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Uncertainty Analysis with the AFCI1.2 Covariance Matrix

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AFCI covariance matrix

- A first release of the matrix (AFCI1.0) was made in November last year. The first applications of AFCI1.0 were presented at the data adjustment meeting held at INL in December 2008 and at the Nuclear Physics Working Group meeting held in San Diego (CA) in May 2009. The matrix was used to calculate the uncertainty of the multiplication factor of all fast systems investigated in the Sg26 activity (ABTR, SFR, EFR, GFR, LFR, ADMAB).

- An updated version of the matrix, called AFCI1.1, was released by BNL and LALN in May 2009: Pu239 (only ν), Fe56, Cr50, Ni58, C, O, Na23, B10, Zr90 and Mn55 were reprocessed. Applications were presented at the NNDC meeting in Port Jefferson, June 2009 (see also ANS paper, Nov. 2009).

- The AFCI1.2 matrix was released in August 2009: 14 MAs were updated as guided by Maslov review and missing correlation matrices were recovered; U235 capture and Pu239 nu were updated; Structural materials (Cr, Fe, Ni, Pb, Bi) were reviewed and updated.

- The present work shows an extensive application of the recent AFCI1.2 matrix, with the determination of the uncertainty for the main integral parameters (multiplication factor, power peaking factor, Doppler reactivity coefficient, coolant void reactivity worth and burnup reactivity swing) of a series of fast reactors (ABR metal core, ABR oxide core, SFR, EFR, GFR, LFR, ADMAB).
  The obtained AFCI1.2 parameter uncertainties are also compared with the results presented in previous studies with the BOLNA correlation matrix.

AFCI1.2 Covariance Matrix at a Glance

- Processed/used isotopes:
  U234, U235, U236, U238, Np237, Pu238, Pu239, Pu240, Pu241, Pu242, Am241, Am242m, Am243, Cm242, Cm243, Cm244, Cm245, Cm246, Fe56, Fe57, Cr50, Cr52, Ni58, Ni60, Zr90, Zr91, Zr92, Zr94, Na23, O, He4, Si28, C, N15, B10, B11, P204, Pb206, Pb207, Pb208, Bi209, Mn55, Mo92, Mo94, Mo95, Mo96, Mo97, Mo98, Mo100.

- Processed/used reactions:
  ν, fission, capture, elastic, inelastic and n2n for fissile isotopes and **capture, elastic, inelastic and n2n** for structural isotopes.

- For most of the isotopes AFCI1.2 contains covariance data for the reaction itself, only for **U235, U238, Pu239, Cm246, Fe56, Cr52, Ni58, O, Zr90, C, B10, B11, Mn55, N15** some cross-correlations have been also provided.

- In the AFCI1.2 matrix there are no "cross-material" correlations.

Features of the Investigated Systems

System	Coolant	Fuel Type	%TRU in (U+TRU)	% MA[(a)] in (U+TRU)	Power [MW_{th}]
ABR Metal Core	Na	Metal	18.5 – 24.2 [(b)]	1.5 – 2.2 [(b)]	1000
ABR Oxide Core	Na	MOX	23.2 – 37.1[(b)]	2.2 – 4.1 [(b)]	1000
SFR	Na	Metal	60.5	10.6	840
EFR	Na	MOX	23.7	1.2	3600
GFR	He	Carbide	21.7	5.0	2400
LFR	Pb	Metal	23.3	2.4	900
ADMAB	LBE	Nitride	100	68.0	380

[(a)] MA: Minor Actinides;

[(b)] Inner Core – Outer Core.

Improvements of AFCI1.2 based on the Results of AFCI1.1 Applications

In the AFCI1.1 matrix, the correlation matrices for several reactions of the isotopes from the Maslov evaluation (all actinides except U235, U238 and Pu239) had no correlations in energy and, as consequence, contain diagonal values only (i.e. no "off-diagonal" energy correlation terms were provided).

SFR k_{eff} Uncertainties (%) by Isotope and Reaction

	Diagonal BOLNA	Diagonal AFCI1.1	Full BOLNA	Full AFCI1.1
Pu238 fission	0.32	0.61	0.56	0.61
Pu240 fission	0.27	0.20	0.35	0.20
Pu241 fission	0.54	0.37	1.01	0.37
Pu242 fission	0.25	0.20	0.38	0.20
Am242m fission	0.38	0.27	0.77	0.27
Cm244 fission	0.27	0.06	0.41	0.06
Cm245 fission	0.20	0.14	0.41	0.14
Total [(a)]	**1.10**	**0.92**	**1.86**	**1.09**

[(a)] Total of all isotopes (not listed too)

AFCI1.1 correlation matrices with diagonal values only:

U234 (inelastic, fission, ν)
U236 (elastic, fission, capture, ν)
Np237 (elastic, fission, ν)
Pu238 (fission, ν)
Pu240 (fission, ν)
Pu241 (elastic, fission, capture, ν)
Pu242 (fission, ν)
Am241 (elastic, fission, capture, ν)
Am242m (fission, capture, ν)
Am243 (fission, capture, ν)
Cm242 (fission, ν)
Cm243 (elastic, fission, ν)
Cm244 (fission, ν)
Cm245 (elastic, fission, capture, ν)

All the correlation matrices missing in AFCI1.1 have been added in AFCI1.2.

SFR k_{eff} Uncertainties (%) by Isotope and Reaction

	Diagonal BOLNA	Diagonal AFCI1.1	Diagonal AFCI1.2	Full BOLNA	Full AFCI1.1	Full AFCI1.2
Pu238 fission	0.32	0.61	0.61	0.56	0.61	1.36
Pu240 fission	0.27	0.20	0.20	0.35	0.20	0.38
Pu241 fission	0.54	0.37	0.40	1.01	0.37	1.02
Pu242 fission	0.25	0.20	0.21	0.38	0.20	0.40
Am242m fission	0.38	0.27	0.25	0.77	0.27	0.69
Cm244 fission	0.27	0.06	0.07	0.41	0.06	0.15
Cm245 fission	0.20	0.14	0.16	0.41	0.14	0.43
Total [(a)]	**1.10**	**0.92**	**0.94**	**1.86**	**1.09**	**2.16**

[(a)] Total of all isotopes (not listed too)

Improvements of AFCI1.2 based on the Results of AFCI1.1 Applications

In AFCI1.1, U235 Capture standard deviations were considered suspicious!

U235 Standard Deviations (%)

Gr.	[MeV]	U235: BOLNA 15Gr					U235: AFCI1.1 33Gr				
		ν	σ_{fiss}	σ_{inel}	σ_{el}	σ_{capt}	ν	σ_{fiss}	σ_{inel}	σ_{el}	σ_{capt}
1	1.964E+1	0.9	0.5	21.7	9.6	61.1	1.0	0.5	25.5	6.9	60.6
2	1.000E+1						1.0	0.6	15.9	6.3	62.7
3	6.065E+0	0.7	0.5	6.8	4.2	37.0	0.8	0.5	8.9	5.1	46.4
4	3.679E+0						0.6	0.5	6.4	4.0	26.5
5	2.231E+0	0.6	0.5	6.4	4.5	19.1	0.6	0.5	6.4	4.6	19.1
6	1.353E+0	0.6	0.5	7.6	3.6	16.1	0.6	0.5	7.0	4.1	16.2
7	8.209E-1						0.6	0.5	8.5	3.3	16.8
8	4.979E-1	0.6	0.5	11.3	2.9	22.1	0.6	0.6	10.5	3.2	20.4
9	3.020E-1						0.6	0.6	12.7	2.7	25.2
10	1.832E-1	0.7	0.5	15.0	2.4	30.6	0.7	0.6	15.0	2.4	30.1
11	1.111E-1						0.7	0.6	15.1	2.4	31.5
12	6.738E-2	0.7	0.5	14.7	2.6	32.9	0.7	0.5	15.1	2.5	32.2
13	4.087E-2						0.7	0.6	19.4	2.8	34.0
14	2.479E-2	0.7	0.6	50.0	3.2	34.0	0.7	0.7	50.0	3.0	34.0
15	1.503E-2						0.7	0.5	50.0	3.4	34.0
16	9.119E-3	0.7	3.2	48.5	5.2	33.9	0.7	0.5	50.0	4.0	34.0
17	5.531E-3						0.7	0.5	50.0	4.6	34.0
18	3.355E-3						0.7	5.7	41.8	6.3	29.4
19	2.035E-3	0.7	0.8	0.0	2.1	4.6	0.7	3.1	0.0	3.8	13.1
20	1.234E-3						0.7	0.4	0.0	2.3	5.2
21	7.485E-4						0.7	0.3	0.0	1.6	2.5
22	4.540E-4	0.7	0.4	0.0	1.3	0.6	0.7	0.4	0.0	1.5	1.6
23	3.043E-4						0.7	0.3	0.0	1.4	1.3
24	1.486E-4						0.7	0.4	0.0	1.4	1.1
25	9.166E-5						0.7	0.4	0.0	1.5	1.3
26	6.790E-5						0.7	0.4	0.0	1.4	1.1
27	4.017E-5						0.7	0.6	0.0	1.6	1.1
28	2.260E-5	0.7	0.6	0.0	1.5	0.7	0.7	0.6	0.0	1.6	1.0
29	1.371E-5						0.7	0.5	0.0	1.5	1.2
30	8.315E-6						0.7	1.2	0.0	1.7	1.8
31	4.000E-6	0.7	0.4	0.0	1.8	1.4	0.7	0.8	0.0	1.7	2.2
32	5.400E-7	0.7	0.3	0.0	3.4	1.6	0.7	0.4	0.0	3.1	1.6
33	1.000E-7	0.7	0.3	0.0	4.9	1.7	0.7	0.4	0.0	4.8	1.7

In AFCI1.1, correlation effects in U235 capture matrix were considered more suspicious than standard deviations.

GODIVA k_{eff} Uncertainties (%)

	BOLNA diagonal	AFCI1.1 diagonal	BOLNA full	AFCI1.1 full
Isotope	**U235**	**U235**	**U235**	**U235**
ν	0.27	0.21	0.56	0.56
σ_{fiss}	0.14	0.11	0.26	0.26
σ_{inel}	0.22	0.16	0.32	0.32
σ_{el}	0.07	0.05	0.11	0.11
σ_{capt}	0.51	0.37	0.99	1.01
Total	**0.63**	**0.47**	**1.22**	**1.24**
Overall [a]	**0.64**	**0.47**	**1.23**	**1.24**

[a] Total of all isotopes

GODIVA k_{eff} AFCI1.1 Diagonal Uncertainties (%) Energy Breakdown

		U235				
Gr.	**[MeV]**	**ν**	**σ_{fiss}**	**σ_{inel}**	**σ_{el}**	**σ_{capt}**
1	1.964E+1	-	-	-	-	-
2	1.000E+1	0.02	0.01	0.01	-	-
3	6.065E+0	0.06	0.02	0.04	0.01	0.01
4	3.679E+0	0.09	0.04	0.04	0.01	0.03
5	2.231E+0	0.09	0.05	0.05	0.02	0.06
6	1.353E+0	0.08	0.05	0.08	0.02	0.07
7	8.209E-1	0.08	0.05	0.09	0.02	0.10
8	4.979E-1	0.07	0.04	0.06	0.02	0.14
9	3.020E-1	0.05	0.03	0.04	0.02	0.18
10	1.832E-1	0.04	0.02	0.01	0.01	0.19
11	1.111E-1	0.02	0.01	-	-	0.14
12	6.738E-2	0.01	-	-	-	0.08
13	4.087E-2	0.01	-	-	-	0.05
14	2.479E-2	-	-	-	-	0.02
15	1.503E-2	-	-	-	-	0.01
16	9.119E-3	-	-	-	-	0.01
17	5.531E-3	-	-	-	-	-
to		-	-	-	-	-
33	1.000E-7	-	-	-	-	-
Total		**0.21**	**0.11**	**0.16**	**0.05**	**0.37**

Improvements of AFCI1.2 based on the Results of AFCI1.1 Applications

U235 Standard Deviations (%)

Gr.	[MeV]	U235: BOLNA 15Gr					U235: AFCI1.1 33Gr					U235: AFCI1.2 33Gr				
		ν	σ_{fiss}	σ_{inel}	σ_{el}	σ_{capt}	ν	σ_{fiss}	σ_{inel}	σ_{el}	σ_{capt}	ν	σ_{fiss}	σ_{inel}	σ_{el}	σ_{capt}
1	1.964E+1	0.9	0.5	21.7	9.6	61.1	1.0	0.5	25.5	6.9	60.6	0.8	0.5	25.5	7.5	60.6
2	1.000E+1						1.0	0.6	15.9	6.3	62.7	0.2	0.6	15.9	6.5	62.7
3	6.065E+0	0.7	0.5	6.8	4.2	37.0	0.8	0.5	8.9	5.1	46.4	0.2	0.5	8.9	5.0	46.4
4	3.679E+0						0.6	0.5	6.4	4.0	26.5	0.2	0.5	6.4	4.0	26.5
5	2.231E+0	0.6	0.5	6.4	4.5	19.1	0.6	0.5	6.4	4.6	19.1	0.2	0.5	6.4	4.5	19.1
6	1.353E+0	0.6	0.5	7.6	3.6	16.1	0.6	0.5	7.0	4.1	16.2	0.1	0.5	7.0	4.0	16.2
7	8.209E-1						0.6	0.5	8.5	3.3	16.8	0.1	0.5	8.5	3.3	16.8
8	4.979E-1	0.6	0.5	11.3	2.9	22.1	0.6	0.6	10.5	3.2	20.4	0.1	0.6	10.5	3.1	19.6
9	3.020E-1						0.6	0.6	12.7	2.7	25.2	0.2	0.6	12.7	2.7	20.0
10	1.832E-1	0.7	0.5	15.0	2.4	30.6	0.7	0.6	15.0	2.4	30.1	0.3	0.6	15.0	2.3	20.0
11	1.111E-1						0.7	0.6	15.1	2.4	31.5	0.2	0.6	15.1	2.1	20.0
12	6.738E-2	0.7	0.5	14.7	2.6	32.9	0.7	0.5	15.1	2.5	32.2	0.3	0.5	15.1	2.1	20.0
13	4.087E-2						0.7	0.6	19.4	2.8	34.0	0.3	0.6	19.4	2.2	20.0
14	2.479E-2	0.7	0.6	50.0	3.2	34.0	0.7	0.7	50.0	3.0	34.0	0.2	0.7	50.0	2.4	20.0
15	1.503E-2						0.7	0.5	50.0	3.4	34.0	0.3	0.5	50.0	2.6	20.0
16	9.119E-3	0.7	3.2	48.5	5.2	33.9	0.7	0.5	50.0	4.0	34.0	0.3	0.5	50.0	2.9	20.0
17	5.531E-3						0.7	0.5	50.0	4.6	34.0	0.3	0.5	50.0	3.3	20.0
18	3.355E-3						0.7	5.7	41.8	6.3	29.4	0.3	5.7	41.8	4.7	18.3
19	2.035E-3	0.7	0.8	0.0	2.1	4.6	0.7	3.1	0.0	3.8	13.1	0.6	3.1	0.0	3.8	13.1
20	1.234E-3						0.7	0.4	0.0	2.3	5.2	0.4	0.4	0.0	2.3	5.2
21	7.485E-4						0.7	0.3	0.0	1.6	2.5	0.7	0.3	0.0	1.6	2.5
22	4.540E-4	0.7	0.4	0.0	1.3	0.6	0.7	0.4	0.0	1.5	1.6	1.1	0.4	0.0	1.5	1.6
23	3.043E-4						0.7	0.3	0.0	1.4	1.3	1.1	0.3	0.0	1.4	1.3
24	1.486E-4						0.7	0.4	0.0	1.4	1.1	0.1	0.4	0.0	1.4	1.1
25	9.166E-5						0.7	0.4	0.0	1.5	1.3	0.1	0.4	0.0	1.5	1.3
26	6.790E-5						0.7	0.4	0.0	1.4	1.1	0.1	0.4	0.0	1.4	1.1
27	4.017E-5						0.7	0.6	0.0	1.6	1.1	0.1	0.6	0.0	1.6	1.1
28	2.260E-5	0.7	0.6	0.0	1.5	0.7	0.7	0.6	0.0	1.6	1.0	0.1	0.6	0.0	1.6	1.0
29	1.371E-5						0.7	0.5	0.0	1.5	1.2	0.1	0.5	0.0	1.5	1.2
30	8.315E-6						0.7	1.2	0.0	1.7	1.8	0.1	1.2	0.0	1.7	1.8
31	4.000E-6	0.7	0.4	0.0	1.8	1.4	0.7	0.8	0.0	1.7	2.2	0.1	0.8	0.0	1.7	2.2
32	5.400E-7	0.7	0.3	0.0	3.4	1.6	0.7	0.4	0.0	3.1	1.6	0.1	0.4	0.0	3.1	1.6
33	1.000E-7	0.7	0.3	0.0	4.9	1.7	0.7	0.4	0.0	4.8	1.7	0.1	0.4	0.0	4.8	1.7

GODIVA k_{eff} Uncertainties (%)

	BOLNA diagonal	AFCI1.1 diagonal	AFCI1.2 diagonal	BOLNA full	AFCI1.1 full	AFCI1.2 full
Isotope	**U235**	**U235**	**U235**	**U235**	**U235**	**U235**
ν	0.27	0.21	0.06	0.56	0.56	0.08
σ_{fiss}	0.14	0.11	0.11	0.26	0.26	0.26
σ_{inel}	0.22	0.16	0.16	0.32	0.32	0.33
σ_{el}	0.07	0.05	0.05	0.11	0.11	0.01i
σ_{capt}	0.51	0.37	0.29	0.99	1.01	0.79
Total	**0.63**	**0.47**	**0.36**	**1.22**	**1.24**	**0.90**
Overall [(a)]	**0.64**	**0.47**	**0.37**	**1.23**	**1.24**	**0.90**

[(a)] Total of all isotopes

Improvements of AFCI1.2 based on the Results of AFCI1.1 Applications

In AFCI1.1, unrealistic standard deviations were observed for Cm242 reactions.

GFR Burnup Uncertainties (%)

	AFCI1.1 diagonal	BOLNA diagonal	AFCI1.1 full	BOLNA full
Isotope	**Cm242**	**Cm242**	**Cm242**	**Cm242**
σ_{capt}	2.92	0.40	7.03	0.63
σ_{fiss}	8.17	3.62	8.17	6.87
ν	1.14	1.07	1.14	1.83
σ_{inel}	0.29	0.06	0.49	0.09
Total	**8.75**	**3.79**	**10.85**	**7.13**
Overall [(a)]	**11.87**	**9.77**	**14.64**	**16.94**

[(a)] Total of all isotopes

Cm242 Standard Deviations (%)

Gr.	[MeV]	Cm242: BOLNA 15Gr ν	BOLNA 15Gr σ_{fiss}	BOLNA 15Gr σ_{inel}	BOLNA 15Gr σ_{capt}	Cm242: AFCI1.1 33Gr ν	AFCI1.1 33Gr σ_{fiss}	AFCI1.1 33Gr σ_{inel}	AFCI1.1 33Gr σ_{capt}
1	1.964E+1	10.6	31.5	34.4	52.8	11.0	50.0	↑	52.8
2	1.000E+1					11.4	85.5		157.2
3	6.065E+0	11.1	52.6	11.0	37.4	11.5		100.0	
4	3.679E+0					11.2			
5	2.231E+0	10.7	19.0	11.4	23.6	11.0		↓	
6	1.353E+0	5.5	23.4	18.0	19.0				
7	8.209E-1							44.0	
8	4.979E-1	5.6	66.0	27.2	18.2			10.1	
9	3.020E-1							37.0	
10	1.832E-1	5.6	62.7	53.2	20.3		↑	53.2	↑
11	1.111E-1							39.8	
12	6.738E-2	5.6	28.2	31.7	22.4			-	
13	4.087E-2					↑		-	
14	2.479E-2	5.6	16.2	-	21.3			-	
15	1.503E-2							-	
16	9.119E-3	5.6	21.0	-	18.7			-	
17	5.531E-3						100.0	-	200.0
18	3.355E-3							-	
19	2.035E-3	5.6	11.7	-	6.8	10.0		-	
20	1.234E-3							-	
21	7.485E-4							-	
22	4.540E-4	5.6	9.3	-	4.6			-	
23	3.043E-4							-	
24	1.486E-4						↓	-	↓
25	9.166E-5					↓		-	
26	6.790E-5							-	
27	4.017E-5							-	
28	2.260E-5	5.6	24.0	-	3.7			-	
29	1.371E-5							-	
30	8.315E-6							-	
31	4.000E-6	5.6	35.6	-	32.5			-	
32	5.400E-7	5.6	41.2	-	39.2			-	
33	1.000E-7	5.6	42.6	-	40.8		50.0	-	

Improvements of AFCI1.2 based on the Results of AFCI1.1 Applications

Cm242 Standard Deviations (%)

		Cm242: BOLNA 15Gr				Cm242: AFCI1.1 33Gr				Cm242: AFCI1.2 33Gr			
Gr.	[MeV]	ν	σ_{fiss}	σ_{inel}	σ_{capt}	ν	σ_{fiss}	σ_{inel}	σ_{capt}	ν	σ_{fiss}	σ_{inel}	σ_{capt}
1	1.964E+1	10.6	31.5	34.4	52.8	11.0	50.0	↑	52.8	11.0		↑	
2	1.000E+1					11.4	85.5		157.2	11.4			
3	6.065E+0	11.1	52.6	11.0	37.4	11.5		100.0		11.5		100.0	↑
4	3.679E+0					11.2				11.2	↑		
5	2.231E+0	10.7	19.0	11.4	23.6	11.0		↓		11.0		↓	
6	1.353E+0	5.5	23.4	18.0	19.0					10.0			
7	8.209E-1							44.0		10.0		68.9	
8	4.979E-1	5.6	66.0	27.2	18.2			10.1		10.0		50.0	100.0
9	3.020E-1							37.0		10.0	100.0	50.0	
10	1.832E-1	5.6	62.7	53.2	20.3		↑	53.2	↑	10.0		50.0	
11	1.111E-1							39.8		10.0		37.5	
12	6.738E-2	5.6	28.2	31.7	22.4			-		10.0		-	↓
13	4.087E-2					↑		-		10.0		-	
14	2.479E-2	5.6	16.2	-	21.3			-		10.0		-	
15	1.503E-2							-		10.0	↓	-	
16	9.119E-3	5.6	21.0	-	18.7			-		10.0		-	99.9
17	5.531E-3						100.0	-	200.0	8.0		-	79.7
18	3.355E-3							-		6.7		-	67.4
19	2.035E-3	5.6	11.7	-	6.8	10.0		-		6.0	99.9	-	59.8
20	1.234E-3							-		6.0	94.9	-	44.7
21	7.485E-4							-		6.0	91.9	-	35.6
22	4.540E-4	5.6	9.3	-	4.6			-		6.0	90.0	-	30.0
23	3.043E-4							-		6.0	90.0	-	30.0
24	1.486E-4						↓	-	↓	6.0	90.0	-	30.0
25	9.166E-5					↓		-		6.0	90.0	-	30.0
26	6.790E-5							-		6.0	90.0	-	30.0
27	4.017E-5							-		6.0	90.0	-	30.0
28	2.260E-5	5.6	24.0	-	3.7			-		6.0	90.0	-	30.0
29	1.371E-5							-		6.0	90.0	-	30.0
30	8.315E-6							-		6.0	90.0	-	30.0
31	4.000E-6	5.6	35.6	-	32.5			-		6.0	90.0	-	30.0
32	5.400E-7	5.6	41.2	-	39.2			-		6.0	50.0	-	30.0
33	1.000E-7	5.6	42.6	-	40.8		50.0	-		6.0	50.0	-	30.0

GFR Burnup Uncertainties (%)

	BOLNA diagonal	AFCI1.1 diagonal	AFCI1.2 diagonal	BOLNA full	AFCI1.1 full	AFCI1.2 full
Isotope	**Cm242**	**Cm242**	**Cm242**	**Cm242**	**Cm242**	**Cm242**
σ_{capt}	0.40	2.92	1.22	0.63	7.03	2.73
σ_{fiss}	3.62	8.17	8.17	6.87	8.17	20.12
ν	1.07	1.14	1.14	1.83	1.14	2.54
σ_{inel}	0.06	0.29	0.30	0.09	0.49	0.52
Total	**3.79**	**8.75**	**8.34**	**7.13**	**10.85**	20.46
Overall [(a)]	**9.77**	**11.87**	**11.58**	**16.94**	**14.64**	**27.47**

[(a)] Total of all isotopes

Improvements of AFCI1.2 based on the Results of AFCI1.1 Applications

Standard Deviations (%)

		Pu238 σ_{fiss}			Pu240 σ_{capt}			Pu241 σ_{fiss}			Cm244 σ_{fiss}		
Gr.	[MeV]	BOLNA	AFCI1.1	AFCI1.2	BOLNA	AFCI1.1	AFCI1.2	BOLNA	AFCI1.1	AFCI1.2	BOLNA	AFCI1.1	AFCI1.2
1	1.964E+1	25.2	20.0	20.0	52.2	55.0	55.0	24.1	10.0	10.0	17.9	20.0	20.0
2	1.000E+1		20.0	20.0		40.8	40.8		6.5	6.5		20.0	20.0
3	6.065E+0	20.5	20.0	20.0	32.5	35.0	35.0	14.2	5.0	5.0	31.3	20.0	20.0
4	3.679E+0		13.8	13.8		28.8	35.0		5.0	5.0		20.0	20.0
5	2.231E+0	33.8	10.0	10.0	19.7	25.0	35.0	21.3	5.0	5.0	43.8	20.0	20.0
6	1.353E+0	17.1	50.0	50.0	16.3	100.0	100.0	16.6	16.6	15.0	50.0	10.0	15.0
7	8.209E-1		50.0	50.0		56.5	56.5		14.7	16.2		10.0	11.9
8	4.979E-1	17.1	50.0	50.0	14.3	29.9	29.9	13.5	13.6	17.0	36.5	10.0	10.0
9	3.020E-1		50.0	50.0		17.5	17.5		17.5	18.9		10.0	10.0
10	1.832E-1	8.8	50.0	50.0	13.8	10.0	10.0	19.9	19.9	20.0	47.6	10.0	10.0
11	1.111E-1		50.0	50.0		10.0	10.0		12.9	16.9		10.0	10.0
12	6.738E-2	11.9	50.0	50.0	11.3	10.0	10.0	8.7	8.8	15.0	26.3	10.0	10.0
13	4.087E-2		50.0	50.0		10.1	10.0		10.3	11.9		10.0	10.0
14	2.479E-2	11.2	50.0	50.0	10.2	10.2	10.0	11.3	11.3	10.0	19.0	10.0	10.0
15	1.503E-2		50.0	50.0		7.0	6.9		10.8	10.0		10.0	10.0
16	9.119E-3	7.5	50.0	50.0	4.4	5.0	5.0	10.4	10.4	10.0	11.9	10.0	10.0
17	5.531E-3		50.0	50.0		5.0	5.0		11.6	10.0		10.0	12.5
18	3.355E-3		50.0	50.0		5.0	5.0		12.3	10.0		10.0	14.1
19	2.035E-3	4.3	50.2	49.9	1.5	5.0	5.0	12.7	12.7	10.0	5.3	10.0	15.0
20	1.234E-3		65.3	39.8		5.0	5.0		16.1	7.5		7.8	17.6
21	7.485E-4		74.4	33.7		5.0	5.0		18.1	5.9		6.5	19.1
22	4.540E-4	8.1	80.0	30.0	1.6	5.0	5.0	19.4	19.4	5.0	5.7	5.7	20.0
23	3.043E-4		58.8	24.8		5.2	4.7		14.1	5.0		9.7	20.0
24	1.486E-4		36.7	19.4		5.4	4.3		8.6	5.0		13.8	20.0
25	9.166E-5		28.7	17.4		5.4	4.2		6.6	5.0		15.3	20.0
26	6.790E-5		25.4	16.6		5.4	4.1		5.8	5.0		15.9	20.0
27	4.017E-5		21.5	15.6		5.5	4.0		4.8	5.0		16.6	20.0
28	2.260E-5	19.0	19.0	15.0	5.5	5.5	4.0	4.2	4.2	5.0	17.1	17.1	20.0
29	1.371E-5		12.1	15.0		3.1	4.0		15.0	5.0		19.4	20.0
30	8.315E-6		7.9	15.0		1.6	4.0		21.6	5.0		20.9	20.0
31	4.000E-6	4.6	4.6	15.0	0.4	0.4	4.0	26.8	26.8	5.0	22.0	22.0	20.0
32	5.400E-7	4.6	4.6	5.0	3.2	3.2	1.0	2.9	2.9	1.0	26.4	26.4	20.0
33	1.000E-7	4.9	4.9	5.0	4.8	4.8	1.0	3.3	3.3	1.0	27.2	27.2	20.0

Standard Deviations (%)

		Na σ_{inel}			Fe56 σ_{inel}			Pb206 σ_{inel}			B10 σ_{capt}		
Gr.	[MeV]	BOLNA	AFCI1.1	AFCI1.2	BOLNA	AFCI1.1	AFCI1.2	BOLNA	AFCI1.1	AFCI1.2	BOLNA	AFCI1.1	AFCI1.2
1	1.964E+1	18.8	10.8	10.8	13.0	2.6	5.1	19.8	42.0	42.0	15.0	0.9	0.9
2	1.000E+1		4.9	4.9		2.3	4.5		3.6	3.6		1.2	1.2
3	6.065E+0	8.9	5.1	5.1	7.2	1.4	2.9	5.5	4.6	4.6	15.0	0.8	0.8
4	3.679E+0		5.3	5.3		1.2	2.4		23.1	23.1		1.2	1.2
5	2.231E+0	12.6	8.1	8.1	25.4	1.4	2.8	14.2	29.9	29.9	15.0	0.9	0.9
6	1.353E+0	28.0	11.1	11.1	16.1	1.4	2.8	9.2	18.4	18.4	15.0	0.7	0.7
7	8.209E-1		11.6	11.6		-	-		2.2	2.2		0.9	0.9
8	4.979E-1	50.0	38.3	38.3	-	-	-	-	-	-	15.0	1.0	1.0
9	3.020E-1		-	-		-	-		-	-		1.0	1.0
10	1.832E-1	-	-	-	-	-	-	-	-	-	10.0	1.0	1.0
11	1.111E-1		-	-		-	-		-	-		0.8	0.8
12	6.738E-2	-	-	-	-	-	-	-	-	-	10.0	0.8	0.8
13	4.087E-2		-	-		-	-		-	-		0.7	0.7
14	2.479E-2	-	-	-	-	-	-	-	-	-	8.0	0.7	0.7
15	1.503E-2		-	-		-	-		-	-		0.7	0.7
16	9.119E-3	-	-	-	-	-	-	-	-	-	8.0	0.7	0.7
17	5.531E-3		-	-		-	-		-	-		0.7	0.7
18	3.355E-3		-	-		-	-		-	-		0.7	0.7
19	2.035E-3	-	-	-	-	-	-	-	-	-	5.0	0.7	0.7
20	1.234E-3		-	-		-	-		-	-		0.7	0.7
21	7.485E-4		-	-		-	-		-	-		0.7	0.7
22	4.540E-4	-	-	-	-	-	-	-	-	-	5.0	0.7	0.7
23	3.043E-4		-	-		-	-		-	-		0.7	0.7
24	1.486E-4		-	-		-	-		-	-		0.7	0.7
25	9.166E-5		-	-		-	-		-	-		0.7	0.7
26	6.790E-5		-	-		-	-		-	-		0.7	0.7
27	4.017E-5		-	-		-	-		-	-		0.7	0.7
28	2.260E-5	-	-	-	-	-	-	-	-	-	5.0	0.7	0.7
29	1.371E-5		-	-		-	-		-	-		0.7	0.7
30	8.315E-6		-	-		-	-		-	-		0.7	0.7
31	4.000E-6	-	-	-	-	-	-	-	-	-	3.0	0.7	0.7
32	5.400E-7	-	-	-	-	-	-	-	-	-	1.0	0.7	0.7
33	1.000E-7	-	-	-	-	-	-	-	-	-	1.0	0.7	0.7

Sodium Cooled Fast Neutron Systems: Nominal Values and Total Uncertainties (%)

Reactor		Multiplication Factor	Power Peaking Factor	Doppler Coefficient	Coolant Void Worth	Burnup Reactivity Swing [a]
ABR Metal	Nominal Value	0.972326			1402 pcm [1]	
	BOLNA	1.47			13.10	
	AFCI1.1	1.22			9.10	
	AFCI1.2	1.54			10.32	
ABR Oxide	Nominal Value	0.988232			2443 pcm [2]	
	BOLNA	1.44			7.82	
	AFCI1.1	1.08			5.38	
	AFCI1.2	1.49			5.60	
SFR	Nominal Value	1.05280	1.53 [3]	231 pcm [4]	1831 pcm [5]	-3981.1 pcm [6]
	BOLNA	1.86	0.45	5.57	17.11	3.55
	AFCI1.1	1.09	0.19	3.92	10.88	1.94
	AFCI1.2	2.16	0.22	6.88	14.02	4.25
EFR	Nominal Value	1.10848	1.63 [7]	1289 pcm [8]	1934.5 pcm [9]	-9123.9 pcm [10]
	BOLNA	1.27	1.18	3.80	7.83	3.49
	AFCI1.1	1.15	0.96	3.50	5.10	1.58
	AFCI1.2	1.29	1.01	4.03	5.40	3.43

[a] The uncertainties show the component due to cross section uncertainties (the component due to the isotope buildup is not taken into account)

ABR Metal

[1] Na loss at the core center

ABR Oxide

[2] Na loss at the core center

SFR

[3] (R , Z) =(66.59 , 143.03)$_{cm}$

[4] T_{fuel}=300K - T_{fuel}=850K

[5] Na loss in core

[6] 155 days

EFR

[7] (R , Z) =(153.24 , 125)$_{cm}$

[8] T_{fuel}=300K - T_{fuel}=1520K

[9] Na loss in core and blanket

[10] 1700 days

Fast Neutron Systems: Nominal Values and Total Uncertainties (%)

Reactor		Multiplication Factor	Power Peaking Factor	Doppler Coefficient	Coolant Void Worth	Burnup Reactivity Swing [a]
GFR	Nominal Value	1.01049	1.45 [1]	1549 pcm [2]	350.1 pcm [3]	1081.3 pcm [4]
	BOLNA	1.89	1.68	5.51	7.67	16.94
	AFCI1.1	1.66	1.66	4.67	6.47	14.64
	AFCI1.2	1.95	1.71	5.44	6.75	27.47
LFR	Nominal Value	1.00023	1.29 [5]	228.1 pcm [6]	6575.5 pcm [7]	-1464 pcm [8]
	BOLNA	1.40	0.64	4.35	7.18	2.42
	AFCI1.1	1.19	0.31	7.96	9.05	1.62
	AFCI1.2	1.67	0.58	6.20	9.81	3.39
ABMAB	Nominal Value	0.94816	2.67 [9]	28.3 pcm [10]	3138.4 pcm [11]	-1347.6 pcm [12]
	BOLNA	2.90	21.42	-	15.49	56.63
	AFCI1.1	1.22	9.07	-	11.37	48.69
	AFCI1.2	2.46	17.99	-	13.89	105.11

[a] The uncertainties show the component due to cross section uncertainty
(the component due to the isotope buildup is not taken into account)

GFR

[1] Center core radially and axially
[2] T_{fuel}=300K - T_{fuel}=1263K
[3] He loss in core and reflector
[4] 415 days

LFR

[5] (R , Z) =$(100.96 , 117.90)_{cm}$
[6] T_{fuel}=300K - T_{fuel}=900K
[7] Pb loss in core
[8] 310 days

ADMAB

[9] (R , Z) =$(20 , 102.5)_{cm}$
[10] T_{fuel}=1773K - T_{fuel}=980K
[11] Pb-Bi loss in core
[12] 366 days

Isotope/Reaction Contributing to 90% of Multiplication Factor Uncertainty with AFCI1.2

		ABR Metal	ABR Oxide	SFR	EFR	GFR	LFR	ADMAB
U238	inelastic	1.00	0.78		0.90	1.49	0.74	
U238	capture				0.25			
Pu238	fission	0.56	0.57	1.36	0.34	0.53	0.94	0.53
Pu239	capture				0.25			
Pu240	nu	0.31	0.31	0.42	0.27		0.34	
Pu240	fission	0.28	0.30					
Pu240	capture		0.30	0.46	0.34		0.39	
Pu241	fission	0.67	0.77	1.02	0.39	0.79	0.64	1.05
Am241	fission							0.94
Am241	capture							0.79
Am242m	fission			0.69				
Am243	fission							0.44
Cm244	nu							0.50
Cm244	fission							0.65
Cm245	fission			0.43				1.09
Pb206	inelastic						0.41	
Total [(a)]		**1.39**	**1.35**	**1.98**	**1.18**	**1.77**	**1.51**	**2.22**
Overall [(b)]		**1.54**	**1.49**	**2.16**	**1.29**	**1.95**	**1.67**	**2.46**

[(a)] Total uncertainty yield by the cross sections listed in the Table;

[(b)] Overall uncertainty yield by all cross sections.

Isotope/Reaction Contributing to 90% of Multiplication Factor Uncertainty with BOLNA

		ABR Metal	ABR Oxide	SFR	EFR	GFR	LFR	ADMAB
U238	**inelastic**	0.97	0.76		0.87	1.42	0.73	
U238	**capture**	0.28	0.33		0.37	0.41	0.25	
Pu238	**nu**			0.36			0.23	
Pu238	**fission**	0.22		0.56			0.34	
Pu239	**capture**				0.25			
Pu240	**nu**	0.30	0.31	0.41	0.27		0.33	
Pu240	**fission**	0.27	0.26				0.29	
Pu240	**capture**		0.25		0.26		0.27	
Pu241	**fission**	0.65	0.77	1.01	0.39	0.82	0.61	1.04
Pu242	**fission**			0.38				
Am241	**fission**							0.82
Am242m	**fission**			0.77				
Cm244	**fission**			0.41				1.90
Cm245	**fission**		0.26	0.41			0.22	1.04
Fe56	**inelastic**	0.35	0.35	0.46				0.83
C	**elastic**					0.31		
O16	**capture**				0.29			
B10	**capture**						0.44	
Total		**1.33**	**1.30**	**1.71**	**1.16**	**1.72**	**1.28**	**2.67**
Overall		**1.47**	**1.44**	**1.86**	**1.27**	**1.89**	**1.40**	**2.90**

Pu238 Fission, Pu240 Capture, Pb206 Inelastic are much larger with AFCI1.2

Pu241 Fission, Cm244 Fission, Na Inelastic, Fe56 Inelastic, B10 Capture are much larger with BOLNA

Conclusions

The present work shows the first application of the recent AFCI1.2 matrix, with the determination of the uncertainty for the main integral parameters (multiplication factor, power peaking factor, Doppler reactivity coefficient, coolant void reactivity worth and burnup reactivity swing) of a series of fast reactors (ABR metal core, ABR oxide core, SFR, EFR, GFR, LFR, ADMAB). The obtained AFCI1.2 parameter uncertainties are also compared with the results presented in previous studies with the BOLNA correlation matrix.

The impact in terms of parameters uncertainties of the improvements made in the AFCI1.2 matrix with respect to the previous matrix AFCI1.1 has been analyzed.

In AFCI1.2, all covariance data related to the reactions from the Maslov evaluations have been completed with the inclusion of energy correlation terms that were missing in AFCI1.1.

With AFCI1.2 data, U235 capture has reduced standard deviations in the energy range 2 keV - 0.2 MeV compared to the AFCI1.1 data but it still brings a large component of uncertainty (0.8%) on the GODIVA multiplication factor because of the strong effects associated to the energy correlation terms.

With AFCI1.2 data, the component of uncertainty from Cm242 capture (which is relevant for parameters like the GFR burnup reactivity swing) is decreased compared to AFCI1.1 because of the reduced standard deviations, however large uncertainties are still associated with Cm242 fission.

As with AFCI1.1 data, compared to the BOLNA results the use of AFCI1.2 data yields much larger components of uncertainty from Pu238 fission, Pu240 capture and Pb206 inelastic, while smaller uncertainties are obtained from Pu241 fission, Cm244 fission, Na inelastic, Fe56 inelastic, B10 capture.

The overall parameter uncertainties estimated with AFCI1.2 data generally are larger than the AFCI1.1 uncertainties (the biggest effects, especially for SFR and ADMAB, show even a factor of 2) and quite comparable with the BOLNA results (except for parameters like GFR or ADMAB burnup reactivity).