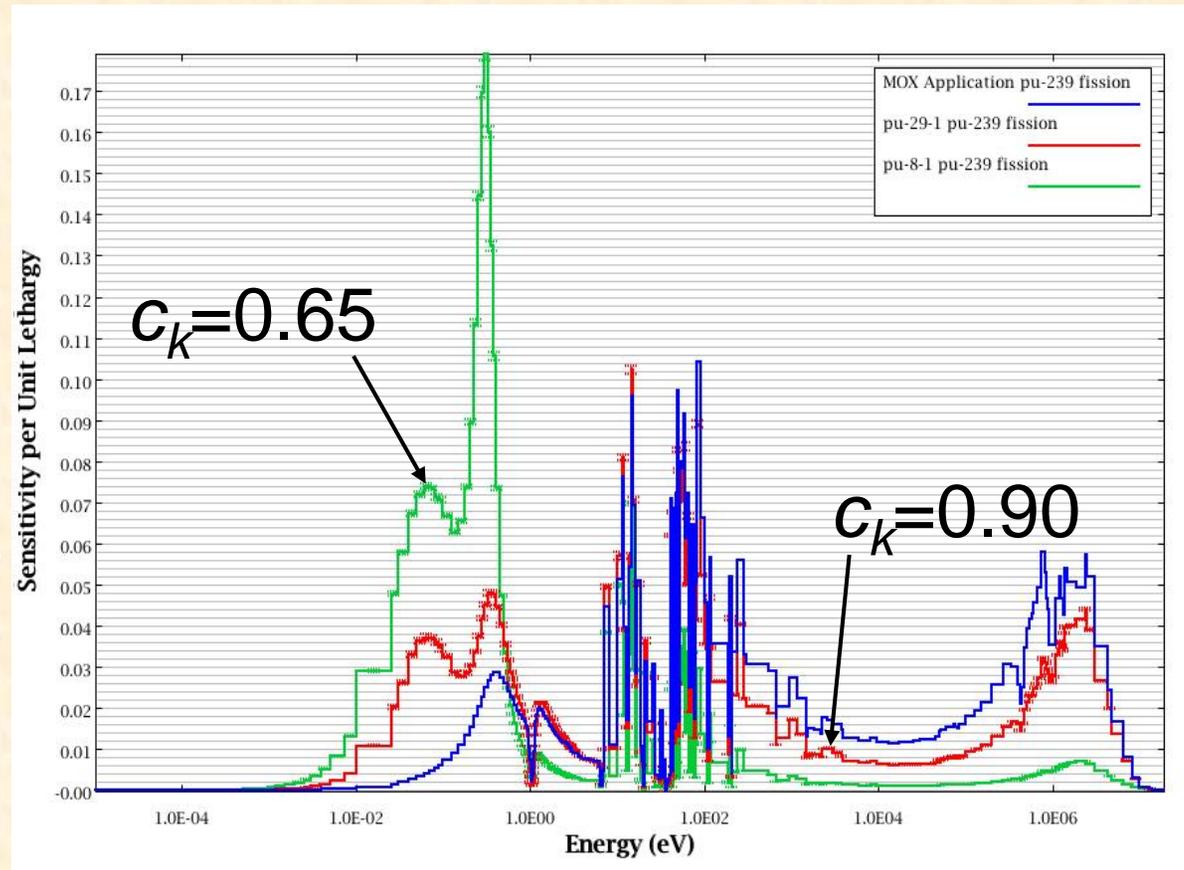
- Irradiation and decay simulation code
- Explicit simulation of 1484 unique nuclides (1946 nuclides in database)
 - ✦ 129 actinides
 - ✦ 1119 fission products
 - ✦ 698 structural activation materials
 - ✦ Other depletion codes typically track a minimum subset of isotopes that are important for reactivity
- Detailed radionuclide compositions
- Decay heat sources (neutron/photon), including energy spectra
- Radio-toxicity
- One of few codes available with comprehensive isotopic characterization of fuel over time scale of seconds to millennia
 - ✦ Accident analyses
 - ✦ Storage and handling
 - ✦ Transportation
 - ✦ Disposal or reprocessing
 - ✦ Repository analysis (storage, migration, dose assessment)



TSUNAMI: Tool for S/U Analysis with XSDRN (1-D) and KENO-VI (3-D)

- **Determination of critical experiment benchmark applicability to nuclear criticality safety analyses**
- **The design of critical general physics experiments (GPE)**
- **The estimation of computational biases and uncertainties for the determination of safety subcritical margins**

^{239}Pu Fission Sensitivity Profiles:
Sensitivity of k_{eff} to cross-section



That is what we have... but what are we doing?

➤ Analysis

✦ Reactors

- ◆ Gen-IV / GNEP (DOE)
 - LS-VHTR
- ◆ Gen-III (NRC)
- ◆ Space Reactors (NASA)

✦ Shielding / criticality safety

- ◆ Transportation
- ◆ Space
- ◆ Facilities

✦ Optimization and S/U

- ◆ GA system optimization
- ◆ S/U of design on nuclear data

✦ Others

- ◆ GA Optimization
- ◆ Medical physics
- ◆ Yucca mountain
- ◆ Nuclear materials

➤ Code Development

✦ Incorporation and integration

- ◆ Generalized geometry input
- ◆ TORT within SCALE
- ◆ TSUNAMI with NEWT/TRITON

✦ Incremental improvements

- ◆ MONACO variance reduction
- ◆ Uncertainty propagation
- ◆ ORIGEN-S improvements
- ◆ Many others...

✦ High-performance computing

- ◆ Multi-physics Reactor Simulation
- ◆ Genetic Algorithm Design Optimization

Your opportunities at ORNL

- **NESLS – Physics & Engineering Students**
 - ✦ Nuclear Science & Technology Division
 - ✦ Highly competitive stipends
- **SULI – Nuclear Engineering Students**
 - ✦ Less competitive, but only \$475/week
- **Young Professionals @ ORNL**
 - ✦ Full and part-time employees
 - ✦ For social and recreational activities
 - ✦ So you don't just sit at home every night...
- **SCALE is cheap**
 - ✦ Source code is free to NE students and faculty
 - ✦ Training is only ~\$500 (cheap for a professor)

NESLS	Weekly Stipend
First Year (Freshman)	\$604
Second Year (Sophomore)	\$668
Third Year (Junior)	\$728
Fourth Year (Senior)	\$801
Fifth Year (Graduate)	\$938
Masters Completed	\$1010

www.ornl.gov/sci/nuclear_science_technology/nstip/internship.htm

Conclusions

- **ORNL has a complete set of nuclear analysis tools**
 - ✦ Nuclear data and data analysis
 - ✦ Advanced cross section generation techniques
 - ✦ Deterministic & stochastic transport with CE and MG
 - ✦ Sensitivity and uncertainty propagation and assessment
- **We are utilizing these tools for many applications**
 - ✦ Reactors: air, land, and sea
 - ✦ Shield design & criticality safety
 - ✦ Fuel performance, waste and transportation
- **We are working with many institutions to unite the nuclear energy simulation field for GNEP**
 - ✦ Currently three labs, two universities
 - ✦ In the near future... five labs and three universities
- **You can join us to learn in a 3-month job interview, explore Knoxville and the Smokies, and get paid very well**