OAK RIDGE National Laboratory

Critical Experiment Correlations

B.J. Marshall

SCALE Users Group Meeting

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Outline

- Correlation sources and computational methodology
- Fuel rod position uncertainty, effect, and model creation
- Impact of correlations on validation

Correlation sources and complications

- Shared fissile material common source of correlations
  - 239 LEU array cases in Handbook from PNL: only 2 unique enrichments
  - 109 of the 239 cases at 2.35 wt% ^{235}U: only 2 unique square pitch values
- Current validation approaches use trending and non-trending techniques, but both approaches assume uncorrelated data points
- The data points are clearly not completely uncorrelated, but current methods neglect the correlations
- This work develops a procedure for calculating these critical experiment correlation coefficients via Monte Carlo sampling
  - Further development is needed to incorporate correlations in validation techniques

Correlation coefficient calculation methodology

- Random sampling of virtually all input parameters: compositions, geometry, and temperatures
- Hundreds of complete inputs are created for each experiment
- Components that are shared between experiments get the same sampled value in each realization
- Correlation coefficient is ratio of covariance to product of standard deviations of each individual experiment

$$\rho_{xy} = \frac{\mathrm{cov}(x, y)}{\sigma_x \sigma_y}$$

- Essentially this is the fraction of total uncertainty shared between the two experiments

Fuel rod position uncertainty

- Fuel rod positions can have a huge impact on correlations for LCT systems

- Systems that are not near optimum moderation are sensitive to fuel rod placement as it controls the moderation in the system

- Two main assumptions about pin positions have been investigated:
  1. Pin pitch is fundamental uncertain parameter and all pin pitches in the experiment are identical
  2. Pin position is fundamental uncertain parameter and all pin pitches are unique based on random placement of pins

- Shared pitch assumption leads to large, shared uncertainty and thus high correlation coefficients

LCT-042 results for different pin placements

	42-1	42-2	42-3	42-4	42-5	42-6	42-7
42-1	1	0.97	0.99	0.97	0.99	0.99	0.98
42-2	0.97	1	0.97	0.96	0.97	0.98	0.96
42-3	0.99	0.97	1	0.97	0.99	0.99	0.97
42-4	0.97	0.96	0.97	1	0.98	0.98	0.96
42-5	0.99	0.97	0.99	0.98	1	0.99	0.98
42-6	0.99	0.98	0.99	0.98	0.99	1	0.98
42-7	0.98	0.96	0.97	0.96	0.98	0.98	1

Pitch sampled: all pitches are the same and are the same for all cases

Coefficients range from 0.96–0.99

	42-1	42-2	42-3	42-4	42-5	42-6	42-7
42-1	1	0.33	0.52	0.42	0.52	0.63	0.43
42-2	0.33	1	0.32	0.48	0.42	0.37	0.19
42-3	0.52	0.32	1	0.29	0.59	0.61	0.48
42-4	0.42	0.48	0.29	1	0.46	0.31	0.26
42-5	0.52	0.42	0.59	0.46	1	0.67	0.49
42-6	0.63	0.37	0.61	0.31	0.67	1	0.46
42-7	0.43	0.19	0.48	0.26	0.49	0.46	1

All fuel rod positions are sampled independently and differently in each case

Coefficients range from 0.19–0.67

So it makes a big difference, but how do I build that kind of model in SCALE?

Mechanics of Model Building

- Perturbing each pin in the model requires unique units in KENO
- Generating hundreds of units effectively requires scripting
- SCALE 6.2 contains a TemplateEngine to automate input generation
  - Template input generated by hand (shown on future slides)
  - Template indexed so each unit gets a unique number
  - Thousands of lines of input generated in seconds
- Both KENO (20,000+ lines) and Sampler inputs generated with TemplateEngine (~70,000 – 100,000 lines)
- All inputs built using SCALE – *NO OUTSIDE SCRIPTING*

Mechanics of Model Building – KENO Template

TemplateEngine Input

```
#for(i=1; i<=459; i=i+1){
unit #{i+1000}
' bottom end plug - below lower grid plate
 cylinder 2 1  0.47                    0.97 0.00 origin 0.63 0.63
 cuboid   4 1  1.26 0.0  1.26  0.0  0.97 0.00
unit #{i+2000}
' bottom end plug - in lower grid plate
 cylinder 2 1    0.47                    0.25 0.0 origin 0.63 0.63
 cylinder 4 1    0.5                     0.25 0.0 origin 0.63 0.63
 cuboid   1000 1  1.26 0.0  1.26  0.0    0.25 0.0
```

TemplateEngine Output is KENO Input

```
unit 1001
' bottom end plug - below lower grid plate
 cylinder 2 1  0.47                    0.97 0.00 origin 0.63 0.63
 cuboid   4 1  1.26 0.0  1.26  0.0  0.97 0.00
unit 2001
' bottom end plug - in lower grid plate
 cylinder 2 1    0.47                    0.25 0.0 origin 0.63 0.63
 cylinder 4 1    0.5                     0.25 0.0 origin 0.63 0.63
 cuboid   1000 1  1.26 0.0  1.26  0.0    0.25 0.0
```

Mechanics of Model Building – Sampler Template

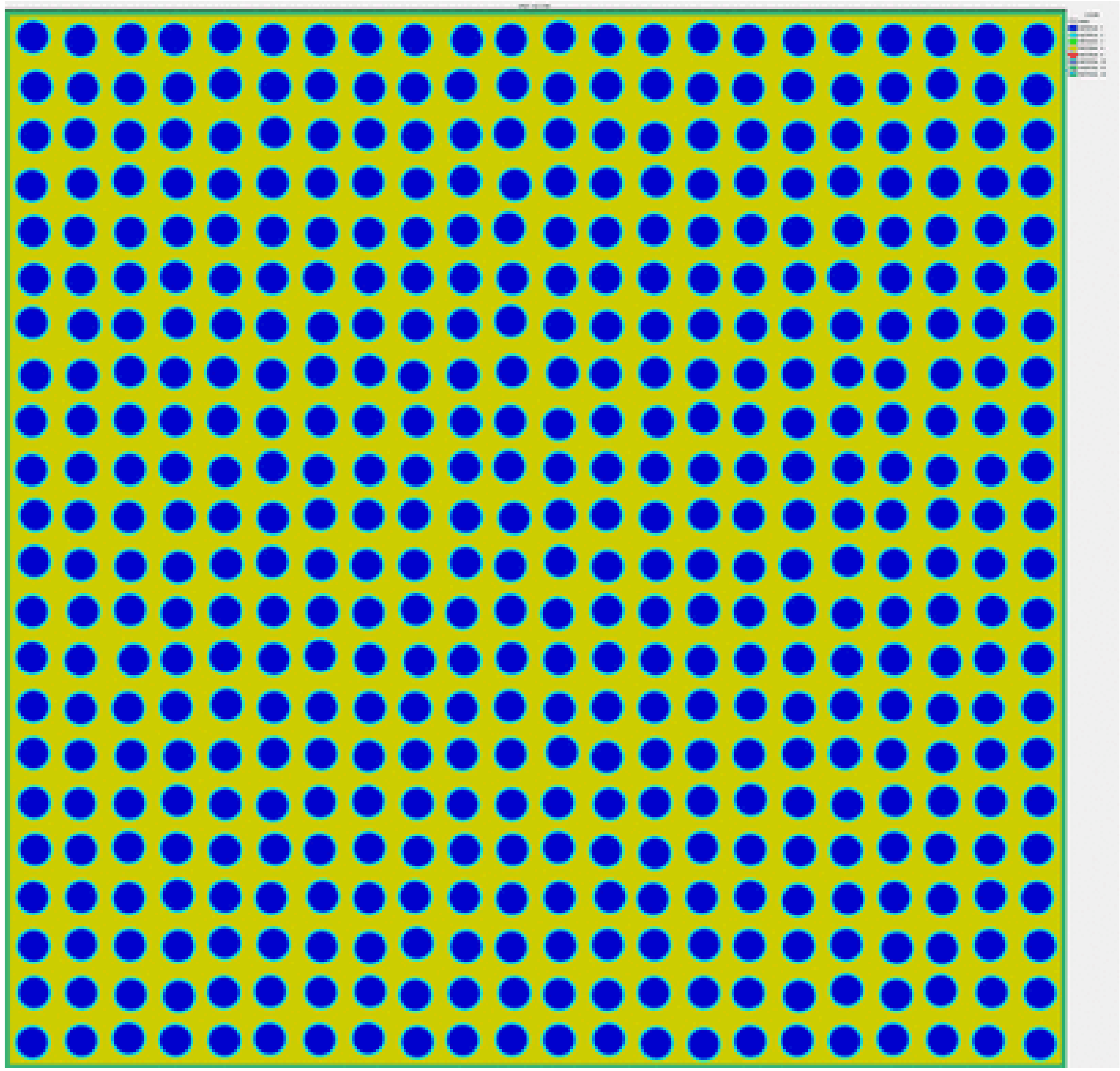
TemplateEngine
Input

```
read variable[origin_x_1000_#{i}_039_001]
   distribution=normal
   value = 0.63
   stddev = 0.0351
   minimum = 0.5
   maximum = 0.76
   siren="/csas5/geometry/unit[id='#{i+1000}',id='#{i+3000}',id='#{i+9000}']/cylinder/region_origin[decl='origin']/value[1:5:2]"
   cases = Case39_1 end
end variable
```

TemplateEngine Output
is Sampler Input

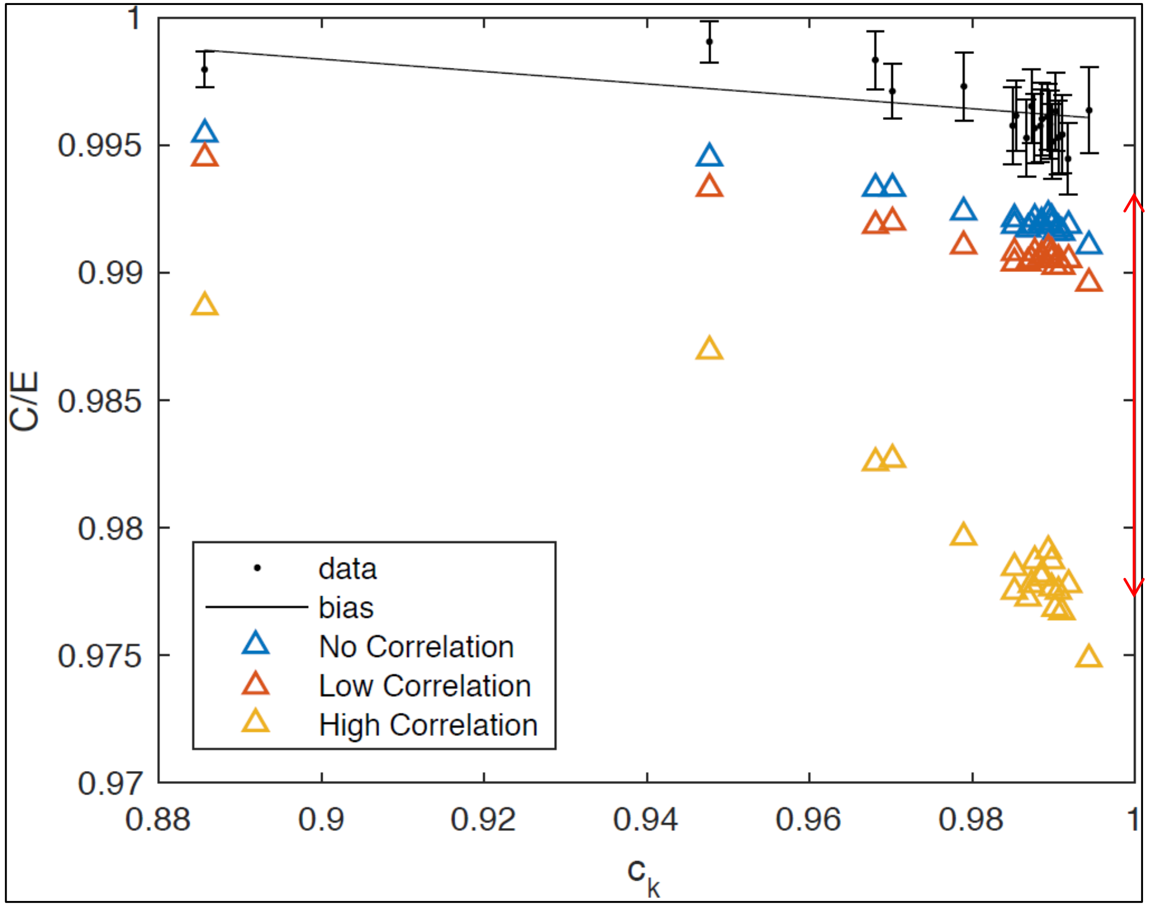
```
read variable[origin_x_1000_1_039_001]
   distribution=normal
   value = 0.63
   stddev = 0.0351
   minimum = 0.5
   maximum = 0.76
   siren="/csas5/geometry/unit[id='1001',id='3001',id='9001']/cylinder/region_origin[decl='origin']/value[1:5:2]"
   cases = Case39_1 end
end variable
```

Random pin models

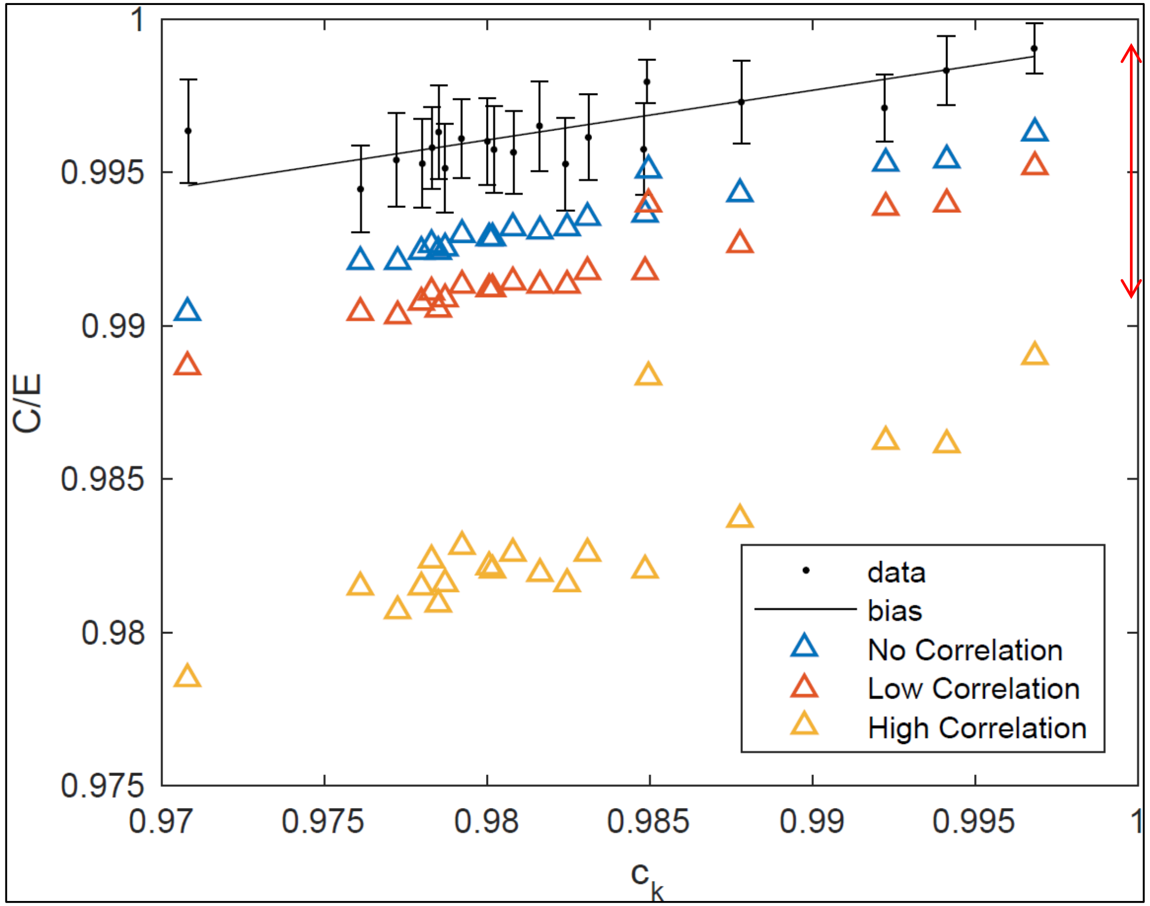


75 realizations, looped

Trending results: qualitative results



LCT-079-001
High correlation ~1.5% Δk
Low correlation ~0.1 % Δk



LCT-079-006
High correlation ~1.0% Δk
Low correlation ~0.1 % Δk

Validation impacts

- Extremely high correlation coefficients can change trending USL by 1.0% Δk or more (including uncertainty)
- Impact of correlations is case dependent
  - 1.5% Δk for LCT-079-001 vs. 1.0% Δk for LCT-079-006
- Results for low correlation coefficients are close to the uncorrelated results
  - ~0.1% Δk impact for the two LCT-079 cases (trending)

Conclusions: All systems

- Methodology for determination of critical experiment correlations developed based on Monte Carlo sampling technique
- Important parameters for correlations can be determined, and may be different from important parameters of the systems
- Correlation coefficients for the experiments are different than the correlation coefficients for the uncertainties of the experiments
- In-depth knowledge of the critical experiments is essential for accurate correlation coefficient determination
  - Detail of current ICSBEP evaluations does not provide the required level of information