Determination of Correlations among Benchmark Experiments by Monte Carlo Sampling Techniques

Matthias Bock, Maik Stuke

Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) mbH

September 30, 2013

NCSD 2013

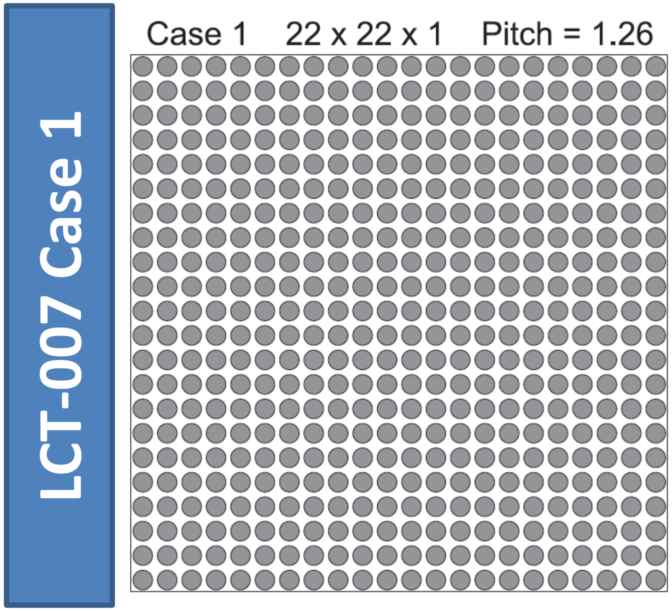
Wilmington, NC, USA

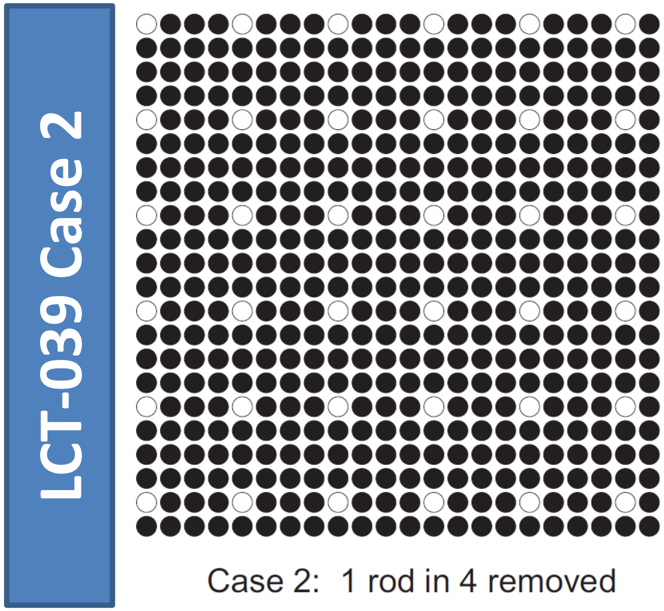
Motivation

- Code validation is an important issue in criticality safety assessments
- Collections of benchmark experiments provide a source to test codes against qualified experimental results
- The ICSBEP Handbook contains additional information about the major experimental uncertainties of each experiment
  - Allows uncertainty analysis based on the Monte Carlo sampling technique
- Uncertainty analyses can be used to determine correlations among benchmark experiments
  - Cases sharing manufacturing tolerances due to the use of the same fuel rods
  - These correlations may influence the subsequent bias determination for an application case

UACSA Phase IV Benchmark Proposal

- Discussed during last year's Expert Group meeting at the OECD/NEA's WPNCS
- Goal: Determine the "Impact of correlations between different criticality safety benchmark experiments on the estimation of the computational bias of k_{eff}"
- Benchmark experiments under consideration (taken from ICSBEP Handbook):
  - LEU-COMP-THERM-007: Cases 1 to 4
  - LEU-COMP-THERM-039: all 17 cases
  - The experiments share the experimental apparatus and the fuel rods





Case 2: 1 rod in 4 removed

Uncertain Parameters

- Analyzing manufacturing tolerances
- Two types of uncertain parameters:
  - Those common to all 21 cases
  - Those individual for each experiment
- Probability density functions:
  - Uniform distribution between a and b: U(a,b)
  - Normal distribution: $N(\mu,\sigma^2)$

Common uncertain parameters

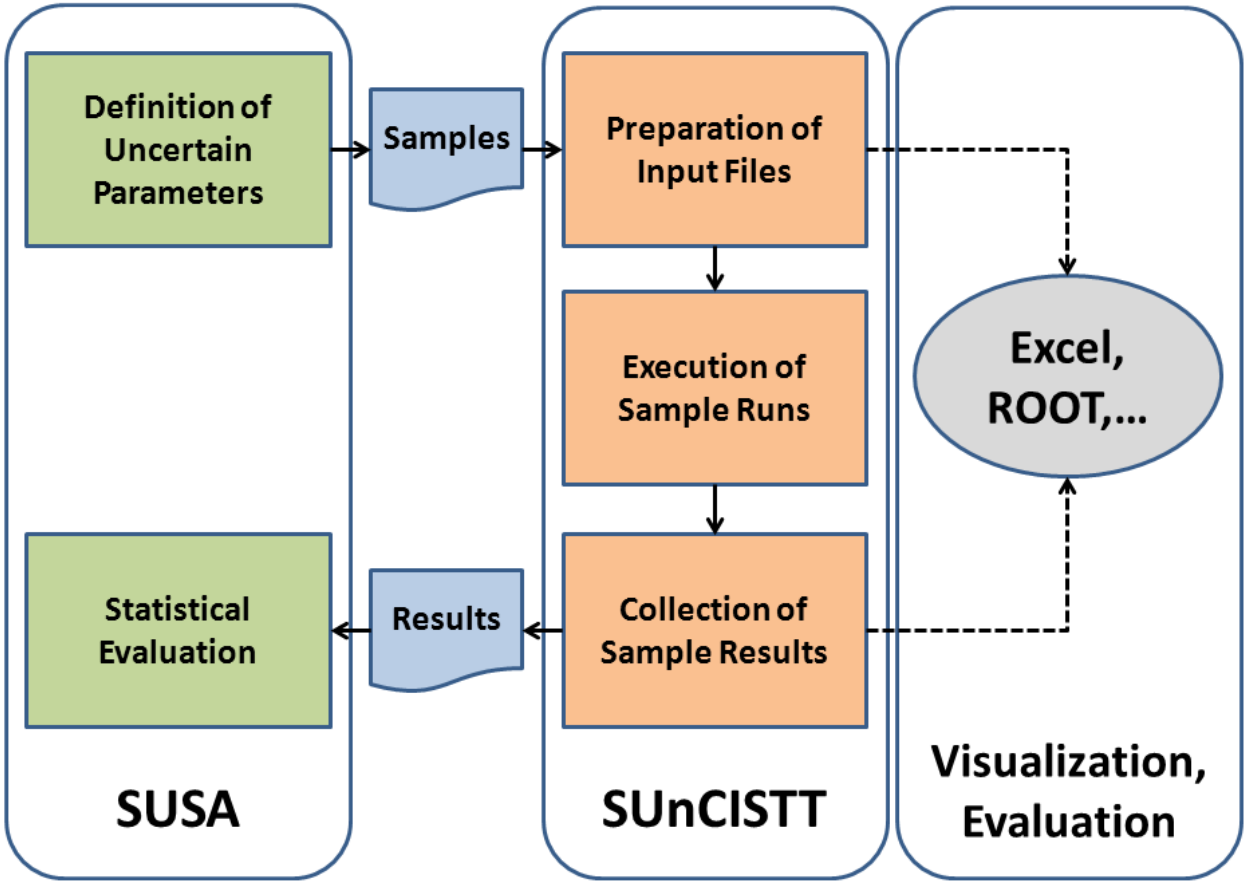
Parameter	Distribution Model	Model Parameters	
		a or μ	b or σ
Fuel rod inner diameter	U(a,b)	0.81 cm	0.83 cm
Fuel rod thickness	U(a,b)	0.055 cm	0.065 cm
Fuel pellet diameter	$N(\mu,\sigma^2)$	0.7892 cm	0.0017 cm
Fuel density	$N(\mu,\sigma^2)$	10.38 g/cm^3	0.0133 g/cm^3
Height of fissile column	$N(\mu,\sigma^2)$	89.7 cm	0.3 cm
U-234 content	$N(\mu,\sigma^2)$	0.0307 At.-%	0.0005 At.-%
U-235 content	$N(\mu,\sigma^2)$	4.79525 At.-%	0.002 At.-%
U-236 content	$N(\mu,\sigma^2)$	0.1373 At.-%	0.0005 At.-%

Individual uncertain parameter

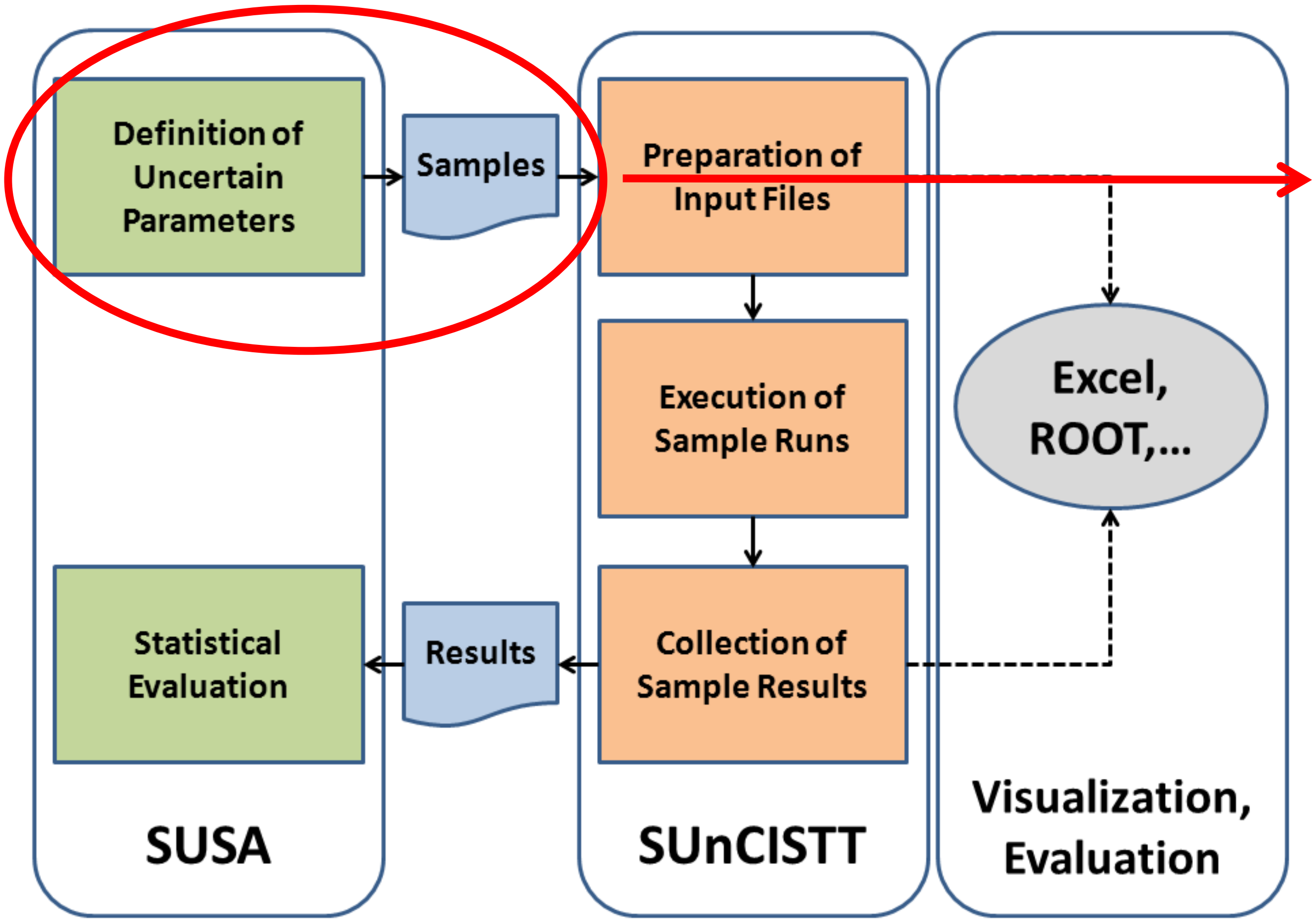
Parameter	Experiment	Distribution Model	Model Parameters	
			μ	σ
Critical water height	LCT-007-001	$N(\mu,\sigma^2)$	90.69 cm	0.10 cm
	LCT-007-002		73.53 cm	0.10 cm
	LCT-007-003		77.98 cm	0.06 cm
	LCT-007-004		79.85 cm	0.10 cm
	LCT-039-001		81.36 cm	0.07 cm
	LCT-039-002		77.69 cm	0.06 cm
	LCT-039-003		73.05 cm	0.06 cm
	LCT-039-004		89.07 cm	0.06 cm
	LCT-039-005		84.37 cm	0.06 cm
	LCT-039-006		58.77 cm	0.06 cm
	LCT-039-007		69.71 cm	0.06 cm
	LCT-039-008		66.79 cm	0.06 cm
	LCT-039-009		64.47 cm	0.07 cm
	LCT-039-010		58.37 cm	0.07 cm
	LCT-039-011		81.34 cm	0.06 cm
	LCT-039-012		75.38 cm	0.07 cm
	LCT-039-013		72.52 cm	0.06 cm
	LCT-039-014		71.14 cm	0.06 cm
	LCT-039-015		69.88 cm	0.06 cm
	LCT-039-016		69.40 cm	0.06 cm
	LCT-039-017		68.75 cm	0.06 cm

Individual Uncertainty Analysis with the SUnCISTT

- The SUnCISTT is the GRS tool to perform uncertainty analyses in criticality safety assessments
  - It uses a MC sampling method and the GRS tool SUSA to analyzes the impact of uncertain technical parameters

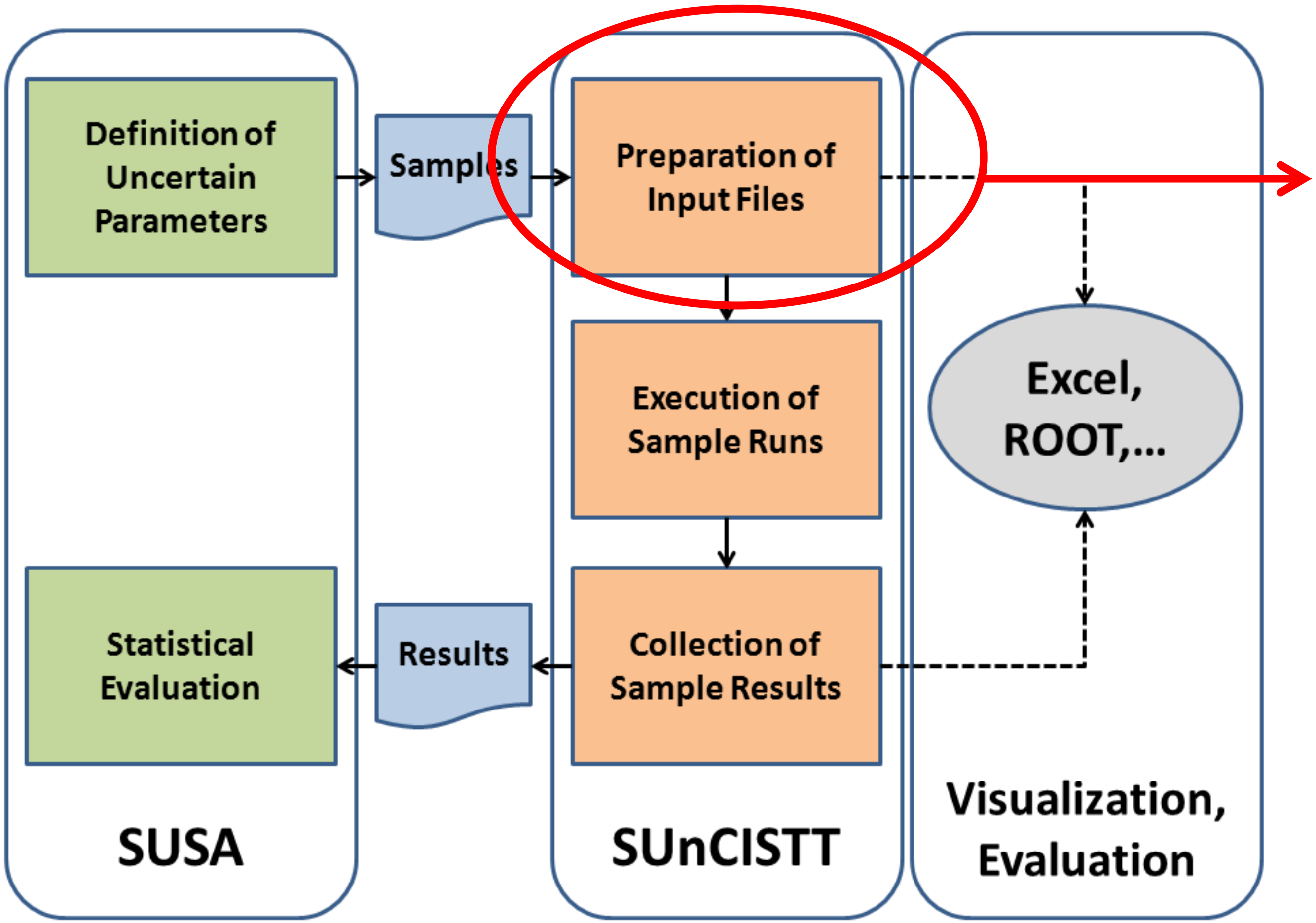


Individual Uncertainty Analysis with the SUnCISTT



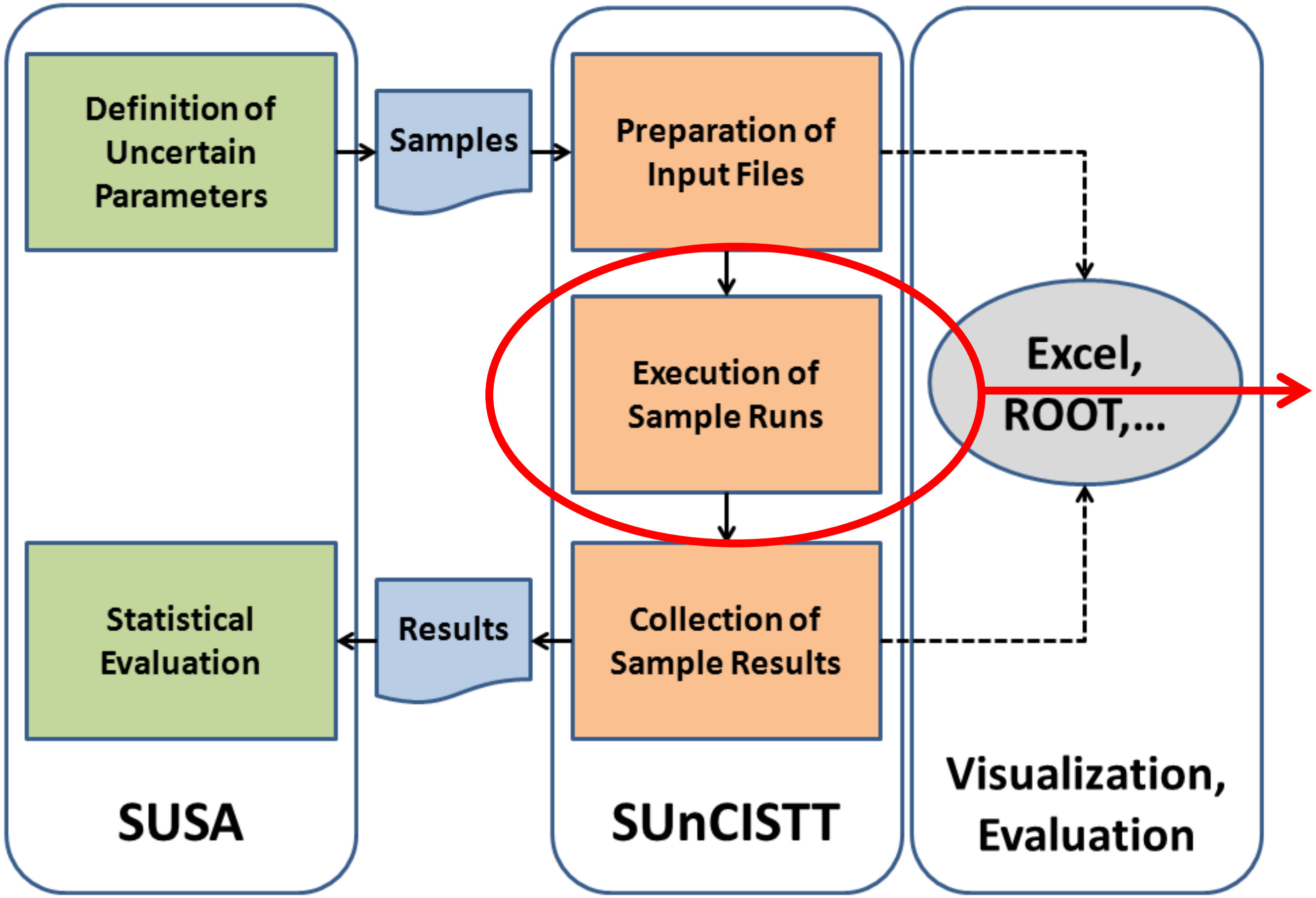
- Creates a list of randomly chosen values for each uncertain parameter according to the user defined probability function
- User defined template file: Input file for SCALE, MCNP,… which contains keywords at the places of the uncertain parameters

Individual Uncertainty Analysis with the SUnCISTT



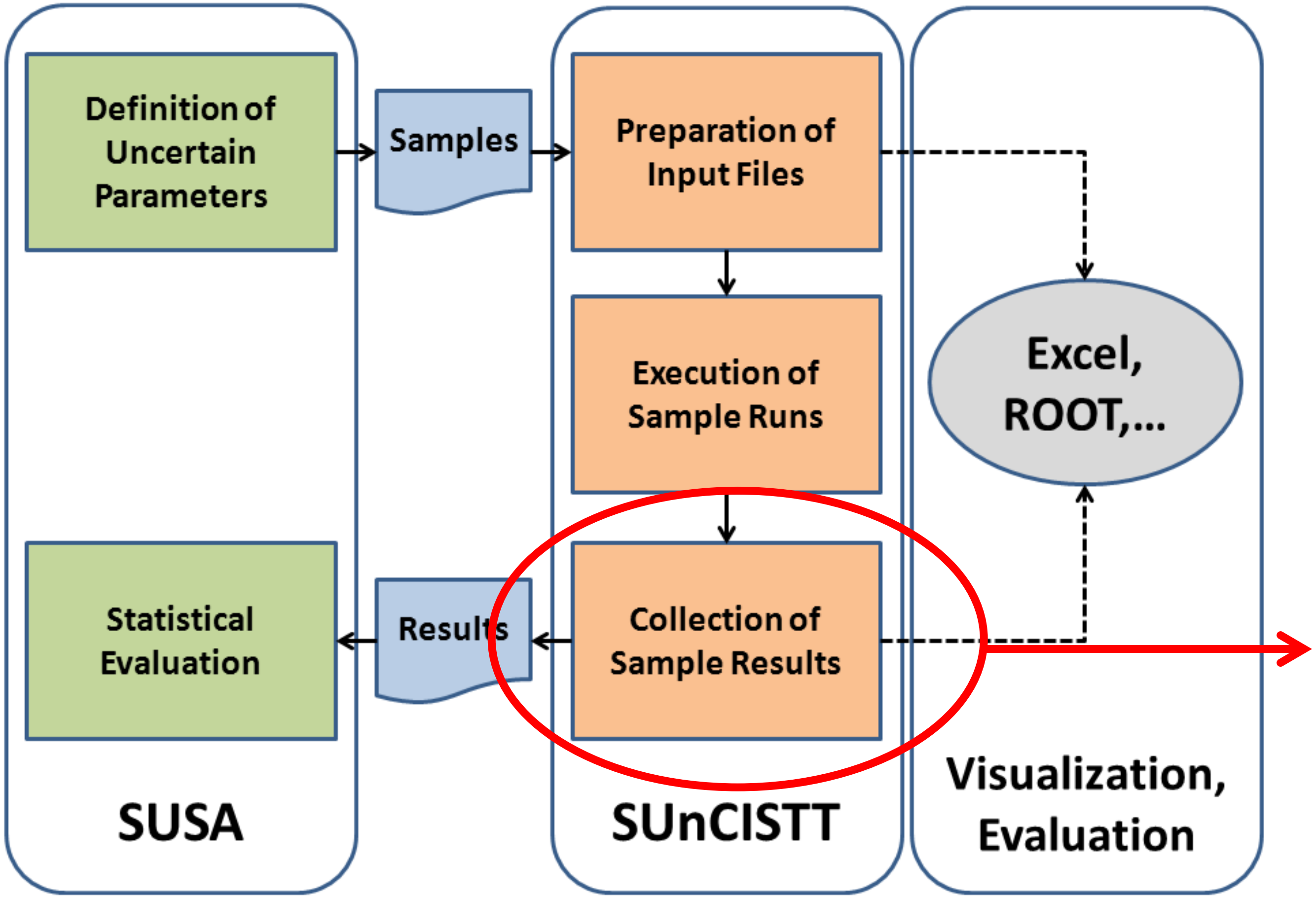
- For each sample: Copy of the template file is created and the keywords are replaced by the corresponding values to get a valid SCALE, MCNP,… input file

Individual Uncertainty Analysis with the SUnCISTT



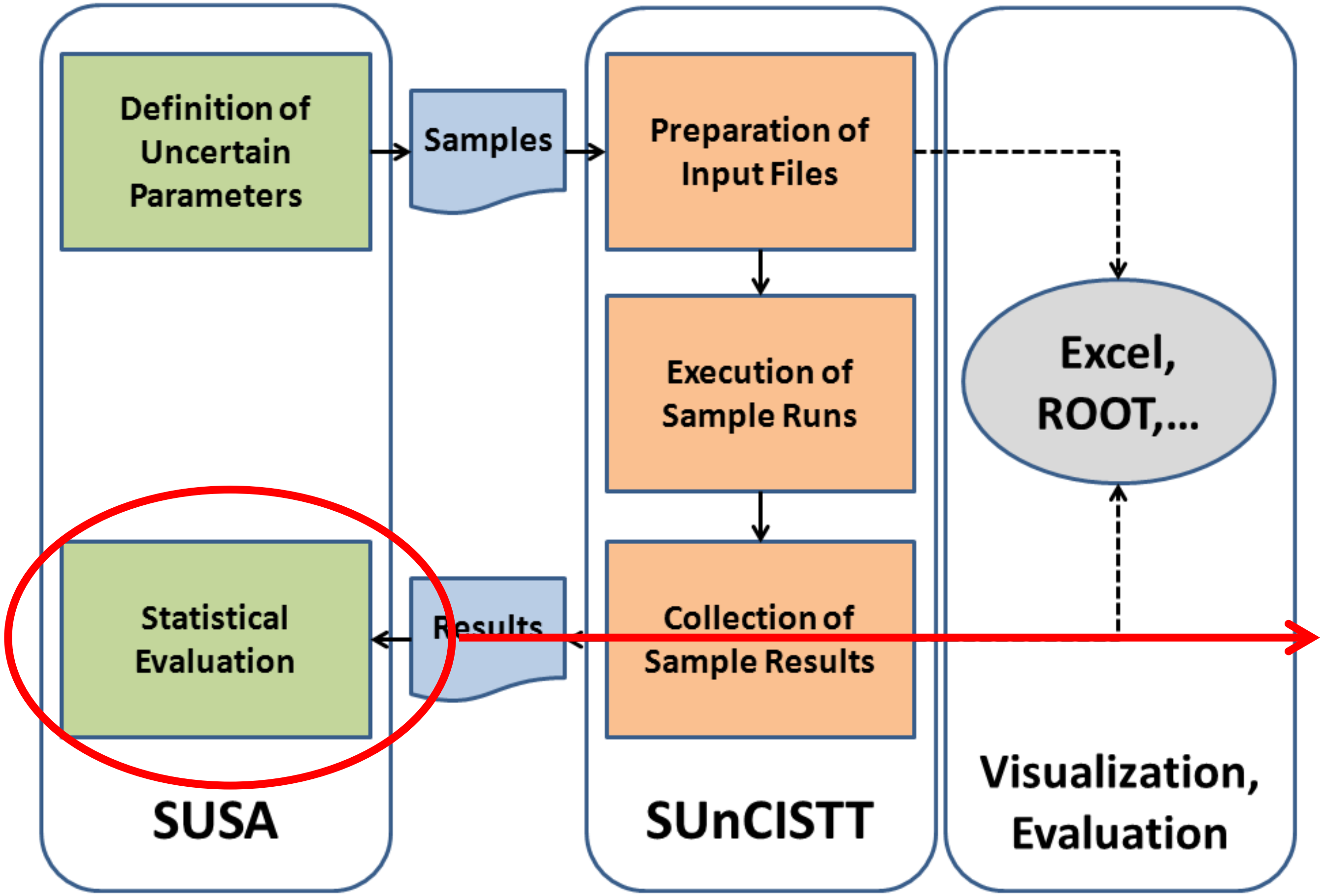
- Runs the SCALE, MCNP,… input file

Individual Uncertainty Analysis with the SUnCISTT



- Collects results for each input file

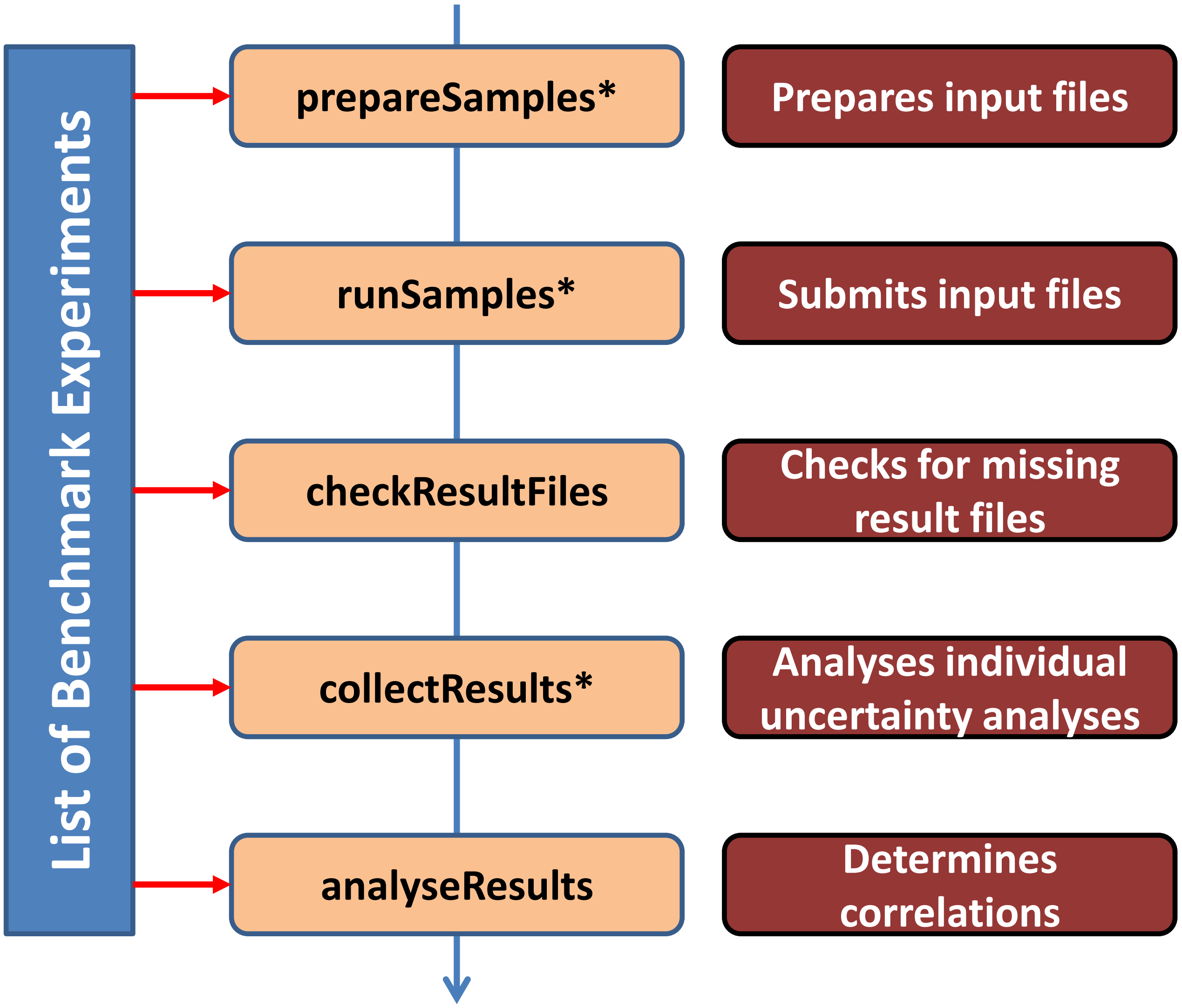
Individual Uncertainty Analysis with the SUnCISTT



- Statistical evaluation of the results (→ uncertainties and sensitivities)

Extending the SUnCISTT for Correlation Analyses

- Several uncertainty analyses are steered at the same time
- In the first mode, the option is included to consider the common variation of uncertain parameters (using the same values in all experiments)



Determination of correlation

- Pearson correlation of benchmark experiments *A* and *B* is determined using the calculated k_{eff} values

$$\Sigma_{AB} = \frac{1}{\sigma_A \sigma_B} \sum_{i=1}^{n} \left(k_{A,i} - \bar{k}_A\right)\left(k_{B,i} - \bar{k}_B\right)$$

with i: sample number

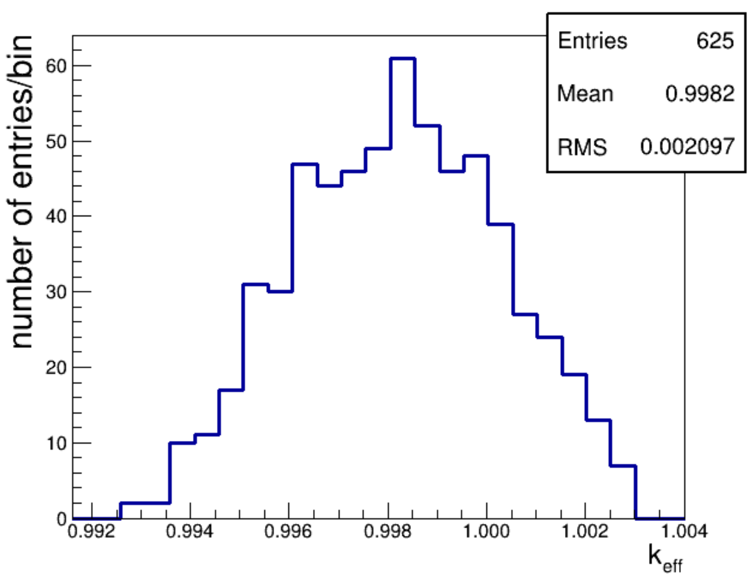
$$\bar{k}_{A/B} = \frac{1}{n} \sum_{i=1}^{n} k_{A/B,i}$$

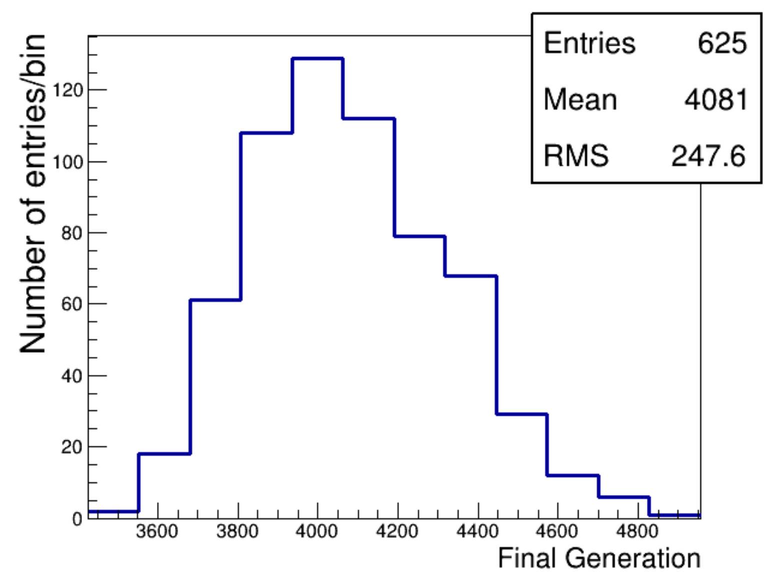
$$\sigma_{A/B} = \sqrt{\sum_{i=1}^{n} \left(k_{A/B,i} - \bar{k}_{A/B}\right)^2}$$

Benchmark analysis

- The criticality calculations are performed with SCALE’s CSAS5 sequence of SCALE 6.1.2
- 625 samples were prepared and run for each experiment
- Neutrons per generation: 100k, Convergence criterion: 5.0E-05
  - Sufficiently small to be negligible w.r.t. the uncertainty arising from the manufacturing tolerances

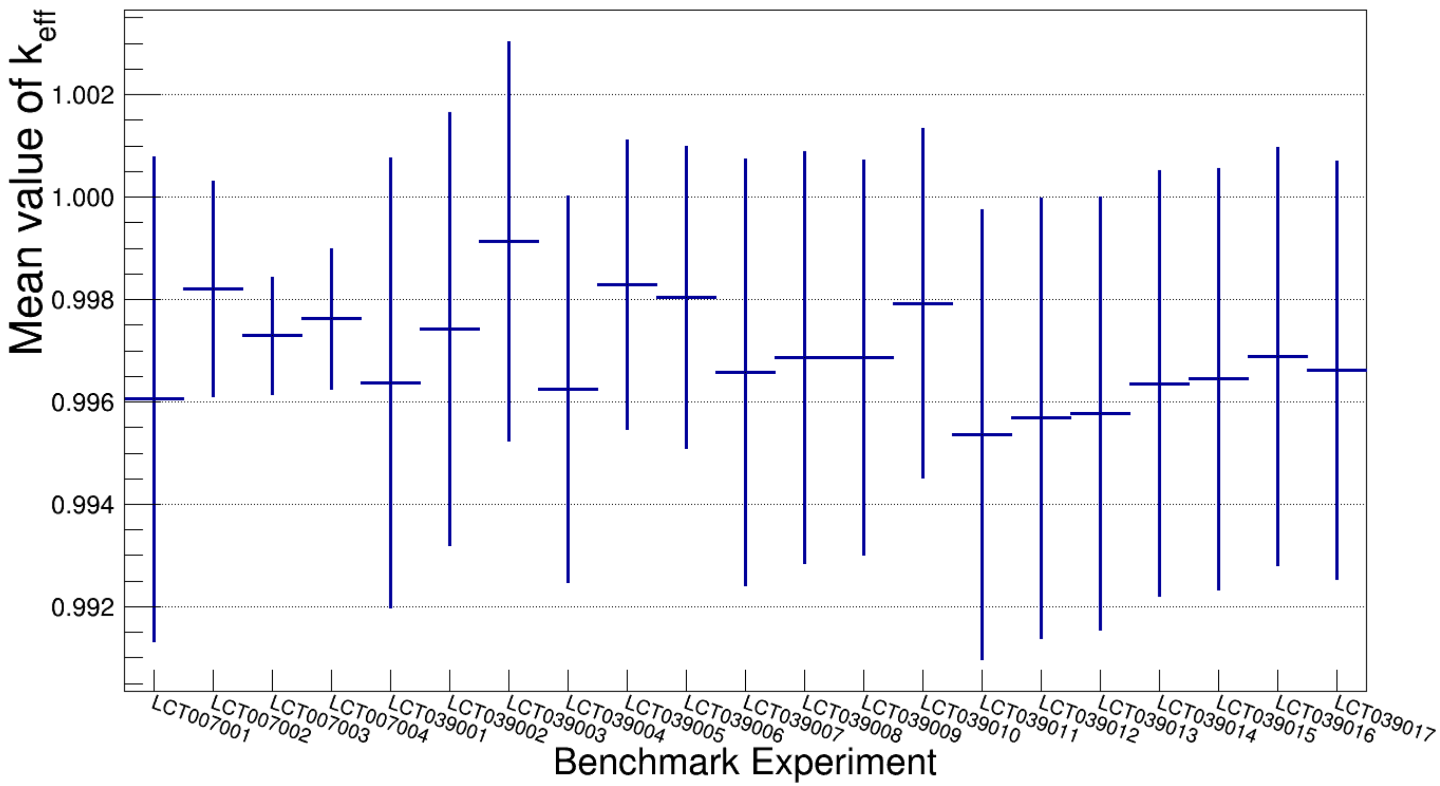
Example results of LCT-007-002





Results: Mean Value and Standard Deviation

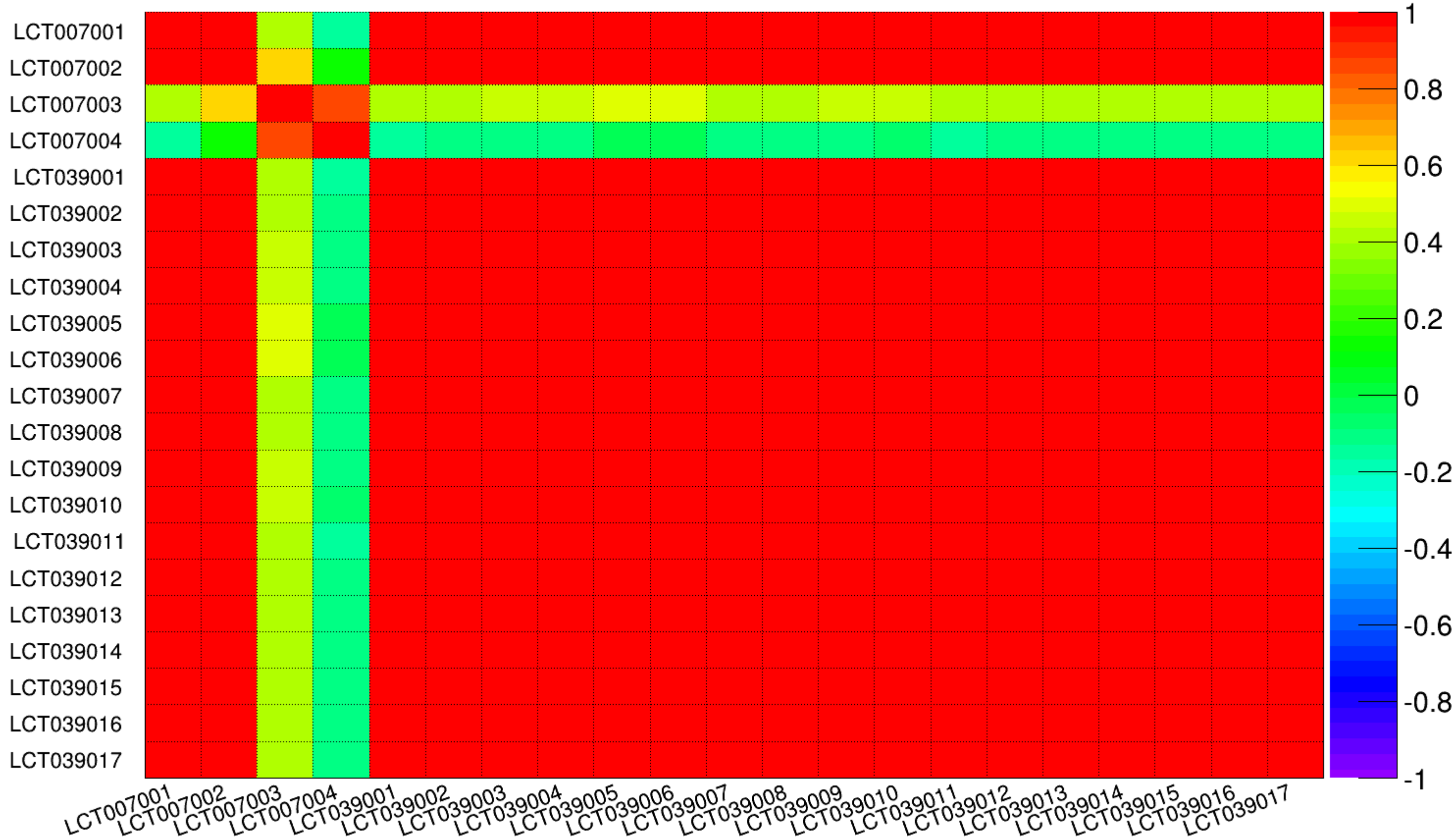
- All mean value below $k_{eff} = 1$
  - In agreement with the calculations reported in the ICSBEP Handbook
- Standard deviations are between 1.1E-03 and 4.7E-03
  - Well above the convergence limit, but in most cases greater than the uncertainties reported in the ICSBEP Handbook (up to factor ~ 3)



Correlation Results, Common variation of uncertain parameters

- High correlations up to almost 100% between benchmark experiments
  - However, two cases have significantly lower correlation coefficients
  - Effect of the pitch and thus of the neutron spectrum

LEU-COMP-THERM-007	
Case number	Pitch [cm]
1	1.26
2	1.60
3	2.10
4	2.52



Summary & Outlook

- GRS has extended the capabilities of its SUnCISTT to determine correlations between k_{eff} results of benchmark experiments
- This new utility was applied to a benchmark proposal of the UACSA Expert Group
- Results indicate:
  - Qualitative correlation information in the DICE database is insufficient for further use
    - LCT-007 and LCT-039 are highly correlated
    - However, w.r.t. correlation coefficients spectral effects of the individual configuration dominate the impact of the common variation of shared technical uncertainties
    - Case-by-case correlation coefficients are required
  - Differences in the uncertainties for the individual analyses compared to the ICSBEP Handbook

- The next step is to take the derived correlation matrices into account and investigate their influence on the bias determination

Determination of Correlations among Benchmark Experiments by Monte Carlo Sampling Techniques

Matthias Bock, Maik Stuke

Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) mbH

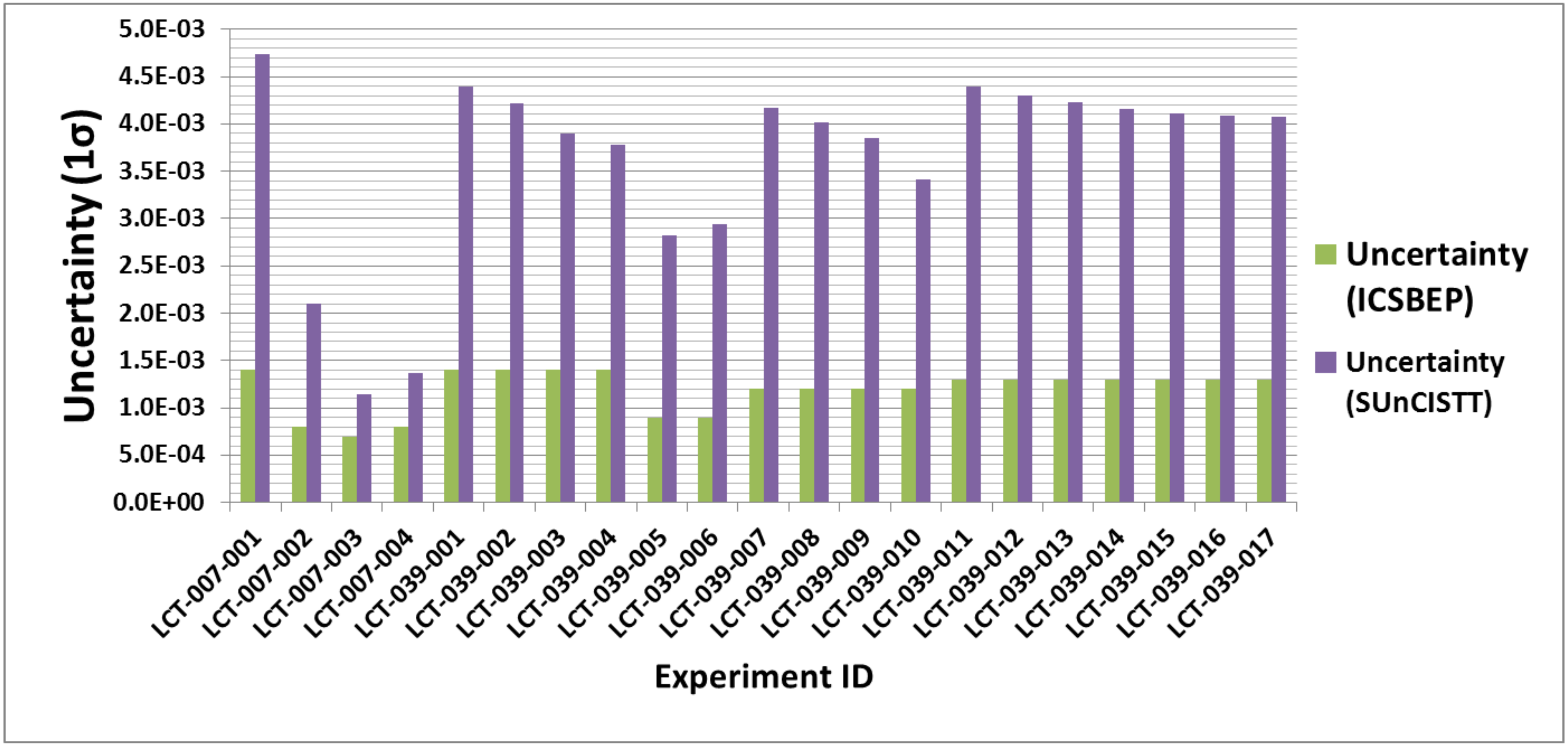
September 30, 2013

NCSD 2013

Wilmington, NC, USA

Comparison of Uncertainties

- The ICSBEP Handbook states uncertainties for each benchmark experiment
  - They have often been used as input to the validation procedure
- However, there is a discrepancy between calculated (SUnCISTT) and the reported (ICSBEP) uncertainty estimates



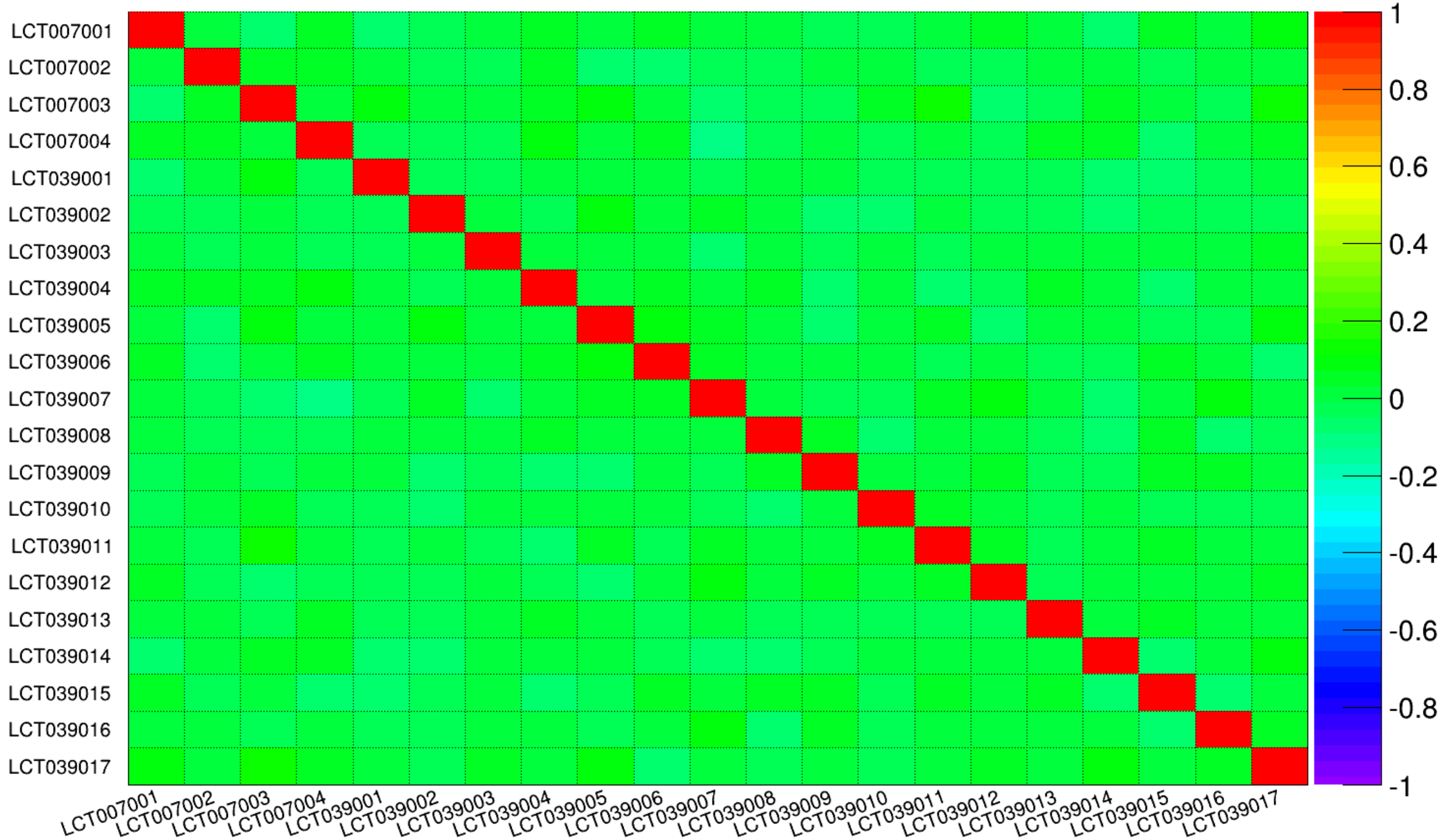
Publicly Available Correlation Information

- The DICE database contains information about the correlations among benchmark experiments
- However, for most cases – especially those interesting for us – the available information is
  - only qualitatively
  - only for the whole experiment series
- Goal: determine the correlation coefficients between the different cases of the experimental series

	LCT 004	LCT 005	LCT 006	LCT 007	LCT 009	LCT 010	LCT 011
LCT032							
LCT034				+			
LCT035			+				
LCT036							
LCT037				+			
LCT038				+			
LCT039				+			
LCT040				+			
LCT041							
LCT042	+	+			+	+	
LCT043							

Correlation Results I: Individual Variation

- Definition of correlation coefficient according to Pearson
- Off-diagonal elements are in agreement with statistical fluctuations



Results for the Trend Parameter EALF

- EALF = Energy of average lethargy causing fission
  - Common parameter to describe thermal neutron spectra
- Displays the spectral effect of the increasing fuel rod pitch