KENO Monte Carlo Code Capabilities

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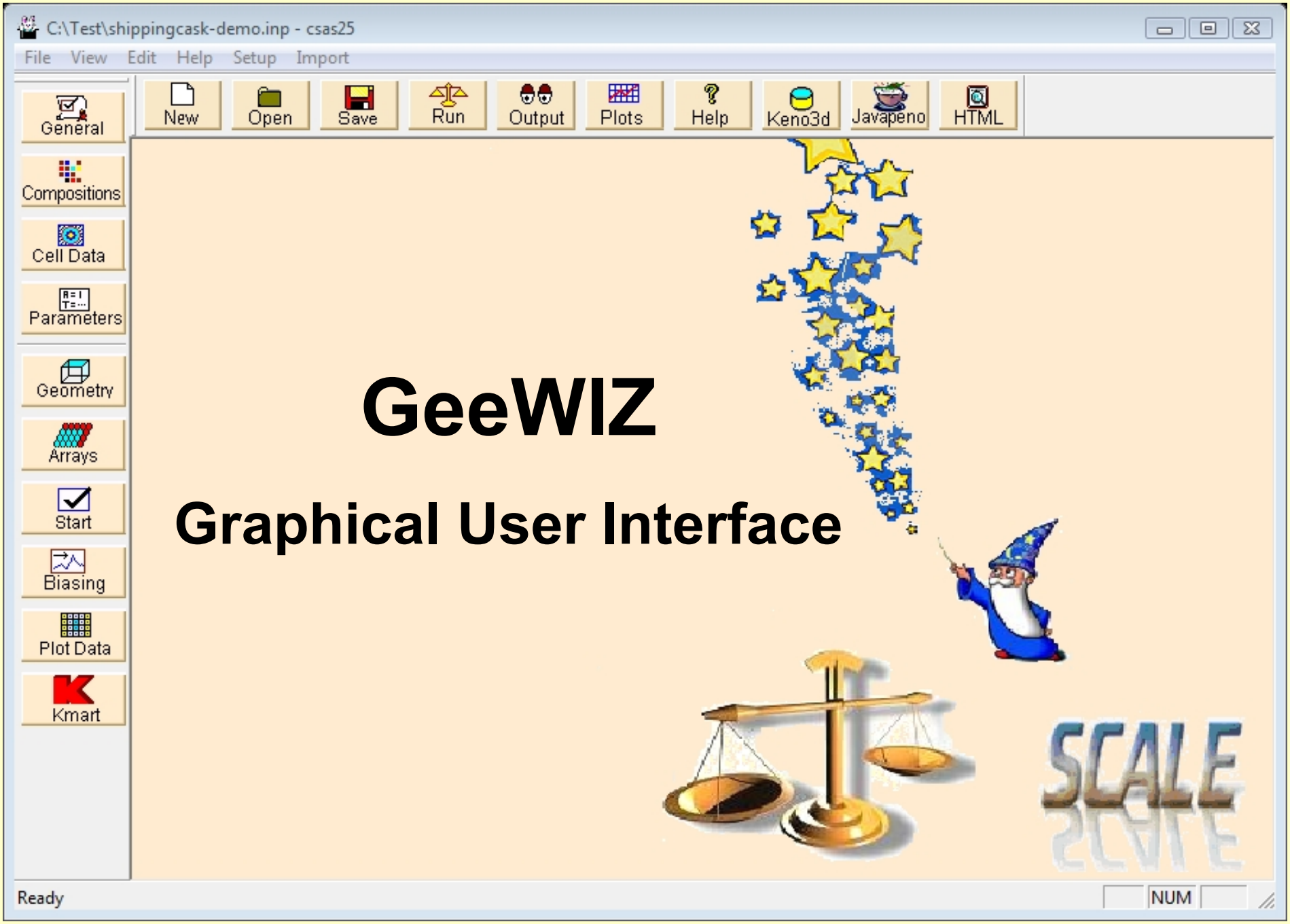
KENO

- KENO series of codes maintained at ORNL as part of SCALE (Standardized Computing Analyses for Licensing Evaluation) System
- KENO V.a and KENO-VI are three-dimensional Monte Carlo codes that are widely used to model fissionable systems
- KENO codes part of Criticality Safety Analyses Sequences (CSAS) in SCALE

Background

- **Current release**
  - **Multigroup solution to Boltzmann transport equation**
- **Next release (SCALE 6)**
  - **Continuous energy treatment in both KENO codes**
- **Calculate k_{eff}, angular & group-dependent fluxes, absorptions, fissions, etc.**


C:\Test\shippingcask-demo.inp - csas25
File View Edit Help Setup Import
General
Compositions
Cell Data
Parameters
Geometry
Arrays
Start
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Javapeno
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GeeWIZ
Graphical User Interface
SCALE
Ready
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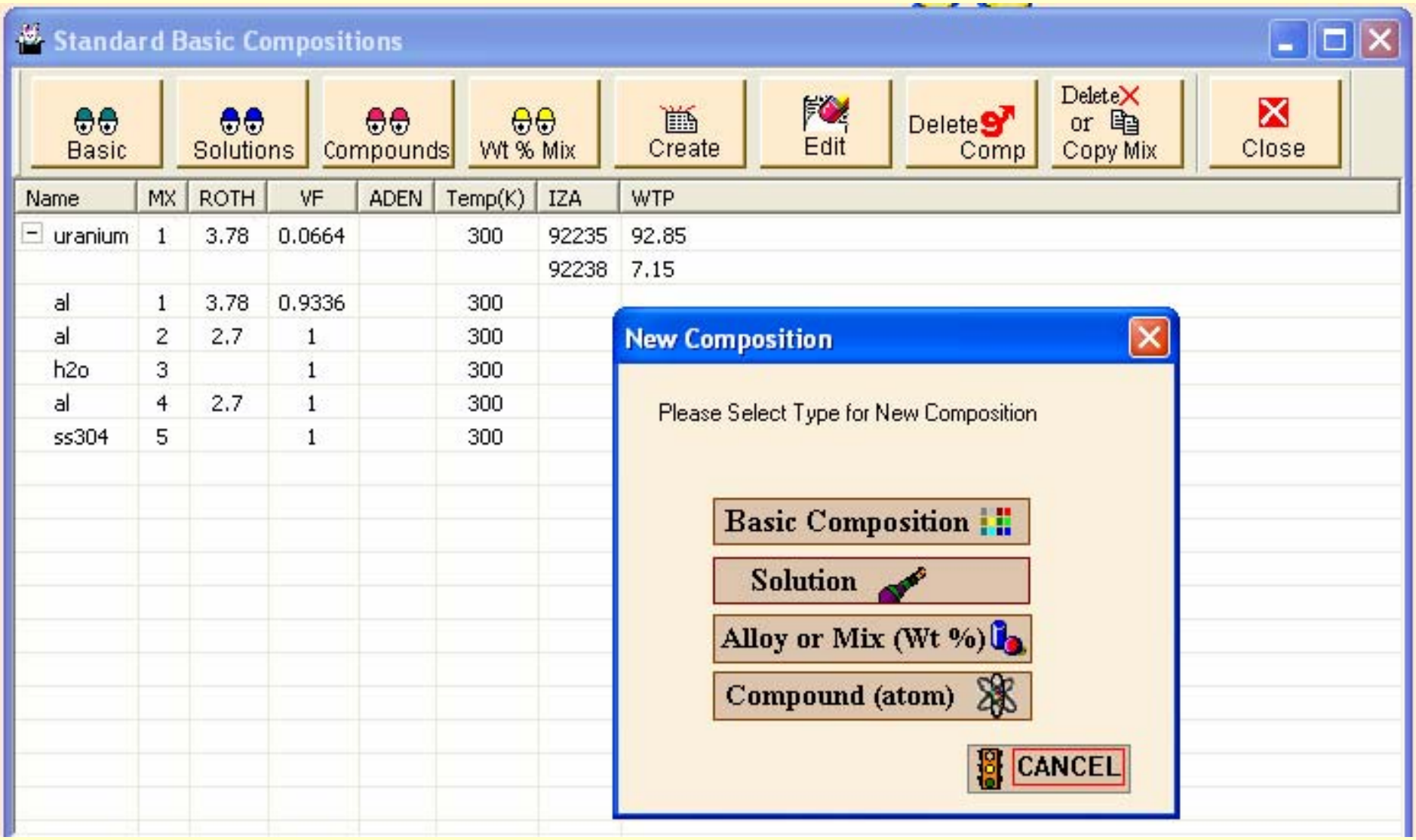
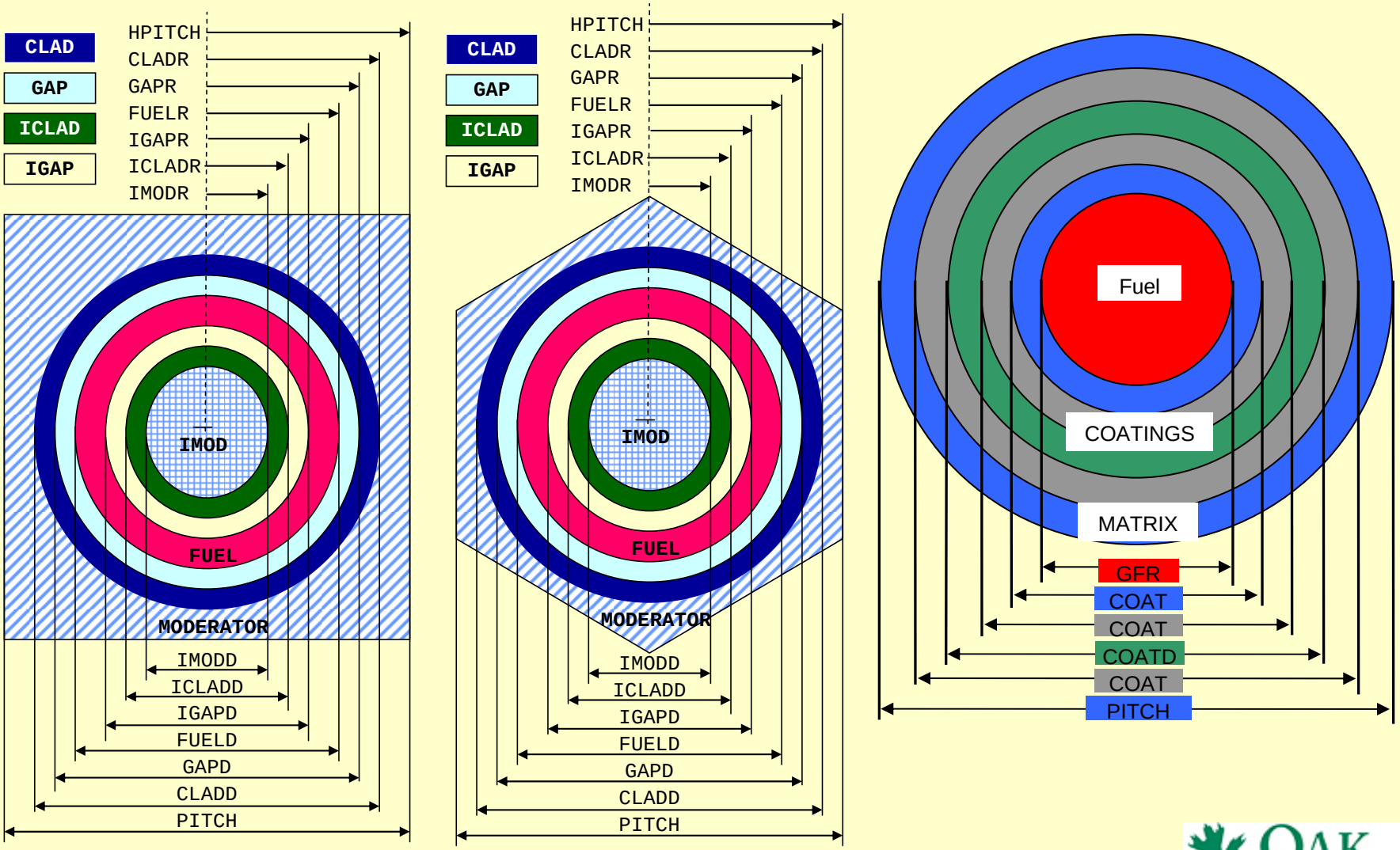
Compositions

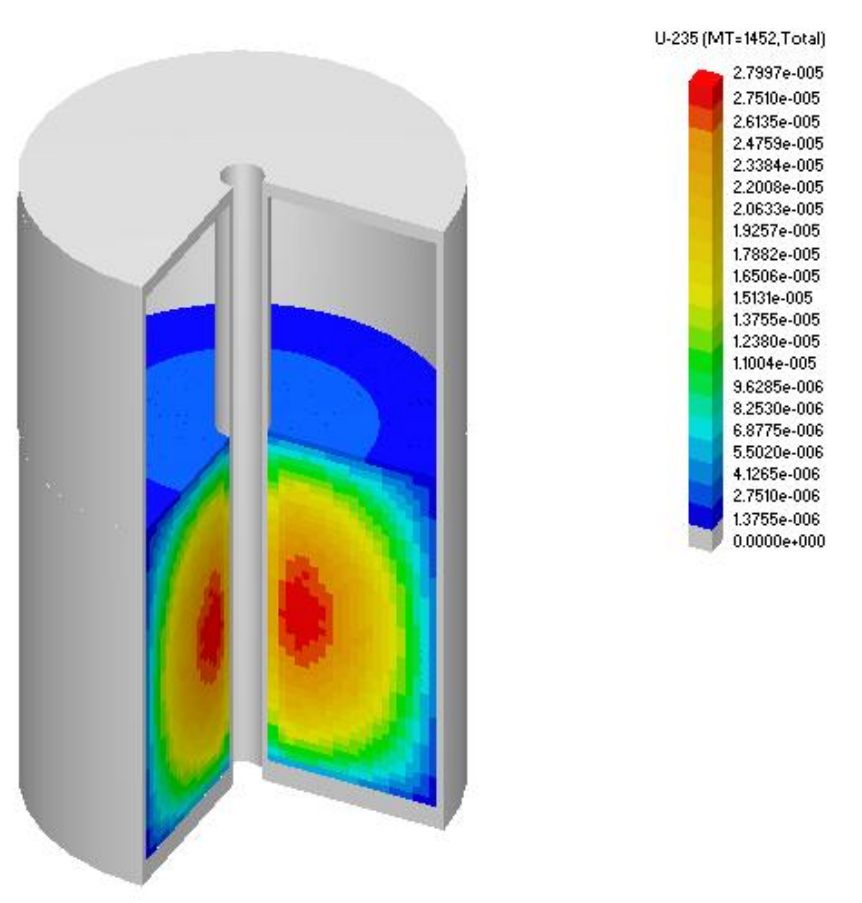


Unit Cell Data for Multigroup Energy Treatment

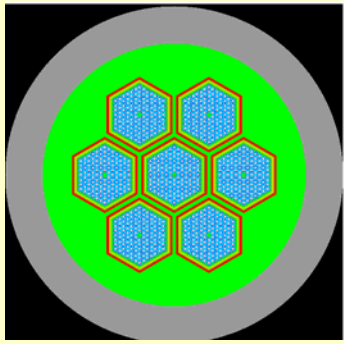


Easy to Use Features

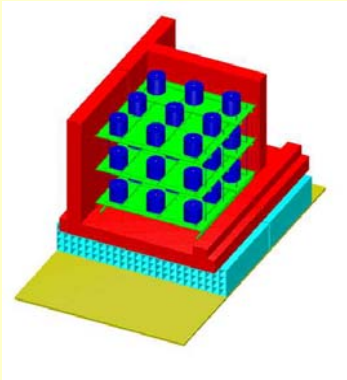
- **Simple input for starting neutron distribution (8 different start types)**
- **Flexible 2-D Plot capability within KENOs**
- **Post-processing for activities using KMART/KENO3D**



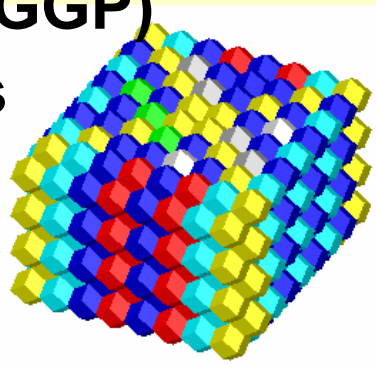
Geometry



- **Versatile geometry package permits the modeling of wide variety of problems**
  - **Units, arrays, holes**
- **KENO V.a: building-block type geometry package**
  - **Cuboids, spheres, cylinders, rectangular arrays**
  - **Orthogonal geometry, no intersections**



- **KENO VI: more complex geometries**
  - **SCALE Generalized Geometry Package (SGGP)**
  - **cones, wedges, parallel planes, hexprisms**
  - **Intersecting regions**
  - **Body rotations to any angle**
  - **Hexagonal and dodecahedral arrays**



SCALE OUTPUT - Mozilla Firefox

File Edit View History Bookmarks Tools Help

file:///C:/workshop/3_cask.html

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SCALE OUTPUT

3_cask

Select an Output Below

---

shipping cask containing 92.85 w% u-235/al plate fuel

1. KENO V.a

Comments, Suggestions, User Assistance:

Contact SCALE Help

scalehelp@ornl.gov

or visit the SCALE website

http://www.ornl.gov/sci/scale

KENO V.a - Mozilla Firefox

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file:///C:/workshop/3_cask.htmd/KENO%20V.a.0001.html

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General Information

Messages

Input Data

Derived Data

Results

- Final Results
- Problem Characterization
- k_{eff} Results
- Fissions and Absorptions

KENO V.a - Final Results
shipping cask containing 92.85 w% u-235/al plate fuel

Best Estimate System k_{eff}	0.8832 ± 0.0015
Energy of Average Lethargy of Fission (eV)	9.83384E-002 ± 3.00668E-004
System $\bar{\nu}$	2.43825E+000 ± 5.90645E-006
System Mean Free Path (cm)	9.57893E-001 ± 1.18192E-003
Number of Warning Messages	17
Number of Error Messages	0
k_{eff} satisfies the χ^2 for normality at the 95 % level	

Congratulations! You have successfully traversed the perilous path through KENO V.a in 0.78333 minutes

KENO V.a - Mozilla Firefox

File Edit View History Bookmarks Tools Help

file:///C:/workshop/3_cask.htmd/KENO%20V.a.0001.html

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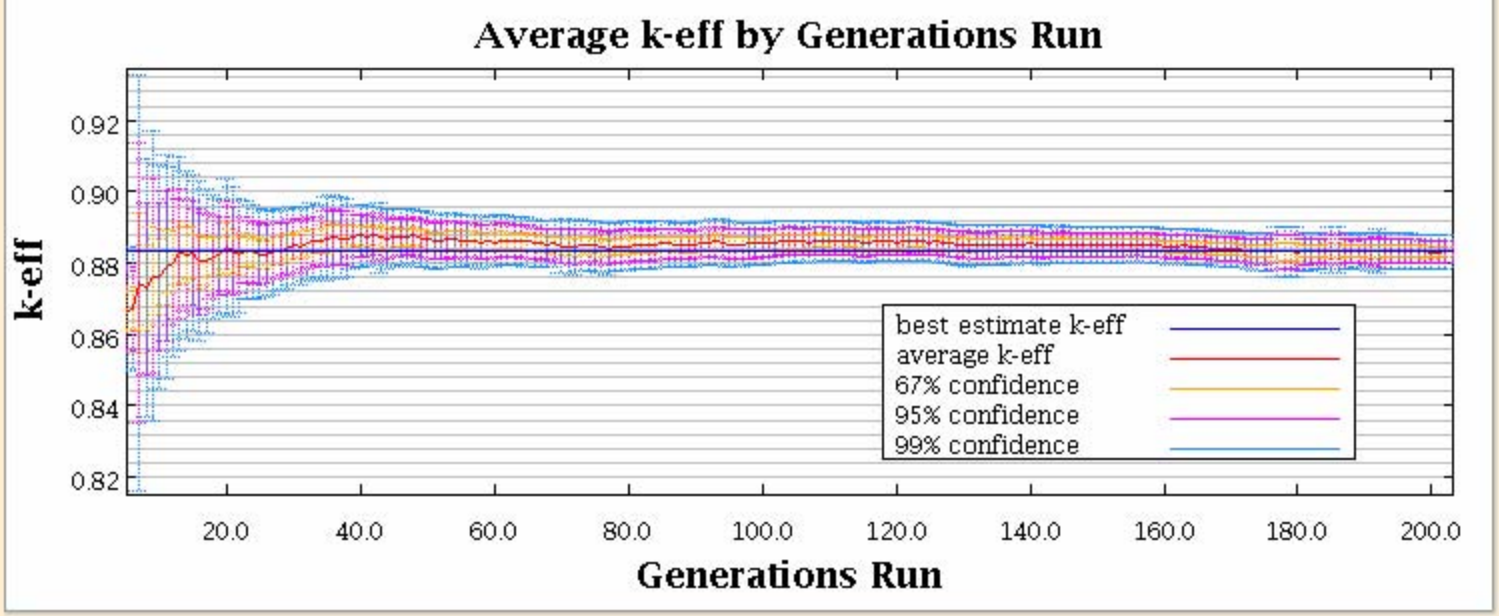
- General Information
- Messages
- Input Data
- Derived Data
- Results
  - Final Results
  - Problem Characterization
  - k_{eff} Results
    - k_{eff} by Generations Plots
    - k_{eff} by Generations Run
    - k_{eff} by

KENO V.a - Average k_{eff} by Generation Plots
shipping cask containing 92.85 w% u-235/al plate fuel

Minimum k_{eff} = 0.8610, Maximum k_{eff} = 0.8878

File Options Format Window Help

Average k-eff by Generations Run



Applet javapeno.javapeno started

C:\workshop\3_cask.inp - csas25

File View Edit Help Setup Import

General | Compositions | Cell Data | Parameters | Geometry | Arrays | Start | Biasing | Plot Data | Kmart

New | Open | Save | Run | Output | Plots | Help | Keno3d | Javapeno | HTML

Parameter Data

Key Parameters | Numeric Parameters | Logical Parameters | I/O Unit Numbers

- [ ] ADJ - Adjoint Calculation
- [ ] AMX - All mixture cross-sections
  - [ ] P1D - Extra 1-D cross-sections
  - [ ] PKI - Fission Spectrum
  - [ ] XAP - Cross-section angles problems
  - [ ] XS1 - 1-d Cross-sections
  - [ ] XS2 - 2-d Cross-sections
- [ ] MKA - Matrix by array
  - [ ] CKA - Cofactor k by array
  - [ ] FMA - Fission product by array
  - [ ] HAL - MKA at highest level
- [ ] MKH - Matrix by hole
  - [ ] CKH - Cofactor k by hole
  - [ ] FMH - Fission product by hole
  - [ ] HHL - MKH at highest level
- [ ] MKP - Matrix by location
  - [ ] CKP - Cofactor k by location
  - [ ] FMP - Fission product by location
- [ ] MKU - Matrix by unit
  - [ ] CKU - Cofactor k by unit
  - [ ] FMU - Fission product by unit
- [x] NUB - Neutrons per fission
- [ ] BUG - Debug print
- [ ] PAX - Albedo-cross-section array
- [ ] PGM - Unprocessed geometry
- [ ] PWT - Print average weight
- [ ] SMU - self-multiplication
- [ ] TRK - Print neutron tracks

**Warning! Reset Defaults cannot be cancelled or undone

Reset | Help | OK | CANCEL

CE-KENO Design Objectives

- **Develop and test new versions of KENO V.a and KENO-VI that use continuous-energy cross sections to model radiation transport**
- **Design Objectives**
  - **Completely independent transport capability**
  - **Integrate transport capability in SCALE Package**
  - **Minimize changes for experienced KENO users**
  - **Increased material modeling flexibility**

AMPX Code System for Continuous Energy KENO

- **Modular code system since 1970's to process full range of ENDF/B formats**
- **Specifically for continuous energy KENO**
  - **Process ENDF/B collision kinematics data to generate energy and angle distributions for secondary particles**
  - **Process S(α,β) data for thermal moderators**
  - **Process free-gas kinematics data for nuclides without thermal scattering law data**
  - **Process 1-D data to generate 1-D continuous energy cross-sections**

KENO Continuous Energy Cross Sections by AMPX

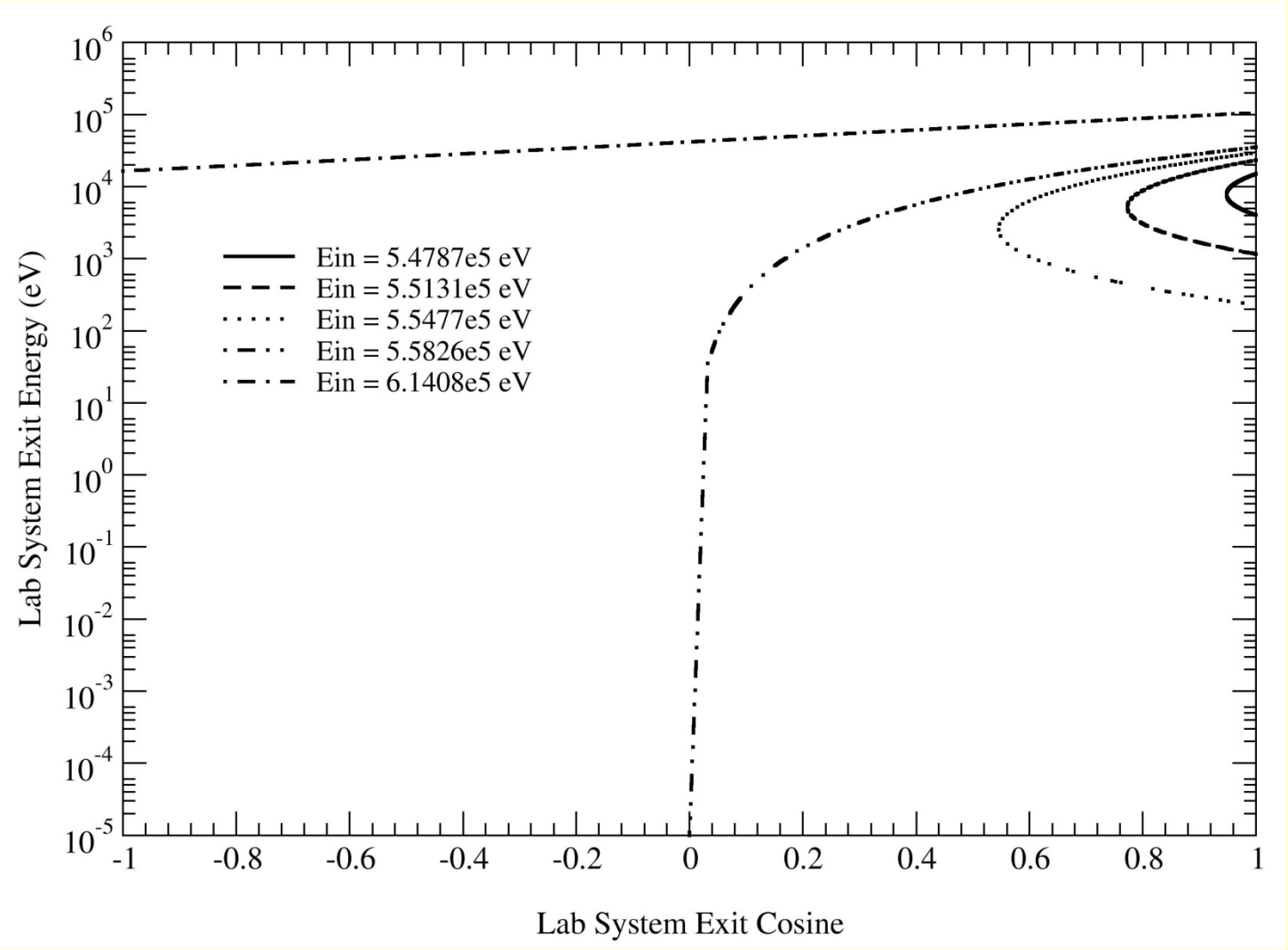
- **Average number of neutrons (delayed and prompt)**
- **1-D cross sections as a function of temperature, $\sigma(E,T)$**
- **2-D pointwise joint probability distributions (PDF), $f(E \rightarrow E', \mu, T)$**
- **Probability tables for unresolved resonance region**

KENO Cross Sections

- **Continuous energy joint PDFs and CDFs (coupled in energy and angle)**
- **All data in Lab system**
  - **KENO CE does not have to transform between coordinate systems**
  - **Energy and angle distributions are more complex; an isotropic distribution in center of mass system is anisotropic in the lab system.**
  - **Secondary energy distributions as a function of exit angle cosine in the lab system can become double-valued for certain incident energies**

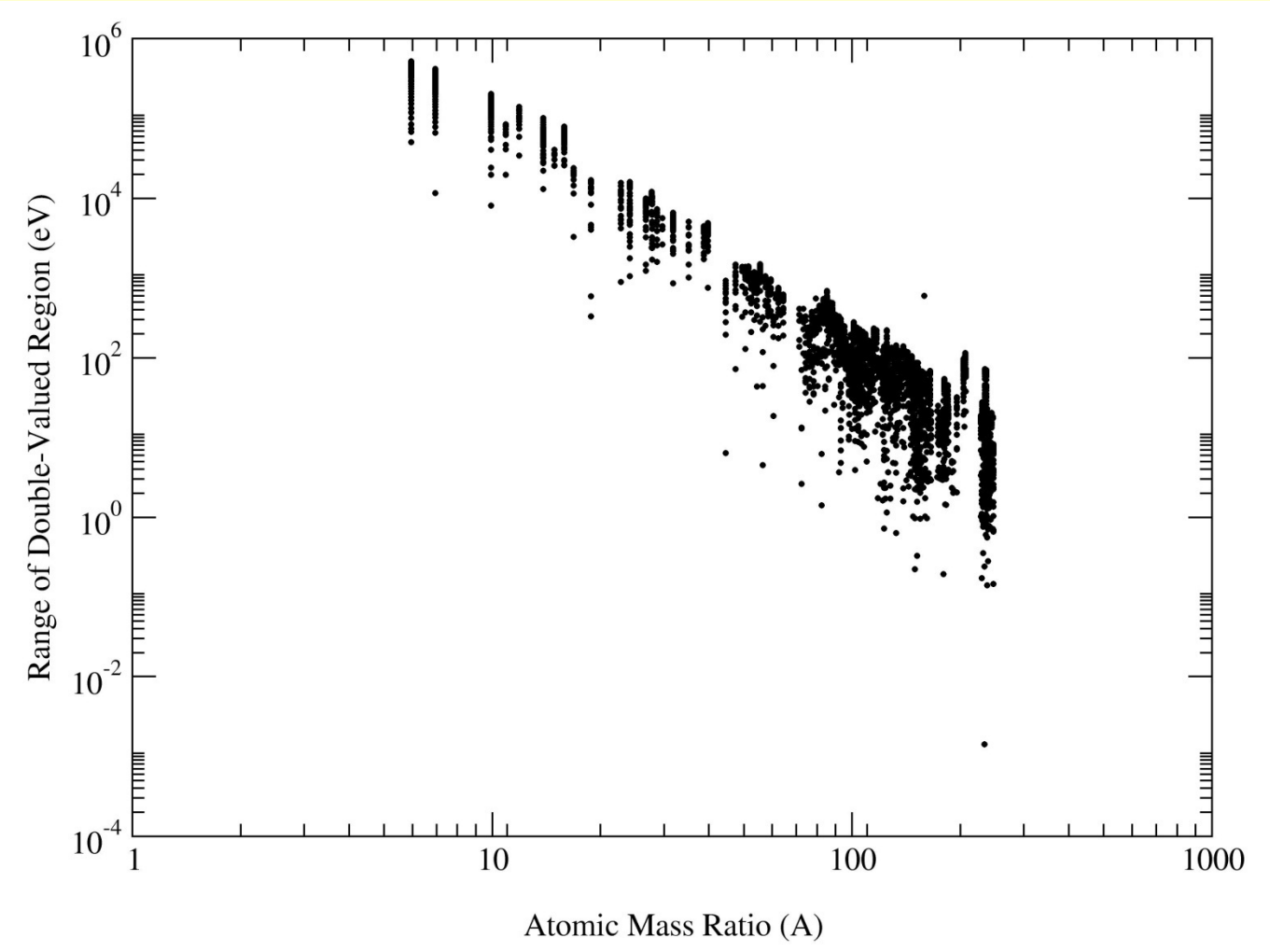
Must Account for Double-valued Region

Example: Discrete-Level Inelastic Scattering ^{7}Li MT=51



Range of Discrete-Level Inelastic Scattering Double-Value Region as a Function of Atomic Mass Ratio in Lab System

Note: hydrogen elastic scattering in lab system is double-valued for all incident energies



KENO CE Transport Development

- **Continuous-energy transport development started with SCALE 5 versions of KENO V.a and KENO VI**
- **Conforms to free-form FORTRAN 90/95 standard**
- **Minimized number of changes to user interface**
- **New material format specifications for a problem**
  - **Additional flexibility—override default cross-section data for a material**
  - **Easily substitute materials from different evaluation sources in a single problem**
- **New input parameters**
  - **Enable/disable probability-table treatment**
  - **Specify energy group/bin structure for calculated quantities and statistics**
  - **Control initial energy for sampling fission spectrum in first generation**

KENO CE Transport Development

- **Obsolescent features**
  - **Pre-calculated albedo data for selected materials no longer valid**
  - **No continuous-energy adjoint capability**
  - **Currently no cross-section plotting capability in transport code**
  - **All other KENO capabilities maintained in KENO CE (geometry, neutron starting distributions, biasing schemes, calculated quantities, etc.)**
- **KENO modifications/developments**
  - **Subroutines to read and process KENO CE cross-section data structure**
  - **Subroutines to read new material specification options**
  - **New transport procedures to sample KENO CE cross-section data**

KENO CE Transport Development

- **Continuous-energy transport**
  - **KENO processes user-specified number of neutron "histories" for a specified number of "generations"**
  - **Calculation begins by estimating fission source for problem in first generation**
    - **MG KENO spatial starting distributions maintained in CE KENO**
    - **Initial energy for each neutron sampled from pointwise fission spectrum for fissionable nuclide in mixture**
    - **For multiple fissionable nuclides in mixture, appropriate nuclide selected based on macroscopic fission cross section**
    - **Typically starting direction cosines sampled from isotropic distribution**
  - **Starting neutrons tracked until death or leakage from system**

Changes in the Sequences

- **A simple change in library name to initiate continuous energy mode**
- **CE_V7.0 to run with the ENDF/B-VII-based continuous energy cross sections**

multigroup		continuous energy
=csas25		=csas25
v6-238	→	ce_v7.0
read comp		read comp
….		….

Changes in the KENO codes

- **If fluxes are requested, they may be in one of the default multigroup structure or user may provide boundaries**
- **Probability table sampling for unresolved resonance range may be turned off**
- **Default cross section filename may be overriden by using extensions provided in the material information processor composition specifications**

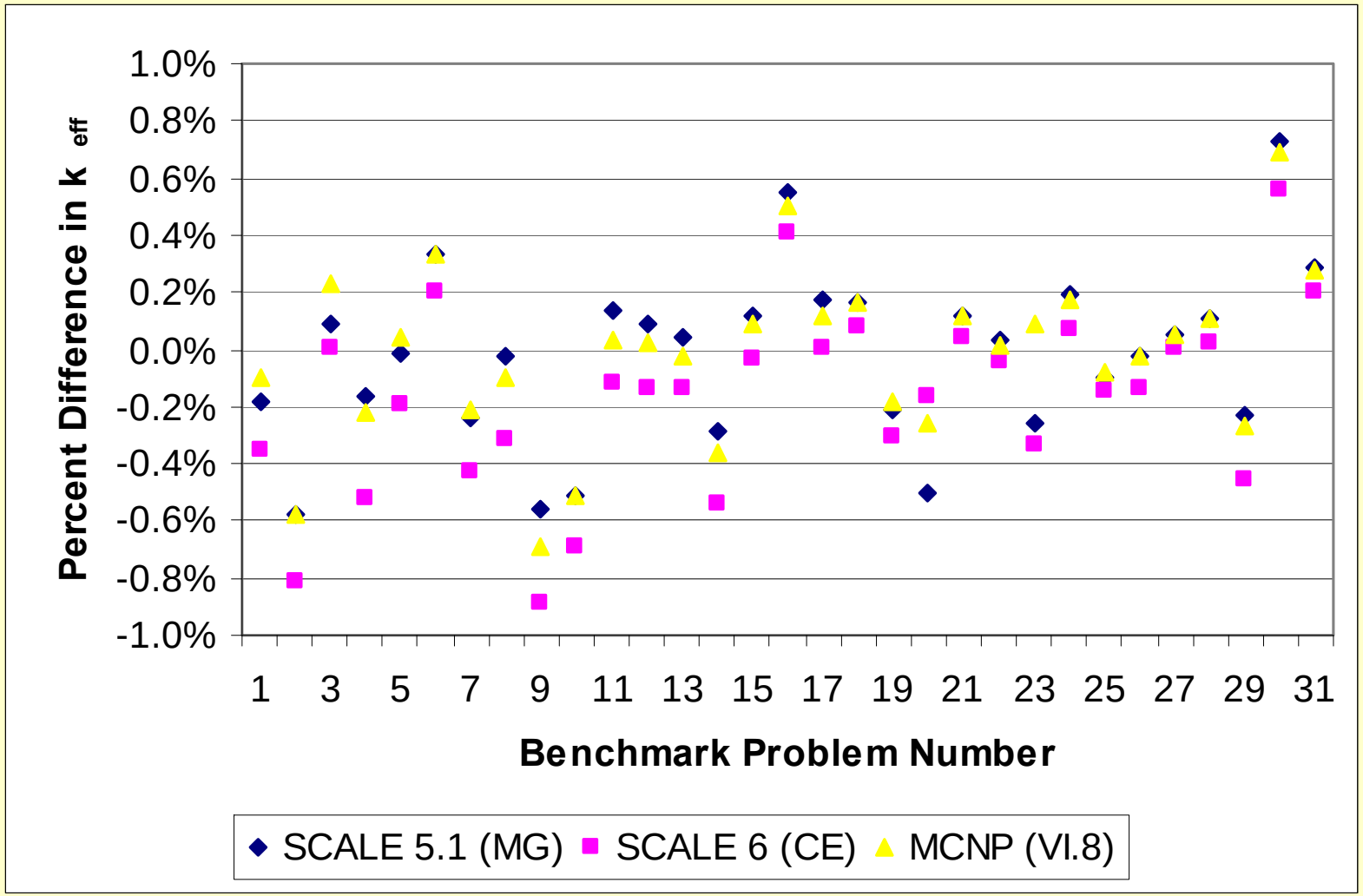
Selected SCALE Sample Problems

Sample problem	Description	KENO V.a multigroup	KENO V.a continuous energy	KENO-VI continuous energy	MCNP continuous energy
1	Case 2c8 bare	0.9940	0.9934	0.9927	0.9957
3	2c8 15.24 cm paraffin refl	0.9914	0.9935	0.9949	0.9975
6	One 2c8 unit (single unit)	0.7409	0.7411	0.7423	0.7447
9	Infinite array of 2c8 units	2.2586	2.2589	2.2588	2.2643
12	4 aqueous 4 metal arrays	0.9951	0.9976	0.9948	0.9995
13	Two cuboids in a cyl. annulus	0.9883	0.9922	0.9916	0.9929
14	U metal cylinder in annulus	0.9922	0.9963	0.9918	0.9943
15	Small water reflected sphere on Plexiglas collar	0.9983	0.9973	0.9954	0.9991
20	Triangular pitched array	0.9998	0.9919	0.9911	0.9933
21	Partially filled sphere	0.9951	0.9933	0.9943	0.9926

Validation

- **Selected problems from International Handbook of Evaluated Criticality Safety Benchmark Experiments**
- **Highly enriched (93%) solutions of uranyl nitrate**
- **Water-reflected spheres of enriched (93%) uranium oxyfluoride solutions**
- **Unreflected sphere of uranyl (93%) nitrate**
- **Unreflected cylinders of enriched (93%) uranyl nitrate solutions**

Validation


1.0%
0.8%
0.6%
0.4%
0.2%
0.0%
-0.2%
-0.4%
-0.6%
-0.8%
-1.0%
Percent Difference in k eff
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
Benchmark Problem Number
SCALE 5.1 (MG)
SCALE 6 (CE)
MCNP (VI.8)

Conclusions

- **Versatile, easy to use Monte Carlo codes**
- **User-friendly input and output capabilities**
  - **GeeWIZ, KENO-3D, HTML, Javapeno**
- **Continuous energy capability in SCALE 6**
- **Extensive validation**