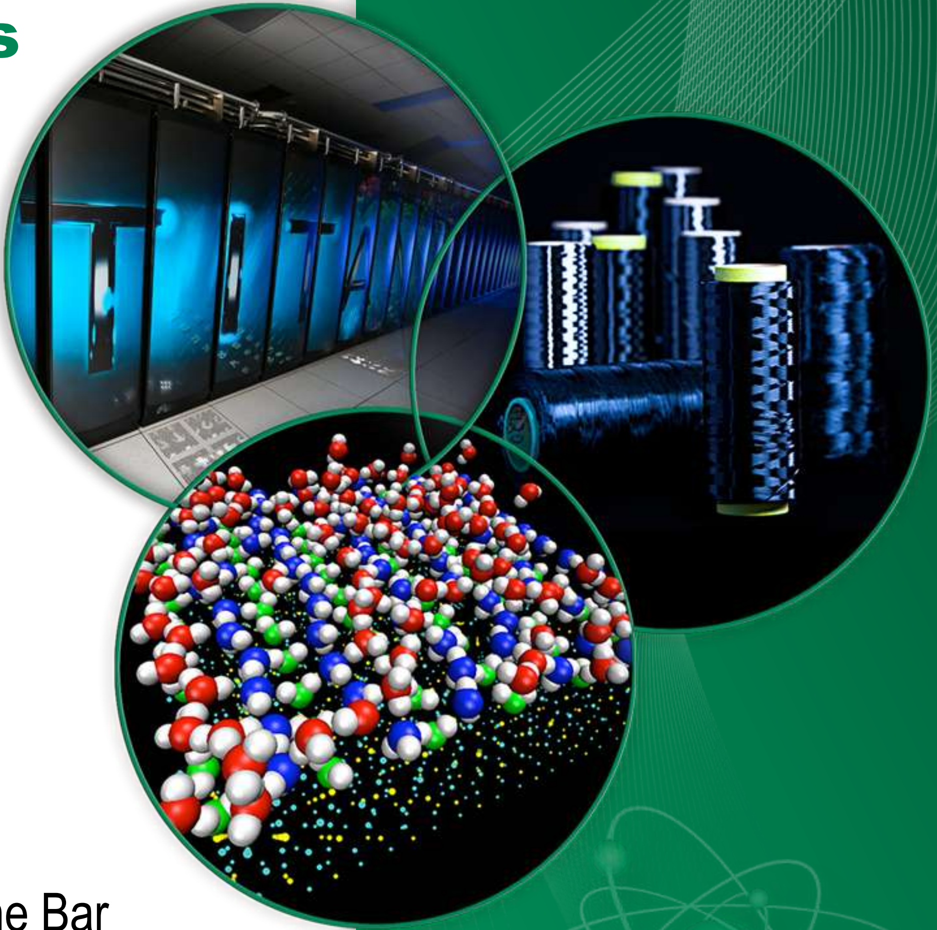
Quantification of Uncertainties and Correlations in Criticality Experiments with SCALE



B. T. Rearden
Oak Ridge National Laboratory
K. J. Dugan
Texas A&M University
F. Havlůj
Nuclear Research Institute at Řež

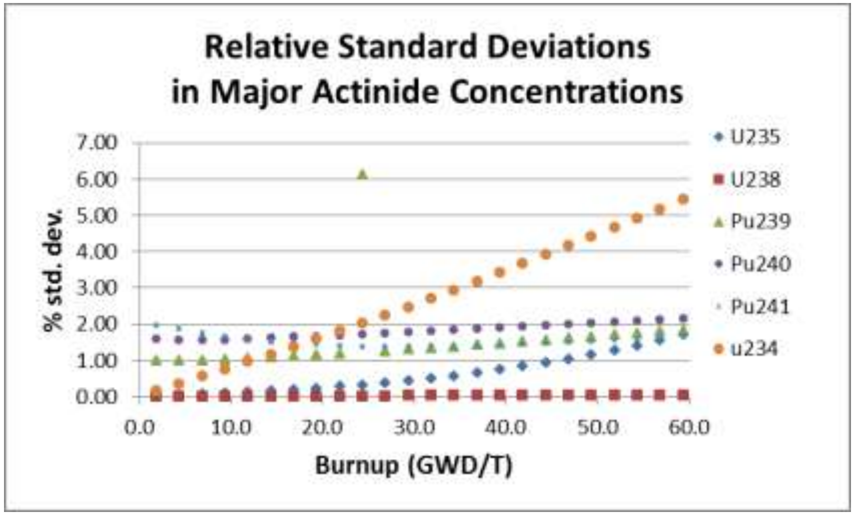
ANS NCSD 2013
Criticality Safety in the Modern Era: Raising the Bar
Wilmington, NC

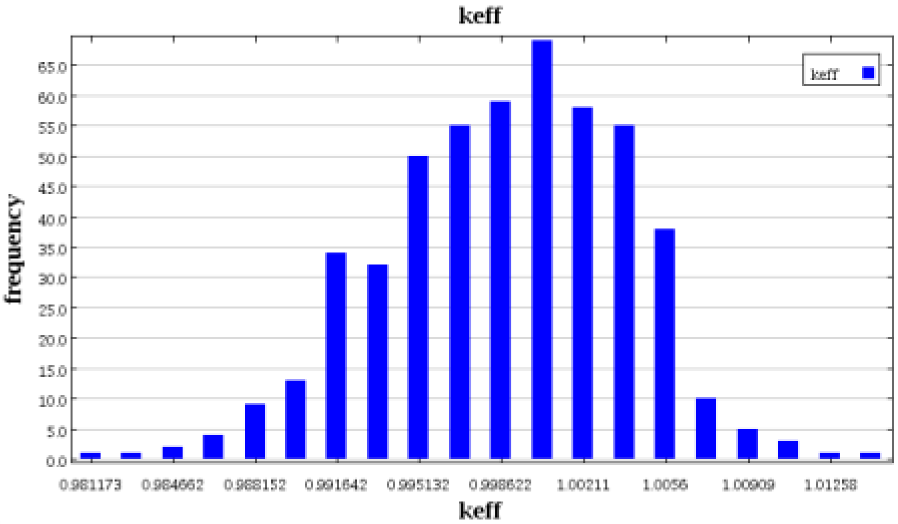
Parametric Uncertainty

- In safety analysis modeling, uncertainties in dimensions, concentrations, densities, enrichment, etc. introduce uncertainties in the final results.
- It is possible to quantify the impact of these uncertainties in input parameter by performing numerous calculations with perturbed inputs and performing a statistical assessment of the results.
  - Randomly sample a set of perturbed parameters within input model
  - Run perturbed simulation and retrieve desired parameter(s).
  - Repeat calculation N times to get a distribution of the desired parameter(s)
  - After sufficient perturbations, output parameter should approach a mean value with standard deviation ($\mu \pm \sigma$)
  - Correlations between sampled parameters are quantified

Sampler: A Module for Statistical Uncertainty Analysis with SCALE Sequences

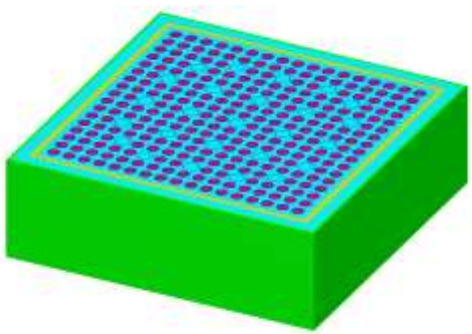
- Sampler provides uncertainty in any computed result from any SCALE sequence due to uncertainties in:
  - neutron cross sections
  - fission yield and decay data
  - geometry and composition
- Sampler propagates uncertainties through complex analysis sequences such depletion calculations
- Correlations between systems are also computed





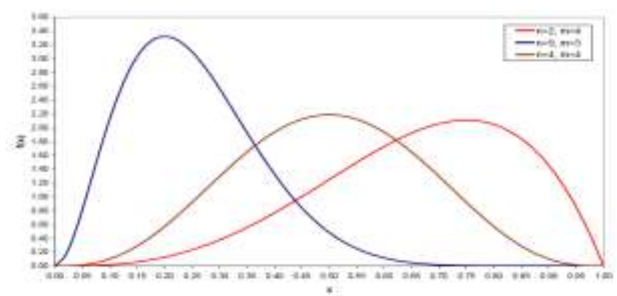
Description of OECD/NEA/WPNCS UACSA Phase II Benchmark

- Reflected assembly with surrounding neutron absorbing material
- ~30 uncertain parameters (fuel cladding thickness, isotopic concentrations, etc.)
- Gaussian and beta distribution describing uncertain parameters



AREVA Benchmark Model

Beta Distribution



$$f(x;n,m) = \frac{\Gamma(n+m)}{\Gamma(n)\Gamma(m)} x^{m-1}(1-x)^{n-1}, \quad 0 \le x \le 1$$

Parsed Input (SCALE InputViewer)

```
/
/csas6
/csas6/Declarator(=)
/csas6/type(csas6)
...
/csas6/read composition
/csas6/read composition/Declarator(read composition)
/csas6/read composition/uo2
/csas6/read composition/uo2/Declarator(uo2)
/csas6/read composition/uo2/mixture(1)
/csas6/read composition/uo2/den
/csas6/read composition/uo2/den/Declarator(den)
/csas6/read composition/uo2/den/=(=)
/csas6/read composition/uo2/den/value(10.65)
/csas6/read composition/uo2/vf(1)
/csas6/read composition/uo2/temp(300)
/csas6/read composition/uo2/wtptPair
/csas6/read composition/uo2/wtptPair/id(92235)
/csas6/read composition/uo2/wtptPair/wtpt(3.95)
/csas6/read composition/uo2/wtptPair
/csas6/read composition/uo2/wtptPair/id(92238)
/csas6/read composition/uo2/wtptPair/wtpt(96.05)
/csas6/read composition/uo2/end(end)
```

Sampler Input

```
'Sampler Input for UACSA
=sampler
UACSA
read parameter
 samples=250
end parameter
read case[UACSA]
   import = "/home/wm4/UACSA_Sampler/k5_UACSA/UACSA_k5.inp"
   read variable[uo2dens]
      distribution = beta
      value = 10.65
      minimum = 10.525
      maximum = 10.775
      beta_a = 4
      beta_b = 2
      siren = "//uo2/dens/value"
   end variable
   read variable[BSS_Wi_dx_tot]
      distribution = constant
      minimum = 0
      maximum = 0.2
      value=0
   end variable
…
end case
```

Set number of samples

Provide path to input

Distribution parameters

InputSelector statement

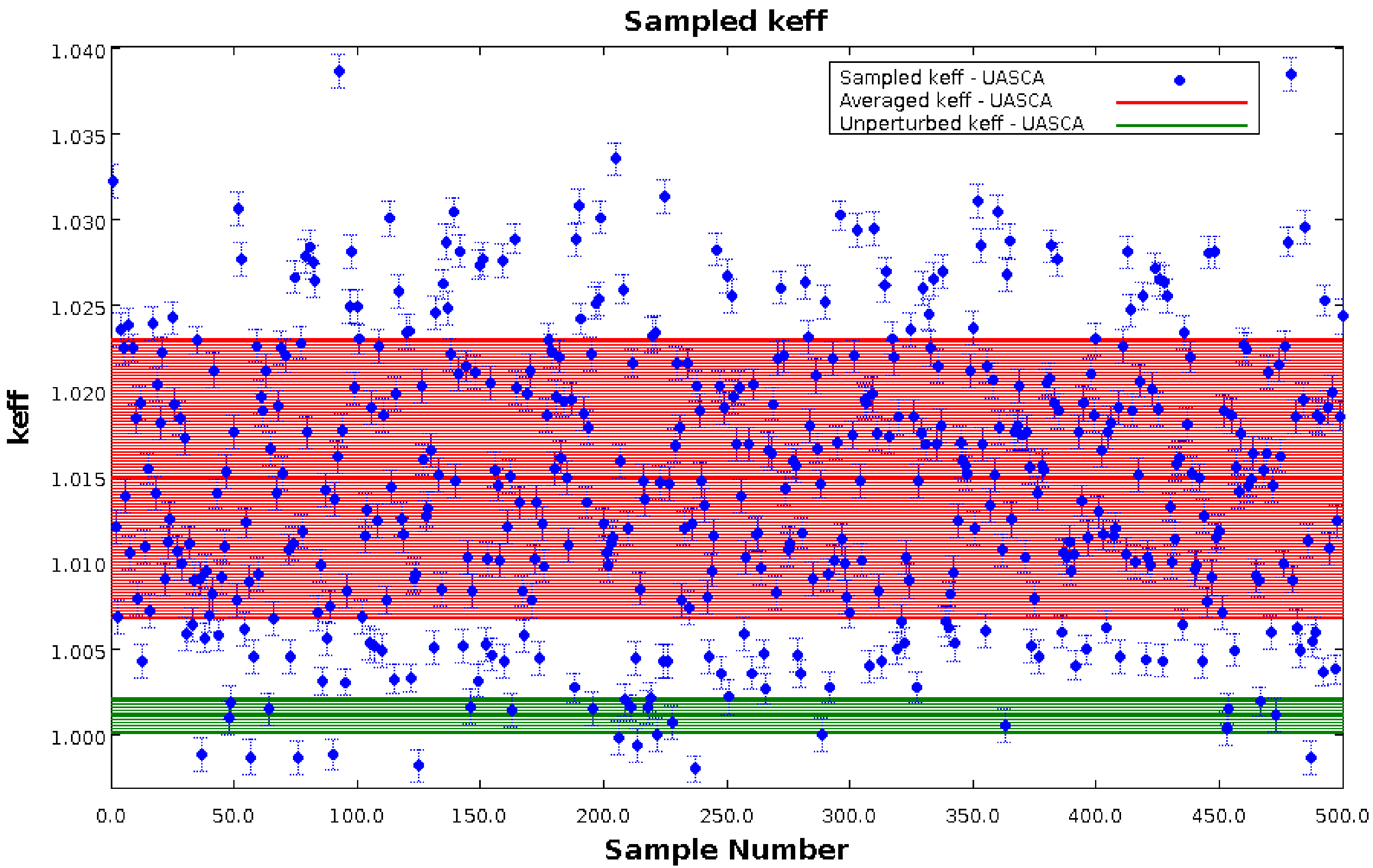
Variable defined, but not used directly to alter input

Sampler Input (continued)

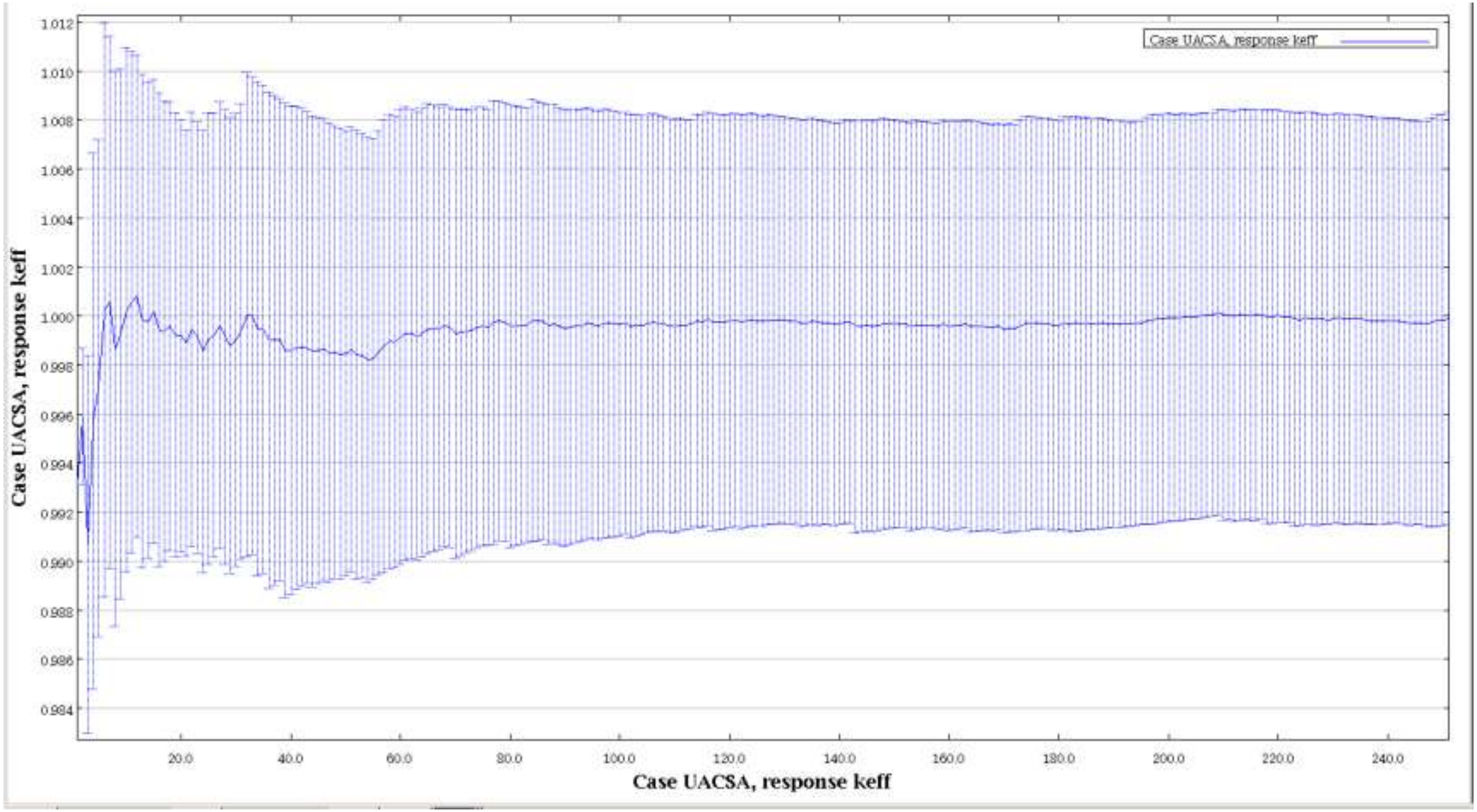
```
read variable[rclad]
    distribution = beta
    value = 0.475
    minimum = 0.4725
    maximum = 0.4775
    beta_a = 4
    beta_b = 4
    siren = "//unit[id='1']/cylinder[3]/Dimensions/r"
end variable
read variable[rclad_lattice]
    distribution = expression
    expression = "rclad"
    siren = "//latticecell/cladr/dimension"
end variable
…
read variable[BSS_Cr]
   distribution = expression
   expression = "(1.0 - BSS_B/100.0)*BSS_Cr_tol"
   siren = "//wtptBSS/atomWtptPair/[id='24000']/wtpt"
end variable
```

Use of expressions to determine variables based on value of a different variable

Distribution for Individual Benchmark
500-sample case



Benchmark Results – k_{eff} Distribution



For 250 samples, average k_{eff} = 0.99990 ± 0.00842
Nominal k_{eff} = 0.99270 ± 0.00048

Experimental Correlations

- Uncertainties in benchmark k_{eff} values due to uncertainties in physical components and measurement techniques are rigorously quantified and documented in the ICSBEP and other experiment documents
- Where experiments use the same materials or same measurement devices, uncertainties quantified for different experiments will be correlated.
- Of the ~4800 experiments in ICSBEP, only ~60 have experimental correlations quantified.
- Needed for TSURFER analysis:

$$\chi^2 = [\alpha' - \alpha]^{\dagger} [C_{\alpha\alpha}]^{-1} [\alpha' - \alpha] + [K'_m - K_m]^{\dagger} [C_{mm}]^{-1} [K'_m - K_m]$$

Cross section covariance data

Experimental uncertainty covariance data

Approach to Quantifying Correlations Between Uncertain Parameters Shared by Multiple Systems

- Based on empirical approach presented by Areva
  - Oliver Buss, Axel Hoefer, Jens Christian Neuber, Michael Schmid, “Hierarchical Monte-Carlo approach to bias estimation for criticality safety calculations,” PHYSOR 2012
- Generate SCALE/CSAS inputs for each model
- Identify “sets” of systems with shared uncertain parameters
- Generate single Sampler input using multiple models and multiple parameters
- Analyze results

HEU-SOL-THERM-001 Benchmarks

- 10 HEU solution tanks measuring critical solution volumes
- Some experiments use the same tank or the same solution
  - Potential for correlations exists among experiments
- Same enrichment
- Four core tanks
- Varying solution properties

HEU-SOL-THERM-001 Model

Define Multiple Cases for Same Sampler Run

Run all 10 cases with 100 perturbations = 1000 KENO calculations

Case identifier

File location

```
=sampler

read parameters
  n_samples = 100
  perturb_geometry = yes
  library = "v7-238"
  continue_if_errors = no
end parameters

'======================================================================
'          Input Files
'======================================================================
read case[HST001]
  import = "/home/kdu/SamplerPlayground/HST-001/HST_inp/HEU-SOL-THERM-001-001.inp"
end case
read case[HST002]
  import = "/home/kdu/SamplerPlayground/HST-001/HST_inp/HEU-SOL-THERM-001-002.inp"
end case
…
read case[HST010]
  import = "/home/kdu/SamplerPlayground/HST-001/HST_inp/HEU-SOL-THERM-001-010.inp"
end case
```

Define Shared Uncertain Parameters by Case

```
'=============================================
'    Inner Tank Radius
'=============================================
read variable[r_inner_case12]
  distribution = normal
  value = 13.96
  stddev = 0.19
  minimum = 13.77
  maximum = 14.15
  siren = "//zcylinder/[mixture='1']/Dimensions/r"
  cases = HST001 HST002 end
end variable
…
read variable[r_inner_case12_celldata]
  distribution = expression
  expression = "r_inner_case12"
  siren = "//multiregion/zone/[mixture='1']/radius"
  cases = HST001 HST002 end
end variable
…
read variable[r_inner_case10_celldata]
  distribution = expression
  expression = "r_inner_case10"
  siren = "//multiregion/zone/[mixture='1']/radius"
  cases = HST010 end
end variable
```

Distribution parameters

InputSelector statement

Assign to cases

Applying *Expression* to Multiple Cases

```
'================================================
'   Tank Outer Radius
'================================================
read variable[r_outer_case12]
  distribution = expression
  expression = "r_inner_case12 + 0.32"
  siren = "//zcylinder/[mixture='2']/Dimensions/r"
  cases = HST001 HST002 end
end variable
read variable[r_outer_case12_celldata]
  distribution = expression
  expression = "r_outer_case12"
  siren = "//multiregion/zone/[mixture='2']/radius"
  cases = HST001 HST002 end
end variable
read variable[r_outer_case34]
  distribution = expression
  expression = "r_inner_case34 + 0.32"
  siren = "//zcylinder/[mixture='2']/Dimensions/r"
  cases = HST003 HST004 end
end variable
```

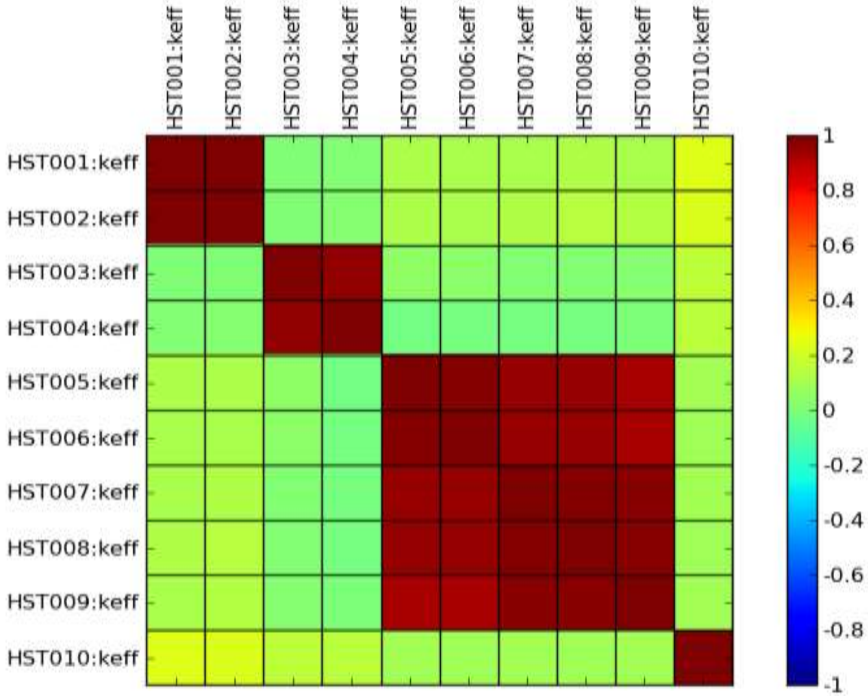
Distribution parameters

InputSelector statement

Assign to cases

Use new variable again

Preliminary Correlation Matrix



Sampler

	HST 001 001	HST 001 002	HST 001 003	HST 001 004	HST 001 005	HST 001 006	HST 001 007	HST 001 008	HST 001 009	HST 001 010
HST001-001	1	0.47	0.46	0.44	0.42	0.42	0.46	0.57	0.44	0.44
HST001-002	0.47	1	0.42	0.58	0.42	0.42	0.41	0.44	0.58	0.46
HST001-003	0.46	0.42	1	0.46	0.43	0.43	0.46	0.46	0.42	0.43
HST001-004	0.44	0.58	0.46	1	0.42	0.42	0.42	0.44	0.77	0.46
HST001-005	0.42	0.42	0.43	0.42	1	0.54	0.48	0.47	0.46	0.48
HST001-006	0.42	0.42	0.43	0.42	0.54	1	0.48	0.47	0.46	0.48
HST001-007	0.46	0.41	0.46	0.42	0.48	0.48	1	0.51	0.45	0.43
HST001-008	0.57	0.44	0.46	0.44	0.47	0.47	0.51	1	0.48	0.44
HST001-009	0.44	0.58	0.42	0.77	0.46	0.46	0.45	0.48	1	0.46
HST001-010	0.44	0.46	0.43	0.46	0.48	0.48	0.43	0.44	0.46	1

DICE

Future Work

- Continue development of Sampler tool
- Develop detailed Sampler model of HST-001 for demonstration
  - Impurities, additional solution parameters, etc.
- Resolve any discrepancies with data provided in DICE
- Develop Sampler input specifications for benchmarks available in ORNL VALID library distributed with ICSBEP
- Generate TSURFER data for use in validation assessment
- Provide guidance on use of correlated experimental measurements in validation

Questions?

http://scale.ornl.gov

scalehelp@ornl.gov

scale

Nuclear Systems Modeling & Simulation