Recent Use of Covariance Data for Criticality Safety Analysis

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Workshop on Neutron Cross Section Covariances

Port Jefferson, New York

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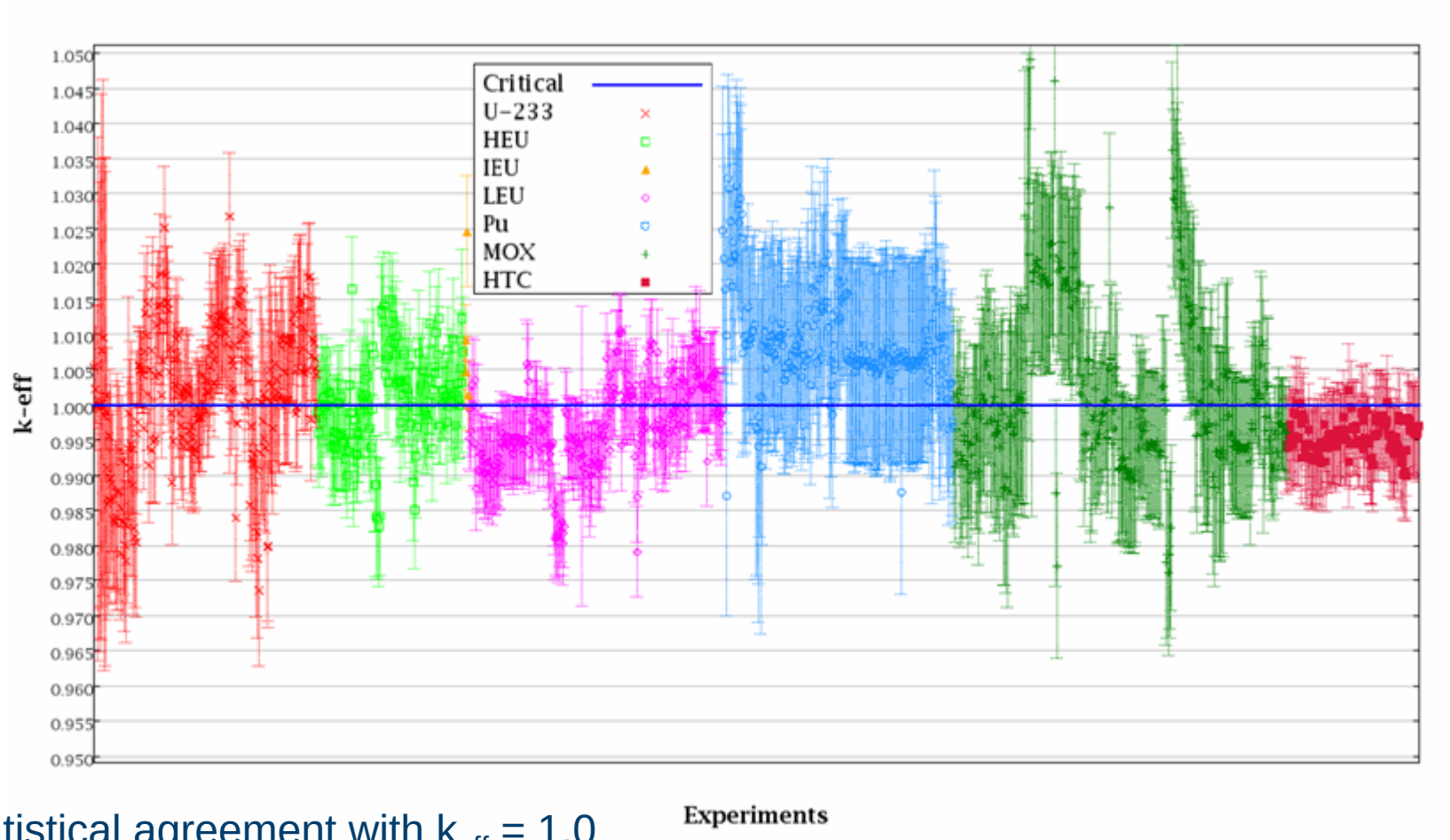
Criticality Safety Assessment

- **ANS/ANSI 8.24 Standard requires validation of computational methods with comparison to experimental data that are similar to the safety application.**
- **Bias and uncertainty in bias must be quantified with defensible methods.**
- **Subcriticality of safety application must be ensured.**
- **An Upper Subcritical Limit (USL) is established as maximum allowed *computed* value of k_{eff} for safety application.**

Uses of Covariance Data in TSUNAMI Criticality Safety Assessment

- **Uncertainty quantification for applications and benchmark experiments**
  - **Uncertainty should bound most computational bias**
- **Rigorous assessment of similarity between applications and benchmarks**
- **Trending bias as a function of similarity leads to accurate bias prediction**
- **Gap analysis – quantification of uncertainty in application that is not covered by benchmarks (penalty assessment)**
- **Data adjustment to quantify bias in application**

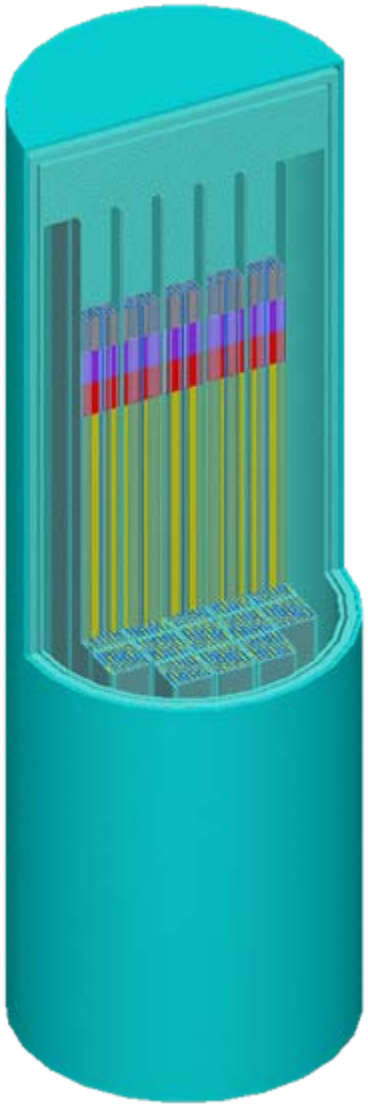
k_{eff} and Uncertainty for 1378 Critical Experiments

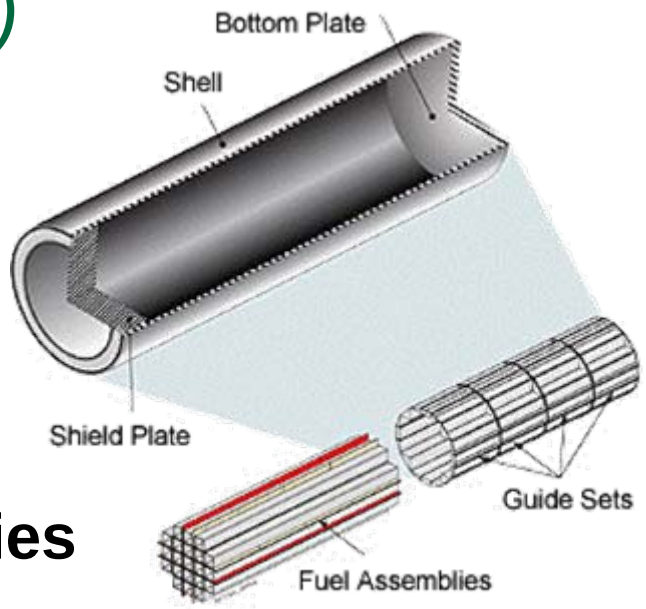


Statistical agreement with k_{eff} = 1.0

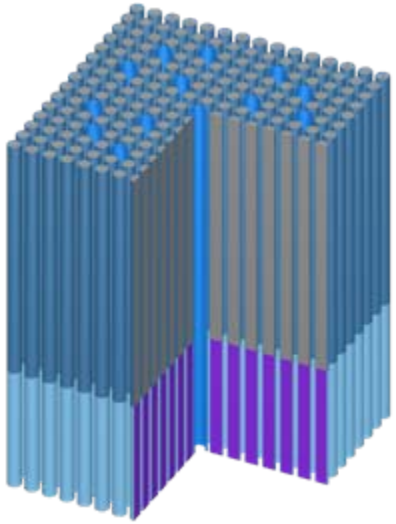
- 68% agree within 1 σ
- 95% agree within 2 σ
- 98% agree within 3 σ

Yucca Mountain Transportation, Aging and Disposal Canister (TAD)





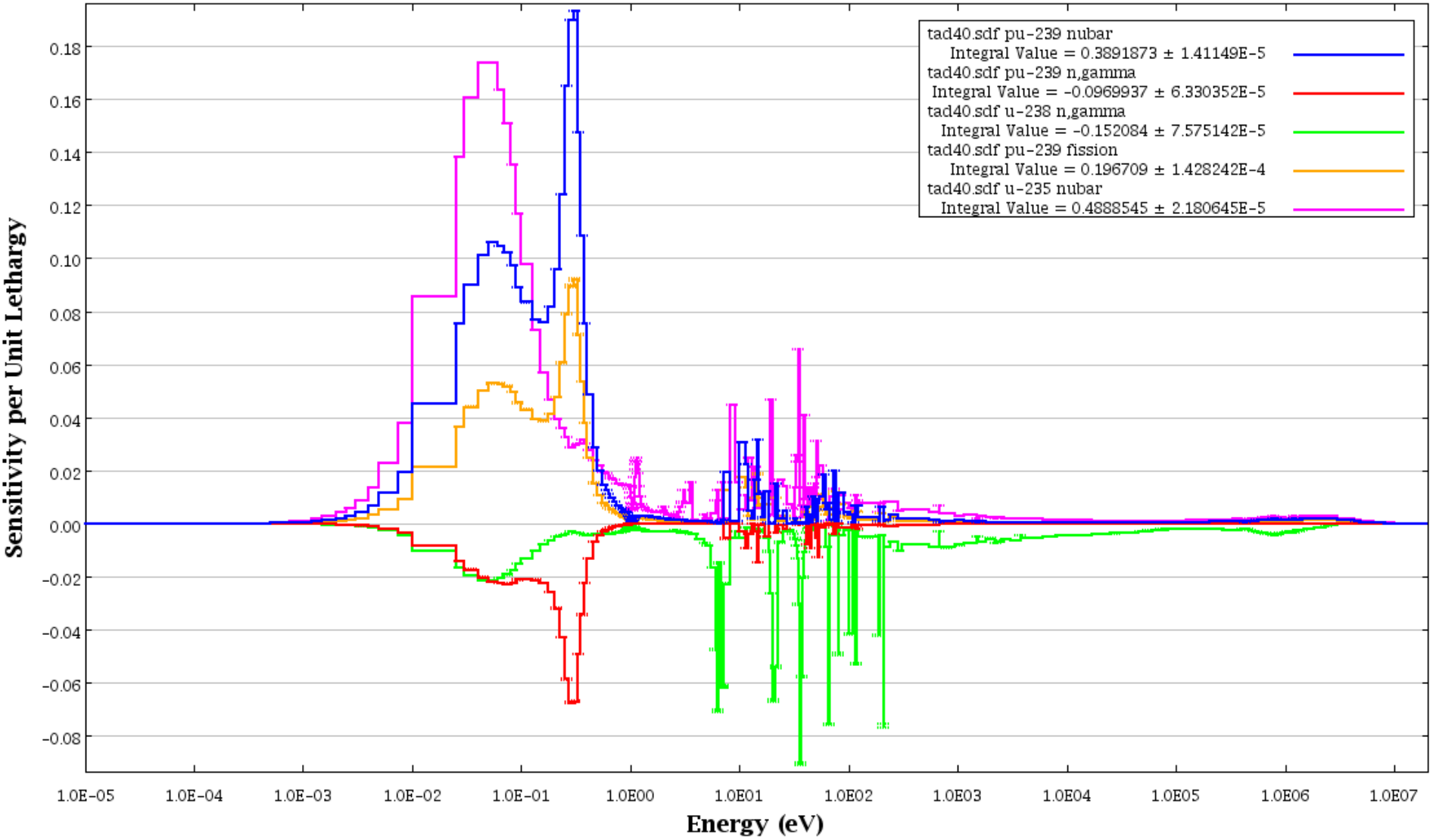
- **21 15×15 PWR Assemblies**
- **Initial enrichment of 4 wt-%**
- **Burned to 40 GWD/MT**
- **Flooded waste package surrounded by tuff**
- **Stainless steel sheaths and borated steel plates**



Nuclides in TAD Model

Spent Fuel		Cladding		Moderator	Steel Sheaths		Borated Steel		Tuff
^{16}O	^{233}U	^{16}O	^{112}Sn	^{1}H	C	^{54}Fe	^{10}B	^{55}Mn	^{16}O
^{95}Mo	^{234}U	^{50}Cr	^{114}Sn	^{16}O	^{14}N	^{56}Fe	^{11}B	^{54}Fe	^{23}Na
^{99}Tc	^{235}U	^{52}Cr	^{115}Sn		Si	^{57}Fe	C	^{56}Fe	Mg
^{101}Ru	^{236}U	^{53}Cr	^{116}Sn		^{31}P	^{58}Fe	^{14}N	^{57}Fe	^{27}Al
^{103}Rh	^{238}U	^{54}Cr	^{117}Sn		^{32}S	^{58}Ni	Si	^{58}Fe	Si
^{109}Ag	^{237}Np	^{54}Fe	^{118}Sn		^{50}Cr	^{60}Ni	^{31}P	^{59}Co	^{31}P
^{143}Nd	^{238}Pu	^{56}Fe	^{119}Sn		^{52}Cr	^{61}Ni	^{32}S	^{58}Ni	K
^{145}Nd	^{239}Pu	^{57}Fe	^{120}Sn		^{53}Cr	^{62}Ni	^{50}Cr	^{60}Ni	Ca
^{147}Sm	^{240}Pu	^{58}Fe	^{122}Sn		^{54}Cr	^{64}Ni	^{52}Cr	^{61}Ni	Ti
^{149}Sm	^{241}Pu	Zr	^{124}Sn		^{55}Mn	Mo	^{53}Cr	^{62}Ni	^{55}Mn
^{150}Sm	^{242}Pu						^{54}Cr	^{64}Ni	^{54}Fe
^{151}Sm	^{241}Am								^{56}Fe
^{152}Sm	^{242}Am								^{57}Fe
^{151}Eu	^{243}Am								^{58}Fe
^{153}Eu									
^{155}Gd									

Sensitivity Profiles for TAD



Uncertainty Assessment

the relative standard deviation of k_{eff} (% Δk/k) is: 0.5982 ± 0.0001 percent

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

Values colored Blue represent default covariance data

Values colored RoyalBlue represent default covariance data used to correct zeros or large values in some groups

Covariance Matrix		% Δk/k
Nuclide-Reaction	Nuclide-Reaction	Due to this Matrix
^{239}Pu nubar	^{239}Pu nubar	4.0032E-01 ± 7.5161E-06
^{239}Pu n,gamma	^{239}Pu n,gamma	2.2350E-01 ± 8.7365E-05
^{238}U n,gamma	^{238}U n,gamma	2.2281E-01 ± 1.0662E-04
^{239}Pu fission	^{239}Pu fission	1.5511E-01 ± 4.8605E-05
^{235}U nubar	^{235}U nubar	1.3980E-01 ± 3.5216E-06

Covariance Corrections

the relative standard deviation of k_{eff} (% Δk/k) is: 0.5982 ± 0.0001 percent

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

Values colored Blue represent default covariance data

Values colored RoyalBlue represent default covariance data used to correct zeros or large values in some groups

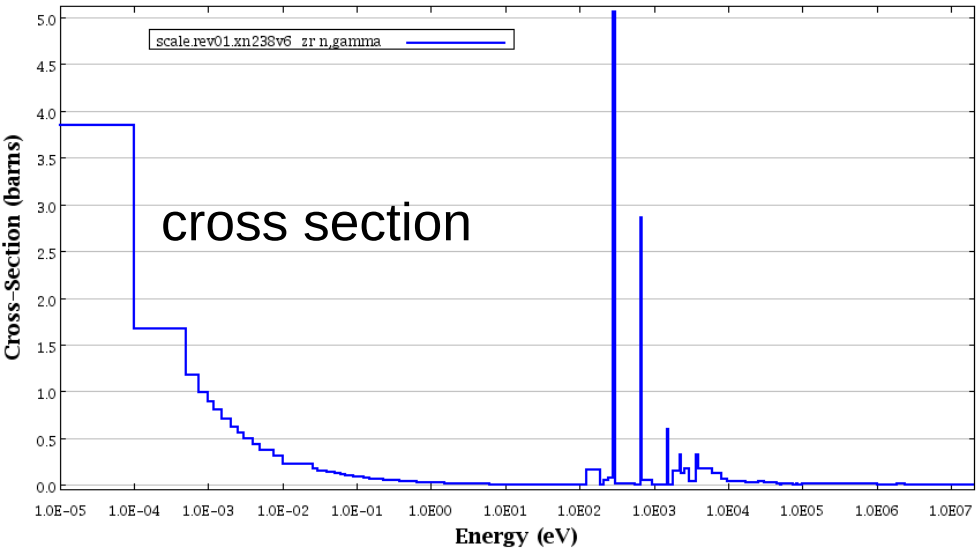
Zr n,gamma	Zr n,gamma	4.7340E-02 ± 3.4363E-05
^{1}H elastic	^{1}H elastic	4.6046E-02 ± 4.8722E-04
^{240}Pu n,gamma	^{240}Pu n,gamma	4.5968E-02 ± 1.9746E-05
^{143}Nd n,gamma	^{143}Nd n,gamma	4.1819E-02 ± 1.4049E-05
^{16}O n,alpha	^{16}O n,alpha	4.1657E-02 ± 2.9547E-05
^{238}U nubar	^{238}U nubar	3.7379E-02 ± 1.3133E-06
^{1}H n,gamma	^{1}H n,gamma	2.9560E-02 ± 1.8114E-05

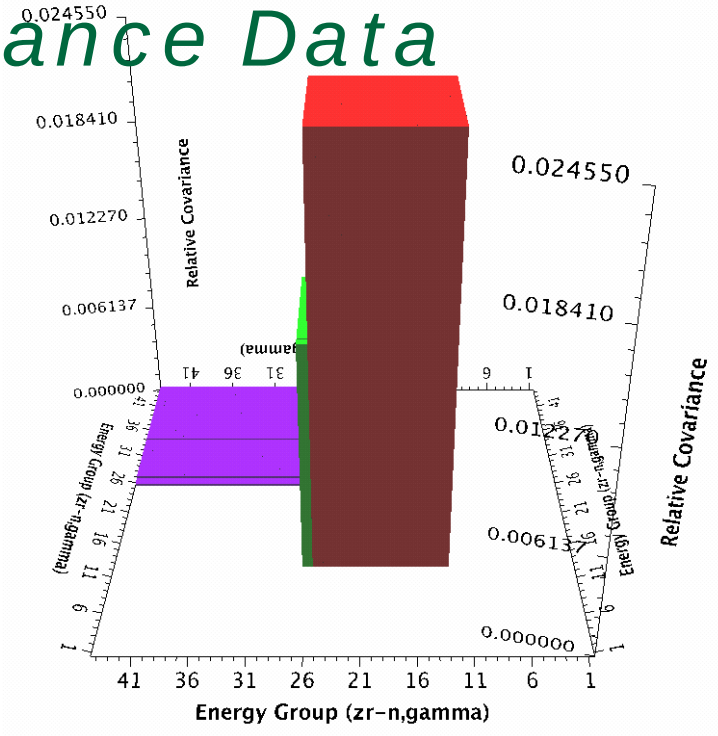
TSUNAMI-IP cov_fix

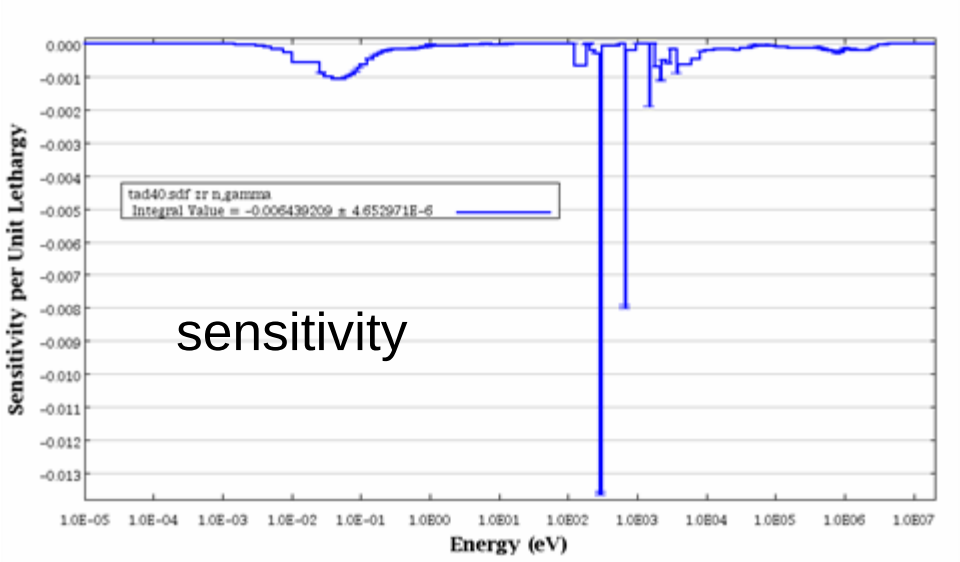
Covariance Warnings for Application #1 tad40

WARNING: cov_fix applied for application 1 zr n,gamma
Default standard deviation data value 0.0500 will replace 0.0000 for group 1
Default standard deviation data value 0.0500 will replace 0.0000 for group 2
Default standard deviation data value 0.0500 will replace 0.0000 for group 3
Default standard deviation data value 0.0500 will replace 0.0000 for group 4
Default standard deviation data value 0.0500 will replace 0.0000 for group 5
Default standard deviation data value 0.0500 will replace 0.0000 for group 6
Default standard deviation data value 0.0500 will replace 0.0000 for group 7
Default standard deviation data value 0.0500 will replace 0.0000 for group 8
Default standard deviation data value 0.0500 will replace 0.0000 for group 9
Default standard deviation data value 0.0500 will replace 0.0000 for group 10
Default standard deviation data value 0.0500 will replace 0.0000 for group 11
Default standard deviation data value 0.0500 will replace 0.0000 for group 12

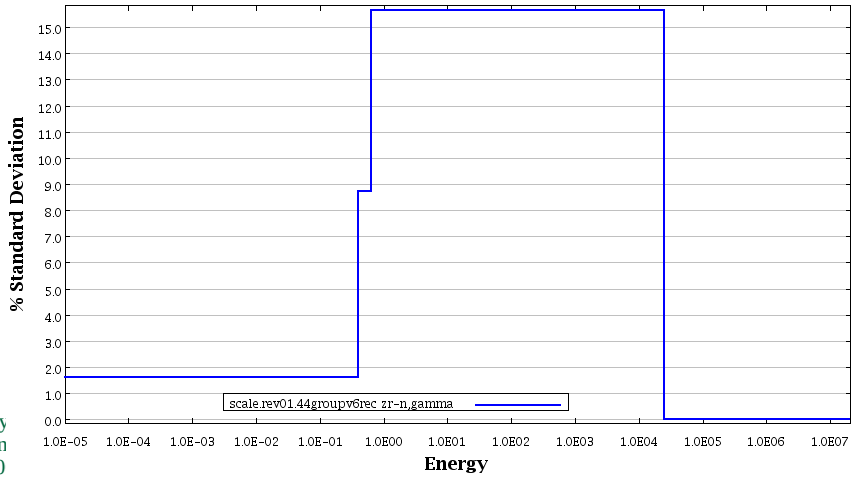
Zr n,gamma Low-Fi Covariance Data



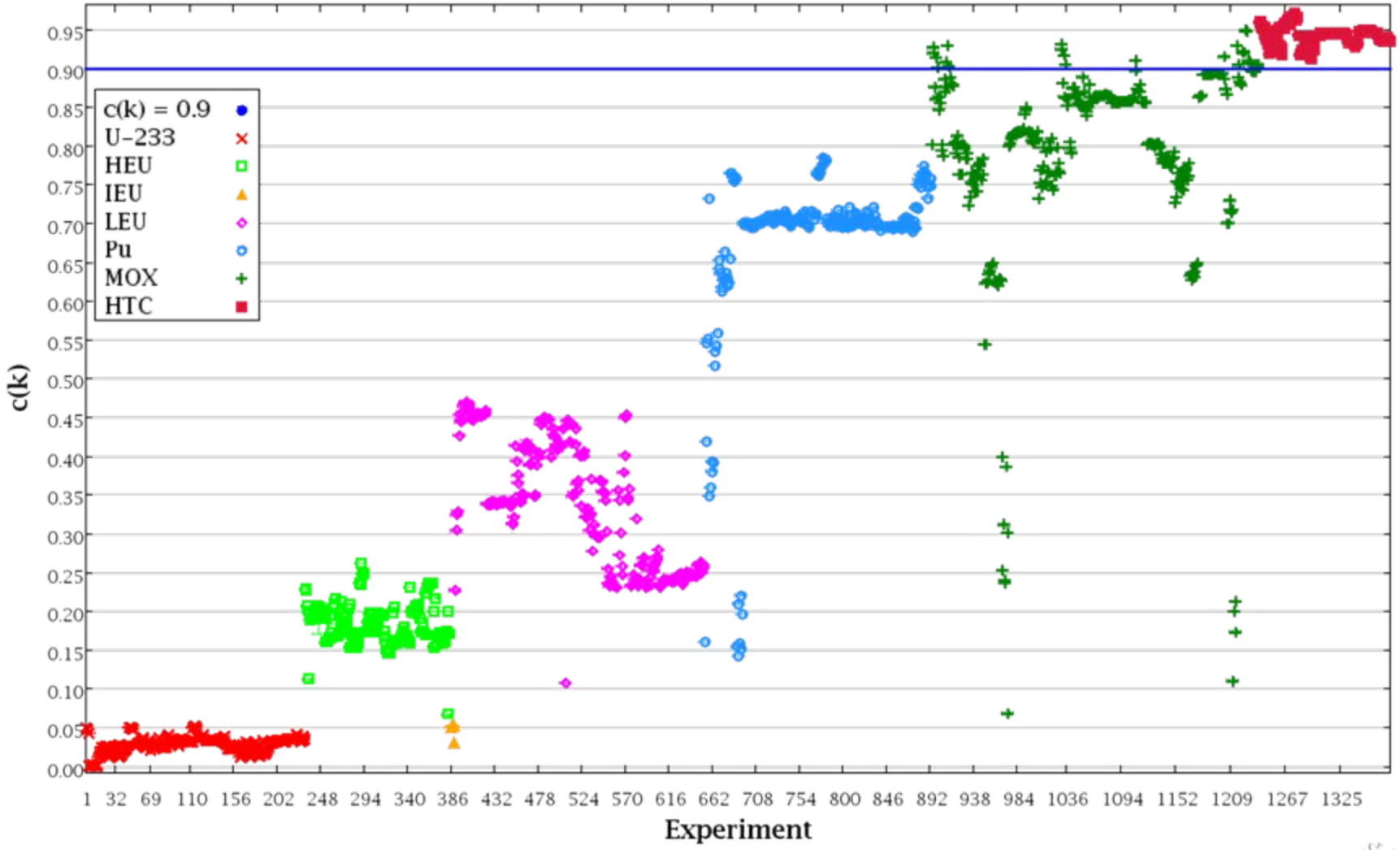




Uniform uncertainty in intermediate energies and no values for fast data



c_k Values for 1378 Experiments Relative to TAD Canister



Acceptable Benchmark Set

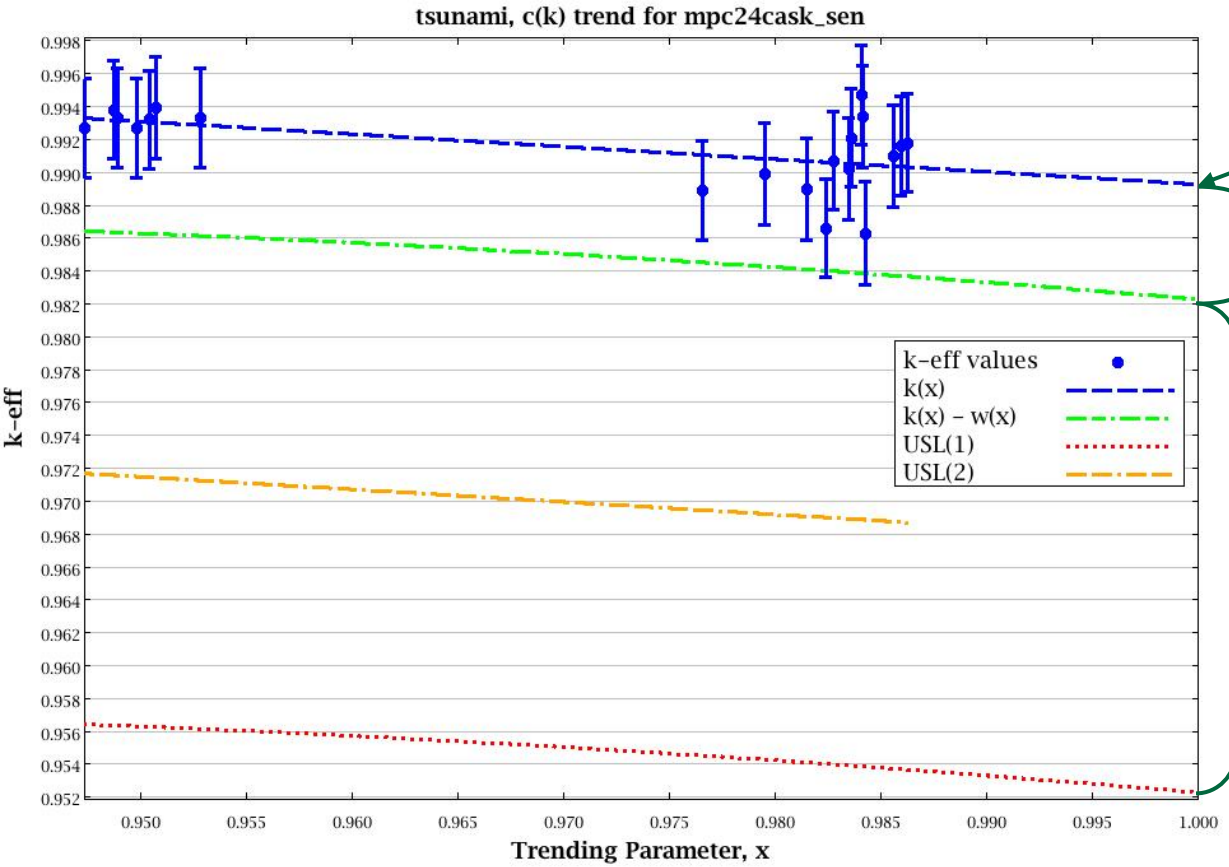
TRAINING MATERIAL

USLSTATS

Examine normality of data
Perform regression/extrapolation

WARNING *** the test for normal may be unreliable due to insufficient data

χ^2 = 3.0000 (upper bound = 9.49). The data tests normal



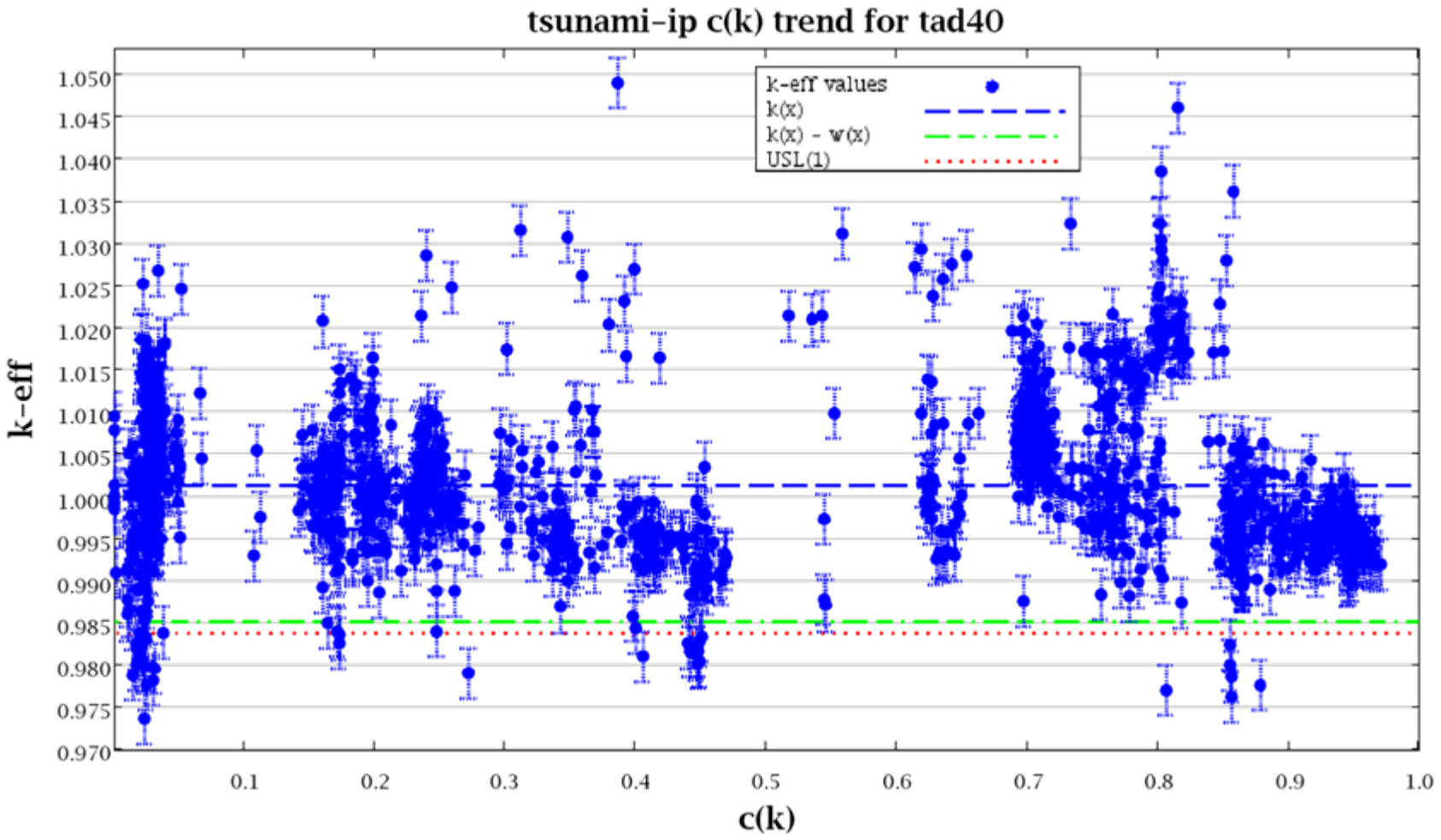
Biased k_{eff} for Application
(bias is this intercept - 1.0)

Confidence band
(uncertainty in bias)

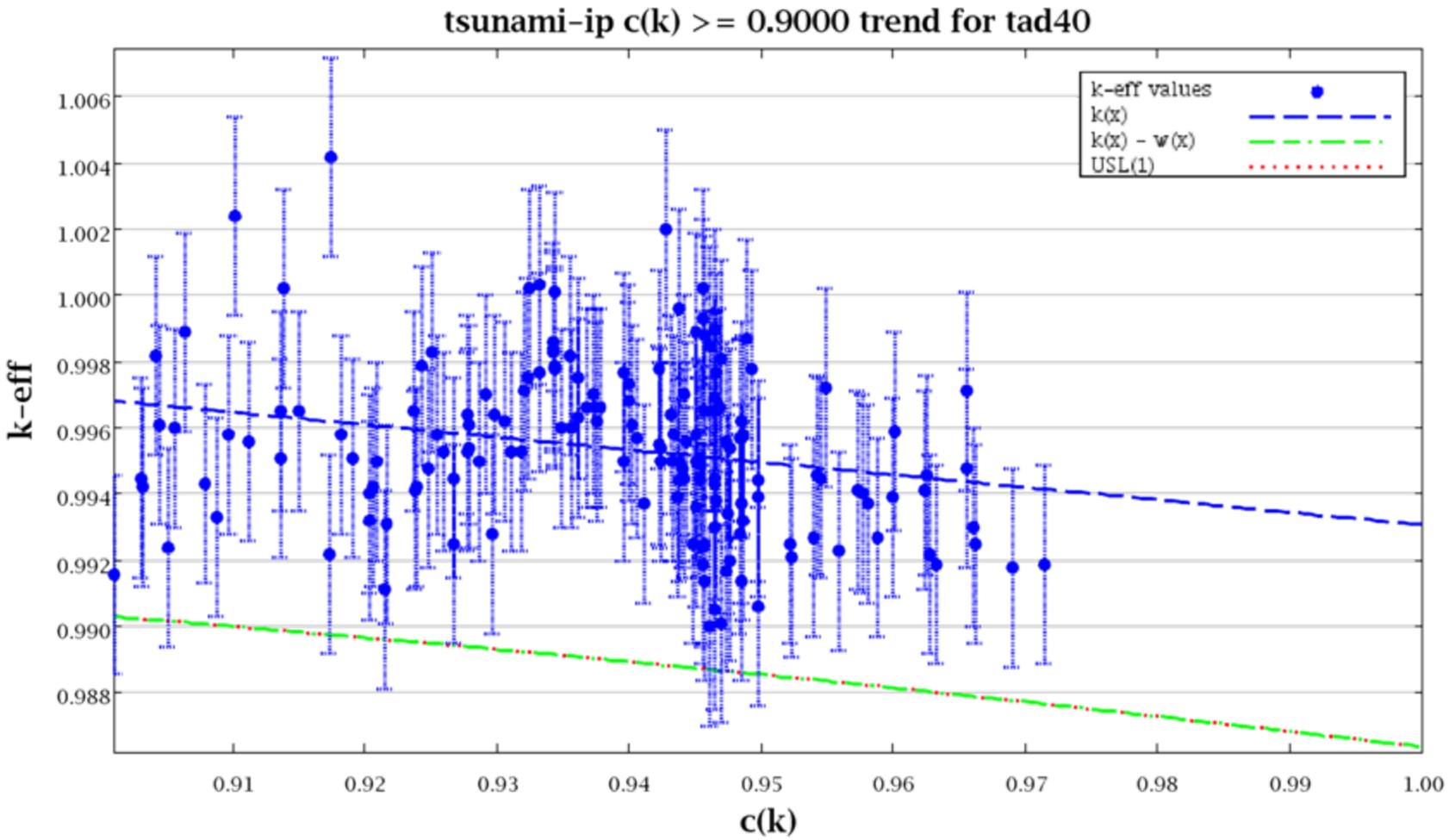
Administrative margin
(user input $\Delta k_m = 0.03$)

OAK RIDGE National Laboratory

TAD Bias Assessment with USLSTATS using all 1378 Experiments



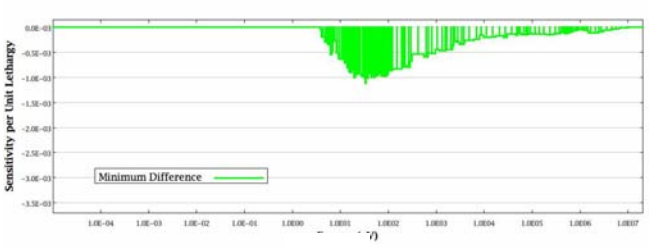
Improved TAD Bias Assessment with USLSTATS using only Best Experiments



Demonstration of Penalty for B-10

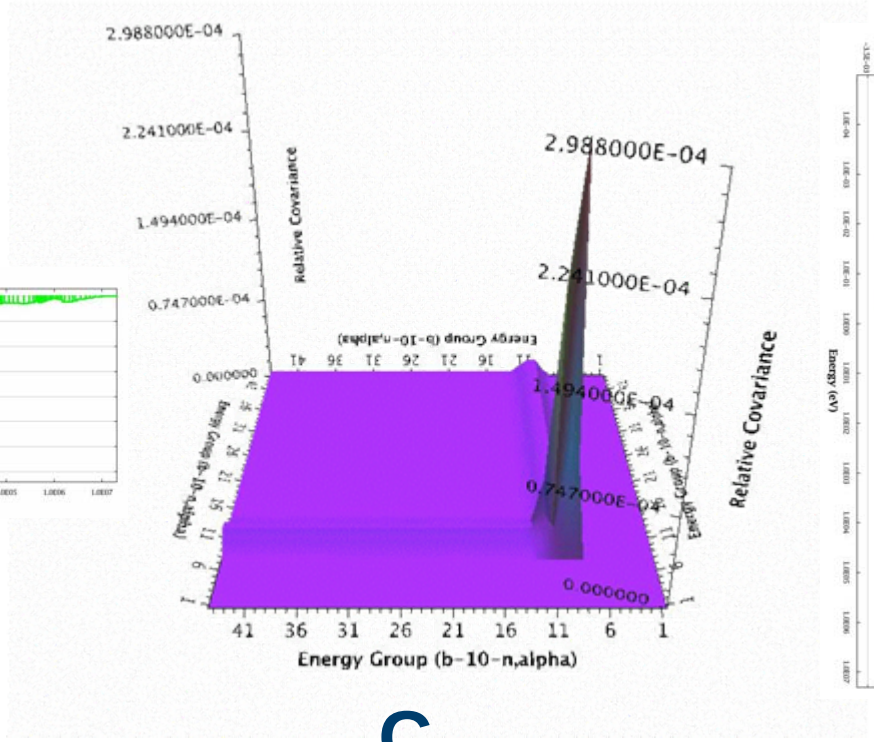
Quantification of uncertainty that is not included in bias calculation with benchmarks

TRAINING MATERIAL



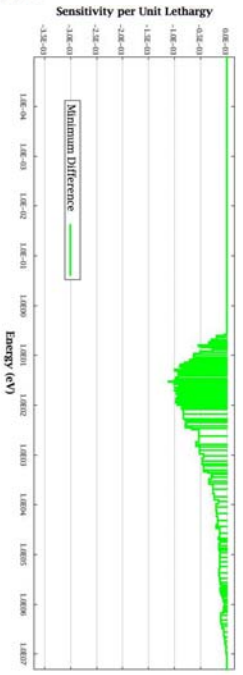
$$\mathbf{Z}$$

$$\frac{dk/k}{d\Sigma/\Sigma}$$



$$\mathbf{C_{\alpha\alpha}}$$

$$\left(\frac{\Delta\Sigma}{\Sigma}\right)^2$$



$$\mathbf{Z^T}$$

$$\frac{dk/k}{d\Sigma/\Sigma}$$

$$= \sigma^2$$

$$\mathbf{C_{kk}}$$

$$\left(\frac{\Delta k}{k}\right)^2$$

Penalty Assessment for TAD

the relative standard deviation of k_{eff} (% Δk/k) due to uncovered sensitivity data is:
0.1829 ± 0.0000 percent

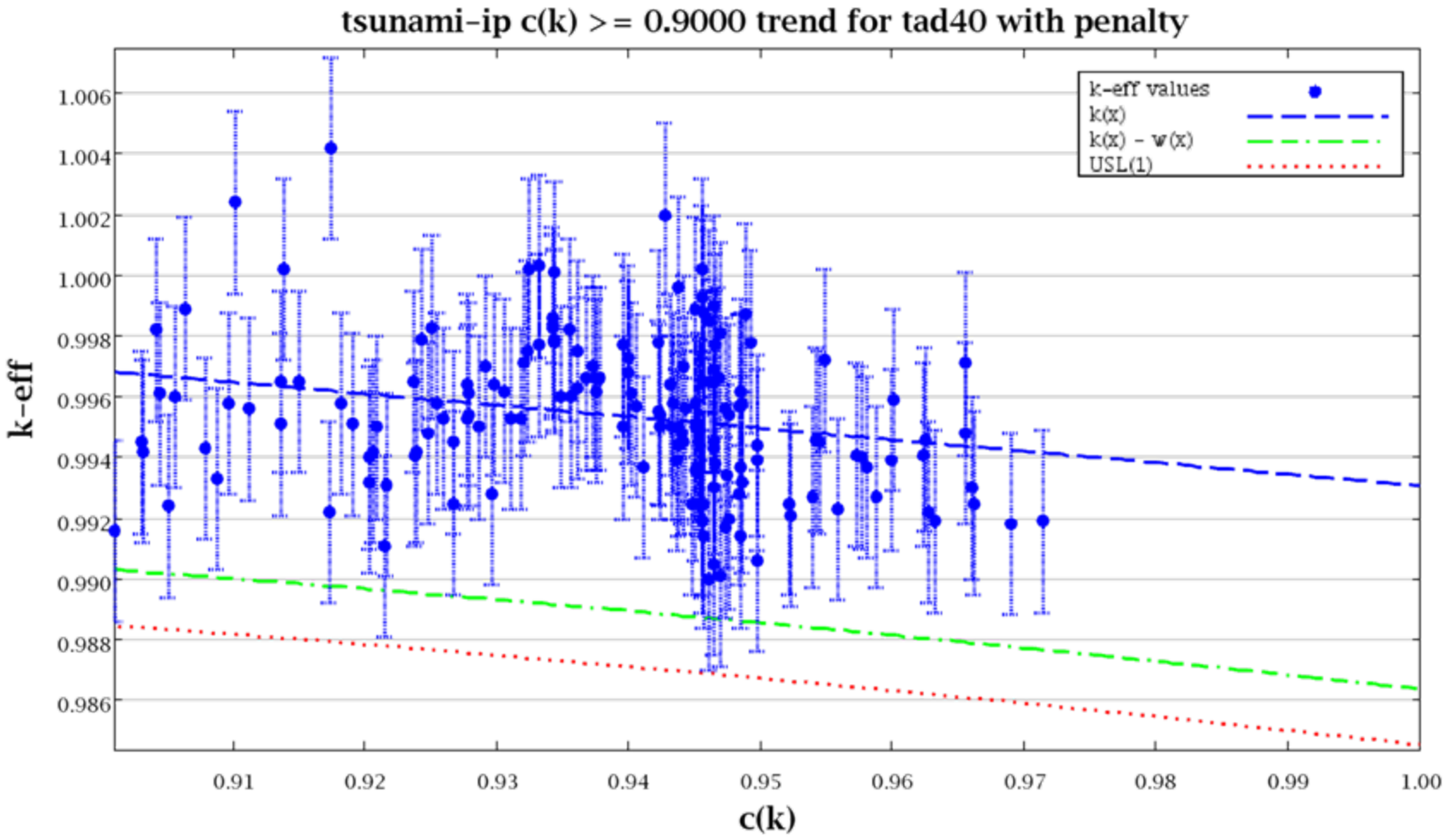
contributions to uncertainty in k_{eff} (% Δk/k) by individual energy covariance matrices:

Values colored Blue represent default covariance data

Values colored RoyalBlue represent default covariance data used to correct zeros or large values in some groups

Covariance Matrix			% Δk/k
Nuclide-Reaction		Nuclide-Reaction	Due to this Matrix
^{239}Pu nubar		^{239}Pu nubar	7.0692E-02 ± 5.5661E-06
^{239}Pu n,gamma		^{239}Pu n,gamma	6.5976E-02 ± 6.9402E-05
^{239}Pu fission		^{239}Pu fission	6.2445E-02 ± 4.1232E-05
^{56}Fe n,gamma		^{56}Fe n,gamma	5.1023E-02 ± 5.5337E-05
^{235}U fission		^{235}U fission	5.0409E-02 ± 3.0036E-05
^{238}U n,gamma		^{238}U n,gamma	4.7994E-02 ± 9.7189E-05
^{235}U chi		^{235}U chi	4.4762E-02 ± 8.3535E-06

Addition of Penalty to Upper Subcritical Limit



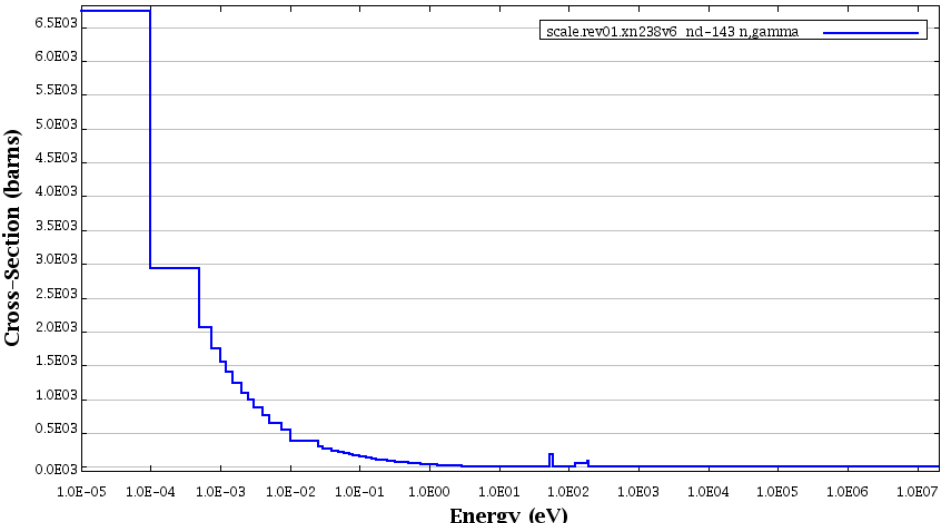
Fission Product Uncertainties

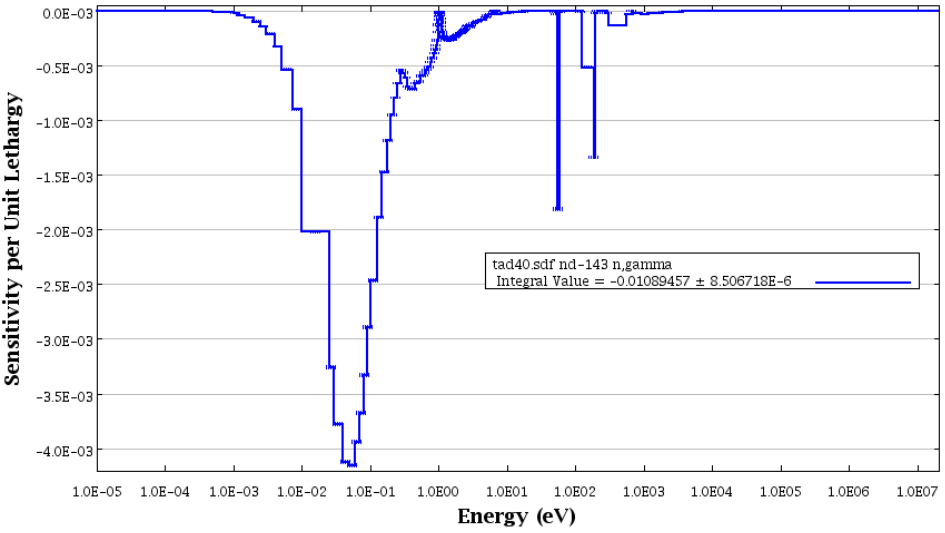
- **With few exceptions, fission products are absent from experimental database and ENDF covariance data.**
- **Use of data adjusment techniques not possible because of lack of available experimental data.**
- **Fission product penalty is 0.07% Δk/k of 0.18% Δk/k total penalty**

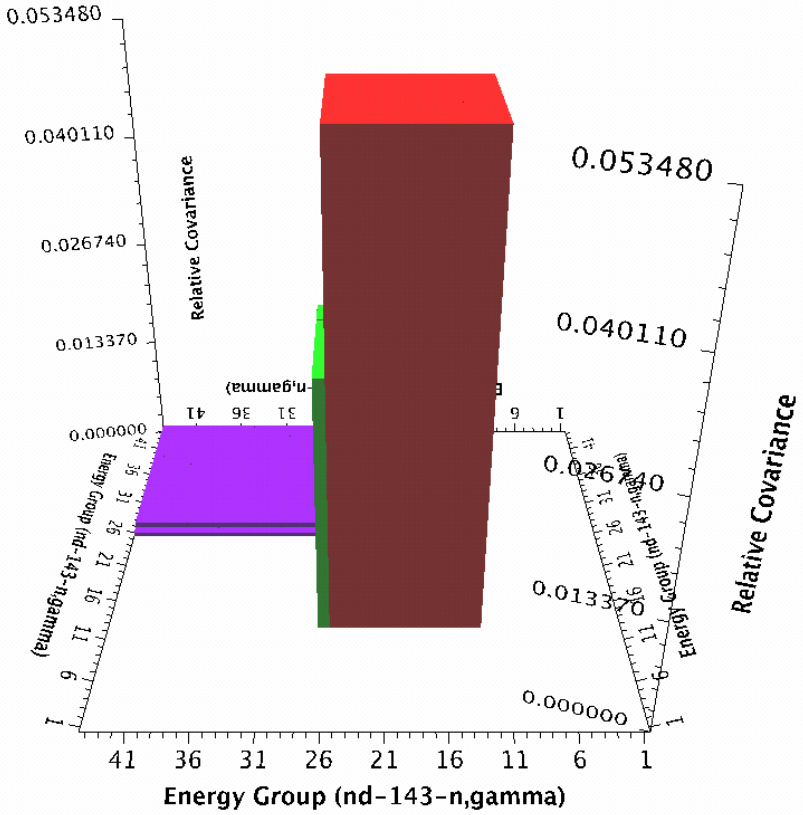
Nuclide	Reaction	Penalty Contribution %Δk/k
^{143}Nd	n,gamma	4.18E-02
^{103}Rh	n,gamma	2.69E-02
^{145}Nd	n,gamma	2.30E-02
^{149}Sm	n,gamma	2.20E-02
^{101}Ru	n,gamma	2.13E-02
^{99}Tc	n,gamma	1.47E-02
^{151}Sm	n,gamma	1.37E-02
^{147}Sm	n,gamma	1.12E-02
^{153}Eu	n,gamma	1.02E-02
^{152}Sm	n,gamma	9.08E-03
^{150}Sm	n,gamma	5.99E-03
^{95}Mo	n,gamma	5.35E-03
^{109}Ag	n,gamma	3.40E-03
^{155}Gd	n,gamma	2.75E-03

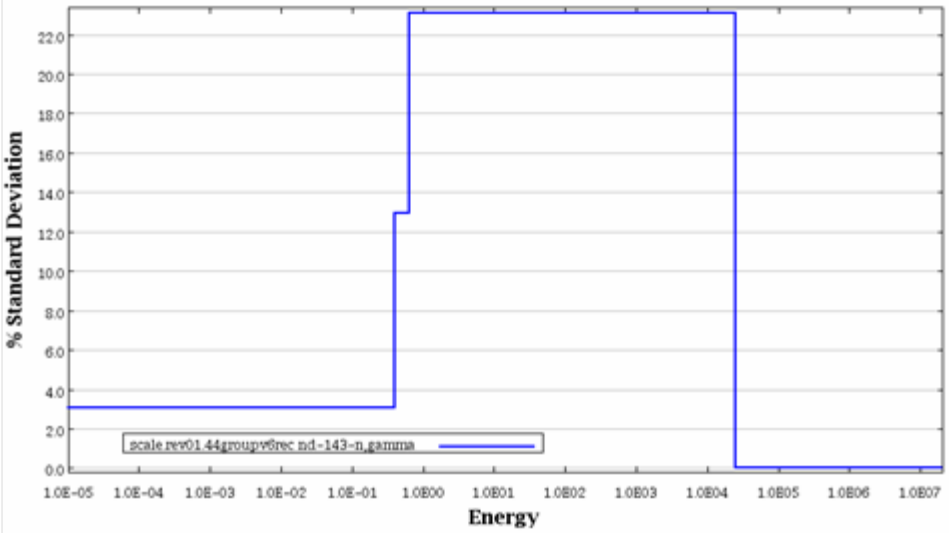
Nd-143

DEMONSTRATION OF USER TOOLS









Perspective

- **Covariance data are essential in many stages of the TSUNAMI procedure for criticality safety assessment.**
  - **Identification of important processes that could cause bias**
  - **Ranking of benchmark experiments**
  - **Bias determination**
  - **Penalty calculation for gap analysis**
- **All we need are accurate covariance data for all nuclides, reactions and energies!**
- **TSUNAMI analysis can be used to prioritize new data evaluations to meet user needs.**

Growing Use

- **The relatively easy-to-use TSUNAMI codes, GUIs, documentation, training courses and user support have brought sensitivity and uncertainty analysis into the mainstream.**
- **Distributed as part of SCALE by RSICC and NEA Data Bank.**
- **OECD/NEA Expert groups:**
  - **Uncertainty Analysis in Methods (UAM)**
  - **Uncertainty Analysis in Criticality Safety Assessment (UACSA)**
- **Recent and upcoming TSUNAMI training courses:**
  - **January 2008, NRC Headquarters, Washington, D.C. – 2 day refresher**
  - **February 2008, NEA Headquarters, Paris – 5 days**
  - **April 2008, WSMS Offices, SRNL – 2 day refresher**
  - **October 2008, NEA course hosted by KFKI, Budapest, Hungary – 5 days**
  - **November 2008, ORNL – 4 days**

Questions?