Naval Nuclear Laboratory Analysis of the ENDF/B-VIII.β4 Library

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Outline

- Suite of 169 ICSBEP critical models run using:
  - ENDF/B-VII.1 and ENDF/B-VIII.β4
  - *C/E* comparisons
  - Above thermal leakage fraction (ATLF) and above thermal fission fraction (ATFF) comparisons for HST and LST series
  - Neutron balance analysis for selected models

- FUND_IPPE_VDF_MULTI_TRANS_001 Iron streaming benchmark

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ICSBEP Suite

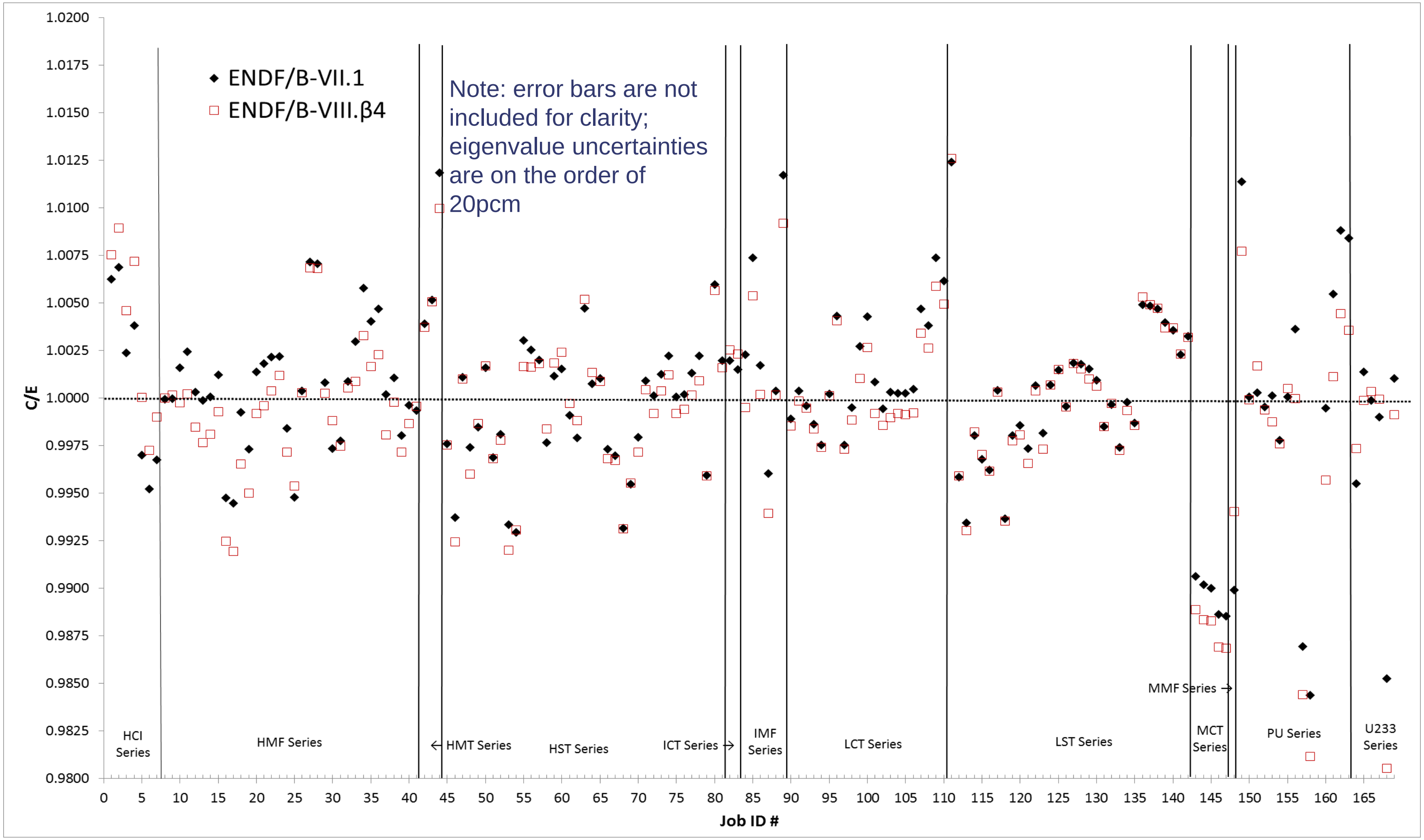
Model #	Benchmark Name	Model k-eff	Exp. Unc.
1	HCI_003_01	1.00000	0.00570
2	HCI_003_02	1.00000	0.00610
3	HCI_003_03	1.00000	0.00560
4	HCI_003_04	1.00000	0.00550
5	HCI_003_05	1.00000	0.00470
6	HCI_003_06	1.00000	0.00470
7	HCI_003_07	1.00000	0.00500
8	HMF_001_01A	1.00000	0.00100
9	HMF_001_01B	1.00000	0.00100
10	HMF_002_01	1.00000	0.00300
11	HMF_002_02	1.00000	0.00300
12	HMF_002_03	1.00000	0.00300
13	HMF_002_04	1.00000	0.00300
14	HMF_002_05	1.00000	0.00300
15	HMF_002_06	1.00000	0.00300
16	HMF_003_01	1.00000	0.00500
17	HMF_003_02	1.00000	0.00500
18	HMF_003_03	1.00000	0.00500
19	HMF_003_04	1.00000	0.00300
20	HMF_003_05	1.00000	0.00300
21	HMF_003_06	1.00000	0.00300
22	HMF_003_07	1.00000	0.00300
23	HMF_004_01	1.00200	0.00010
24	HMF_009_01	0.99920	0.00150
25	HMF_015_01	0.99960	0.00170
26	HMF_018_01	1.00000	0.00140
27	HMF_019_01	1.00000	0.00280
28	HMF_019_02	1.00000	0.00280
29	HMF_020_01	1.00000	0.00280
30	HMF_021_01	1.00000	0.00240
31	HMF_022_01	1.00000	0.00190
32	HMF_027_01	1.00000	0.00250
33	HMF_028_01	1.00000	0.00300
34	HMF_029_01	1.00000	0.00200
35	HMF_032_01	1.00000	0.00160
36	HMF_032_02	1.00000	0.00270
37	HMF_032_03	1.00000	0.00170
38	HMF_032_04	1.00000	0.00170
39	HMF_034_01	0.99900	0.00120
40	HMF_034_02	0.99900	0.00120
41	HMF_034_03	0.99900	0.00120
42	HMT_001_01	1.00100	0.00600

Model #	Benchmark Name	Model k-eff	Exp. Unc.
43	HMT_001_01D	1.00100	0.00600
44	HMT_014_01	0.99390	0.00150
45	hst_001_01	1.00040	0.00600
46	hst_001_02	1.00210	0.00720
47	hst_001_03	1.00030	0.00350
48	hst_001_04	1.00080	0.00530
49	hst_001_05	1.00010	0.00490
50	hst_001_06	1.00020	0.00460
51	hst_001_07	1.00080	0.00400
52	hst_001_08	0.99980	0.00380
53	hst_001_09	1.00080	0.00540
54	hst_001_10	0.99930	0.00540
55	hst_009_01	0.99900	0.00430
56	hst_009_02	1.00000	0.00390
57	hst_009_03	1.00000	0.00360
58	hst_009_04	0.99860	0.00350
59	hst_010_01	1.00000	0.00290
60	hst_010_02	1.00000	0.00290
61	hst_010_03	1.00000	0.00290
62	hst_010_04	0.99920	0.00290
63	hst_011_01	1.00000	0.00230
64	hst_011_02	1.00000	0.00230
65	hst_012_01	0.99990	0.00580
66	hst_013_01	1.00120	0.00260
67	hst_013_02	1.00070	0.00360
68	hst_013_03	1.00090	0.00360
69	hst_013_04	1.00030	0.00360
70	hst_032_01	1.00150	0.00260
71	hst_042_01	0.99570	0.00390
72	hst_042_02	0.99650	0.00360
73	hst_042_03	0.99940	0.00280
74	hst_042_04	1.00000	0.00340
75	hst_042_05	1.00000	0.00340
76	hst_042_06	1.00000	0.00370
77	hst_042_07	1.00000	0.00360
78	hst_042_08	1.00000	0.00350
79	hst_043_01	0.99860	0.00310
80	hst_043_02	0.99950	0.00260
81	hst_043_03	0.99900	0.00250
82	ICT_003_C132	0.99865	0.00015
83	ICT_003_C133	1.00310	0.00015
84	IMF_003	1.00000	0.00170

Model #	Benchmark Name	Model k-eff	Exp. Unc.
85	IMF_004	1.00000	0.00300
86	IMF_005	1.00000	0.00210
87	IMF_006	1.00000	0.00230
88	IMF_007	0.99480	0.00130
89	IMF_009	1.00000	0.00530
90	LCT_002_01	0.99970	0.00200
91	LCT_002_02	0.99970	0.00200
92	LCT_002_03	0.99970	0.00200
93	LCT_002_04	0.99970	0.00180
94	LCT_002_05	0.99970	0.00190
95	LCT_008_02	1.00070	0.00120
96	LCT_010_01	1.00000	0.00210
97	LCT_010_08	1.00000	0.00210
98	LCT_010_12	1.00000	0.00210
99	LCT_010_17	1.00000	0.00280
100	LCT_010_21	1.00000	0.00280
101	LCT_010_30	1.00000	0.00280
102	LCT_029_01	1.00000	0.00100
103	LCT_029_02	1.00000	0.00100
104	LCT_029_03	1.00000	0.00100
105	LCT_029_04	1.00000	0.00100
106	LCT_029_05	1.00000	0.00100
107	LCT_061_03	1.00050	0.00230
108	LCT_061_04	1.00050	0.00230
109	LCT_061_05	1.00050	0.00230
110	LCT_061_06	1.00050	0.00230
111	lst_001_01	0.99910	0.00290
112	lst_002_01	1.00380	0.00400
113	lst_002_02	1.00240	0.00370
114	lst_002_03	1.00240	0.00440
115	lst_003_01	0.99970	0.00390
116	lst_003_02	0.99930	0.00420
117	lst_003_03	0.99950	0.00420
118	lst_003_04	0.99950	0.00420
119	lst_003_05	0.99970	0.00480
120	lst_003_06	0.99990	0.00490
121	lst_003_07	0.99940	0.00490
122	lst_003_08	0.99930	0.00520
123	lst_003_09	0.99960	0.00520
124	lst_004_01	0.99940	0.00080
125	lst_004_29	0.99990	0.00090
126	lst_004_33	0.99990	0.00090

Model #	Benchmark Name	Model k-eff	Exp. Unc.
127	lst_004_34	0.99990	0.00100
128	lst_004_46	0.99990	0.00100
129	lst_004_51	0.99940	0.00110
130	lst_004_54	0.99960	0.00110
131	lst_007_14	0.99610	0.00090
132	lst_007_30	0.99730	0.00090
133	lst_007_32	0.99850	0.00100
134	lst_007_36	0.99880	0.00110
135	lst_007_49	0.99830	0.00110
36	lst_016_105	0.99960	0.00130
137	lst_016_113	0.99990	0.00130
138	lst_016_125	0.99940	0.00140
139	lst_016_129	0.99960	0.00140
140	lst_016_131	0.99950	0.00140
141	lst_016_140	0.99920	0.00150
142	lst_016_196	0.99940	0.00150
143	MCT_006_08	1.00350	0.00440
144	MCT_006_09	1.00350	0.00440
145	MCT_006_10	1.00210	0.00440
146	MCT_006_11	1.00320	0.00440
147	MCT_006_12	1.00320	0.00440
148	MMF_008_07	1.03000	0.00250
149	PCI_001	1.00000	0.01100
150	PMF_001	1.00000	0.00200
151	PMF_002	1.00000	0.00200
152	PMF_003_103	1.00000	0.00300
153	PMF_006	1.00000	0.00300
154	PMF_008	1.00000	0.00060
155	PMF_011	1.00000	0.00100
156	PST_021_03	1.00000	0.00650
157	PST_031_01	1.00000	0.00510
158	PST_031_02	1.00000	0.00510
159	PST_031_03	1.00000	0.00390
160	PST_031_04	1.00000	0.00440
161	PST_031_05	1.00000	0.00370
162	PST_031_06	1.00000	0.00340
163	PST_031_07	1.00000	0.00230
164	UMF_005_02	1.00000	0.00300
165	UCT_001_03	1.00070	0.00250
166	UMF_001	1.00000	0.00100
167	UMF_006	1.00000	0.00140
168	USI_001	1.00000	0.00830
169	UST_008	1.00060	0.00290

C/E Plots: ENDF/B-VIII.β4 and ENDF/B-VII.1



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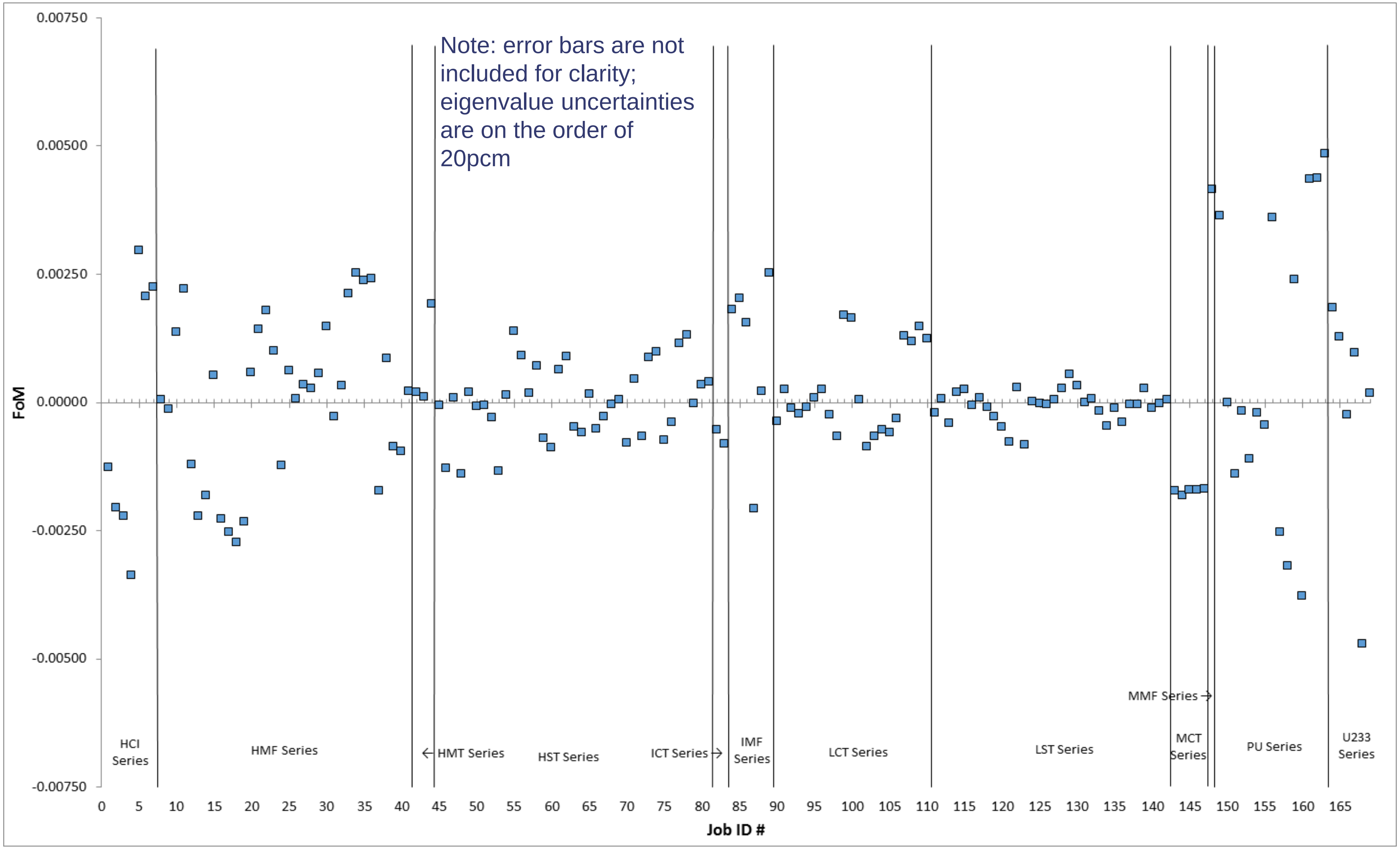
C/E Figure of Merit



$$\mathrm{FoM} = \left| \left(\frac{C}{E}\right)_{VII.1} - 1 \right| - \left| \left(\frac{C}{E}\right)_{VIII.\beta 4} - 1 \right|$$

C/E Series Average Results

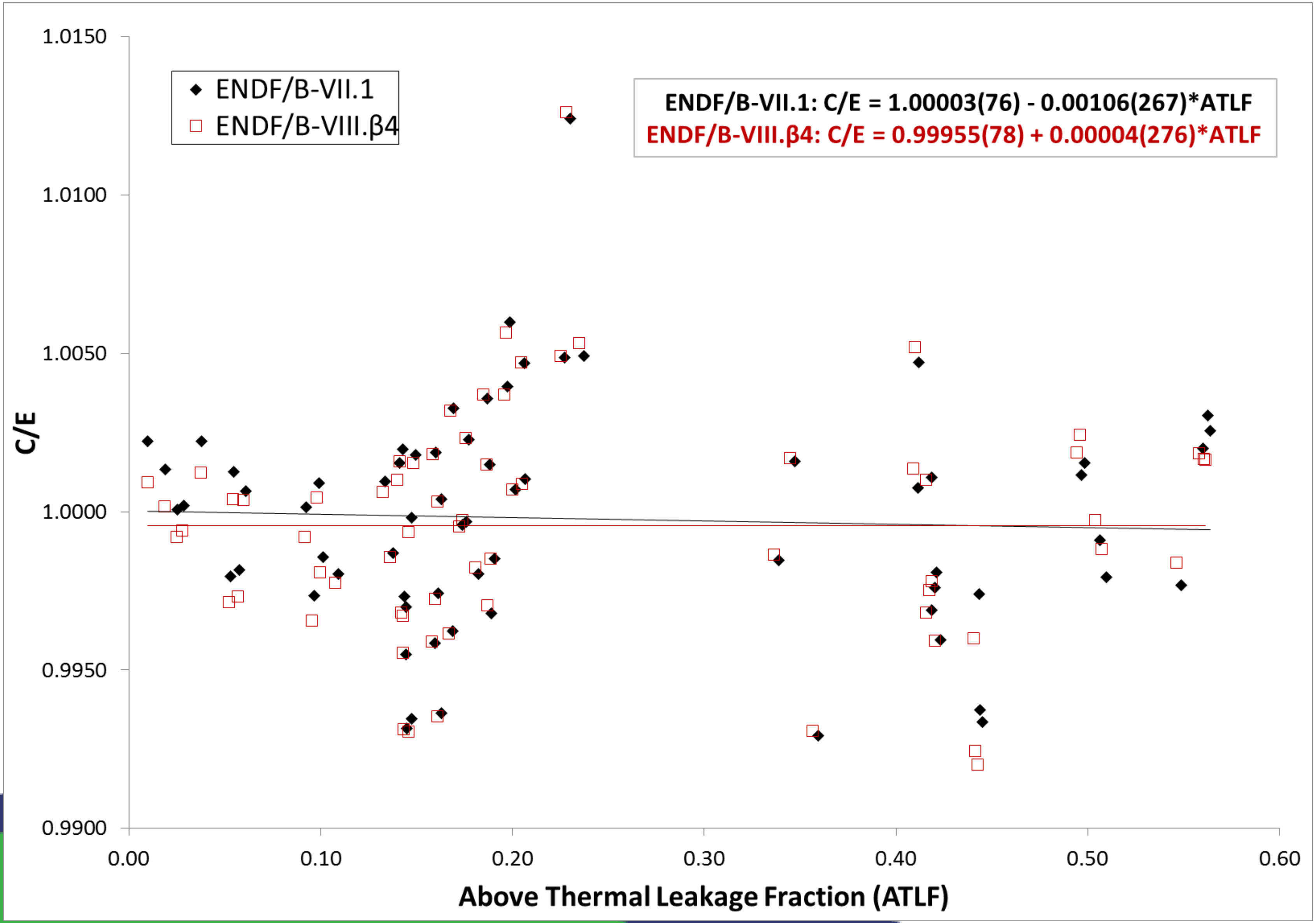
- Some notable changes observed for HCI Series
  - 233pcm increase away from 1.0 in ENDF/B-VIII.β4

- *C/E* deviation from 1.0 is about the same overall

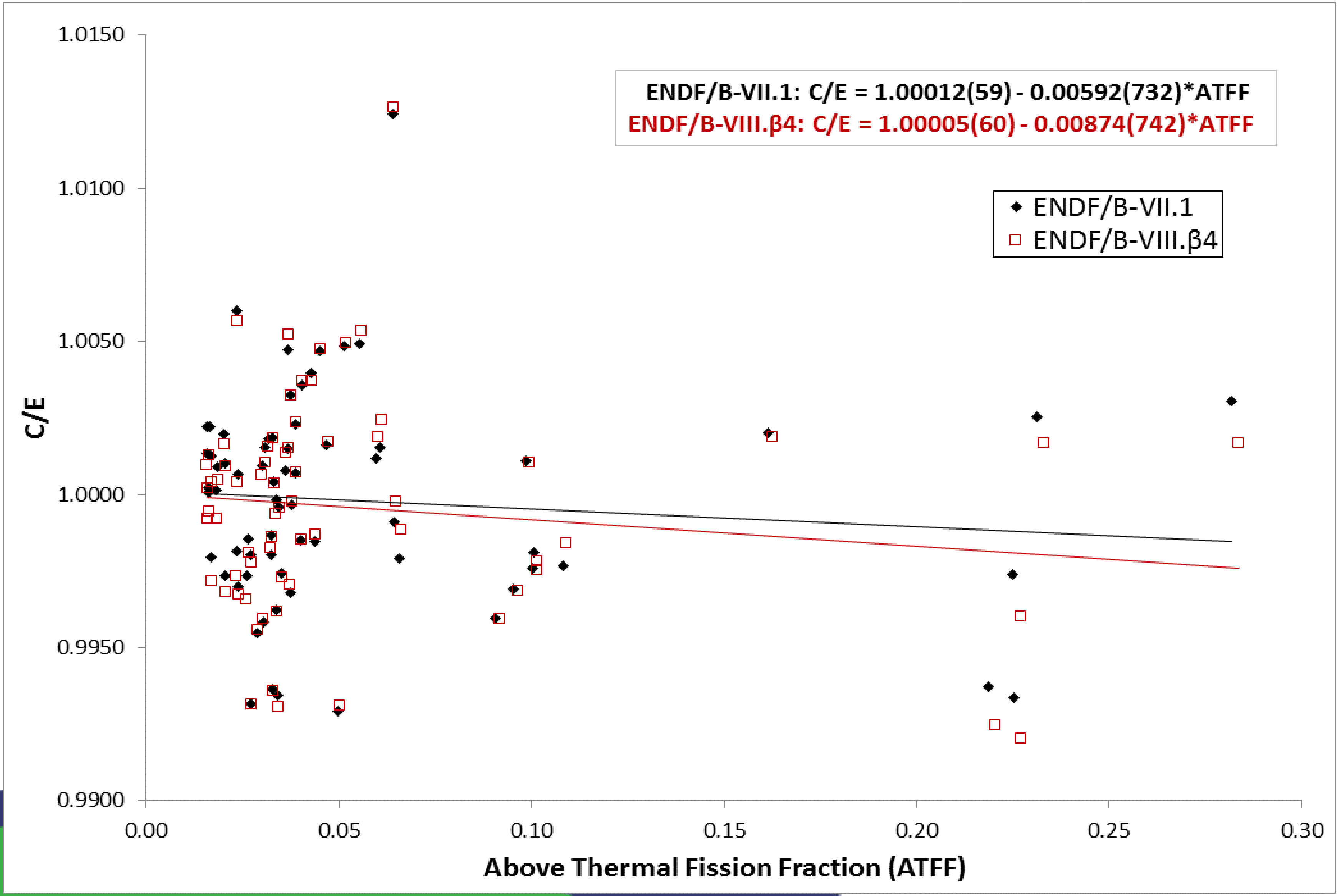
	ENDF/B-VII.1	ENDF/B-VIII.β4	Diff.
All	1.00020(20)	0.99951(20)	-0.00069(28)
HCI	1.00119(20)	1.00352(20)	0.00233(28)
HMF	1.00057(20)	0.99927(20)	-0.00130(28)
HMT	1.00699(13)	1.00625(13)	-0.00074(18)
HST	0.99935(18)	0.99903(18)	-0.00032(25)
ICT	1.00174(23)	1.00242(23)	0.00068(33)
IMF	1.00326(19)	1.00140(18)	-0.00186(26)
LCT	1.00038(20)	0.99975(21)	-0.00063(29)
LST	1.00029(20)	1.00016(19)	-0.00013(28)
MCT	0.98960(21)	0.98786(22)	-0.00174(30)
MMF	0.98990(21)	0.99404(20)	0.00414(29)
Pu	1.00201(20)	0.99982(21)	-0.00219(29)
U233	0.99702(20)	0.99621(20)	-0.00081(28)

Red highlight indicates C/E has gotten further from 1.0 in ENDF/B-VIII.β4

Trend Analysis (HST & LST Series): Above Thermal Leakage Fraction (ATLF)



Trend Analysis (HST & LST Series): Above Thermal Fission Fraction (ATFF)



Comparison of ENDF/B-VII.1 and ENDF/B-VIII.β4

Population *C/E*

Library	Average	Std. Dev.	χ^2
ENDF/B-VII.1	1.00020	0.00492	0.00734
ENDF/B-VIII.β4	0.99951	0.00497	0.00701

$$\chi^2 = \frac{1}{N-1}\sum_{i=1}^{N} \frac{\left(1-\frac{C_i}{E_i}\right)^2}{\sqrt{\sigma_{C,i}^2+\sigma_{E,i}^2}}$$

Notable Changes (*C/E*)

Benchmark	ENDF/B-VII.1	ENDF/B-VIII.β4	Difference
USI_001	0.98527(20)	0.98055(19)	-0.00472(28)
MMF_008_07	0.98990(21)	0.99404(20)	0.00414(29)
PST_021_03	1.00362(19)	0.99997(18)	-0.00365(26)
PCI_001	1.01137(20)	1.00773(20)	-0.00364(28)
HCI_003_04	1.00383(28)	1.00721(23)	0.00337(36)

Red highlight indicates C/E has gotten further from 1.0 in ENDF/B-VIII.β4

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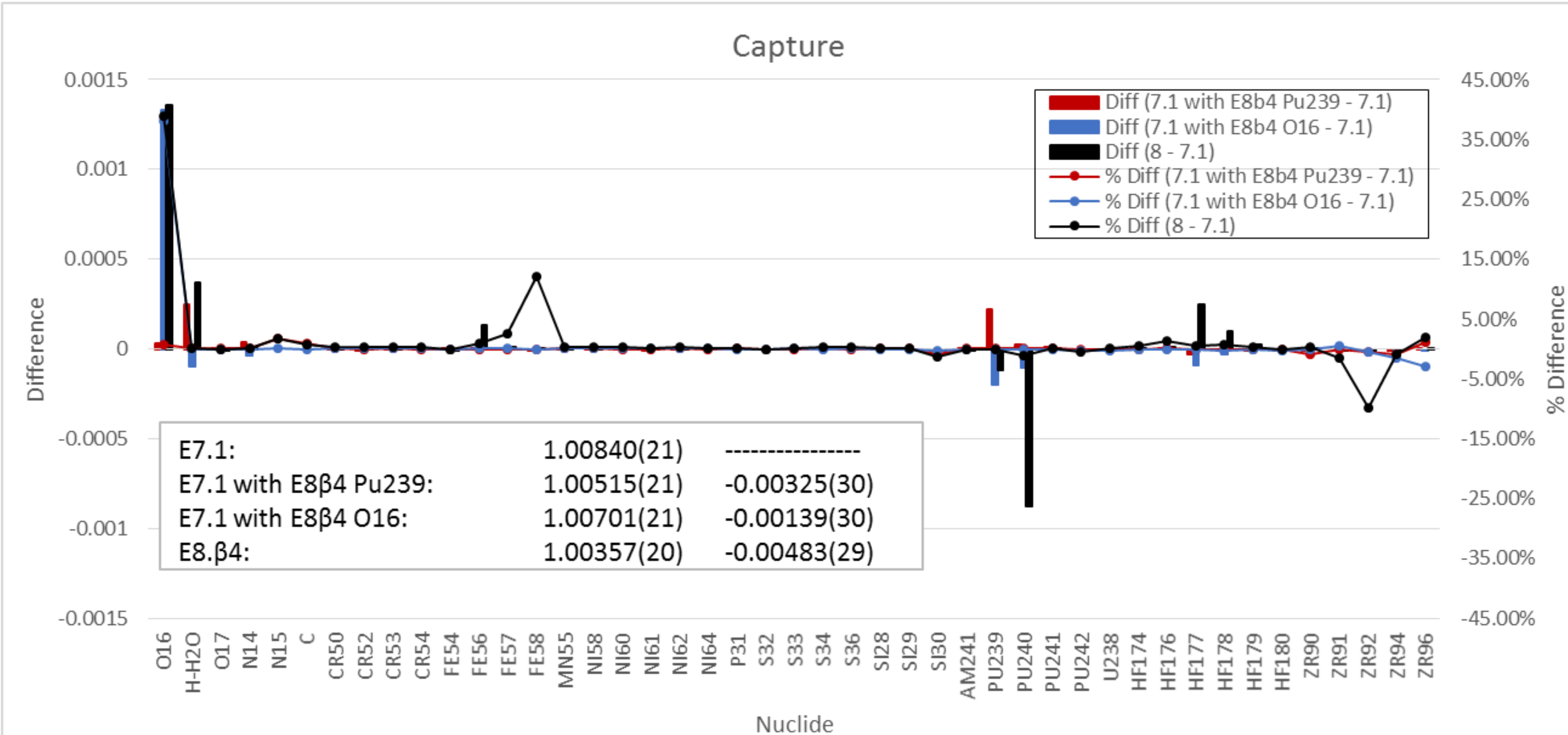
PST031_07 Benchmark

Library	*C/E*	Diff
E7.1	1.00840(21)	---
E8.β4	1.00357(20)	-0.00483(29)
E7.1 + Pu-239 E8.β4	1.00515(21)	-0.00325(30)
E7.1 + O-16 E8.β4	1.00701(21)	-0.00139(30)

- Hafnium changes in E8.β4 are above resonance range, so this model is insensitive to hafnium changes

PST031_07 Benchmark



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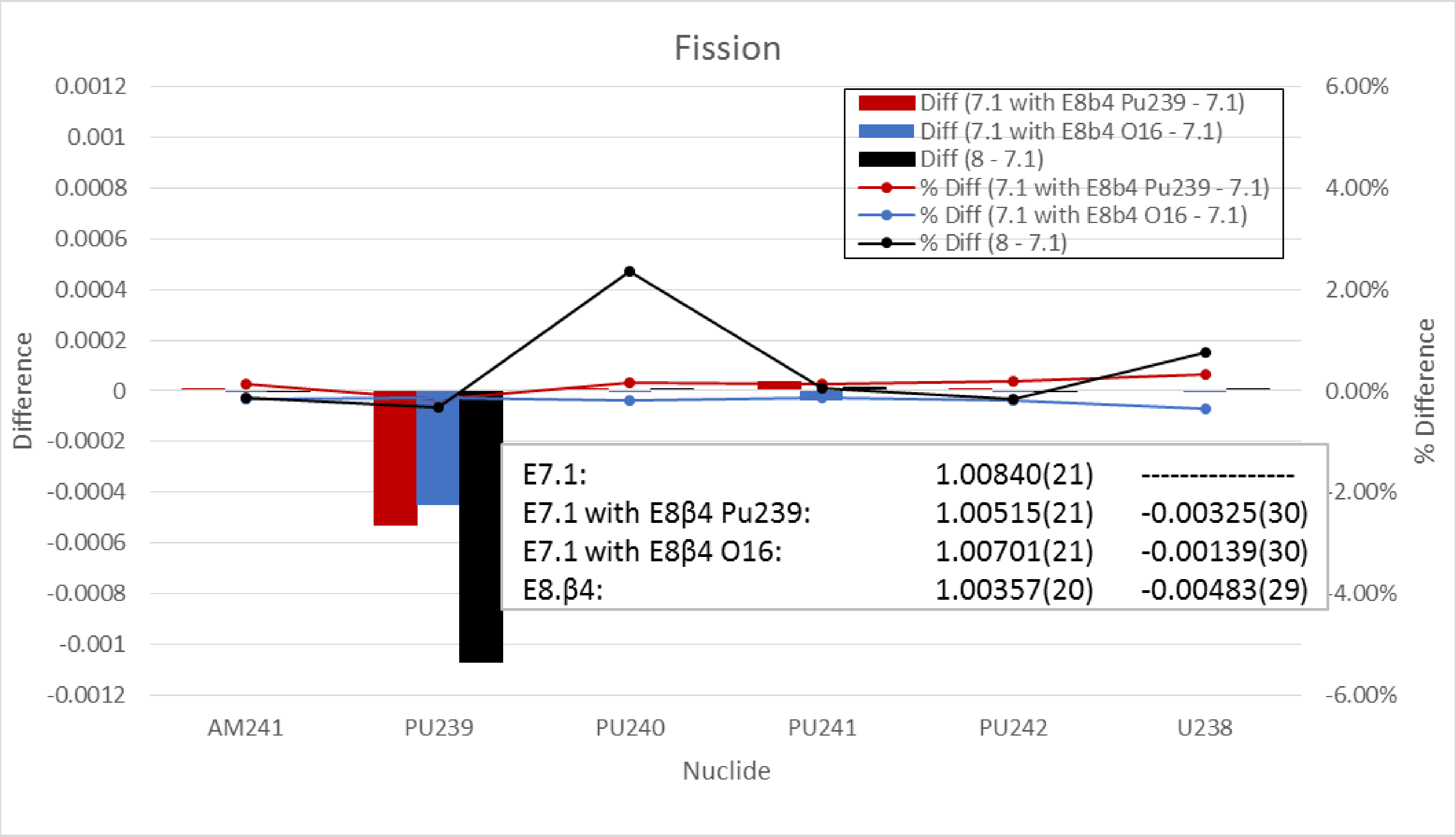
PST031_07 Benchmark



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PST031_07 Benchmark

- *C*/*E* improves by -483pcm in ENDF/B-VIII.β4
  - Pu-239: capture ↓, fission ↓ ↓
  - Pu-240: capture ↓ ↓, fission ↑

- *C*/*E* improves by -325pcm when using ENDF/B-VII.0 with Pu-239 from ENDF/B-VIII.β4
  - Pu-239: capture ↑ , fission ↓ ↓
  - Pu-240: capture ↑ ↑ , fission ↑

- *C*/*E* improves by -139pcm when using ENDF/B-VII.0 with O-16 from ENDF/B-VIII.β4
  - Pu-239: capture ↓ , fission ↓ ↓
  - Pu-240: capture ↓ ↓ , fission ↓
  - Change in capture profile dominated by O-16 (n,α) increase

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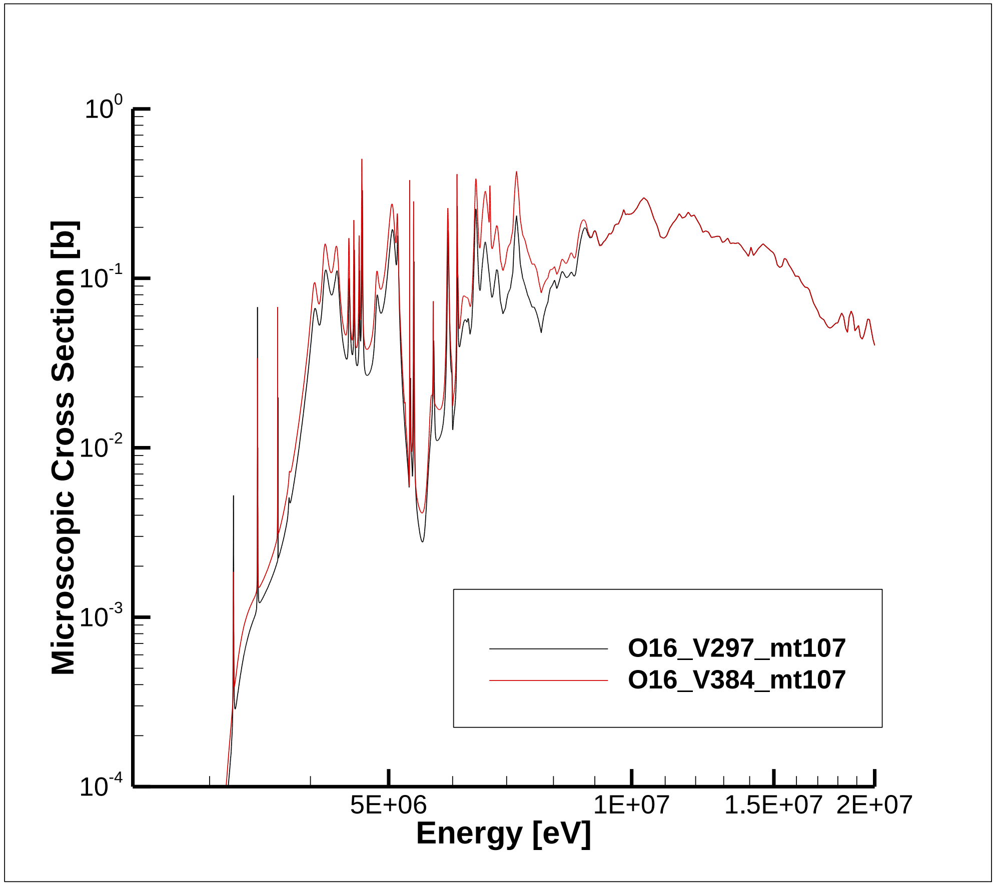
O-16 (n,α) Cross Section



V297 = ENDF/B-VII.0
V384 = ENDF/B-VIII.β4

Library	0.5 Res. Int. (n,α)
ENDF/B-VII.1	1.978E-01
ENDF/B-VIII.β4	2.283E-01
Difference	+15.4%

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ICT_003_C133 Benchmark

- TRIGA benchmark

Library	C/E	Diff
E7.1	1.00151(28)	---
E8.β4	1.00232(28)	0.00081(40)
E7.1 + Zr E8.β4	1.00159(24)	0.00008(37)
E7.1 + H-H2O E8.β4	1.00120(25)	-0.00031(38)
E7.1 + U235 E8.β4	1.00348(25)	0.00197(38)
E7.1 + O16 E8.β5	1.00096(23)	-0.00055(36)

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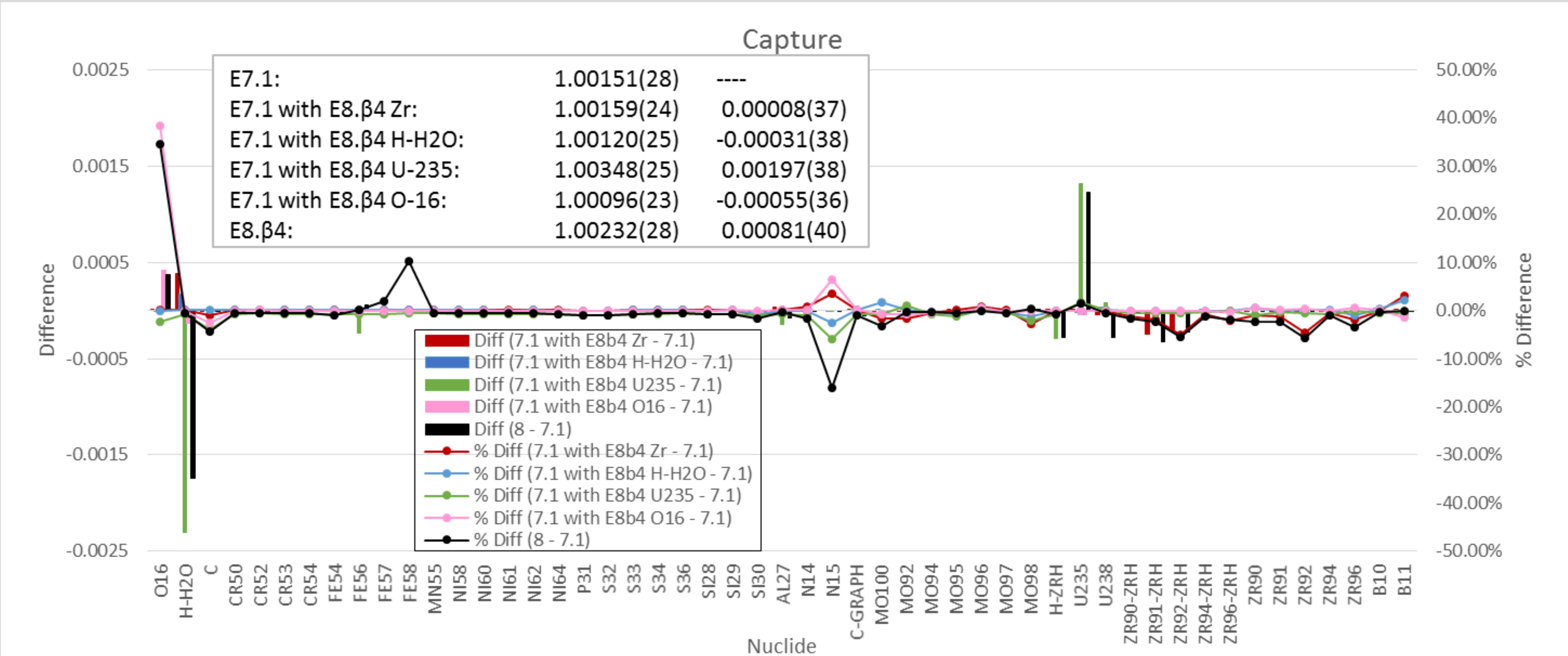
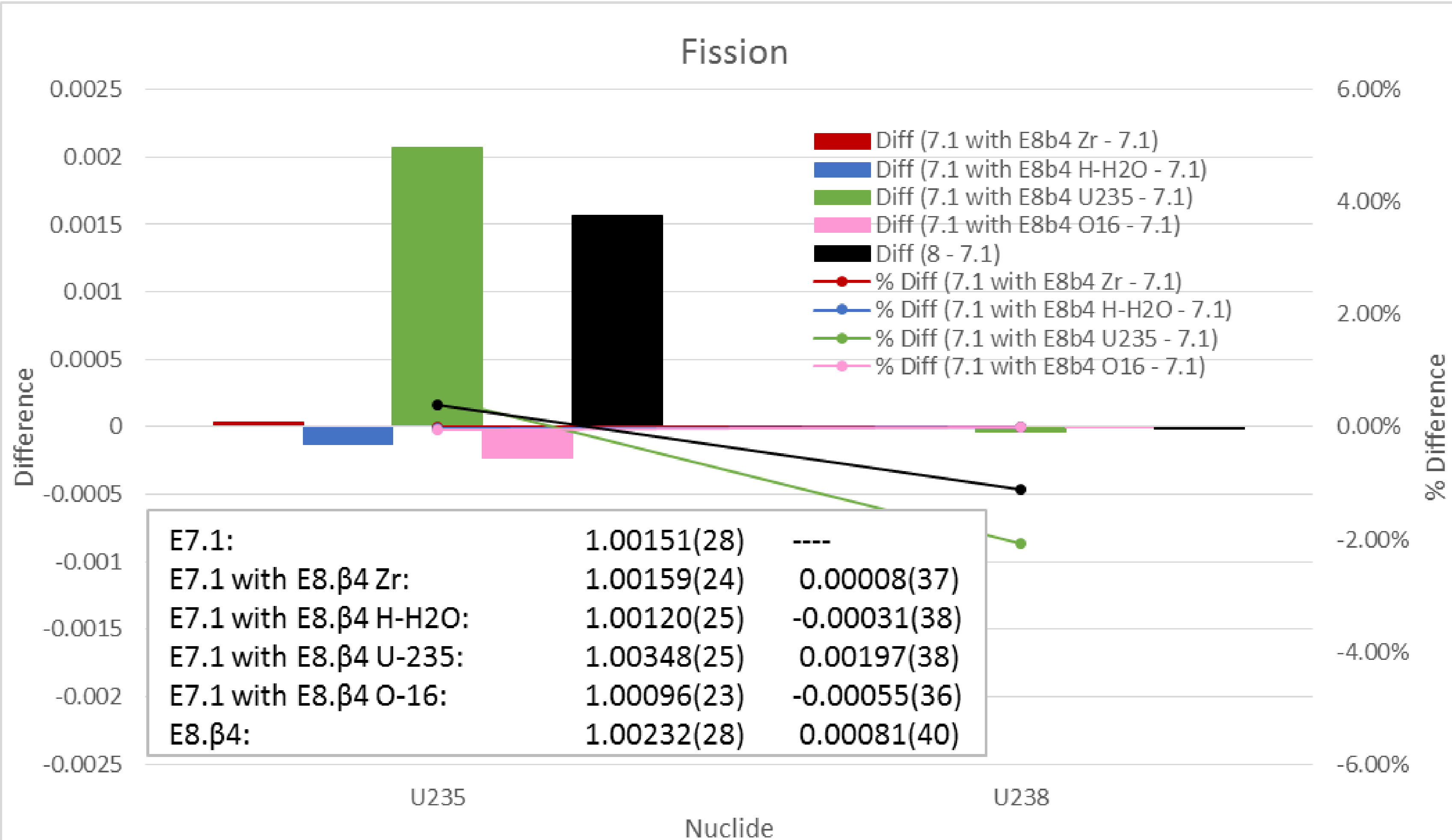
ICT_003_C133 Benchmark



0.5 eV Capture Resonance Integral:

	Zr-90	Zr-91	Zr-92	Zr-94	Zr-96
ENDF/B-VII.1	1.632E-01	6.060E+00	6.948E-01	3.211E-01	5.169E+00
ENDF/B-VIII.β4	1.635E-01	5.827E+00	5.899E-01	3.143E-01	5.100E+00
Difference	+0.2%	-3.9%	-15.1%	-2.1%	-1.3%

ICT_003_C133 Benchmark



Iron Streaming Benchmark

- FUND_IPPE_VDF_MULTI_TRANS_001 ICSBEP model
- Transmission measurements for a collimated neutron beam incident on iron samples of various thicknesses:
  - 1.62 cm, 4.81 cm, 9.57 cm, 31.74 cm, 44.44 cm
- Uniform in energy from 100 keV to 4 MeV
- Tallies binned for six energy groups:
  - 100 keV, 200 keV, 400 keV, 800 keV, 1.4 MeV, 2.5 MeV, 4.0 MeV

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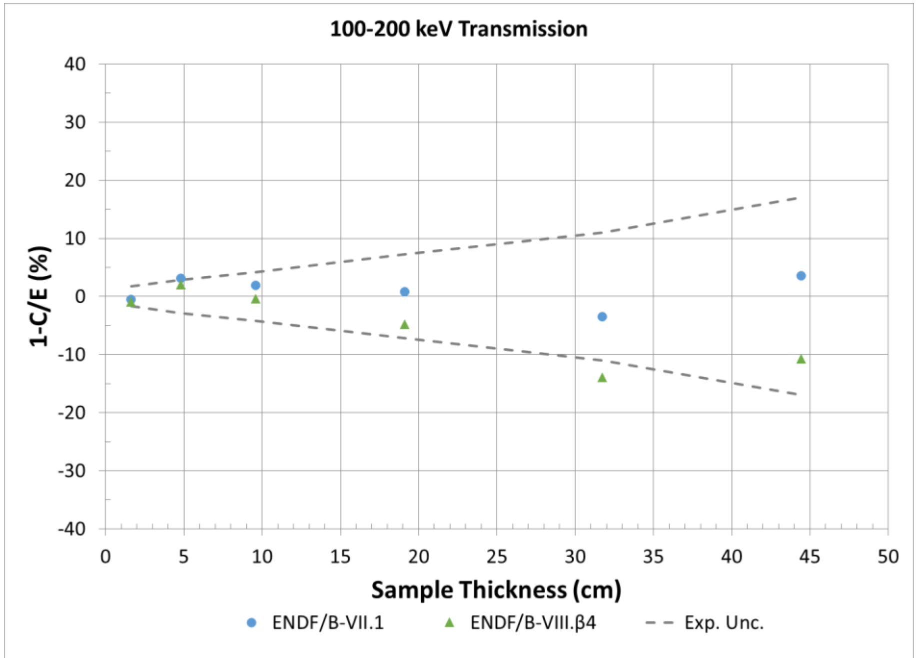
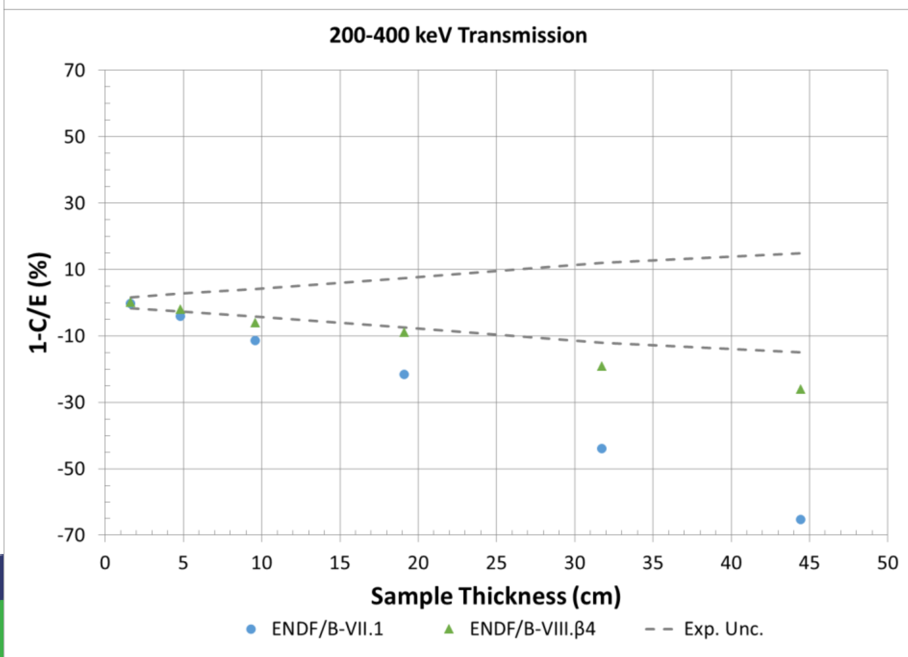
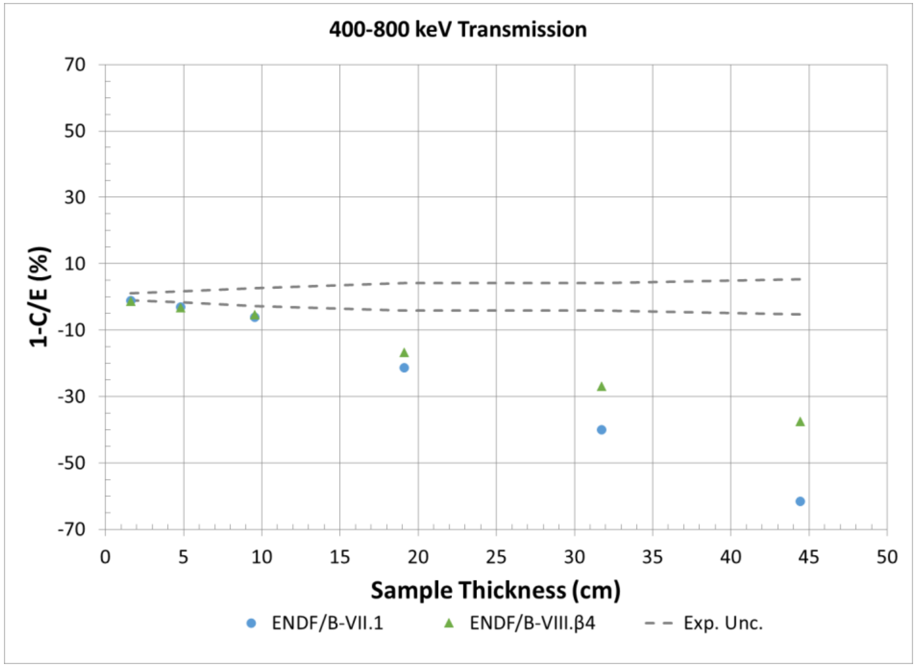
Transmission Results

- ENDF/B-VII.1 outperforms ENDF/B-VIII.β4 in the 100-200 keV range
- Above 200 keV, ENDF/B-VIII.β4 performs better







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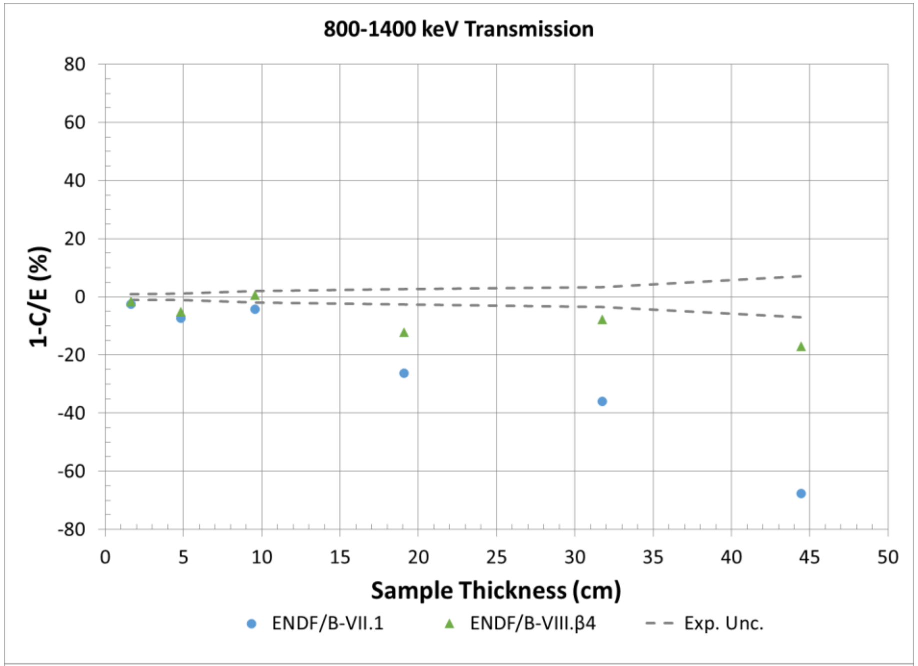
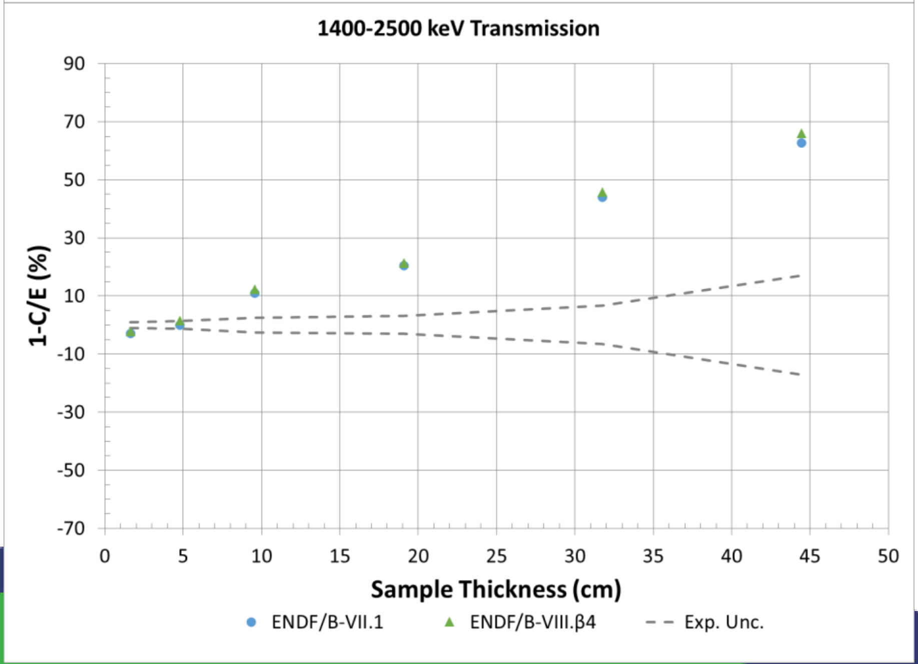
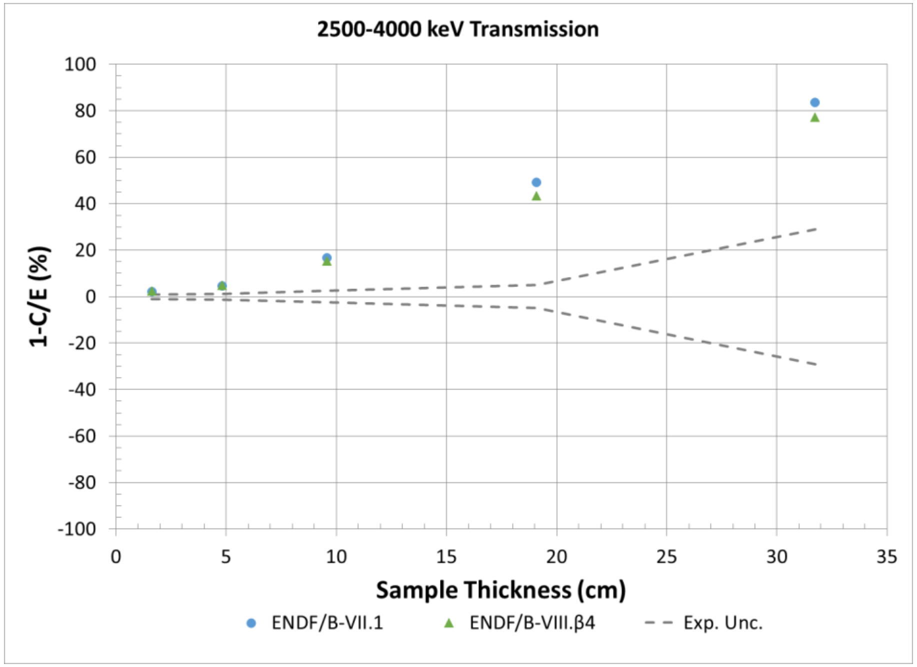
Transmission Results

- ENDF/B-VIII.β4 performs better at higher energy ranges
  - Improvement of Fe-56 in the new evaluation







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FCA-IX (Fast Critical Assembly) Benchmarks

Notable Changes

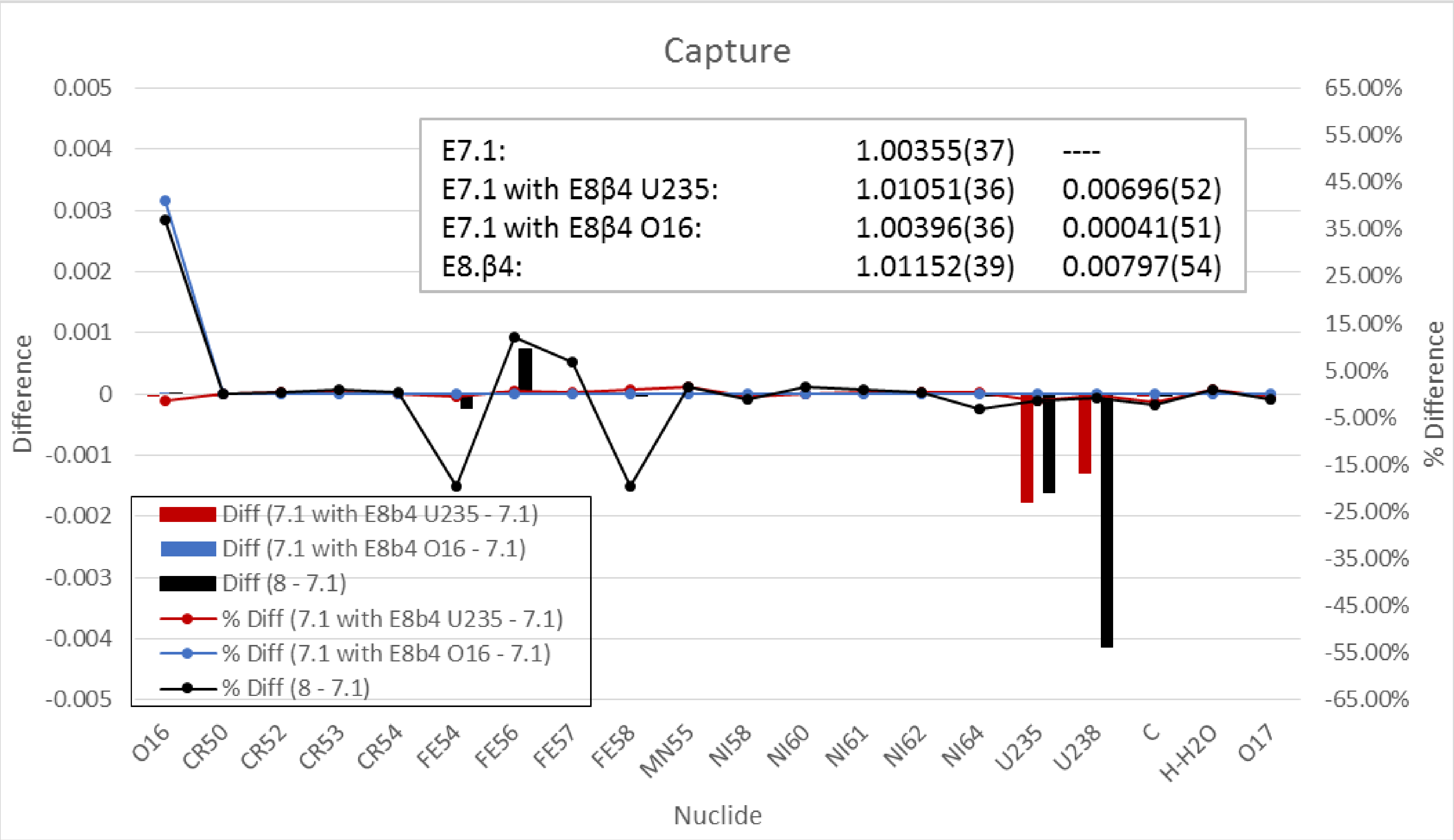
Benchmark	*C/E* E7.1	*C/E* E8.β4	Difference
IX_1	1.00355(37)	1.01152(39)	0.00797(54)
IX_2	1.00983(31)	1.01198(31)	0.00215(44)
IX_3	1.01499(28)	1.01476(29)	-0.00023(41)

Swapping nuclides …

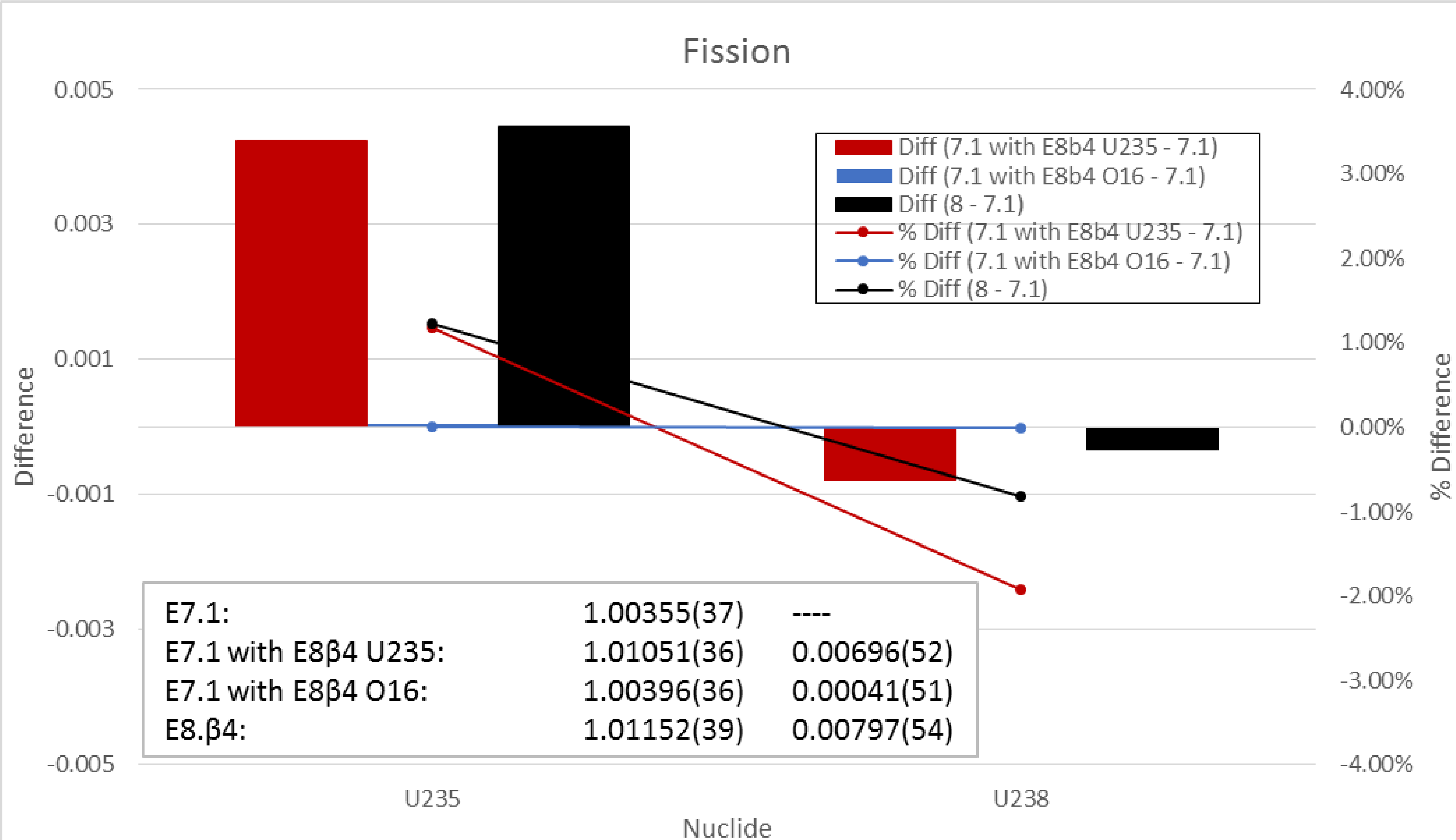
Benchmark	*C/E* E7.1	*C/E* E7.1 + U-235 E8.β4	Difference from E7.1	*C/E* E7.1 + O-16 E8.β4	Difference from E7.1
IX_1	1.00355(37)	1.01051(36)	0.00696(52)	1.00396(36)	0.00041(51)
IX_2	1.00983(31)	1.01185(31)	0.00201(44)	1.01012(33)	0.00029(45)
IX_3	1.01499(28)	1.01431(29)	-0.00068(41)	1.01544(29)	0.00045(40)

Red highlight indicates C/E has gotten further from 1.0 in ENDF/B-VIII.β4

FCA (Fast Critical Assembly) IX-1



FCA (Fast Critical Assembly) IX-1



Summary of Analysis

- ENDF/B-VIII.β4 data result in a net decrease in *C*/*E* for ICSBEP models of 69pcm – overall good agreement with ENDF/B-VII.1

- Hafnium and zirconium ICSBEP benchmarks also show a net increase in *C*/*E*
  - Differences are not dominated by the Hf and Zr evaluations
    - O-16 (n,α) capture increases + U-235 fission increases

- ENDF/B-VIII.β4 Fe-56 is an improvement from ENDF/B-VII.1
  - Transmission analysis shows improvement of Fe-56 from 200 keV to 2.5 MeV

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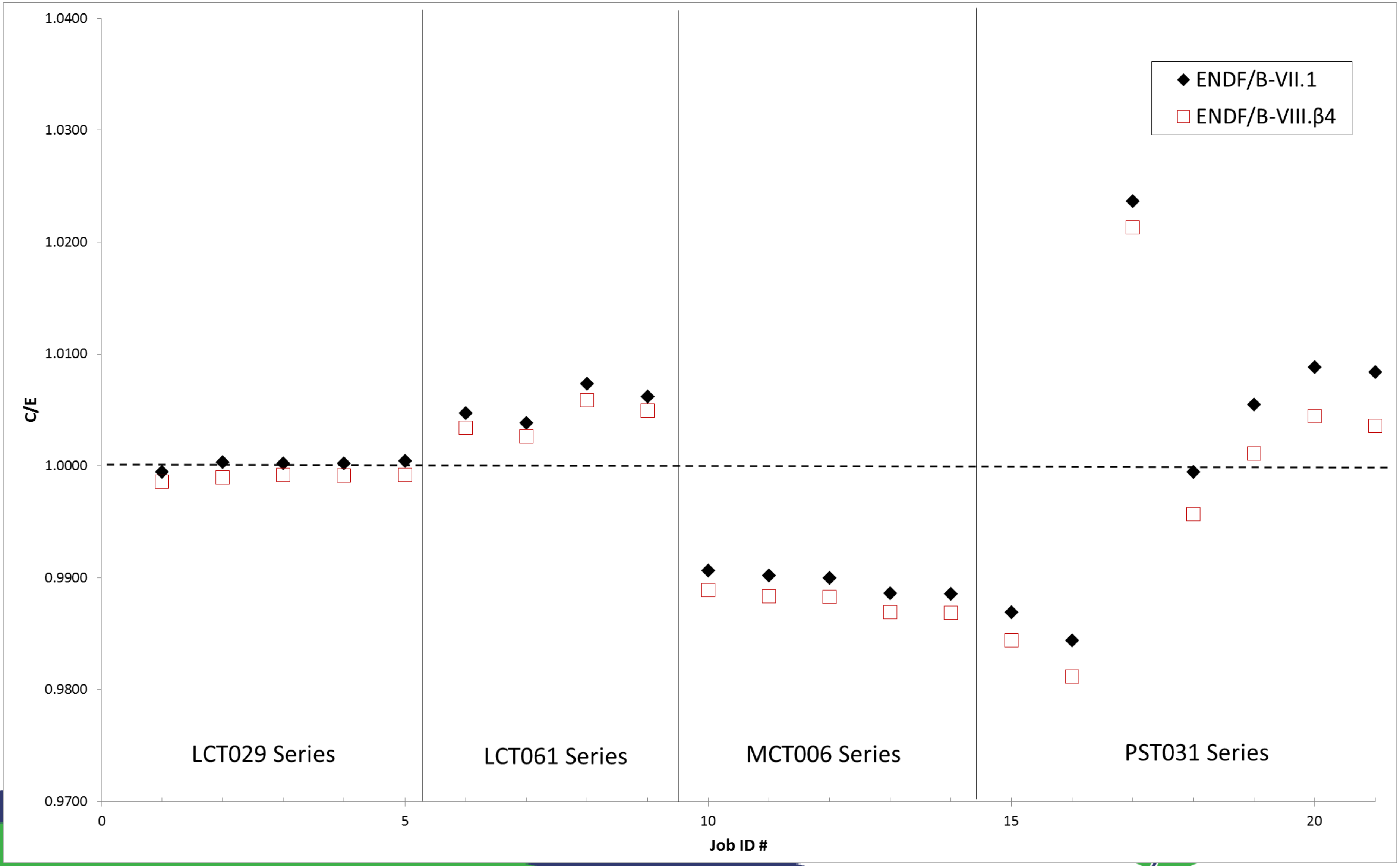
Backup Slides

LCT029, LCT061, MCT006, PST031



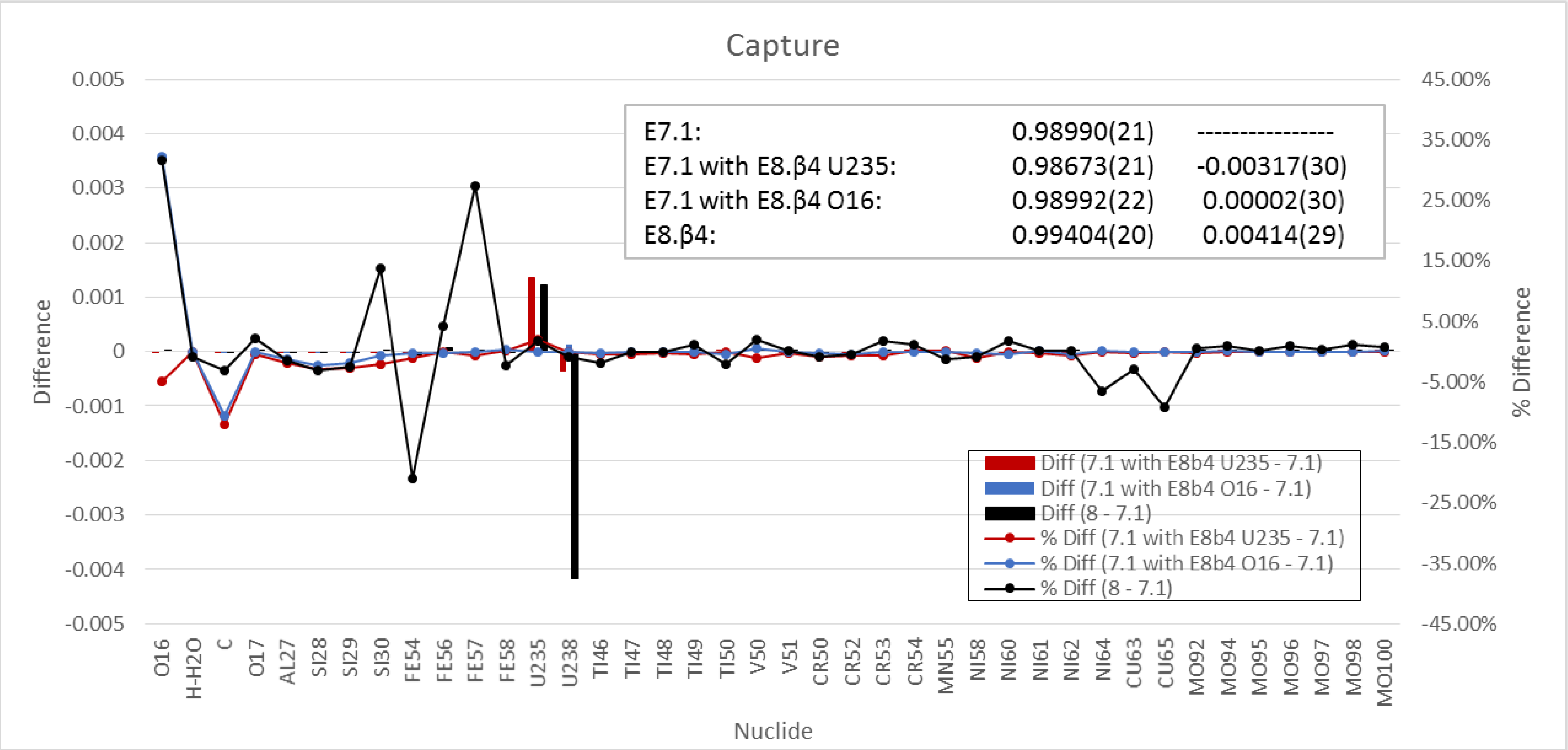
MMF_008_07 Benchmark

Library	C/E	Diff
E7.1	0.98990(21)	---
E8.β4	0.99404(20)	0.00414(29)
E7.1 + U-235 E8.β4	0.98673(21)	-0.00317(30)
E7.1 + O-16 E8.β4	0.98992(22)	0.00002(30)

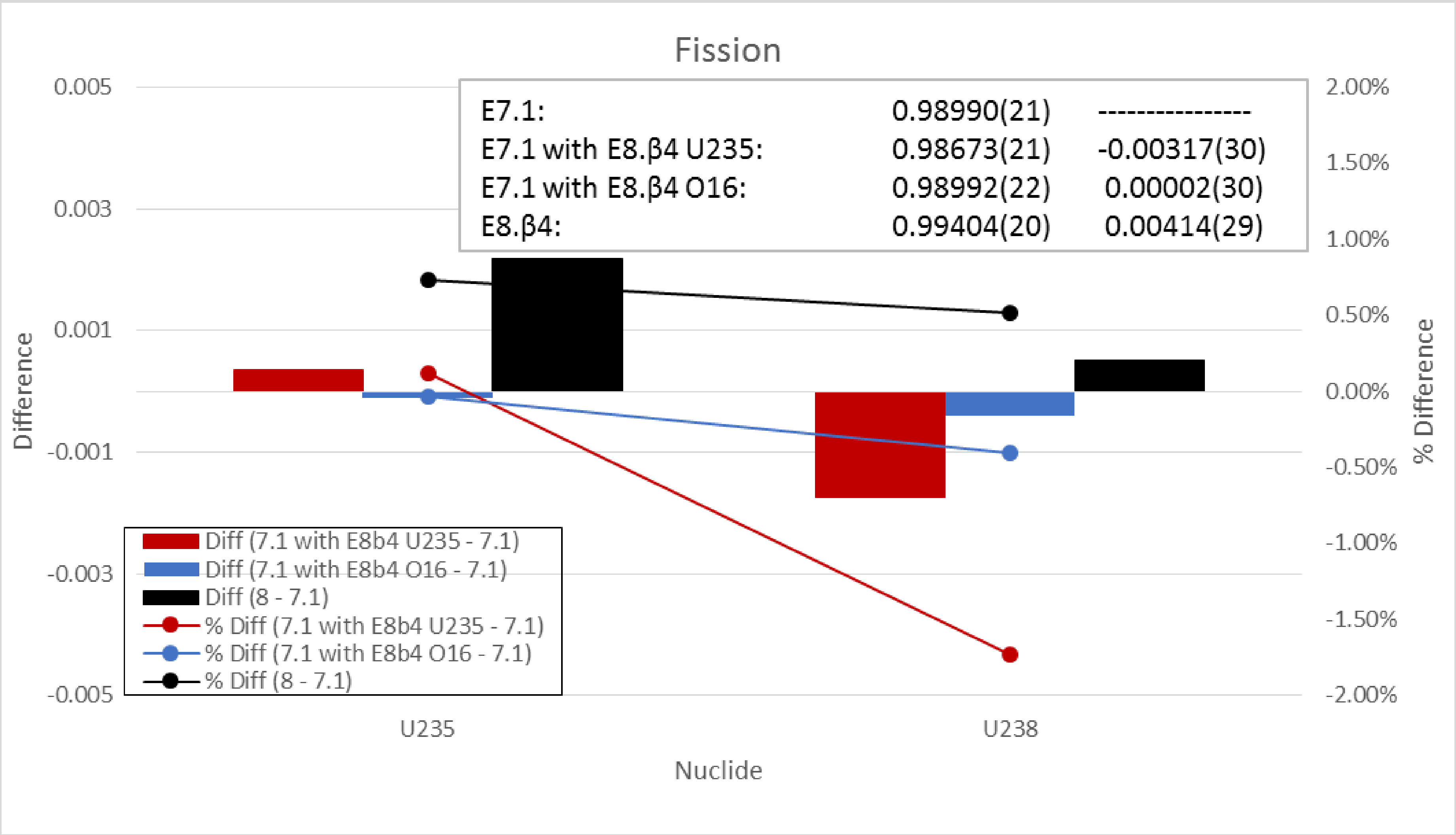
Red highlight indicates C/E has gotten further from 1.0 in ENDF/B-VIII.β4

NAVAL NUCLEAR LABORATORY

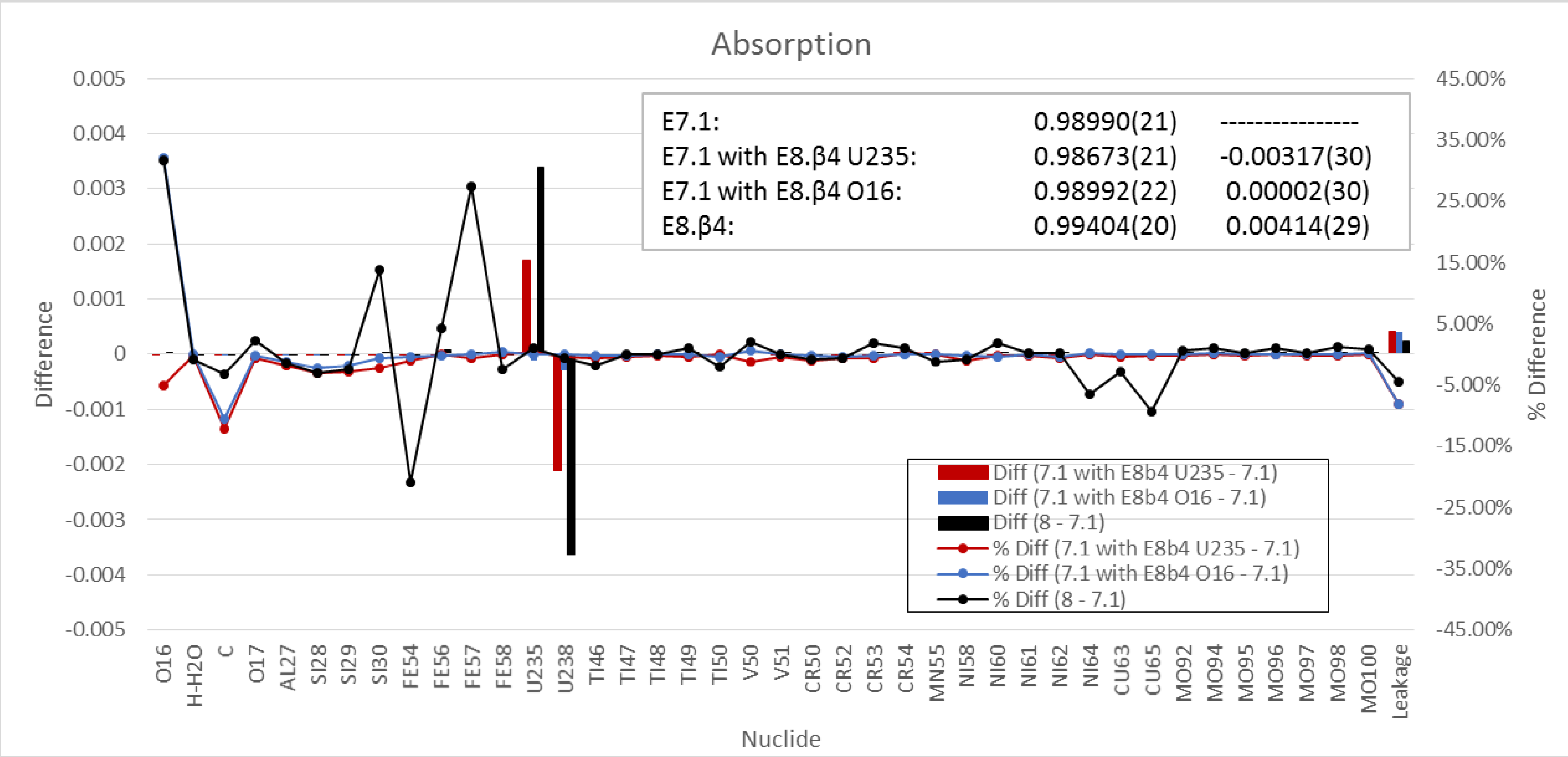
MMF_008_07 Benchmark



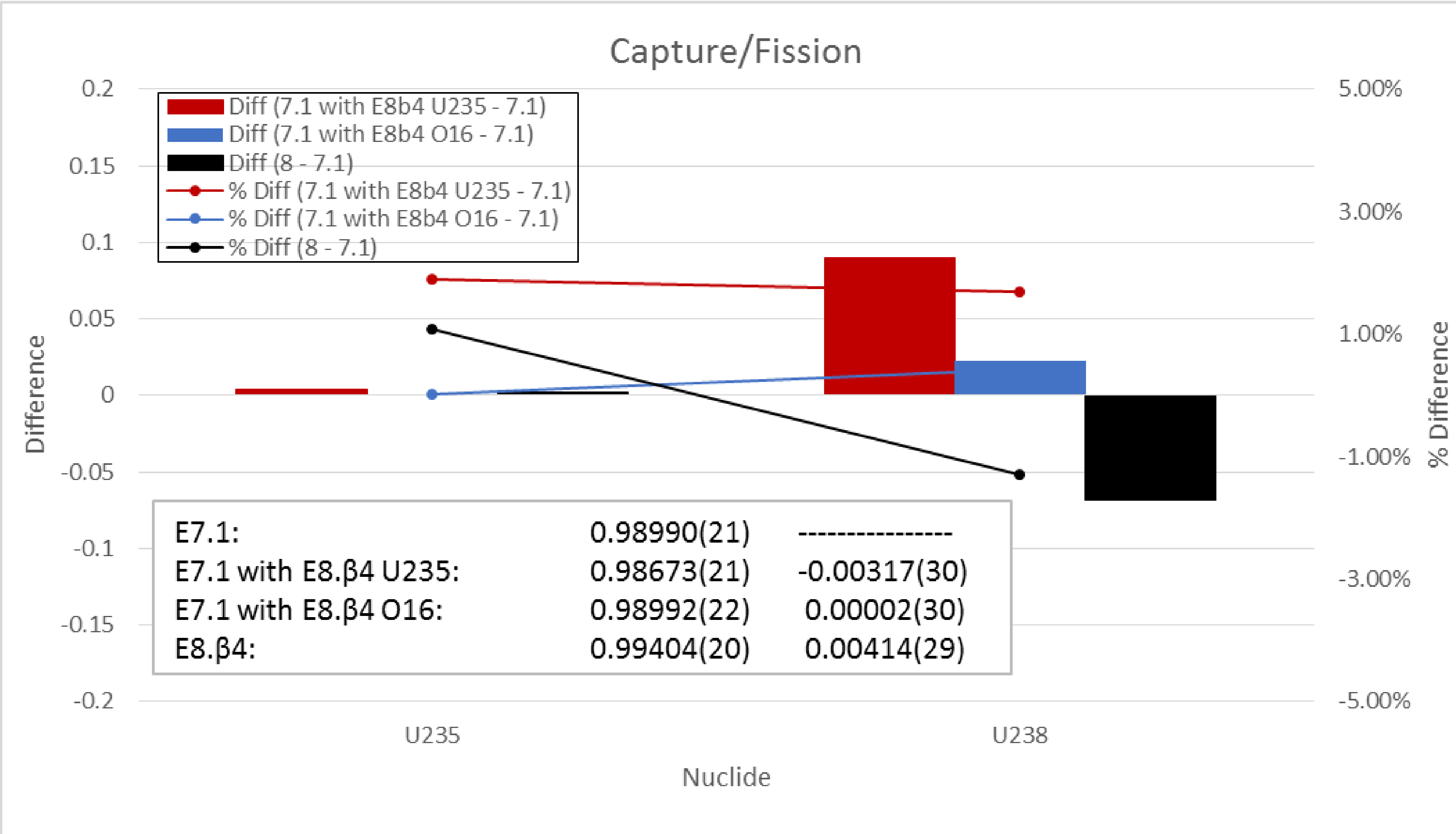
MMF_008_07 Benchmark



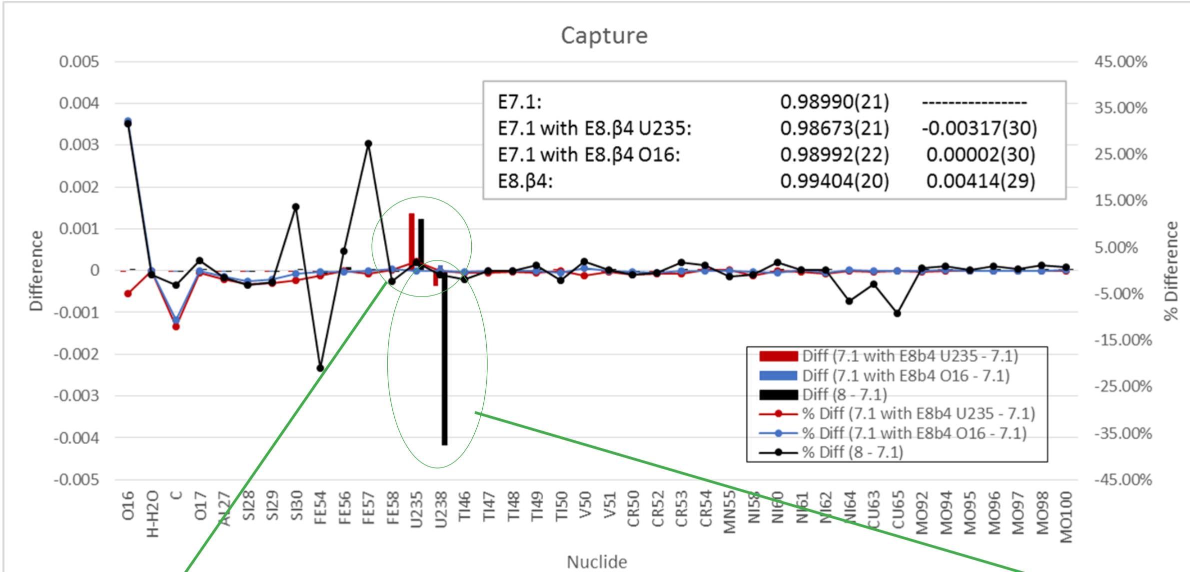
MMF_008_07 Benchmark

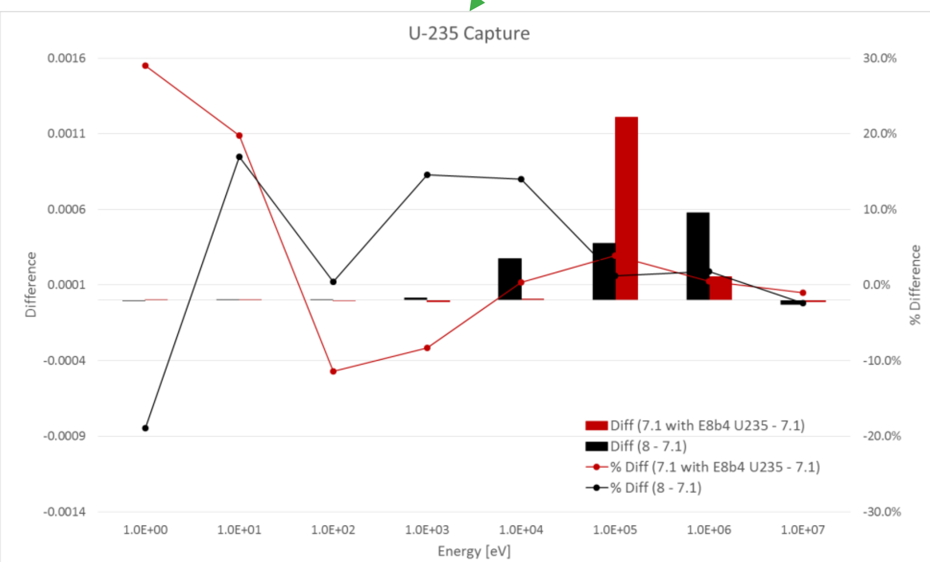


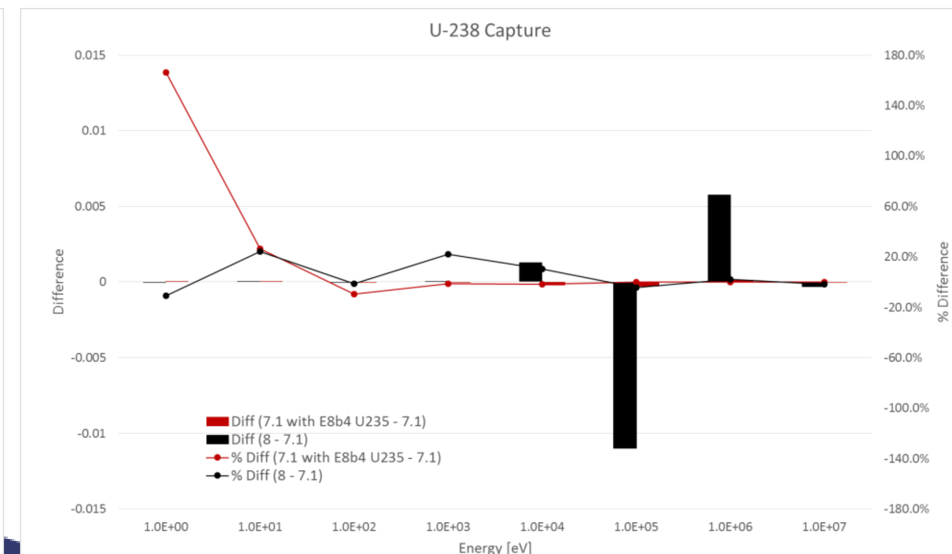
MMF_008_07 Benchmark



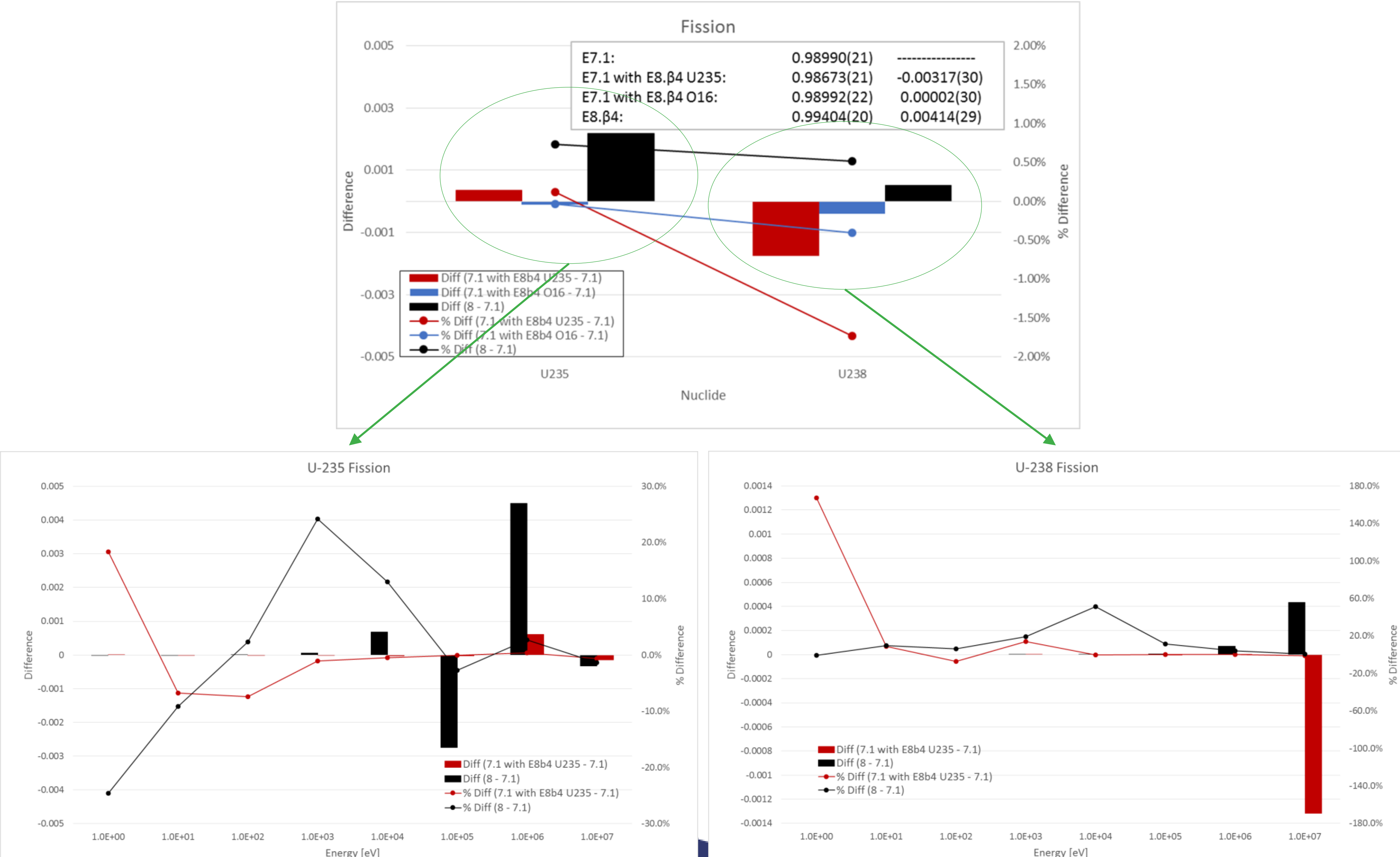
MMF_008_07 Benchmark - Capture







MMF_008_07 Benchmark - Fission



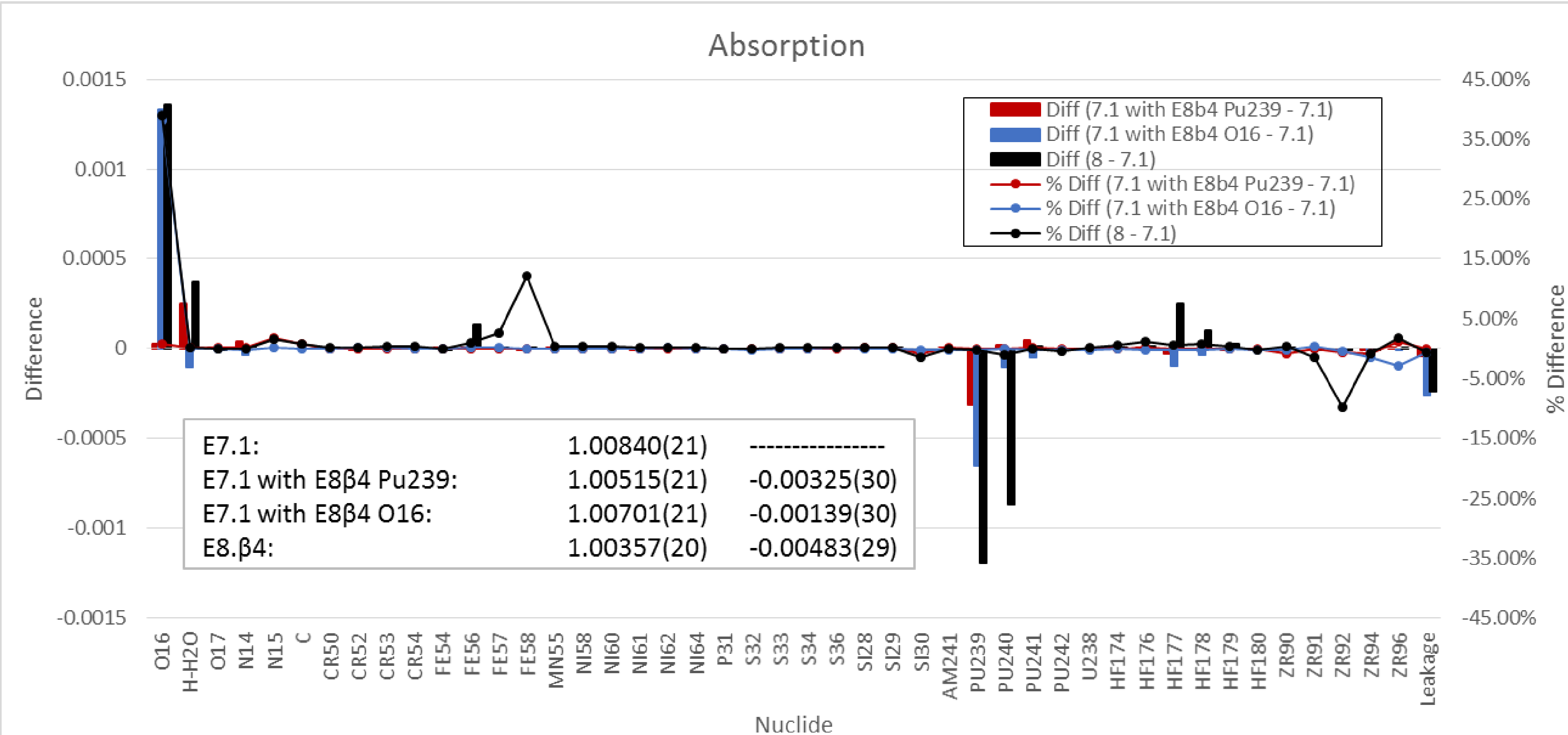
MMF_008_07 Benchmark

- *C/E* improves by +414pcm in ENDF/B-VIII.β4
  - U-235: capture ↑, fission ↑↑
  - U-238: capture ↓↓, fission ↑

- *C/E* worsens by -317pcm when using ENDF/B-VII.0 with U-235 from ENDF/B-VIII.β4
  - U-235: capture ↑↑, fission ↑
  - U-238: capture ↓ , fission ↓↓

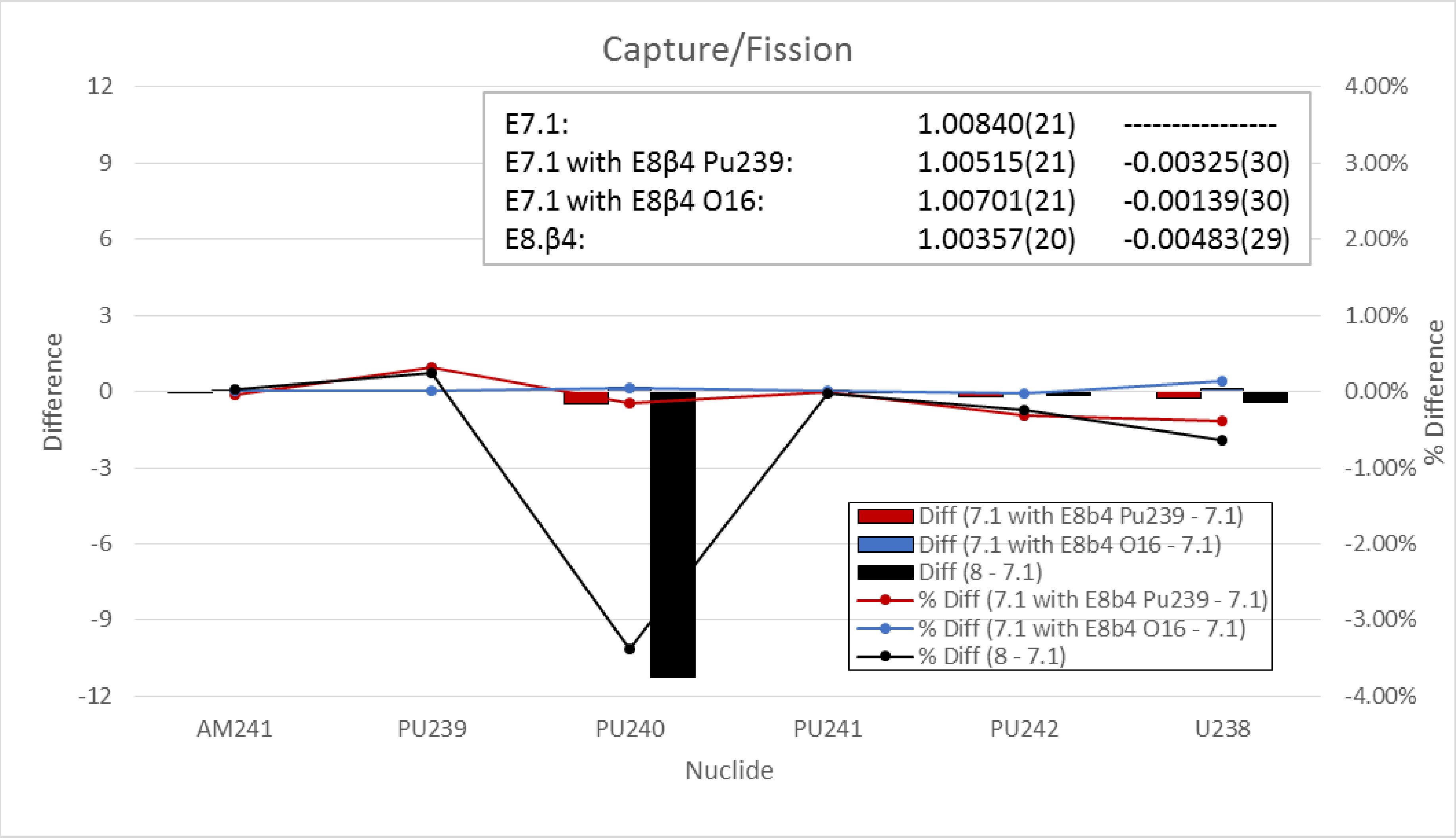
NAVAL NUCLEAR LABORATORY

PST031_07 Benchmark



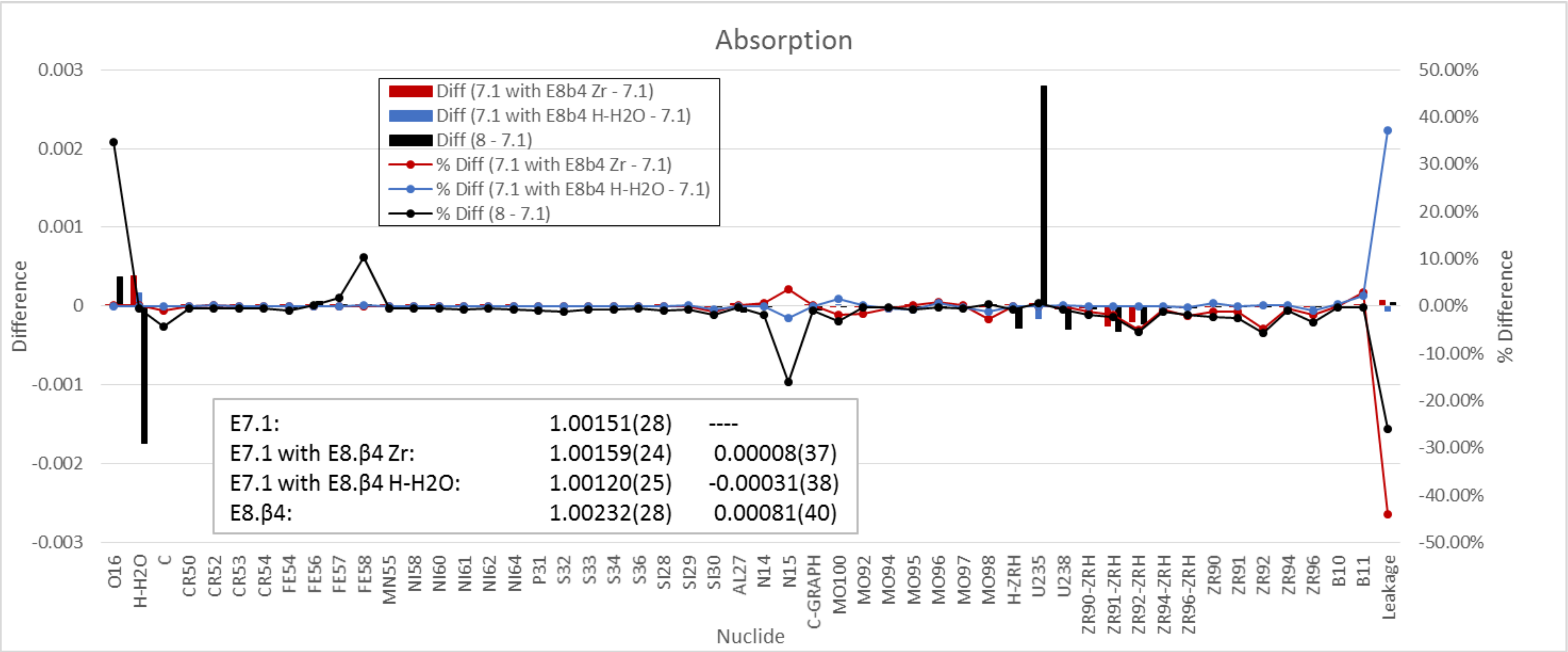
NAVAL NUCLEAR LABORATORY

PST031_07 Benchmark



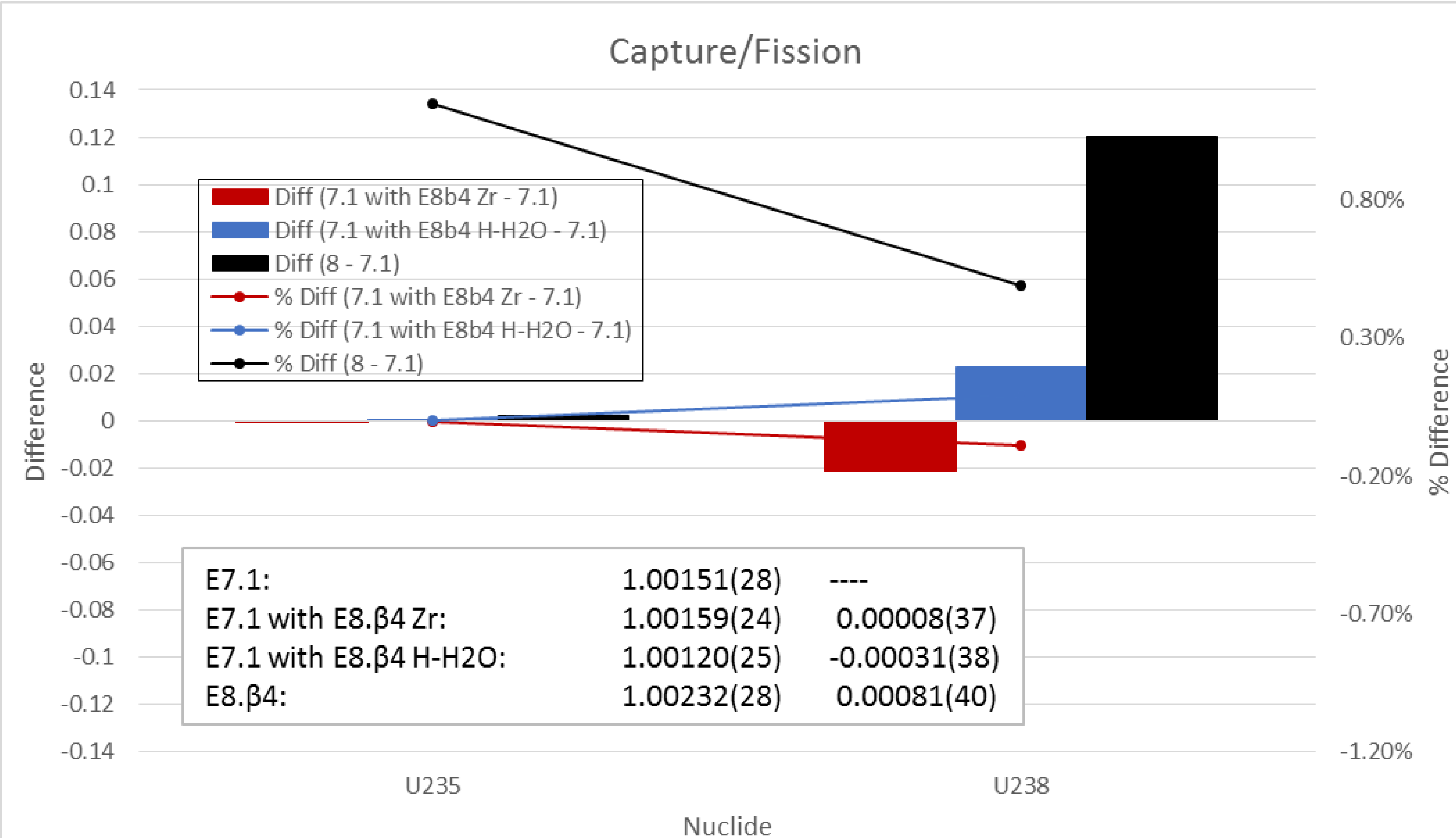
LABORATORY

ICT_003_C133 Benchmark



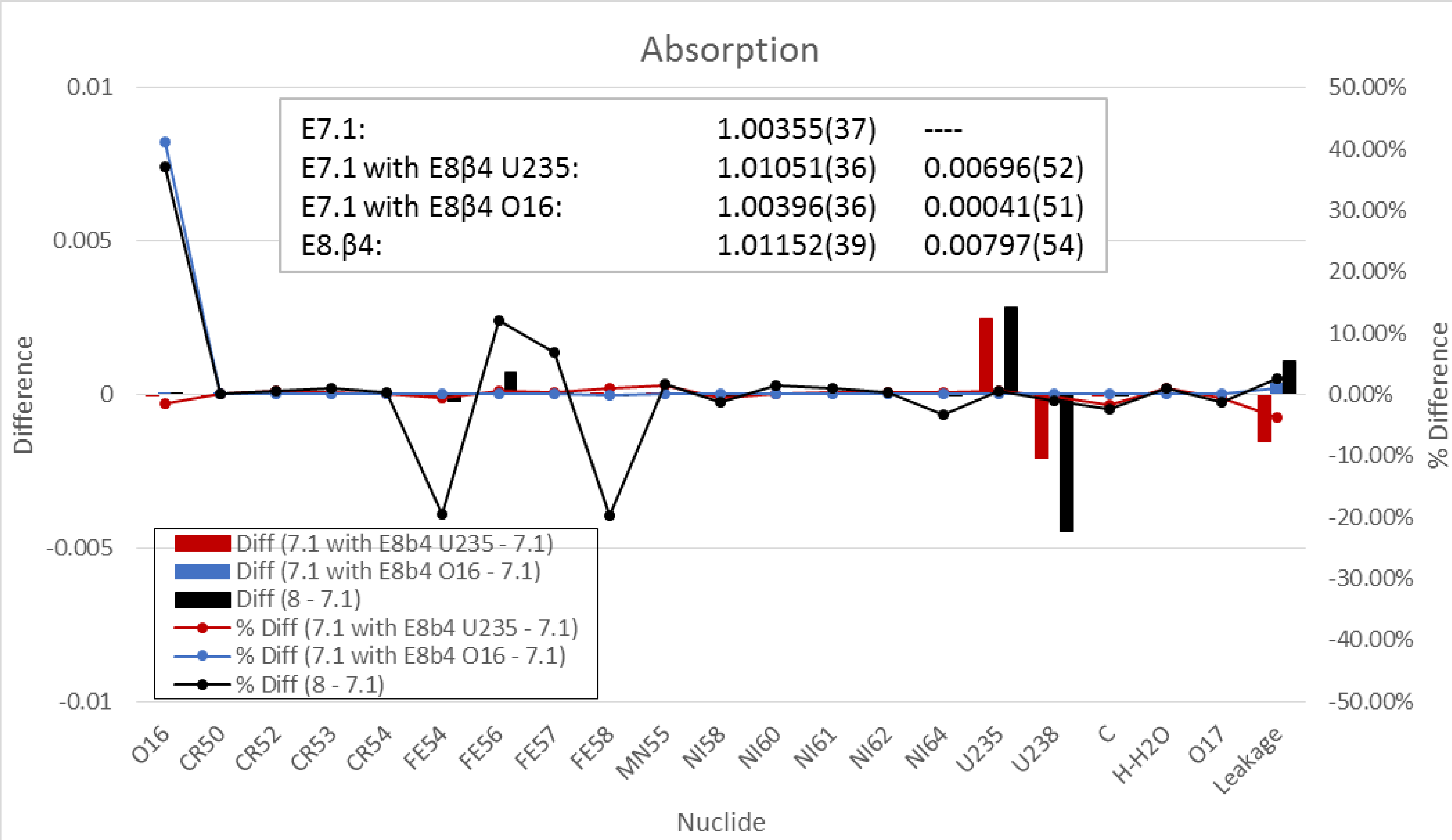
NAVAL NUCLEAR LABORATORY

ICT_003_C133 Benchmark

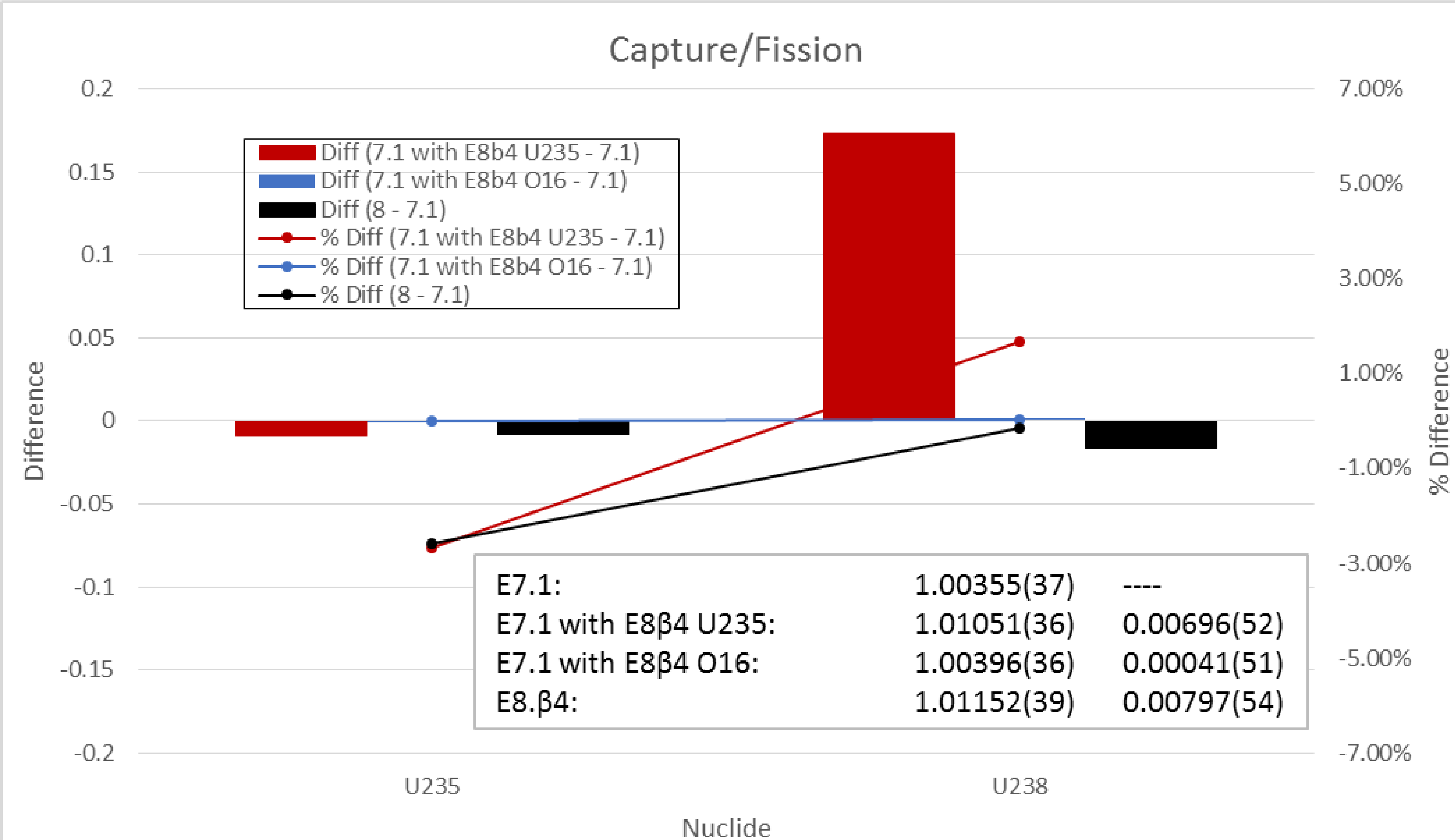


NAVAL NUCLEAR LABORATORY

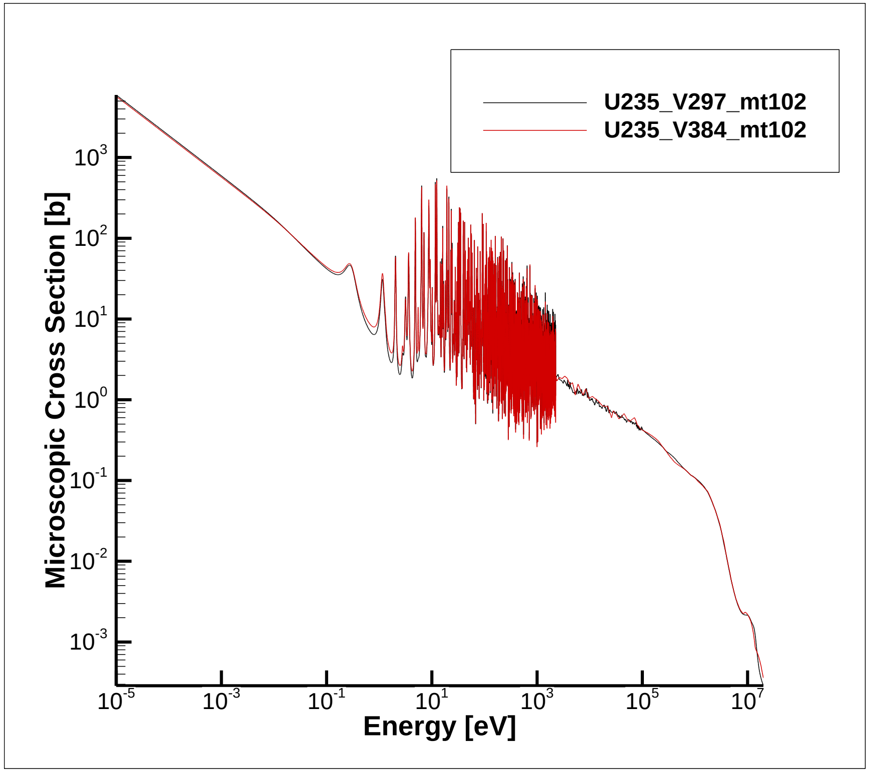
FCA (Fast Critical Assembly) IX-1

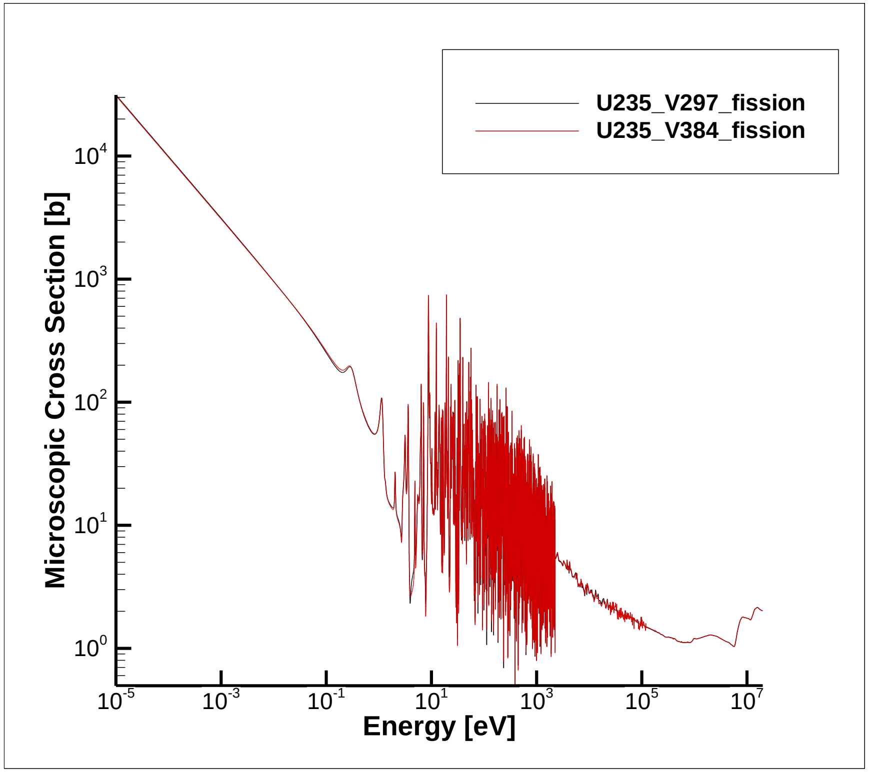


FCA (Fast Critical Assembly) IX-1



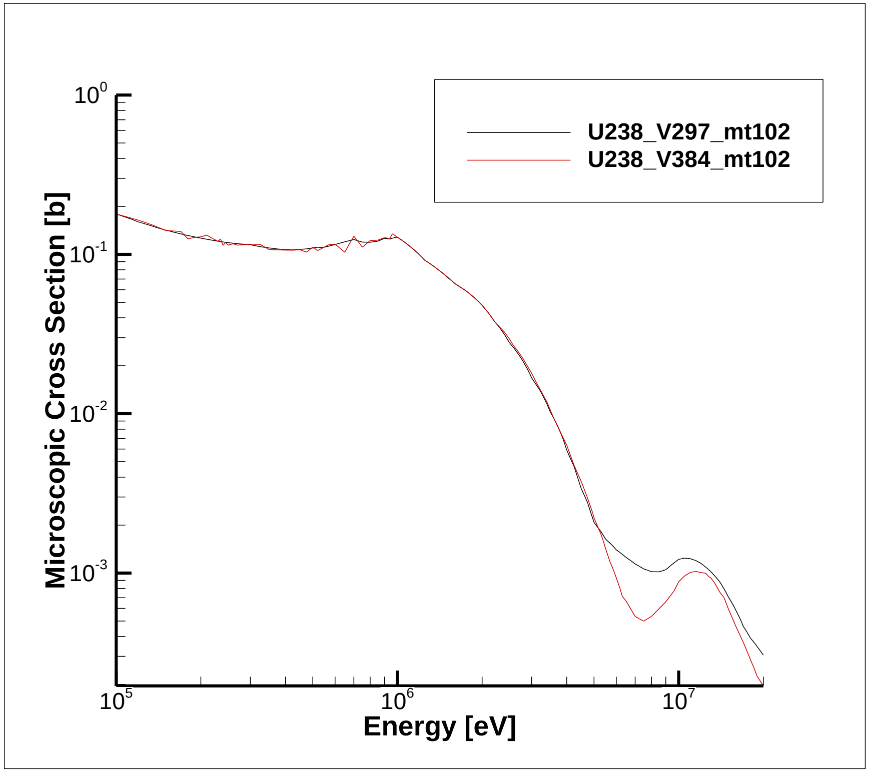
U-235 Cross Sections

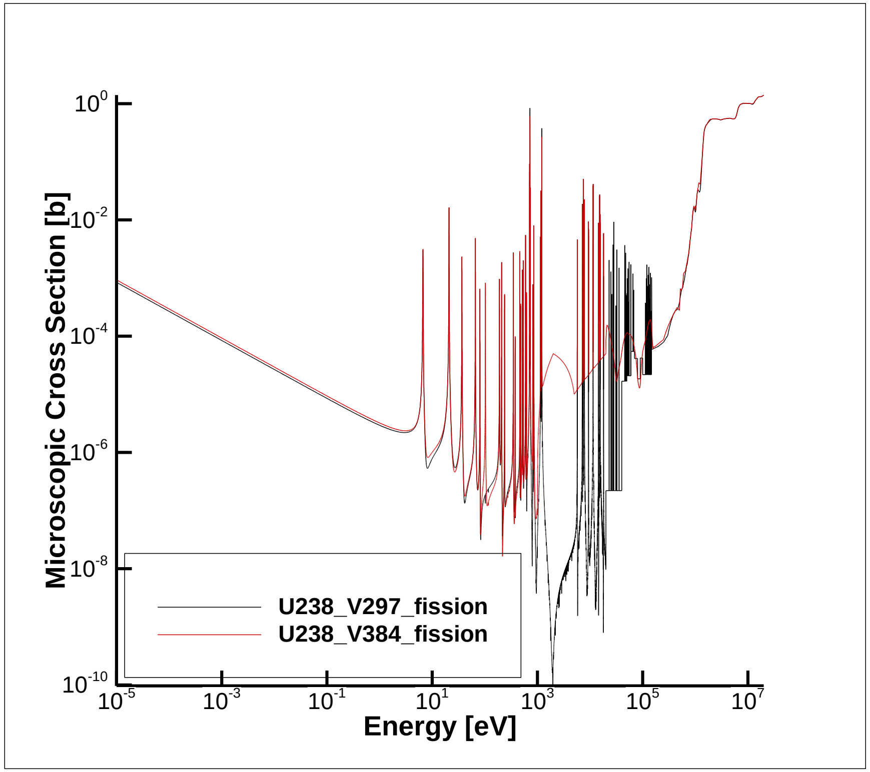




NAVAL NUCLEAR LABORATORY

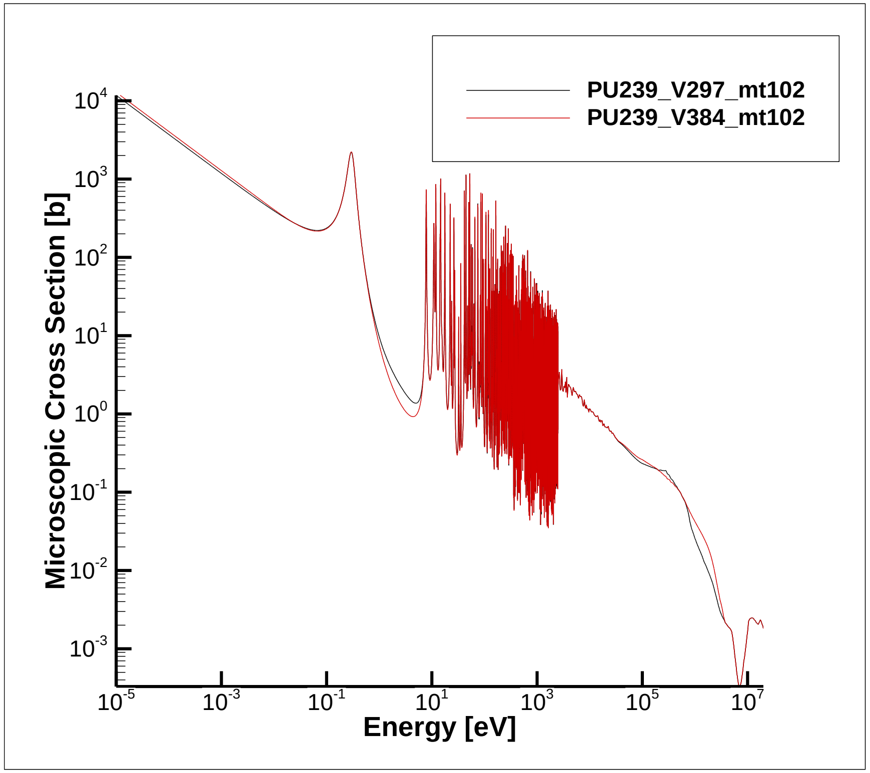
U-238 Cross Sections

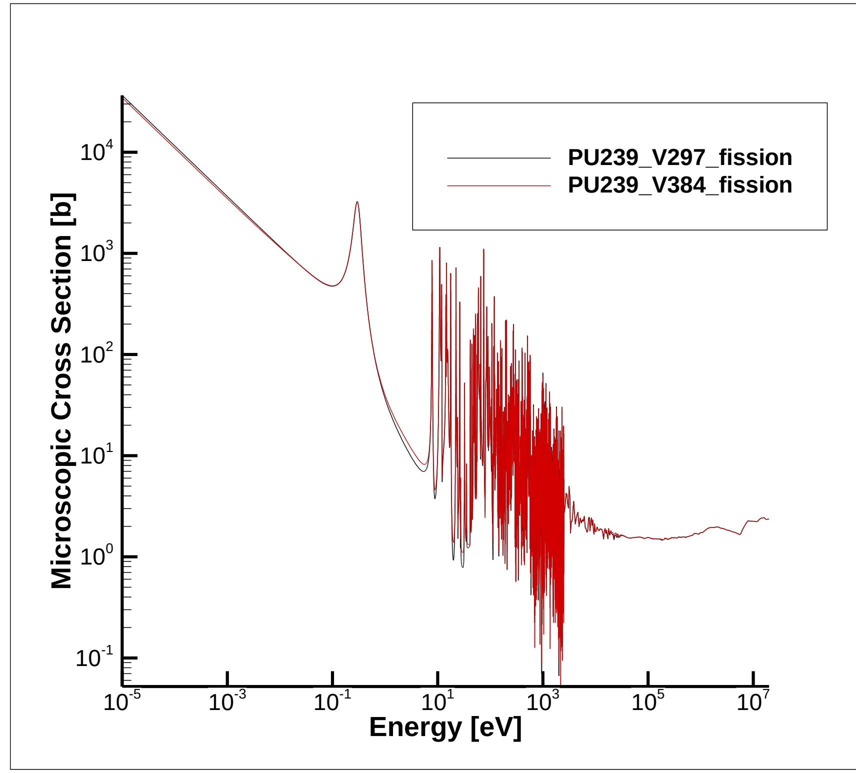




NAVAL NUCLEAR LABORATORY

Pu-239 Cross Sections





Pu-240 Cross Sections