Results for Exercise I-3 with COBAYA: Analysis of the peaking power factors

E. Castro, S. Sánchez-Cervera, N. García-Herranz, D. Cuervo
emilio.castro@upm.es

UAM-11, AREVA (Erlangen, Germany) May 10-12, 2017

Outline

- Background
- Objectives
- Methodology
- Results of k_{eff}
- Results of power distributions
- Results of peaking power factors
- Conclusions

Background

- **UPM methodology for Uncertainty Quantification is based in two tools:**
  - SCALE 6.2.1: NEWT and Sampler.
  - COBAYA: core simulator with nodal and pin-by-pin capabilities

- **Random few-group libraries for COBAYA can be generated in an automatic way using SCALE** by stochastic sampling of nuclear data with Sampler(NEWT) → presented in UAM-9

- **UQ capabilities in COBAYA** → presented in UAM-9
  - 1st. Order PT (full covariance matrix required)
  - Sampled-based (set of random few-group libraries required)

- **Preliminary results of Exercise I-3** → presented in UAM-10

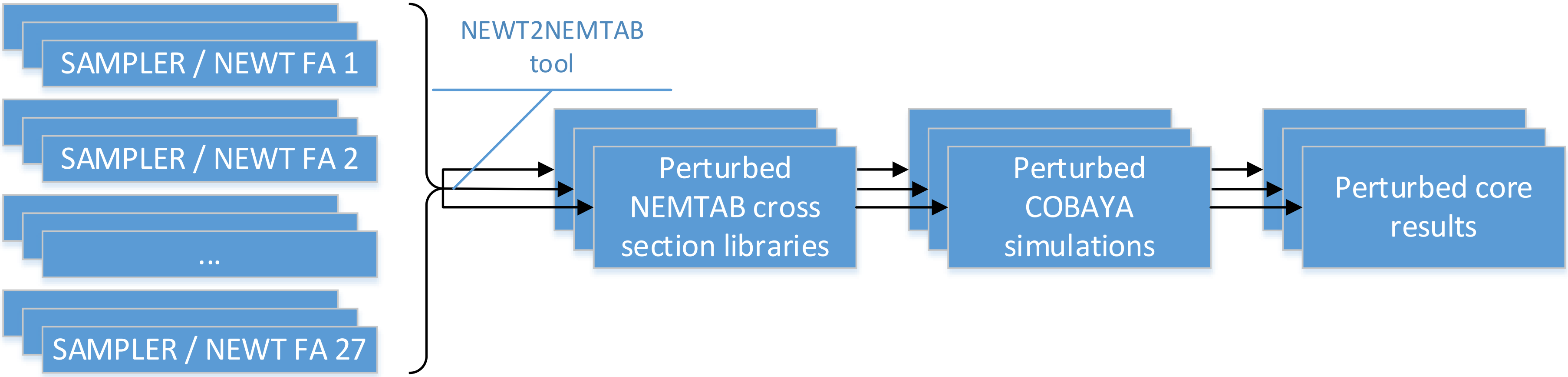
Objectives

- **Exercise I-3: UQ in TMI-1 full core calculations using SCALE(NEWT)/COBAYA at both nodal and pin-by-pin levels**
- **Specific objectives:**
  - Contribute with updated results to Ex I-3, computing uncertainties in k-eff, radial power distributions and peak factors.
  - Compare nodal and pin-by-pin results.
  - Evaluate the probability distribution of core parameters.
- **TMI-1 ARI core definition:**

1	2	3	2	4	5	6	6	R
2	7	2	6	2	3	8	9	R
3	2	7	2	7	5	4	6	R
2	6	2	4	10	7	8	R	R
4	2	7	10	3	11	2	R	
5	3	5	7	11	3	R	R	
6	8	4	8	2	R	R		
6	9	6	R	R	R			
R	R	R	R					

FA	Enrichment (w/o)	BP(%)	Gd (pins)
1	4.00	-	-
2	4.95	3.5	4
3	5.00	-	4
4	4.40	-	-
5	5.00	3.5	4
6	4.85	-	4
7	4.95	-	4
8	5.00	-	8
9	4.95	-	8
10	4.95	3.5	-
11	5.00	-	-

Methodology

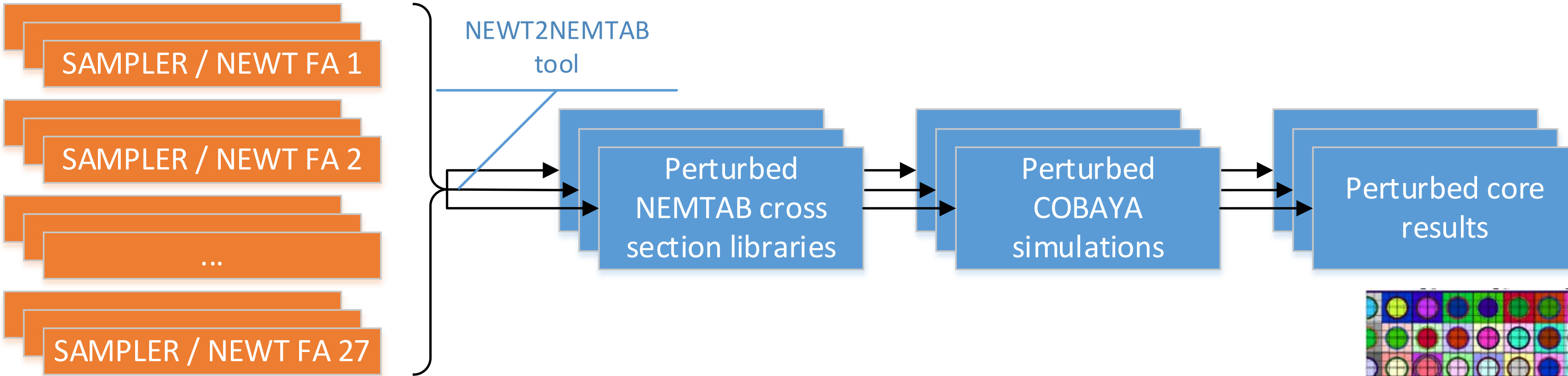


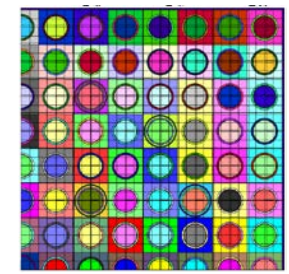
A sampling-based approach using SCALE and COBAYA was used to propagate uncertainties in nuclear data to core parameters.

Advantages:

- Very easy to implement.
- Any kind of observable can be analyzed.
- Does not involve linear approximations.

Methodology

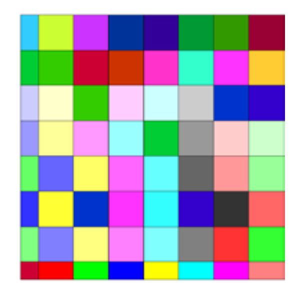




NEWT (SCALE 6.2.1) was used as lattice code.

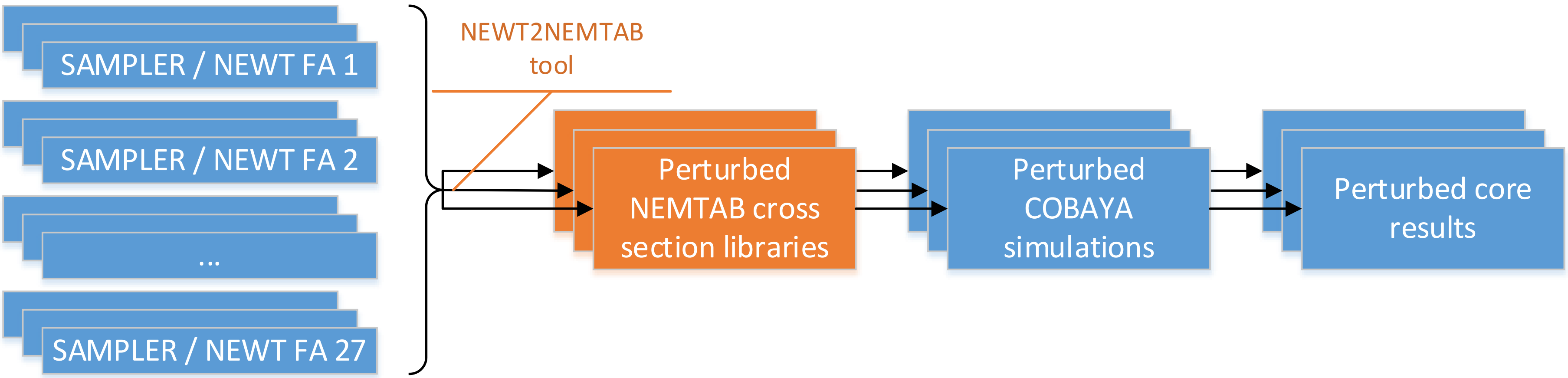
- SAMPLER was used to produce perturbed NEWT inputs.
- 56g-v7.1 cross sections and covariance library.

- 11 unrodded FA, 7 rodded FA, 1 reflector.



- 900 random samples for each fuel assembly type:
  - 900 * 19 lattice calculations.
  - Nodal homogenization.
  - Pin-wise homogenization.

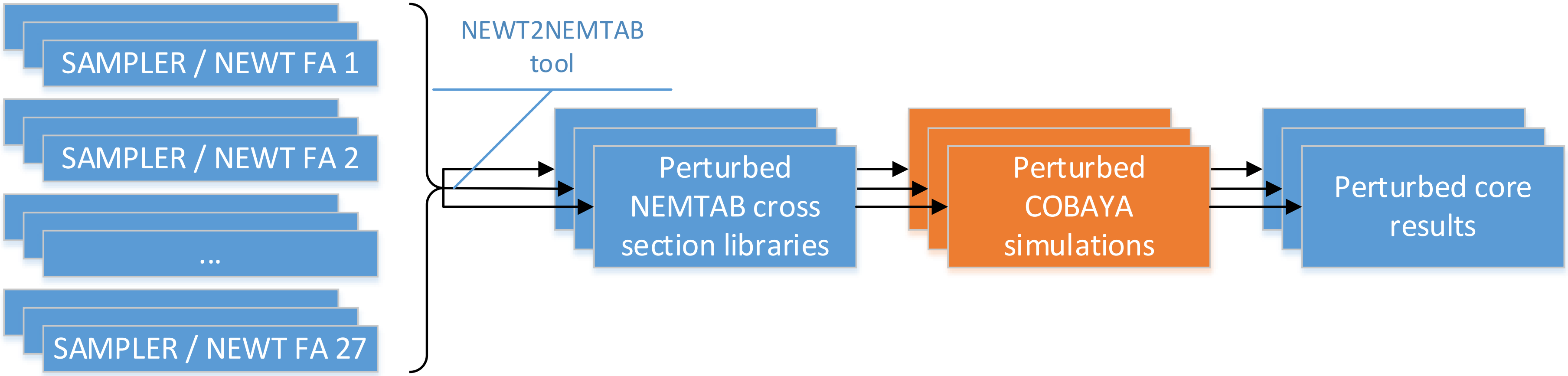
Methodology



NEWT outputs are grouped together in NEMTAB-formatted libraries:

- NEWT2NEMTAB tool.
- Parametrized libraries as a function of coolant density, coolant temperature, fuel temperature and boron concentration.
- Nodal library contains 19 materials.
- Pin-by-pin library contains 1153 materials.

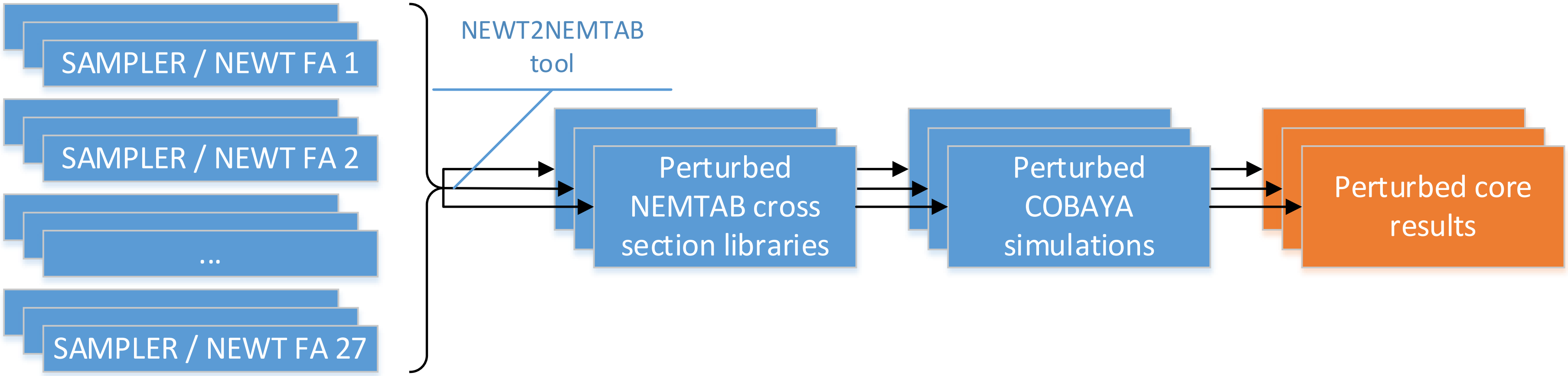
Methodology



COBAYA core simulator:

- Solves the multigroup neutron diffusion equation corrected by interface discontinuity factors.
- <u>Nodal</u> solver: Analytic Coarse-Mesh Finit-Difference (ACMFD).
- <u>Pin-by-pin</u> solver: Fine-Mesh Finite-Difference (FMFD).

Methodology



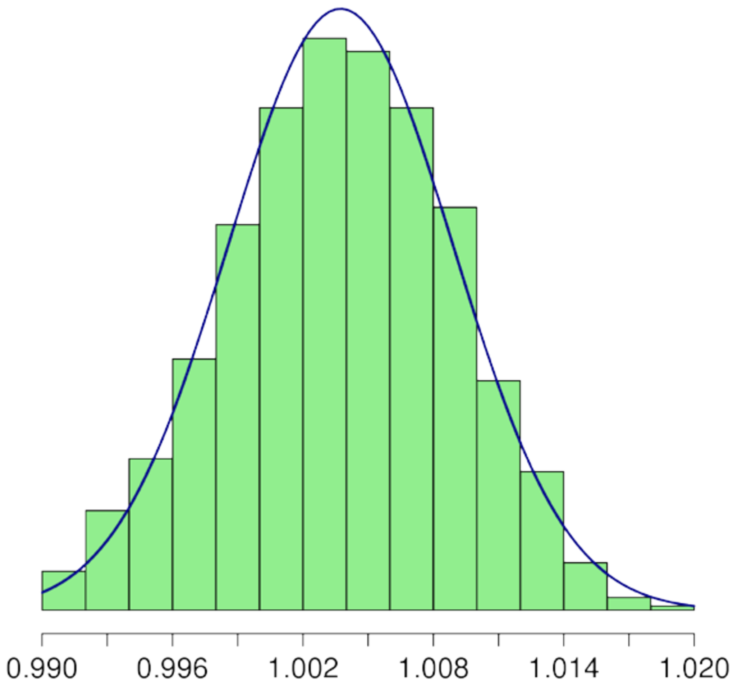
A statistical analysis of the 900 core results is performed:

- Mean values.
- Standard deviations.
- Moments of higher order.
- Histograms.
- Analysis of convergence.

Results of k_{eff}

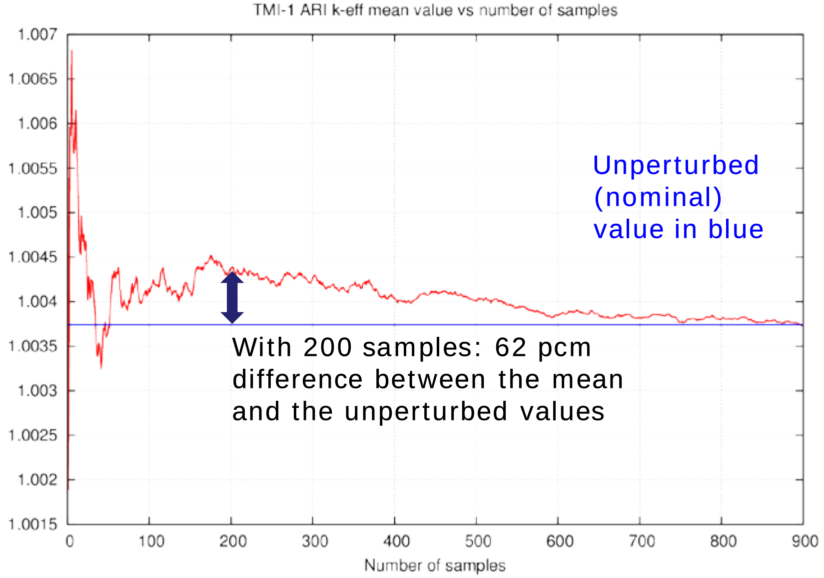
	k_{eff}	$\Delta k/k(\%)$
Nodal	1.00373	0.515
Pin-by-pin	1.00350	0.515

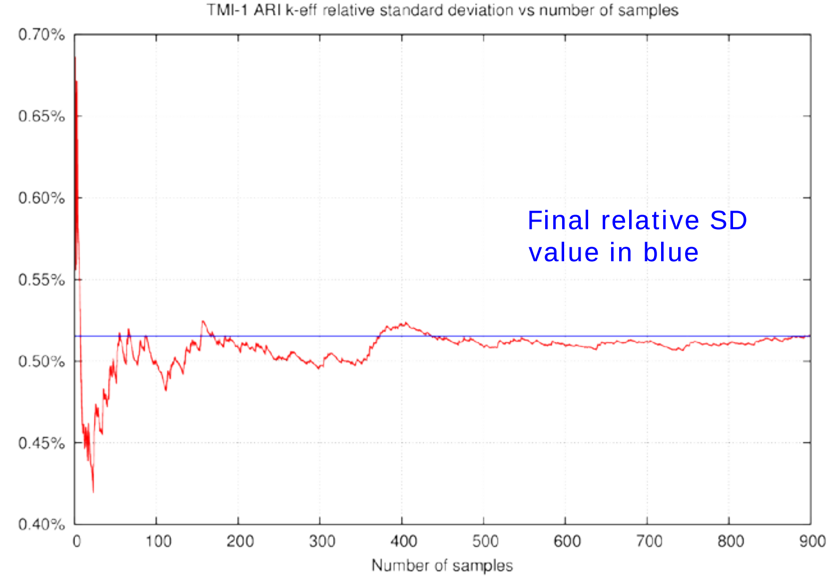
Good agreement between the two solvers.

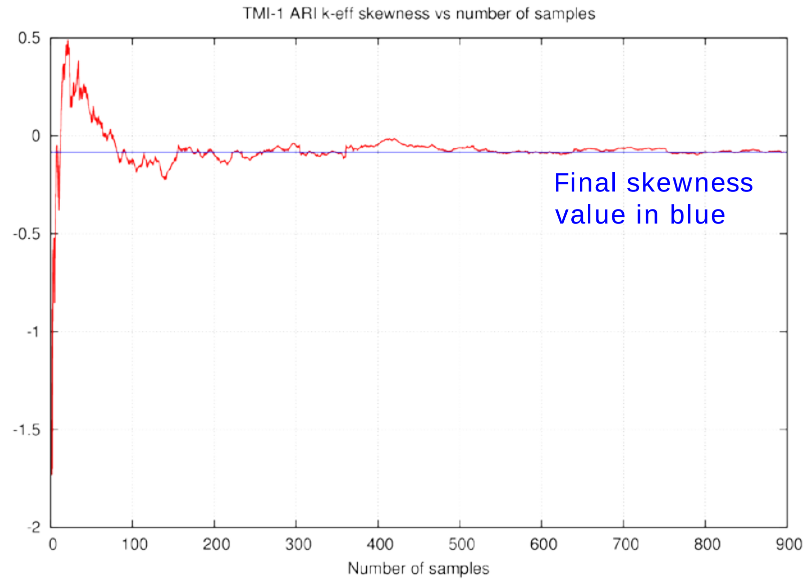


Results normally distributed.

Results of k_{eff}

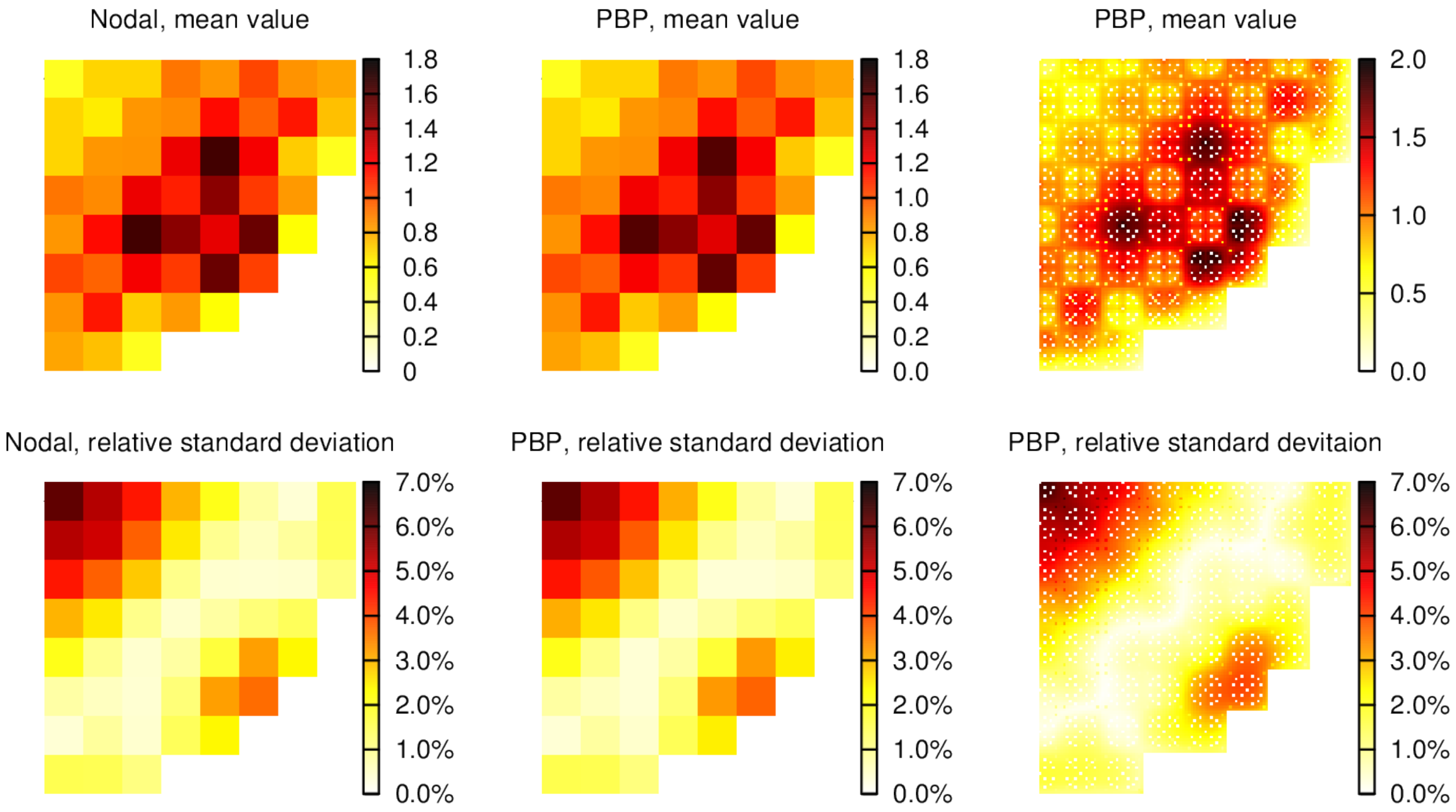






Results of power distributions

ARI power per fuel assembly



Results of peaking power factors

$$F_{\Delta H} = \frac{P_{max}}{\overline{P}}$$

$$F_{xy} = max\left(\frac{PD(z)_{max}}{\overline{PD(z)}}\right)$$

$$F_q = \frac{PD_{max}}{\overline{PD}}$$

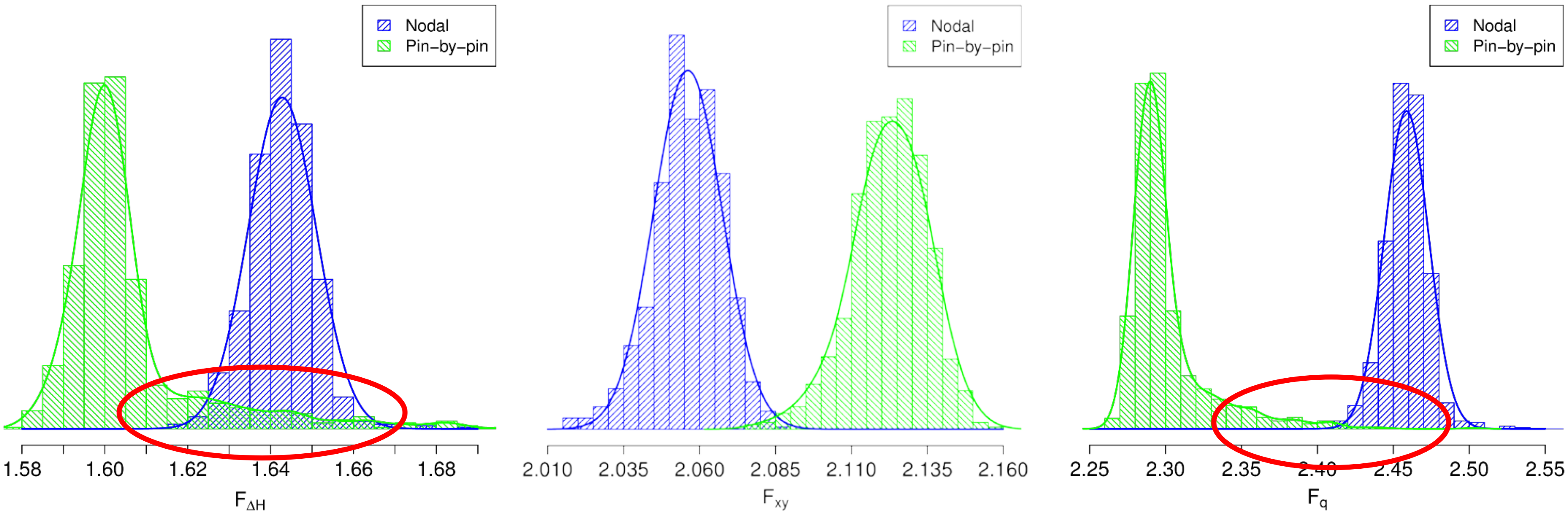
	Nodal	Pin-by-pin
$F_{\Delta H}$ node/pin	1.71 (2.1%)	1.91 (2.8%)
$F_{\Delta H}$ assembly	1.64 (0.4%)	1.60 (1.1%)
F_{xy} node/pin	2.11 (0.5%)	2.46 (0.7%)
F_{xy} assembly	2.05 (0.5%)	2.12 (0.5%)
F_q node/pin	2.56 (2.3%)	2.74 (2.7%)
F_q assembly	2.45 (0.5%)	2.30 (1.1%)

Relative standard deviation in brackets.

- Assembly averaged results can be used to compare both solvers.
- Mean values are consistent between solvers.
- Standard deviations show large differences.
- Are they normally distributed?

Results of peaking power factors

Assembly-averaged peaking factors

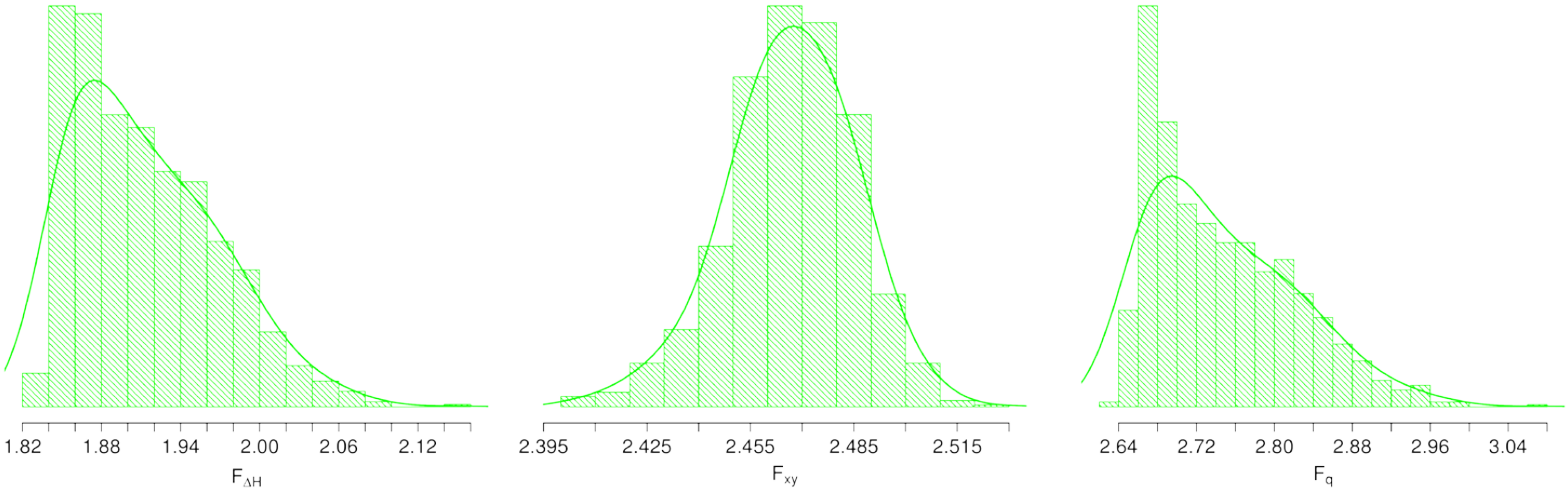


Pin-by-pin solver yields non-normal peaking factors, in contrast to the nodal solution.

Peaking factors uncertainty seems very sensitive to spatial meshing.

Results of peaking power factors

Pin peaking factors



Again, pin peaking power factors show non-normal distributions.

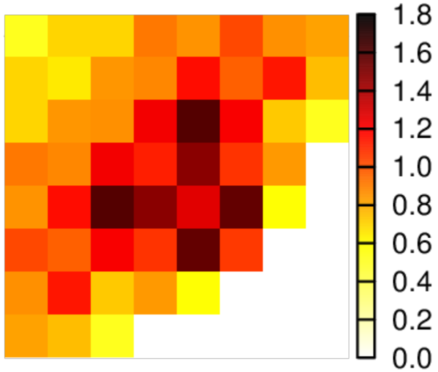
This implies that providing a mean value and a standard deviation is not enough to properly describe the uncertainty.

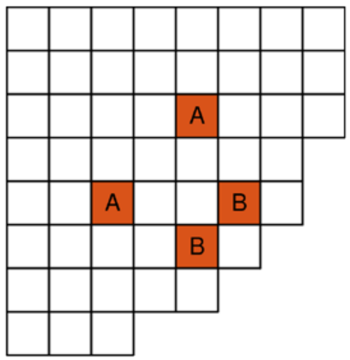
What is the reason for these behaviors?

Results of peaking power factors

Focusing on the assembly-averaged $F_{\Delta H}$ obtained using the pin-by-pin solver.
$F_{\Delta H}$ = Normalized power of the hottest fuel assembly.

PBP, mean value

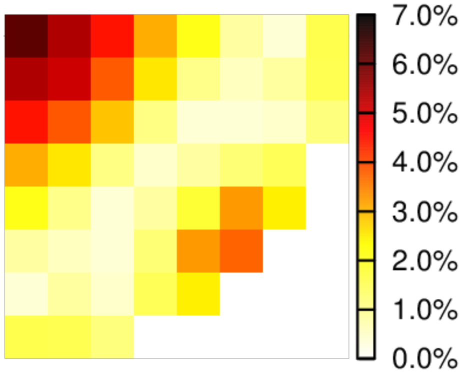


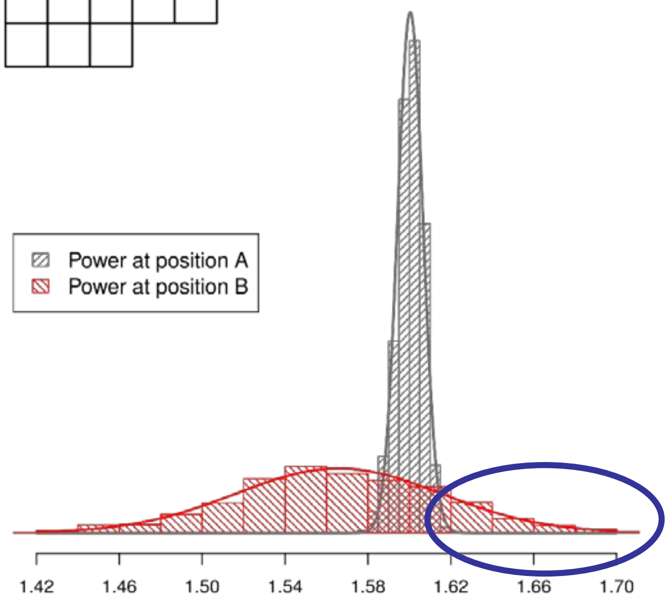


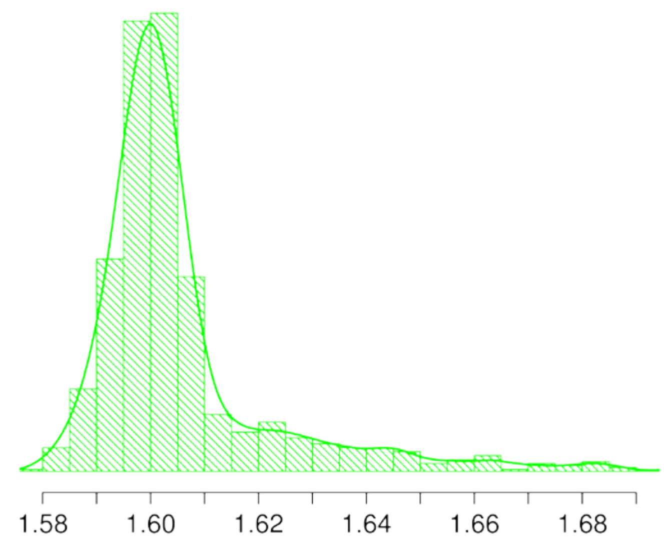
Hottest fuel assembly position in PBP simulations:

- Position A: 77 % of the random samples.
- Position B: 23 % of the random samples.

PBP, relative standard deviation







Power of assemblies in positions A and B follow a normal distribution, but they overlap, causing the right tail in the peaking factor distribution.

Conclusions

- **SCALE/COBAYA is a suitable tool for UQ at both nodal and pin levels. It has been applied to Exercise I-3 / TMI-1**

- **Uncertainties in k_{eff}**
  - Consistent values between nodal and pin-by-pin simulations (Δk ≈ 500 pcm)
  - Normally distributed results -> confirms that the mean value and the standard deviation permit establishing confidence intervals
  - A large number of simulations mandatory to obtain a mean value in perfect agreement with the nominal value.

- **Uncertainties in peaking power factors**
  - The spatial mesh impacts the assembly-averaged peaking factors.
  - Values computed with the pin solver (both pin- and assembly-averaged) do not follow a normal distribution -> mean value and the standard deviation are not sufficient and their PDF are mandatory to construct the confidence intervals required for safety analysis.

- **This behavior highlights the need of performing full core calculations at the pin-level to get reliable estimates of the uncertainties in peaking factors.**
  - It would be of interest the comparison to the uncertainty predictions provided by nodal solvers with pin-power reconstruction methods.

Thank you for your attention!

This work was supported by the
Spanish Nuclear Safety Council
(CSN)