Naval Nuclear Laboratory Analysis of the ENDF/B-VIII.0β5 Library

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Naval Nuclear Laboratory

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NAVAL NUCLEAR LABORATORY

Outline

- Suite of 180 ICSBEP critical models run using:
  - ENDF/B-VII.1 and ENDF/B-VIII.0β5
  - *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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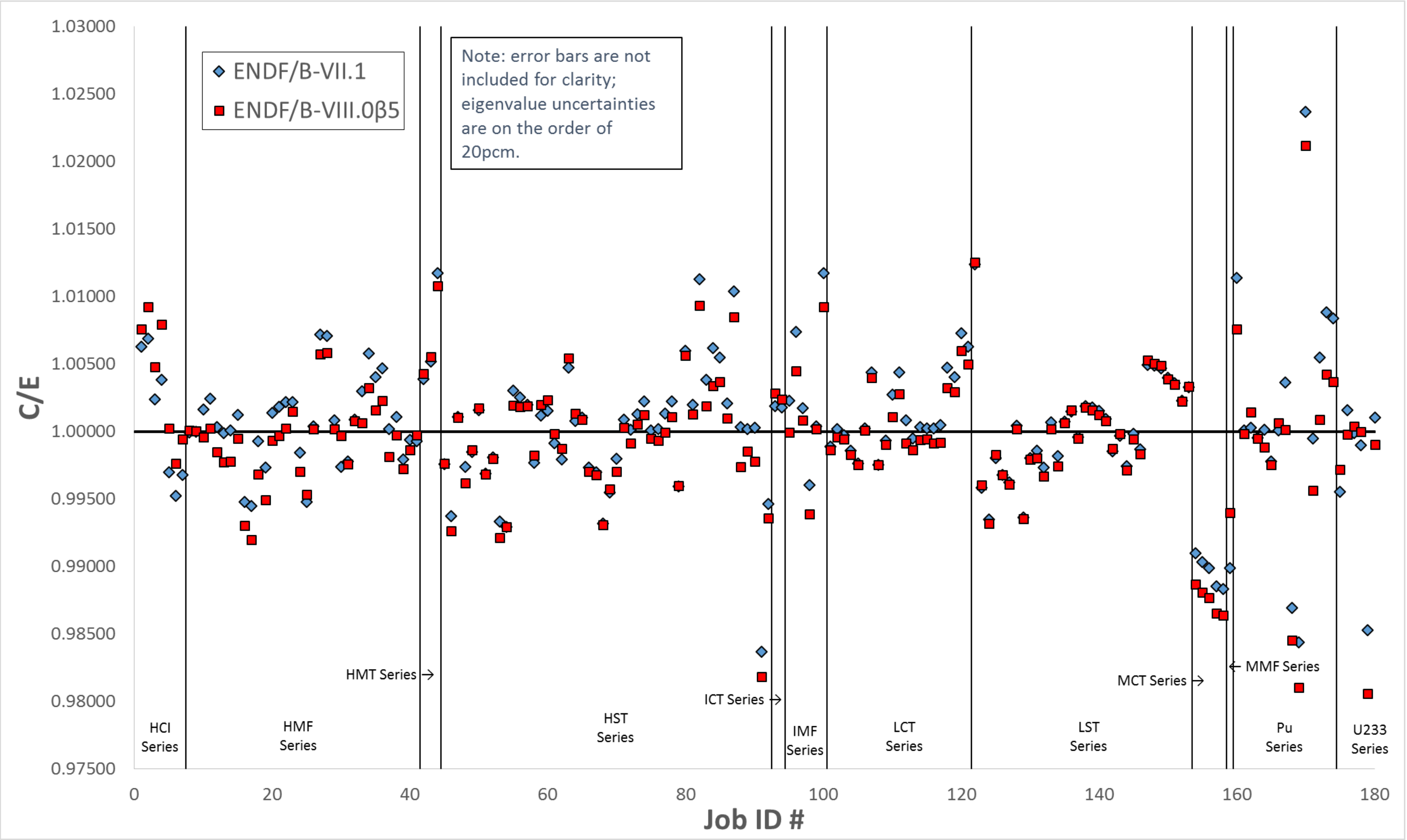
Model #	Benchmark Name	Model k-eff	Exp. Unc.
1	HCI_003_01	1.00000	0.00570
2	HCI_003_02	1.00000	0.00610
3	HCI_003_03	1.00000	0.00560
4	HCI_003_04	1.00000	0.00550
5	HCI_003_05	1.00000	0.00470
6	HCI_003_06	1.00000	0.00470
7	HCI_003_07	1.00000	0.00500
8	HMF_001_01A	1.00000	0.00100
9	HMF_001_01B	1.00000	0.00100
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
43	HMT_001_01D	1.00100	0.00600
44	HMT_014_01	0.99390	0.00150
45	hst_001_01	1.00040	0.00600

Model #	Benchmark Name	Model k-eff	Exp. Unc.
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	hst_050_01	0.99530	0.00860
83	hst_050_02	0.99870	0.00830
84	hst_050_03	0.99840	0.00790
85	hst_050_04	0.99870	0.00840
86	hst_050_05	0.99850	0.00850
87	hst_050_06	0.99850	0.00810
88	hst_050_07	0.99780	0.00780
89	hst_050_08	0.99750	0.00840
90	hst_050_09	0.99660	0.00820

Model #	Benchmark Name	Model k-eff	Exp. Unc.
91	hst_050_10	0.99660	0.00900
92	hst_050_11	0.99640	0.00890
93	ICT_003_C132	0.99865	0.00015
94	ICT_003_C133	1.00310	0.00015
95	IMF_003	1.00000	0.00170
96	IMF_004	1.00000	0.00300
97	IMF_005	1.00000	0.00210
98	IMF_006	1.00000	0.00230
99	IMF_007	0.99480	0.00130
100	IMF_009	1.00000	0.00530
101	LCT_002_01	0.99970	0.00200
102	LCT_002_02	0.99970	0.00200
103	LCT_002_03	0.99970	0.00200
104	LCT_002_04	0.99970	0.00180
105	LCT_002_05	0.99970	0.00190
106	LCT_008_02	1.00070	0.00120
107	LCT_010_01	1.00000	0.00210
108	LCT_010_08	1.00000	0.00210
109	LCT_010_12	1.00000	0.00210
110	LCT_010_17	1.00000	0.00280
111	LCT_010_21	1.00000	0.00280
112	LCT_010_30	1.00000	0.00280
113	LCT_029_01	1.00000	0.00100
114	LCT_029_02	1.00000	0.00100
115	LCT_029_03	1.00000	0.00100
116	LCT_029_04	1.00000	0.00100
117	LCT_029_05	1.00000	0.00100
118	LCT_061_03	1.00050	0.00230
119	LCT_061_04	1.00050	0.00230
120	LCT_061_05	1.00050	0.00230
121	LCT_061_06	1.00050	0.00230
122	lst_001_01	0.99910	0.00290
123	lst_002_01	1.00380	0.00400
124	lst_002_02	1.00240	0.00370
125	lst_002_03	1.00240	0.00440
126	lst_003_01	0.99970	0.00390
127	lst_003_02	0.99930	0.00420
128	lst_003_03	0.99950	0.00420
129	lst_003_04	0.99950	0.00420
130	lst_003_05	0.99970	0.00480
131	lst_003_06	0.99990	0.00490
132	lst_003_07	0.99940	0.00490
133	lst_003_08	0.99930	0.00520
134	lst_003_09	0.99960	0.00520
135	lst_004_01	0.99940	0.00080

Model #	Benchmark Name	Model k-eff	Exp. Unc.
136	lst_004_29	0.99990	0.00090
137	lst_004_33	0.99990	0.00090
138	lst_004_34	0.99990	0.00100
139	lst_004_46	0.99990	0.00100
140	lst_004_51	0.99940	0.00110
141	lst_004_54	0.99960	0.00110
142	lst_007_14	0.99610	0.00090
143	lst_007_30	0.99730	0.00090
144	lst_007_32	0.99850	0.00100
145	lst_007_36	0.99880	0.00110
146	lst_007_49	0.99830	0.00110
147	lst_016_105	0.99960	0.00130
148	lst_016_113	0.99990	0.00130
149	lst_016_125	0.99940	0.00140
150	lst_016_129	0.99960	0.00140
151	lst_016_131	0.99950	0.00140
152	lst_016_140	0.99920	0.00150
153	lst_016_196	0.99940	0.00150
154	MCT_006_08	1.00350	0.00440
155	MCT_006_09	1.00350	0.00440
156	MCT_006_10	1.00210	0.00440
157	MCT_006_11	1.00320	0.00440
158	MCT_006_12	1.00320	0.00440
159	MMF_008_07	1.03000	0.00250
160	PCI_001	1.00000	0.01100
161	PMF_001	1.00000	0.00200
162	PMF_002	1.00000	0.00200
163	PMF_003_103	1.00000	0.00300
164	PMF_006	1.00000	0.00300
165	PMF_008	1.00000	0.00060
166	PMF_011	1.00000	0.00100
167	PST_021_03	1.00000	0.00650
168	PST_031_01	1.00000	0.00510
169	PST_031_02	1.00000	0.00510
170	PST_031_03	1.00000	0.00390
171	PST_031_04	1.00000	0.00440
172	PST_031_05	1.00000	0.00370
173	PST_031_06	1.00000	0.00340
174	PST_031_07	1.00000	0.00230
175	UMF_005_02	1.00000	0.00300
176	UCT_001_03	1.00070	0.00250
177	UMF_001	1.00000	0.00100
178	UMF_006	1.00000	0.00140
179	USI_001	1.00000	0.00830
180	UST_008	1.00060	0.00290

C/E Plots: ENDF/B-VIII.0β5 and ENDF/B-VII.1



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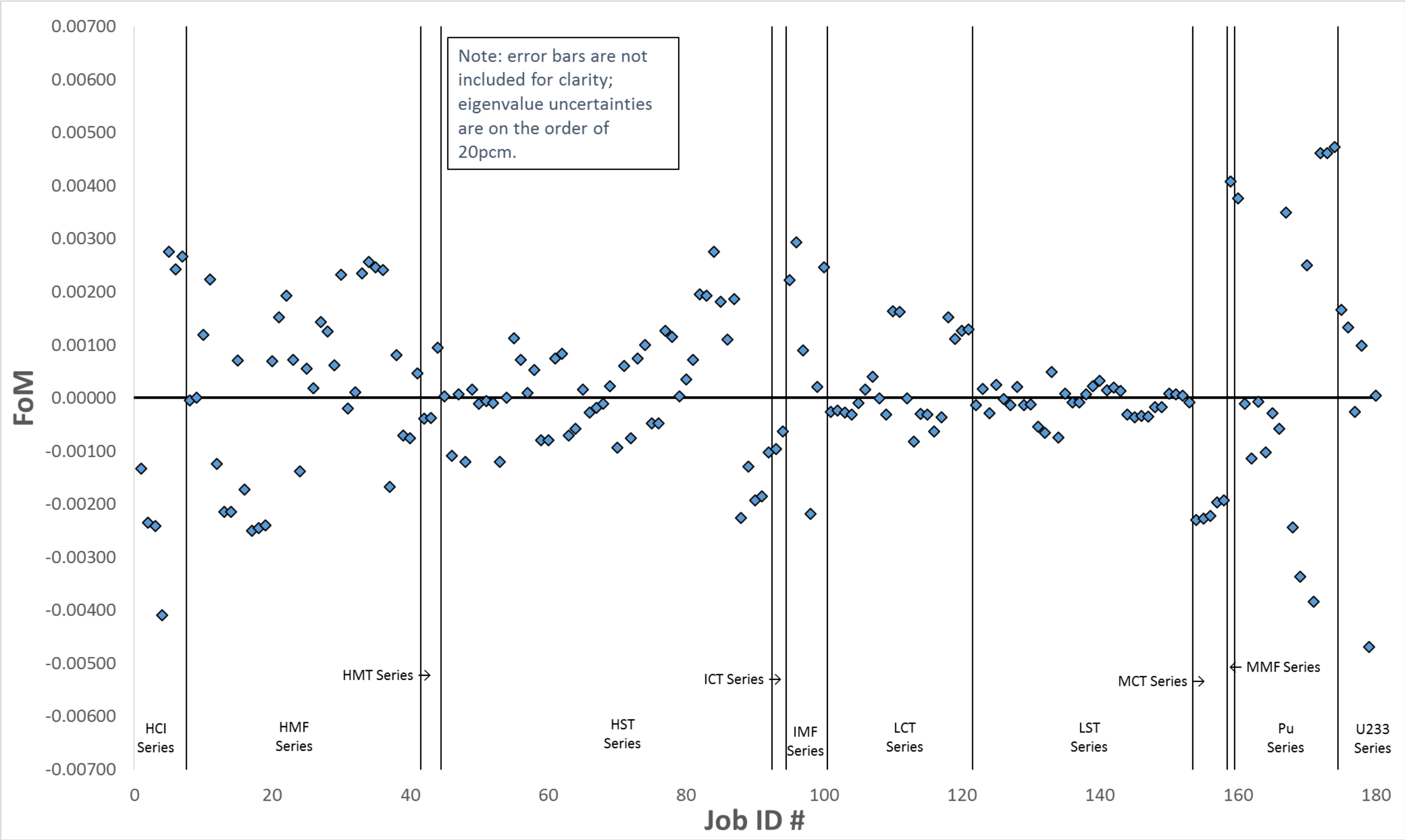
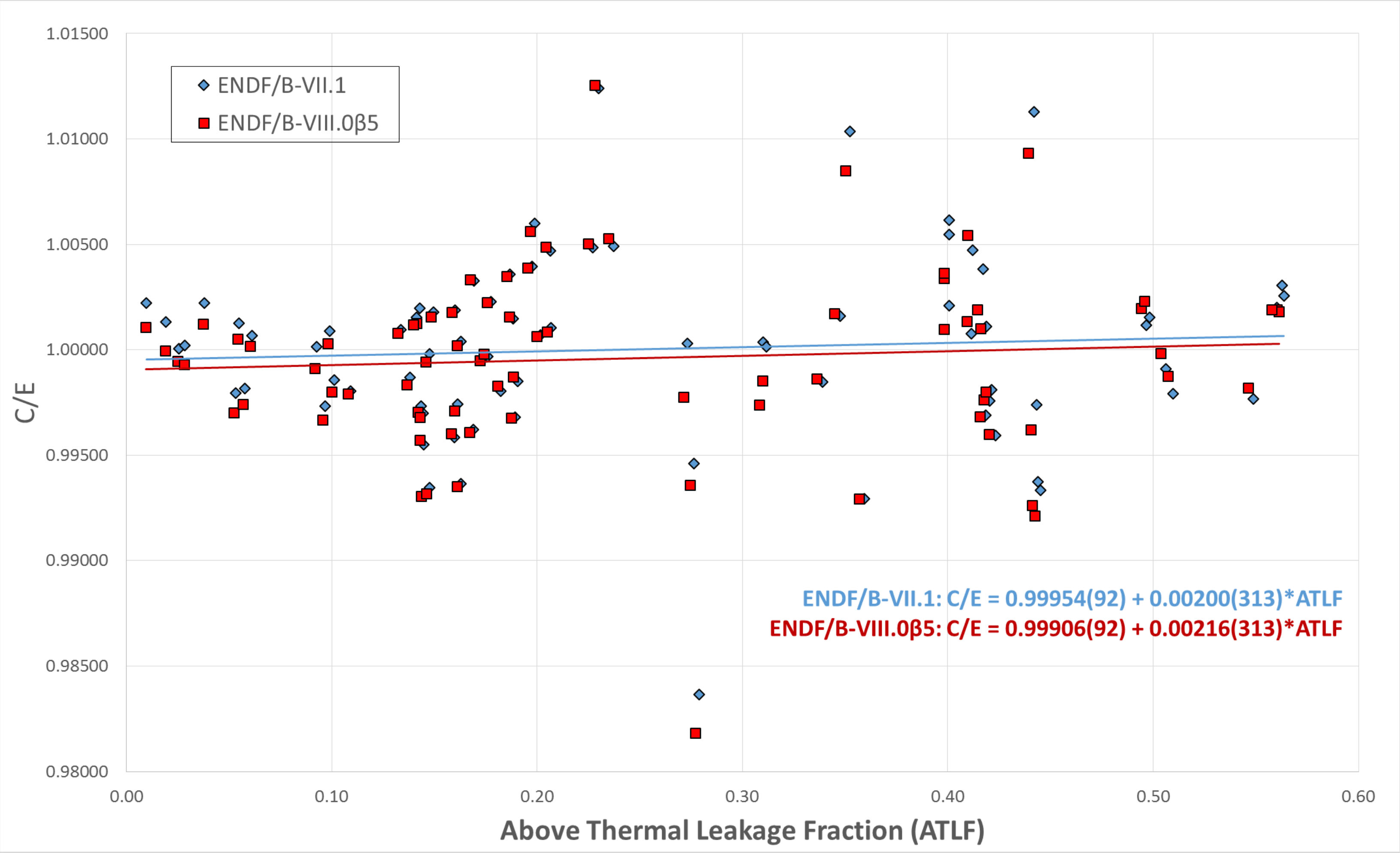
C/E Figure of Merit - ICSBEP



$$\text{FoM} = \left|\left(\frac{C}{E}\right)_{VII.1} - 1\right| - \left|\left(\frac{C}{E}\right)_{VIII.0\beta5} - 1\right|$$

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



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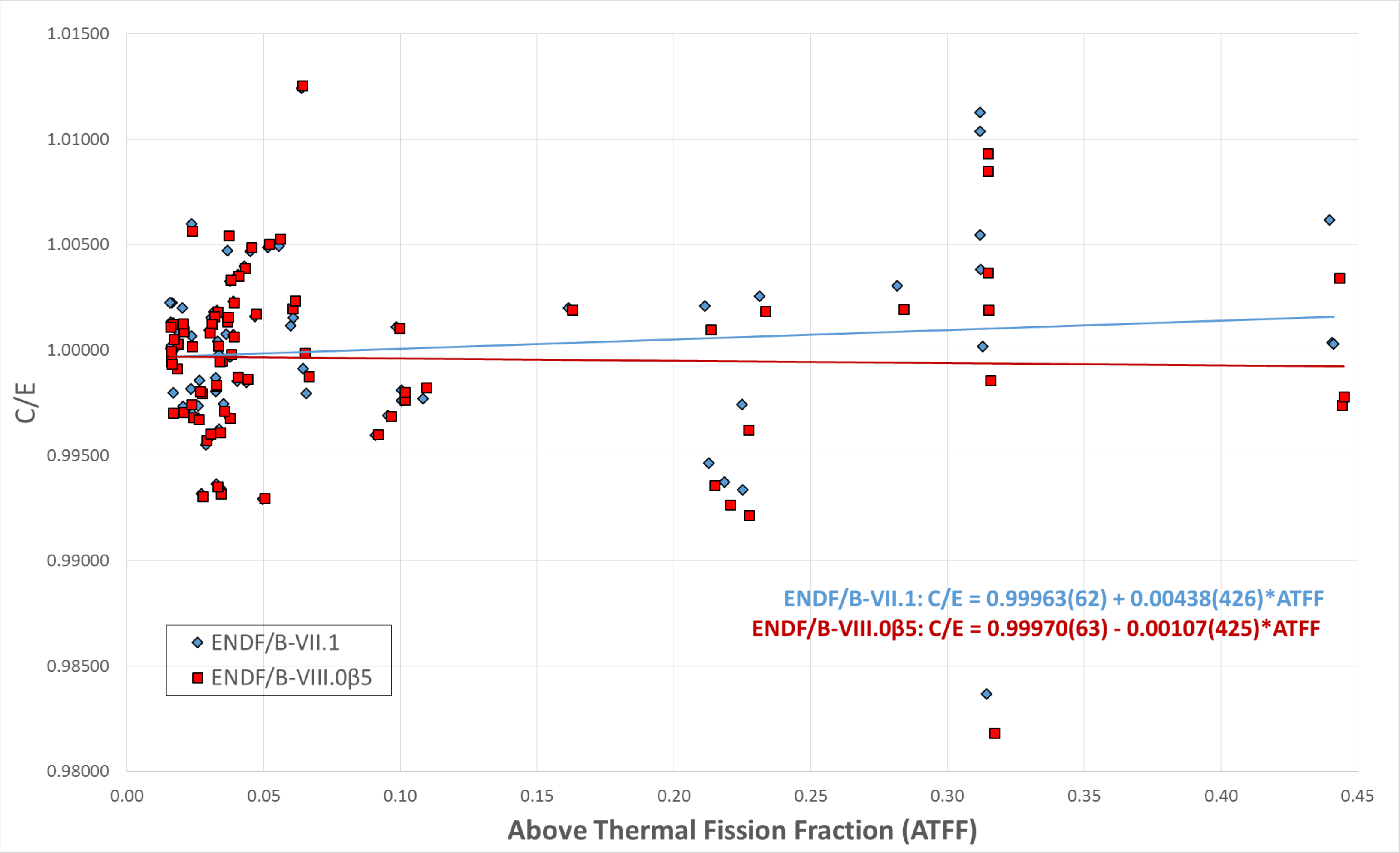
Trend Analysis (HST & LST Series): Above Thermal Fission Fraction (ATFF)



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C/E Series Average Results

- Some notable changes observed for HCI and MCT series
  - 264 pcm increase and 214 pcm decrease, respectively, away from 1.0 in ENDF/B-VIII.0β5
- *C/E* deviation from 1.0 is about the same overall

	# Models	ENDF/B-VII.1	ENDF/B-VIII.0β5	Diff.
All	180	1.00029(21)	0.99954(21)	-0.00075(30)
HCI	7	1.00119(20)	1.00384(20)	0.00264(28)
HMF	34	1.00056(20)	0.99925(20)	-0.00131(28)
HMT	3	1.00693(14)	1.00687(13)	-0.00006(19)
HST	48	0.99988(19)	0.99922(19)	-0.00066(27)
ICT	2	1.00182(24)	1.00261(23)	0.00079(33)
IMF	6	1.00326(19)	1.00141(18)	-0.00185(27)
LCT	21	1.00131(31)	1.00047(31)	-0.00084(44)
LST	32	1.00029(20)	1.00017(19)	-0.00012(27)
MCT	5	0.98960(22)	0.98746(22)	-0.00214(31)
MMF	1	0.98990(21)	0.99398(21)	0.00408(30)
Pu	15	1.00201(20)	0.99977(20)	-0.00224(29)
U233	6	0.99705(20)	0.99615(20)	-0.00090(28)

Red highlight indicates C/E has gotten further from 1.0 in ENDF/B-VIII.0β5

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Comparison of ENDF/B-VII.1 and ENDF/B-VIII.0β5

Population *C/E*

	ENDF/B-VII.1	ENDF/B-VIII.0β5
Average	1.00029	0.99954
Std. Dev.	0.00511	0.00516
χ^2	0.00776	0.00754

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

Notable Changes (*C/E*)

Closer to 1.0:

Benchmark	ENDF/B-VII.1	ENDF/B-VIII.0β5	Difference
PST_031_07	1.00840(21)	1.00368(20)	-0.00473(29)
PST_031_06	1.00883(21)	1.00421(21)	-0.00462(30)
PST_031_05	1.00549(21)	1.00087(21)	-0.00461(30)
MMF_008_07	0.98990(21)	0.99398(21)	0.00408(30)
PCI_001	1.01137(20)	1.00761(20)	-0.00377(28)

Further from 1.0:

Benchmark	ENDF/B-VII.1	ENDF/B-VIII.0β5	Difference
USI_001	0.98527(20)	0.98057(19)	-0.00470(28)
HCI_003_04	1.00383(28)	1.00792(25)	0.00409(38)
PST_031_04	0.99947(22)	0.99564(21)	-0.00383(31)
PST_031_02	0.98438(22)	0.98101(22)	-0.00337(31)
HST_050_07	1.00035(18)	0.99739(21)	-0.00296(28)

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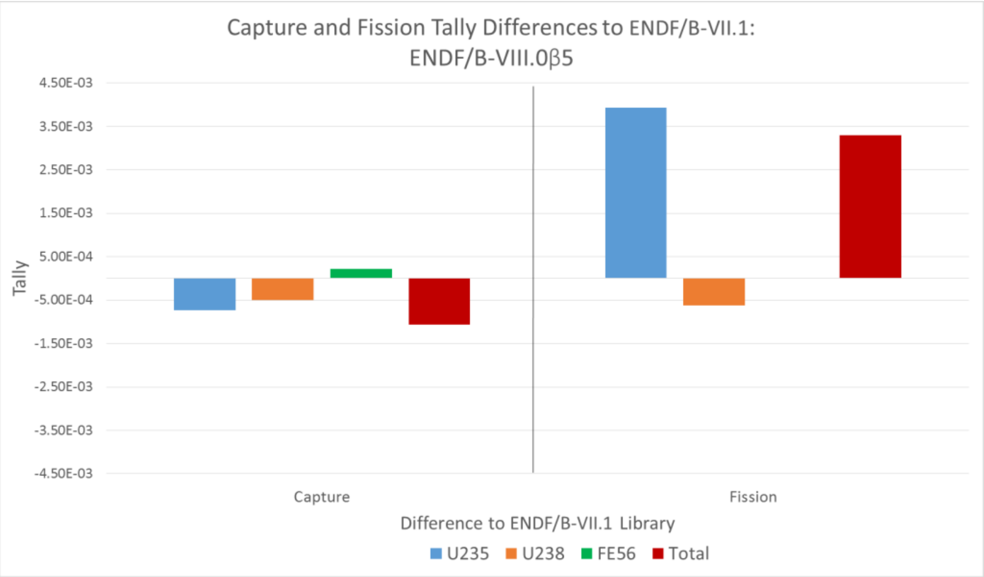
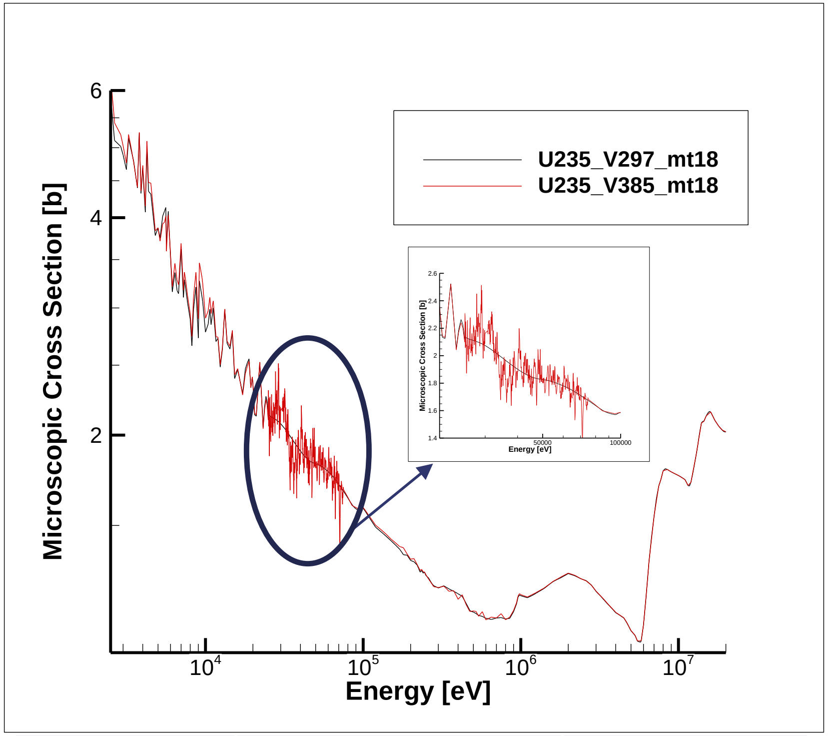
HCI_003_04 Benchmark: Capture and Fission Tallies



Library	*C/E*	Diff. to E7.1
E7.1	1.00383(28)	---
E8.0β5	1.00792(25)	+0.00409(38)



Version	Library	0.625 eV RI MT 18
V297	ENDF/B-VII.1	2.599E+02
V385	ENDF/B-VIII.0β5	2.638E+02
	Difference	+1.5%

Large increase in eigenvalue between E7.1 and E8.0β5 driven primarily by increase in U-235 fission

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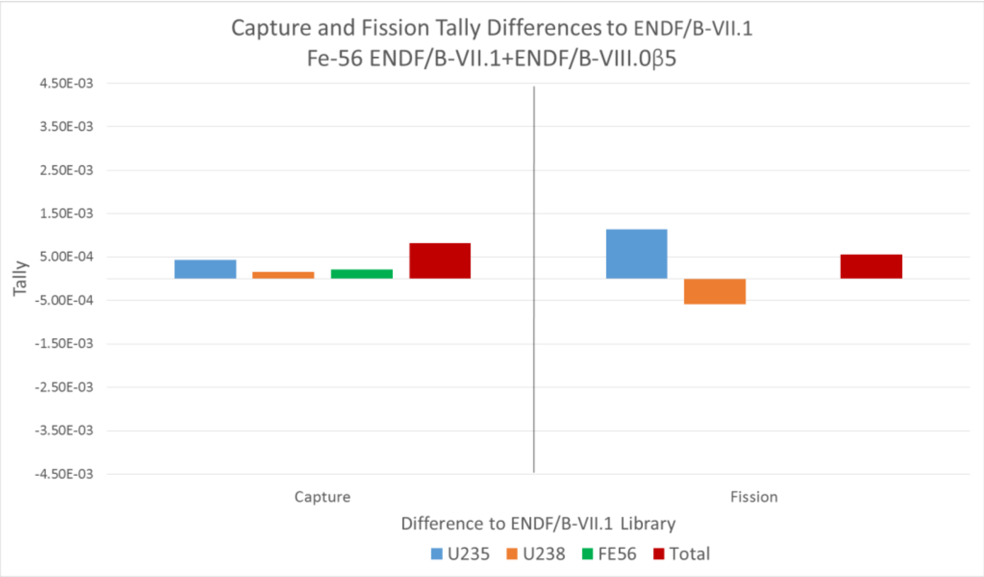
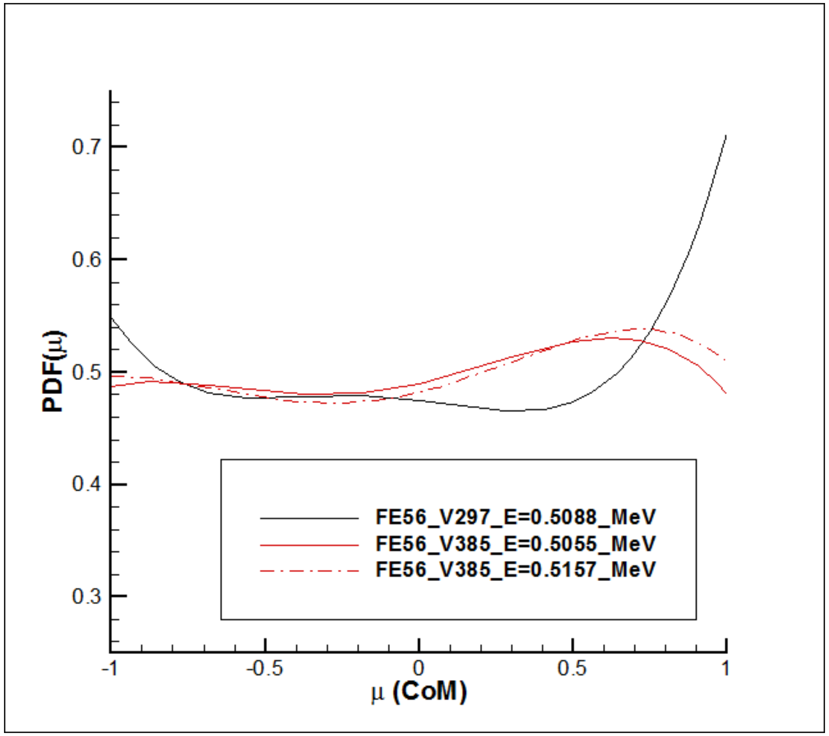
HCI_003_04 Benchmark: Fe-56 Substitution



Library	*C/E*	Diff. to E7.1
E7.1	1.00383(28)	---
E7.1 + Fe-56 E8.0β5	1.00487(25)	+0.00104(37)



Substituting Fe-56 results in even more U-235 fissions, likely due to the redistribution of neutrons from the changes made to the elastic scattering angular distributions (ESAD)

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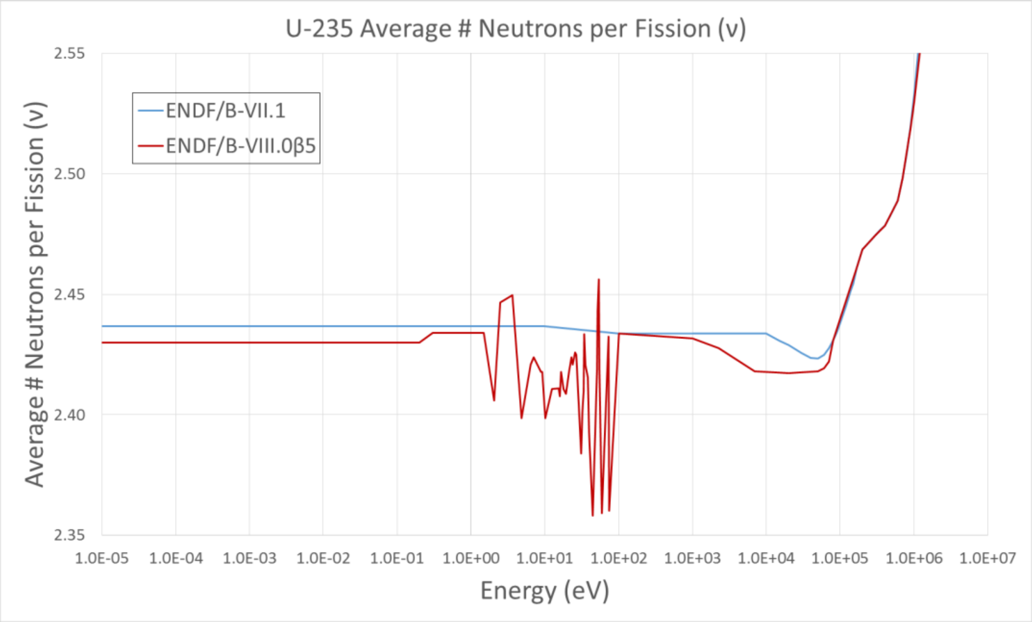
HCI_003_04 Benchmark: Effect of ν

	E7.1	E7.1 + U-235 E8.0β5	Difference [%]
Capture ($\Sigma_\gamma \phi$)	2.094E-01	2.084E-01	-0.466
Leakage ($DB^2\phi$)	3.908E-01	3.889E-01	-0.470
Fission ($\Sigma_f \phi$)	3.998E-01	4.026E-01	+0.703
Nu (ν)	2.511	2.502	-0.351
Nu-Fission ($\nu\Sigma_f \phi$)	1.00383	1.00734	+0.349
k-eff (k)	1.00383	1.00734	+0.349

$$k = \frac{\nu\Sigma_f\phi}{\Sigma_\gamma\phi + \Sigma_f\phi + DB^2\phi} = \nu\Sigma_f\phi$$

Average neutrons per fission (nu) dropped from 2.511 to 2.502 between E7.1 and E8.0β5



- 409 pcm increase from:
  - Fe-56 ESAD/capture
  - U-235 capture/fission
  - U-235 ν

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Comparison of ENDF/B-VII.1 and ENDF/B-VIII.0β5

Population *C/E*

	ENDF/B-VII.1	ENDF/B-VIII.0β5
Average	1.00029	0.99954
Std. Dev.	0.00511	0.00516
χ^2	0.00776	0.00754

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

Notable Changes (*C/E*)

Closer to 1.0:

Benchmark	ENDF/B-VII.1	ENDF/B-VIII.0β5	Difference
PST_031_07	1.00840(21)	1.00368(20)	-0.00473(29)
PST_031_06	1.00883(21)	1.00421(21)	-0.00462(30)
PST_031_05	1.00549(21)	1.00087(21)	-0.00461(30)
MMF_008_07	0.98990(21)	0.99398(21)	0.00408(30)
PCI_001	1.01137(20)	1.00761(20)	-0.00377(28)

Further from 1.0:

Benchmark	ENDF/B-VII.1	ENDF/B-VIII.0β5	Difference
USI_001	0.98527(20)	0.98057(19)	-0.00470(28)
HCI_003_04	1.00383(28)	1.00792(25)	0.00409(38)
PST_031_04	0.99947(22)	0.99564(21)	-0.00383(31)
PST_031_02	0.98438(22)	0.98101(22)	-0.00337(31)
HST_050_07	1.00035(18)	0.99739(21)	-0.00296(28)

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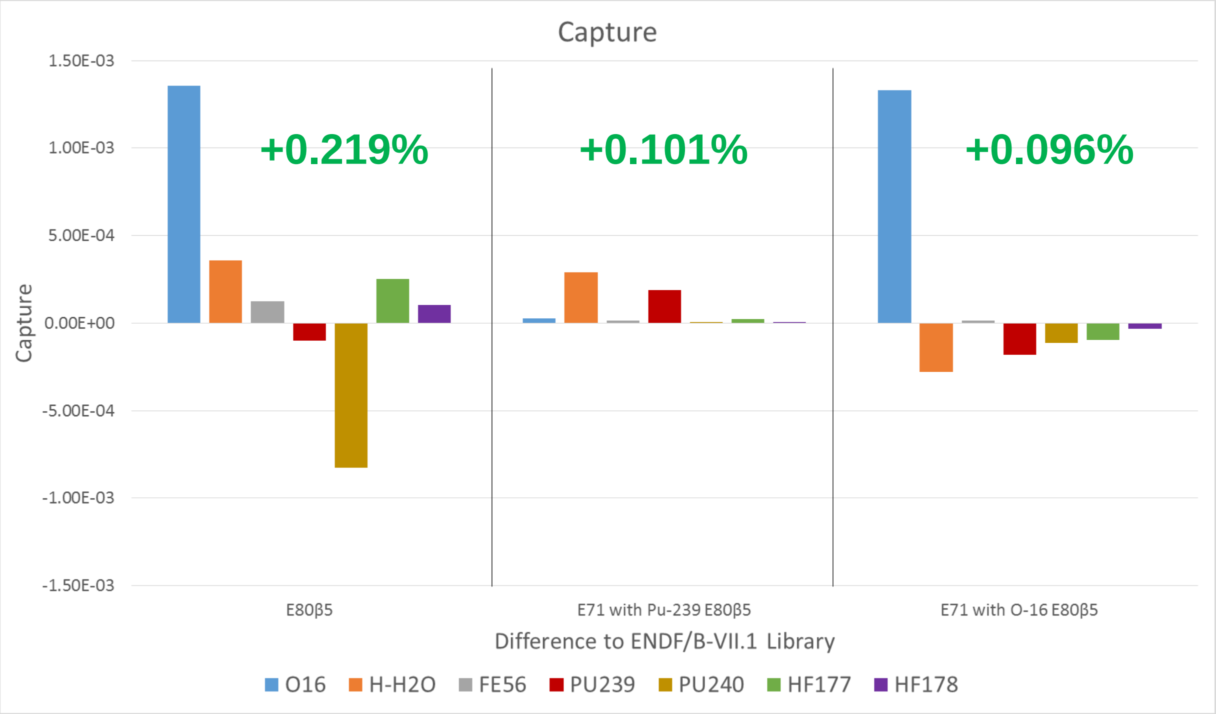
PST_031_07 Benchmark

Library	C/E	Diff. to E7.1
E7.1	1.00840(21)	---
E8.0β5	1.00368(20)	-0.00473(29)
E7.1 + Pu-239 E8.0β5	1.00495(21)	-0.00345(30)
E7.1 + O-16 E8.0β5	1.00711(21)	-0.00130(30)



- Large decrease in eigenvalue between E7.1 and E8.0β5 driven by:
  - Increase in O-16 capture (accounts for ~25% of eigenvalue change)
  - Changes in Pu-239 evaluation account for remaining difference (~75%).

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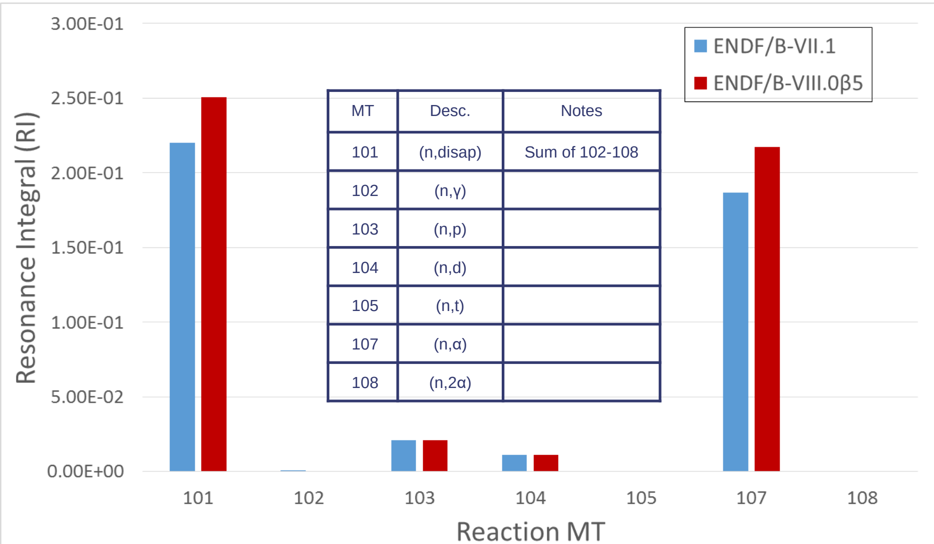
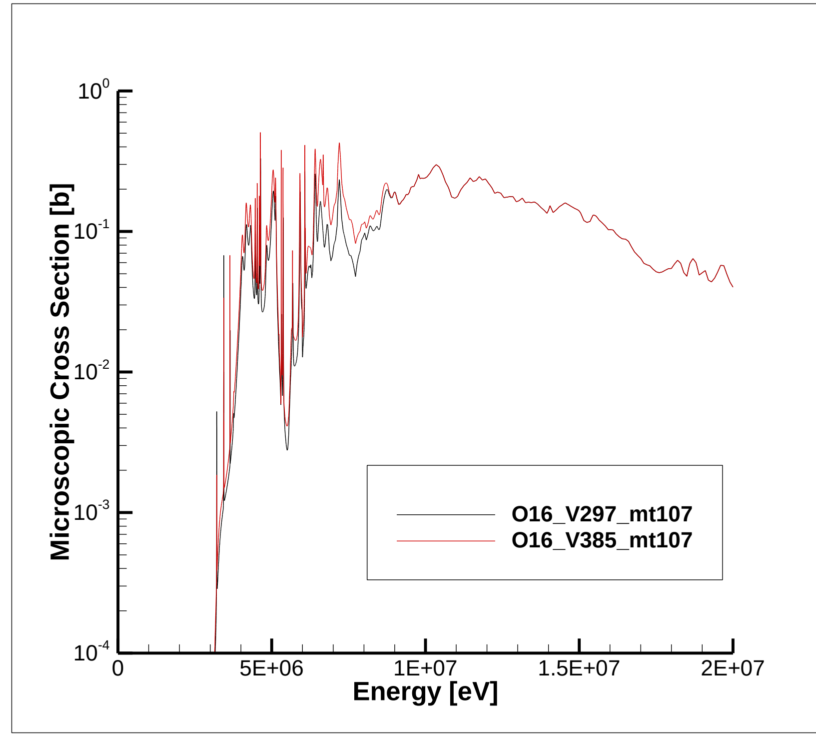
O-16 (n,α) Cross Section – 293.6K



Library	0.625 eV RI MT 101	0.625 eV RI MT 107
ENDF/B-VII.1	2.203E-01	1.870E-01
ENDF/B-VIII.0β5	2.507E-01	2.175E-01
Difference	+13.8%	+16.4%



V297 = ENDF/B-VII.0
V385 = ENDF/B-VIII.0β5

Change in capture profile dominated by O-16 (n,α) increase

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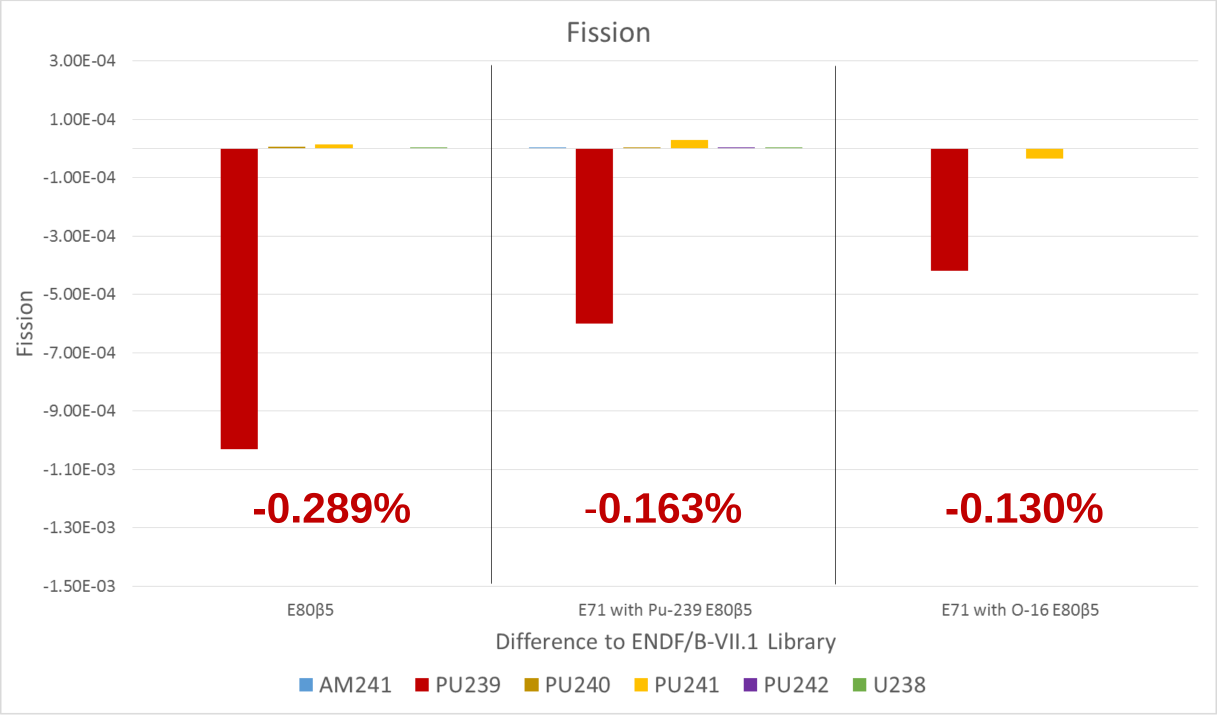
PST_031_07 Benchmark

Library	*C/E*	Diff. to E7.1
E7.1	1.00840(21)	---
E8.0β5	1.00368(20)	-0.00473(29)
E7.1 + Pu-239 E8.0β5	1.00495(21)	-0.00345(30)
E7.1 + O-16 E8.0β5	1.00711(21)	-0.00130(30)



- Decrease in Pu-239 fission caused by
  - Overall increase in capture making less neutrons available for fission
  - New Pu-239 evaluation from CIELO

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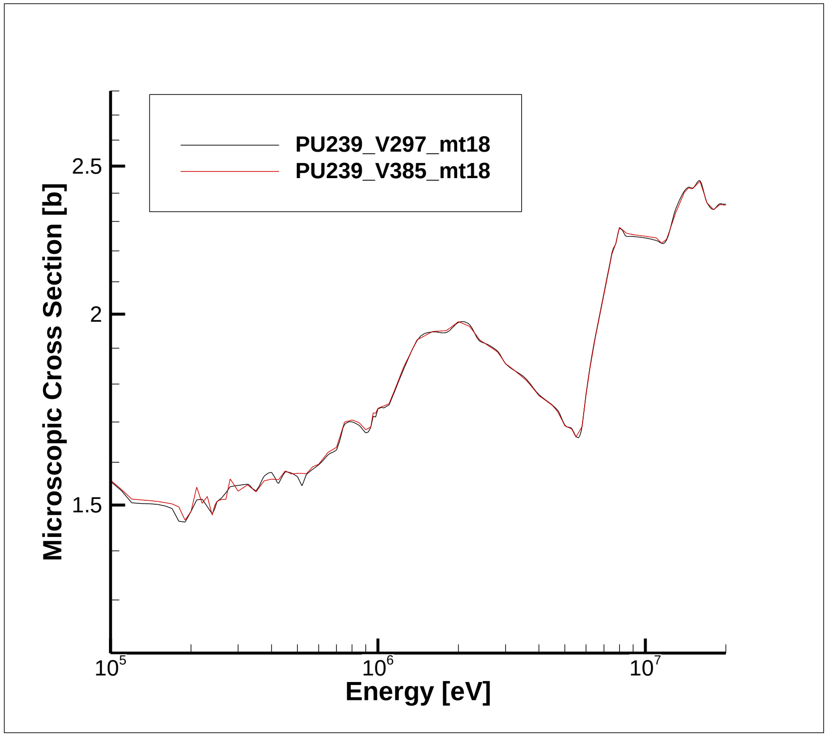
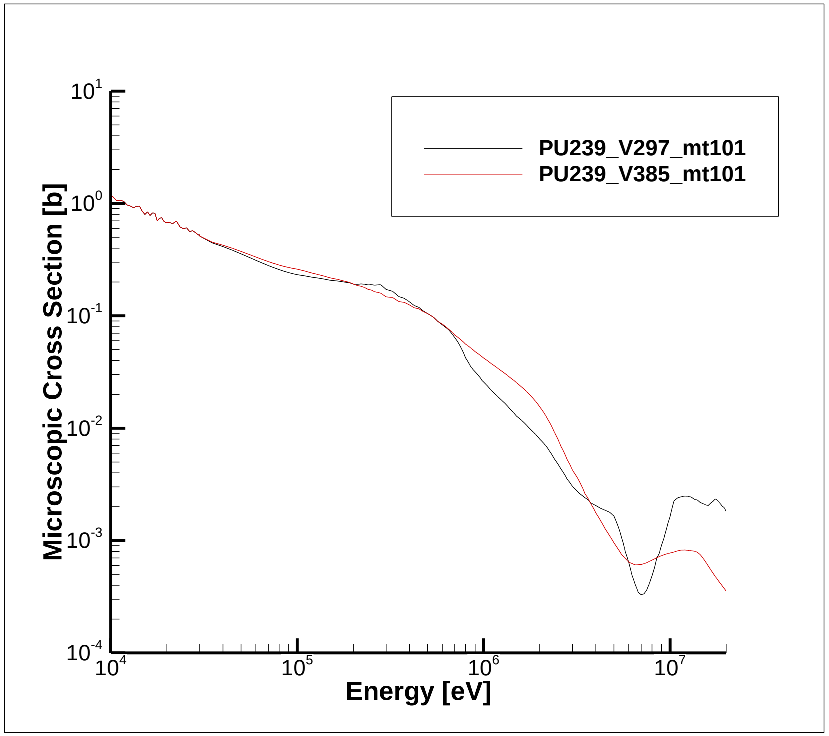
Pu-239 (n,f) and (n,disapp.) Cross Sections – 293.6K





Version	Library	0.625 eV RI MT 18	0.625 eV RI MT 101
V297	ENDF/B-VII.1	2.713E+02	1.678E+02
V385	ENDF/B-VIII.β5	2.769E+02	1.666E+02
	Difference	+2.1%	-0.5%

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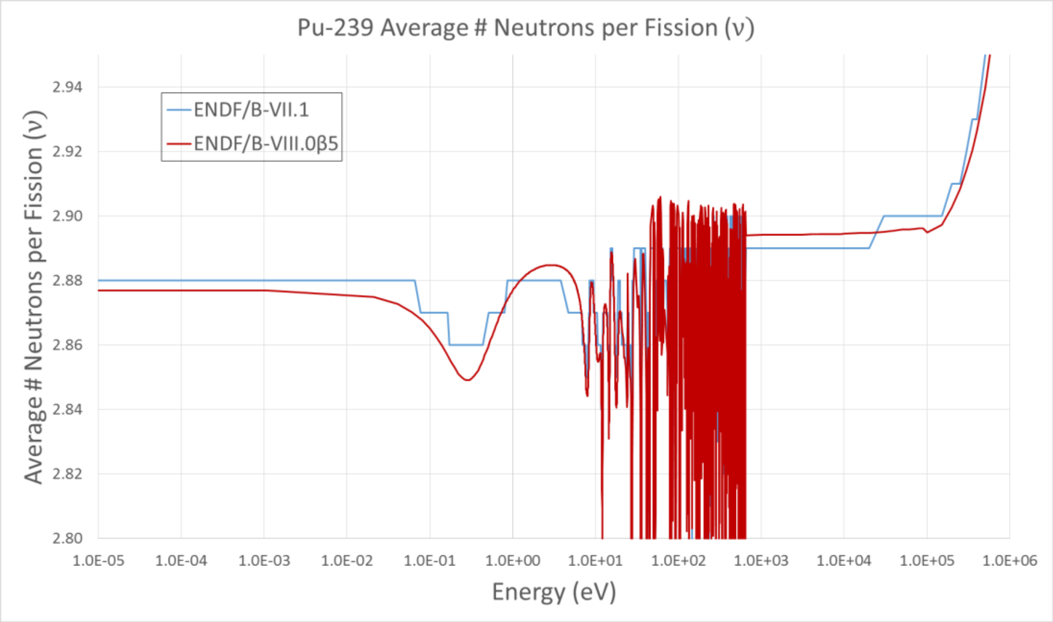
PST_031_07 Benchmark

	E7.1	E7.1 + Pu-239 E8.0β5	Difference [%]
Capture ($\Sigma_\gamma \phi$)	6.100E-01	6.106E-01	+0.101
Leakage ($DB^2\phi$)	3.992E-02	3.988E-02	-0.109
Fission ($\Sigma_f \phi$)	3.501E-01	3.496E-01	-0.163
Nu (ν)	2.880	2.875	-0.180
Nu-Fission ($\nu\Sigma_f \phi$)	1.00840	1.00495	-0.342
k-eff (k)	1.00840	1.00495	-0.342

$$k = \frac{\nu\Sigma_f\phi}{\Sigma_\gamma\phi + \Sigma_f\phi + DB^2\phi} = \nu\Sigma_f\phi$$

Average neutrons per fission (nu) dropped from 2.880 to 2.875 (-0.18%) between E7.1 and E8.0β5



- 473 pcm drop from:
  - O-16 (n,α) (-130 pcm)
  - Pu-239 ν (-180 pcm)
  - Pu-239 other changes (-163 pcm)

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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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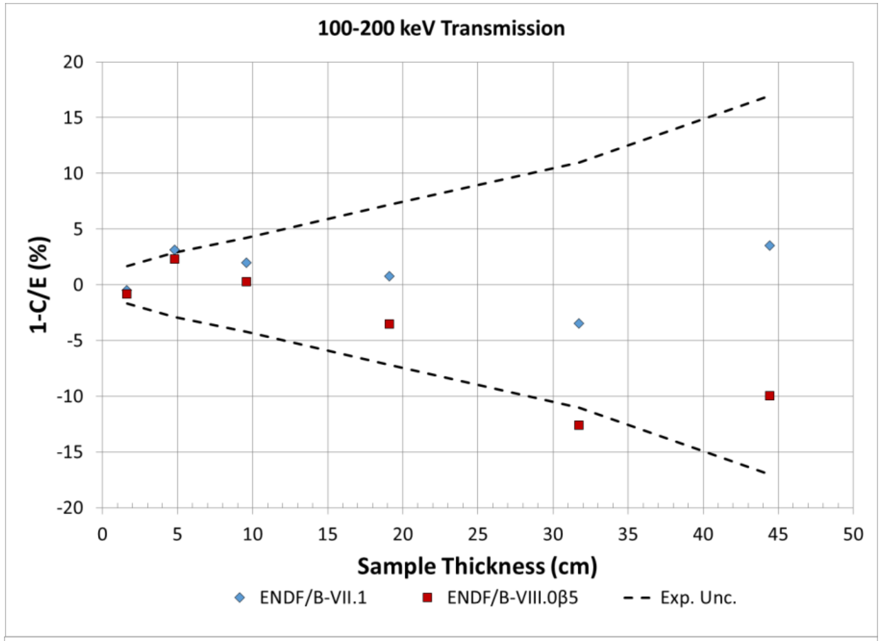
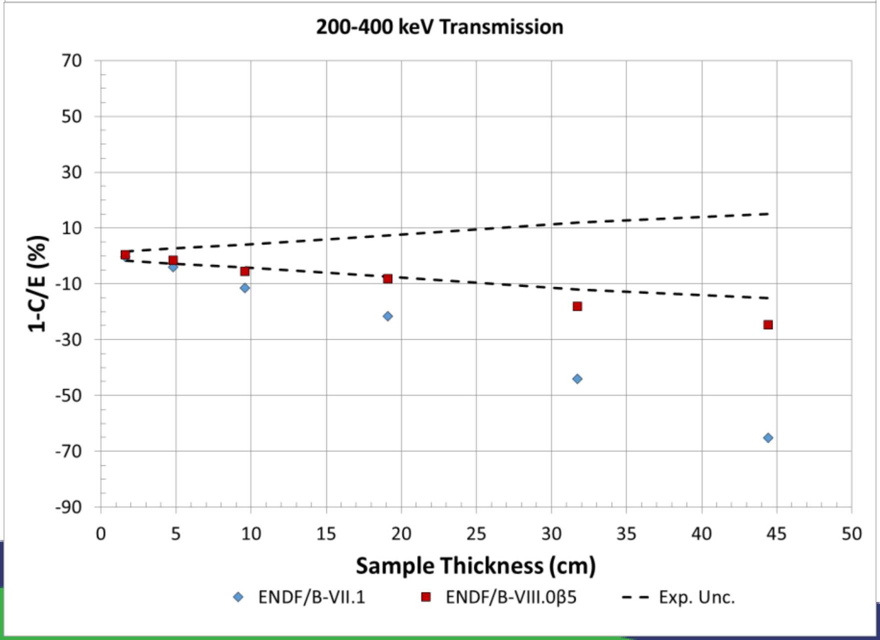
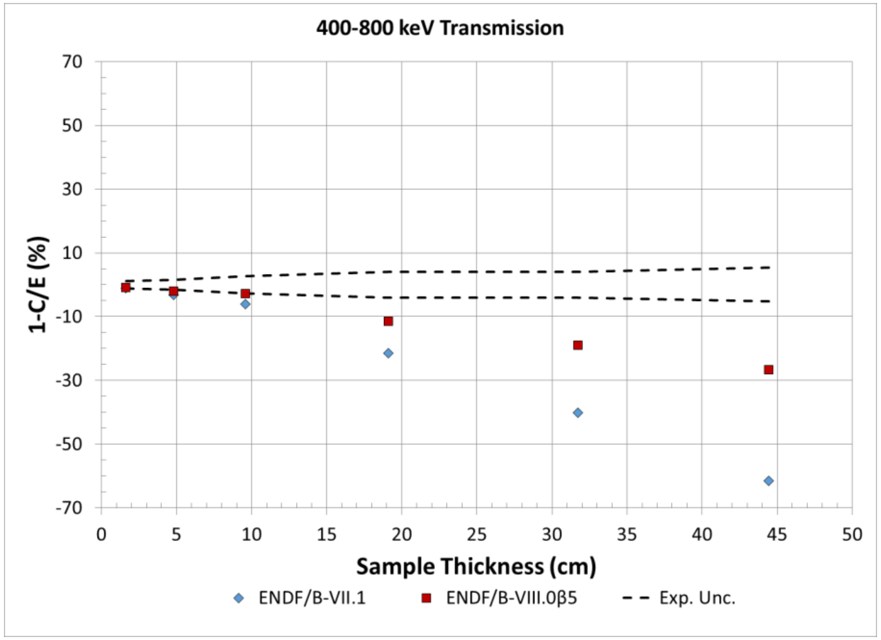
Transmission Results

- ENDF/B-VII.1 outperforms ENDF/B-VIII.0β5 in the 100-200 keV range
- Above 200 keV, ENDF/B-VIII.0β5 performs better







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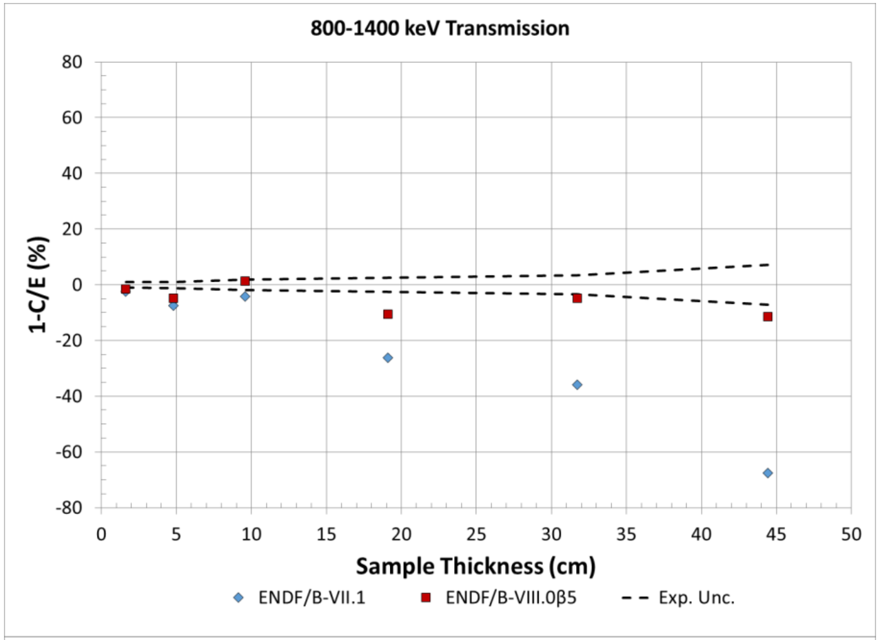
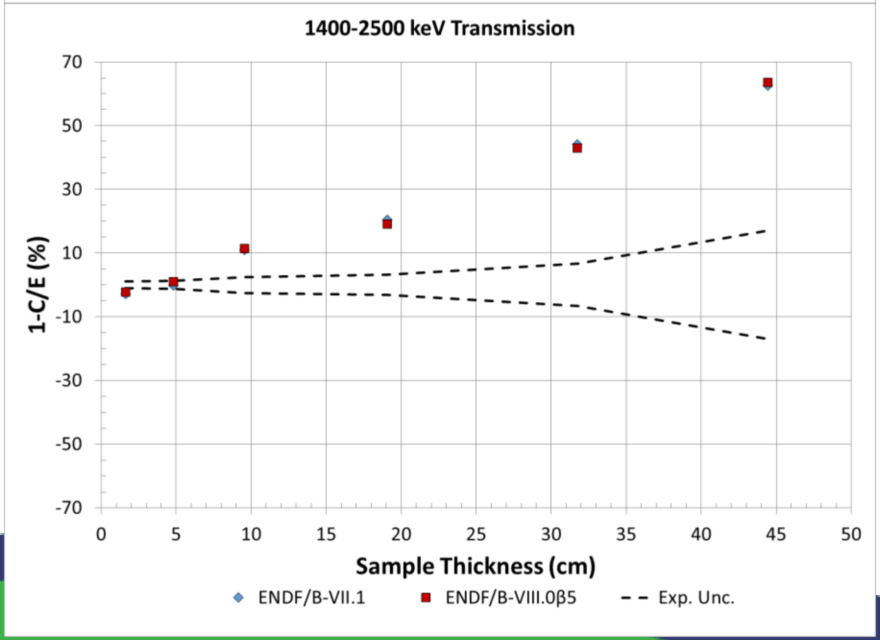
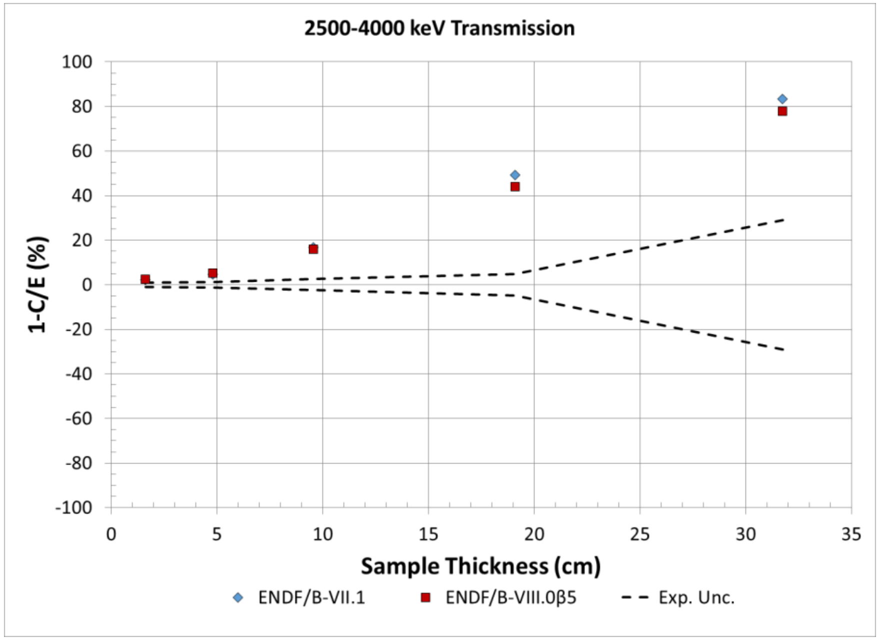
Transmission Results

- ENDF/B-VIII.0β5 performs better at higher energy ranges
  - Improvement of Fe-56 in the new evaluation







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Summary of ENDF/B-VIII.0β5 Analysis

- ENDF/B-VIII.0β5 data result in a net decrease in *C*/*E* for ICSBEP models of 75pcm – overall good agreement with ENDF/B-VII.1.

- HEU intermediate-spectrum models (HCI) are sensitive to changes in U-235 and O-16
  - nubar change has a 300-400 pcm affect
  - Fe-56 ESAD have changed substantially

- ENDF/B-VIII.0β5 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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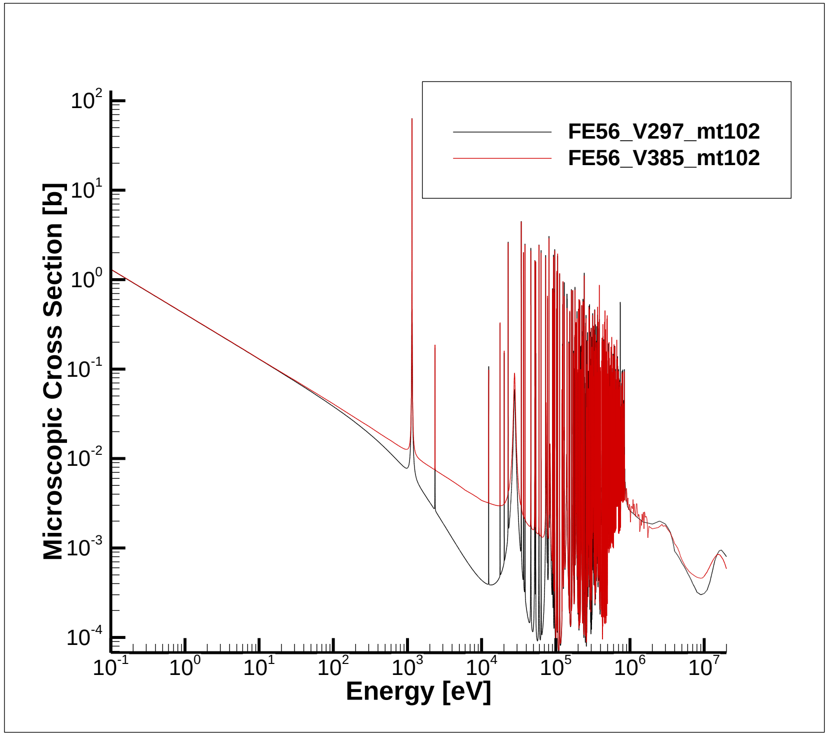
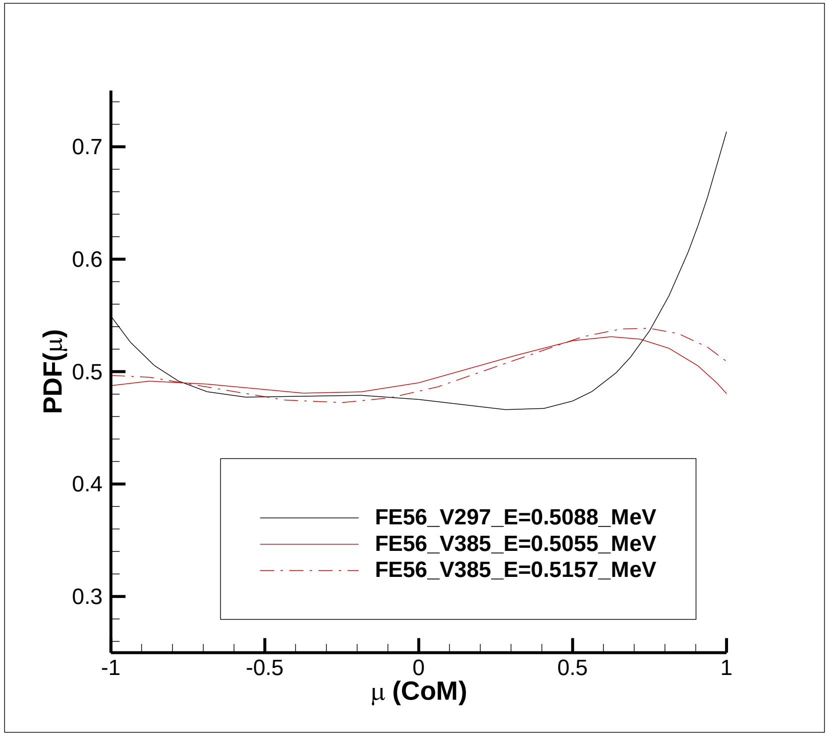
EXTRA

Fe-56 (n,γ) Cross Section and ESAD – 293.6K





Version	Library	0.625 eV RI MT 102
V297	ENDF/B-VII.1	1.223E+00
V385	ENDF/B-VIII.0β5	1.254E+00
	Difference	+2.6%

- Despite more captures in Fe-56, ESAD change increases neutron economy available to fission by U-235

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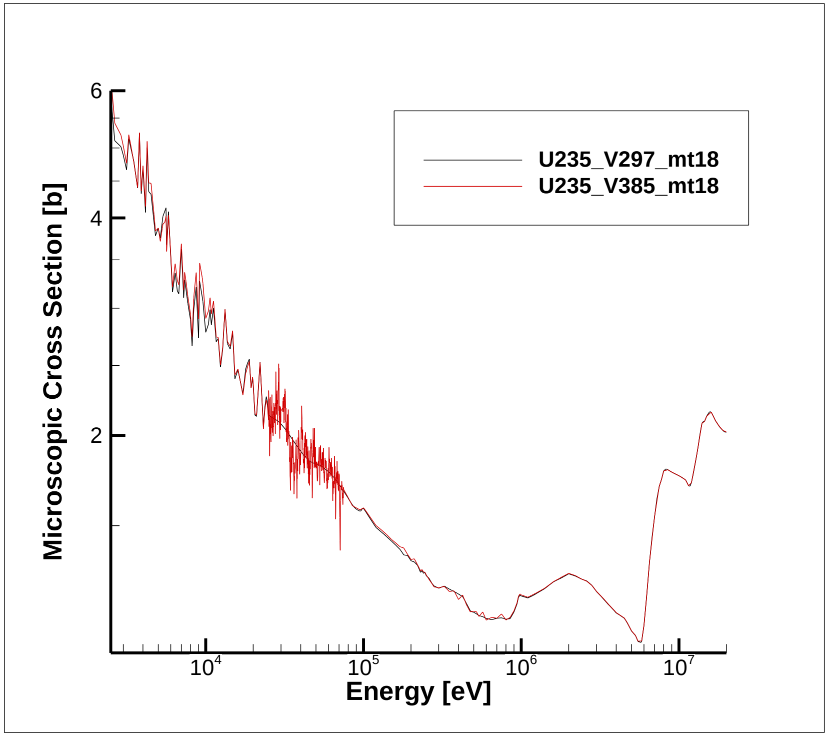
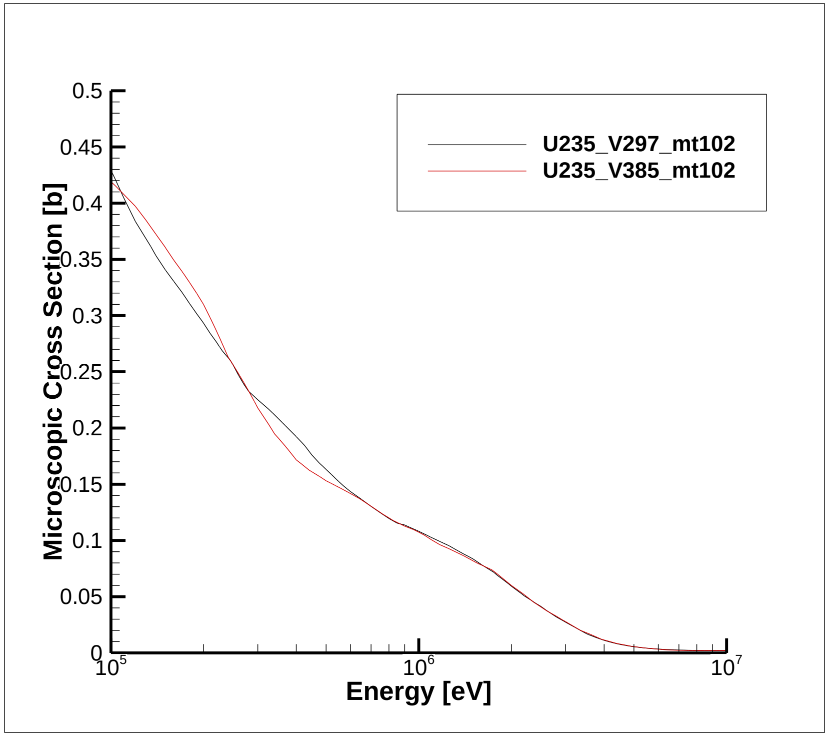
U-235 (n,f) and (n,γ) Cross Sections – 293.6K





Version	Library	0.625 eV RI MT 18	0.625 eV RI MT 102
V297	ENDF/B-VII.1	2.599E+02	1.384E+02
V385	ENDF/B-VIII.0β5	2.638E+02	1.407E+02
	Difference	+1.5%	+1.6%

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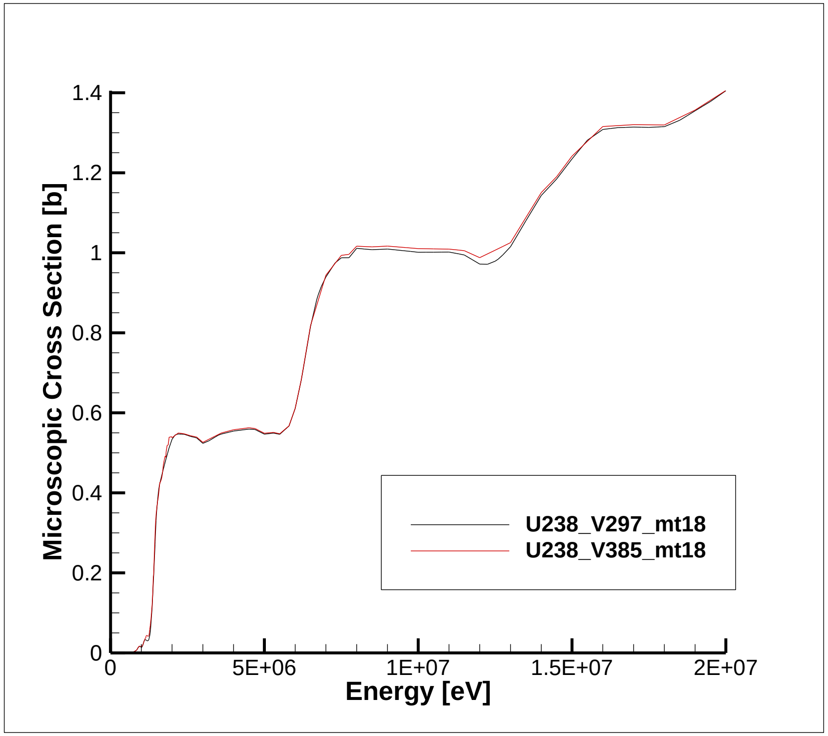
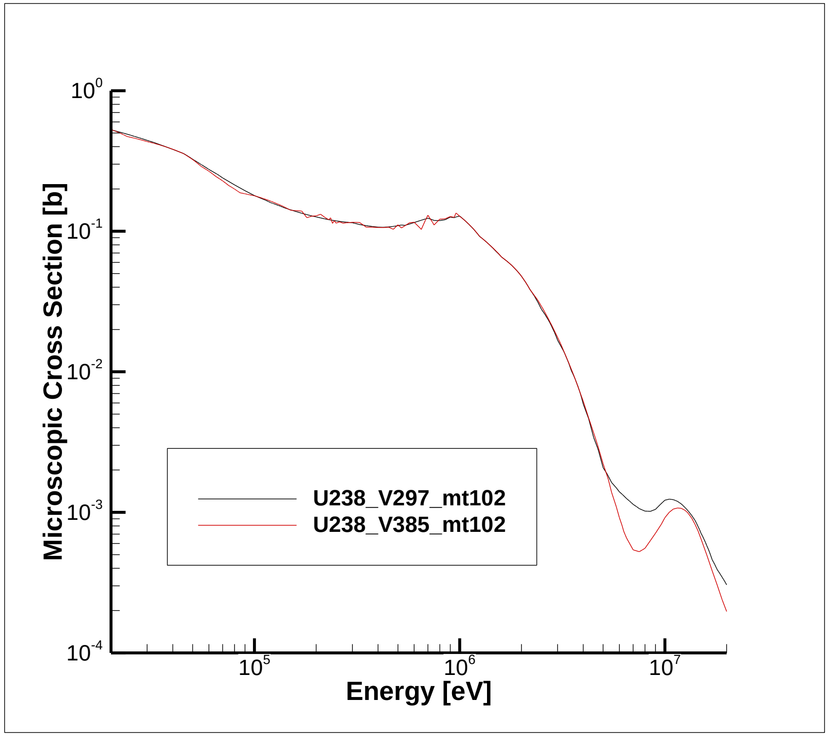
U-238 (n,f) and (n,γ) Cross Sections – 293.6K





Version	Library	0.625 eV RI MT 18	0.625 eV RI MT 102
V297	ENDF/B-VII.1	2.054E+00	2.754E+02
V385	ENDF/B-VIII.0β5	2.070E+00	2.749E+02
	Difference	+0.7%	-0.2%

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