IRSN
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ET DE SÛRETÉ NUCLÉAIRE

Faire avancer la sûreté nucléaire

Criteria and practice for selection and setting up of new experiments

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Sub-Group 46
"Efficient and Effective Use of Integral Experiments for Nuclear Data Validation",
kick-off meeting,
November 20 and 21,
Nuclear Energy Agency (NEA),
46, quai Alphonse Le Gallo, 92100, Boulogne-Billancourt, FRANCE

IEs selection, major challenges

- Axe #1 : Application Object
  - V&UQ: V&UQ is an application-dependent process, XS correction is a kind of by-products of an adjustment of a reactor physics parameter*
  - Generally an application object (AO) is a physical model of core or of phenomena
  - Question is how to define an AO for XS validation?
- Axe #2 : Representativity and Quality of IEs data
  - no one IE fully represents an AO – suitable set of benchmarks is needed
  - less representative ⇔ more benchmarks
  - higher uncertainties ⇔ more benchmarks
  - if correlated ⇔ more benchmarks
- Axe #3 : Consistency of V&UQ process
  - consistency of IEs evaluation
  - double use of benchmarks in calibration and validation
  - “ouroboros“ problem – impact of calculations inherent to measurements

** The subject of reactor physics is control of neutronic configuration (techniques, measures and limits of controllability of neutron’s population)*

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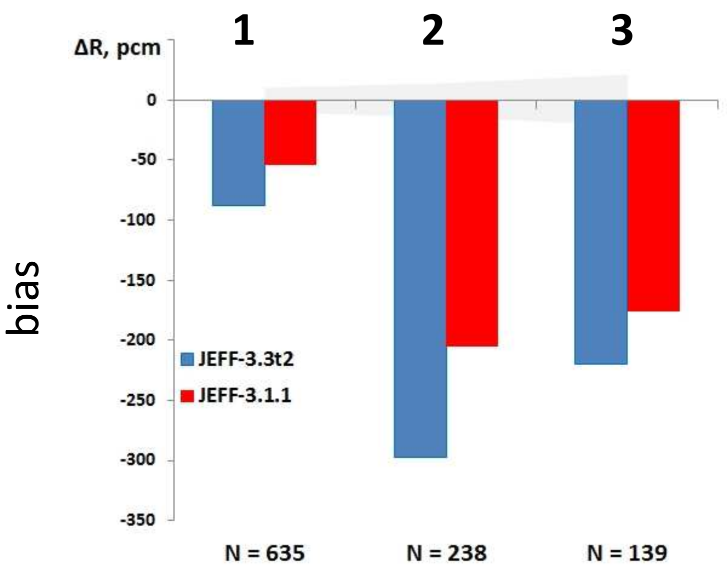
Ambiguity of weighted average and AOs

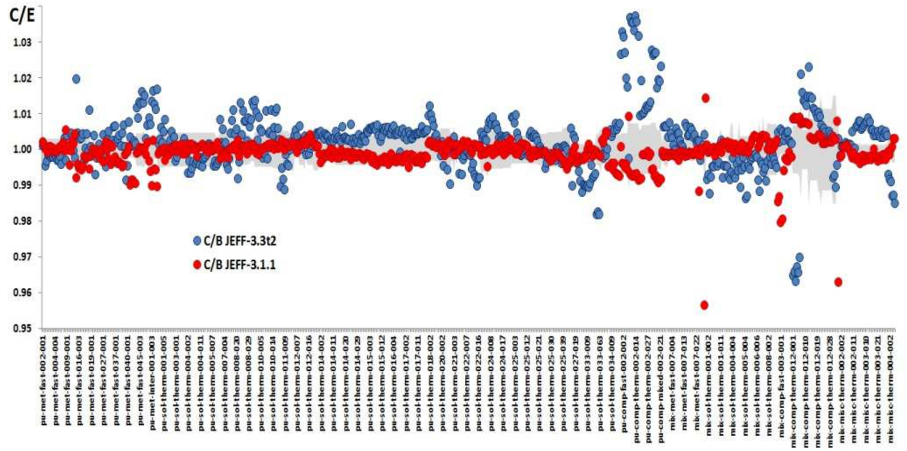


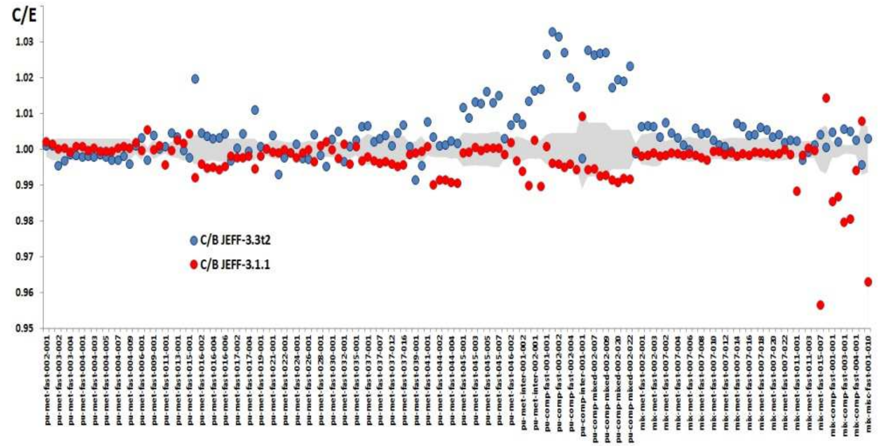
User dependent results of V&UQ<=> non representative IEs

Traditional approach

1. all available benchmarks including solution experiments (N=635 cases)
2. all benchmarks except for solution experiments (N=238 cases)
3. the only fast and intermediate spectra benchmarks (N=139 cases)

- largest bias ~ **<u>300 pcm</u>** (Δk_{eff})





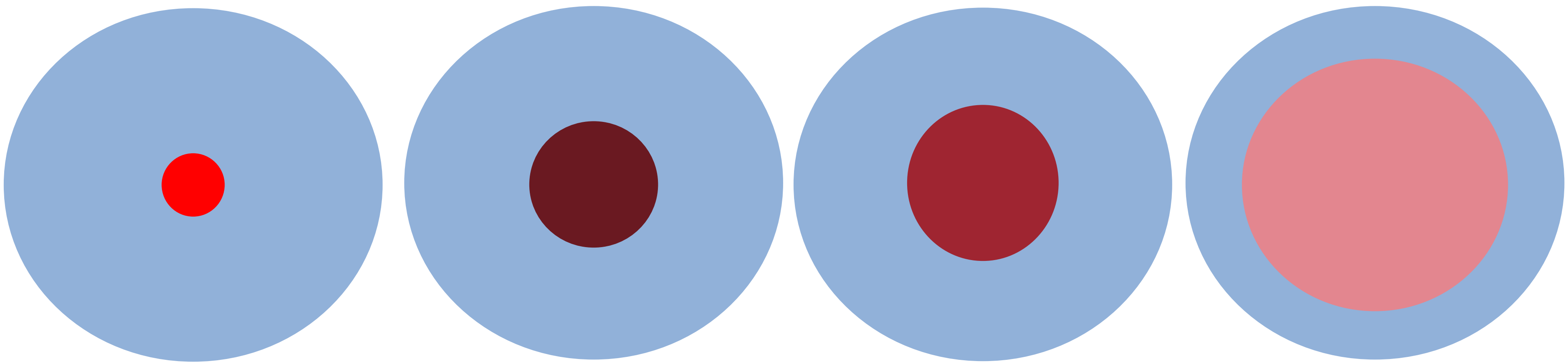
An ambiguity of weighted average and AOs

"Application objects" (model tasks)

4 simplified safety case models:

Spheres of MOX powder with parametrically changing humidity surrounded by water

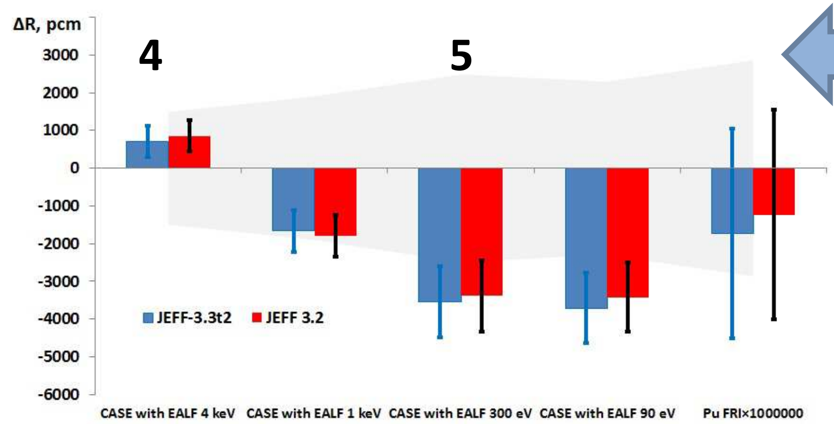
EALF by cases **4 keV**, **1 keV**, **300 eV** and **90 eV**



Data assimilation: practical application

Prior consensus: bias expectation of ~ 300 pcm
The resulted bias in DA approach ~ 4000 pcm (~ 10-15% of MCR)

bias



Data assimilation approach for different spectra

- 1÷4 criticality safety cases

4. At 4 keV EALF bias is **Positive**
5. Lower Energy EALF bias is **Negative**

- largest bias ~ **4000 pcm** (Δk_{eff})
- ^{239}Pu fission resonance integral bias and uncertainty ~ 0.12% and 0.28% (times 1M on the figure)

Pseudo AO definition for XS adjustment/validation

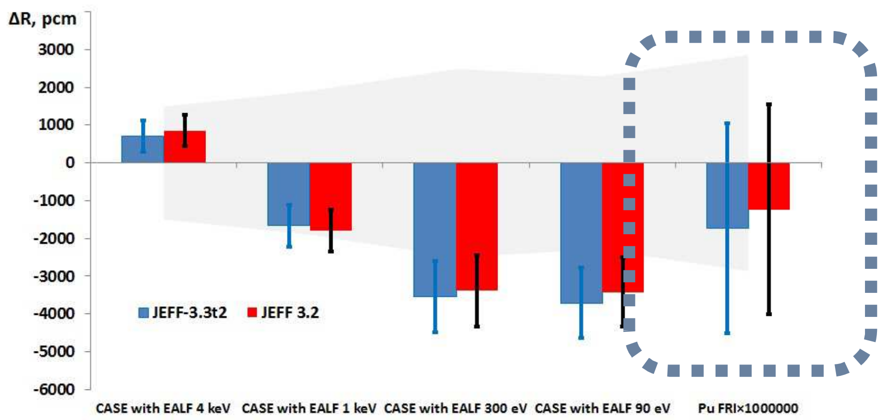
“Application objects” (model tasks)

4 simplified safety case models:

Spheres of MOX powder with parametrically changing humidity surrounded by water

EALF by cases **4 keV**, **1 keV**, **300 eV** and **90 eV**

pseudo AO for validation of XS of interest (example) =>



An integral of ^{239}Pu fission

$$RI_{FISS} = \int_{INTR} \sigma_{239}^{FISS} \cdot \frac{dE}{E}$$

^{239}Pu fission resonance integral bias and uncertainty ~ 0.12% and 0.28% (times 1M on the figure)

Other integral functions and algebraic transformations can be taken as AOs

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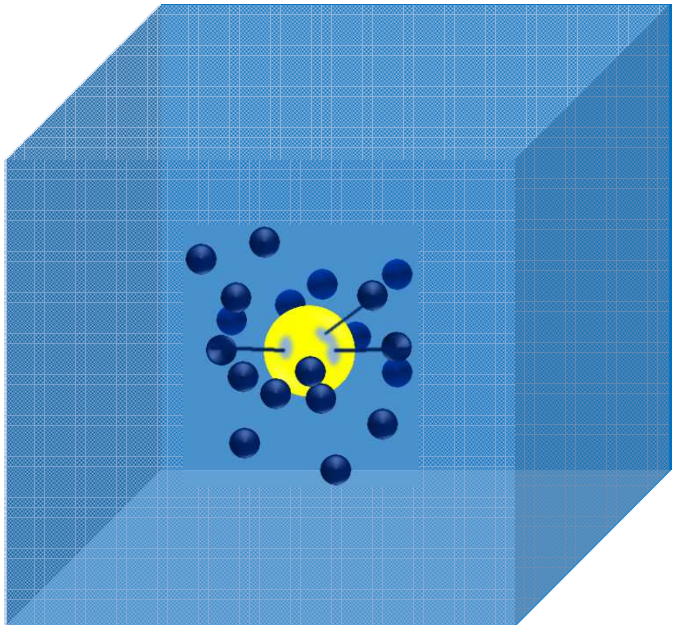
V&UQ according to goals of ICSBEP and IRPhE



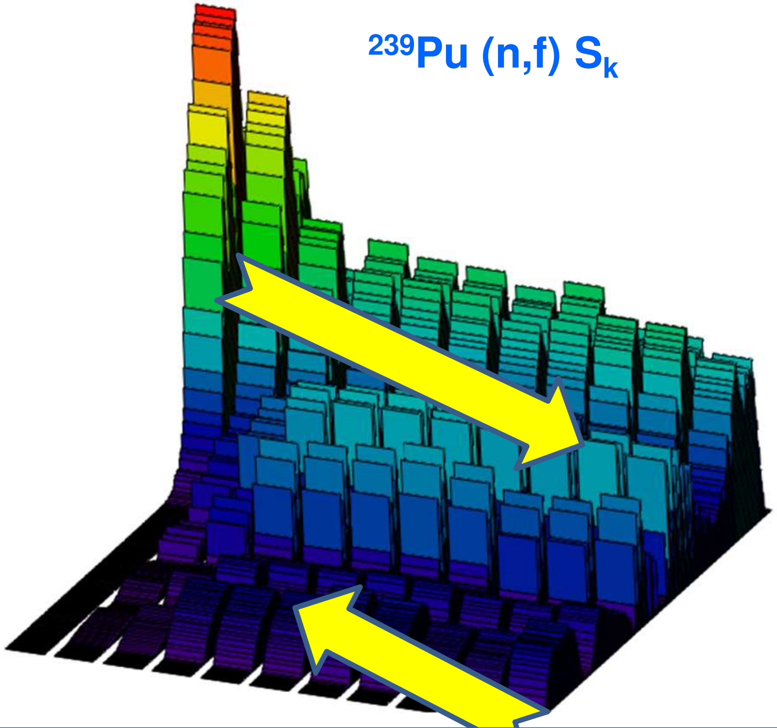
an application object

selected experimental benchmarks

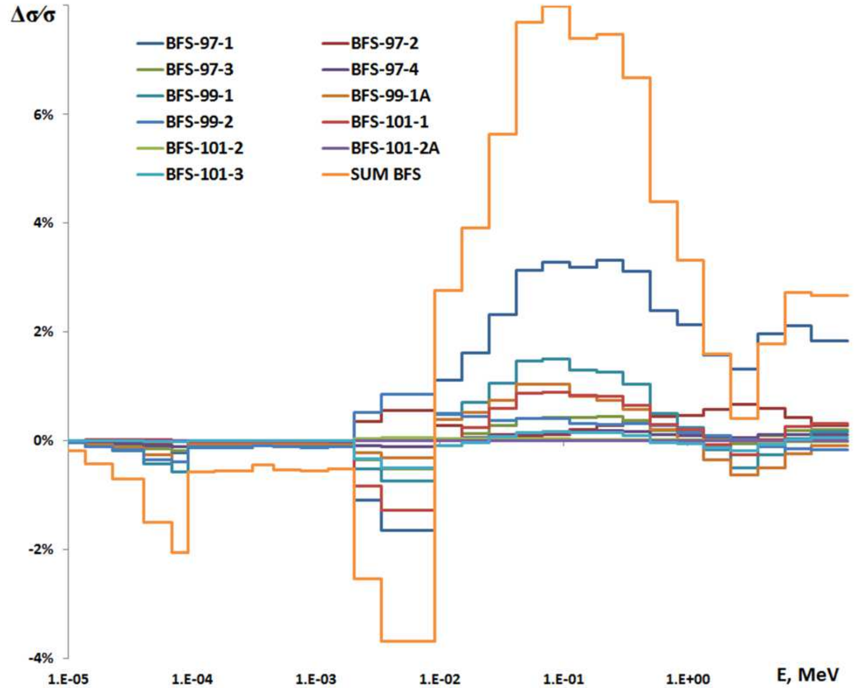
Selected suite of the experimental benchmarks completely envelopes the application domain in the "phase space"

Data Assimilation, Bias and uncertainty

Parametrically varying spectra and energy spanned sensitivity

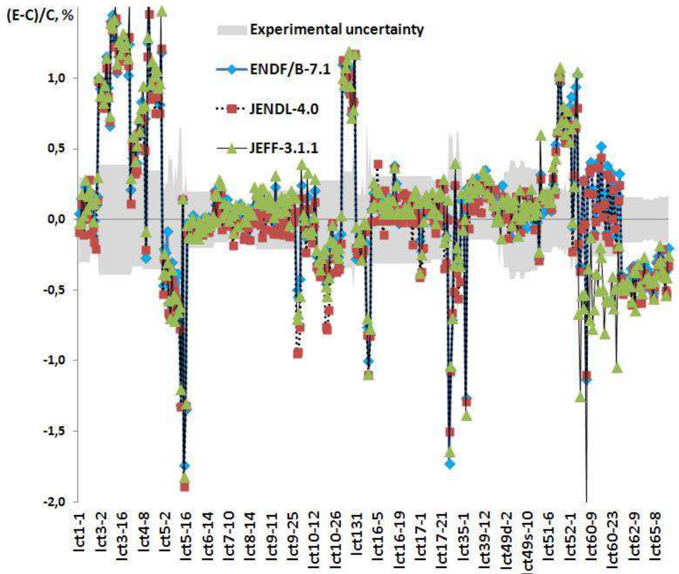


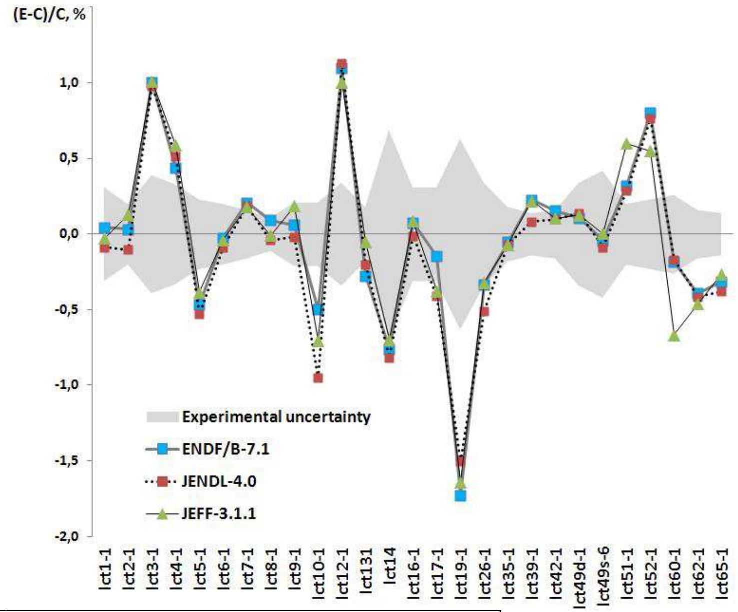
BFS-MOX integral experiments series contribution to ^{239}Pu (n,γ) cross sections



Integral experiments designed as <u>mock-ups</u> or dedicated to the <u>given problem</u> are available nowadays (using advanced analytical and statistical tools) as the experimental based benchmarks for the ND studies

Integral Correlations role in assessment (Example)





Number of LEU-COMP-THERM configurations	Weighted k_{eff} bias, pcm		
	ENDF/B-VII.1	JENDL-4.0	JEFF-3.1.1
388 configurations	-63.3	-14.9	180.0
27 configurations	53.8	113.9	183.3

IEs data correlate due to facilities, equipment, materials and techniques

Ignorance of correlations => under-estimation of uncertainties

Use of only non-correlated cases => over-estimation of uncertainties

Tatiana Ivanova, Evgeny Ivanov, Giulio Emilio Bianchi "Establishment of Correlations for Some Critical and Reactor Physics Experiments", Nuclear Science and Engineering, Volume 178, Number 3, November 2014

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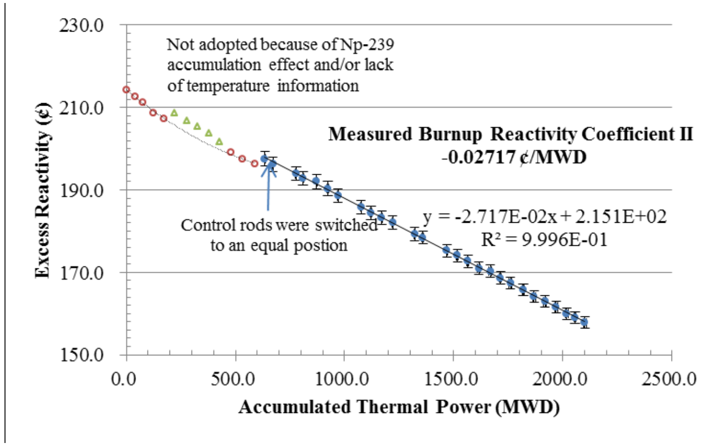
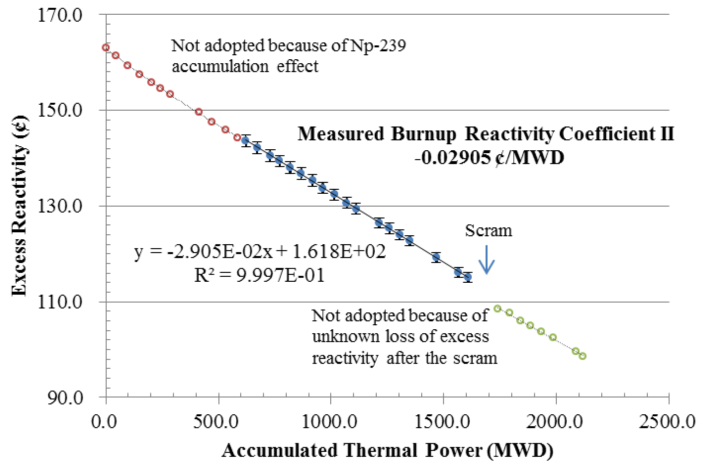
IEs evaluations: ignorance of sufficient factors

Important for an inferred values assessment:
Other physics (multi-physics) effects are well bounded – slow transients





Example: JOYO burn-up tests evaluation

[unexplained area on reactivity swing curves]

- Reference to ^{239}Np is not relevant - could be corrected using high fidelity computing
- Issue is in different place:
  other physics impact a “reactor physics” data

Note again:
Physics differs from criticality to depletion due to field-type equations and weak non-linearity

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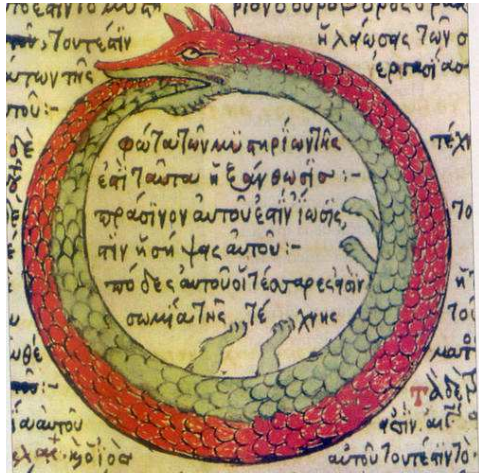
Role of computations: “ouroboros“ problem 1/3



How far can we rely on a benchmark in V&UQ process if it includes computations?

- Example: ORSphere β_{eff} measurement (other β_{eff} cases also contain numerically computed correction factors)
- Given:

  ρ_{CLC} computed in absolute values (MCNP)
  ρ_{EXP} measured in units of $
  computed in absolute values using MCNP
  $\beta_{eff} = \rho_{CLC} / \rho_{EXP}$
  50% of calculations?

Role of computations: “ouroboros“ problem 2/3

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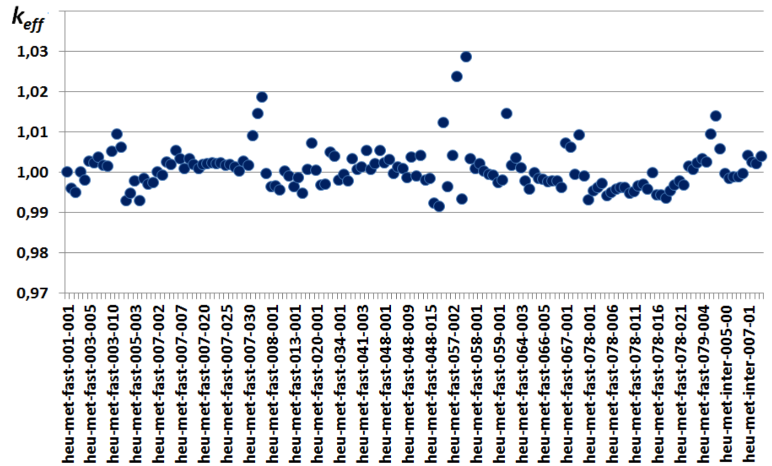
- If simulation tool is validated against representative experiments of another kind (critical in our case)
  $\Delta\rho$ due to validated calculations ~ 0.55%
- In this case “service” IEs (ICSBEP) to be added to a “given” IE (ORSphere-KIN)



$$\delta\rho / \rho \approx \sqrt{2} \cdot \left(\delta k_{eff} / k_{eff} \right)$$

Role of computations: “ouroboros“ problem 3/3

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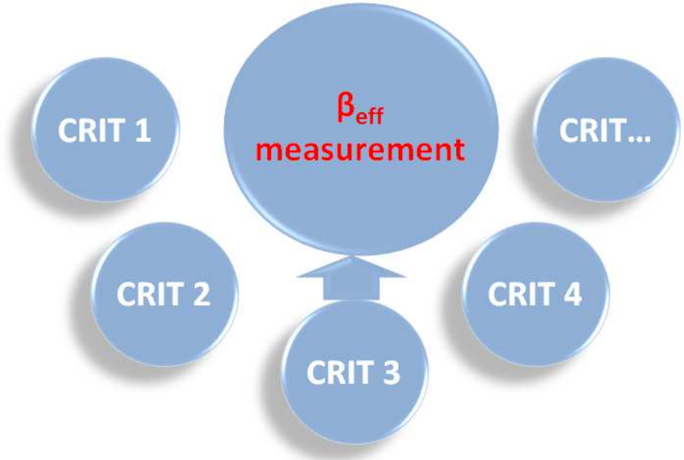

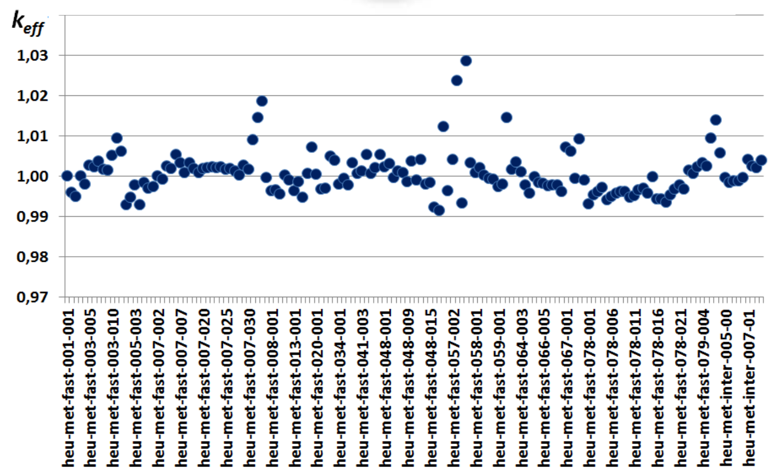

$$\delta\rho/\rho \approx \sqrt{2}\cdot\left(\delta k_{eff}/k_{eff}\right)$$

Inferred data evaluation, role of simulations

Type of functional	Comments	Role of calibration
CRIT	no assumptions/ minimal corrections	
REAC	point-wise / corrections if MIXed	
SPEC/RRATE	extrapolation/ minimal corrections	
KIN	point-wise / calculated worth	
POWR	extrapolation/ minimal corrections	
MISC	corrections if Ψ^+ importance function	

Many cases include calculations inherent to measurements

To be assessed: impact of simulations

To be presented: relevant "validation matrices"

i.e. references on a validation report or/and a list of "service" IEs data used in a validation of "service" tool

Shared "service" codes and "service" experiments => correlations between different experiments at different facilities

Bayesian approach - bias and uncertainty

- Bias – the expectation of correction factor to be associate with simulation results basing on available observations

$\Delta R \sim \Theta \cdot \Theta_{IE} \cdot S_{AO} \cdot S_{IE} \cdot \Delta r_B$

depends on observations [Δr_B], physics of the IEs and of application [S_{IE} and S_{AO}], and basic and IE data uncertainties (freedom degree) [Θ] ,[Θ_{IE}]

- Uncertainty of the bias – the measure of the bias confidence

$\sigma(\Delta R) \sim \Theta \cdot \Theta_{IE} \cdot S_{AO} \cdot S_{IE}$

depends physics of the IEs and of application [S_{IE} and S_{AO}], and basic and IE data uncertainties [Θ],[Θ_{IE}], does not depend on observations [Δr_B]

Parameters to determine uncertainties and to determine the bias are different

Practical conclusions:
Space of uncertainty is orthogonal to the space of value
Model of uncertainty evolution (extrapolation) is needed

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Criteria of IEs selection: through uncertainty reduction and bias conservation

Major adding value cases

	C1	C2	C3	C4	RI
PU-MET-FAST-003-001					**
PU-MET-FAST-003-003					**
PU-MET-FAST-003-005	*	*	*	*	**
PU-MET-FAST-009-001	*	**	*	*	*
PU-MET-FAST-019-001	*	***	***	***	***
PU-MET-FAST-021-001	*				**
PU-MET-FAST-021-002		**	**	**	**
PU-MET-FAST-025-001		*	*	*	**
PU-MET-FAST-026-001	*	*	*	*	**
PU-MET-FAST-032-001					***
PU-MET-FAST-035-001		**	**	**	***
PU-MET-FAST-036-001	*	*	*	*	**
PU-MET-FAST-041-001	*	**	*	*	**
PU-MET-FAST-045-003	*	*	*	*	**
PU-MET-INTER-002-001	*	***	**	**	*
PU-COMP-FAST-002-003		*	**	**	
PU-COMP-FAST-002-004		*	**	**	*
PU-COMP-FAST-002-005		**	**	**	
MIX-MET-FAST-003-001	**	***	*	*	***
MIX-MET-FAST-007-009		*	*	*	**
IEU-MET-FAST-013-001	***	***	*	*	*

Criteria of IEs selection

- High fidelity evaluated integral experiment data
- Limited/well estimated residual uncertainty
- Potential contribution in uncertainty ≥ criteria based on χ^2 and 1/Number of benchmarks

$$\overline{\mathbf{S}}_{\mathrm{AO}}^{\mathrm{T}} \hat{\mathbf{W}} \hat{\mathbf{S}}_{\mathrm{B}} \cdot \left(\hat{\mathbf{V}}_{\mathrm{EXP}} + \hat{\mathbf{V}}_{\mathrm{CLC}} + \hat{\mathbf{S}}_{\mathrm{B}}^{\mathrm{T}} \hat{\mathbf{W}} \hat{\mathbf{S}}_{\mathrm{B}} \right)^{-1} \cdot \hat{\mathbf{S}}_{\mathrm{B}}^{\mathrm{T}} \hat{\mathbf{W}} \overline{\mathbf{S}}_{\mathrm{AO}}$$

- Visible potential contribution in the expected ultimate bias

$$\left(\overline{\mathbf{S}}_{\mathrm{B}}^{\mathrm{T}} \cdot \hat{\mathbf{W}} \cdot \hat{\mathbf{S}}_{\mathrm{B}} \right) \cdot \left(\hat{\mathbf{V}}_{\mathrm{EXP}} + \hat{\mathbf{V}}_{\mathrm{CLC}} + \hat{\mathbf{S}}_{\mathrm{B}}^{\mathrm{T}} \cdot \hat{\mathbf{W}} \cdot \hat{\mathbf{S}}_{\mathrm{B}} \right)^{-1}$$

Table can be used for express validation (90% of success) and to provide the first guess for an estimator like TMC

Suggestions and conclusions

- V&UQ heavily depends on well elaborated and representative set of experimental benchmarks

- Selection of IEs for validation is a non-trivial but feasible task

- Major challenges are arisen by the following axes:

A.1 how to define an AO for XS validation?

A.2 how to use non fully representative and correlated benchmarks

A.3 how to avoid double use of the same benchmarks (for calibration and for validation) and how to eliminate an “ouroboros“ effect

- The methodology of knowledge transposition/extrapolation should be elaborated and adopted for ND validation process
- The experimental data libraries/data bases and ND libraries should inform users on IEs that are already used in ND evaluations

Thank you for your time