Application of Sampler to the UAM Benchmark

ORNL

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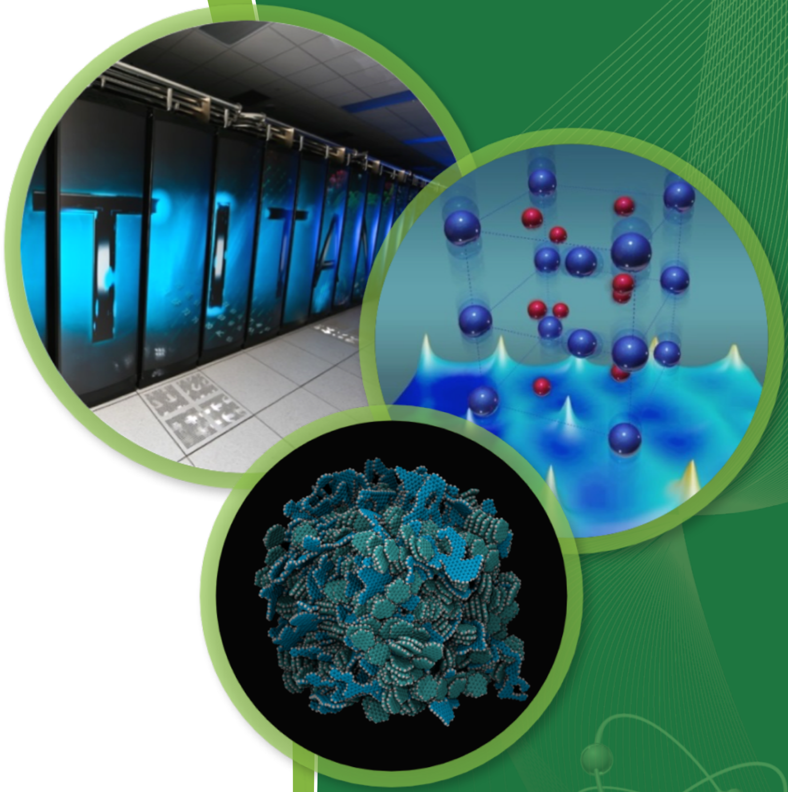

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LWR Uncertainty Analysis in Modeling (UAM) OECD/NEA Benchmark

- **Purpose:** apply UQ methods to reactor physics problems
  - Pin, Assembly, Core
  - With/without depletion
  - PWR, BWR, VVER
- https://www.oecd-nea.org/science/wprs/egrsltb/UAM/
- First meeting in 2005

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Phases

- **Phase I (Neutronics Phase)**
  - Exercise I-1: Derivation of the multi-group microscopic cross-section libraries (nuclear data and covariance data, selection of multi-group structure, etc.).
  - Exercise I-2: Derivation of the few-group macroscopic cross-section libraries (energy collapsing, spatial homogenisation of cross-sections and covariance data, etc.).
  - Exercise I-3: Criticality (steady state) stand-alone neutronics calculations with confidence bounds (keff calculations, diffusion approximation, etc.).
- **Phase II (Core Phase)**
  - Exercise II-1: Fuel thermal properties relevant for transient performance.
  - Exercise II-2: Neutron kinetics stand-alone performance (kinetics data, space-time dependence treatment, etc.).
  - Exercise II-3: Thermal-hydraulic fuel bundle performance.
- **Phase III (System Phase)**
  - Exercise III-1: Coupled neutronics/thermal-hydraulics core performance (coupled steady state, coupled depletion, and coupled core transient with boundary conditions)
  - Exercise III-2: Thermal-hydraulics system performance
  - Exercise III-3: Coupled neutronics kinetics thermal-hydraulic core/thermal-hydraulic system performance

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NOTE: For the core and systems applications three main LWRs types are selected, based on previous benchmark experiences and available data: BWR (Peach Bottom-2),PWR TMI and VVER-1000 (Kozloduy-6, Kalinin-3).

ORNL Participation in Phases

- **Phase I (Neutronics Phase)**
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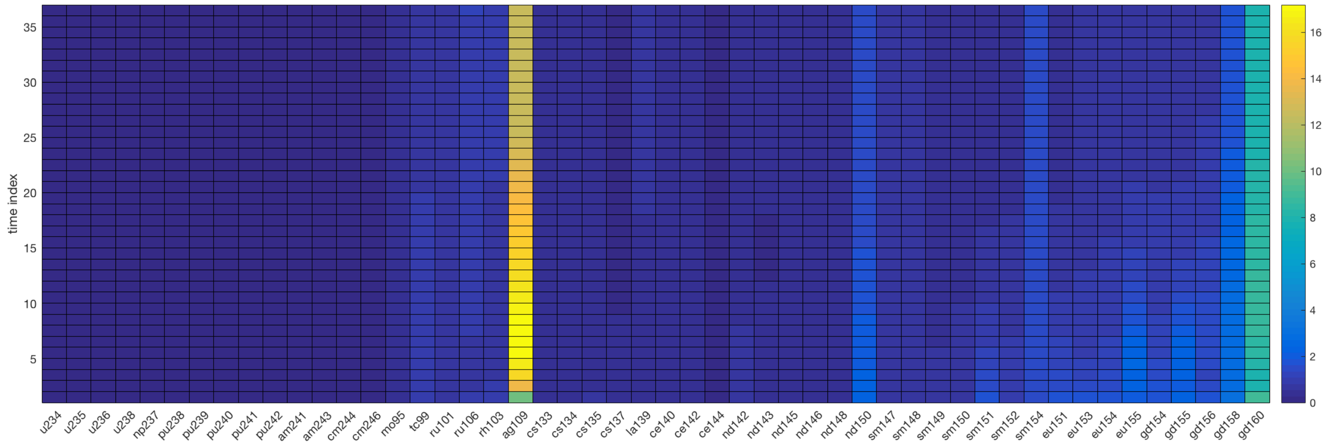
Selected Results

- Full-core UQ with Polaris+PARCS (collaboration with Univ. of Michigan)

0.89± 1.3681%	0.84± 1.3991%	0.681± 1.0523%					
0.902± 0.4264%	1.115± 0.7234%	0.801± 0.5889%	0.942± 1.2776%	0.757± 2.0515%			
0.982± 0.8295%	0.979± 0.4983%	1.165± 0.31%	1.112± 1.1698%	1.509± 2.7164%	1.258± 3.0202%		
0.843± 1.9418%	1.086± 1.0843%	1.512± 0.257%	1.398± 0.6856%	1.295± 1.6478%	1.509± 2.7166%	0.757± 2.0515%	
0.835± 2.9384%	0.848± 2.3588%	1.129± 1.1473%	1.126± 0.4431%	1.398± 0.6853%	1.112± 1.1697%	0.942± 1.2771%	
0.666± 4.1967%	0.763± 3.6741%	0.822± 2.6871%	1.129± 1.1473%	1.512± 0.2568%	1.165± 0.3098%	0.801± 0.5889%	0.681± 1.0528%
0.623± 5.1571%	0.611± 4.7987%	0.763± 3.6741%	0.848± 2.3588%	1.086± 1.0843%	0.979± 0.4982%	1.115± 0.7233%	0.84± 1.399%
0.501± 5.7349%	0.623± 5.1572%	0.666± 4.1967%	0.835± 2.9383%	0.843± 1.9418%	0.982± 0.8295%	0.902± 0.4264%	0.89± 1.3683%

- Exercise I-b simple depletion calculation to test new fission yield uncertainty.



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Full-core UQ with Polaris+PARCS

Overview

- Uncertainty
  - eigenvalue
  - radial power factor
  - nodal power factor
- Compared
  - 44-group ENDF/B-VII.0
  - 56-group ENDF/B-VII.1

- Heavily-borated HFP

  Q: Why is uncertainty lower at 2600 ppm?

  A: Because location of maximum changes.

Case	k_{eff}	Maximum Nodal Power	Maximum Radial Power
1900 ppm, E7.0 (44g)	1.0481 ± 0.45%	2.32 ± 2.05%	1.567 ± 2.7%
1900 ppm, E7.1 (56g)	1.0482 ± 0.51%	2.31 ± 2.23%	1.566 ± 3.0%
2600 ppm, E7.0 (44g)	1.0064 ± 0.45%	2.23 ± 0.65%	1.512 ± 0.26%
2600 ppm, E7.1 (56g)	1.0064 ± 0.52%	2.23 ± 0.84%	1.512 ± 0.25%

Exercise I-3 TMI-1 (E7.0)

0.942± 1.4094%	0.887± 1.4334%	0.72± 1.0779%					
0.921± 0.4401%	1.147± 0.7271%	0.821± 0.5802%	0.972± 1.2514%	0.785± 2.0377%			
0.971± 0.8965%	0.969± 0.5671%	1.16± 0.2333%	1.121± 1.1256%	1.567± 2.7095%	1.327± 3.0263%		
0.818± 2.052%	1.056± 1.1988%	1.493± 0.2224%	1.391± 0.6122%	1.311± 1.6282%	1.567± 2.7097%	0.785± 2.0379%	
0.792± 3.0944%	0.809± 2.4929%	1.093± 1.2603%	1.108± 0.5255%	1.391± 0.6122%	1.121± 1.1257%	0.972± 1.2515%	
0.619± 4.4014%	0.713± 3.8604%	0.779± 2.8291%	1.093± 1.2604%	1.493± 0.2223%	1.16± 0.2336%	0.821± 0.5802%	0.72± 1.078%
0.573± 5.408%	0.564± 5.0285%	0.713± 3.8604%	0.809± 2.4929%	1.056± 1.1989%	0.969± 0.5672%	1.147± 0.7271%	0.887± 1.4333%
0.463± 5.9846%	0.573± 5.408%	0.619± 4.4013%	0.792± 3.0945%	0.818± 2.052%	0.971± 0.8962%	0.921± 0.4401%	0.942± 1.4096%

1900 ppm

position of maximum changes!

0.89± 1.3681%	0.84± 1.3991%	0.681± 1.0523%					
0.902± 0.4264%	1.115± 0.7234%	0.801± 0.5889%	0.942± 1.2776%	0.757± 2.0515%			
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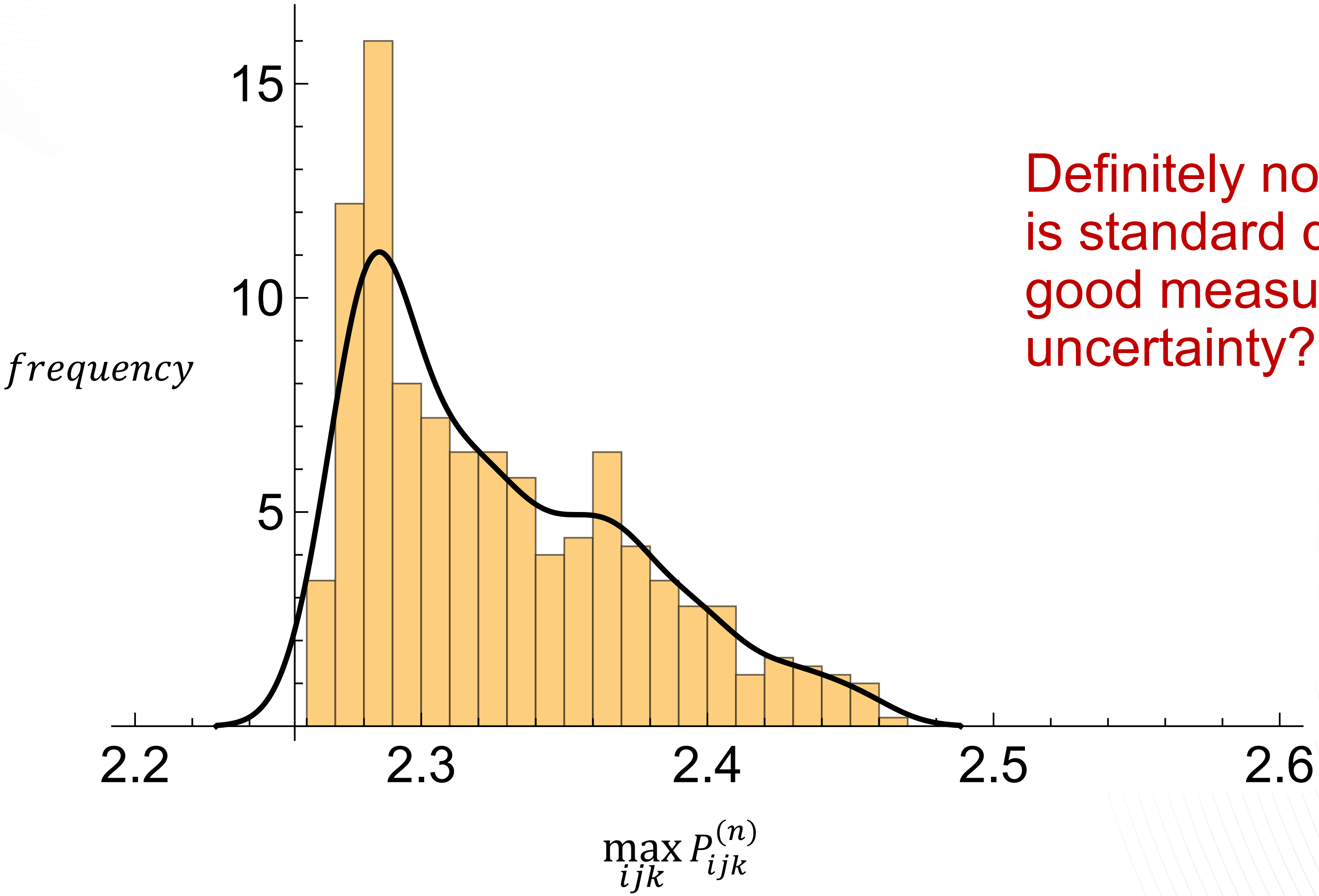
2600 ppm

Maximum Nodal Power Histogram (500 samples)



Definitely not normal…
is standard deviation still a good measure of uncertainty?

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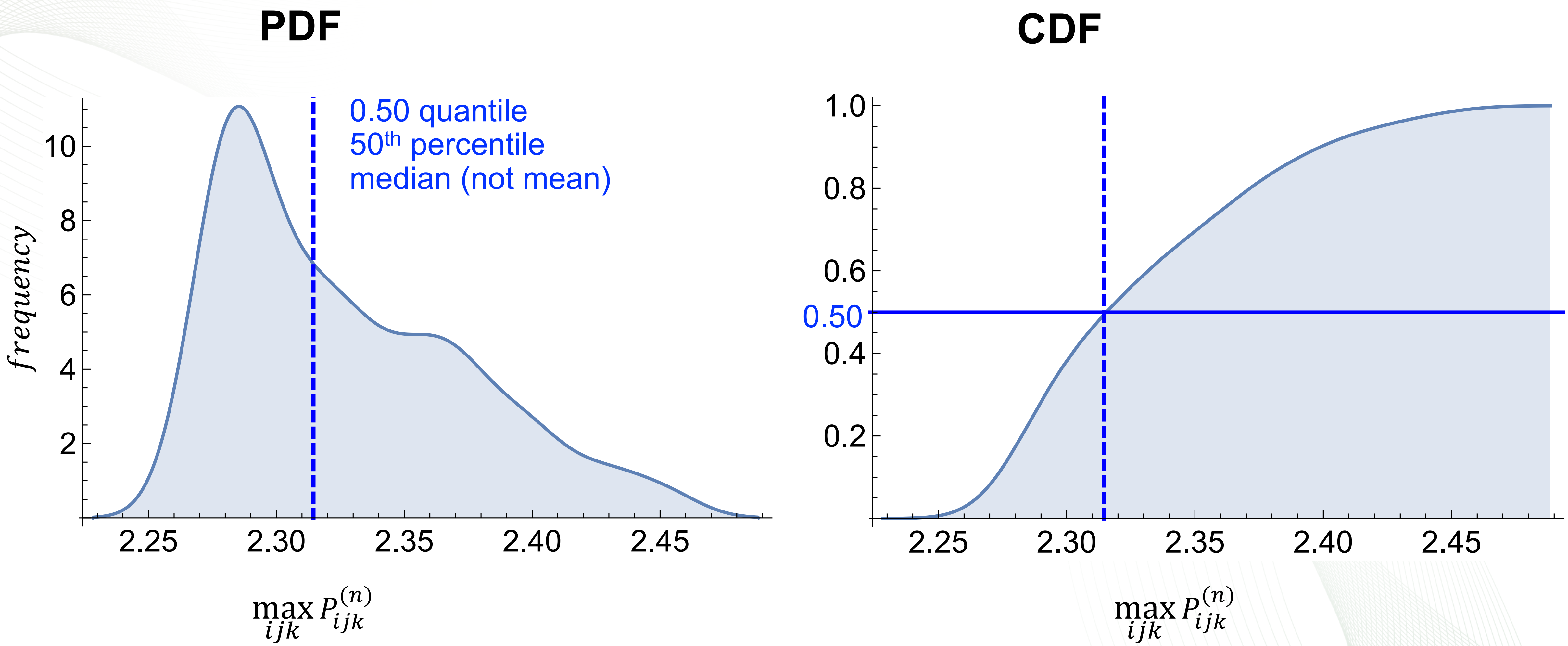
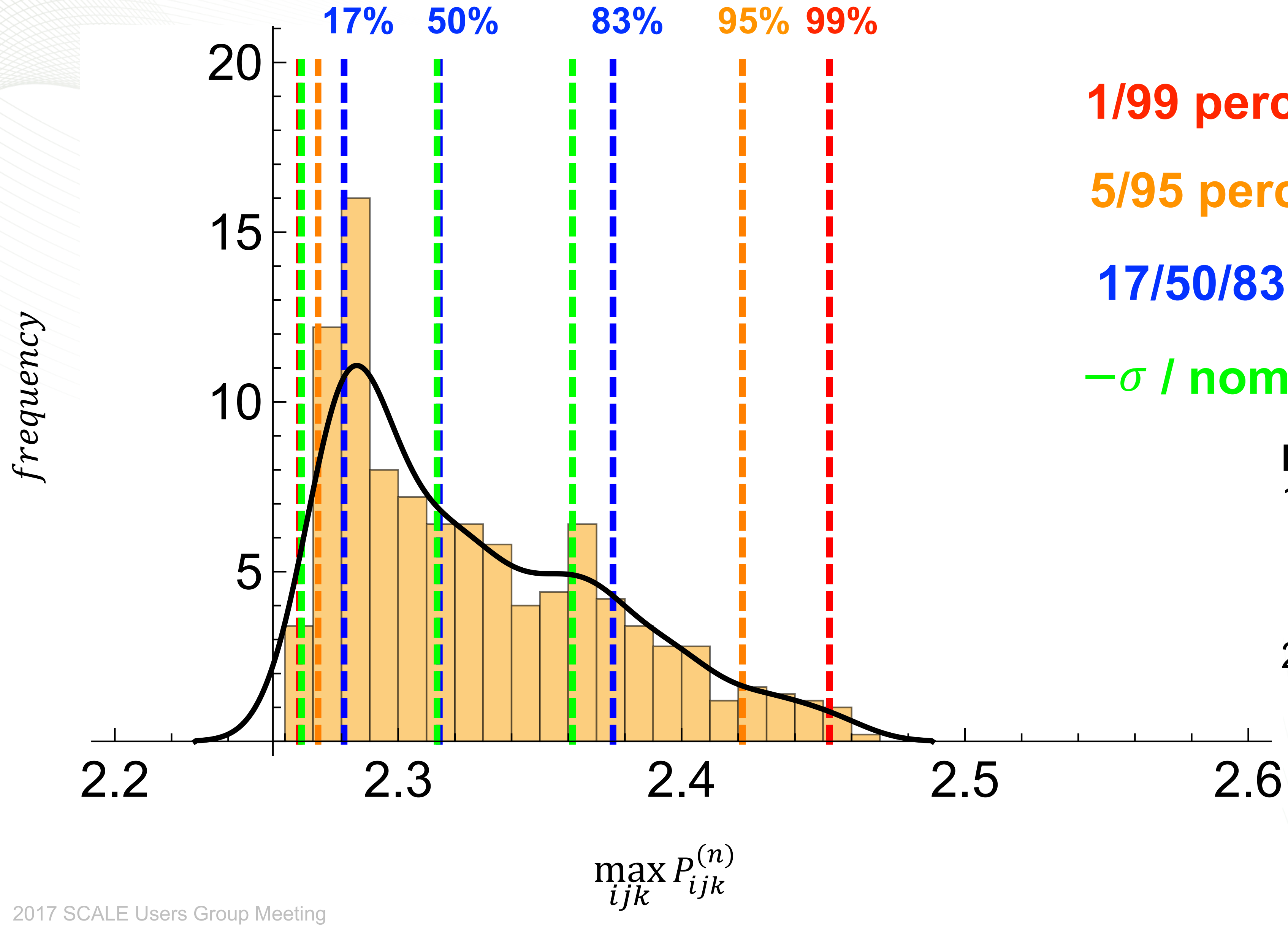
Robust summary statistics: quantiles



Quantiles of Maximum Nodal Power (500 samples)



1/99 percentiles - red

5/95 percentiles - orange

17/50/83 percentiles - blue

$-\sigma$ / nominal / $+\sigma$ - green

REMARKS

1) If nodal power calculation was "linear", then blue and green 50% line would be the same.
2) If nodal powers were normally distributed, 17 and -std. dev. and 83 and + std. dev. would be the same.

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Fission Yield Uncertainty

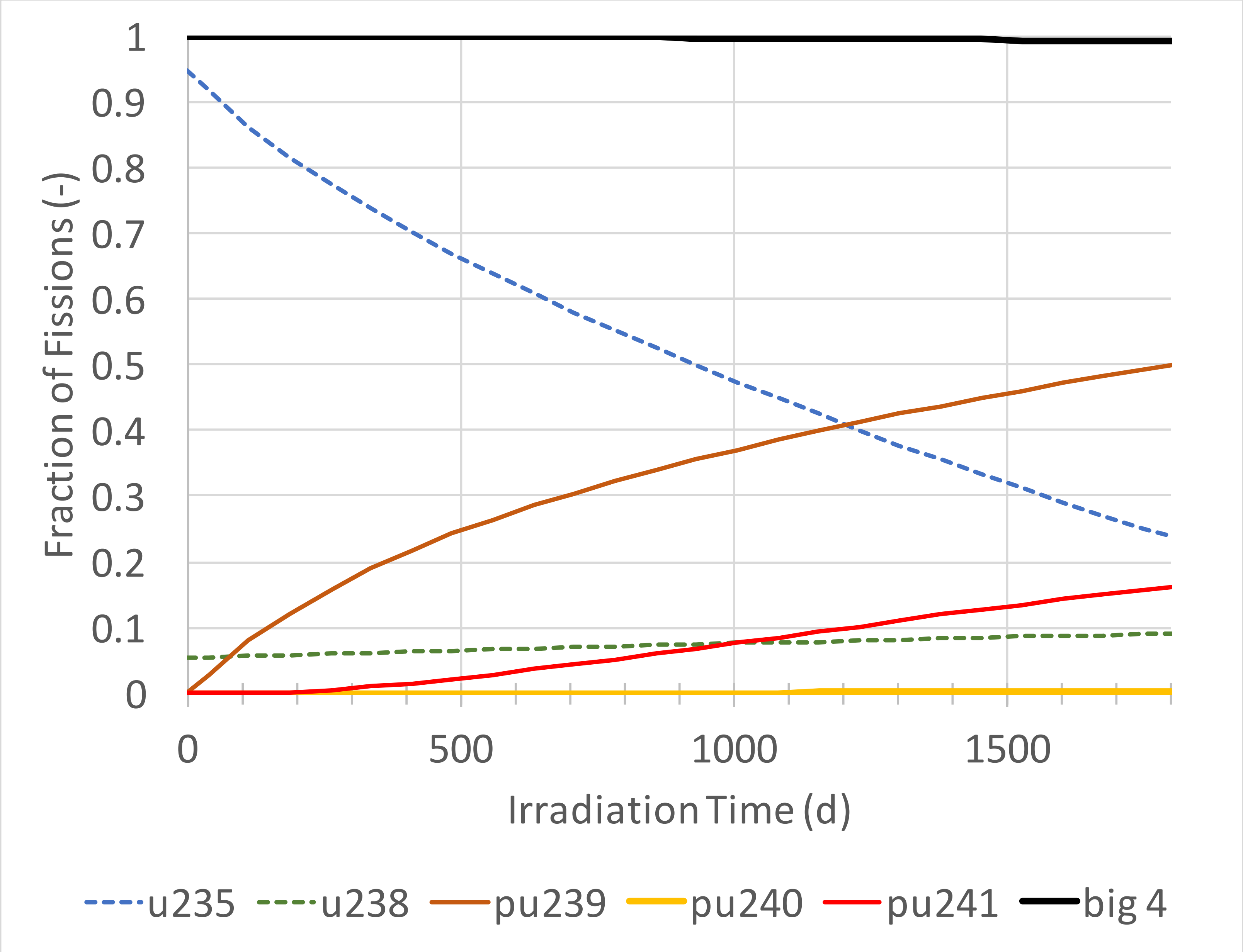
Fission Yield Uncertainty

- Developed extensive new fission yield uncertainty data
- All fissionable actinides at all energies will have *correlated* yield uncertainty in 6.3!

A black '-' indicates that nominal data for fission at that energy is not available in ENDF/B-VII. A red 'x' marks new uncertainty data that will be available in SCALE 6.3 and a black 'o' marks old data available in SCALE 6.2 and updated in SCALE 6.3.

nuclide	fast	intermediate	thermal
th227	-	-	x
th229	-	-	x
th232	x	-	-
pa231	-	x	-
u232	-	-	x
u233	-	x	x
u234	-	x	x
u235	o	o	o
u236	x	x	-
u238	o	o	-
np237	-	-	x
np238	-	x	-
pu238	-	x	-
pu239	o	o	o
pu240	x	x	x
pu241	-	x	x
pu242	x	x	x
am241	-	x	x
am242	-	-	x
am243	-	x	-
cm242	-	x	-
cm243	-	x	x
cm244	-	x	-
cm245	-	-	x
cm246	-	x	-
cm247	-	-	-
cm248	-	x	-
cf249	-	-	x
cf251	-	-	x
es254	-	-	x

Exercise I-B pincell depletion case



simple PWR pincell that is depleted from beginning-of-life (BOL) to end-of-life (EOL) at constant power for a total discharge burnup of 60 GWD/MTIHM

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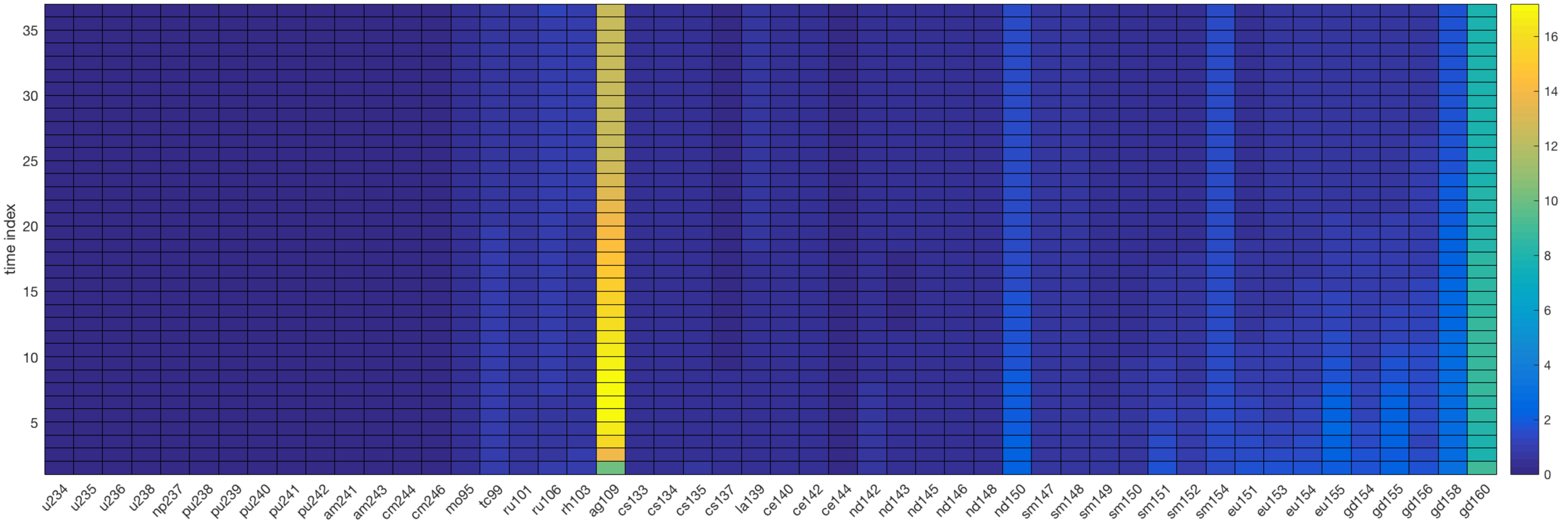
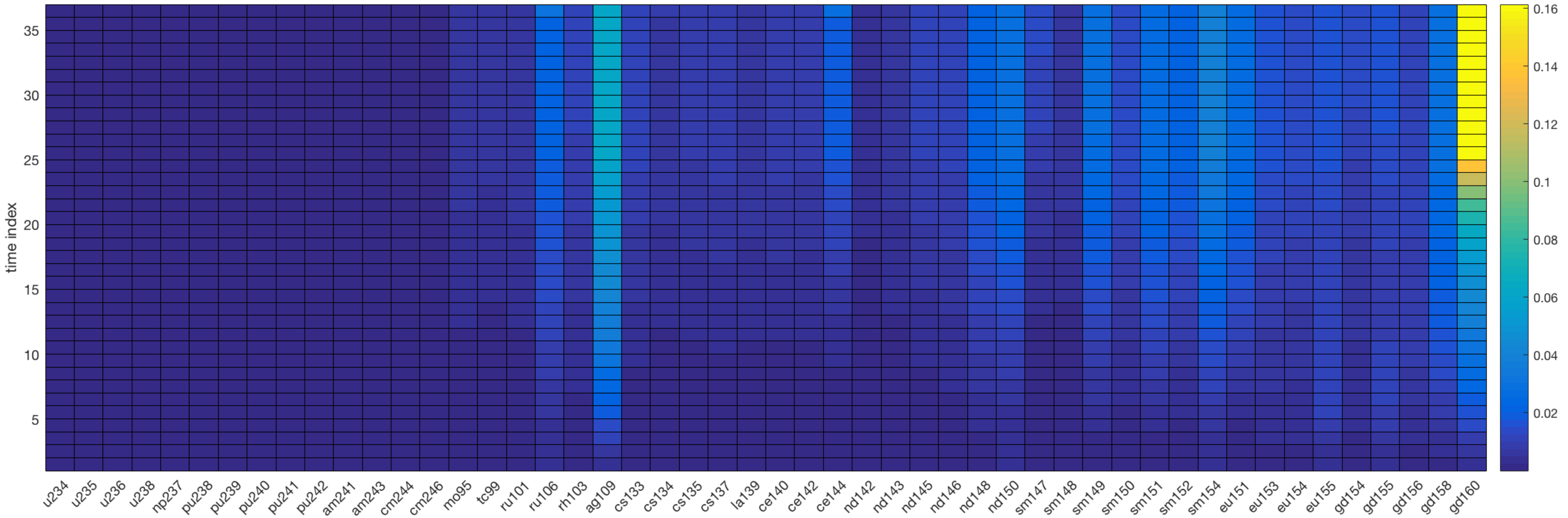
Uncertainty only due to fission yield (all isotopes)



- The uncertainty is very low for most isotopes, in the 1% to 3% range.
- The most notable exceptions are
  - ^{109}Ag with ~15% uncertainty and
  - ^{160}Gd with ~10% uncertainty.

Uncertainty only due to fission yield (only new isotopes)



- Scale decreased two orders of magnitude from 16% to 0.16%!
- Maximum of only 0.16% for ^{109}Ag
- **CONCLUSION: New data does not impact LWR UO2 depletion uncertainty.**

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Conclusions

- LWR UAM Benchmark has provided a testbed for SCALE/Sampler applied to reactor physics problems
  - Nodal power uncertainty study emphasizes need for quantiles (or something more complex than standard deviation) to represent complex uncertainty
  - Fission yield uncertainty test verifies that LWR uncertainty is not impacted by new uncertainties (for SCALE 6.3)
- Rise of the sampling-based UQ methods
  - Need to be able to handle all types of uncertainty: nuclear data, manufacturing uncertainty, etc.
  - Methodology applicable to coupled, time-dependent systems, essentially "black-box"
  - UQ (not SA) is primary focus

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Future Work applicable to UAM

- Kinetics Uncertainty UQ
  - Necessary for Phase III kinetics analysis
  - Collaboration with Tomasz Kozlowski (Prof. U. Illinois) and Majdi Radaideh (PhD candidate)
- Development of 33-group fast reactor data library
  - To participate in SFR UAM (just starting)
- Perturbed nuclear data as responses

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