IRSN
INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

Uncertainty Assessment for Criticality Safety Studies: An Overview of Techniques

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Outline

Introduction:

- Uncertainty analysis for CSA: key issues

Results of EG UACSA activity

- Validation Techniques: State of the Art
- Benchmark Exercises Phase I

Summary

- Lessons learned
- Requirements to validation techniques
- Requirements to integral experiments

Uncertainty Analysis for CSA: Requirements

New Conditions Today and Tomorrow

- Expand of existing fuel technologies
- New fuel, absorbers, structural materials
- New reprocessing technologies
- Increasing cost of the integral experiments
- Demand of nuclear energy in countries with no experience to operate with fissile materials…

Demands of Industry

- Maximum design flexibility
- Reduce redundant safety margins

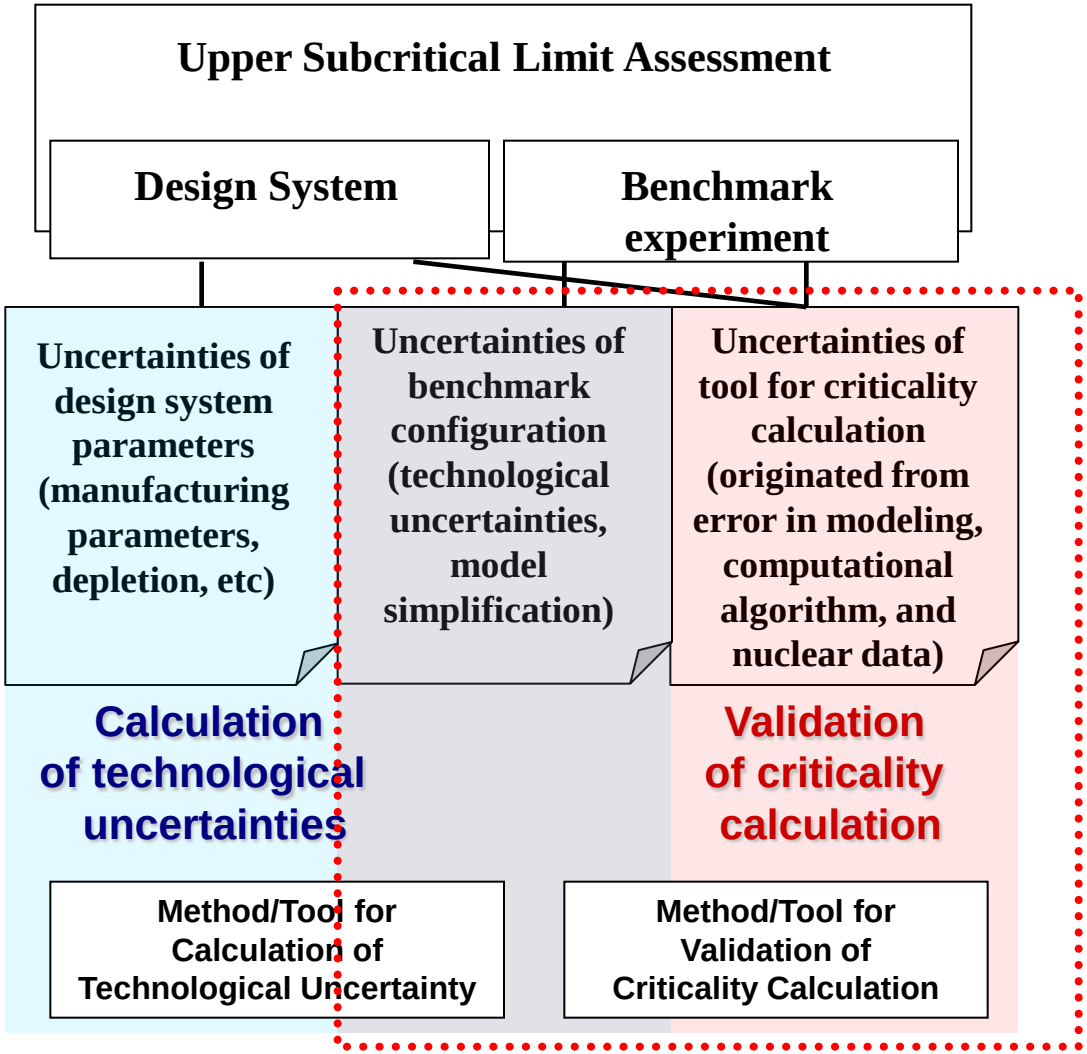
Requirements to Criticality Validation and Integral Experiments

To be discussed

OECD/NEA WPNCS Expert Group on Uncertainty Analysis for Criticality Safety Assessment (EG UACSA): Aims

- Study methods and issues of the uncertainty analysis in criticality safety area;
- Provide comprehensive examination of the methods;
- Assess impact of initial data sets involved into uncertainty studies and test performance of the code processing the data;
- Assist in selection and development of efficient and safe methodology(ies) for uncertainty assessment;
- Provide feedback to standards for nuclear criticality safety in operation with fissile materials.

OECD/NEA WPNCS Expert Group on Uncertainty Analysis for Criticality Safety Assessment (EG UACSA): Area of Interest



Validation of Criticality Calculation

Validation of criticality calculation determines an appropriate **bias** and bias **uncertainty** for use in determining subcriticality with a specific confidence level

- What degree of correlation between the experiment and the application is necessary to validate the application area?
- How many experiments are needed to verify an application?
- What are requirements to integral experiments?
- What methodology provides better validation?

Summary Table: Validation Methods

Lab.	Criticality Calculation		Validation of Criticality Calculation		
	Code	Nuclear Data	Similarity Assessment	Method of Validation	Software Tool
AREVA Germany	SCALE 5.1 *Monte Carlo*	ENDF/B-V *238-gr.* ENDF/B-VI *238-gr.*	*S/U based parameter ck* & *Expert judgment*	**MC sampling** & **Trending analysis**	**MOCADATA**
CEA France	CRISTAL (TRIPOLI-4.3) *Monte Carlo*	JEF-2.2 *CE*	*S/U based parameter* = c_k & *Expert judgment*	**GLLSM** based (“adjustment”)	**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 ck* & Others	*Expert judgment*	None
JAEA Japan	MVP II *Monte Carlo*	JENDL-3.2 *CE*	*Expert judgment*	**Statistical method** using non-central t-distribution	None
IPPE Russia	MMK KENO *Monte Carlo*	ABBN *299-gr.* (Subgroups)	**Benchmark quality** & *Sensitivity comparison* & **χ2 filter**& *Expert judgment*	**GLLSM** based (“adjustment”)	**INDECS**
IRSN France	CRISTAL (APOLLO2-MORET 4) *Monte Carlo*	JEF-2.2 *172-gr.*	Physical parameters & *Expert judgment*	**Trending analysis** (3D trend vs combined parameters)	**MACSENS**
ORNL USA	SCALE 5.1 *Monte Carlo*	ENDF/B-VI *238-gr.*	*S/Ubased parameter* c_k **Benchmark quality** & No prior assessment or *S/U based parameter* c_k	**Trending analysis** **GLLSM** based (“adjustment”)	**USLSTATS** **TSURFER**
PSI Switzerland	MCNPX *Monte Carlo*	ENDF/B-VII.0 *CE* JEFF-3.1 *CE*	*Expert judgment* based on benchmark quality and *analysis of numerous physical parameters*	**Statistical method**	None

EG UACSA Benchmark Exercises Phase I

How to validate validation method?

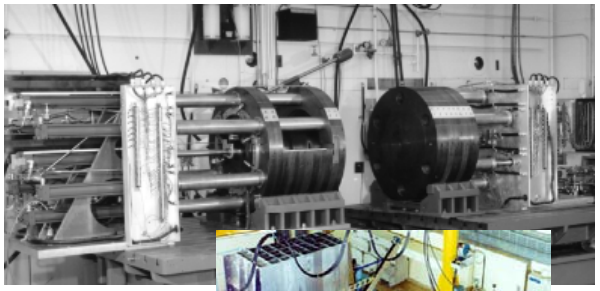
Systems with ***known biases*** were selected in ICSBEP Handbook as applications to determine whether the validation method employed can ***reproduce the bias within the bias uncertainty***

Aim of the Benchmark Exercises

- Illustrate predicting capabilities of criticality validation methods
- Assess impact of data sets involved into the validation

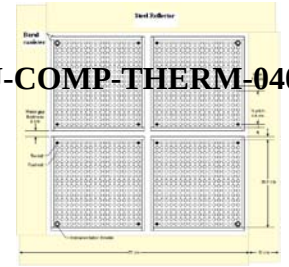
EG UACSA Benchmark Exercises: Application Systems

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

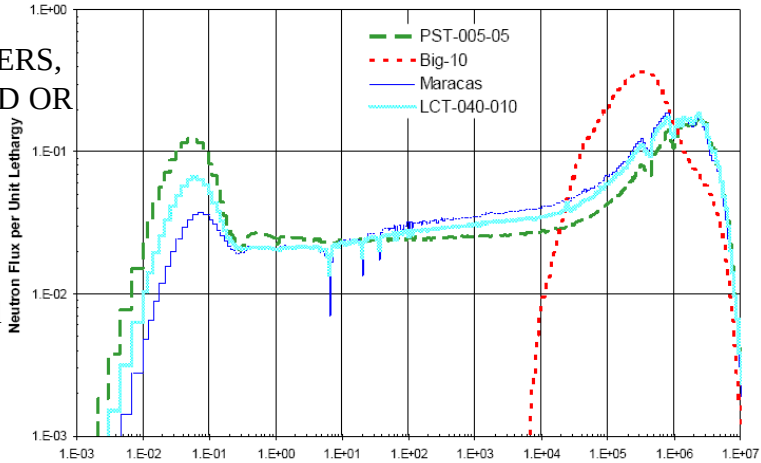


IEU-MET-FAST-007-001: BIG TEN: A LARGE, MIXED-URANIUM-METAL CYLINDRICAL CORE WITH 10% AVERAGE ^{235}U ENRICHMENT, SURROUNDED BY A THICK ^{238}U REFLECTOR

LEU-COMP-THERM-049-007: MARACAS PROGRAMME: POLYTHENE-REFLECTED CRITICAL CONFIGURATIONS WITH LOW-ENRICHED AND LOW-MODERATED URANIUM DIOXIDE POWDER, $U(5)O_2$

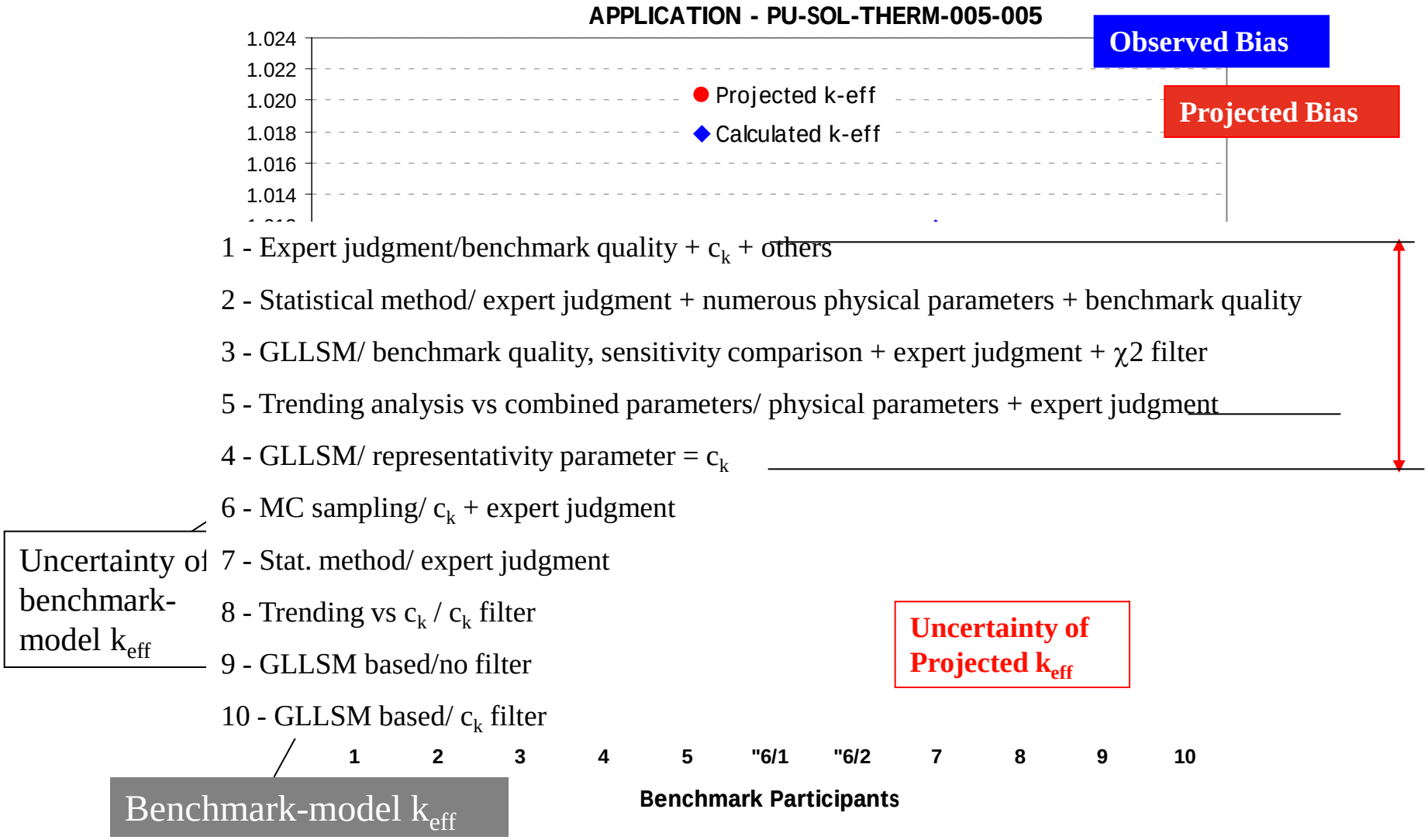


LEU-COMP-THERM-040-010: FOUR 4.738-WT.%-ENRICHED URANIUM DIOXIDE ROD ASSEMBLIES CONTAINED IN BORATED STAINLESS STEEL OR BORAL SQUARE CANISTERS, WATER MODERATED AND REFLECTED BY LEAD OR STEEL



ANALYTICAL BENCHMARK: WATER-REFLECTED LOW-MODERATEDMOX FUEL CYLINDER (Proposed by A. Santamarina and C. Venard – CEA, France)

EG UACSA Benchmark Exercises Phase I: Results Analysis (1/8)



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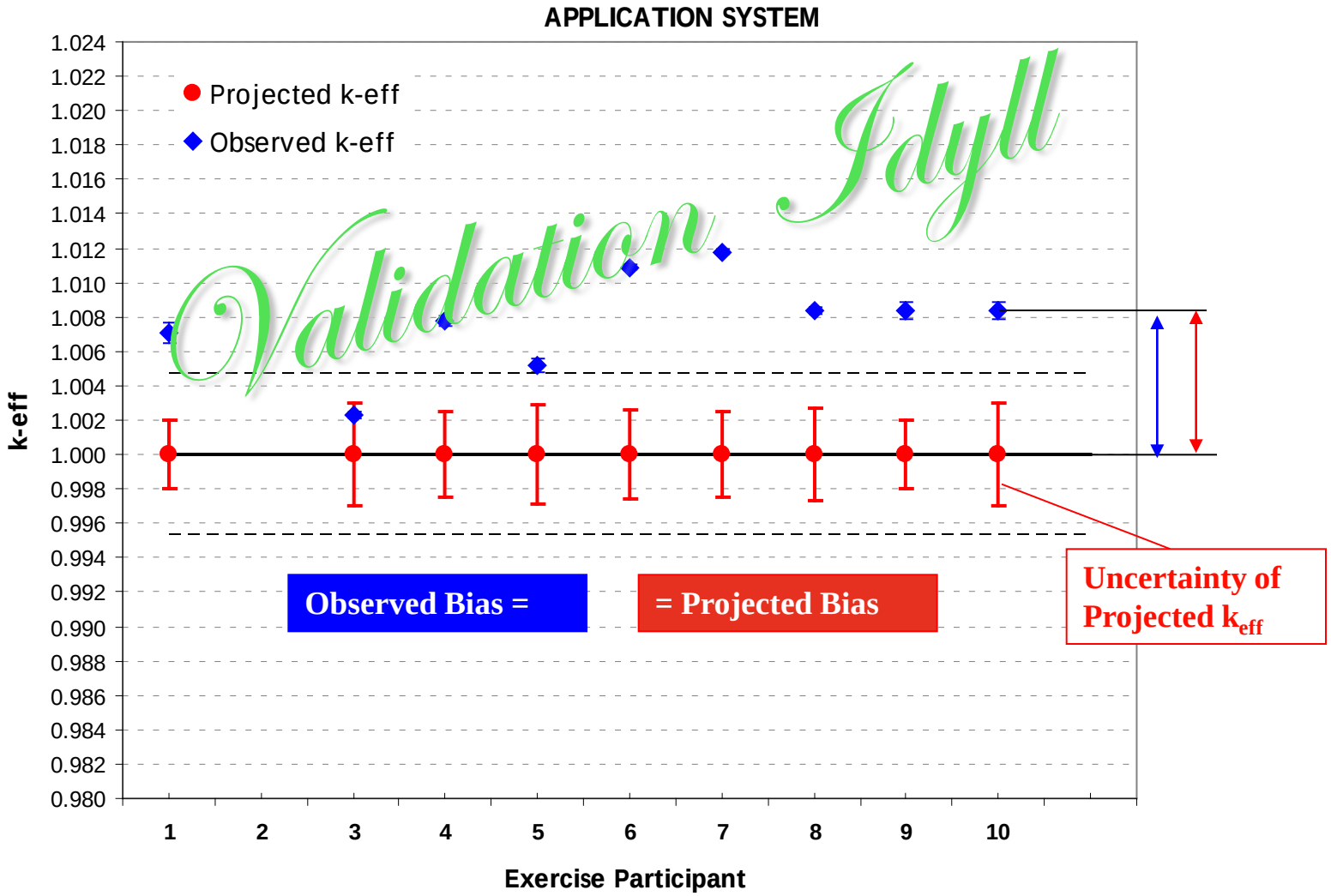
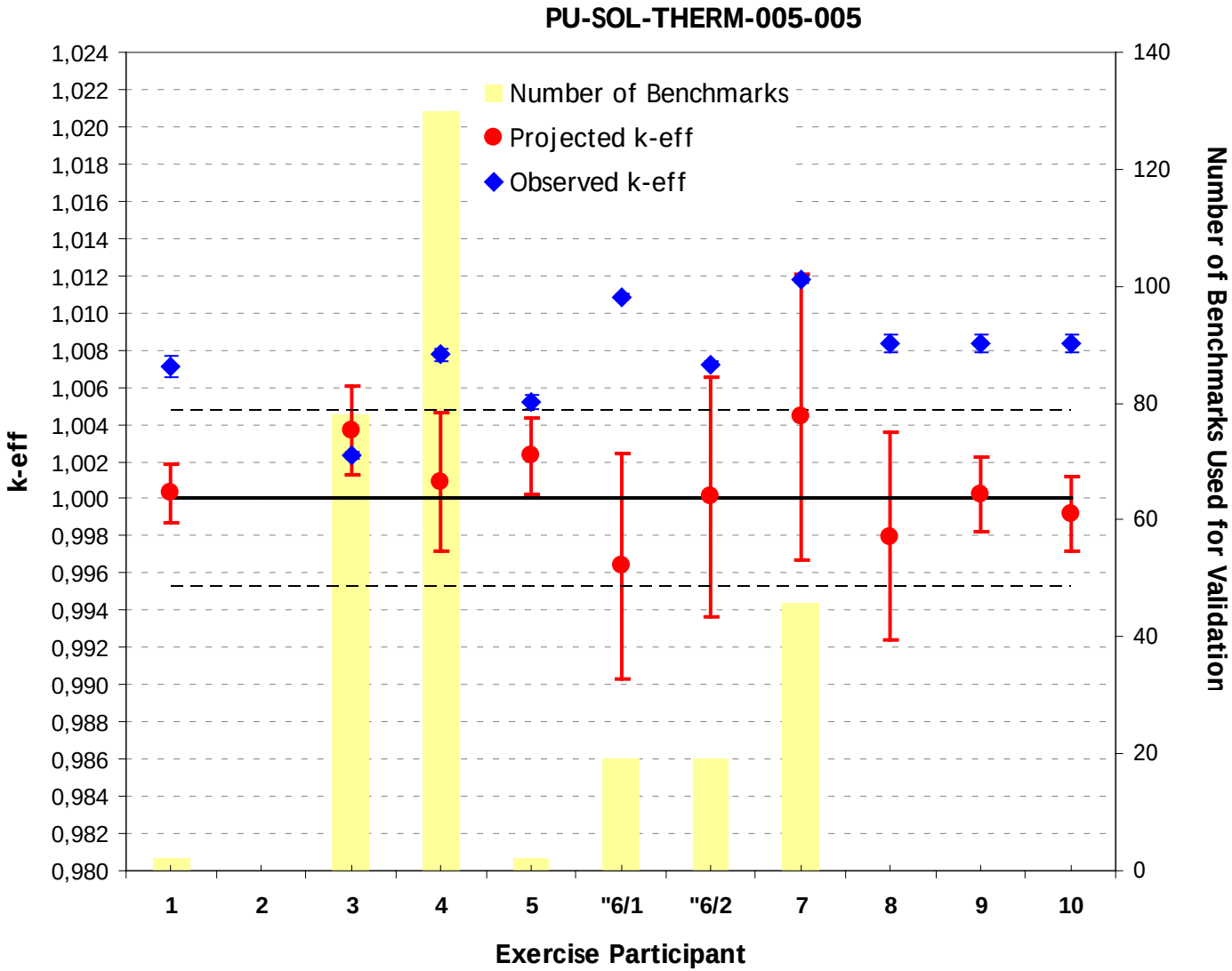
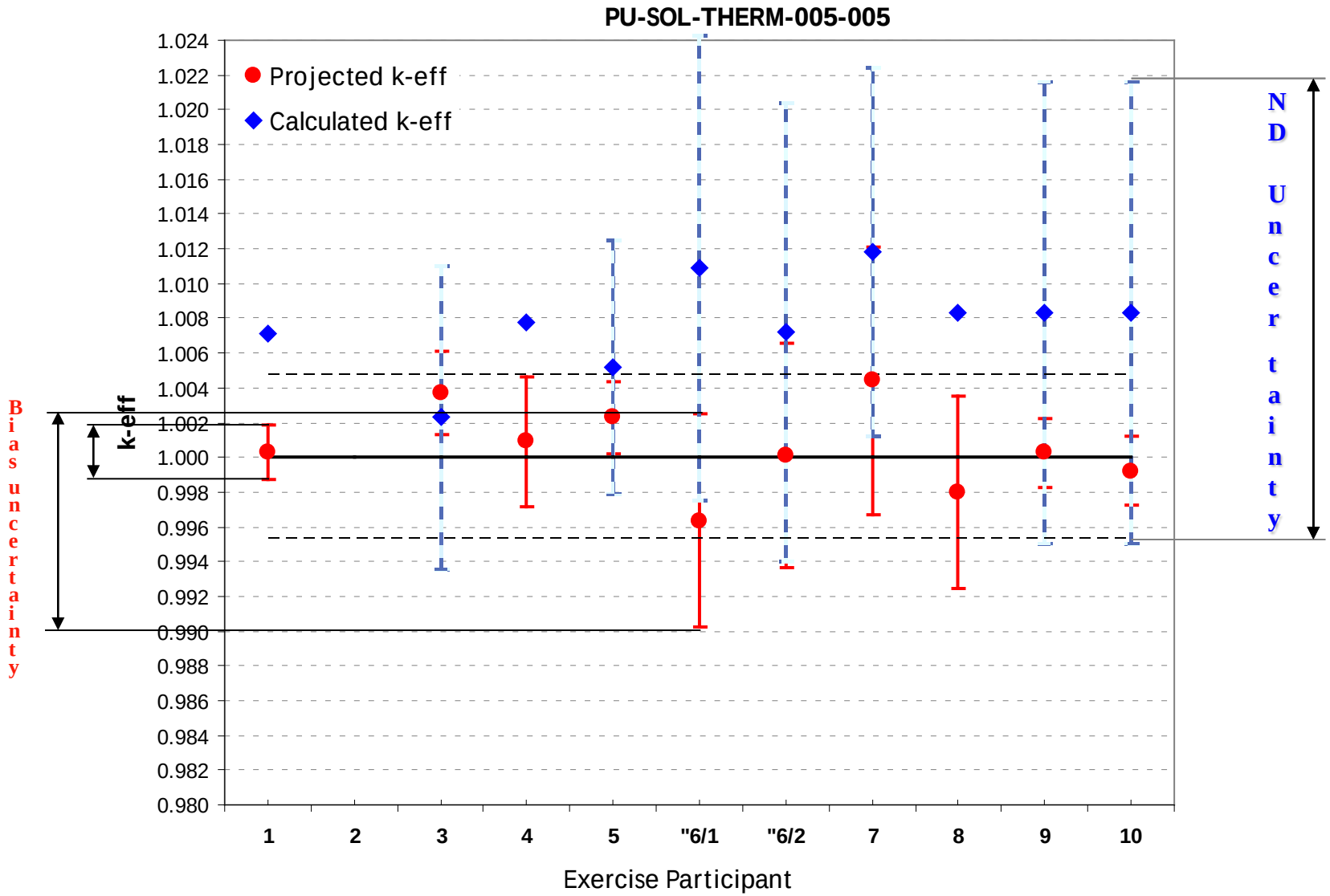


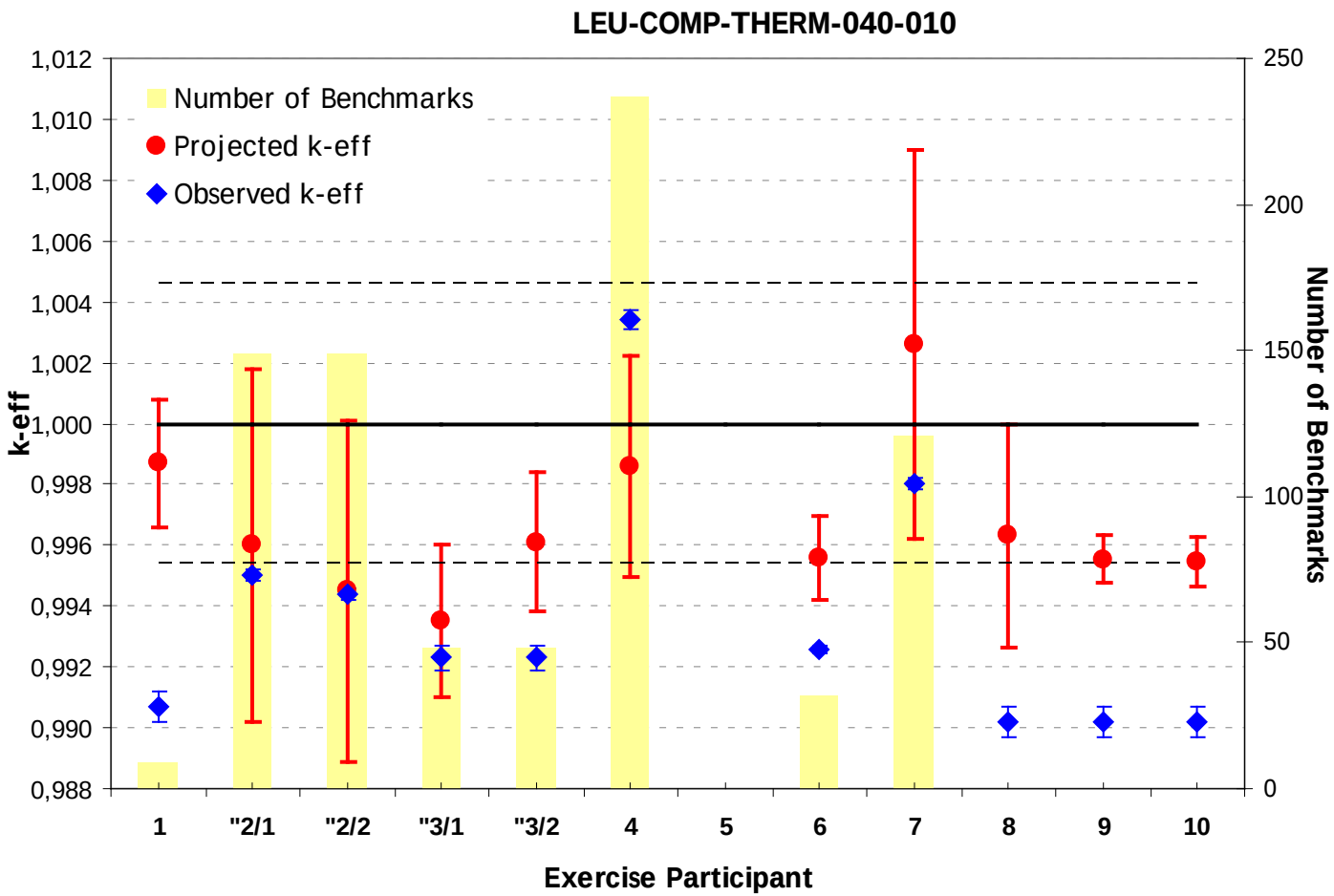
EG UACSA Benchmark Exercises Phase I: Results Analysis (3/8)



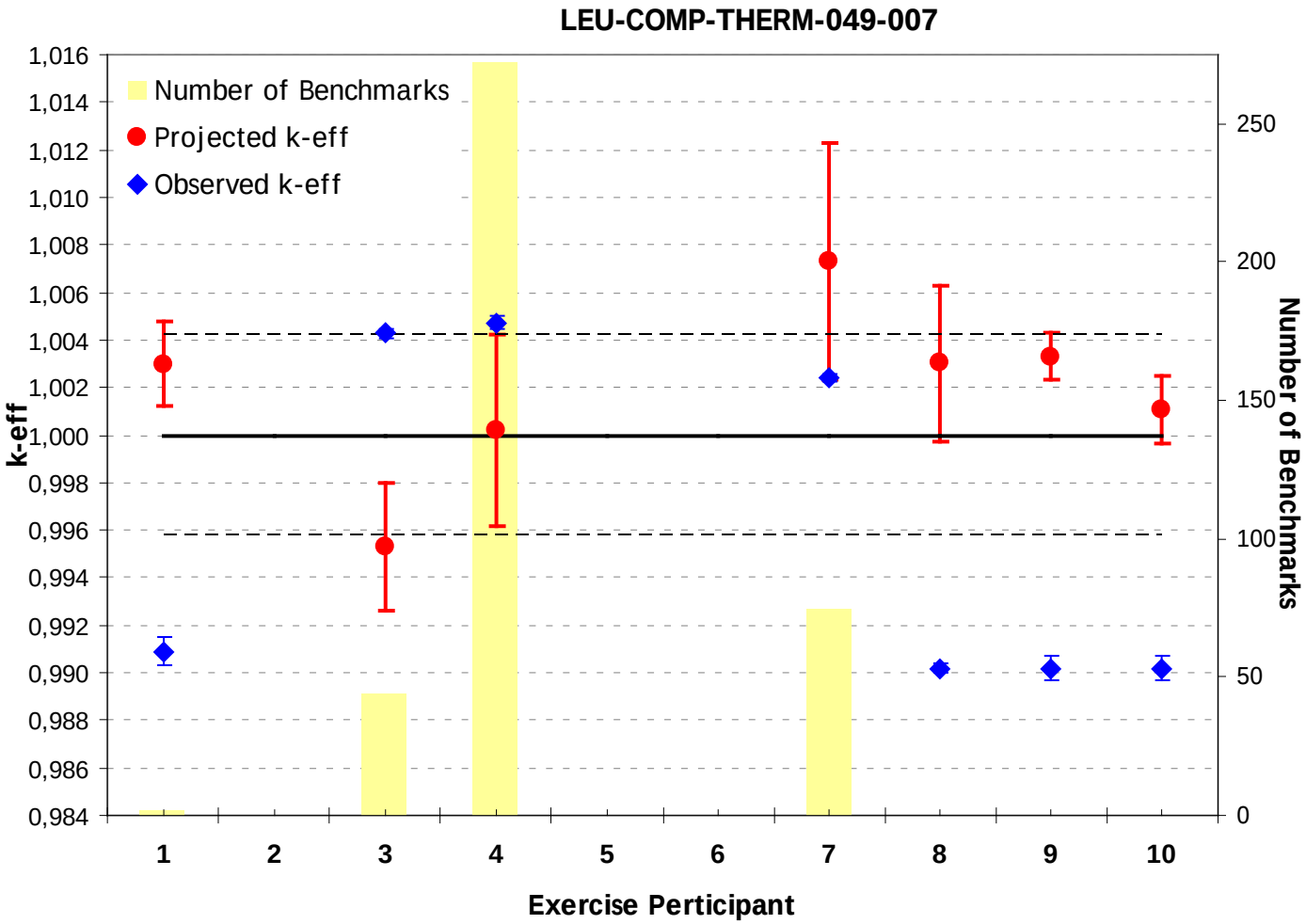
EG UACSA Benchmark Exercises Phase I: Results Analysis (4/8)



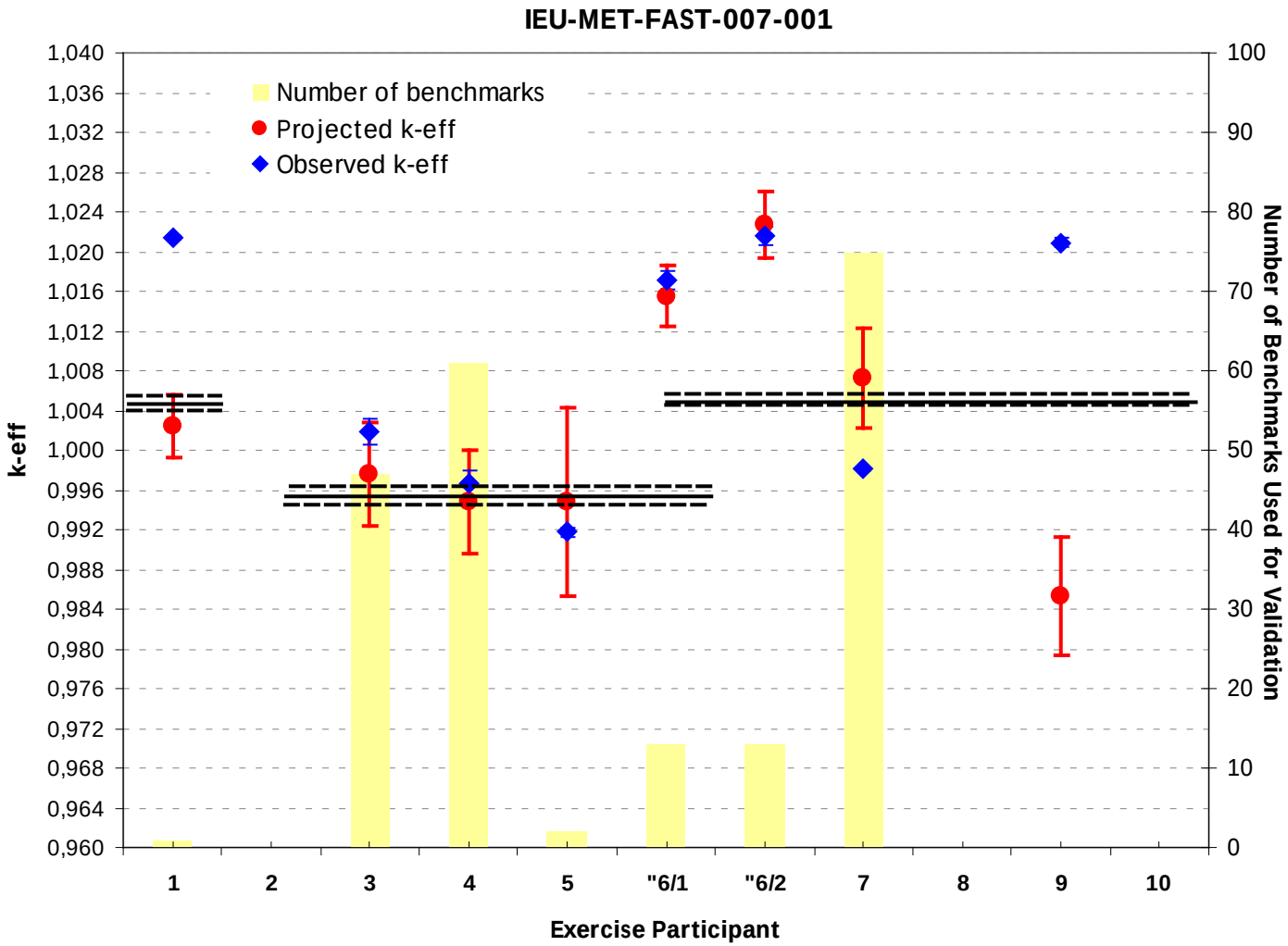
EG UACSA Benchmark Exercises Phase I: Results Analysis (5/8)



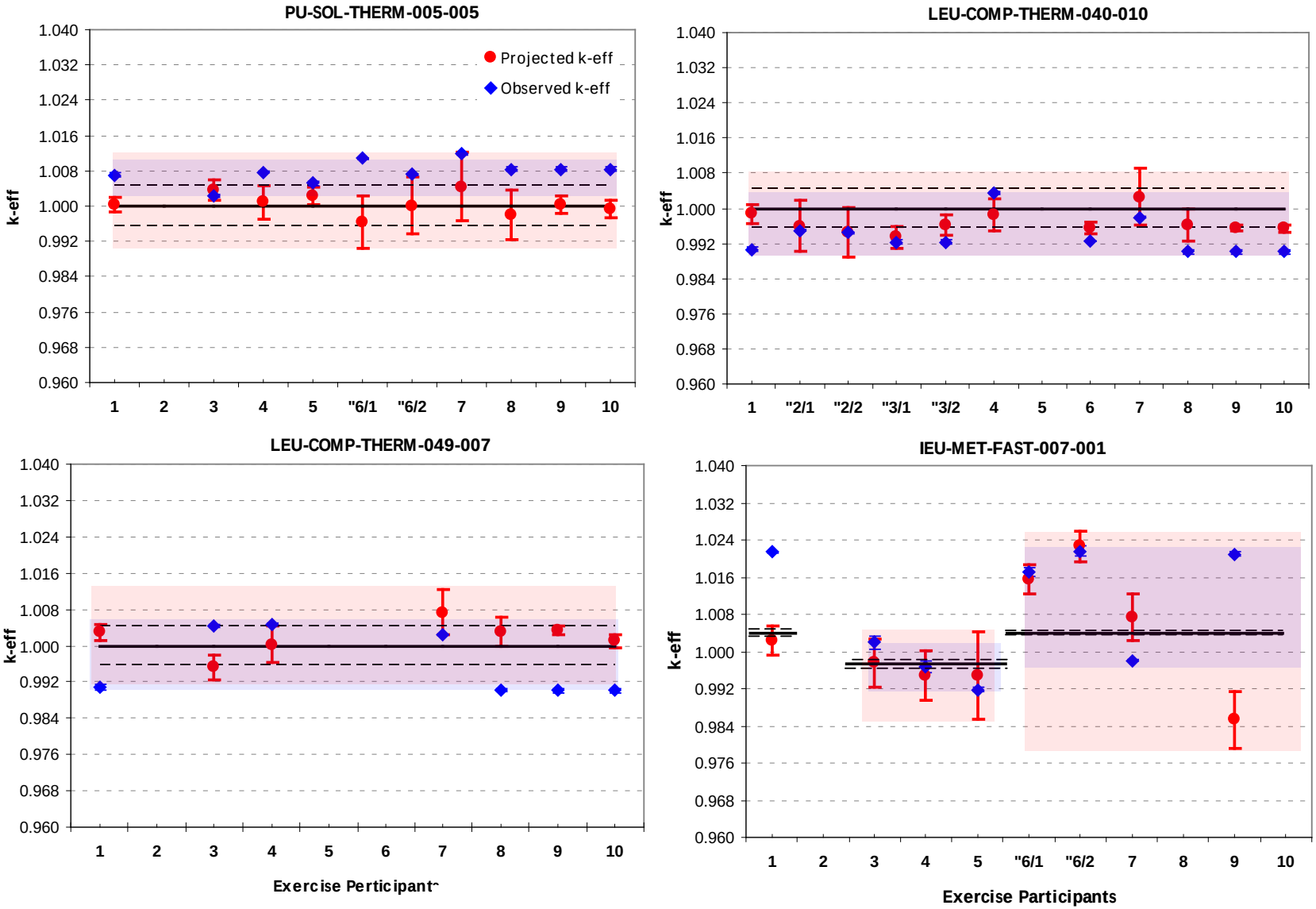
EG UACSA Benchmark Exercises Phase I: Results Analysis (6/8)



EG UACSA Benchmark Exercises Phase I: Results Analysis (7/8)



EG UACSA Benchmark Exercises Phase I: Results Analysis (8/8)



Validation Methods: Summary

- ICSBEP Handbook is the main source of integral data
- Rigor of the techniques is sometime limited to engineering judgment on similarity assessment stage
- Sensitivity data are commonly used for experiments selection and similarity assessment
- Techniques for bias and uncertainty projection are (1) Expert judgment; (2) “Simple” statistical treatment; (3)Trending analysis; (4) Monte Carlo Sampling; (5) GLLSM-based (“adjustment”)
- Validation software tools are commonly used for criticality validation

Results of Benchmark Exercises: Summary

- All validation techniques show good performance for application system PST-005-005 and LCT-040-010, which are common for criticality safety practice
- Some methods do not predict bias for more “exotic” systems
- Validation techniques significantly decrease uncertainties due to nuclear data
- Different techniques set different requirements to quantity of benchmark experiments
- Fully formal validation shows good performance for the applications if benchmarks are carefully selected

Requirements to Validation Techniques

- Provide adequate selection of benchmark experiments
- Provide high-confidence validation while using limited experimental data
- Provide reasonably formalized validation
- Separately validate portions of the application area, even though none can be considered entirely similar
- Extract biases due to specific materials (FPs, structural materials…)
- Indicate area where the limited integral experiment data are available for a specific validation needs
- Design new integral experiments…

Statistical data adjustment is expected to be of value for criticality safety validation

Requirements to Benchmark Experiments

- The benchmark uncertainties are established and well understood

- The correlation between the experimental uncertainties are established and physically based

- The set of the selected experiments is consistent, e.g. the deviations in the calculation-to-experiment differences for different experimental series are well understood

Where to go?

- Test techniques and software tools for sensitivity calculations
- Test impact of cross-section covariance data
- Test techniques and software tools establishing technological uncertainties and uncertainty of depletion calculation…