IRSN
INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

OECD/NEA EXPERT GROUP ON UNCERTAINTY ANALYSIS FOR CRITICALITY SAFETY ASSESSMENT: CURRENT ACTIVITIES

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WPEC Subgroup 33 Meeting

Issy-les-Moulineaux

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EG UACSA: Objectives

Expert Group on Uncertainty Analysis for Criticality Safety Assessment

created in December 2007 within the

Working Party on Nuclear Criticality Safety (WPNCS) with an aim to:

- Study methods and issues of the uncertainty analysis in criticality safety area;
- Provide examination of the methods;
- Assess impact of input data involved in uncertainty studies and test performance of tools which process the data;
- Assist in selection and development of efficient and safe methodologies for uncertainty assessment;
- Improve the state of the art of criticality safety in the longer-term.

http://www.nea.fr/science/wpncs/UACSA/index.html

Validation of Criticality Safety Calculation

Validation of criticality safety calculation is a procedure that allows quantifying computational bias and the bias uncertainty for a design system (could be a potentially abnormal scenario).

The validation is conducted through comparison of the calculated results with benchmarks based on evaluated experimental data.

The design system, for which the subcritical limit is established, must fall within the area of applicability of the benchmarks chosen for the validation.

The validation approach includes:

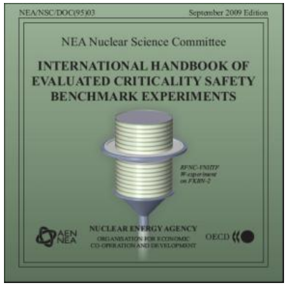
- ✓ Selection of benchmark experiments;
- ✓ Similarity assessment of the benchmark experiments and design system;
- ✓ Bias and bias uncertainty definition.

Validation Approaches: Summary Table

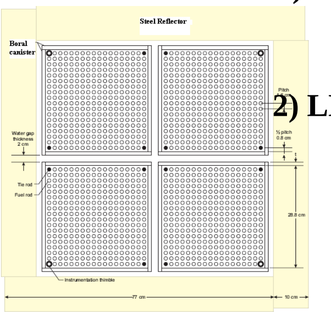
Participants (Organisation Country)	Criticality Calculation		Validation of Criticality Calculation		
	Code	Nuclear Data	Similarity Assessment	Method for Bias and Bias Uncertainty Establishment	Software Tool
AREVA Germany	SCALE 5.1 Monte Carlo	ENDF/B-V 44-gr. and 238-gr. ENDF/B-VI 238-gr.	S/U-based parameter c_k & Expert judgment	Bayesian MC regression analysis	TSUNAMI-IP MOCADATA
CEA France	CRISTAL (TRIPOLI-4.3) Monte Carlo	JEF-2.2 CE (Continuous Energy)	Benchmark quality S/U-based parameter	GLLSM based	R.I.B.
EMS Sweden	SCALE 5.1 Monte Carlo	ENDF/B-VI 238-gr.	Expert judgment based on benchmark quality & S/U-based parameter c_k Other parameters may be used.	Expert judgment, including consideration of benchmark quality and correlations	TSUNAMI-IP
JAEA Japan	MVP II Monte Carlo	JENDL-3.2 CE	Expert judgment	Statistical method	None
IPPE Russia	MMK KENO Monte Carlo	ABBN 299-gr. Subgroups	Benchmark quality & Sensitivity comparison & $\chi 2$ filter& Expert judgment	GLLSM based	INDECS
IRSN France	CRISTAL (APOLLO2-MORET 4) Monte Carlo	CEA93.V6 (JEF-2.2 172-gr.)	Physical parameters & Expert judgment	Trending analysis (trend vs. combined parameters)	MACSENS
KINS Korea	SCALE 6.0 Monte Carlo	ENDF/B-VII.0 238-gr.	EALF, S/U-based parameter c_k, Expert judgment	Statistical method	TSUNAMI-IP
ORNL USA	SCALE 6.0 Monte Carlo	ENDF/B-VII.0 238-gr.	H/X, EALF and others or S/U-based parameter c_k	Trending analysis	USLSTATS TSUNAMI-IP
			S/U-based parameter c_k $\chi 2$ filter	GLLSM based	TSURFER
PSI Switzerland	MCNPX Monte Carlo	ENDF/B-VII.0 CE JEFF-3.1 CE	Expert judgment, benchmark quality and analysis of physical parameters	Statistical method	None

Exercise Phase I: Objective and Test Systems

Objective: determine whether or not a tested validation method can reproduce bias within the bias uncertainty

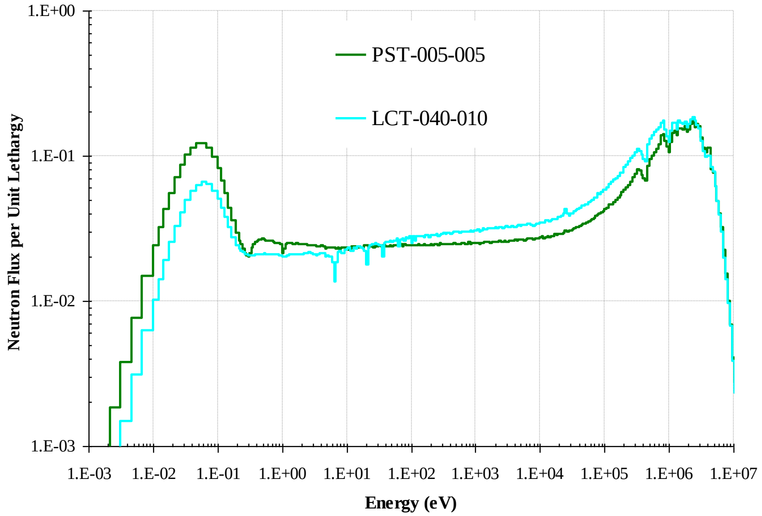


Test Systems: 4 configurations with known biases from the *ICSBEP Handbook* and 1 blind test



1) PU-SOL-THERM-005-005: WATER-REFLECTED 14-INCH DIAMETER SPHERE OF PLUTONIUM NITRATE SOLUTION 4.05% ^{240}Pu

2) LEU-COMP-THERM-040-010: FOUR 4.738-WT.%-ENRICHED URANIUM DIOXIDE ROD ASSEMBLIES CONTAINED IN BORATED STAINLESS STEEL OR BORAL SQUARE CANISTERS, WATER MODERATED AND REFLECTED BY STEEL

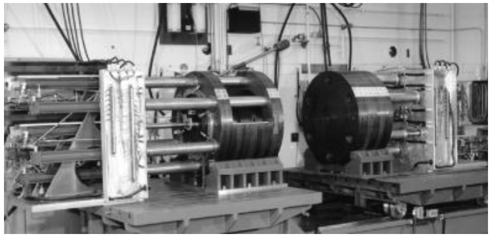


Exercise Phase I: Test Systems (cont'd)

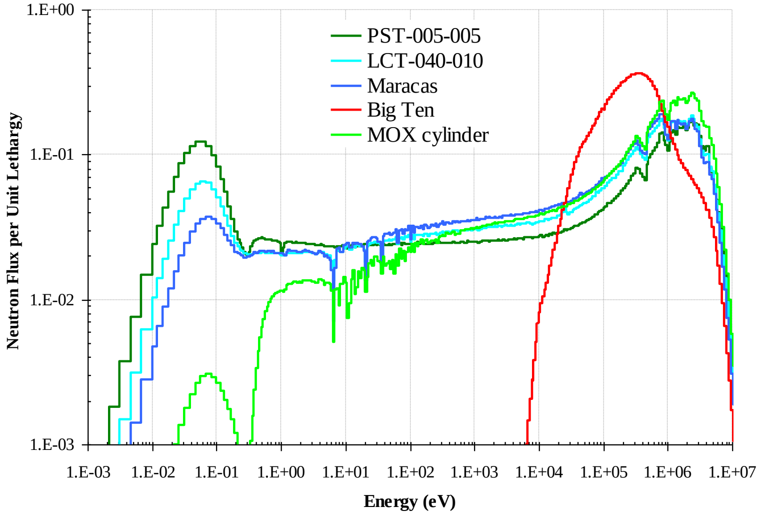
Test Systems: 4 configurations from the *ICSBEP Handbook*, 1 blind test

3) **LEU-COMP-THERM-049-007: MARACAS** PROGRAMME: POLYTHENE-REFLECTED CRITICAL CONFIGURATIONS WITH LOW-ENRICHED AND LOW-MODERATED URANIUM DIOXIDE POWDER, **U(5)O**$_2$

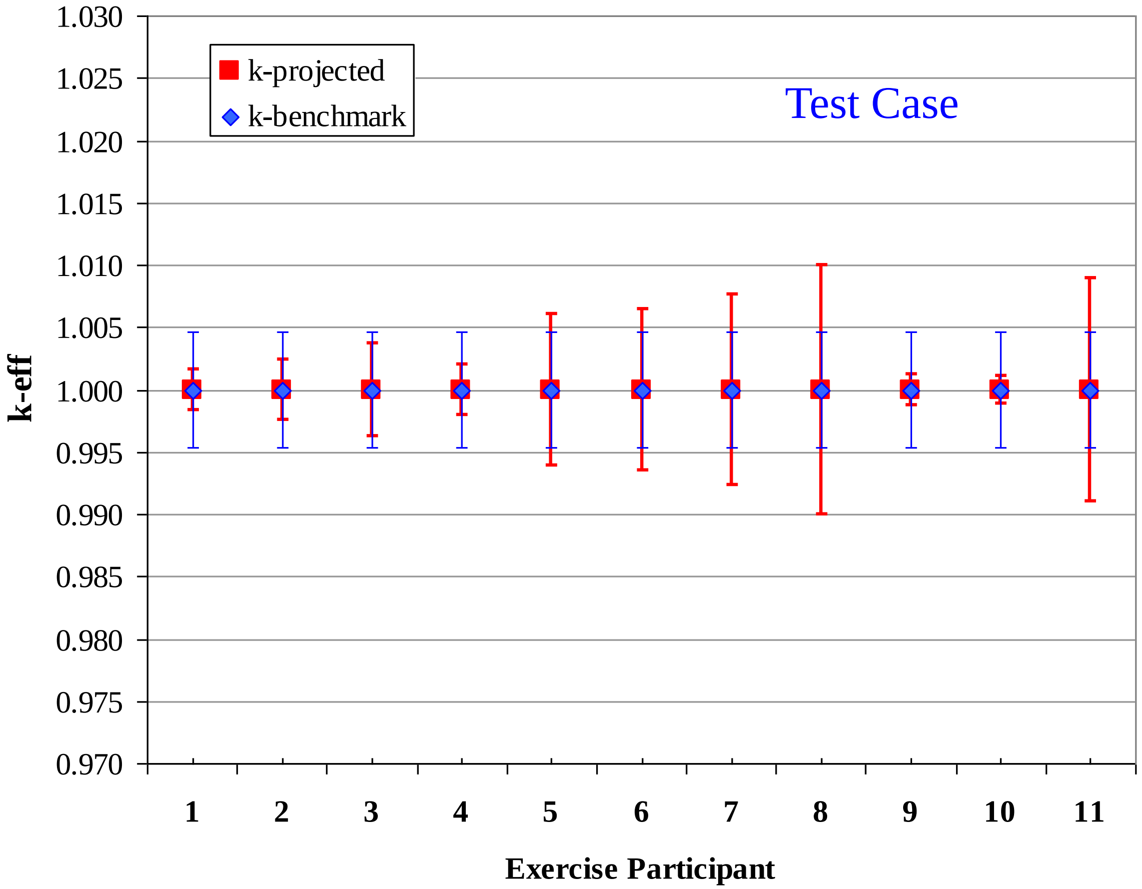
4) **IEU-MET-FAST-007-001: BIG TEN**: A LARGE, MIXED-URANIUM-METAL CYLINDRICAL CORE WITH 10% AVERAGE ^{235}U ENRICHMENT, SURROUNDED BY A THICK ^{238}U REFLECTOR



5) **BLIND TEST:** WATER-REFLECTED **LOW-MODERATED MOX** FUEL CYLINDER



Exercise Phase I: Expected Results (1/2)



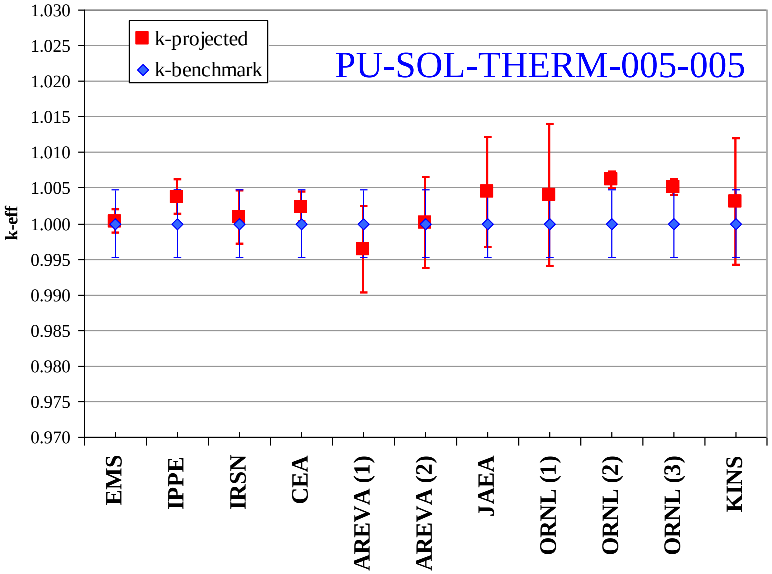
K-benchmark is k_{eff} for benchmark experiment selected as test case

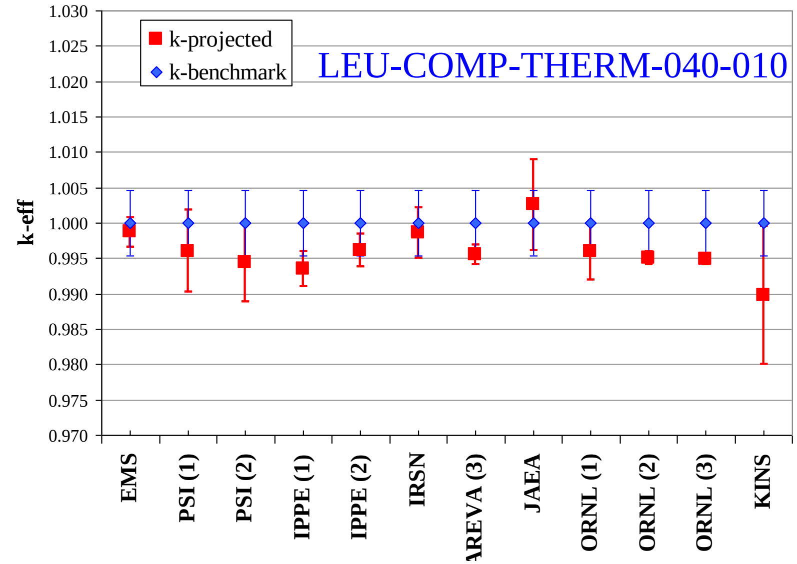
K-projected is k_{eff} established by validation approach for test case

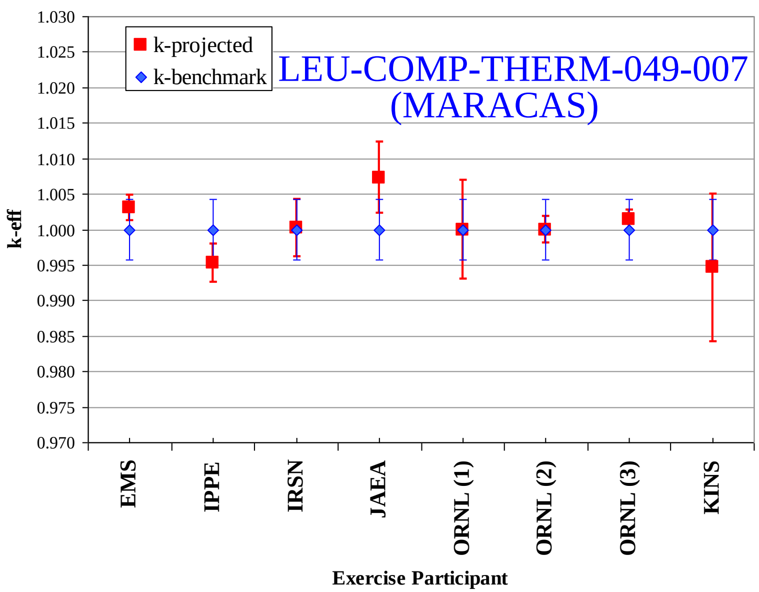
Exercise Phase I: Details of Validation Study

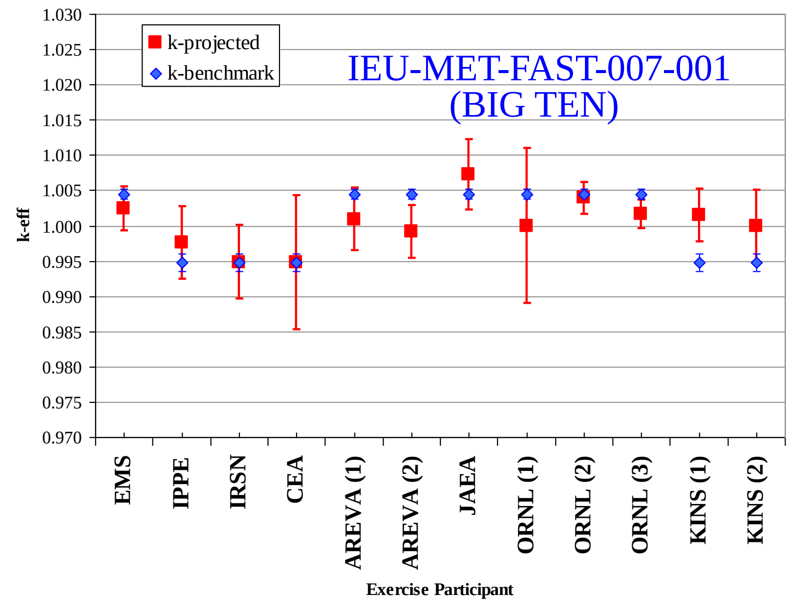
Designation used	Variation in the criticality calculation or validation method
AREVA (1)	Criticality computation: SCALE 5.1 & CSAS25/CSAS26 with NITAWL and 238GROUPNDF5 cross-section library Nuclear data uncertainty calculated based on 44GROUPV5REC covariance matrix.
AREVA (2)	Criticality computation: SCALE 5.1 & CSAS25/CSAS26 with CENTRM and V6-238 and continuous energy cross-section libraries Nuclear data uncertainty calculated based on 44GROUPV6REC covariance matrix.
AREVA (3)	Criticality computation: SCALE 5.1 & CSAS25 with NITAWL and 44GROUPNDF5 cross-section library Nuclear data uncertainty calculated based on 44GROUPV5REC covariance matrix
PSI (1)	Criticality calculation: MCNPX & JEFF-3.1 continuous energy library
PSI (2)	Criticality calculation: MCNPX & ENDF/B-VII continuous energy library
IPPE (1)	Same methods for criticality calculation and validation but different sets of benchmarks used for the validation study
IPPE (2)	
ORNL (1)	Trending analysis vs S/U based c_k parameter with preliminary c_k filter
ORNL (2)	GLLSM-based validation method with preliminary c_k filter
ORNL (3)	GLLSM-based validation method without filter
KINS (1)	Same methods for criticality calculation and validation but different sets of benchmarks used for the validation study
KINS (2)	

Exercise Phase I: Results (1/3)

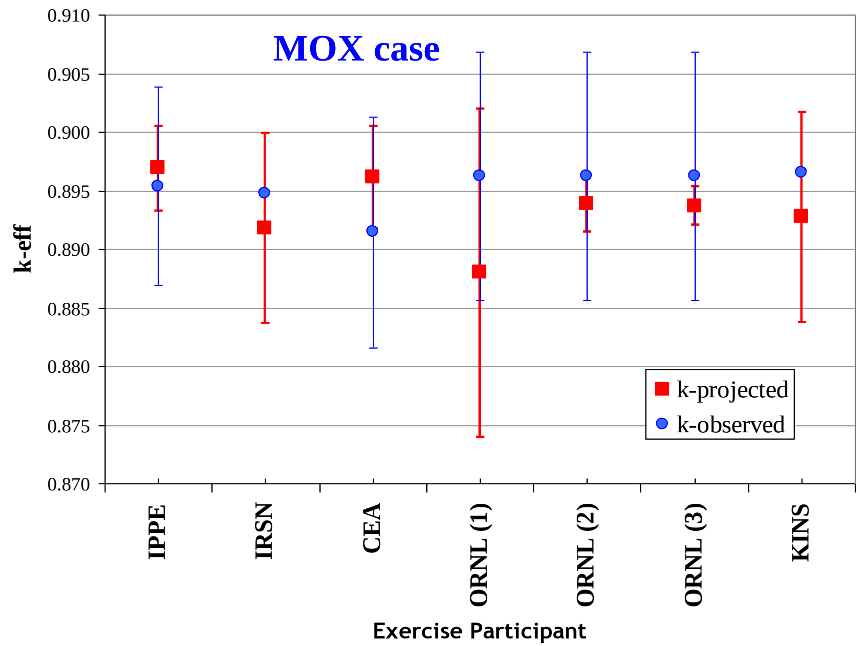








Exercise Phase I: Results (2/3)

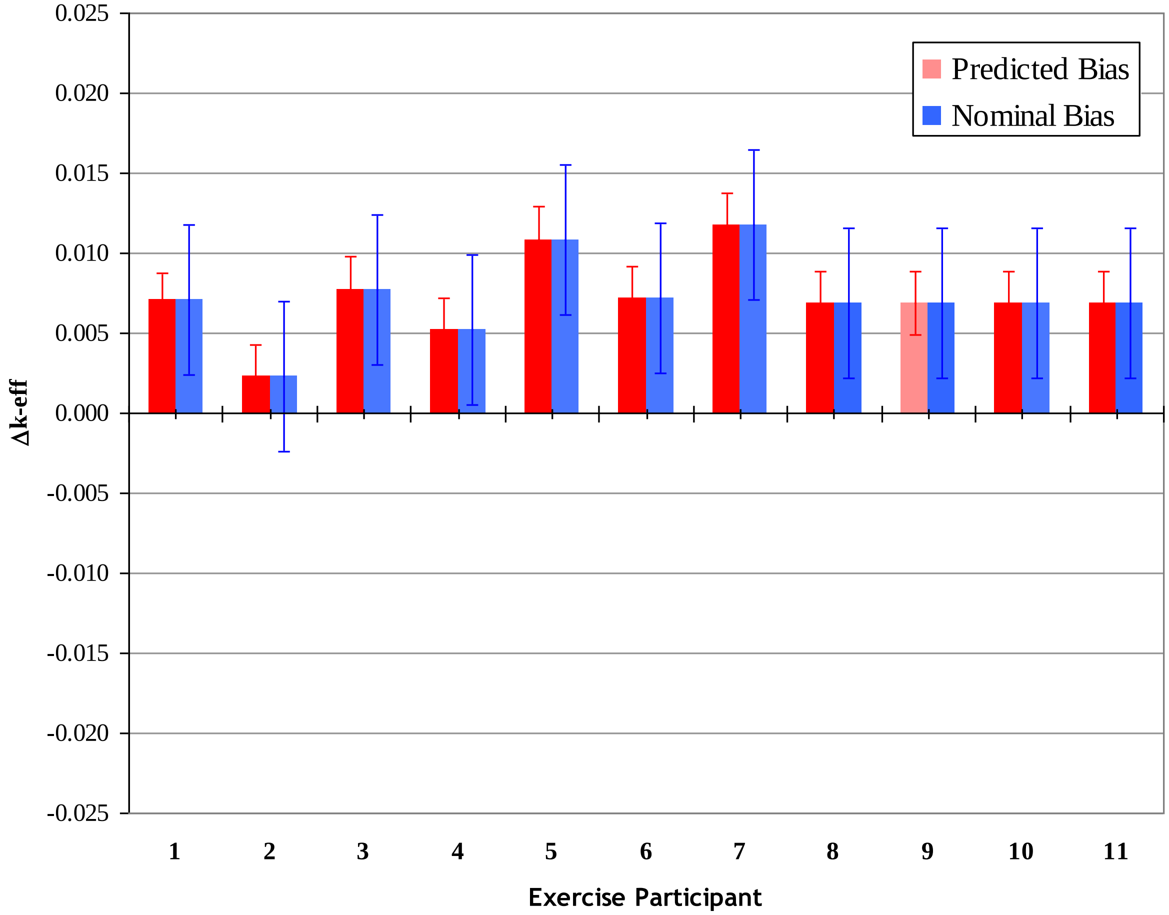


For the blind test case – low moderated MOX cylinder – no reference value is available. Agreement with the other results may be an indicator of good performance for validation approach only if one or more of those methods are validated for similar applications.

Observation:

Uncertainties established by the GLLSM-based approach [IPPE, CEA, ORNL(2, 3)] are significantly lower than the prior uncertainty due to nuclear data.

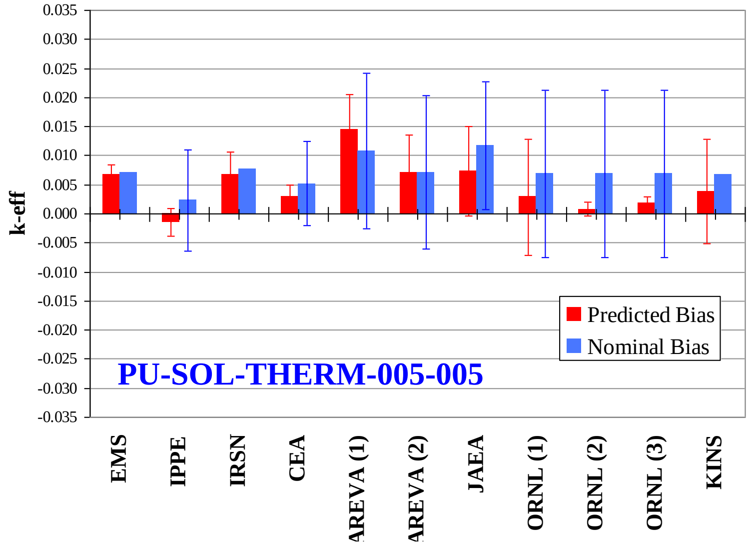
Exercise Phase I: Expected Results (2/2)

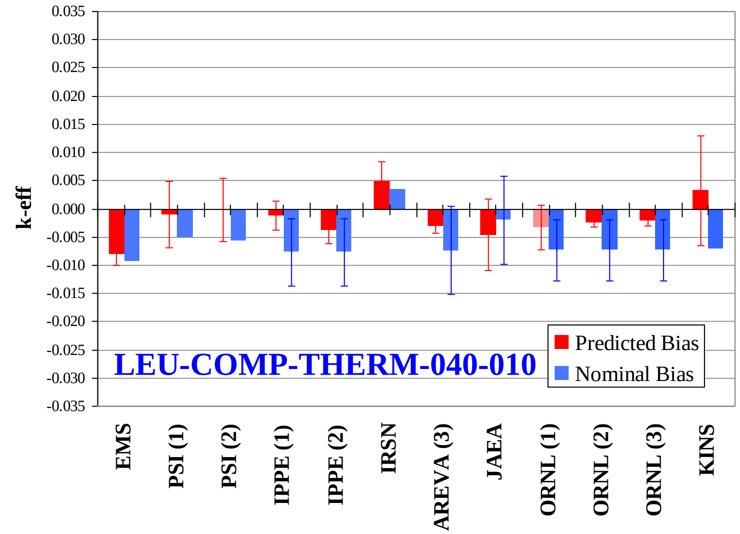


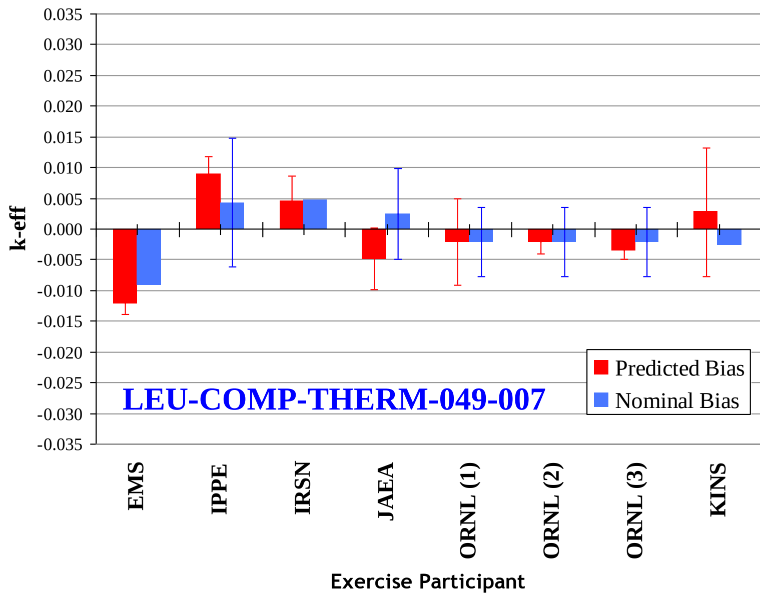
Nominal Bias = benchmark k_{eff} – calculated k_{eff}

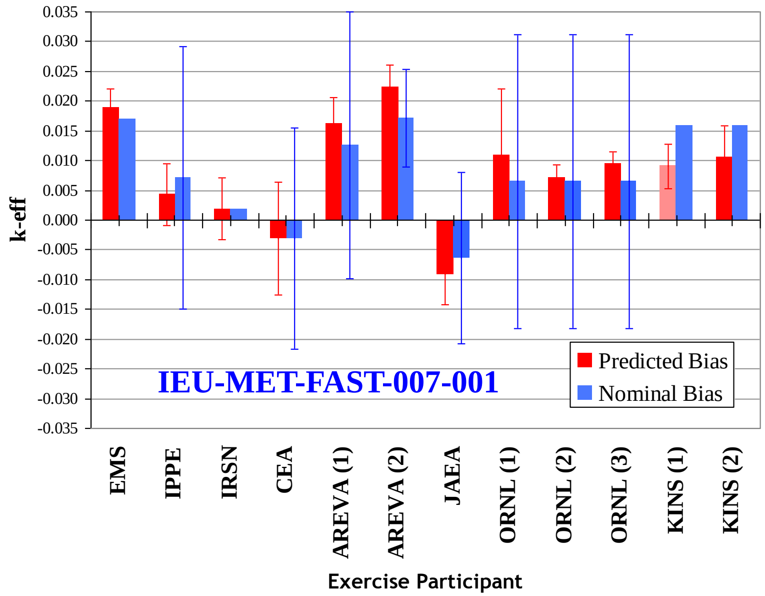
Predicted Bias = calculated k_{eff} – projected k_{eff}

Exercise Phase I: Results (3/3)









Some Lessons Learnt (1/3)

To assess similarity, most participants used their expert judgment supported by analysis of numerous physical characteristics (for example, those reported in the ICSBEP Handbook), or a sensitivity/uncertainty-based integral similarity index.

The k_{eff} sensitivity to multigroup neutron cross sections is typically applied in similarity assessments or/and in validation algorithms.

Monte Carlo codes with explicit 3D geometry are commonly used to compute the sensitivities along with one- or two-dimensional deterministic methods.

A wide range of the methods is employed to establish k_{eff} bias and bias uncertainty. They include:

- ✓ expert judgment;
- ✓ statistical treatment of the ratio of C/E values;
- ✓ trending analysis;
- ✓ Bayesian Monte Carlo regression analysis; and
- ✓ the generalized linear least-squares based method.

Some Lessons Learnt (2/3)

All the tested validation approaches reproduce bias within the bias uncertainty for the test cases typical for current fuel cycle (PU-SOL-THERM-005-005 and LEU-COMP-THERM-040-010); for more “exotic” Big Ten configuration some approaches do not show good performance;

The number of benchmarks selected for the exercises depends on validation approach and varies considerably – from 1 to 252;

Trending analysis and statistical treatment of C/E approaches require more similar benchmarks to be used for the validation to provide statistically defensible results;

Uncertainties established by the GLLSM-based approach are usually significantly lower than the prior uncertainty due to nuclear data.

Some Lessons Learnt (3/3)

Selection of benchmarks is of primary importance for quality of validation, e.g.,

- ✓ Similarity of benchmarks with application systems should be assessed;
- ✓ k_{eff} uncertainties for the benchamark experiments should be well evaluated;
- ✓ Correlations between the uncertainties should be established.

Since the presented test cases selected from the ICSBEP Handbook were not blind tests, a detailed examination of the validation approaches is required. Further exercises will be proposed to test the different steps of the approaches.

Current Activities (1/6)

Describe and test techniques and software tools that establish technological uncertainties. Exercise Phase II.

Benchmark specification is prepared by J. C. NEUBER

Describe and test techniques and software tools for calculation of k_{eff} sensitivity to neutron cross sections. Exercise Phase III.

Benchmark specification is prepared by T. Ivanova

Review methods that establish correlations between experimental uncertainties. Requested by **I**nternational **C**riticality **S**afety **B**enchmark **E**valuation **P**roject (ICSBEP)

Report, Due in 2012

Current Activities (2/6)

Benchmark Phase III:
Computation of k_{eff} Sensitivity to Nuclear Data

EG UACSA State-of-the-art report

“…k_{eff} sensitivities to neutron cross sections provide important information both for the identification of suitable benchmarks and in estimation/propagation of uncertainties. In view of this a further EG exercise (Phase III) is proposed to compute k_{eff} sensitivities to cross-section data…”

Current Activities (3/6)

Sensitivity Computation: Challenges

What is our expectation for sensitivity computation?

- 1^{st} order perturbation or direct perturbation
- Desired precision

  *Implicit component *, scattering in MC computations, and others*
- Request to input model

  Detailed or simplified model

* Implicit effect is associated with changes in *resonance-shielded* multigroup cross sections

Current Activities (4/6)

Phase III-1: Water-Reflected Mixed Plutonium-Uranium Oxide (20wt% Pu) Pins*

Based on description for MIX-COMP-THERM-001-001 available in the ICSBEP Handbook

Four models are proposed:

1. Detailed 3-D Model as presented in Section 3 of the Handbook with slight simplifications
2. X-Y-Z Model/ pin cell computed by a cell code
3. R-Z Model/ pin cell computed by a cell code
4. Pin cell Model

* *International Handbook of Evaluated Criticality Safety Benchmark Experiments*, Organization for Economic Cooperation and Development—Nuclear Energy Agency, NEA/NSC/DOC(95)03 (2009 Edition)

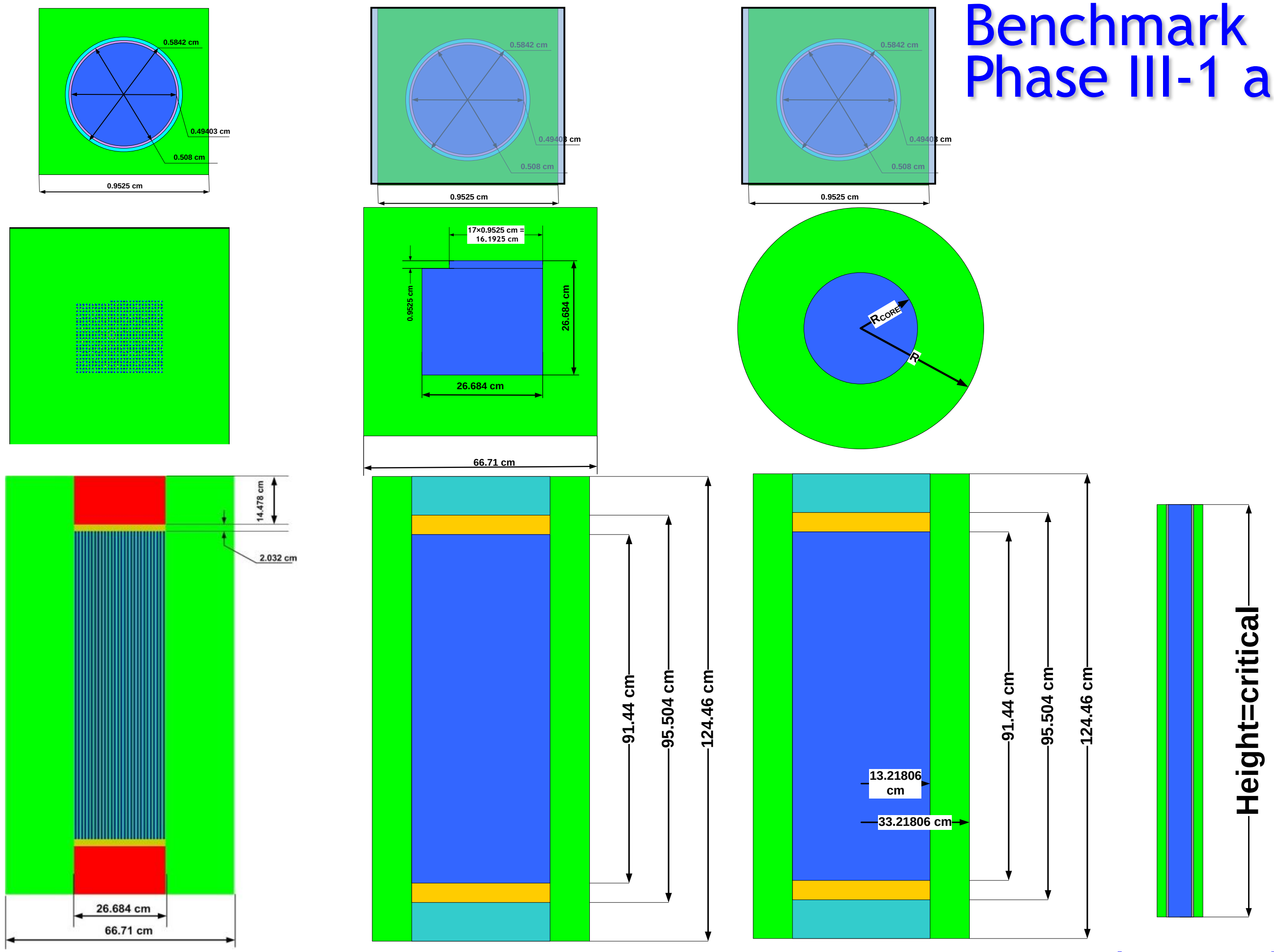
Current Activities (5/6)

Benchmark
Phase III-1 a, b, c, d

Fuel Cell

Radial view

Axial view

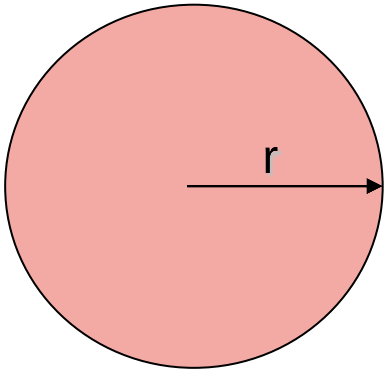


a) Detailed 3D
b) X-Y-Z
c) R-Z
d) Pin cell

Current Activities (6/6)

Phase III-3: Bare Spheres Filled with Homogeneous Mixture of Uranium Fluoride and Paraffin

- Model 1: low enriched uranium (~2 atom %) fluoride and paraffin *
- Model 2: intermediate enriched uranium (~50 atom %) fluoride and paraffin



	Model 1	Model 2
r, cm	36	18.2
Isotope	Atom density, 10^{24} cm^{-3}	
^{235}U	1.3303E-4	3.2850E-03
^{238}U	6.4370E-3	3.2850E-03
H	3.9097E-2	3.9097E-02
C	1.8797E-2	1.8797E-02
F	2.6280E-2	2.6280E-02

* *S.J. Raffety, J.T.Mihalczo*. "Homogenized Critical Assemblies of 2 and 3 % Enriched Uranium in Paraffin." Y-DR-14, Union Carbide Corp., Nuclear Division, Oak Ridge Y-12 Plant, 1969

* *M.L. Williams, B.L.Broadhead, C.V. Parks*. "Eigenvalue Sensitivity Theory for Resonance-Shielded Cross Sections." Nucl. Sci. Eng., Vol 138, pp. 177-191, 2001.