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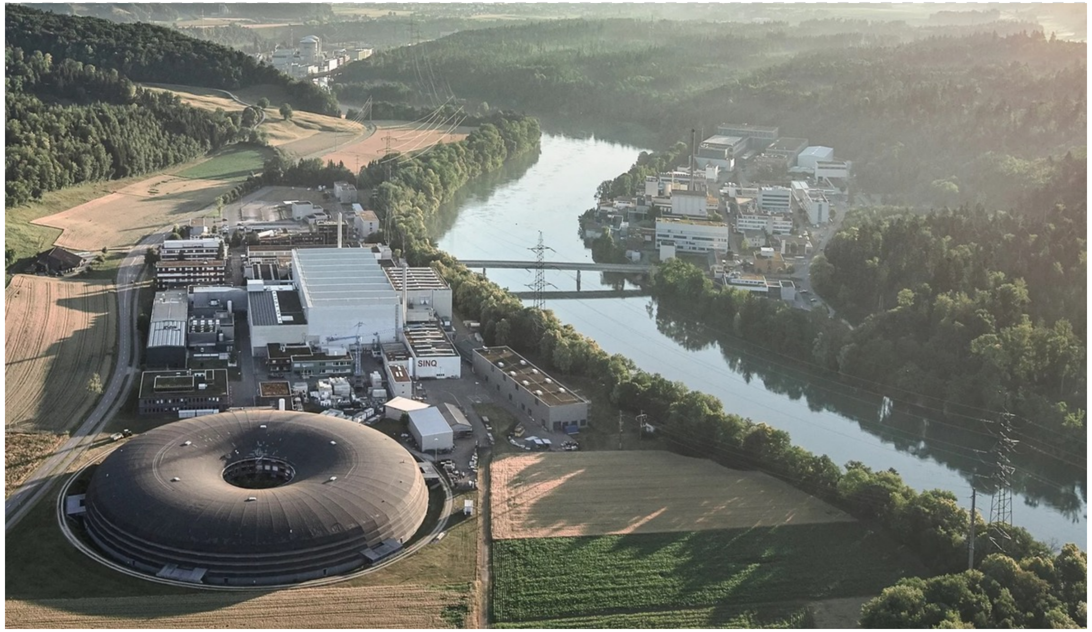


Overview of the results – SG16

D. Rochman

WPNCS SG16 Meeting, June 18th, 2025, OECD NEA, Paris

Summary

PSI

- Status of the results
- Some examples
- Publication

The 0E2 benchmarks for PWR UO_2 decay heat: an analysis from the NEA WPNCS

D. Rochman[a], F. Alvarez-Velarde[b], J. Bess[c], S. Bonthoux[d], O. Cabellos[e], C. Carmouze[f], S. Dabiran-Zohoory[g], R. Dagan[h], L. Fiorito[i], J. García[b], L. Giot[j], F. Gomez Salcedo[k], V. Hannstein[l], S. Häkkinen[n], M. Hursin[o], R. Ichou[d], P. Juutilainen[n], F. Kesting[m], M. Kromar[p], S. Lahaye[q], A. Launay[r], V. Léger[s], J.F. Martin[g], R. Mills[t], U. Mertyurek[u], P. Ortego[w], S. Portolan[a], M. Pöyhönen[n], G. Procop[u], P. Romojaro[i], B. Ruprecht[m], B. Torrente[a], S. Tittelbach[l], S. Sato[v], A. Shama[u], D. Schulze Grachtrup[m], T. Simeonov[x], V. Solans[y], V. Vallet[f], A. Vasiliev[a], and G. Žerovnik[m]

[a]Paul Scherrer Institute (PSI), Villigen, Switzerland
[b]Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain
[c]JFoster & Associates, LLC (JFA), Idaho Falls, USA
[d]Nuclear Safety and Radiation Protection Authority (ASNR), Fontenay-aux-Roses, France
[e]Universidad Politécnica de Madrid (UPM), Madrid, Spain
[f]Commissariat à l'énergie atomique et aux énergies alternatives (CEA), Cadarache, France
[g]OECD Nuclear Energy Agency (NEA), Paris, France
[h]Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany
[i]Belgian Nuclear Research Centre (SCK CEN), Mol, Belgium
[j]Subatech (CNRS/IN2P3, IMT Atlantique, Université de Nantes), Nantes, France
[k]ENRESA, Madrid, Spain
[l]Gesellschaft für Zwischenlagerung (BGZ), Essen, Germany
[m]Bundesamt für die Sicherheit der nuklearen Entsorgung (BASE), Salzgitter, Germany
[n]VTT Technical Research Centre of Finland (VTT), Espoo, Finland
[o]EPFL, Lausanne, Switzerland
[p]Jožef Stefan Institute (JSI), Ljubljana, Slovenia
[q]Commissariat à l'énergie atomique et aux énergies alternatives (CEA), Saclay, France
[r]ORANO, Beaumont Hague, France
[s]ORANO, Montigny-le-Bretonneux, France
[t]National Nuclear Laboratory (NNL), Seascale, United Kingdom
[u]Oak Ridge National Laboratory (ORNL), Oak Ridge, TN, USA
[v]Central Research Institute of Electric Power Industry (CRIEPI), Nagasaka, Japan
[w]SEA Ingeniería (SEA), Madrid, Spain
[x]Studsvik Scandpower, Inc., Newton, MA, USA
[y]Nagra, Wettingen, Switzerland

Overview of the results

- 18 participating organizations delivering results:
  - ASNR
  - BGZ
  - CIEMAT
  - EPFL
  - Nagra
  - ORNL
  - SEA Ingenieria
  - SCK CEN
  - VTT
  - BASE
  - CEA
  - CRIEPI
  - JSI
  - ORANO
  - PSI
  - Studsvik
  - UPM
  - WTI
- Two models considered
  - Pincell: 38 calculations
  - Assembly: 43 calculations

Overview of the results

- > 160 requested quantities
- Results presented as
  - Simple averages
  - Tolerance intervals
  - Analyzed with unique inputs (codes, libraries and users)

2.4. Calculated quantities

The main interest of the benchmark resides in the calculation of the decay heat values at the time of the measurements (see Table 1). These six decay heat calculated values are therefore required as output of the benchmark (both for the pincell and assembly models):

- at the six cooling time of measurements, the calculated decay heat values (in Watts),
- at the six cooling time of measurements, the contributions (in %) to the total decay heat for $^{238-240}$Pu, ^{241}Am, ^{244}Cm, ^{90}Sr, ^{90}Y, ^{134,137}Cs, ^{137m}Ba and ^{154}Eu.

In addition, in order to help for the understanding of possible spread of results, as well as to estimate possible agreement or disagreement during the depletion calculations, the following quantities are also requested for both the pincell and the assembly calculations:

- k_∞ at the beginning and end of each of the four irradiation cycles,
- burnup value (MWd/kg) at the beginning and end of each of the four cycles,
- similarly, at the beginning and end of each of the four cycles: mass densities (in g/tHM[3]) for $^{234-236,238}$U, $^{238-242}$Pu, ^{241,242m,243}Am, $^{242-244}$Cm, ^{90}Sr, ^{134,137}Cs, ^{148}Nd and ^{154}Eu,
- at the end of each cycle, the integrated number of fissions for ^{235,238}U and ^{239,241}Pu (in % of the total fissions).

Overview of the results

Beginning of Table 2

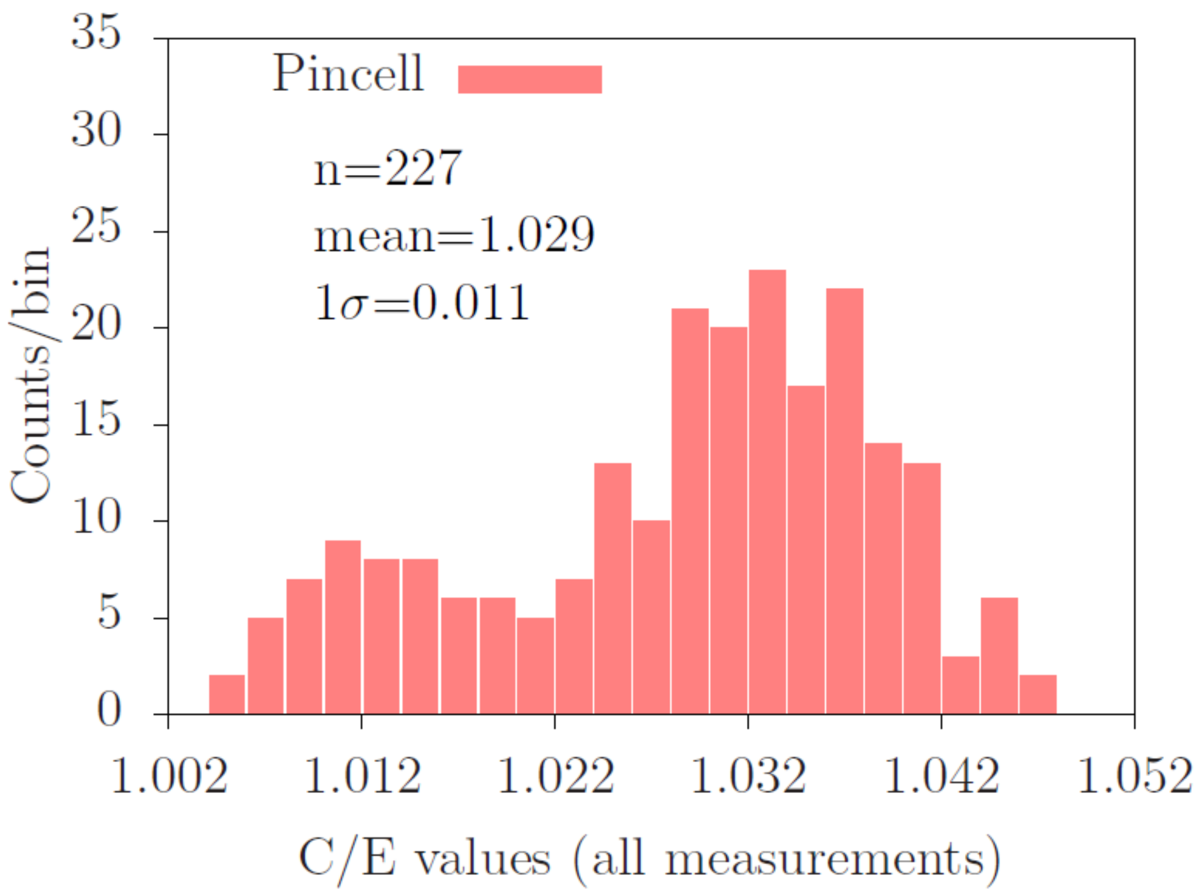
Index	Code	Transport, FY, decay data libraries (XS/FY/DD)	Benchmark (p/a/pa)	Institute/user
1	CASMO-5 v2.13	ENDF/B-VII.1 + XS ^{239}Pu JENDL-4.0	pa	1
2	SERPENT v2.2.0	ENDF/B-VII.1	pa	2
3	SERPENT v2.1.30	ENDF/B-VII.0	pa	3
4	SERPENT v2.2.1	ENDF/B-VIII.0	a	4
5	SERPENT v2.2.1	JEFF-3.2	a	4
6	SERPENT v2.2.1	JEFF-3.3	a	4
7	SCALE/TRITON v6.2.4	ENDF/B-VII.1	pa	4
8	SERPENT v2.2.1	ENDF/B-VII.1	pa	4
9	SCALE/POLARIS v6.3.1	ENDF/B-VII.1 (XS+FY) JEFF-3.0/A (DD)	pa	5
10	SERPENT v2.2.1	ENDF/B-VII.1	pa	5
11	SERPENT v2.2.1	JEFF-3.2 (XS) JEFF-3.1.1 (FY+DD)	pa	5
12	DARWIN v2.3	JEFF-3.1.1	pa	6
13	EVOLCODE v2.0	ENDF/B-VIII.0	pa	7
14	EVOLCODE v2.0	JEFF-3.3	pa	7
15	SCALE/ORIGEN v6.3.1	ENDF/B-VII.1	a	8
16	MVP v3	JENDL-4.0 (XS+FY) JENDL/DDF-2015 (DD)	pa	8
17	MVP v3	JENDL-4.0 (XS+FY) JENDL-5.0 (DD)	pa	8
18	MVP v3	JENDL-5.0 (XS+FY) JENDL/DDF-2015 (DD)	pa	8
19	MVP v3	JENDL-5.0 (XS+FY) JENDL-5.0 (DD)	pa	8
20	VESTA v2.2/MORET v5	ENDF/B-VII.1	pa	9
21	SCALE/ORIGEN v6.0	w17x17 v5.1 (XS) ENDF/B-V (FY+DD)	a	10
22	SCALE/TRITON v6.3.2	ENDF/B-VII.1	pa	11
23	MCNPX v2.60 + ORIGEN2	JEFF-3.1.1	pa	12
24	HELIOS2 v2.04.02	ENDF/B-VII.1	pa	13
25	SERPENT v2.2.1	ENDF/B-VIII.0	p	14
26	SERPENT v2.2.1	ENDF/B-VII.1	p	14
27	SERPENT v2.2.1 + DBRC	ENDF/B-VIII.0	p	14
28	SERPENT v2.2.2	JEFF-3.2 (XS) JEFF-3.1.1 (FY+DD)	pa	15
29	SERPENT v2.2.2	ENDF/B-VIII.0	pa	15
30	SERPENT v2.2.2	JENDL-4.0	pa	15
31	SERPENT v2.2.2	ENDF/B-VII.1	pa	15
32	SERPENT v2.2.1	JEFF-3.1.1	p	14
33	SERPENT v2.2.1	ENDF/B-VIII.1	p	14
34	SERPENT v2.2.0	ENDF/B-VII.1	pa	16
35	SCALE/TRITON v6.3.1	ENDF/B-VII.1 (XS+FY) ENDF/B-VII.0 (DD)	pa	17
36	SERPENT v2.2.1	ENDF/B-VII.1	pa	18
37	ALEPH2 v2.9.2	ENDF/B-VII.1	a	19
38	ALEPH2 v2.9.2	ENDF/B-VIII.0	a	19
39	ALEPH2 v2.9.2	ENDF/B-VIII.1	a	19
40	ALEPH2 v2.9.2	JEFF-3.3	a	19
41	ALEPH2 v2.9.2	JEFF-3.1.1	a	19
42	ALEPH2 v2.9.2	JENDL-5.0	a	19
43	SNF v1.07	ENDF/B-VII.1	a	1
44	SCALE/ORIGEN v6.3.1	ENDF/B-VII.1	a	20
45	SCALE/ORIGAMI v6.3.1	ENDF/B-VII.1	a	20
46	DRAGON v5.0.8	ENDF/B-VII.1	p	21
47	DRAGON v5.0.8	ENDF/B-VIII.0	p	21
48	DRAGON v5.0.8	ENDF/B-VIII.1	p	21
49	DRAGON v5.0.8	JEF-2.2	p	21
50	DRAGON v5.0.8	JEFF-3.3	p	21
51	DRAGON v5.0.8	JEFF-3.1.1	p	21
52	DRAGON v5.0.8	JENDL-5.0	p[38]	21
53	CASMO5 v3.08	ENDF/B-VII.1 + XS ^{239}Pu JENDL-4.0	a	9
54	CASMO5 v3.08	ENDF/B-VII.1	a	9
55	HELIOS2 v2.04.02 (no spacers)	ENDF/B-VII.1	a[43]	13

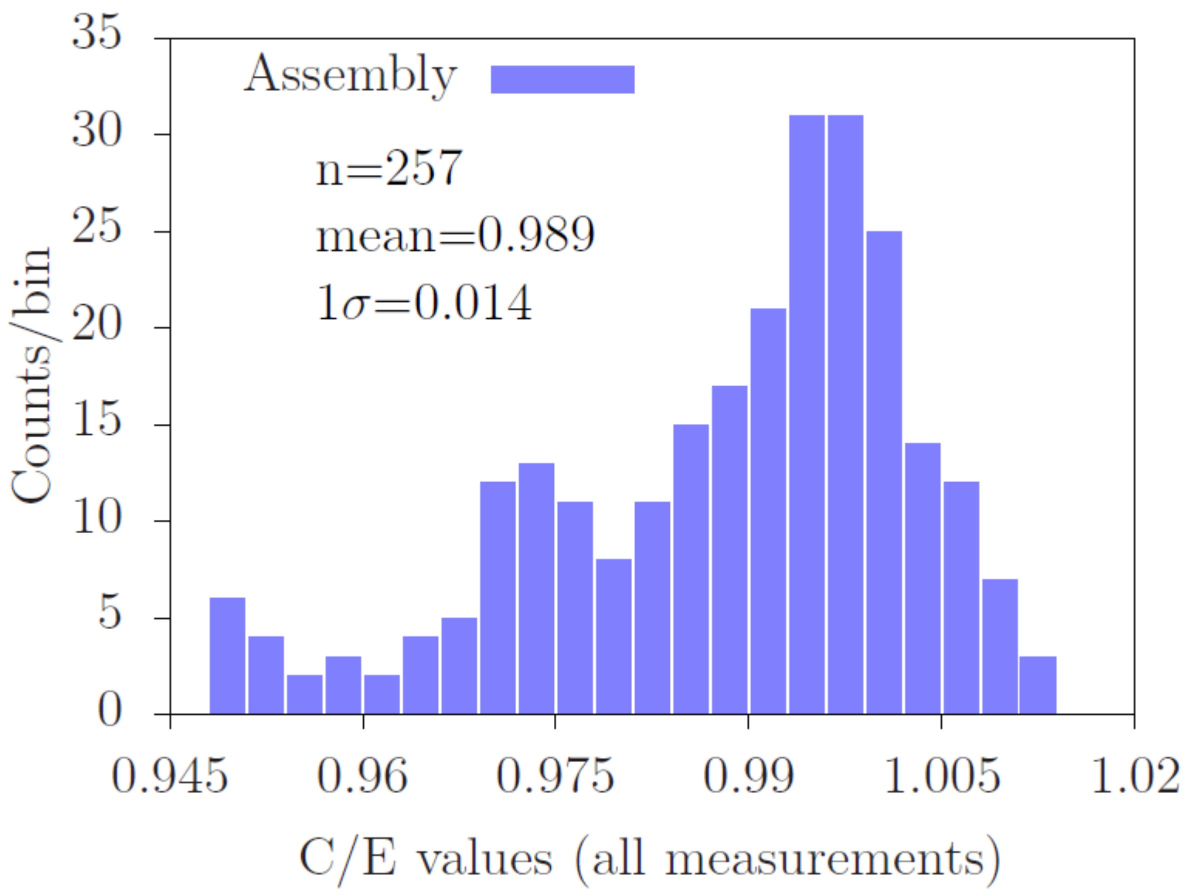
Overview of the results

Code	Pincell	Assembly	Library	Pincell	Assembly
SERPENT	16	14	ENDF/B-VII.0	1	1
MVP	4	4	ENDF/B-VII.1	15	19
MCNP(X)	3	9	ENDF/B-VIII.0	5	4
TRITON	3	3	ENDF/B-VIII.1	2	1
ORIGEN	0	4	JEFF-3.1.1	4	3
POLARIS	1	1	JEFF-3.2	2	3
DARWIN	1	1	JEFF-3.3	2	3
HELIOS2	1	2	JENDL-4.0	3	3
VESTA	1	1	JENDL-5.0	3	3
CASMO5	1	3	JEF-2.2	1	0
SNF-1.7	0	1	Other	0	3
DRAGON	7	0			

- Other options:
  - Different decay data libraries
  - Different transport (DBRC)
  - Different decay data & FY libraries
  - Test libraries (future JEFF-4.0)

Results: decay heat

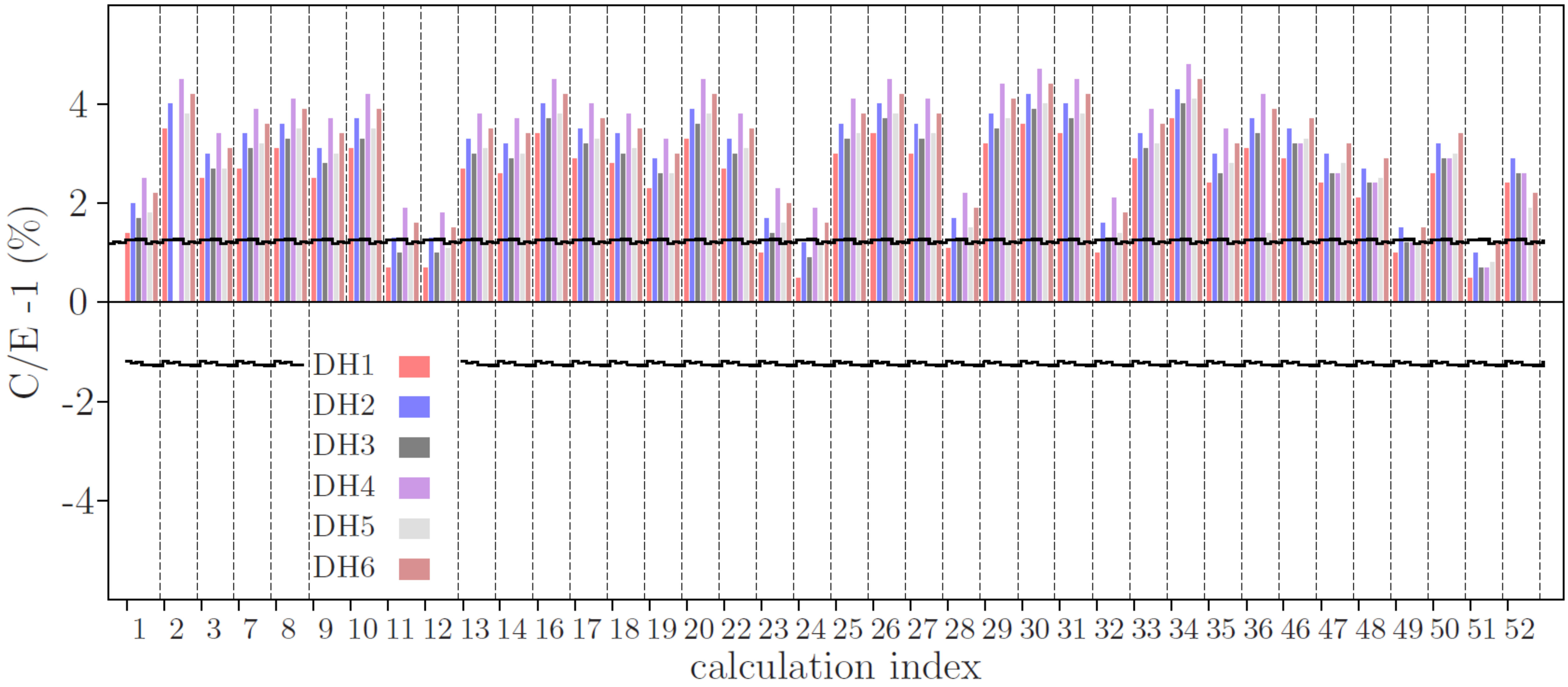




95%/95% Tolerance intervals:	1.008 – 1.050	0.959 – 1.020

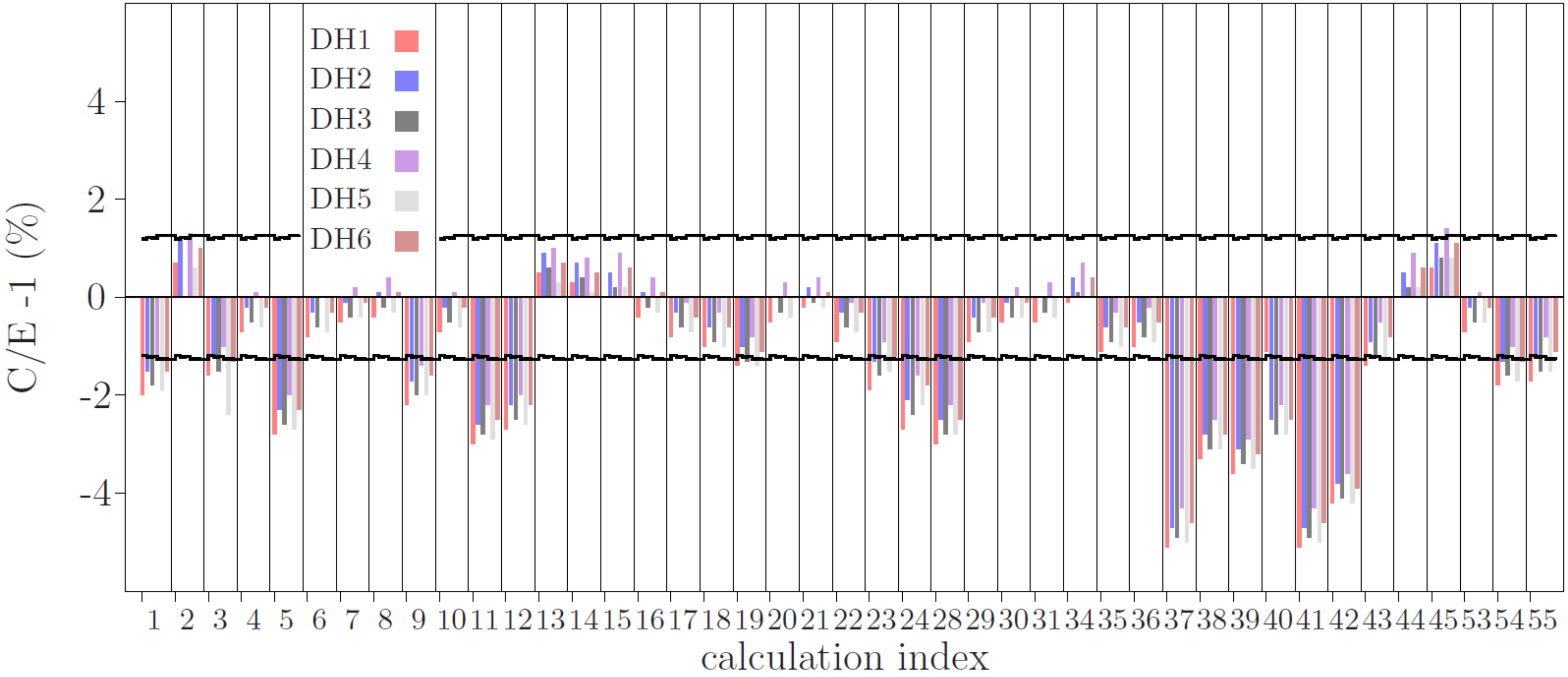
Results: pincell decay heat

Average C/E and 1σ: 1.029 ± 0.011

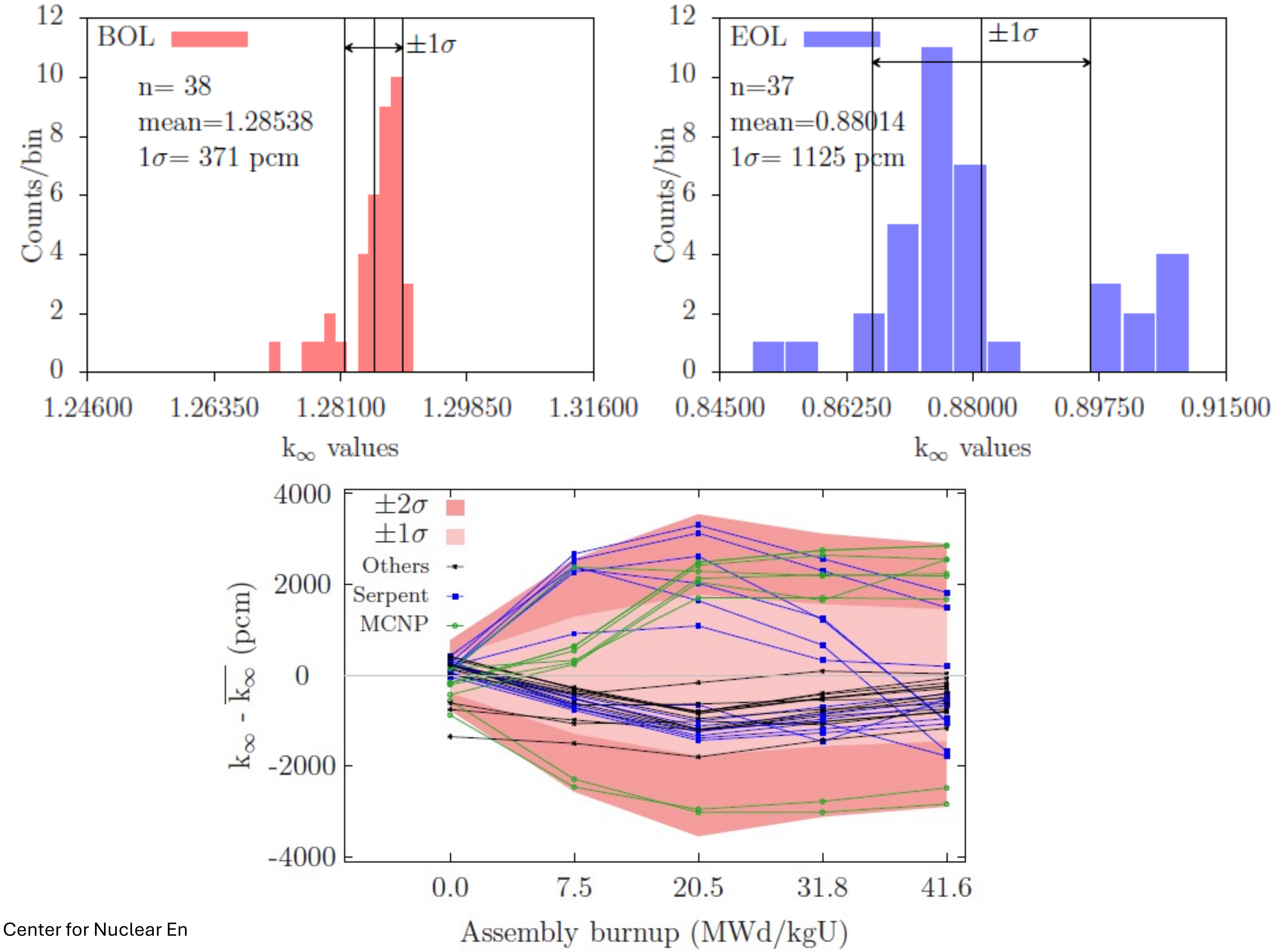


Results: assembly decay heat

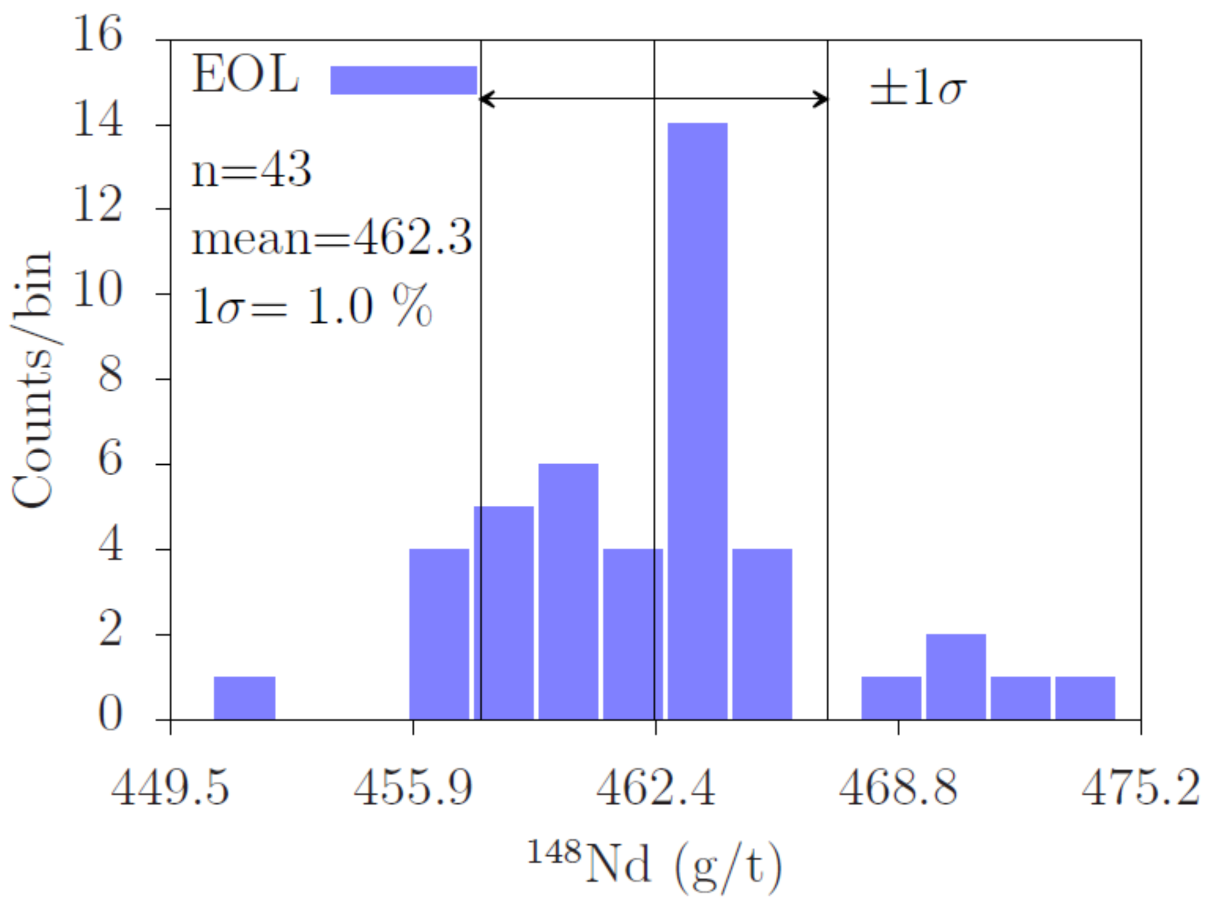
Average C/E and 1σ: 0.989 ± 0.014

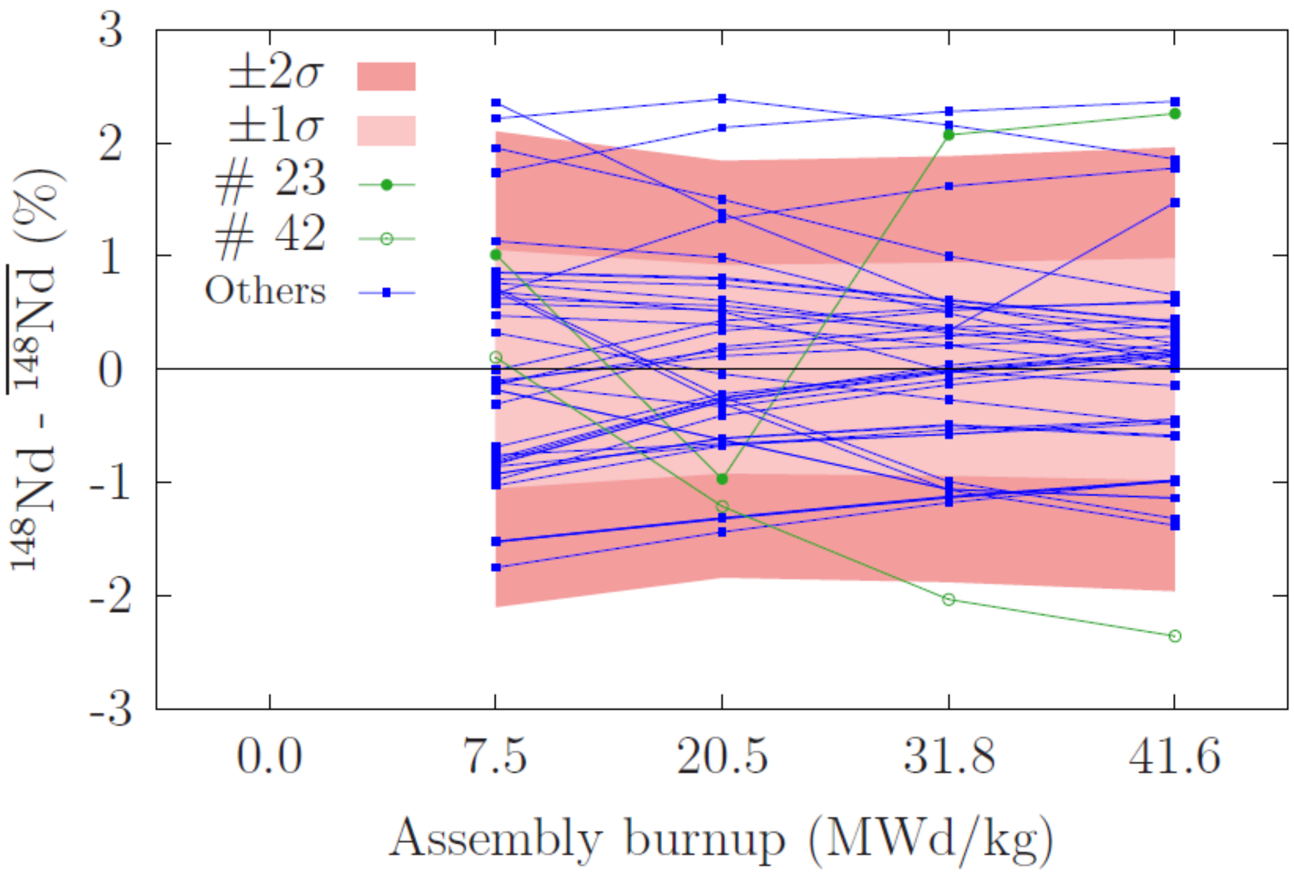


Results: assembly k_inf

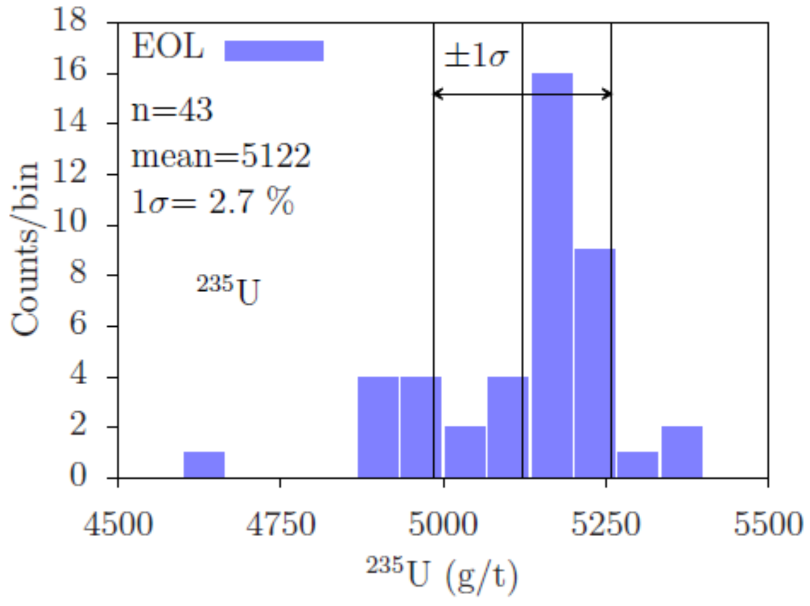


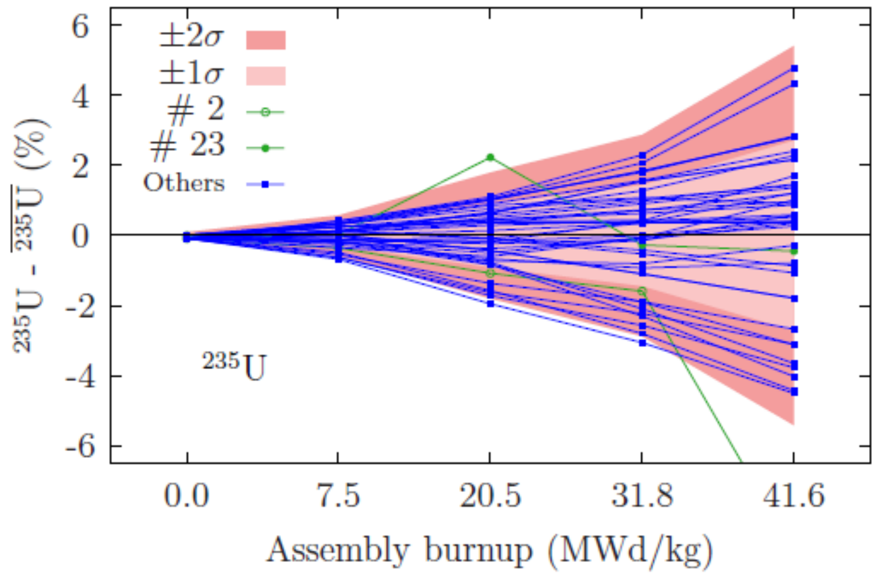
Results: assembly Nd-148

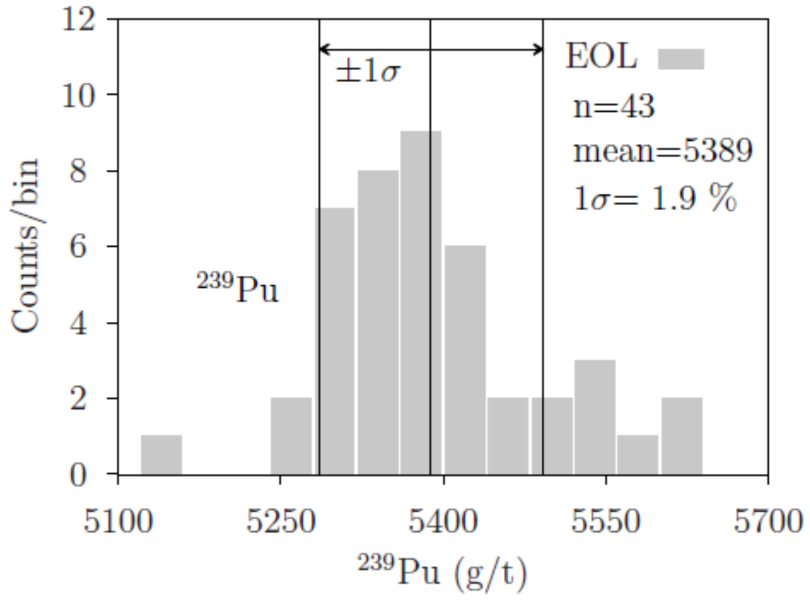


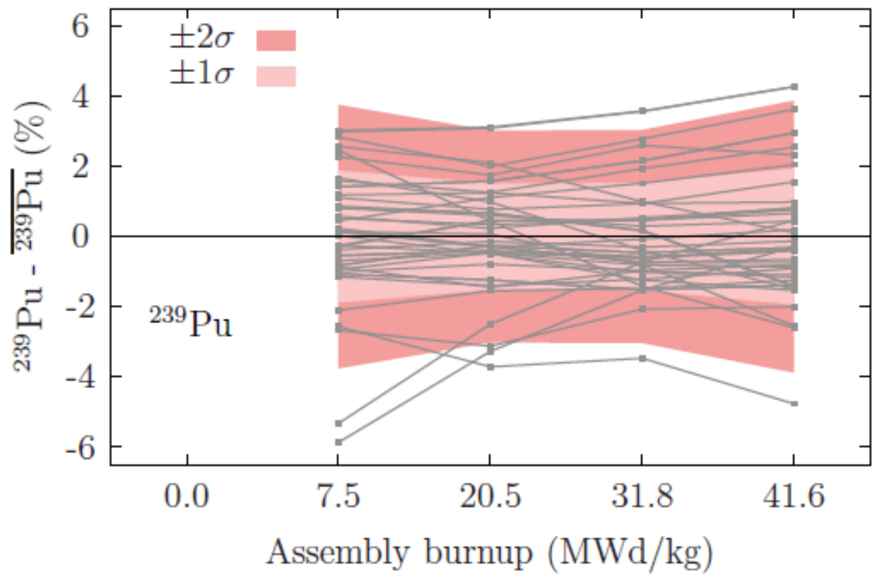


Results: assembly U-235 and Pu-239 concentration (EOL)









Remark 1: Spread of concentrations

	Pincell	Assembly		Pincell	Assembly
Decay heat	$(+2.6 \pm 0.9)$ %	(-1.2 ± 1.2) %	Δk_∞	$\pm$ 551 pcm	$\pm$ 1225 pcm
RR Δ^{235}U	$\pm$ 1.9 %	$\pm$ 1.8 %	RR Δ^{238}U	$\pm$ 3.1 %	$\pm$ 1.1 %
RR Δ^{239}Pu	$\pm$ 0.4 %	$\pm$ 0.7 %	RR Δ^{241}Pu	$\pm$ 1.3 %	$\pm$ 1.2 %
Δ^{234}U	$\pm$ 2.6 %	$\pm$ 2.0 %	Δ^{235}U	$\pm$ 2.1 %	$\pm$ 1.9 %
Δ^{236}U	$\pm$ 1.0 %	$\pm$ 0.7 %	Δ^{238}U	$\pm$ 0.08 %	$\pm$ 0.08 %
Δ^{238}Pu	$\pm$ 3.7 %	$\pm$ 3.9 %	Δ^{239}Pu	$\pm$ 1.0 %	$\pm$ 1.8 %
Δ^{240}Pu	$\pm$ 1.8 %	$\pm$ 2.5 %	Δ^{241}Pu	$\pm$ 1.8 %	$\pm$ 1.3 %
Δ^{242}Pu	$\pm$ 2.9 %	$\pm$ 1.6 %	Δ^{241}Am	$\pm$ 9.7 %	$\pm$ 12 %
Δ^{242m}Am	$\pm$ 23 %	$\pm$ 20 %	Δ^{243}Am	$\pm$ 4.8 %	$\pm$ 6.4 %
Δ^{242}Cm	$\pm$ 7.0 %	$\pm$ 8.1 %	Δ^{243}Cm	$\pm$ 12 %	$\pm$ 14 %
Δ^{244}Cm	$\pm$ 6.5 %	$\pm$ 5.2 %	Δ^{90}Sr	$\pm$ 1.0 %	$\pm$ 0.9 %
Δ^{134}Cs	$\pm$ 4.8 %	$\pm$ 5.3 %	Δ^{137}Cs	$\pm$ 1.2 %	$\pm$ 0.9 %
Δ^{148}Nd	$\pm$ 0.9 %	$\pm$ 1.0 %	Δ^{154}Eu	$\pm$ 6.1 %	$\pm$ 3.1 %

Table 13: Summary table of the calculated uncertainties (Δ corresponds to 1σ) for both benchmarks at EOL. For the decay heat, the $C/E - 1 \pm 1\sigma$ over the six measurements is given. RR means fission reaction rates. If not specified, uncertainties concern nuclide concentrations. Data comes from the ULC analysis.

Remark 2: decay heat and modelling (not in the SG16 documents)

- The current benchmark is based on the description of the SKB 2006 report.

- In 2024, the new EPRI report proposes for the 0E2 assembly
  - Slightly updated burnup
  - Different fuel density (SKB: 10.35 g/cm^3 - benchmark: 10.34 g/cm^3 - EPRI: 10.7 g/cm^3)
  - This matters if calculations are not normalized to the total mass (calculations given in W/g or W/t)

- New (EPRI) fuel density leads to $\overline{C/E} = 1.031$ vs. $\overline{C/E} = 0.986$ (PSI results only, for the assembly, with SERPENT2, ENDF/B-VII.0)

- Such difference > than 4$\boldsymbol{\sigma}$

Conclusion

- Case 0E2 (PWR UO_2 3.1wt% ^{235}U enriched, 41.6 MWd/kg)
- 6 decay heat calorimetric measurements from SKB
- 2 benchmarks (2D pincell and assembly)

- Successful comparison (> 55 calculations)
- Summarized in a draft paper

- Results for decay heat (ULC values):
  - Pincell C/E -1: (+2.6 ± 0.9) %
  - Assembly C/E -1: (-1.2 ± 1.2) %

Next steps

- What's next (to be discussed):
  - Publication (NEA report and journal paper),
  - (missing descriptions for TRITON$^{(BGZ, SEA, WTI)}$, POLARIS$^{(BGZ)}$)

  - Future subgroup:
    - New analysis (blind, or other cases with or without measurements),
    - Uncertainties,
    - Switch to burnup analysis (see talks later in the day)
    - Stop.

Many thanks

- Questions ?