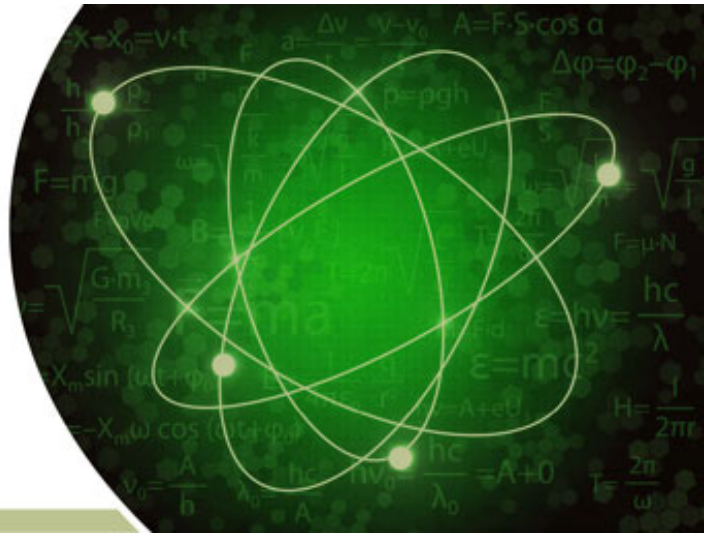
ANS Annual Meeting

2019 THE VALUE OF NUCLEAR



Excluding Benchmark Statistical Outliers in Nuclear Criticality Safety Validation

Jennifer Alwin & Forrest Brown

Los Alamos National Laboratory

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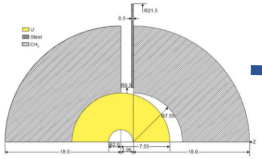
Rejection of Statistical Outliers

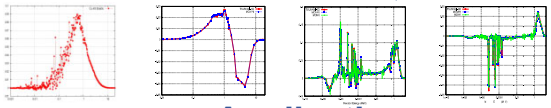
- ANSI/ANS-8.24-2007:
  - "*Rejection of data outliers shall be based on the inconsistency of the data with known physical behavior or on established statistical rejection methods.*"
- ANSI/ANS-8.24-2017:
  - "*Identification of data outliers may be based on established statistical rejection methods; rejection of outliers shall be based on the inconsistency of the data with known physical behavior in the experimental data.*"

– Determine impact of rejection of benchmark outliers on Nuclear Criticality Safety Validation
  – Pu and HEU Systems: metal, oxide, solution
  – Application parameter study models for use with MCNP6.2/Whisper-1.1



Application + Nuclear Data

Monte Carlo Criticality Calculation



Application Sensitivity Profile
Isotopes, reactions, energies

SU-based Analysis
Pattern matching select similar benchmarks

Bias, Bias Uncertainty Margin of Subcriticality Baseline USL

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Rejection of Statistical Outliers

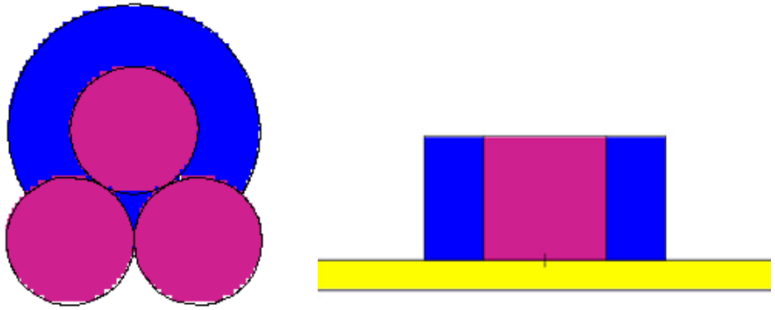
- Whisper Identification of Outliers
  - Generalized Linear Least Squares (GLLS)
    - Used to find the minimum chi-squared
    - Value of chi-squared per number of benchmarks = 1 for perfect regression model
    - Identification of outliers using iterative diagonal chi-squared method until χ^2_{min} < 1.2
    - 10% of Whisper-1.1 library identified as outliers using method
- Whisper Exclusion of Outliers
  - Whisper selects benchmarks neutronically similar to each case
  - User option to include/exclude identified outliers
  - Some neutronically similar benchmarks may be identified outliers
  - Study: Include or exclude identified outliers to determine impacts on USLs for Pu and HEU Systems

Benchmark Series	# Library	# Rejected-ENDF/B-VII.1	% Rejected in Series
HEU-COMP-THERM	25	5	20%
HEU-MET-FAST	251	29	12%
HEU-MET-INTER	4	2	50%
HEU-MET-THERM	4	2	50%
HEU-SOL-THERM	93	2	2%
LEU-COMP-THERM	182	4	2%
LEU-SOL-THERM	27	2	7%
MIX-MET-FAST	32	1	3%
MIX-SOL-THERM	21	9	43%
PU-COMP-MIXED	34	16	47%
PU-MET-FAST	68	3	4%
PU-SOL-THERM	158	15	9%
U233-MET-FAST	9	1	11%
U233-SOL-INTER	33	10	30%
U233-SOL-THERM	106	12	11%
OTHER	54	0	0%
TOTAL	**1101**	**113**	**10%**

Determine Impact of Statistical Outliers on USL

- Application parameter study models for use with MCNP6.2/Whisper
  - Pu and HEU Systems: metal, oxide, solution

  - Metal and Oxide:
  - 3 right circular cylinders in close proximity
  - Water and steel reflection
  - Height-to-Diameter variation
  - Metal cases vary mass per cylinder
  - Oxide cases vary amount of water



  - Solution (Metal-Water Mixture):
  - 2 right circular cylinders in close proximity
  - Water and steel reflection
  - Height-to-Diameter variation
  - Mixed with varying amount of water

  - MCNP6.2 calculations → sensitivity profiles
  - Whisper → bias, bias uncertainty, nuclear data uncertainty margin

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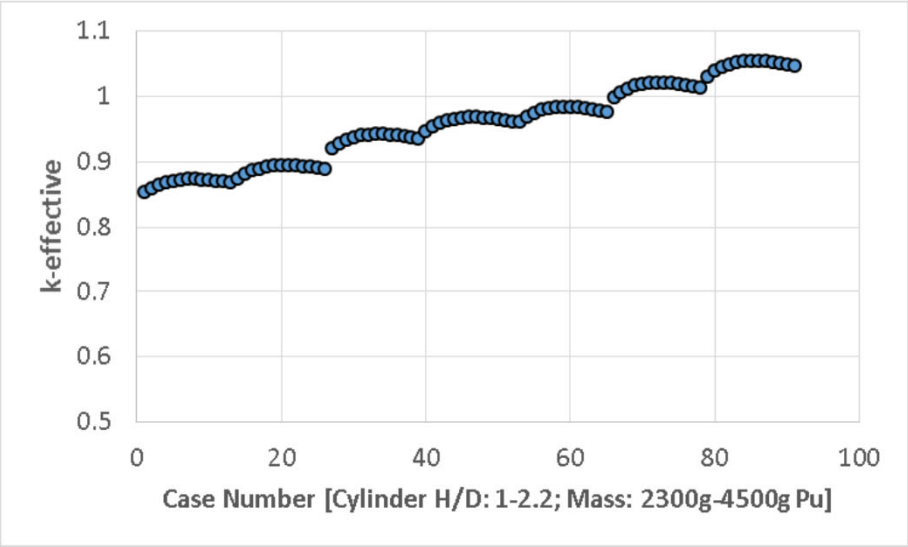
Results-Benchmark Rejection

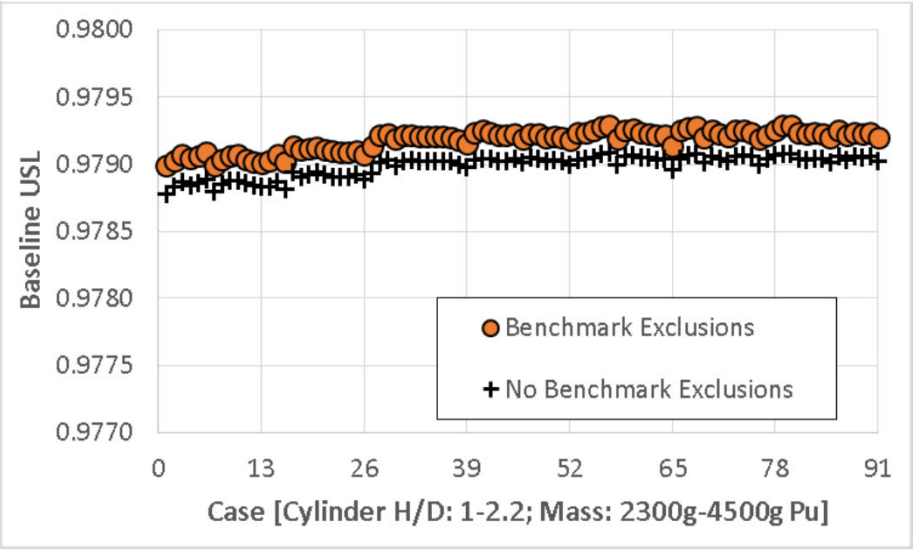
- Pu metal results

– Baseline USL slightly higher when benchmark outliers are excluded

– Magnitude of difference in USL including vs. excluding outliers: 0.00021

Benchmark Exclusions			No Benchmark Exclusions		
Baseline USL = 0.97899			Baseline USL = 0.97878		
Bias = 0.00697			Bias = 0.00859		
Bias Uncertainty = 0.00716			Bias Uncertainty = 0.00575		
Nuclear Data Uncertainty = 0.00072			Nuclear Data Uncertainty = 0.00072		
Benchmark	**C_k**	**Weight**	**Benchmark**	**C_k**	**Weight**
pu-met-fast-022-001.i	0.9961	1.0000	pu-met-fast-022-001.i	0.9961	1.0000
pu-met-fast-001-001.i	0.9957	0.9860	pu-met-fast-001-001.i	0.9957	0.9854
mix-met-fast-009-001.i	0.9955	0.9799	mix-met-fast-009-001.i	0.9955	0.9790
pu-met-fast-023-001.i	0.9949	0.9630	pu-met-fast-023-001.i	0.9949	0.9613
pu-met-fast-025-001.i	0.9948	0.9612	pu-met-fast-025-001.i	0.9948	0.9595
			pu-met-fast-039-001.i	**0.9937**	**0.9236**
pu-met-fast-035-001.i	0.9937	0.9253	pu-met-fast-035-001.i	0.9937	0.9220
pu-met-fast-036-001.i	0.9923	0.8837	pu-met-fast-036-001.i	0.9923	0.8784





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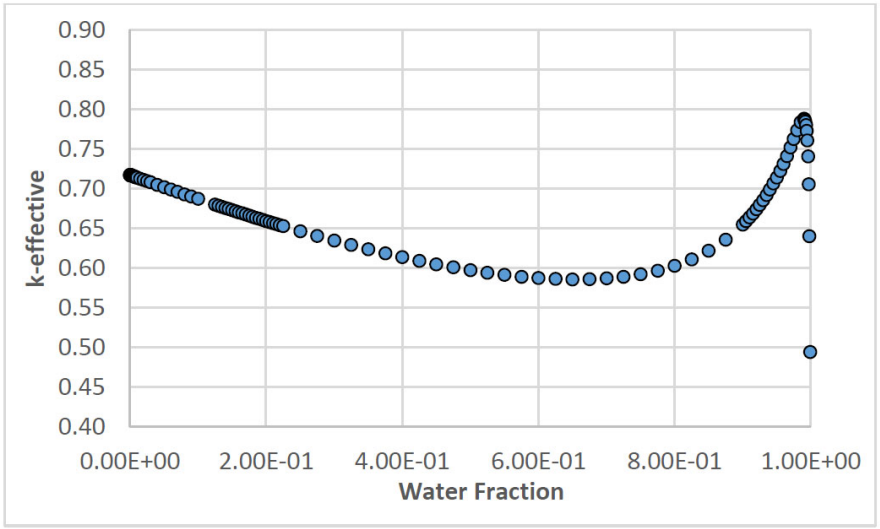
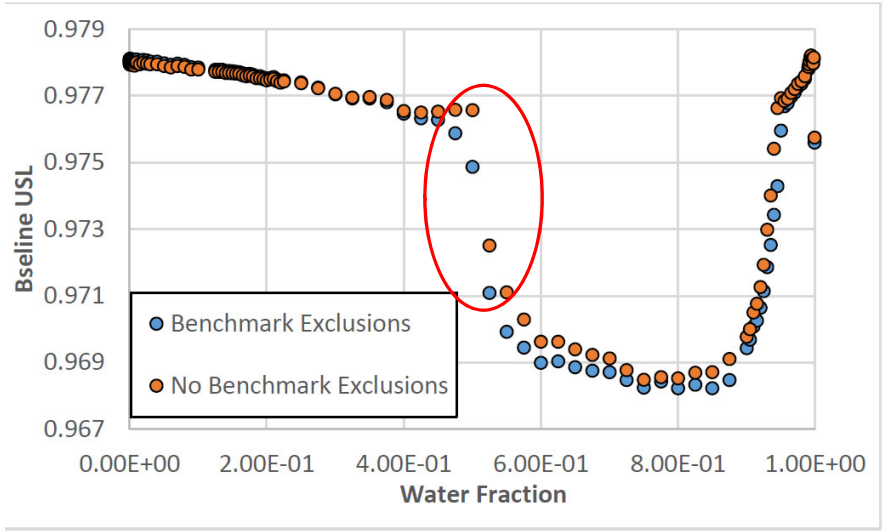
Results of Benchmark Rejection Study

- Pu oxide results
  - Baseline USL can be higher when benchmark outliers are NOT excluded
  - Magnitude of difference in USL including vs. excluding outliers:
  - 0.00234





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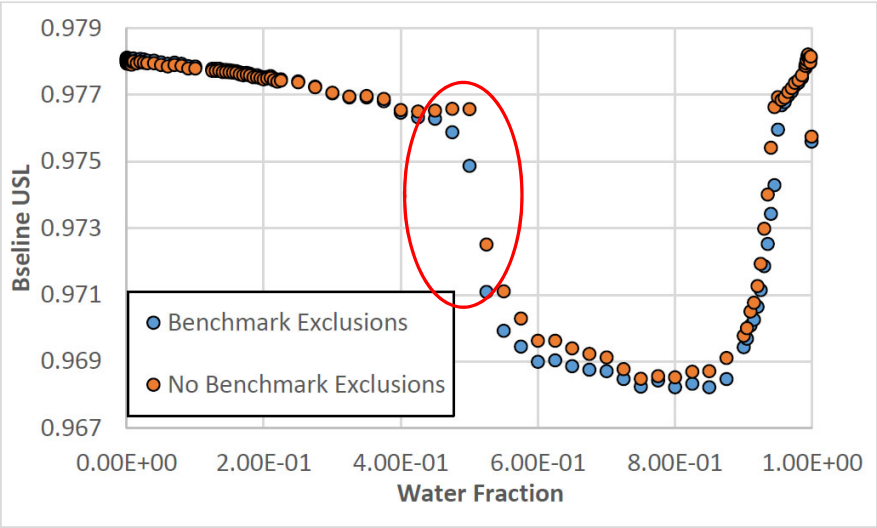
Results-Benchmark Rejection

- Pu oxide results

– Baseline USL can be higher when benchmark outliers are NOT excluded

– Magnitude of difference in USL including vs. excluding outliers: 0.00234



Benchmark Exclusions			No Benchmark Exclusions		
Baseline USL = 0.97429			Baseline USL = 0.97663		
Bias = 0.00692			Bias = 0.00612		
Bias Uncertainty = 0.01042			Bias Uncertainty = 0.00888		
Nuclear Data Uncertainty = 0.0013			Nuclear Data Uncertainty = 0.0013		
Benchmark	**C_k**	**Weight**	**Benchmark**	**C_k**	**Weight**
pu-sol-therm-007-003.i	0.9697	1.0000	pu-sol-therm-007-003.i	0.9697	1.0000
pu-sol-therm-001-006.i	0.9685	0.9759	pu-sol-therm-001-006.i	0.9685	0.9724
pu-sol-therm-007-002.i	0.9683	0.9708	pu-sol-therm-007-002.i	0.9683	0.9666
pu-sol-therm-001-005.i	0.9641	0.8866	pu-sol-therm-001-005.i	0.9641	0.8703
pu-sol-therm-001-004.i	0.9635	0.8742	pu-sol-therm-001-004.i	0.9635	0.8560
pu-sol-therm-001-003.i	0.9620	0.8425	pu-sol-therm-001-003.i	0.9620	0.8198
pu-sol-therm-007-008.i	0.9612	0.8269	pu-sol-therm-007-008.i	0.9612	0.8020
pu-sol-therm-007-009.i	0.9612	0.8264	pu-sol-therm-007-009.i	0.9612	0.8014
pu-sol-therm-007-007.i	0.9608	0.8180	pu-sol-therm-007-007.i	0.9608	0.7917
pu-sol-therm-007-006.i	0.9608	0.8176	pu-sol-therm-007-006.i	0.9608	0.7913
pu-sol-therm-007-010.i	0.9601	0.8042	pu-sol-therm-007-010.i	0.9601	0.7760
pu-sol-therm-007-005.i	0.9599	0.7993	pu-sol-therm-007-005.i	0.9599	0.7704
pu-sol-therm-001-002.i	0.9596	0.7930	pu-sol-therm-001-002.i	0.9596	0.7631
			pu-sol-therm-010-001.i	**0.9587**	**0.7435**
pu-sol-therm-002-007.i	0.9564	0.7289	pu-sol-therm-002-007.i	0.9564	0.6898
pu-sol-therm-002-006.i	0.9553	0.7066	pu-sol-therm-002-006.i	0.9553	0.6643
pu-sol-therm-001-001.i	0.9545	0.6890	pu-sol-therm-001-001.i	0.9545	0.6441
pu-sol-therm-010-002.i	0.9526	0.6510	pu-sol-therm-010-002.i	0.9526	0.6007
pu-sol-therm-002-005.i	0.9514	0.6268	pu-sol-therm-002-005.i	0.9514	0.573
pu-sol-therm-002-004.i	0.9501	0.5989	pu-sol-therm-002-004.i	0.9501	0.5411
pu-sol-therm-010-009.i	0.9500	0.5982	pu-sol-therm-010-009.i	0.95	0.5403
pu-sol-therm-002-003.i	0.9492	0.5811	pu-sol-therm-002-003.i	0.9492	0.5207
			pu-comp-mixed-002-015.i	**0.9476**	**0.4828**
			pu-comp-mixed-002-014.i	**0.9473**	**0.4753**
			pu-comp-mixed-002-013.i	**0.9472**	**0.4733**
pu-sol-therm-002-002.i	0.9457	0.5094	pu-sol-therm-002-002.i	0.9457	0.4387
pu-sol-therm-011-165.i	0.9456	0.5075	pu-sol-therm-011-165.i	0.9456	0.4366
pu-sol-therm-010-004.i	0.9447	0.4897	pu-sol-therm-010-004.i	0.9447	0.4162
pu-sol-therm-034-001.i	0.9443	0.4809	pu-sol-therm-034-001.i	0.9443	0.4060

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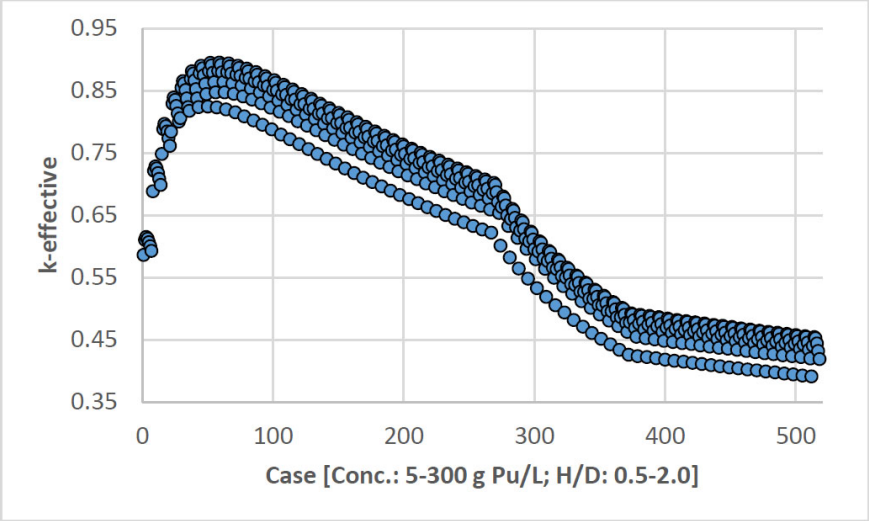
Results-Benchmark Rejection

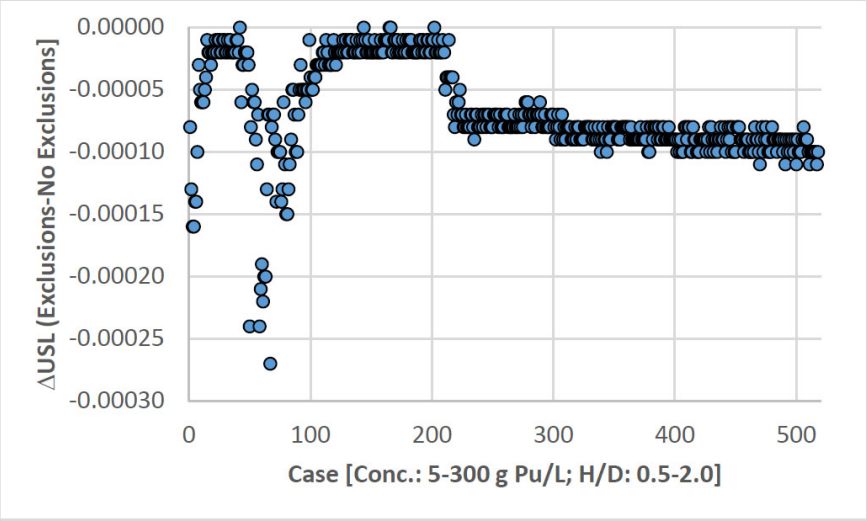
- Pu solution results

– Baseline USL can be higher when benchmark outliers are NOT excluded

– Magnitude of difference in USL including vs. excluding outliers: 0.00026

Benchmark Exclusions			No Benchmark Exclusions		
Baseline USL = 0.97925			Baseline USL = 0.97951		
Bias = 0.00599			Bias = 0.00586		
Bias Uncertainty = 0.0081			Bias Uncertainty = 0.00797		
Nuclear Data Uncertainty = 0.00064			Nuclear Data Uncertainty = 0.00064		
Benchmark	**C_k**	**Weight**	**Benchmark**	**C_k**	**Weight**
pu-sol-therm-011-161.i	0.9986	1.0000	pu-sol-therm-011-161.i	0.9986	1.0000
pu-sol-therm-011-162.i	0.9985	0.9830	pu-sol-therm-011-162.i	0.9985	0.9827
pu-sol-therm-003-008.i	0.9982	0.9117	pu-sol-therm-003-008.i	0.9982	0.9101
pu-sol-therm-011-164.i	0.9981	0.8971	pu-sol-therm-011-164.i	0.9981	0.8952
pu-sol-therm-011-163.i	0.9981	0.8908	pu-sol-therm-011-163.i	0.9981	0.8888
pu-sol-therm-003-007.i	0.9980	0.8740	pu-sol-therm-003-007.i	0.998	0.8717
pu-sol-therm-003-002.i	0.9975	0.7695	pu-sol-therm-003-002.i	0.9975	0.7653
pu-sol-therm-003-001.i	0.9975	0.7625	pu-sol-therm-003-001.i	0.9975	0.7581





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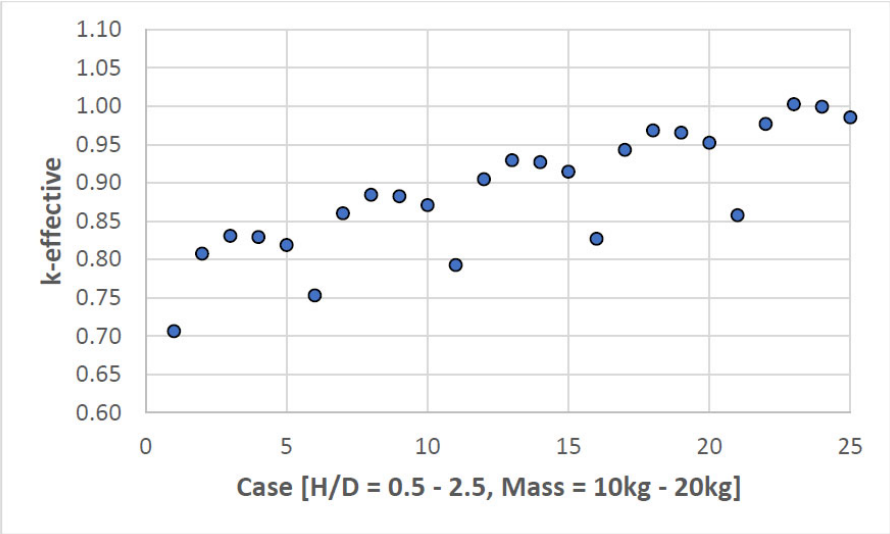
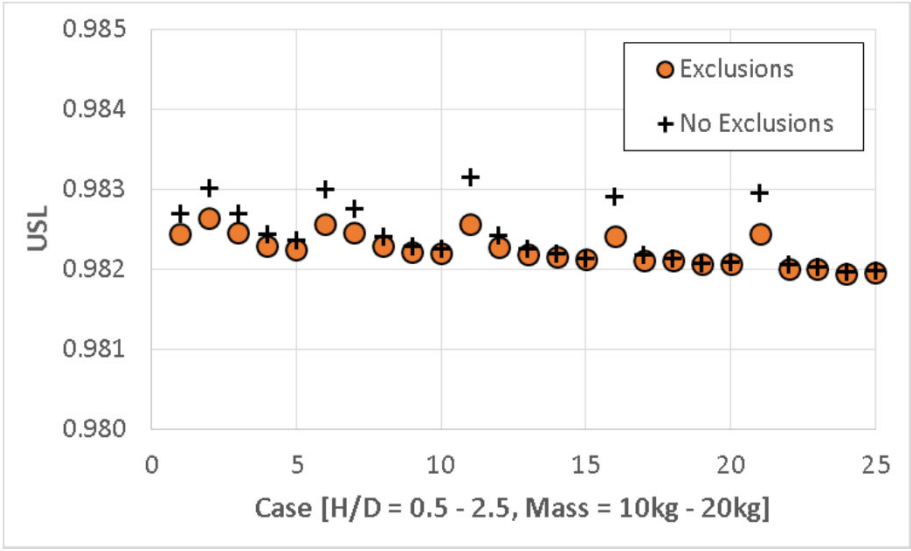
Results-Benchmark Rejection

- HEU metal results
  - Baseline USL can be higher when benchmark outliers are NOT excluded
  - Magnitude of difference in USL including vs. excluding outliers: 0.00050

Benchmark Exclusions			No Benchmark Exclusions		
Baseline USL = 0.98257			Baseline USL = 0.98315		
Bias = 0.00559			Bias = 0.00535		
Bias Uncertainty = 0.00401			Bias Uncertainty = 0.00367		
Nuclear Data Uncertainty = 0.00109			Nuclear Data Uncertainty = 0.00109		
Benchmark	C_k	Weight	Benchmark	C_k	Weight
heu-met-fast-084-019.i	0.9848	1.0000	heu-met-fast-084-019.i	0.9848	1.0000
			heu-met-fast-051-015.i	**0.9845**	**0.9655**
			heu-met-fast-051-001.i	**0.9845**	**0.9564**
heu-met-fast-051-002.i	0.9844	0.9644	heu-met-fast-051-002.i	0.9844	0.9542
			heu-met-fast-051-003.i	**0.9843**	**0.9405**
			heu-met-fast-051-016.i	**0.9842**	**0.9186**
heu-met-fast-051-004.i	0.9838	0.8965	heu-met-fast-051-004.i	0.9838	0.8669
			heu-met-fast-051-014.i	**0.9838**	**0.8658**
			heu-met-fast-051-017.i	**0.9833**	**0.8005**
heu-met-fast-100-002.i	0.9832	0.8391	heu-met-fast-100-002.i	0.9832	0.7932





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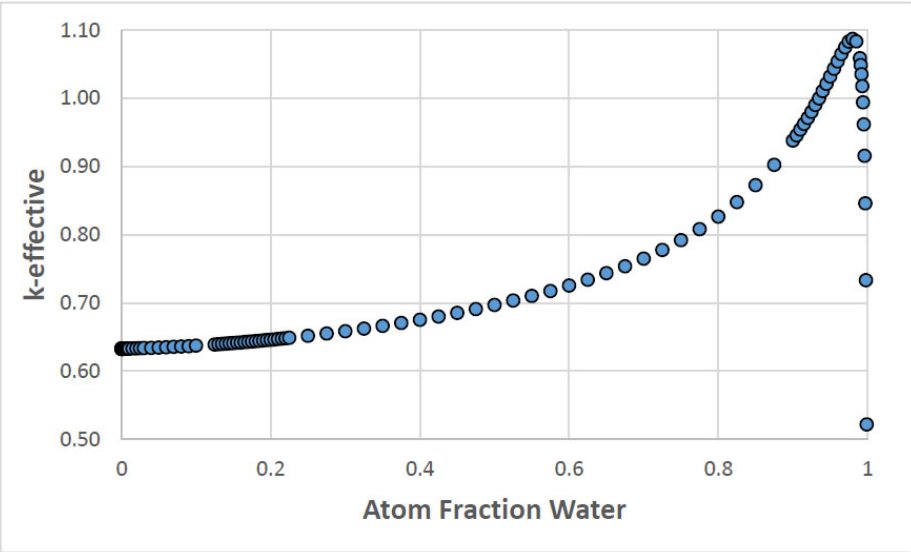
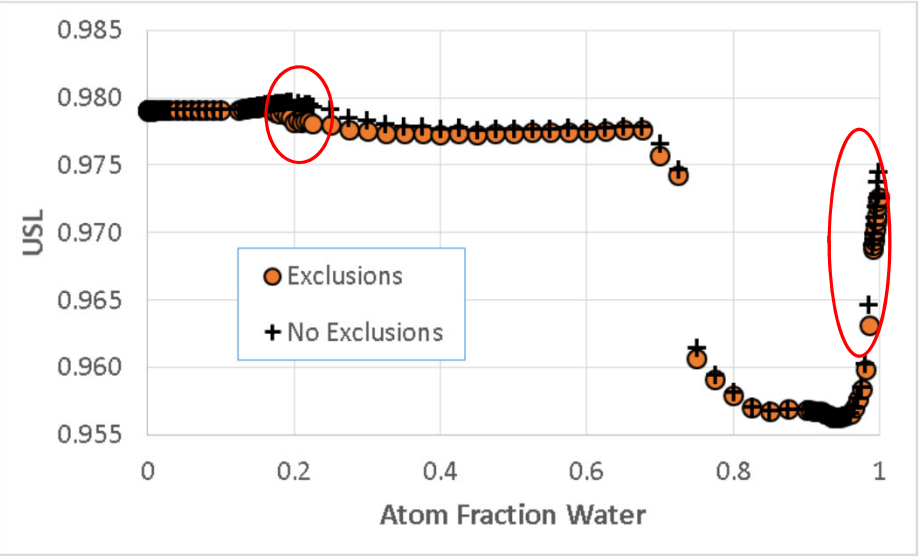
Results of Benchmark Rejection Study

- HEU oxide results
  - Baseline USL can be higher benchmark outliers are NOT excluded
  - Magnitude of difference in USL including vs. excluding outliers:
  - 0.00208





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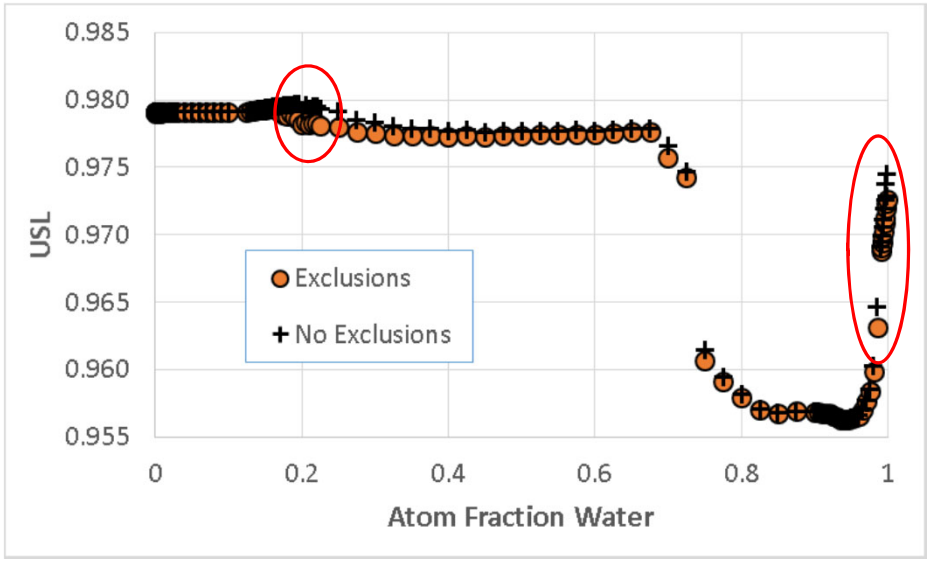
– Baseline USL can be higher benchmark outliers are NOT excluded

– Magnitude of difference in USL including vs. excluding outliers: 0.00208



Benchmark Exclusions			No Benchmark Exclusions		
Baseline USL = 0.97813			Baseline USL = 0.97928		
Bias = 0.00609			Bias = 0.00538		
Bias Uncertainty = 0.00707			Bias Uncertainty = 0.00663		
Nuclear Data Uncertainty = 0.00143			Nuclear Data Uncertainty = 0.00143		
Benchmark	C_k	Weight	Benchmark	C_k	Weight
heu-met-fast-007-030.i	0.9783	1.0000	heu-met-fast-007-030.i	0.9783	1.0000
heu-met-fast-007-031.i	0.9729	0.8578	heu-met-fast-007-031.i	0.9729	0.8309
heu-met-fast-007-025.i	0.9720	0.8329	heu-met-fast-007-025.i	0.9720	0.8011
heu-met-fast-007-010.i	0.9720	0.8328	heu-met-fast-007-010.i	0.9720	0.8010
heu-met-fast-007-026.i	0.9719	0.8321	heu-met-fast-007-026.i	0.9719	0.8002
heu-met-fast-007-011.i	0.9717	0.8246	heu-met-fast-007-011.i	0.9717	0.7913
heu-met-fast-034-002.i	0.9713	0.8158	heu-met-fast-034-002.i	0.9713	0.7809
heu-met-fast-033-001.i	0.9713	0.8144	heu-met-fast-033-001.i	0.9713	0.7791
heu-met-fast-007-012.i	0.9709	0.8048	heu-met-fast-007-012.i	0.9709	0.7678
heu-met-fast-007-015.i	0.9708	0.8027	heu-met-fast-007-015.i	0.9708	0.7652
heu-met-fast-007-016.i	0.9708	0.8011	heu-met-fast-007-016.i	0.9708	0.7634
heu-met-fast-007-014.i	0.9706	0.7971	heu-met-fast-007-014.i	0.9706	0.7586
heu-met-fast-007-013.i	0.9704	0.7903	heu-met-fast-007-013.i	0.9704	0.7505
			heu-met-fast-007-037.i	**0.9687**	**0.6997**
heu-met-fast-007-038.i	0.9686	0.7443	heu-met-fast-007-038.i	0.9686	0.6957
			heu-met-fast-007-040.i	**0.9685**	**0.6914**
			heu-met-fast-007-036.i	**0.9682**	**0.6815**
			heu-met-fast-007-039.i	**0.9681**	**0.6809**
heu-met-fast-033-002.i	0.9680	0.7275	heu-met-fast-033-002.i	0.9680	0.6758
heu-met-fast-007-024.i	0.9679	0.7263	heu-met-fast-007-024.i	0.9679	0.6743
heu-met-fast-034-001.i	0.9677	0.7194	heu-met-fast-034-001.i	0.9677	0.6662
heu-met-fast-007-023.i	0.9675	0.7144	heu-met-fast-007-023.i	0.9675	0.6602
heu-met-fast-031-001.i	0.9659	0.6725	heu-met-fast-031-001.i	0.9659	0.6104
heu-met-fast-007-029.i	0.9657	0.6677	heu-met-fast-007-029.i	0.9657	0.6046
heu-met-fast-034-003.i	0.9647	0.6422	heu-met-fast-034-003.i	0.9647	0.5743
heu-met-fast-078-007.i	0.9625	0.5838	heu-met-fast-078-007.i	0.9625	0.5048
heu-met-fast-004-001.i	0.9620	0.5705	heu-met-fast-004-001.i	0.9620	0.4890
heu-met-mixed-002-001.i	0.9614	0.5531	heu-met-mixed-002-001.i	0.9614	0.4683
heu-met-mixed-003-001.i	0.9609	0.5399	heu-met-mixed-003-001.i	0.9609	0.4525
heu-met-fast-007-022.i	0.9609	0.5398	heu-met-fast-007-022.i	0.9609	0.4525
			heu-met-fast-090-002.i	**0.9607**	**0.4460**

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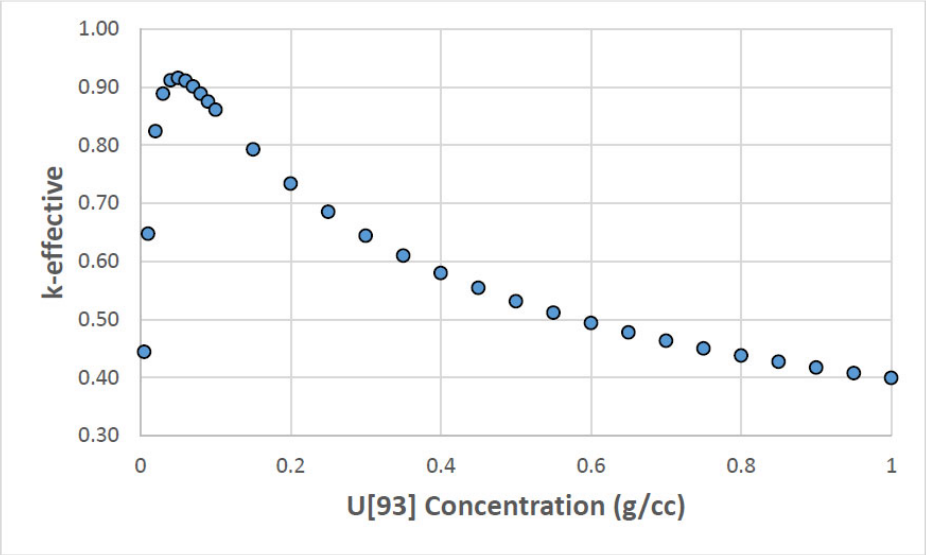
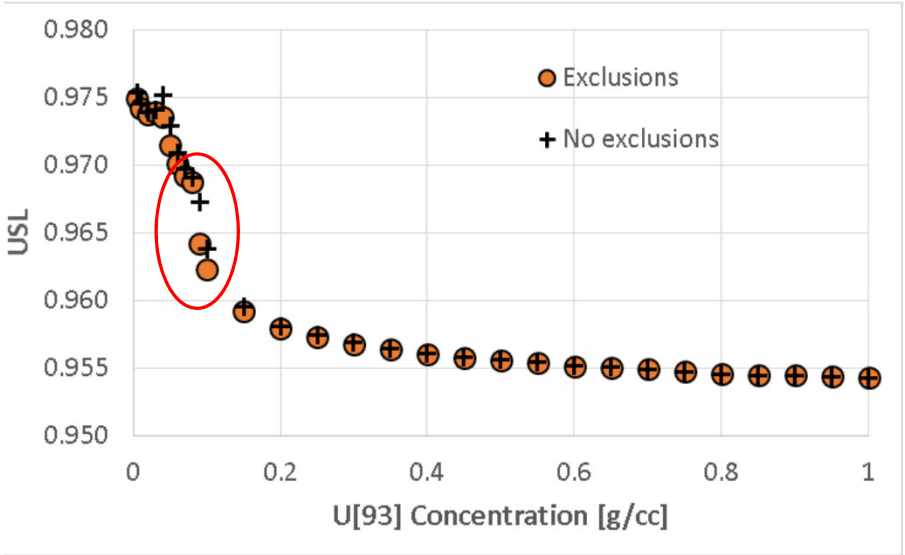
Results of Benchmark Rejection Study

- HEU solution results
  - Baseline USL can be higher when benchmark outliers are NOT excluded
  - Magnitude of difference in USL including vs. excluding outliers:
  - 0.00307





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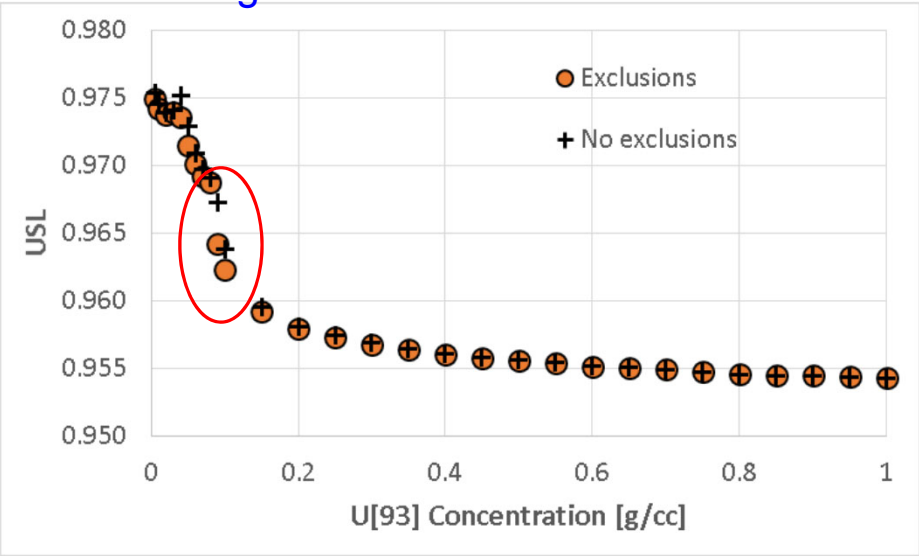
Results of Benchmark Rejection Study

- HEU solution results
  - Baseline USL can be higher when benchmark outliers are NOT excluded
  - Magnitude of difference in USL including vs. excluding outliers: 0.00307



Benchmark Exclusions			No Benchmark Exclusions		
Baseline USL = 0.96419			Baseline USL = 0.96726		
Bias = 0.01035			Bias = 0.01056		
Bias Uncertainty = 0.0183			Bias Uncertainty = 0.01555		
Nuclear Data Uncertainty = 0.00063			Nuclear Data Uncertainty = 0.00063		
Benchmark	C_k	Weight	Benchmark	C_k	Weight
heu-sol-therm-043-001	0.9991	1.0000	heu-sol-therm-043-001	0.9991	1.0000
heu-sol-therm-001-007	0.9988	0.9903	heu-sol-therm-001-007	0.9988	0.9895
heu-sol-therm-001-003	0.9987	0.9884	heu-sol-therm-001-003	0.9987	0.9874
heu-sol-therm-001-008	0.9987	0.9864	heu-sol-therm-001-008	0.9987	0.9852
heu-sol-therm-001-001	0.9986	0.9862	heu-sol-therm-001-001	0.9986	0.9851
heu-sol-therm-010-001	0.9974	0.9461	heu-sol-therm-010-001	0.9974	0.9415
			heu-sol-therm-001-010	**0.9962**	**0.9013**
heu-sol-therm-001-006	0.9961	0.9066	heu-sol-therm-001-006	0.9961	0.8987
heu-sol-therm-001-005	0.9948	0.8648	heu-sol-therm-001-005	0.9948	0.8533
heu-sol-therm-009-003	0.9937	0.8315	heu-sol-therm-009-003	0.9937	0.8172
heu-comp-therm-002-023	0.9925	0.7916	heu-comp-therm-002-023	0.9925	0.7739
heu-comp-therm-002-019	0.9907	0.7364	heu-comp-therm-002-019	0.9907	0.7139
heu-sol-therm-025-005	0.9906	0.7307	heu-sol-therm-025-005	0.9906	0.7078
heu-sol-therm-050-005	0.9899	0.7092	heu-sol-therm-050-005	0.9899	0.6845
heu-sol-therm-011-002	0.9898	0.7065	heu-sol-therm-011-002	0.9898	0.6815
heu-sol-therm-011-001	0.9896	0.7018	heu-sol-therm-011-001	0.9896	0.6764
heu-sol-therm-050-011	0.9895	0.6969	heu-sol-therm-050-011	0.9895	0.6711
heu-comp-therm-002-018	0.9886	0.6700	heu-comp-therm-002-018	0.9886	0.6419
heu-sol-therm-001-002	0.9885	0.6649	heu-sol-therm-001-002	0.9885	0.6364
heu-sol-therm-001-004	0.9878	0.6450	heu-sol-therm-001-004	0.9878	0.6148
			heu-sol-therm-001-009	**0.9878**	**0.6119**
heu-comp-therm-002-024	0.9874	0.6316	heu-comp-therm-002-024	0.9874	0.6002
heu-sol-therm-025-004	0.9857	0.5773	heu-sol-therm-025-004	0.9857	0.5412

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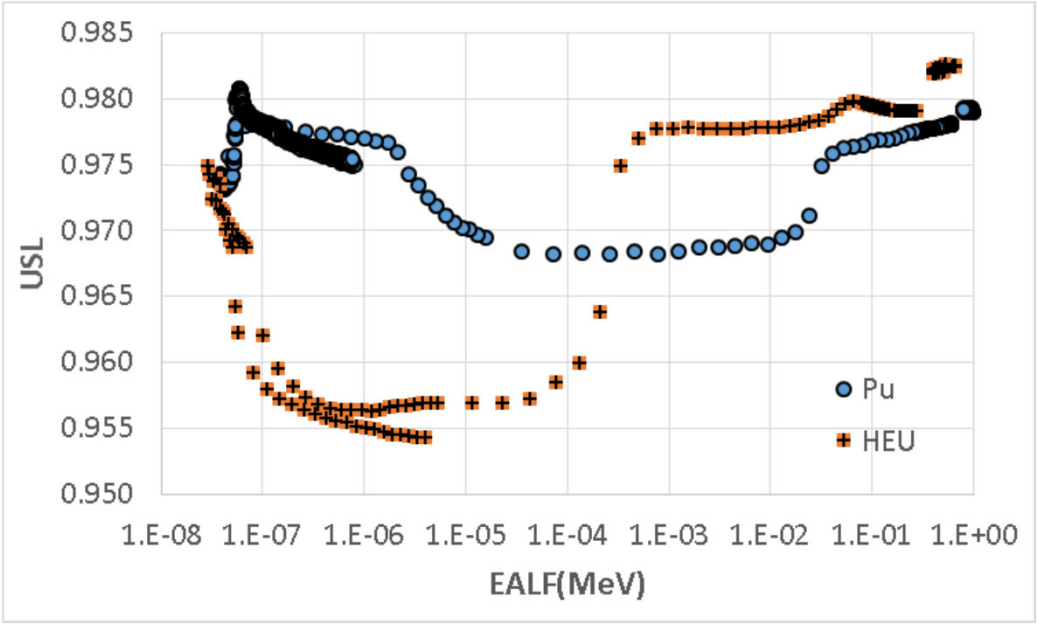
Results and Conclusions

USL Differences are small for Pu & HEU
in this study, regardless of outlier exclusion:

Pu metal	0.00021
Pu oxide	0.00234
Pu solution	0.00026
HEU metal	0.00050
HEU oxide	0.00208
HEU solution	0.00307



- Each USL is case-specific & based upon a set of neutronically similar benchmarks
- USL differences may be higher for other series
- May calculate USLs with and without identified outliers to determine most conservative USL

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Thank you for your attention!

Questions

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