OAK RIDGE National Laboratory

Sensitivity/Uncertainty Comparison Study: Oak Ridge National Laboratory Results

Ellen M. Saylor
B.J. Marshall

ANS Winter Meeting & Expo
Washington, D.C.
November 21, 2019

ORNL is managed by UT-Battelle, LLC for the US Department of Energy

U.S. DEPARTMENT OF ENERGY

Overview

- Various methods and sensitivity/uncertainty tools have been developed over the years to assist in determining upper subcritical limits (USLs)
- Task – compare calculated USLs from various methods on a small set of benchmark problems.
- Benchmark experiments selected (applications):
  - HEU-MET-FAST-013-001
  - HEU-SOL-THERM-001-008
  - PU-MET-FAST-022-001
  - PU-SOL-THERM-001-001

ORNL Results

- Tools for Sensitivity Uncertainty Analysis Methodology Implementation (TSUNAMI) from SCALE 6.2.3 code suite
- Calculational models/sensitivity data files (SDFs) are from VALID
- TSUNAMI-IP used to compare SDFs between selected benchmarks and available benchmark experiments to calculate correlation coefficient c_k
- TSUNAMI-IP also used to generate inputs for the Upper Subcritical Limit Statistical Software (USLSTATS) trending analysis
- ENDF/B-VII.1 cross sections, 252 group MG library, 252 group covariance library

ORNL Results (continued)

- USLSTATS – used c_k as a trending parameter to determine bias and bias uncertainty (no additional margins of safety)
  - Evaluated with c_k thresholds of 0.8, 0.9, and 0.95
  - USL = 1.0 + bias – bias uncertainty
  - No credit for positive biases
  - No additional safety margins
- TSUNAMI-IP run with and without option for correction/patches to the covariance data (when cross-section-covariance data are too large or not available in the covariance library)

ORNL Results (continued)

- Following slides will go through each case
  - Each experimental and calculated value
  - Number of applicable experiments and the USL determined for each c_k threshold (0.8, 0.9, 0.95)
  - Figure (USLSTATS plot) of the biased k_{eff}'s
    - Illustrates effect of changing the pool of applicable experiments

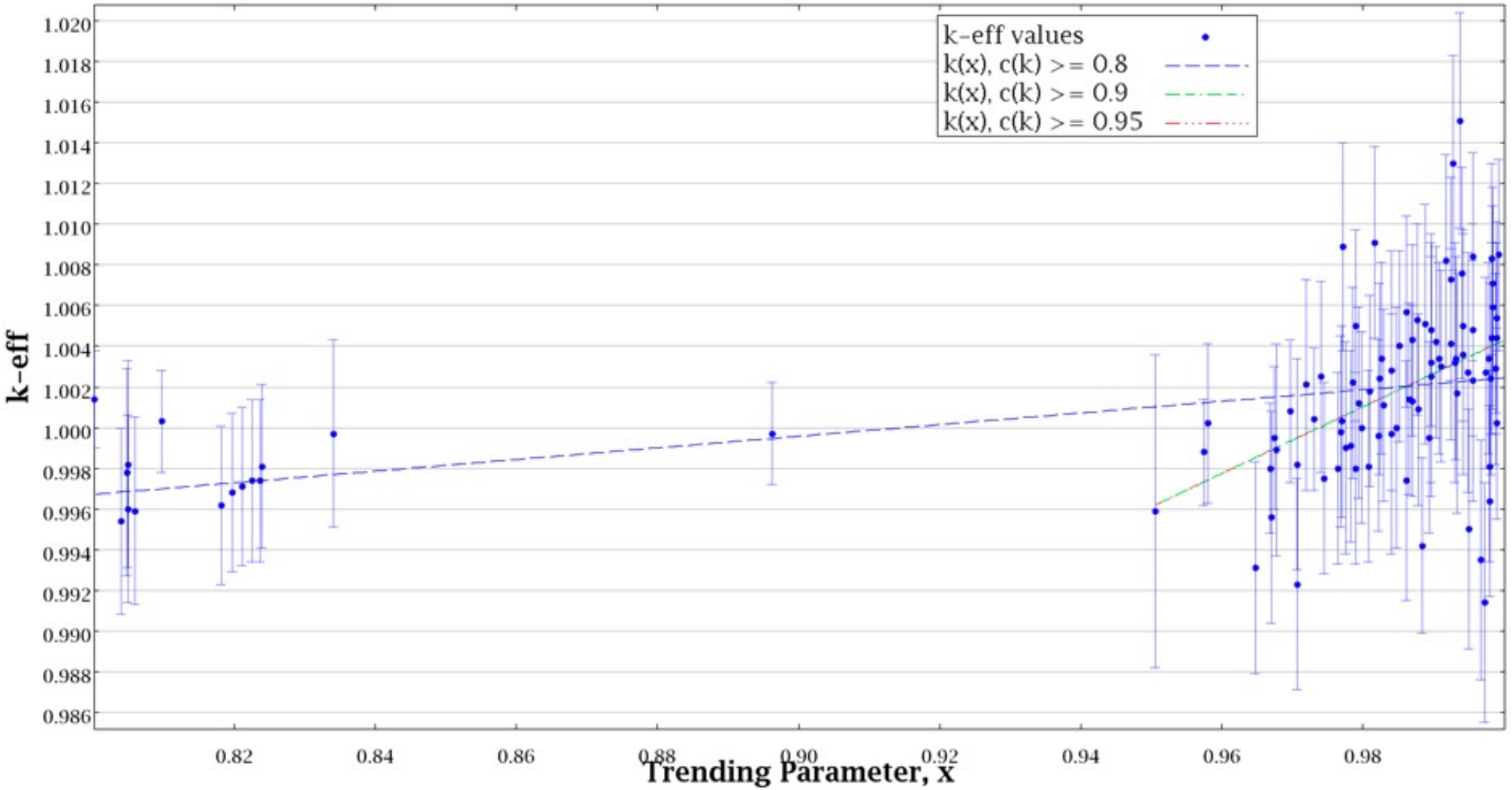
ORNL Results – PU-SOL-THERM-001-001

- Description – critical assembly consisting of sphere of plutonium nitrate solution (73 g/L Pu with acid molarity of 0.2M nitrate)
  - Experimental: 1.0000 ± 0.0050
  - SCALE 6.2.3 : 1.0039 ± 0.0001

Minimum c_k	Number of Experiments	Bias	Bias Uncertainty	USL
0.8	100	0.0025	0.0105	0.9895
0.9	85	0.0043	0.0108	0.9892
0.95	85	0.0043	0.0108	0.9892

ORNL Results – PU-SOL-THERM-001-001 (continued)

- Biased k_{eff} (from USLSTATS)



ORNL Results – PU-SOL-THERM-001-001 (continued)

- Lots of applicable experiments make for similar trends and very similar USLs
- No difference between c_k threshold value of 0.9 and 0.95 – same number of experiments
- Including additional, less applicable experiments (c_k threshold value of 0.8), changes the slope and the resultant USL (negligible in this case)
- Positive bias is well-predicted
  - No credit for positive bias
  - If credited, resultant USL would be 0.9920 (c_k of 0.8) or 0.9935 (c_k of 0.9 or 0.95)

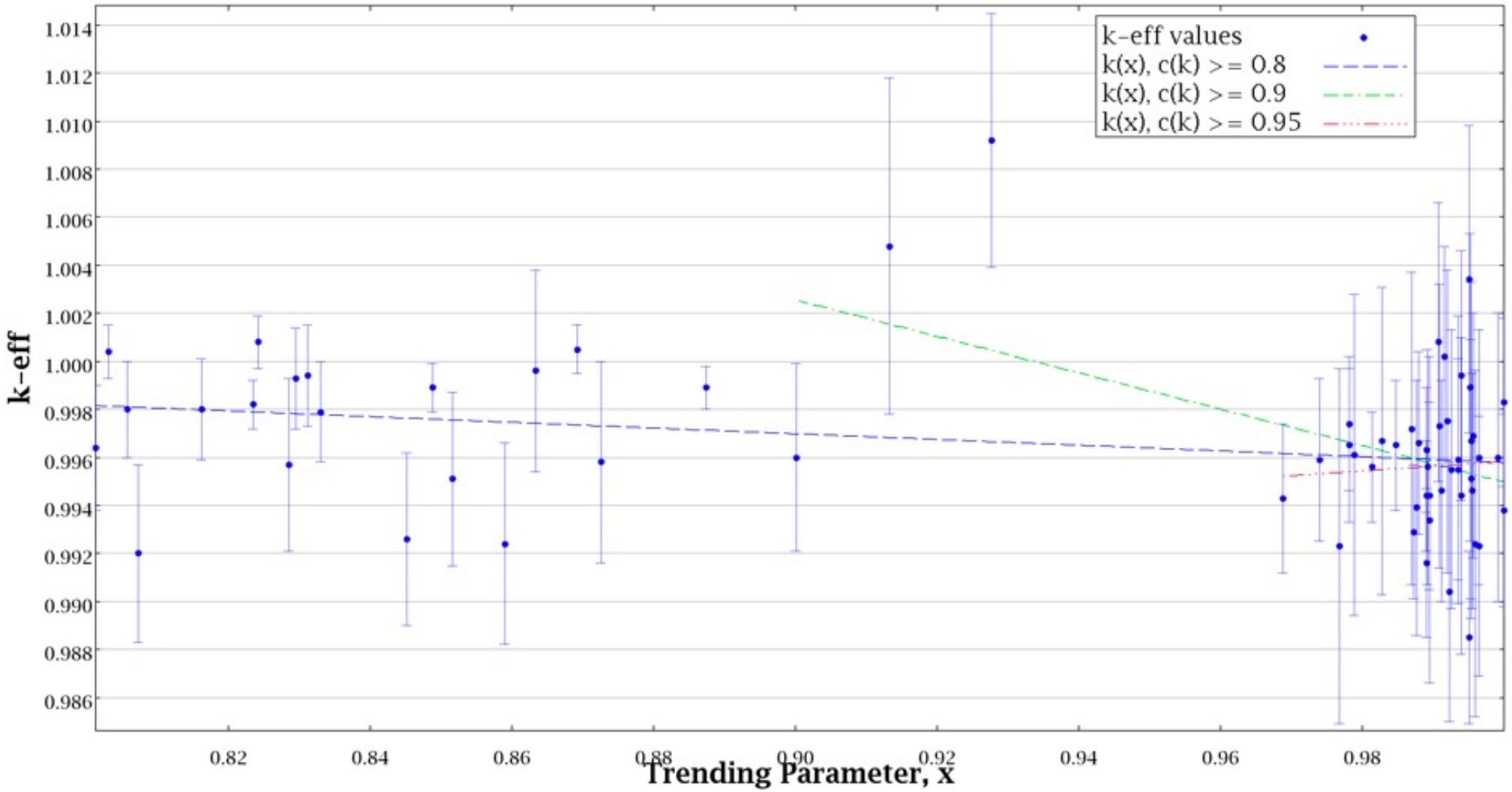
ORNL Results – HEU-SOL-THERM-001-008

- Description – critical assembly consists of cylinder of highly enriched uranyl nitrate solution (146 g/L U with acid molarity of 0.3M nitrate)
  - Experimental: 0.9998 ± 0.0038
  - SCALE 6.2.3 : 0.9959 ± 0.0001

Minimum c_k	Number of Experiments	Bias	Bias Uncertainty	USL
0.8	65	-0.0042	0.0095	0.9863
0.9	46	-0.0050	0.0104	0.9846
0.95	43	-0.0042	0.0101	0.9857

ORNL Results – HEU-SOL-THERM-001-008 (continued)

- Biased k_{eff} (from USLSTATS)



ORNL Results – HEU-SOL-THERM-001-008 (continued)

- Again we see the cluster of points above the c_k threshold value of 0.95
- Again slope changes with different selection of experiments – trend flips with c_k threshold value of 0.95
  - Same bias as with a c_k threshold value of 0.8, but different uncertainty, so slightly different USL
  - Demonstrates the potential hazard of declaring general c_k cutoffs
- Very similar USLs

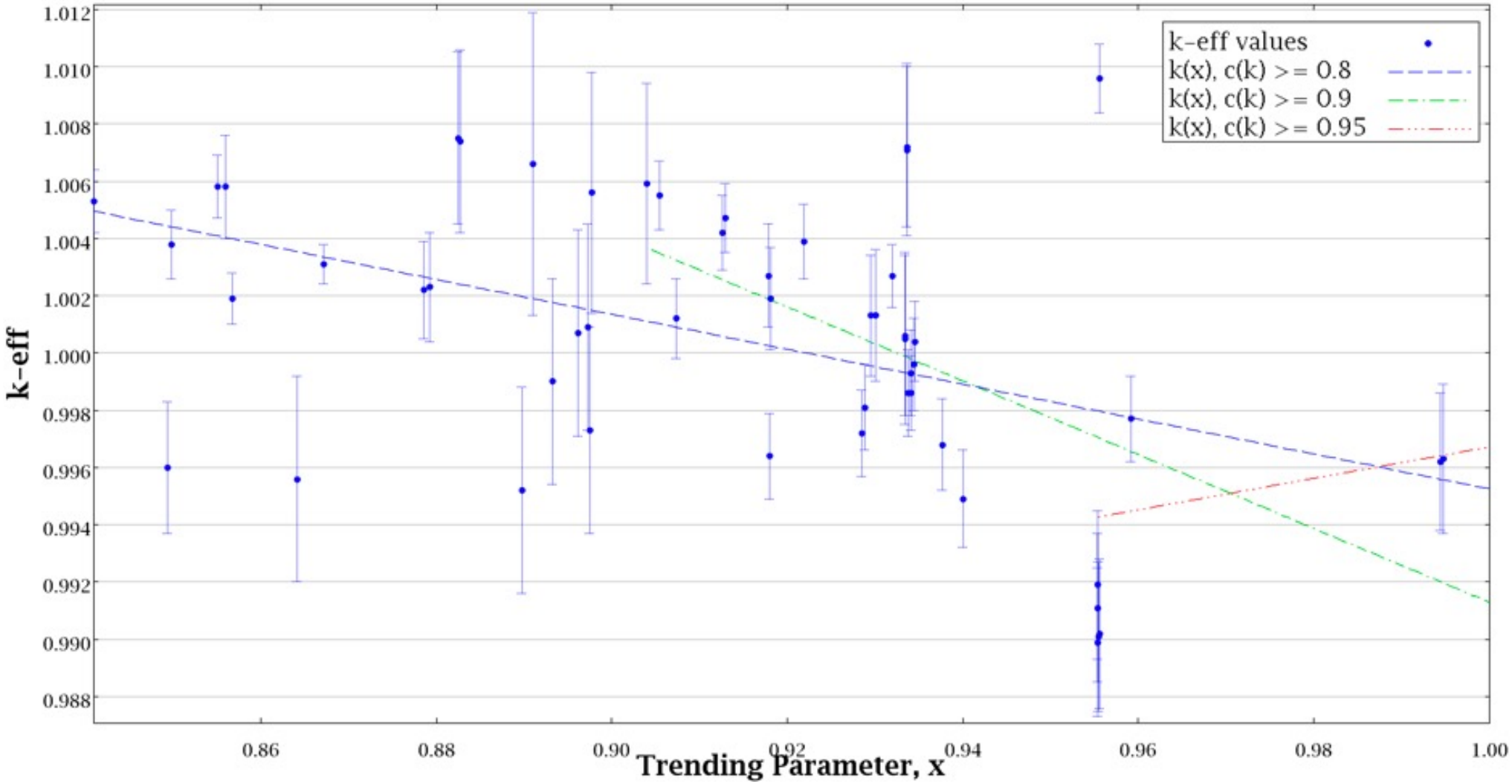
ORNL Results – HEU-MET-FAST-013-001

- Description – critical assembly is a steel reflected sphere of highly enriched uranium metal
  - Experimental: 0.9990 ± 0.0015
  - SCALE 6.2.3 : 0.9973 ± 0.0001

Minimum c_k	Number of Experiments	Bias	Bias Uncertainty	USL
0.8	53	-0.0047	0.0090	0.9863
0.9	34	-0.0087	0.0094	0.9819
0.95	9	-0.0032	0.0173	0.9795

ORNL Results – HEU-MET-FAST-013-001 (continued)

- Biased k_{eff} (from USLSTATS)



ORNL Results – HEU-MET-FAST-013-001 (continued)

- Values are more spread out, not so many grouped on the high end
- Again, slope changes with different c_k threshold value
  - c_k threshold value of 0.95 has different trend
    - Only 9 experiments have a c_k greater than 0.95 (USLSTATS requires a minimum of 25 for its normality test)
    - Bias is smaller but the resultant USL is lower because of its higher bias uncertainty (almost double)
- Using the option for correction/patches to the covariance data yielded slightly different results

ORNL Results – HEU-MET-FAST-013-001 (continued)

- 6 fewer experiments at c_k threshold values of 0.8 and 0.9
  - Vanadium reflector in all 6 experiments (not in HMF-013-001)
  - V-51 scattering reaction is a major contributor to the uncertainty
  - Without the correction/patch, c_k value is 0.94 for all 6 experiments
  - With the correction/patch, c_k value is lower than 0.7, with most being less than 0.5

Min. c_k	No. of Exp.	Bias	Bias Uncert.	USL
With correction/patches option				
0.8	53	-0.0047	0.0090	0.9863
0.9	34	-0.0087	0.0094	0.9819
Without correction/patches option				
0.8	59	-0.0035	0.0090	0.9875
0.9	40	-0.0078	0.0094	0.9828

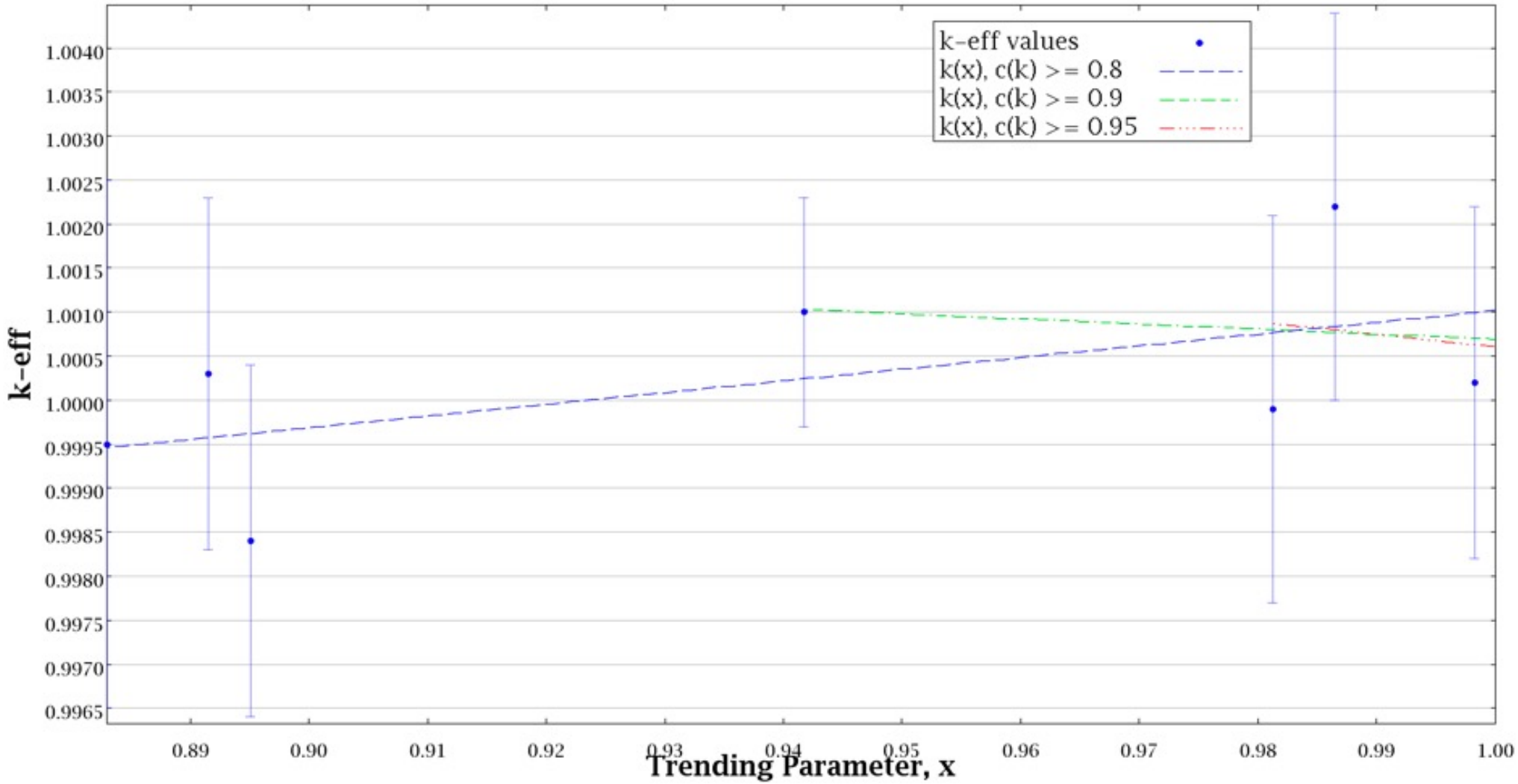
ORNL Results – PU-MET-FAST-022-001

- Description – critical assembly is a bare plutonium metal sphere with a small central cavity
  - Experimental: 1.0000 ± 0.0023
  - SCALE 6.2.3 : 0.9986 ± 0.0001

Minimum c_k	Number of Experiments	Bias	Bias Uncertainty	USL
0.8	7	0.0010	0.0057	0.9943
0.9	4	0.0006	0.0084	0.9916
0.95	3	0.0006	0.0258	0.9742

ORNL Results – PU-MET-FAST-022-001 (continued)

- Biased k_{eff} (from USLSTATS)



ORNL Results – PU-MET-FAST-022-001 (continued)

- Less than the minimum of 25 for the normality test
  - USLSTATS output – 'satisfied a normal distribution test' but flagged as 'unreliable'
- No credit for positive bias
- How many applicable experiments are really needed?

Summary Observations

- Overall, method works well
  - Within a few tenths of a percent on a bias-corrected basis in all cases
- Generally, the larger pools (number of experiments) of applicable experiments resulted here in smaller bias uncertainties
  - Larger pools are for lower c_k thresholds
  - No similar trend in magnitude of bias

Summary Observations (continued)

- The impact of different c_k thresholds depends on the system….has potential to be significant
  - Important to look at the spread in the data
- None of the c_k thresholds used here were low enough to give clearly wrong results
  - May be that it takes much larger number of bad experiments to cause a negative effect
  - May also depend on the spread of the calculated k_{eff}'s
    - Evidenced by switch in slopes

Future Work

- Compare results with others involved in the NCSP task
  - Los Alamos National Laboratory (LANL)
  - Institute for Radiological Protection and Nuclear Safety (IRSN)
- Determine
  - What we each do well
  - What we each don't do so well
  - Areas we can improve

OAK RIDGE National Laboratory

Questions?

This work was supported by the Nuclear Criticality Safety Program, funded and managed by the National Nuclear Security Administration for the Department of Energy.