TSUNAMI Sensitivity and Uncertainty Analysis Capabilities in SCALE 5.1

TSUNAMI

Tools for Sensitivity and UNcertainty Analysis Methodology Implementation

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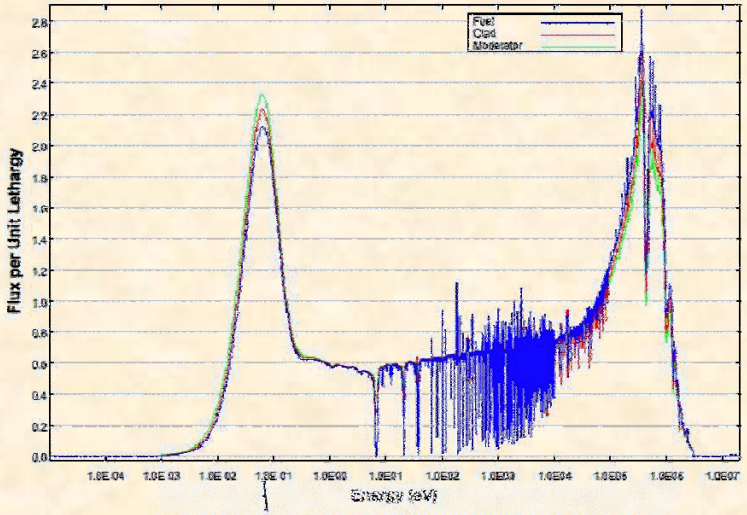
UT-BATTELLE

TSUNAMI for SCALE 5.1

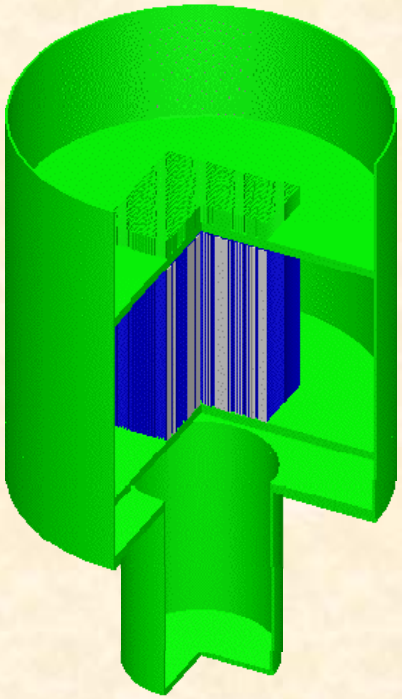
- **Tools for Sensitivity and UNcertainty Analysis Methodology Implementation**
- **TSUNAMI utilizes first-order-linear perturbation theory to produce the sensitivities of a computed k_{eff} value to cross-section data.**
- **The energy-dependent sensitivity data for each reaction of each nuclide in a system model can be quickly computed using TSUNAMI's 1-D and 3-D analysis tools.**
- **These sensitivity data can be coupled with cross-section-covariance data to produce an uncertainty in k_{eff} due to uncertainties in the evaluated nuclear data.**
- **Provides an advanced method to assess system similarity based on sensitivity and uncertainty data.**

TSUNAMI-3D



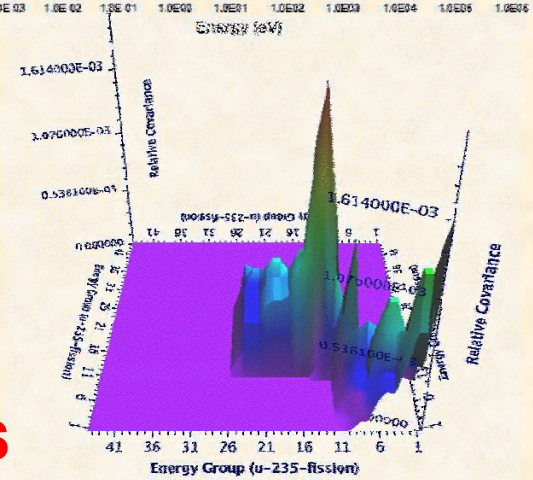
CENTRMST/PMCST

Continuous energy transport for multigroup cross-section preparation with "implicit effect", up to 40% contribution for thermal/intermediate systems

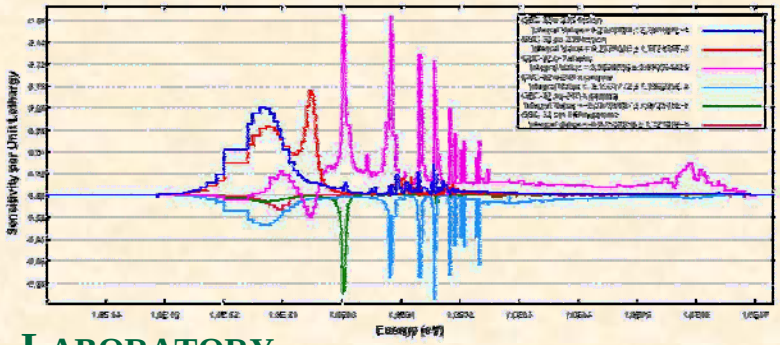


KENO V.a

Forward/Adjoint multigroup Monte Carlo flux calculation with angular moments



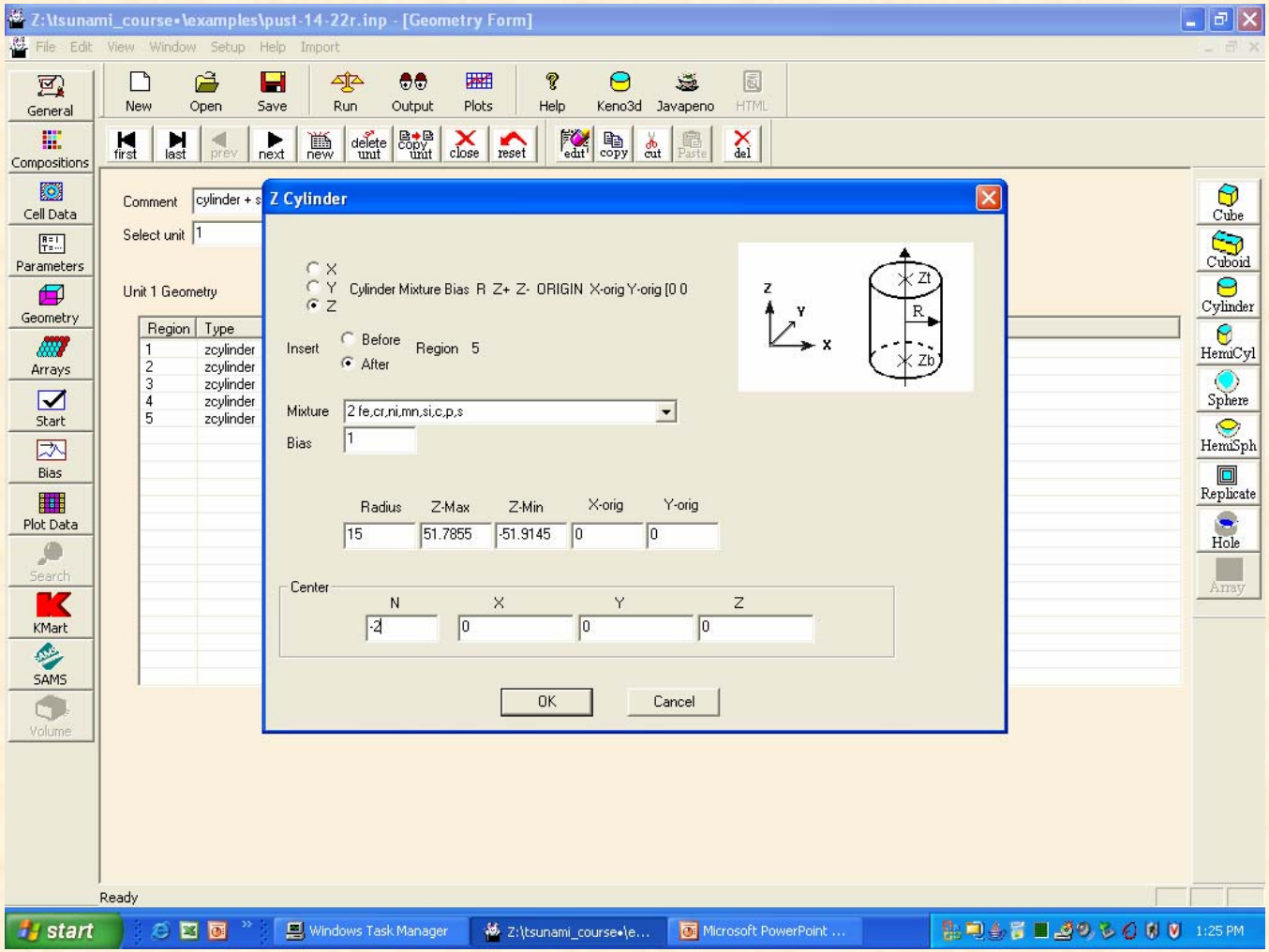
SAMS



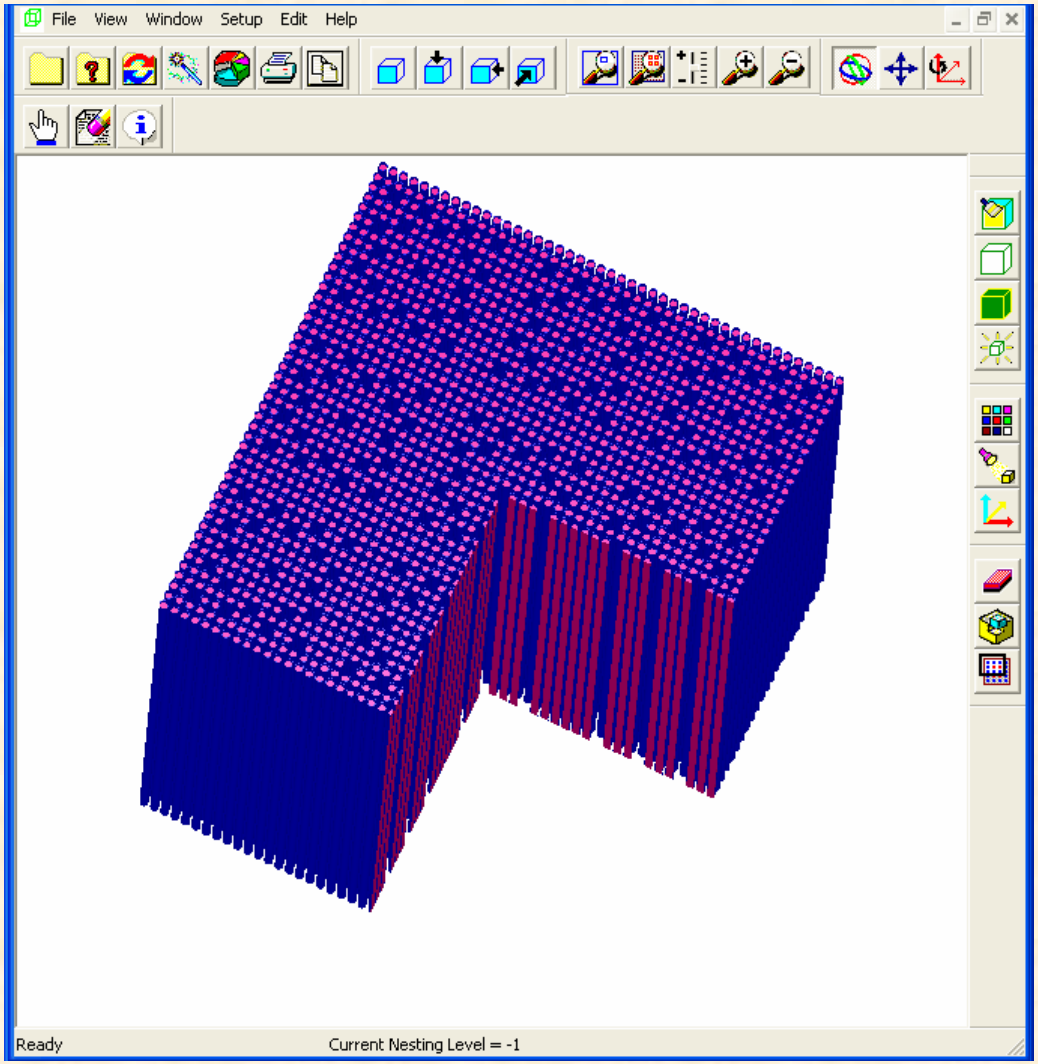
Sensitivity coefficient generation

Uncertainty propagation from cross-section covariance data to k_{eff}

GeeWiz Input GUI - TSUNAMI-3D



KENO3D Model Visualization



HTML Output

General Information

Input Data

Results

- Energy, Region and Mixture Integrated Sensitivity Coefficients for this Problem
- Energy and Region Integrated Sensitivity Coefficients for this Problem
- Sensitivity Coefficients by Region
- Total Sensitivity Coefficients by Nuclide
- Total Sensitivity Coefficients by Mixture
- Sensitivity Data Plot
- Problem Characterization
- Uncertainty Information

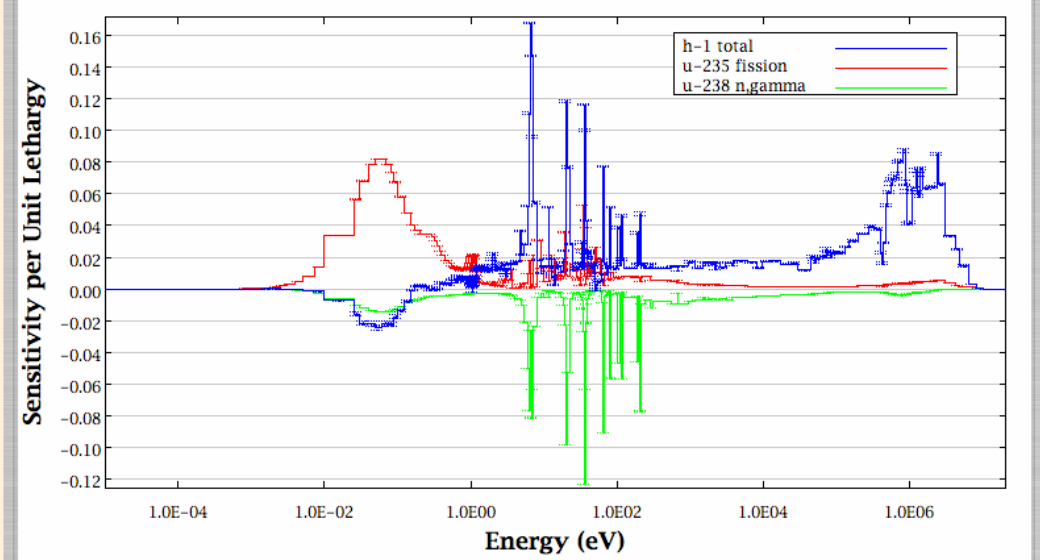
SAMS - Sensitivity Data Plot
u(2)f4 h/x=294

Plot of Sensitivity Data

Double-click an item on right side of window to plot, or select multiple items and right click to plot.

File Options Format Window Help

u-238 n,gamma



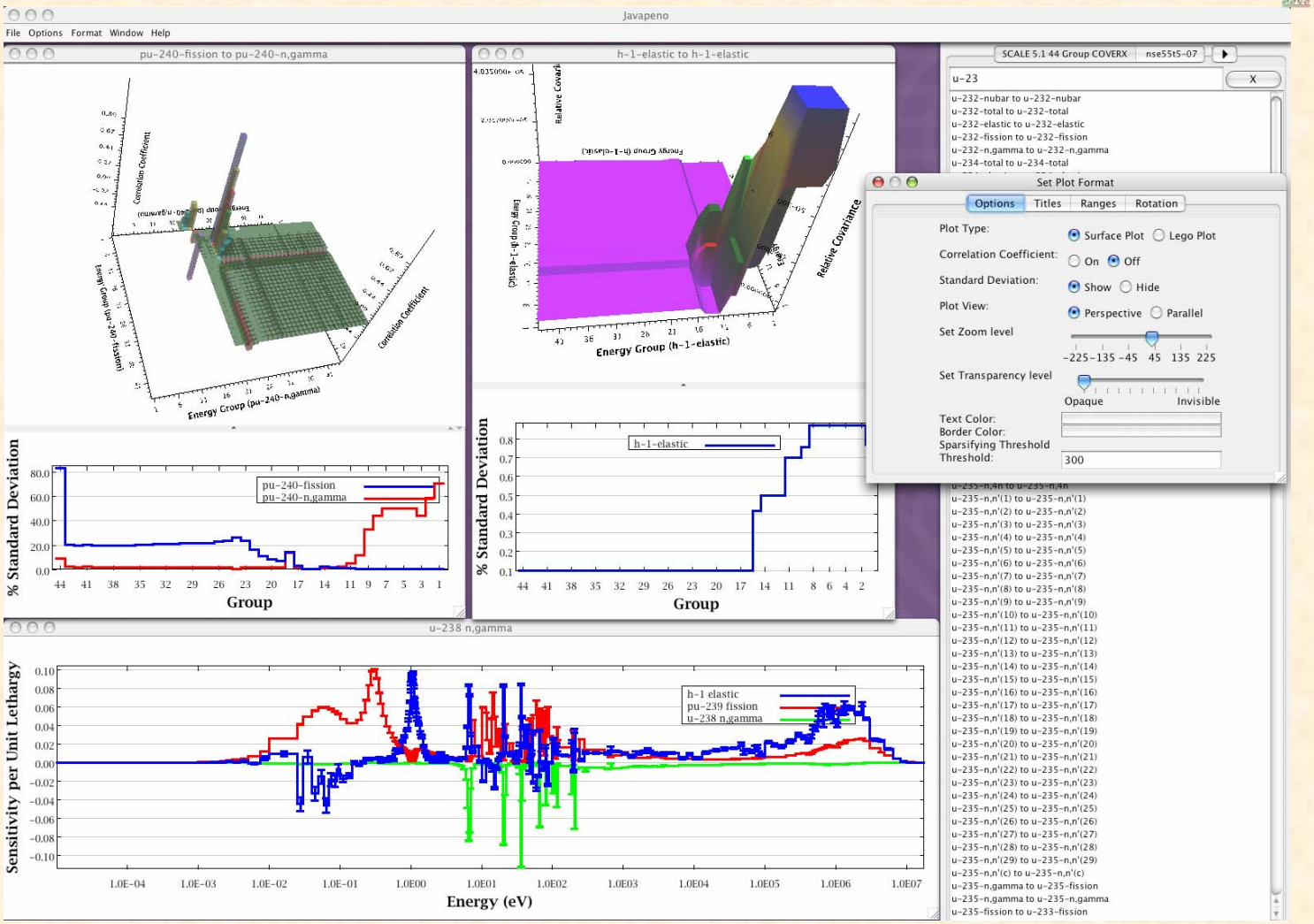
3x3-p800-20c-0gd-cb.sdf

X

Sort List | Unsort List

cu n,2n
cu capture
cu n,gamma
cu n,p
cu n,d
cu n,he-3
cu n,alpha
u-235 total
u-235 scatter
u-235 elastic
u-235 n,n'
u-235 n,2n
u-235 fission
u-235 capture
u-235 n,gamma
u-235 nubar
u-235 chi
u-238 total
u-238 scatter
u-238 elastic
u-238 n,n'
u-238 n,2n
u-238 fission
u-238 capture
u-238 n,gamma

Javapeño for SCALE 5.1

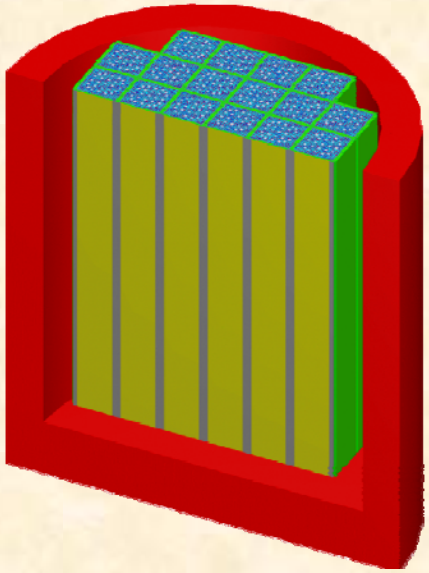


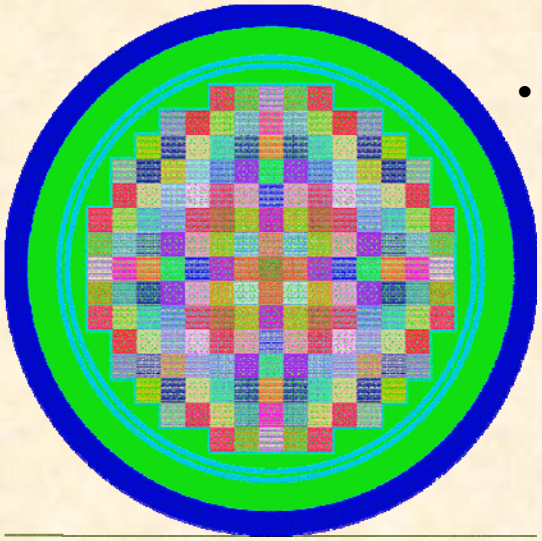
Procedure to Generate Comprehensive Covariance Library

- Process all ENDF/B-VI covariances *(49 nuclides)*
- *Covariance data processed from other sources if cross sections are the same*
  - *ENDF/B-V covariances for 1 nuclide (^{10}B)*
  - *JENDL 3.3 covariances for 7 nuclides*
  - *CENDL 2 covariance for 2 nuclides*
  - *JEF 3.1 covariances for 1 nuclide*
- *Fission spectrum, χ, data generated for 9 nuclides*
- Approximate covariances of other missing nuclides by **integral measurement uncertainties -** Mughabghab data *(>250 nuclides)*
  - **σ_c, σ_f, υ covariance for E<0.5 eV based thermal data uncertainty, with full correlation**
  - **σ_c, σ_f covariance for 0.5<E<5E3 eV based on resonance integral, with full correlation**
  - **σ_s covariance for moderators based on uncertainty in potential cross section, fully correlated**
- *ENDF/B-VII evaluations for Gd, ^{239}Pu, ^{233}U, ^{235}U under final review at ORNL*
- *Additional fast spectrum data are being generated by ANL, LANL, BNL for DOE NCSP*

Applications of TSUNAMI-3D to Complex Models

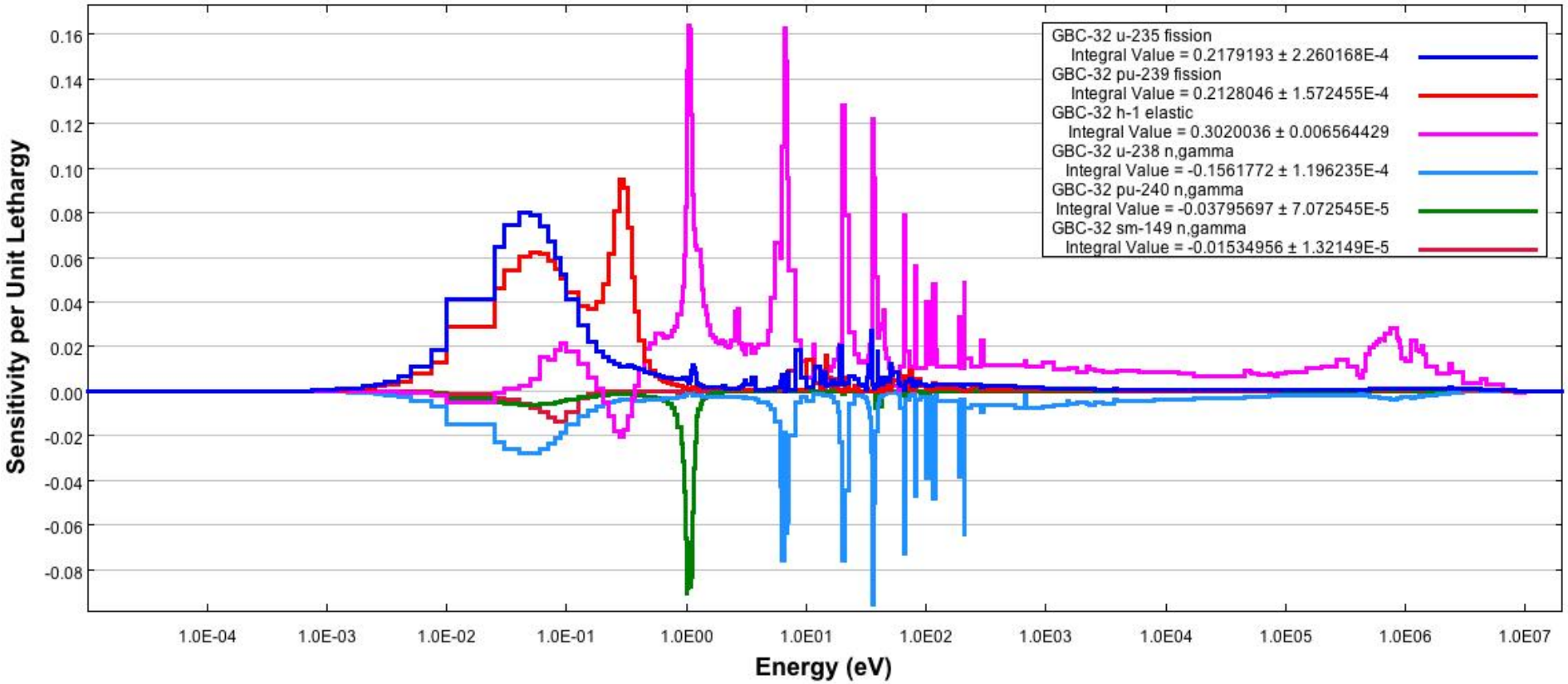
- **Burnup Credit Cask Model**
  - 32 PWR fuel assemblies in flooded cask
  - 18 axial burnup zones
  - Burned to 40 GWd/MTU; Cooled for 5 years
  - BORAL™ plates around each assembly
  - Cask filled with water





- **Commercial Reactor Criticals (CRC)**
  - Startup data from PWRs (Crystal River)
  - 1/2 core models
  - Each pin explicitly modeled with 18 axial zones
  - Sensitivity coefficients for ~47,000 nuclides, ~420,000 44-group profiles

Sample Sensitivity Data
GBC-32 Cask Model



Uncertainties in k_{eff} due to cross-section covariance data

the relative standard deviation of k_{eff} (% Δk/k) is: 0.7801 ± 0.0014 percent

contributions to uncertainty in k_{eff} (% Δk/k) by individual energy covariance matrices:

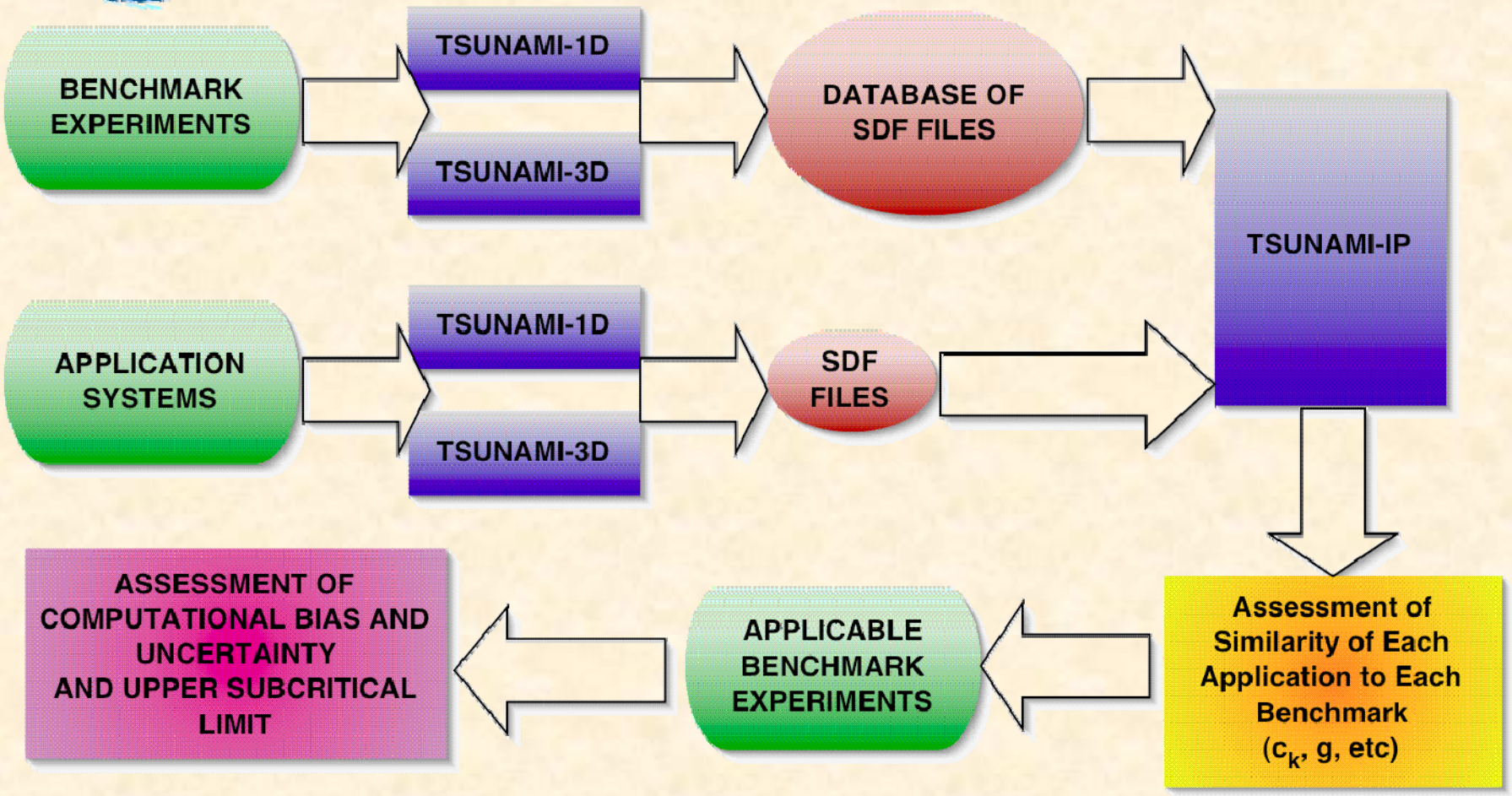
Covariance Matrix		% Δk/k
Nuclide-Reaction	Nuclide-Reaction	Due to this Matrix
^{239}Pu nubar	^{239}Pu nubar	4.0360E-01 ± 2.1906E-05
^{235}U nubar	^{235}U nubar	3.1966E-01 ± 2.4377E-05
^{238}U n,gamma	^{238}U n,gamma	3.0136E-01 ± 1.8184E-04
^{1}H elastic	^{1}H elastic	2.2194E-01 ± 3.1527E-03
^{239}Pu n,gamma	^{239}Pu n,gamma	2.0158E-01 ± 1.2298E-04
^{239}Pu nubar	^{235}U nubar	1.7537E-01 ± 9.3253E-06
^{239}Pu fission	^{239}Pu fission	1.5359E-01 ± 6.4343E-05
^{241}Pu nubar	^{241}Pu nubar	1.3552E-01 ± 7.9327E-06
^{235}U n,gamma	^{235}U n,gamma	1.1715E-01 ± 8.2721E-05
^{239}Pu chi	^{239}Pu chi	1.1106E-01 ± 2.6532E-04

Application of TSUNAMI to Criticality Code Validation

TSUNAMI

Tools for Sensitivity and UNcertainty Analysis Methodology Implementation

Validation Study with TSUNAMI



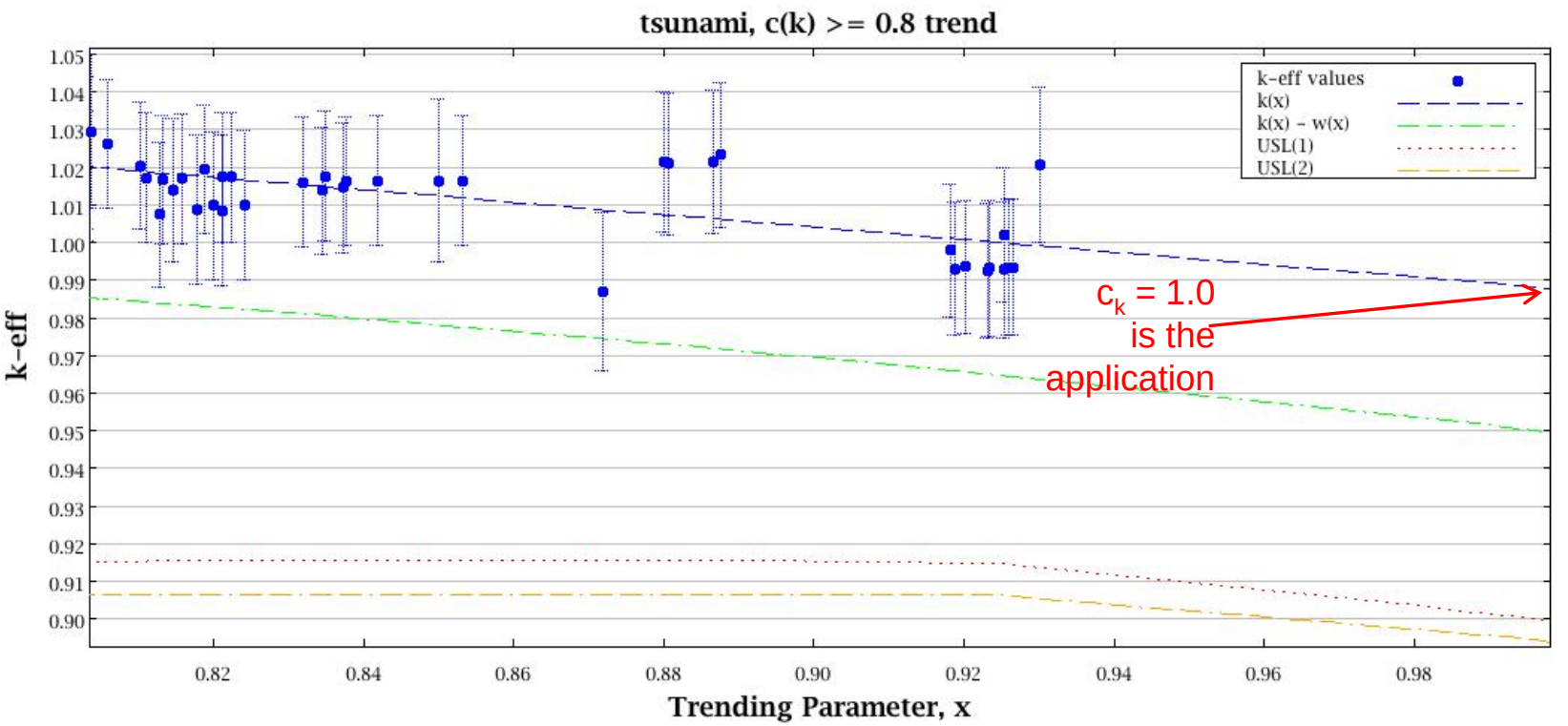
Correlation Coefficient, c_k

- **Basis:**
  - **experimental and methods uncertainties are well quantified**
  - **computational biases are primarily caused by discrepancies in nuclear data, which are bounded by their uncertainties**
- **Correlation of cross-section uncertainties between two systems:**

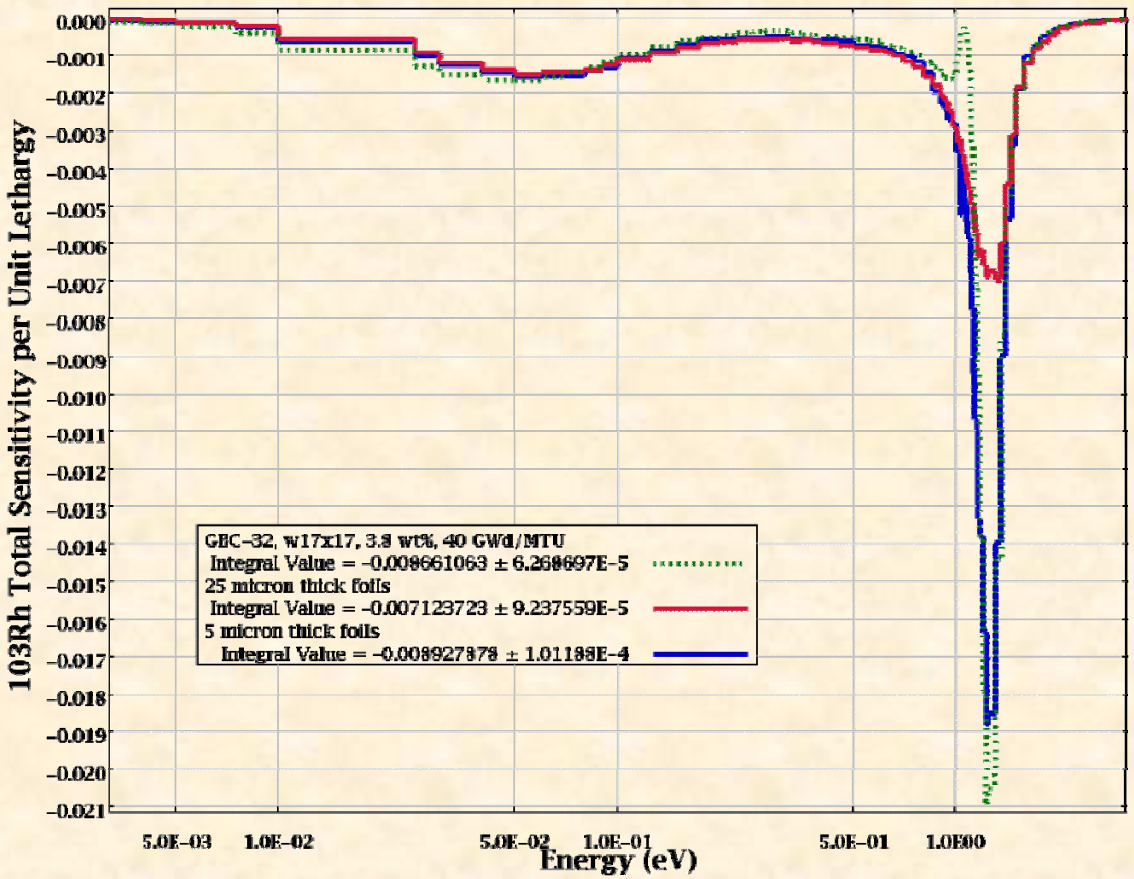
$$c_k = \frac{\sigma_{21}^2}{\sigma_1 \sigma_2}$$

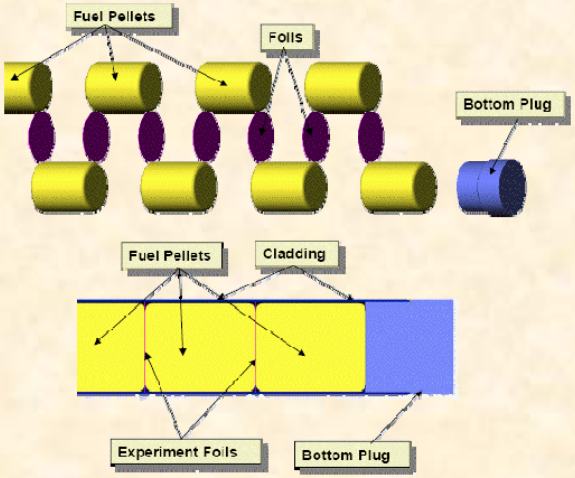
  - **Normalized such that c_k of 1.0 indicates systems are identical; 0.0 indicates systems are completely different.**

Extrapolation to c_k=1.0 to Predict Bias of Application



Experiment Design Optimization: Rh-103 from SNL BUCCX





ORNL Production-Level S/U Capabilities

- **Production level 1-D and 3-D eigenvalue analysis for entire fuel cycle**
- **Graphical interfaces and data visualization for ease-of-use**
- **Specifically mentioned in NRC's ISG-10 for criticality code validation**
- **TSUNAMI training for criticality code validation**
  - **10 multiday classes taught since 2004, ~180 participants**
  - **Next class at OECD/NEA in Paris, February 2008**

TSUNAMI for SCALE 6

- **TSUNAMI-3D with KENO-VI**
- **Allows more accurate geometry representation**
- **Easily model hexagonally pitched arrays**
- **Flexible mesh for flux calculation**
- **Uses standard TSUNAMI multigroup forward/adjoint calculations**
- **Couples directly with other TSUNAMI codes, BONAMIST, NITAWST, CENTRMST, PMCST, SAMS, TSUNAMI-IP**

TSUNAMI for Other Responses

- **Shielding Analysis**
  - **Sensitivity to cross sections of**
    - **n+γ nuclear heating**
    - **n+γ dose**
    - **detector for primary or neutron-capture gammas**
- **Generalized Perturbation Theory**
  - **Sensitivity of breeding ratios to cross sections**
  - **Reactivity sensitivities in single pass**
  - **1-D (XSDRNPM) and 2-D (NEWT) tools under development for SCALE 6**

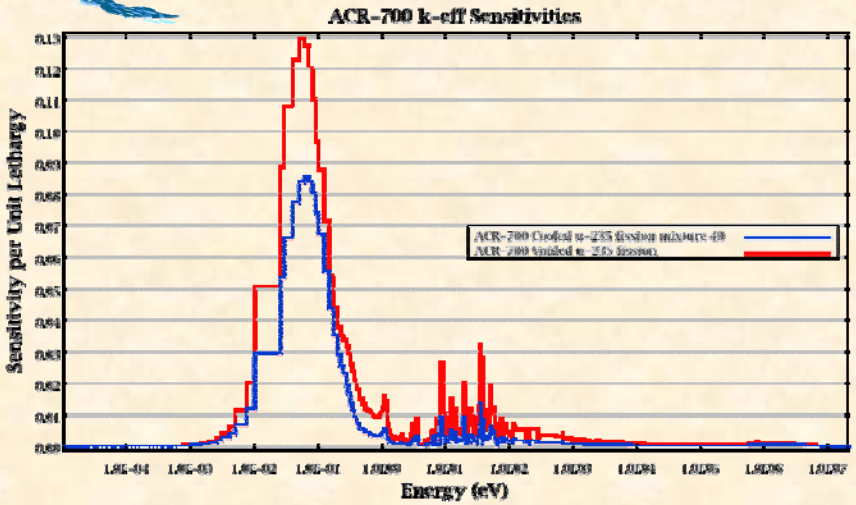
TSUNAMI for SCALE 6

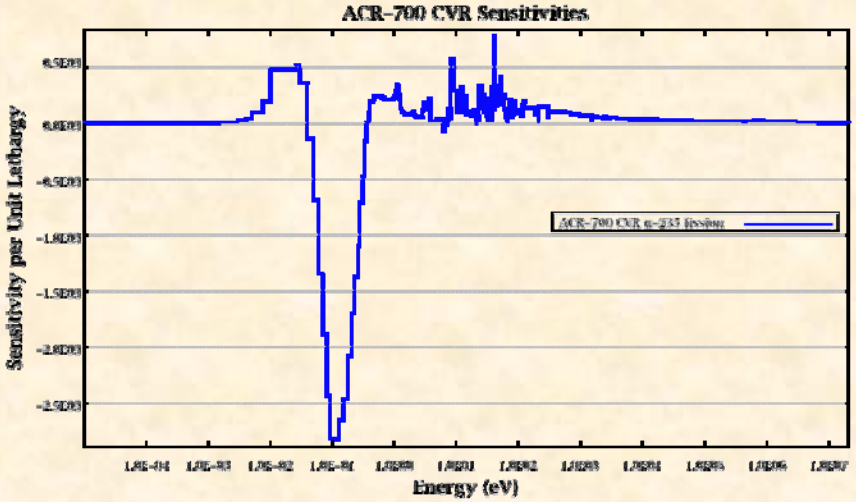
- **Data Adjustment tool TSURFER**
  - **Simultaneously examines measured and calculated data and adjusts integral experiment values within their uncertainties and cross sections within their uncertainties to produce consistency between measured can computed results.**
  - **Uses TSUNAMI sensitivity data for uncertainty propagation and to determine optimum adjustments**
  - **Can consolidate useful data from different types of experiments that each contribute to the validation of the application**

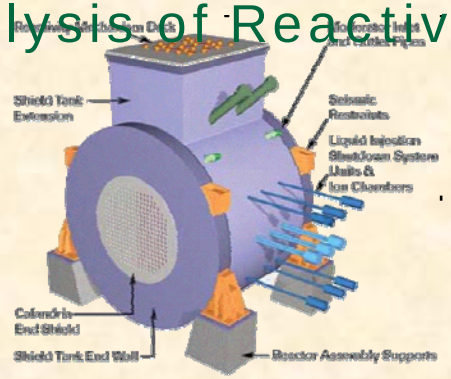
TSUNAMI for SCALE 6

- **Reactivity sensitivity analysis tool TSAR**
- **Uses two TSUNAMI k_{eff} sensitivity calculations and examines the sensitivity of the differences in k_{eff} to the cross section data.**
- **Can determine uncertainties and similarities of k_{eff} changes.**
- **Magnifies important processes that can lead to biases in k_{eff} changes.**
- **Example: When using replacement experiments that test one material in a fuel matrix, the difference in k_{eff} of the experiment with and without the test material is due primarily to any bias introduced by the test material. TSAR will give the sensitivity of the change in k_{eff} due to this test material.**
- **This data can then be used in TSURFER to apply the bias from the test material to system of interest**

Reactivity Sensitivity and Uncertainty Analysis
TSAR - Tool for Sensitivity Analysis of Reactivity

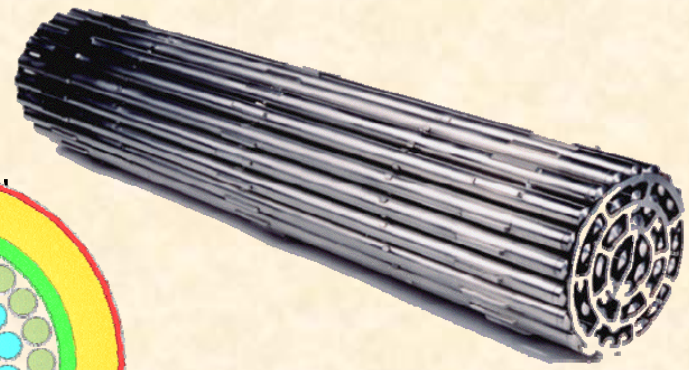


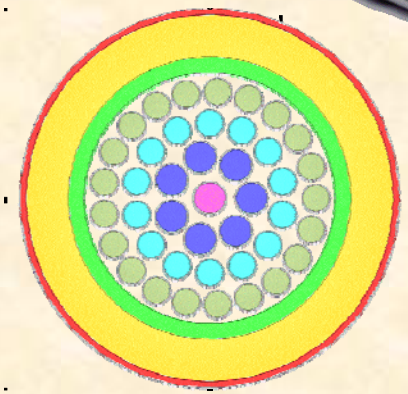




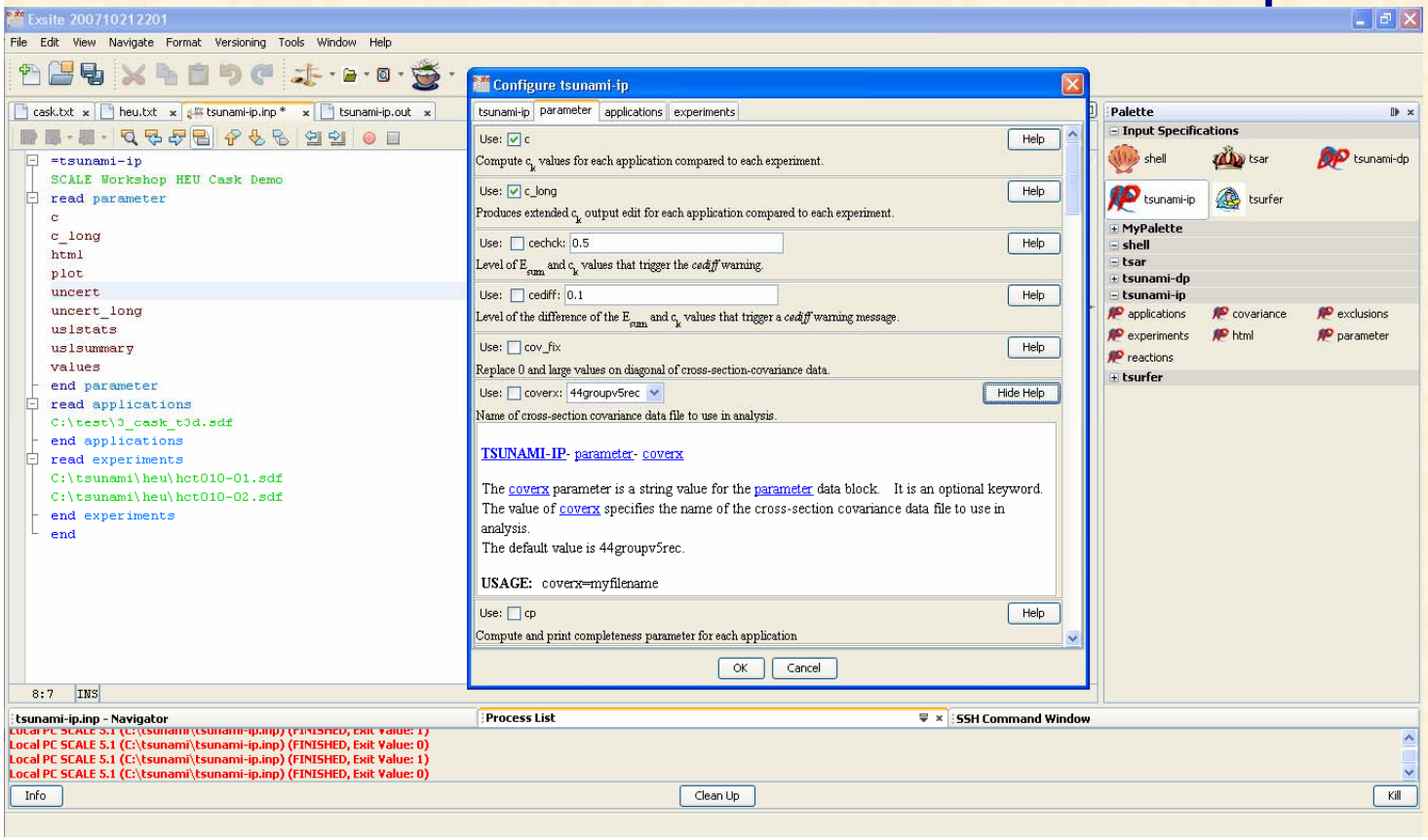
Response Uncertainties Due to Nuclear Data Covariances

Response	Relative Standard Deviation (%)
Multiplication factor for state 1	0.80
Multiplication factor for state 2	0.84
Coolant void reactivity (CVR)	49.8



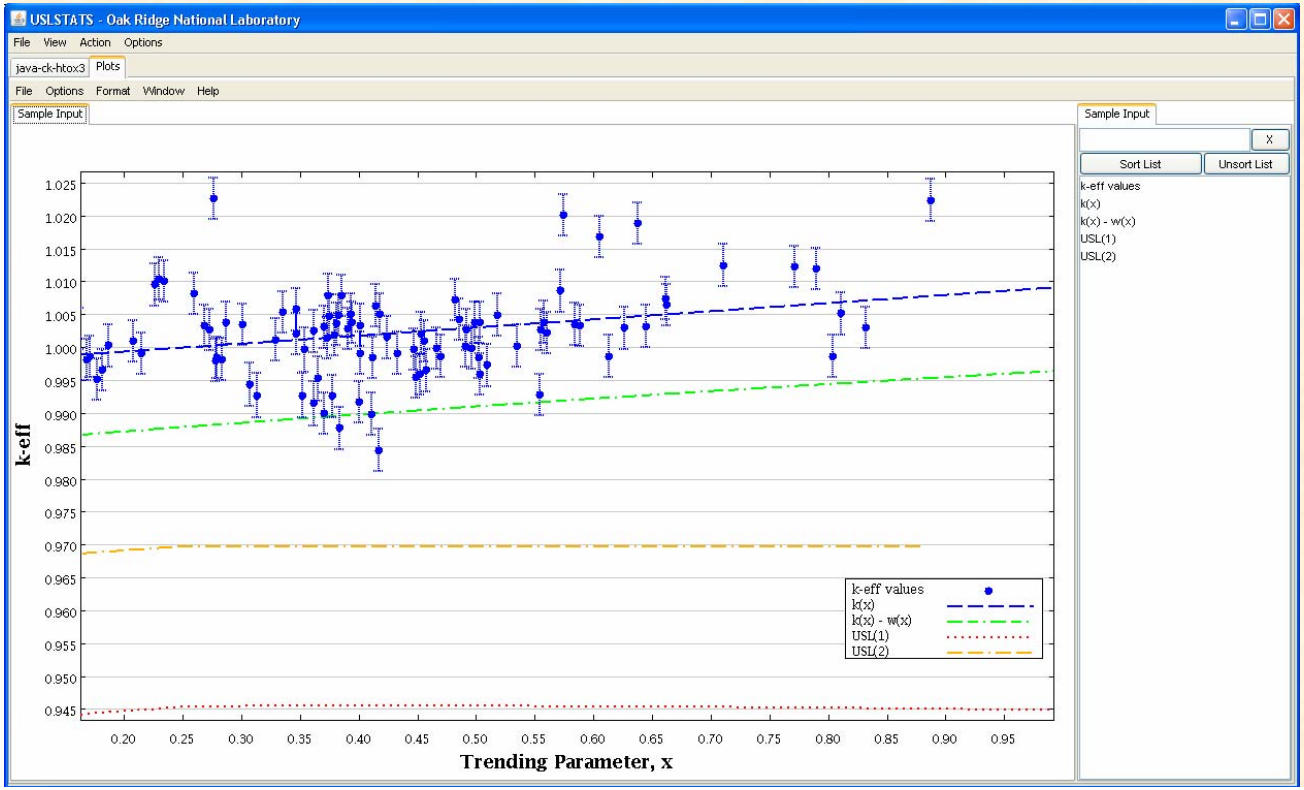


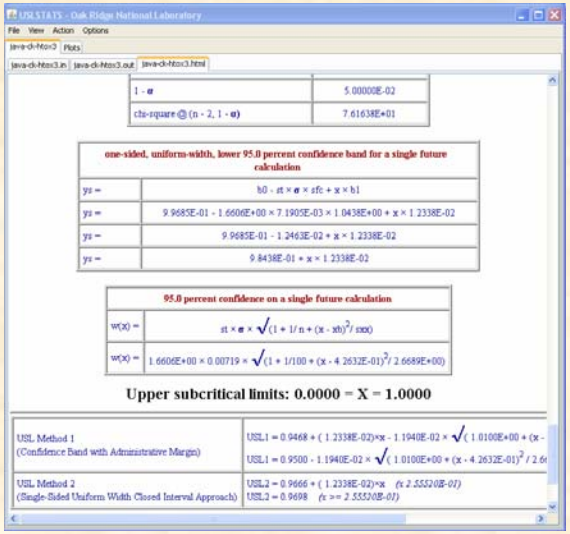
- Versatile GUI for SCALE
- Text input with auto-complete and syntax checking
- Dynamic palette for input assistance
- Works on PC/Linux/Unix/Mac
- Execute SCALE on local or remote systems
- View text or HTML output
- Plot data with Javapeño

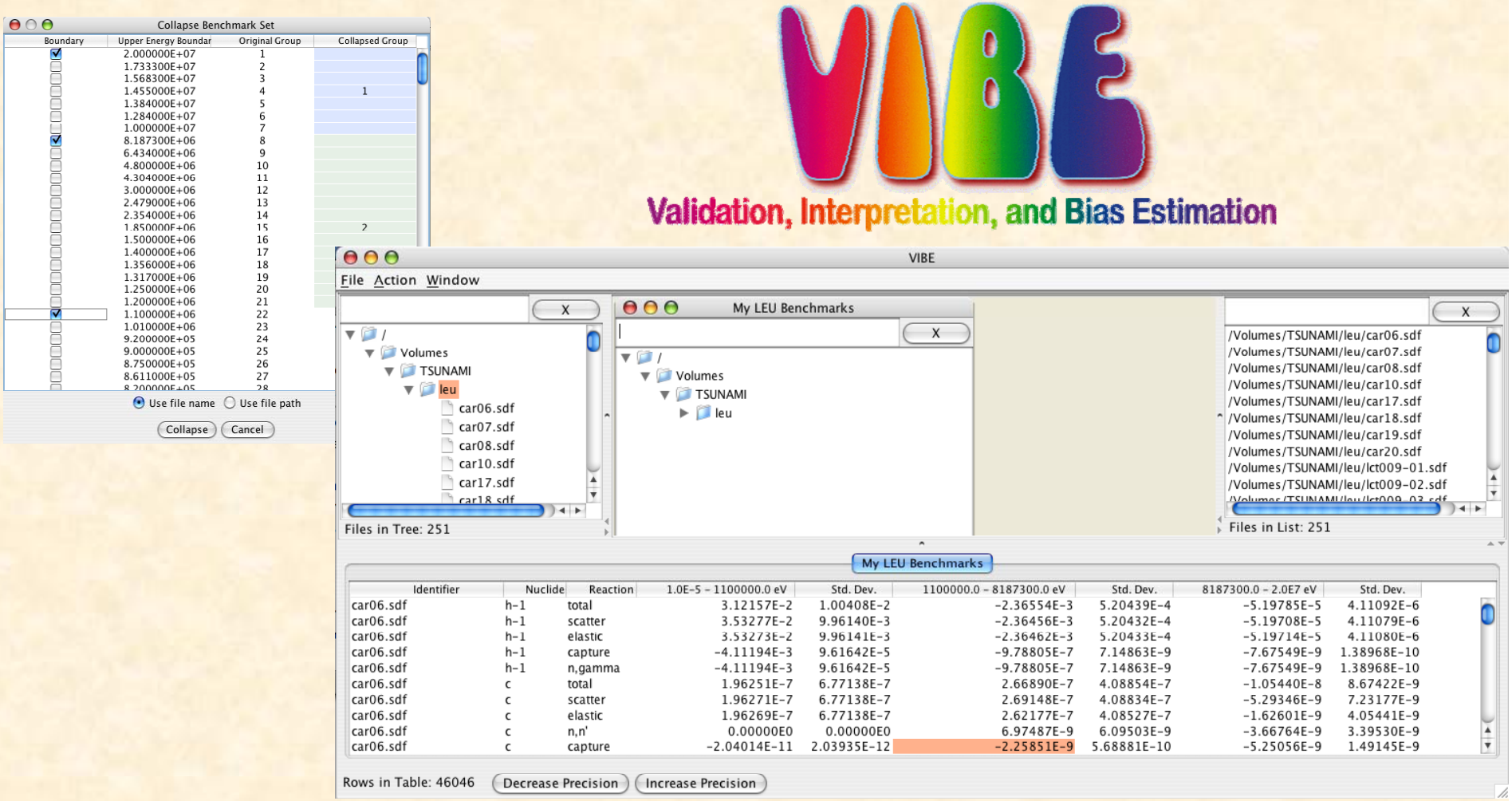


USLSTATS

- Classic statistical package for parametric bias and bias uncertainty estimation; reborn
- Code entirely rewritten in Java with integrated GUI for input, output, plotting
- Linear and non-linear confidence bands
- Interpolation and extrapolation
- HTML formatted output







- **Locate and group TSUNAMI data files for TSUNAMI-IP and TSURFER Input**
- **Perform group collapse of sensitivity data**
- **Filter TSUNAMI files; Sort and filter sensitivity data**
- **Couple with USLSTATS for trending analysis**
- **Developed in collaboration with University of New Mexico**