IRSN
INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

Faire avancer la sûreté nucléaire

Progress Made at WPNCS Expert Group on Uncertainty Analysis for Criticality Safety Assessment (EG UACSA)

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Meeting of WPEC Subgroup 33
1-2 December, 2011
Issy-les-Moulineaux, France

Work Status

Phase	Subject	Status	Due
State-of-the-art report	Methods for criticality safety validation	At NEA	2011?
Benchmark Phase I		To be sent to NEA Article is published PHYSOR 2010	?
Benchmark Phase II	Uncertainties due to manufacturing tolerances	Final report in progress	09/2012
Benchmark Phase III	k_{eff} sensitivity to nuclear data	Draft report in progress Article is submitted PHYSOR 2012	To be discussed in 09/2012
Benchmark Phase IV	Correlations in experimental uncertainties	Specification in progress	02/2012

Phase I: Objectives

- Provide an overview of state of the art in criticality validation approaches;
- Perform exercise to illustrate predictive capabilities of the criticality validation approaches;
- Create a EG glossary.

More details can be found in article by the EG:

T. Ivanova et al, "OECD/NEA Expert group on Uncertainty Analysis for Criticality Safety Assessment: Current Activities," Proceedings of PHYSOR 2010, Pittsburgh, Pennsylvania, USA, May 9-14, 2010, on CD-ROM (2010).

Benchmark Phase I: Participants, Methods, Codes

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. or* 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*	Benchmark quality, *S/U-based parameter, Expert judgment*	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	MMKKENO *Monte Carlo*	ABBN *299-gr.* Subgroups	Benchmark quality, *Sensitivity comparison,* χ^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	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 χ^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

Benchmark Phase II: Objective

Objective: to estimate the uncertainty in k_{eff} due to manufacturing tolerances of the design parameters.

Configuration: a fuel assembly configuration which is derived from typical wet PWR fuel storage rack designs and PWR fuel basket designs for transport/storage casks.

Optional task: to estimate the bias and uncertainty in the k_{eff} due to nuclear data.

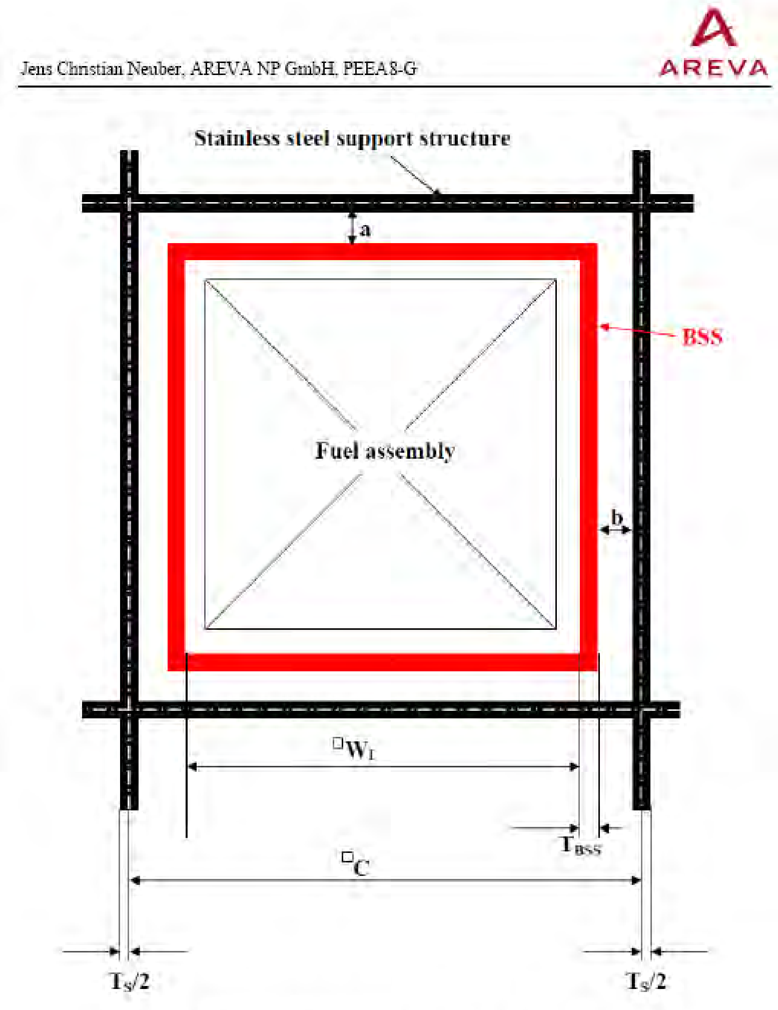


Figure 1: Sketch of the benchmark configuration

Benchmark Phase III: Objective & Specification

The **objectives** are to:

- test performance of sensitivity codes;
- demonstrate if/how geometry simplification impacts sensitivity results;
- demonstrate if/how ‘implicit’ portion of sensitivity is important.

Phase III.1, 2: Water-reflected mixed plutonium-uranium oxide (20wt% Pu) pins

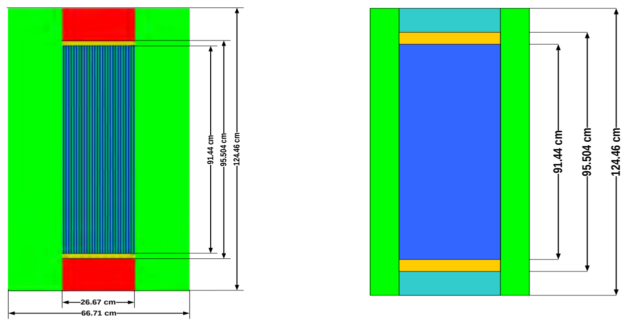
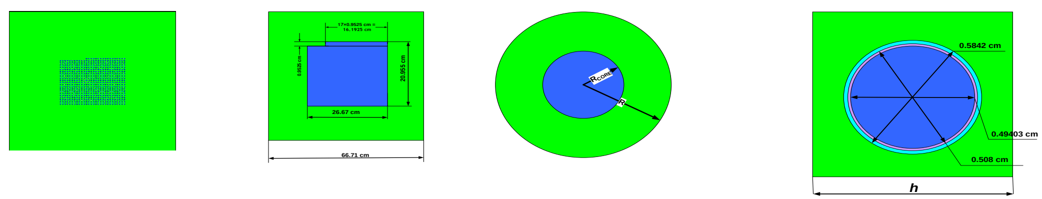


Table I. Pitch Variation for Fuel Rod Pin Cell (Phase III.2)

Case #	Pitch *(h)*, cm
1	0.586
2	0.60
3	0.66
4	0.73
5	0.9525
6	1.05
7	1.15



a) Detailed Model b) Cartesian Model c) Cylindrical Model d) Pin-cell Model

Figure 1. Models for Benchmarks Phase III.1 and III.2

Phase III.3: Bare spheres filled with homogeneous mixture of UF_4 of 2%- and 50%-enrichment and polyethylene

Benchmark Phase III: Participants/Tools

Participant	Country	Code/SCALE Version	Method*	ND Library	Energy Groups	Benchmark Phase III 1.1	1.2	1.3	1.4	2	3.1	3.2
AWE	UK	MONK	DOM/MC	JEF-2.2	13K							
EMS	Sweden	TSUNAMI-3D/6.1	PT/MC	B-VII,-VI,-V	238							
		TSUNAMI-1D/6.1	PT/D	B-VII,-VI,-V	238							
IPPE	Russia	MMKKENO	DOM/MC	ABBN	299							
					299+S/ groups							
		TWODANT based	PT/D		299							
IRSN/ EMP	France/ Canada	TSUNAMI-3D/5.1	PT/MC	B -VI	238							
		TSUNAMI-1D/5.1	PT/D	B -VI	238							
		APOLLO2-MORET5	DP and CSM/MC	JEF-2.2	172							
KINS	Korea	TSUNAMI-3D/6.0	PT/MC	B-VII	238							
LPSC	France	DRAGON4-SUSD3D	PT/D	JEFF-3.1.1	172							
NRC	USA	TSUNAMI-3D/6.0	PT/MC	B-VII	238							
ORNL	USA	TSUNAMI-3D/6.1	PT/MC	B-VII	238							

* **DOM** – Differential operator method; **PT** – adjoint-based first-order-linear perturbation theory; **DP** – direct perturbation; **MC** – 3D Monte Carlo; **D** – deterministic; **CSM** – correlated sampling method

Benchmark Phase III: General Conclusions

- Eight participants from seven countries provided results for the benchmark.
- Seven of the eight contributors used Monte Carlo codes, implementing different techniques:

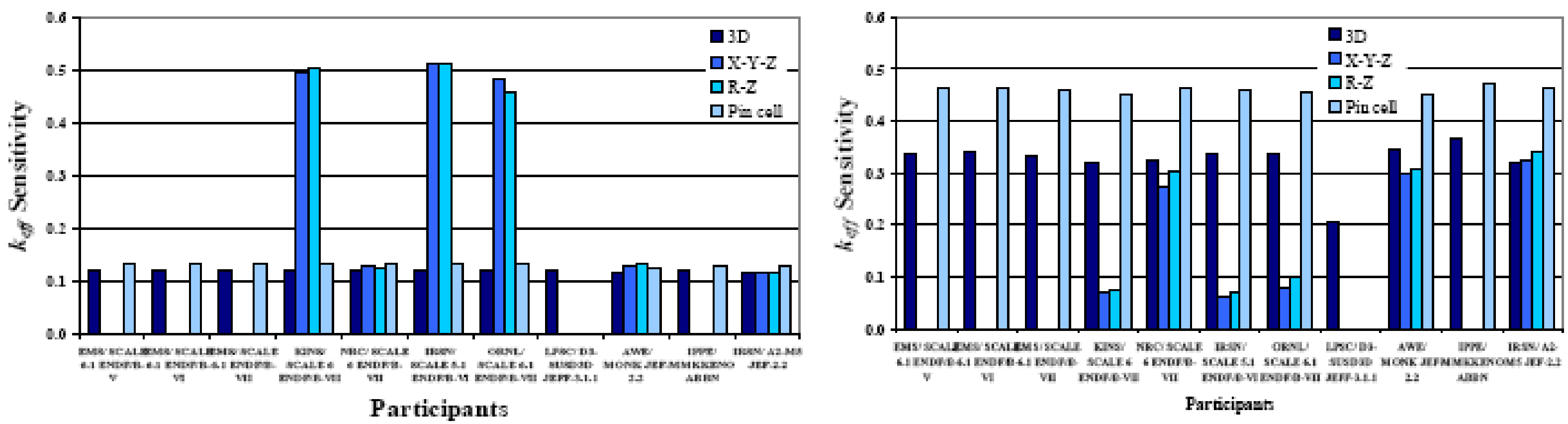
  1) adjoint-based first-order-linear perturbation theory (SCALE/TSUNAMI-3D, US);
  2) differential operator method (MONK, UK and MMKKENO, Russia); and
  3) correlated sampling method (MORET, France).

Benchmark Phase III: General Conclusions

- The major areas for improvement are ^{238}U **scattering sensitivities**. Even though these sensitivities are relatively small, they contribute disproportionately to the k_{eff} uncertainty due to nuclear data.
- As expected, using **different nuclear data libraries** with the same code does not significantly impact the sensitivity results.
- Some **user problems** have been recognized by the participants, for example selection of the spatial mesh for TSUNAMI-3D calculations. The SCALE documentation provides clear recommendation on this concern.

Benchmark Phase III: Conclusions (Model Simplification)

- In general, all the codes perform well.
- Comparison of the results for the 3D, Cartesian and R-Z models shows good agreement if homogenized cross sections are prepared correctly.
- A by-product of the benchmark is that sensitivity data generated from **cell weighted cross sections** are not always correct.
- The results for the **pin-cell** model differ from the results obtained for the detailed 3D model.



a) ^{239}Pu b) ^{1}H

Figure 3. Integrated sensitivities to material number density for ^{239}Pu and ^{1}H (Phase III.1)*

"Complete" Sensitivity for CellMix Transport (SCALE)*

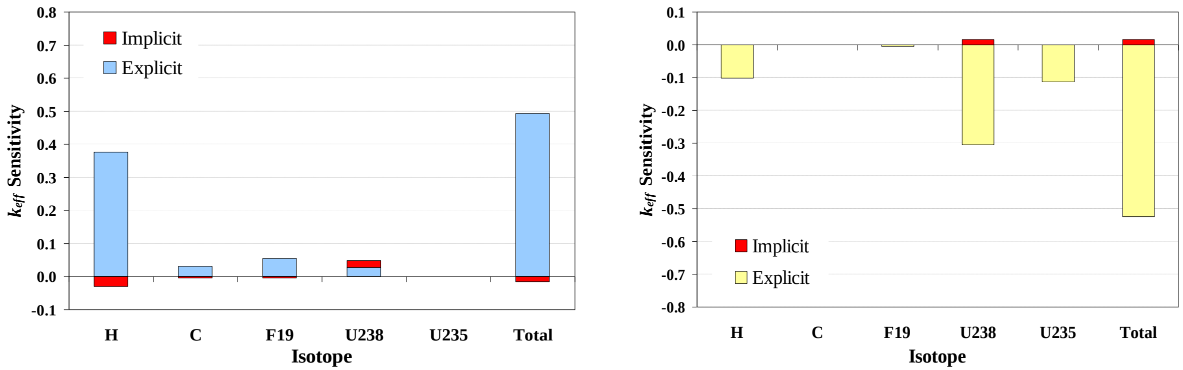
- The "explicit" effect is sensitivity of k_{eff} to resonance self-shielded cross-section data.
- The "implicit" effect is sensitivity of resonance self-shielded cross-section data to infinitely dilute cross sections input data (e.g. Dancoff factors).
- The "cellmix" effect is sensitivity of mixed cross sections to discrete cross sections (not treated in Scale)

$$\left(S_{k,\Sigma^i_{\bar{x},g}}\right)_{complete} = \frac{\Sigma^i_{\bar{x},g}}{k}\frac{dk}{d\Sigma^i_{\bar{x},g}} = \underbrace{\frac{\Sigma^i_{\bar{x},g}}{k}\frac{\partial k}{\partial \Sigma^i_{\bar{x},g}}}_{\text{Explicit}} + \sum_j \sum_h \underbrace{\frac{\Sigma^j_{\bar{y},h}}{k}\frac{\partial k}{\partial \Sigma^j_{\bar{y},h}} \times \frac{\Sigma^i_{x,g}}{\Sigma^j_{\bar{y},h}}\frac{\partial \Sigma^j_{\bar{y},h}}{\partial \Sigma^i_{x,g}}}_{\text{Cellmix}} \times \underbrace{\frac{\Sigma^i_{x,g}}{\Sigma^j_{y,h}}\frac{\partial \Sigma^j_{y,h}}{\partial \Sigma^i_{x,g}}}_{\text{Implicit}}$$

*Slide by Bradley Rearden and Keith C. Bledsoe (ORNL)

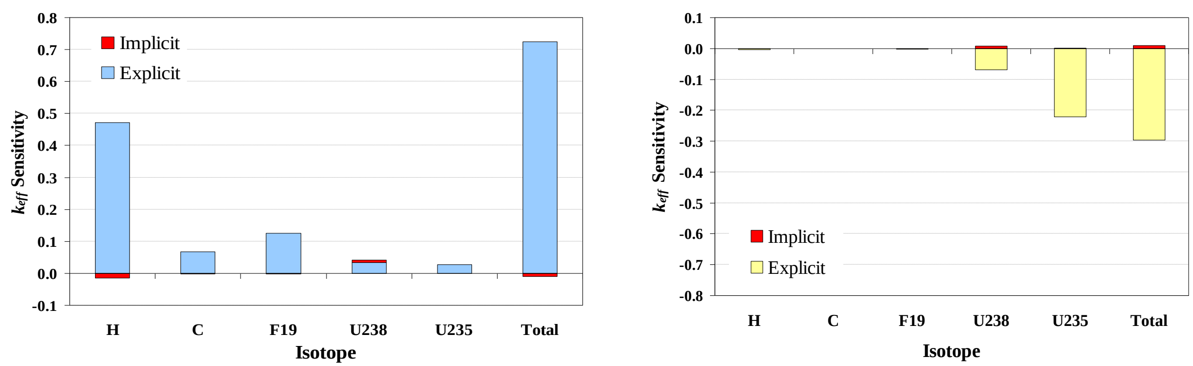
Benchmark Phase III: Conclusions ('Implicit' sensitivity)

- The "implicit" sensitivities were found to be important in some cases (^{238}U scattering for homogeneous sphere filled with low enriched UF_4 and polyethylene).



a) Scattering sensitivities **b) Capture sensitivities**

Figure 1. 'Explicit' and 'implicit' sensitivities for sphere filled with 2%- enriched uranium

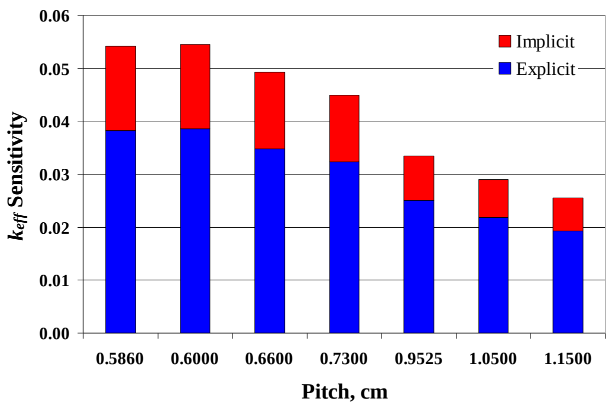


a) Scattering sensitivities **b) Capture sensitivities**

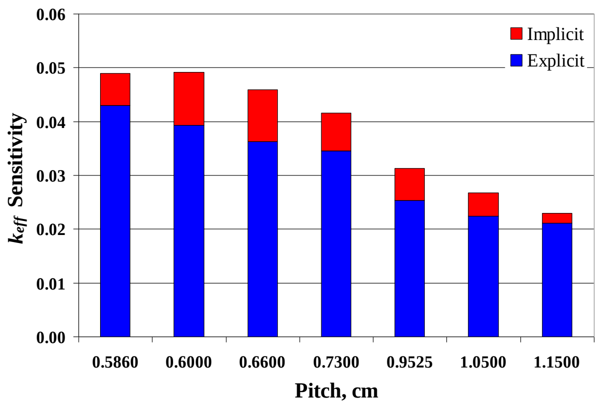
Figure 2. 'Explicit' and 'implicit' sensitivities for sphere filled with 50%- enriched uranium

Benchmark Phase III: Conclusions ('Implicit' sensitivity)

- The "complete" ("implicit" + "explicit") sensitivities were estimated by:
  - applying an algorithm in the sensitivity tool (SCALE/TSUNAMI-3D),
  - running calculations using hyper-fine energy group structure (MONK),
  - using subgroup representation (MMKKENO) for neutron cross sections.
- The comparison of the methods indicates that the different approaches produce comparable results.



a) TSUNAMI-3D results



b) MMKKENO results

Integrated 'explicit' and 'implicit' sensitivities for ^{238}U scattering as a function of pitch variation (Phase III.2)

Further Work: Benchmark Phase IV.1

Problem: Establish correlations in k_{eff} experimental uncertainties for several series of experiments available in the ICSBEP Handbook.

Objective: Test/compare methods used

Status: Benchmark specification in progress (Due: 02/2012)

Potential Participants: ANL, AREVA (Germany), CEA, EMS, IPPE, IRSN, ORNL, others are welcome.