

ABR and FBR Uncertainty Evaluation with AFCI 2.0

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ABR Calculation Data

- The provided RZ model with the detailed 15 core different densities was used
- ENDF/B-VII 33 group cross sections
- AFCI 2.0 covariance data
- Integral parameters: K_{eff} and sodium void only in core regions
- Uncertainties for: capture, fission, ν , elastic, inelastic, n,2n (not reported because quite negligible). Fission spectrum and averaged μ_{bar} not considered at the moment
- Reference K_{eff} : 1.05977
- Reference Sodium Void: 1211 pcm

ABR Ox. Uncertainty on K_{eff} (pcm)

Isotope	σ_{cap}	σ_{fiss}	ν	σ_{el}	σ_{inel}	Total
U238	293	31	117	29	558	643
PU239	331	236	75	9	76	421
FE56	161	0	0	243	146	325
PU240	103	76	86	2	3	155
O16	106	0	0	42	2	114
PU241	11	109	4	0	2	109
NA23	27	0	0	21	82	89
PU242	1	0	0	0	0	2
Total	494	273	164	249	588	868

U238 Uncertainty on K_{eff}

Uncertainty (pcm)

Ener. ev	σ_{cap}	σ_{fiss}	ν	σ_{cl}	σ_{incl}
1.96E+07	0	2	6	0	2
1.00E+07	-1	8	25	1	59
6.07E+06	-2	12	41	5	193
3.68E+06	6	18	72	9	332
2.23E+06	21	19	77	12	345
1.35E+06	23	6	17	11	190
8.21E+05	29	2	1	8	40
4.98E+05	33	1	1	5	21
3.02E+05	44	1	0	7	17
1.83E+05	54	1	0	8	22
1.11E+05	58	0	0	8	41
6.74E+04	62	1	0	8	12
4.09E+04	61	0	0	6	0
2.48E+04	115	1	0	8	0
1.50E+04	120	1	0	1	0
9.12E+03	91	1	0	0	0
5.53E+03	77	0	0	0	0
3.35E+03	55	0	0	0	0
2.03E+03	89	0	0	0	0
1.23E+03	82	0	0	0	0

Standard Deviat. %

Group	σ_{cap}	σ_{fiss}	ν	σ_{cl}	σ_{incl}
1	25.0	0.6	1.4	7.4	31.6
2	25.0	0.7	1.4	12.3	30.3
3	19.9	0.6	1.3	13.1	20.1
4	5.9	0.6	1.3	15.1	19.4
5	6.1	0.6	1.3	18.8	20.6
6	3.1	1.8	1.1	9.5	16.9
7	1.7	4.9	2.0	2.6	5.6
8	1.5	5.1	2.0	2.2	4.3
9	1.5	6.8	2.0	1.8	4.1
10	1.7	5.2	2.0	1.9	6.0
11	1.7	5.1	2.0	2.8	19.2
12	1.7	5.1	2.0	3.4	17.9
13	1.6	5.2	2.0	4.3	0.0
14	3.2	100.0	2.0	2.3	0.0
15	3.9	98.8	2.0	0.9	0.0
16	3.3	100.0	2.0	0.8	0.0
17	2.8	14.5	2.0	0.7	0.0
18	2.9	66.8	2.0	0.8	0.0
19	2.9	68.0	2.0	0.8	0.0
20	2.8	6.9	2.0	1.0	0.0

Pu239 Uncertainty on K_{eff}

Uncertainty (pcm)

Ener. ev	σ_{cap}	σ_{fiss}	ν	σ_{el}	σ_{inel}
1.96E+07	0	2	0	0	0
1.00E+07	0	10	1	0	4
6.07E+06	2	19	3	1	18
3.68E+06	6	34	7	2	33
2.23E+06	11	43	9	2	34
1.35E+06	19	45	10	3	26
8.21E+05	48	63	16	4	35
4.98E+05	57	59	16	2	22
3.02E+05	65	63	22	3	14
1.83E+05	73	83	29	3	22
1.11E+05	81	77	23	2	18
6.74E+04	83	65	22	2	10
4.09E+04	85	57	22	1	4
2.48E+04	111	64	25	2	10
1.50E+04	117	53	21	1	12
9.12E+03	139	29	9	1	1
5.53E+03	139	25	9	1	0
3.35E+03	86	21	6	0	0
2.03E+03	22	55	21	0	0
1.23E+03	18	52	15	0	0

Standard Deviat. %

Group	σ_{cap}	σ_{fiss}	ν	σ_{el}	σ_{inel}
1	36.3	0.8	0.4	5.6	24.1
2	39.9	0.9	0.2	8.7	27.6
3	42.0	0.8	0.2	10.8	25.6
4	34.2	0.9	0.2	9.4	19.5
5	26.6	0.9	0.2	10.7	19.0
6	20.5	0.8	0.2	11.7	27.0
7	15.5	0.8	0.2	9.2	32.6
8	12.1	0.9	0.2	6.4	32.7
9	11.3	0.8	0.3	5.2	36.2
10	9.6	1.0	0.3	4.5	43.7
11	10.8	0.9	0.2	3.6	50.0
12	11.4	0.8	0.3	2.6	45.1
13	8.9	0.9	0.4	2.1	31.9
14	7.2	0.9	0.3	2.1	30.1
15	7.8	1.2	0.4	2.3	26.7
16	16.5	0.8	0.3	3.7	17.1
17	16.5	0.8	0.4	4.3	0.0
18	10.7	0.7	0.5	3.3	0.0
19	1.5	1.2	0.4	0.5	0.0
20	1.5	1.3	0.3	0.7	0.0

Fe56 Uncertainty on K_{eff}

Uncertainty (pcm)

Ener. ev	σ_{cap}	σ_{fiss}	ν	σ_{el}	σ_{inel}
1.96E+07	4	0.0	0.0	0	3
1.00E+07	9	0.0	0.0	1	8
6.07E+06	2	0.0	0.0	6	17
3.68E+06	4	0.0	0.0	12	32
2.23E+06	7	0.0	0.0	23	115
1.35E+06	14	0.0	0.0	30	82
8.21E+05	73	0.0	0.0	102	0
4.98E+05	64	0.0	0.0	101	0
3.02E+05	49	0.0	0.0	74	0
1.83E+05	44	0.0	0.0	82	0
1.11E+05	50	0.0	0.0	74	0
6.74E+04	31	0.0	0.0	43	0
4.09E+04	53	0.0	0.0	70	0
2.48E+04	32	0.0	0.0	50	0
1.50E+04	9	0.0	0.0	47	0
9.12E+03	8	0.0	0.0	33	0
5.53E+03	9	0.0	0.0	23	0
3.35E+03	10	0.0	0.0	27	0
2.03E+03	18	0.0	0.0	18	0
1.23E+03	57	0.0	0.0	65	0

Standard Deviat. %

Group	σ_{cap}	σ_{fiss}	ν	σ_{el}	σ_{inel}
1	61.5	0.0	0.0	5.4	7.6
2	23.8	0.0	0.0	5.9	4.3
3	18.2	0.0	0.0	4.8	4.3
4	21.2	0.0	0.0	6.1	4.5
5	16.6	0.0	0.0	8.8	12.0
6	18.9	0.0	0.0	6.0	11.0
7	25.2	0.0	0.0	12.5	0.0
8	25.2	0.0	0.0	14.1	0.0
9	13.5	0.0	0.0	13.3	0.0
10	10.7	0.0	0.0	12.4	0.0
11	7.0	0.0	0.0	11.5	0.0
12	7.6	0.0	0.0	16.5	0.0
13	10.3	0.0	0.0	10.1	0.0
14	12.4	0.0	0.0	7.7	0.0
15	12.4	0.0	0.0	7.7	0.0
16	12.4	0.0	0.0	7.7	0.0
17	12.4	0.0	0.0	7.7	0.0
18	12.4	0.0	0.0	7.7	0.0
19	9.4	0.0	0.0	7.7	0.0
20	4.8	0.0	0.0	7.7	0.0

Pu240 Uncertainty on K_{eff}

Uncertainty (pcm)

Ener. ev	σ_{cap}	σ_{fiss}	ν	σ_{el}	σ_{inel}
1.96E+07	0	-2	1	0	0
1.00E+07	1	-8	6	0	0
6.07E+06	3	-15	14	0	0
3.68E+06	8	23	23	0	1
2.23E+06	15	37	28	0	1
1.35E+06	33	39	43	0	2
8.21E+05	39	36	45	1	1
4.98E+05	31	17	23	0	1
3.02E+05	29	13	18	1	1
1.83E+05	27	11	15	1	1
1.11E+05	28	12	15	1	1
6.74E+04	29	11	14	0	0
4.09E+04	29	10	13	0	0
2.48E+04	34	11	13	1	0
1.50E+04	25	7	10	0	0
9.12E+03	18	4	7	0	0
5.53E+03	8	5	1	0	0
3.35E+03	5	3	1	0	0
2.03E+03	11	8	2	0	0
1.23E+03	11	7	2	0	0

Standard Deviat. %

Group	σ_{cap}	σ_{fiss}	ν	σ_{el}	σ_{inel}
1	55.0	9.5	1.1	5.0	20.0
2	40.8	6.7	2.2	5.0	16.5
3	35.0	5.5	2.7	5.0	15.0
4	35.0	5.5	2.7	5.0	18.1
5	35.0	5.5	2.7	5.0	20.0
6	100.0	5.5	3.7	5.0	30.0
7	56.5	4.6	4.4	5.0	30.0
8	29.9	4.0	4.8	5.0	30.0
9	17.5	5.1	4.8	5.0	36.3
10	10.0	5.7	4.8	5.0	40.0
11	10.0	6.8	4.8	5.0	58.7
12	10.0	7.5	4.8	5.0	0.0
13	10.0	7.5	4.8	5.0	0.0
14	10.0	7.5	4.8	5.0	0.0
15	6.9	7.8	4.8	5.0	0.0
16	5.0	8.1	4.8	5.0	0.0
17	5.0	20.0	4.4	7.5	0.0
18	5.0	20.0	4.2	9.1	0.0
19	5.0	20.0	4.0	10.0	0.0
20	5.0	20.0	4.0	12.6	0.0

ABR Ox. Uncertainty on Sodium Void (%)

Isotope	σ_{cap}	σ_{fiss}	ν	σ_{el}	σ_{Inel}	Total
U238	3.9	0.1	0.5	0.6	4.1	5.7
NA23	1.6	0.0	0.0	1.9	4.9	5.4
FE56	1.2	0.0	0.0	3.7	0.9	3.9
PU239	1.4	3.2	1.0	0.2	0.8	3.8
PU240	0.7	0.5	0.6	0.0	0.0	1.0
O16	0.8	0.0	0.0	0.5	0.0	0.9
PU241	0.1	0.6	0.0	0.0	0.0	0.6
Pu242	0.0	0.0	0.0	0.0	0.0	0.0
Total	4.7	3.3	1.3	4.2	6.5	9.7

U238 Uncertainty on Sodium Void

Uncertainty (%)

Ener. ev	σ_{cap}	σ_{fiss}	ν	σ_{cl}	σ_{incl}
1.96E+07	0.0	0.0	0.0	0.0	0.0
1.00E+07	0.0	0.0	0.1	0.0	0.6
6.07E+06	0.0	0.1	0.2	0.1	1.5
3.68E+06	0.0	0.1	0.4	0.2	2.8
2.23E+06	0.1	0.0	0.2	0.2	2.1
1.35E+06	0.1	0.0	0.1	0.3	1.4
8.21E+05	0.3	0.0	0.0	0.3	0.2
4.98E+05	0.1	0.0	0.0	0.1	0.2
3.02E+05	0.1	0.0	0.0	0.2	0.1
1.83E+05	0.1	0.0	0.0	0.1	0.2
1.11E+05	0.0	0.0	0.0	0.1	0.4
6.74E+04	0.0	0.0	0.0	0.1	0.2
4.09E+04	0.0	0.0	0.0	0.1	0.0
2.48E+04	0.8	0.0	0.0	0.1	0.0
1.50E+04	1.4	0.0	0.0	0.0	0.0
9.12E+03	1.2	0.0	0.0	0.0	0.0
5.53E+03	-0.3	0.0	0.0	0.0	0.0
3.35E+03	-1.4	0.0	0.0	0.0	0.0
2.03E+03	1.9	0.0	0.0	0.0	0.0
1.23E+03	2.1	0.0	0.0	0.0	0.0

Standard Deviat. %

Group	σ_{cap}	σ_{fiss}	ν	σ_{cl}	σ_{incl}
1	25.0	0.6	1.4	7.4	31.6
2	25.0	0.7	1.4	12.3	30.3
3	19.9	0.6	1.3	13.1	20.1
4	5.9	0.6	1.3	15.1	19.4
5	6.1	0.6	1.3	18.8	20.6
6	3.1	1.8	1.1	9.5	16.9
7	1.7	4.9	2.0	2.6	5.6
8	1.5	5.1	2.0	2.2	4.3
9	1.5	6.8	2.0	1.8	4.1
10	1.7	5.2	2.0	1.9	6.0
11	1.7	5.1	2.0	2.8	19.2
12	1.7	5.1	2.0	3.4	17.9
13	1.6	5.2	2.0	4.3	0.0
14	3.2	100.0	2.0	2.3	0.0
15	3.9	98.8	2.0	0.9	0.0
16	3.3	100.0	2.0	0.8	0.0
17	2.8	14.5	2.0	0.7	0.0
18	2.9	66.8	2.0	0.8	0.0
19	2.9	68.0	2.0	0.8	0.0
20	2.8	6.9	2.0	1.0	0.0

Na23 Uncertainty on Sodium Void

Uncertainty (%)

Ener. ev	σ_{cap}	σ_{fiss}	ν	σ_{el}	σ_{inel}
1.96E+07	0.6	0.0	0.0	0.0	0.2
1.00E+07	1.2	0.0	0.0	0.1	0.8
6.07E+06	0.6	0.0	0.0	-0.2	1.1
3.68E+06	0.2	0.0	0.0	0.3	2.1
2.23E+06	0.3	0.0	0.0	0.6	2.0
1.35E+06	0.3	0.0	0.0	0.2	2.0
8.21E+05	0.1	0.0	0.0	0.1	3.1
4.98E+05	0.1	0.0	0.0	0.9	0.1
3.02E+05	0.2	0.0	0.0	0.6	0.0
1.83E+05	0.2	0.0	0.0	0.8	0.0
1.11E+05	0.0	0.0	0.0	0.8	0.0
6.74E+04	0.1	0.0	0.0	0.4	0.0
4.09E+04	0.2	0.0	0.0	0.2	0.0
2.48E+04	0.0	0.0	0.0	-0.6	0.0
1.50E+04	0.0	0.0	0.0	-0.6	0.0
9.12E+03	0.0	0.0	0.0	-0.4	0.0
5.53E+03	0.1	0.0	0.0	-0.2	0.0
3.35E+03	0.2	0.0	0.0	0.3	0.0
2.03E+03	0.1	0.0	0.0	0.2	0.0
1.23E+03	0.1	0.0	0.0	0.2	0.0

Standard Deviat. %

Group	σ_{cap}	σ_{fiss}	ν	σ_{el}	σ_{inel}
1	61.0	0.0	0.0	8.3	5.5
2	57.8	0.0	0.0	9.6	5.6
3	59.2	0.0	0.0	10.4	6.3
4	61.0	0.0	0.0	10.0	6.9
5	65.9	0.0	0.0	9.3	8.3
6	48.0	0.0	0.0	6.4	14.9
7	33.4	0.0	0.0	3.0	17.5
8	23.6	0.0	0.0	5.2	9.9
9	19.9	0.0	0.0	3.9	0.0
10	18.8	0.0	0.0	5.6	0.0
11	15.2	0.0	0.0	5.6	0.0
12	20.9	0.0	0.0	3.9	0.0
13	15.8	0.0	0.0	5.5	0.0
14	8.1	0.0	0.0	5.4	0.0
15	4.2	0.0	0.0	5.1	0.0
16	2.2	0.0	0.0	4.4	0.0
17	2.9	0.0	0.0	3.2	0.0
18	4.6	0.0	0.0	1.6	0.0
19	2.0	0.0	0.0	5.1	0.0
20	1.8	0.0	0.0	6.3	0.0

Fe56 Uncertainty on Sodium Void

Uncertainty (%)

Ener. ev	σ_{cap}	σ_{fiss}	ν	σ_{el}	σ_{inel}
1.96E+07	0.0	0.0	0.0	0.0	0.0
1.00E+07	0.1	0.0	0.0	0.0	0.1
6.07E+06	0.0	0.0	0.0	0.1	0.1
3.68E+06	0.0	0.0	0.0	0.3	0.2
2.23E+06	0.0	0.0	0.0	0.5	0.5
1.35E+06	0.1	0.0	0.0	0.6	0.7
8.21E+05	0.7	0.0	0.0	2.8	0.0
4.98E+05	0.4	0.0	0.0	1.5	0.0
3.02E+05	0.2	0.0	0.0	1.7	0.0
1.83E+05	0.2	0.0	0.0	1.1	0.0
1.11E+05	0.1	0.0	0.0	0.7	0.0
6.74E+04	0.1	0.0	0.0	0.5	0.0
4.09E+04	-0.2	0.0	0.0	-0.2	0.0
2.48E+04	-0.1	0.0	0.0	0.3	0.0
1.50E+04	0.0	0.0	0.0	-0.2	0.0
9.12E+03	0.0	0.0	0.0	-0.1	0.0
5.53E+03	0.0	0.0	0.0	0.6	0.0
3.35E+03	0.1	0.0	0.0	-0.2	0.0
2.03E+03	-0.1	0.0	0.0	-0.9	0.0
1.23E+03	0.8	0.0	0.0	-0.9	0.0

Standard Deviat. %

Group	σ_{cap}	σ_{fiss}	ν	σ_{el}	σ_{inel}
1	61.5	0.0	0.0	5.4	7.6
2	23.8	0.0	0.0	5.9	4.3
3	18.2	0.0	0.0	4.8	4.3
4	21.2	0.0	0.0	6.1	4.5
5	16.6	0.0	0.0	8.8	12.0
6	18.9	0.0	0.0	6.0	11.0
7	25.2	0.0	0.0	12.5	0.0
8	25.2	0.0	0.0	14.1	0.0
9	13.5	0.0	0.0	13.3	0.0
10	10.7	0.0	0.0	12.4	0.0
11	7.0	0.0	0.0	11.5	0.0
12	7.6	0.0	0.0	16.5	0.0
13	10.3	0.0	0.0	10.1	0.0
14	12.4	0.0	0.0	7.7	0.0
15	12.4	0.0	0.0	7.7	0.0
16	12.4	0.0	0.0	7.7	0.0
17	12.4	0.0	0.0	7.7	0.0
18	12.4	0.0	0.0	7.7	0.0
19	9.4	0.0	0.0	7.7	0.0
20	4.8	0.0	0.0	7.7	0.0

FBR Calculation Data

- The provided RZ simplified model with simplified densities was used
- ENDF/B-VII 33 group cross sections
- AFCI 2.0 covariance data
- Integral parameters: K_{eff} and sodium void only in core regions
- Uncertainties for: capture, fission, ν , elastic, inelastic, n,2n (not reported because quite negligible). Fission spectrum and averaged mubar not considered at the moment
- Reference K_{eff} : 0.99927
- Reference Sodium Void: 1109 pcm

FBR Uncertainty on K_{eff} (pcm)

Isotope	σ_{cap}	σ_{flss}	ν	σ_{el}	σ_{inel}	Total
PU241	94	1063	37	1	19	1068
U238	310	39	145	52	777	851
PU240	204	176	194	4	8	332
PU239	230	181	56	7	63	305
FE56	79	0	0	82	105	155
O16	125	0	0	36	3	131
PU242	88	37	31	2	5	101
NA23	25	0	0	17	85	91
Total	480	1094	253	105	791	1459

Pu241 FBR Uncertainty on K_{eff}

Uncertainty (pcm)

Ener. ev	σ_{cap}	σ_{fiss}	ν	σ_{el}	σ_{inel}
1.96E+07	0	-4	0	0	0
1.00E+07	1	15	2	0	-2
6.07E+06	4	31	3	0	-5
3.68E+06	13	82	5	0	-8
2.23E+06	25	118	7	0	-5
1.35E+06	27	221	7	0	4
8.21E+05	31	314	10	0	12
4.98E+05	24	315	10	0	13
3.02E+05	30	397	11	1	10
1.83E+05	36	451	12	1	6
1.11E+05	33	411	12	1	4
6.74E+04	30	371	11	1	0
4.09E+04	19	249	10	0	0
2.48E+04	14	180	10	0	0
1.50E+04	14	174	10	0	0
9.12E+03	13	152	9	0	0
5.53E+03	10	100	4	0	0
3.35E+03	7	70	3	0	0
2.03E+03	13	125	6	0	0
1.23E+03	11	91	5	0	0

Standard Deviat. %

Group	σ_{cap}	σ_{fiss}	ν	σ_{el}	σ_{inel}
1	55.0	10.0	0.5	6.0	25.0
2	55.0	6.5	0.3	5.3	21.5
3	55.1	5.0	0.3	5.0	20.0
4	83.1	5.0	0.3	5.0	26.3
5	100.0	5.0	0.3	5.0	30.0
6	80.0	15.0	0.3	10.0	30.0
7	48.9	16.2	0.3	10.0	67.3
8	30.0	17.0	0.3	10.0	89.9
9	30.0	18.9	0.3	10.0	65.0
10	30.0	20.0	0.3	10.0	50.0
11	23.8	16.9	0.3	10.0	50.0
12	20.0	15.0	0.3	10.0	0.0
13	13.8	11.9	0.3	10.0	0.0
14	10.0	10.0	0.3	10.0	0.0
15	10.0	10.0	0.3	10.0	0.0
16	10.0	10.0	0.3	10.0	0.0
17	10.0	10.0	0.3	10.0	0.0
18	10.0	10.0	0.3	10.0	0.0
19	10.0	10.0	0.3	10.0	0.0
20	10.0	7.5	0.3	12.6	0.0

FBR Uncertainty on Sodium Void (%)

Isotope	σ_{cap}	σ_{fiss}	ν	σ_{el}	σ_{inel}	Total
U238	3.7	0.2	0.6	1.0	5.8	7.0
NA23	1.6	0.0	0.0	1.4	5.7	6.1
PU241	0.7	5.3	0.2	0.0	0.2	5.3
PU239	1.0	2.4	0.8	0.2	0.6	2.8
PU240	1.1	1.0	1.2	0.1	0.1	1.9
FE56	0.8	0.0	0.0	1.2	0.6	1.6
O16	1.0	0.0	0.0	0.3	0.0	1.1
PU242	0.5	0.2	0.2	0.0	0.0	0.6
Total	4.6	5.9	1.6	2.1	8.2	11.4

Conclusions

- **The uncertainty analysis performed on target design using AFCI 2.0 covariance data has shown:**
 - **For K_{eff} of ABR the significant contributions are coming from U238 (capture and inelastic), Pu239 (capture and fission), and Fe56 (elastic).**
 - **For the ABR sodium void on top of those observed for K_{eff} also Na23 inelastic is giving a major contribution.**
 - **For the FBR K_{eff} the total uncertainty is almost the double of that of the ABR. This is mainly due to the large contribution coming from Pu241.**
- **If one expects to reduce significantly these a priori uncertainties, the adjustment should target the previously named isotopes and reactions.**