Determination of Critical Experiment Correlations for Experiments Involving Highly Enriched Uranium Solutions

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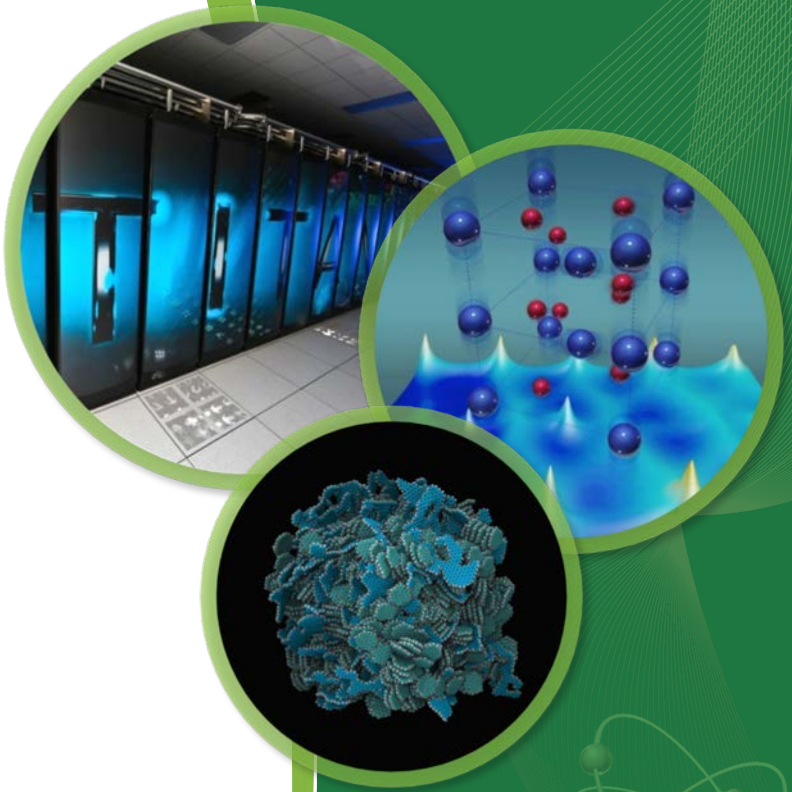

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Outline

1. A word on correlation coefficients and methodology
2. Experiments examined
3. Progression of uncertainties considered
4. Correlations considering:
   - Geometry uncertainties
   - Geometry and tank composition uncertainties
   - Geometry, tank composition, and enrichment uncertainties
   - All uncertainties (geometry, tank composition, enrichment, solution parameters)
5. Conclusions

Correlation coefficient calculation methodology

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

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

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

Experiments examined

- HST-001
- 10 experiments performed at Rocky Flats
- Simple, unreflected cylinders
- 4 tanks
  - 1 stainless steel tank (Cases 1 and 2)
  - 3 aluminum tanks (Cases 3 & 4, Cases 5–9, Case 10)
- 8 solutions
  - Cases 1 and 8 share a solution
  - Cases 4 and 9 share a solution

Progression of uncertainties considered

- Very simple models are used (relatively few uncertainties)
- Models are grouped into 4 categories
  - Geometry: Tank ID, thickness, solution height
  - Tank compositions (considered both independent and shared)
  - Solution enrichment (considered both independent and shared)
  - Solution parameters: U concentration, density, excess acid molarity
- Adding each group allows determination of important contributors
- The uncertainties could have been considered in a different order

Geometry uncertainties

- Tank inner diameter
  - 4 tanks were used, so inner diameter is identical in cases that shared tanks
  - There is no reason to assume correlation of tank size between tanks
  - Tank ID is a large contributor to uncertainty in the evaluation
- Tank thickness
  - The tank used in Cases 1 and 2 was stainless steel; other tanks aluminum
  - Section 2 of the evaluation provides different thickness tolerances for stainless steel plate and aluminum plate
  - Aluminum thickness was assumed to be the same, but it could be different
- Solution height
  - Unique in all 10 cases

Results – geometry uncertainties only

	1-1	1-2	1-3	1-4	1-5	1-6	1-7	1-8	1-9	1-10
1-1	1	1.00	-0.02	-0.02	0.04	0.02	0.01	0.05	0.04	-0.06
1-2	1.00	1	-0.02	-0.02	0.04	0.02	0.01	0.05	0.04	-0.06
1-3	-0.02	-0.02	1	0.99	-0.03	-0.03	-0.02	-0.02	-0.04	0.04
1-4	-0.02	-0.02	0.99	1	-0.02	-0.03	-0.02	-0.02	-0.04	0.04
1-5	0.04	0.04	-0.03	-0.02	1	0.96	0.87	0.98	0.96	0.04
1-6	0.02	0.02	-0.03	-0.03	0.96	1	0.85	0.96	0.94	0.04
1-7	0.01	0.01	-0.02	-0.02	0.87	0.85	1	0.88	0.87	0.02
1-8	0.05	0.05	-0.02	-0.02	0.98	0.96	0.88	1	0.97	0.05
1-9	0.04	0.04	-0.04	-0.04	0.96	0.94	0.87	0.97	1	0.04
1-10	-0.06	-0.06	0.04	0.04	0.04	0.04	0.02	0.05	0.04	1

Note: Scale is green at minimum value (-0.06) to red at maximum value (1)

Adding tank composition uncertainties

- Stainless steel model contains several constituents
- Aluminum is modeled as pure aluminum with a reduced density
- Effects of tank composition uncertainty are expected to be small
- Aluminum impurities considered:
  - Unique in each of the three tanks (material from different lots)
  - Shared among all tanks (material drawn from same lot)
- No differences observed in correlation coefficients

Results – geometry and tank composition uncertainties

Unique tank compositions

	1-1	1-2	1-3	1-4	1-5	1-6	1-7	1-8	1-9	1-10
1-1	1	1.00	-0.02	-0.03	0.04	0.02	0.01	0.05	0.04	-0.06
1-2	1.00	1	-0.02	-0.03	0.04	0.02	0.01	0.05	0.04	-0.06
1-3	-0.02	-0.02	1	0.99	-0.02	-0.02	-0.02	-0.01	-0.03	0.05
1-4	-0.03	-0.03	0.99	1	-0.03	-0.02	-0.02	-0.02	-0.03	0.04
1-5	0.04	0.04	-0.02	-0.03	1	0.96	0.87	0.98	0.96	0.03
1-6	0.02	0.02	-0.02	-0.02	0.96	1	0.86	0.96	0.95	0.04
1-7	0.01	0.01	-0.02	-0.02	0.87	0.86	1	0.88	0.87	0.02
1-8	0.05	0.05	-0.01	-0.02	0.98	0.96	0.88	1	0.96	0.04
1-9	0.04	0.04	-0.03	-0.03	0.96	0.95	0.87	0.96	1	0.04
1-10	-0.06	-0.06	0.05	0.04	0.03	0.04	0.02	0.04	0.04	1

Shared tank compositions

	1-1	1-2	1-3	1-4	1-5	1-6	1-7	1-8	1-9	1-10
1-1	1	1.00	-0.02	-0.03	0.04	0.02	0.01	0.05	0.04	-0.06
1-2	1.00	1	-0.02	-0.03	0.04	0.03	0.01	0.05	0.04	-0.06
1-3	-0.02	-0.02	1	0.99	-0.02	-0.01	-0.02	-0.01	-0.04	0.05
1-4	-0.03	-0.03	0.99	1	-0.02	-0.02	-0.03	-0.01	-0.04	0.05
1-5	0.04	0.04	-0.02	-0.02	1	0.96	0.87	0.98	0.96	0.03
1-6	0.02	0.03	-0.01	-0.02	0.96	1	0.85	0.97	0.94	0.04
1-7	0.01	0.01	-0.02	-0.03	0.87	0.85	1	0.88	0.87	0.02
1-8	0.05	0.05	-0.01	-0.01	0.98	0.97	0.88	1	0.97	0.04
1-9	0.04	0.04	-0.04	-0.04	0.96	0.94	0.87	0.97	1	0.04
1-10	-0.06	-0.06	0.05	0.05	0.03	0.04	0.02	0.04	0.04	1

Note: Scale is green at minimum value (-0.06) to red at maximum value (1)

Adding enrichment uncertainties

- Evaluation did not report if the 8 solutions used were drawn from the same stock solution or different ones (recall that Cases 1 and 8 share a solution as do Cases 4 and 9)
- Enrichment could be different for each solution if drawn from unique stocks, different for some solutions if drawn from a few stocks, or identical if drawn from a single stock solution
- Again, enrichment uncertainties are considered uniquely for all solutions and shared across all solutions
- Considered geometry and shared tank composition uncertainties
- No significant differences were noted in correlation coefficients

Results – geometry, tank composition, enrichment uncertainties

Unique enrichments

	1-1	1-2	1-3	1-4	1-5	1-6	1-7	1-8	1-9	1-10
1-1	1	1.00	-0.02	-0.02	0.04	0.02	0.02	0.05	0.04	-0.07
1-2	1.00	1	-0.02	-0.02	0.04	0.03	0.02	0.05	0.04	-0.07
1-3	-0.02	-0.02	1	0.99	-0.03	-0.03	-0.03	-0.02	-0.05	0.04
1-4	-0.02	-0.02	0.99	1	-0.03	-0.03	-0.03	-0.02	-0.03	0.04
1-5	0.04	0.04	-0.03	-0.03	1	0.96	0.87	0.98	0.96	0.04
1-6	0.02	0.03	-0.03	-0.03	0.96	1	0.85	0.96	0.94	0.05
1-7	0.02	0.02	-0.03	-0.03	0.87	0.85	1	0.88	0.86	0.02
1-8	0.05	0.05	-0.02	-0.02	0.98	0.96	0.88	1	0.96	0.04
1-9	0.04	0.04	-0.05	-0.03	0.96	0.94	0.86	0.96	1	0.04
1-10	-0.07	-0.07	0.04	0.04	0.04	0.05	0.02	0.04	0.04	1

Shared enrichments

	1-1	1-2	1-3	1-4	1-5	1-6	1-7	1-8	1-9	1-10
1-1	1	1.00	-0.01	-0.02	0.05	0.02	0.01	0.05	0.04	-0.06
1-2	1.00	1	-0.01	-0.02	0.05	0.03	0.01	0.05	0.04	-0.06
1-3	-0.01	-0.01	1	0.99	-0.02	-0.02	-0.02	-0.01	-0.02	0.04
1-4	-0.02	-0.02	0.99	1	-0.02	-0.02	-0.02	-0.01	-0.02	0.04
1-5	0.05	0.05	-0.02	-0.02	1	0.96	0.87	0.98	0.96	0.04
1-6	0.02	0.03	-0.02	-0.02	0.96	1	0.85	0.96	0.94	0.04
1-7	0.01	0.01	-0.02	-0.02	0.87	0.85	1	0.88	0.87	0.02
1-8	0.05	0.05	-0.01	-0.01	0.98	0.96	0.88	1	0.96	0.04
1-9	0.04	0.04	-0.02	-0.02	0.96	0.94	0.87	0.96	1	0.03
1-10	-0.06	-0.06	0.04	0.04	0.04	0.04	0.02	0.04	0.03	1

Note: Scale is green at minimum value (-0.07) to red at maximum value (1)

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All uncertainties

- Solution parameters of uranium concentration, density, and excess acid molarity were added to geometry, shared tank composition, and shared enrichment uncertainty scenario
- Since all 8 solutions have different characteristics, there is no way these parameters could be correlated
- Therefore, only unique sampling was considered resulting in significant changes in correlation coefficients

Results – all uncertainties

Cases 1 and 8 share a solution but are in different tanks

Note: Scale is green at minimum value (-0.05) to red at maximum value (1)

	1-1	1-2	1-3	1-4	1-5	1-6	1-7	1-8	1-9	1-10
1-1	1	0.98	0.01	-0.04	0.08	-0.01	0.01	0.08	0.00	-0.05
1-2	0.98	1	0.01	-0.04	0.06	-0.02	0.01	0.05	-0.01	-0.05
1-3	0.01	0.01	1	0.37	-0.04	0.03	-0.02	-0.01	-0.03	0.02
1-4	-0.04	-0.04	0.37	1	-0.04	-0.05	0.00	-0.01	0.67	-0.05
1-5	0.08	0.06	-0.04	-0.04	1	0.79	0.77	0.87	0.51	0.07
1-6	-0.01	-0.02	0.03	-0.05	0.79	1	0.76	0.82	0.44	0.08
1-7	0.01	0.01	-0.02	0.00	0.77	0.76	1	0.83	0.53	0.03
1-8	0.08	0.05	-0.01	-0.01	0.87	0.82	0.83	1	0.56	0.06
1-9	0.00	-0.01	-0.03	0.67	0.51	0.44	0.53	0.56	1	-0.04
1-10	-0.05	-0.05	0.02	-0.05	0.07	0.08	0.03	0.06	-0.04	1

Cases 4 and 9 share a solution but are in different tanks

- Case 1 uncertainty is dominated by tank radius and thickness uncertainties (0.521% Δk of 0.589 % Δk total)
- Solution parameters do not have enough uncertainty to significantly change correlation
- Tank uncertainties are much lower for Cases 4 and 9, so shared solution uncertainties *can* drive correlation

Conclusions

- The impact of shared uncertainty can vary greatly depending on other uncertainties in cases of interest
- The assumption of shared or unique uncertainties has no impact for parameters with small impact
- Comparison with reference results in the ICSBEP Handbook shows significant qualitative and quantitative differences
- Generally, correlations among solution systems are easier to analyze in detail than those in lattice systems due to the smaller number of parameters

Questions?