PFNS ^{239}Pu

Prompt fission neutron spectra

First analysis

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Tested evaluation files

6 evaluation files tested

- JEFF-3.1.1
- BRC-09
- ENDFB-7.0
- JENDL-4.0
- MASLOV(*)
- KORNILOV

LosAlamos Madland Nix Model
Some differences in the data taken into account but the model is the same

More fission neutrons in lower energies range for Maslov and Kornilov

Study principle (first analysis)

- JEFF-3.1.1 as a reference evaluation
- PFNS from other files introduced in JEFF3.1.1 file for ^{239}Pu
- k_{eff} comparison with TRIPOLI-4 Monte Carlo code

(Advantage : TRIPOLI-4 reads the evaluation file as it is, without processing for PFNS ⇒ Just replace MF=5 MT=18)

MASLOV(*) : personal communication

Spectra characterization

Moments

- Spectra moments calculation (mainly 1 and 2)

$$\mu_n = \int_{E\,\min}^{E\,\max} E^n \times \chi(E) \times dE$$

Graphs

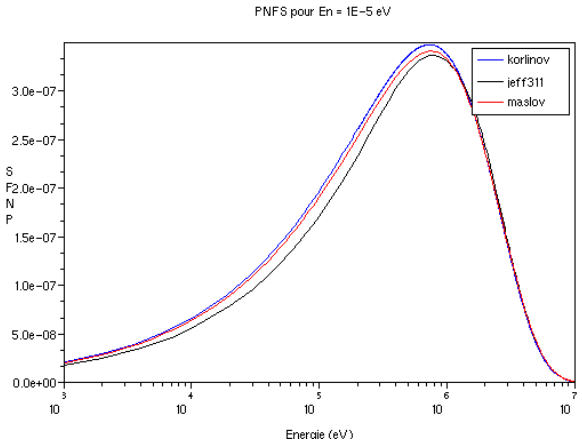
- Graphical spectra comparisons
- Graphical spectra ratio comparisons

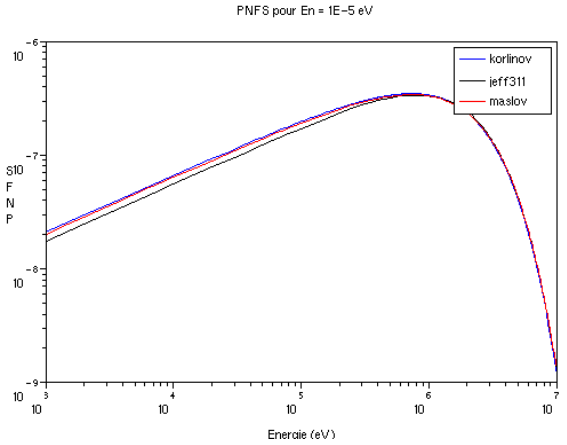
Energetic mesh : UNION of meshes

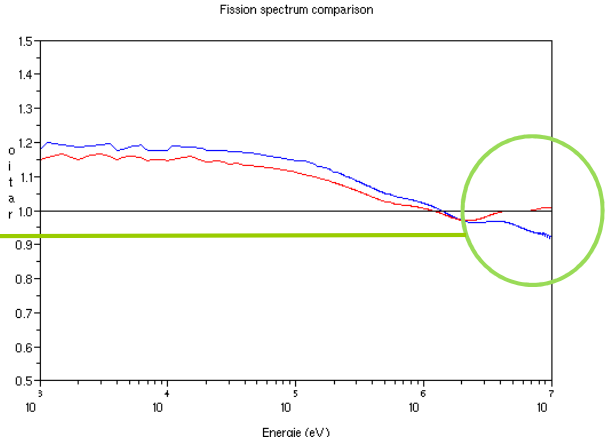
Some problem in the interpolation scheme (LIN LIN assumption)

Graphical comparisons

Graphs : Maslov and Kornilov compared to JEFF-3.1.1 (10^{-5} eV)







Maslov and Kornilov less energy

Ratio equal to 1 :
- Maslov ~1,2 MeV
- Kornilov ~ 1,4 MeV

D. Reynier's work : +0,7% in mean energy leads to +50 pcm on reactivity for MSK ZONA3 sub-assembly

Moments :order 1

Consistent data for JEFF, ENDFB, JENDL

Energie incidente (MeV)	BRC2009	ENDFB7	JEFF311	JENDL4	MASLOV	KORLINOV
1,00E-11	2,113	2,112	2,112	2,116	2,092	2,055
2,53E-08					2,092	
0,0005	2,113					
0,001	2,113					
0,01	2,113					
0,05					2,093	
0,1	2,116		2,115	2,122		
0,2				2,124		
0,5	2,126	2,125	2,126		2,107	2,070
0,75	2,132					
1	2,139	2,138	2,140	2,140	2,122	2,084
1,25	2,146					
1,5	2,152	2,150			2,137	2,100
1,75	2,159					
2	2,165	2,163	2,168	2,165	2,152	2,115
2,25	2,172					
2,5	2,179	2,175			2,167	2,130
2,75	2,185					
2,9					2,180	
3	2,192	2,188	2,195		2,183	2,146
3,5	2,205					
4	2,219	2,212	2,222		2,212	2,175
4,5	2,232					
5	2,236	2,236	2,226	2,237	2,242	2,205
5,5	2,230			2,187	2,255	
6	2,199	2,177	2,201	2,120	2,251	2,233
6,5	2,178			2,086	2,206	
7	2,164	2,133	2,173	2,082	2,185	2,262
7,5	2,162				2,194	
8	2,168	2,130	2,173	2,101	2,215	2,262

-2,7%

-2,4%

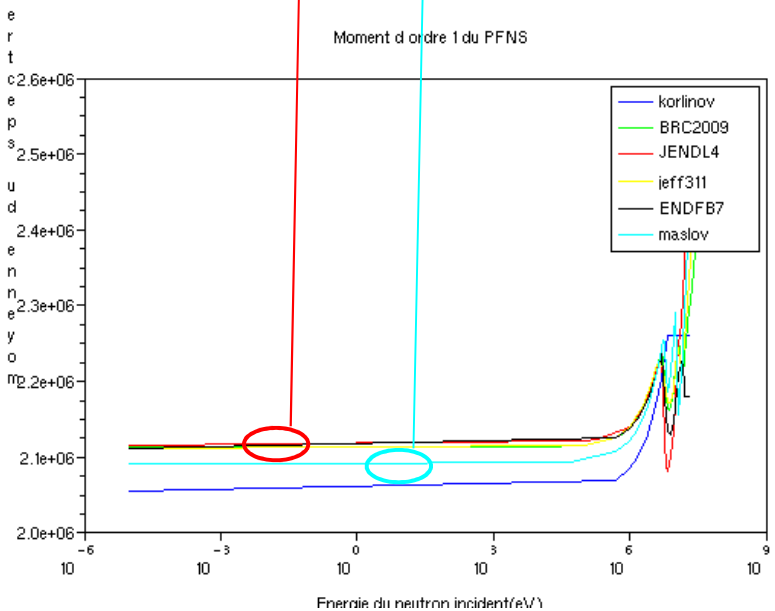
énergie incidente (MeV)	BRC2009	ENDFB7	JEFF311	JENDL4	MASLOV	KORLINOV
8,5	2,177				2,237	
9	2,188	2,145	2,191	2,135	2,255	2,262
9,5	2,200					
10	2,213	2,167	2,215	2,173	2,291	2,262
10,5	2,226					
11	2,238	2,190	2,240	2,217	2,226	2,262
11,5	2,248					
12	2,251	2,209	2,245	2,250	2,157	2,262
12,5	2,242					
13	2,228	2,216	2,227	2,258	2,181	2,262
13,5	2,216					
14	2,211	2,222	2,219	2,279	2,211	2,262
14,5	2,212					
14,7					2,237	
15	2,216	2,233	2,229	2,313	2,249	2,262
15,5	2,222					
16	2,230	2,179		2,356	2,292	2,262
16,5	2,239					
17	2,249			2,407	2,336	
17,5	2,258					
18	2,267		2,300	2,459	2,385	
18,5	2,275					
19	2,283			2,515	2,433	
19,5	2,289					
20	2,295	2,179	2,338	2,575	2,482	2,262
21	2,303					
22	2,311		2,360			
23	2,319					
24	2,329		2,387			
25	2,341					
26	2,353		2,423			
27	2,366					
28	2,377		2,457			
29	2,387					
30	2,396		2,481			

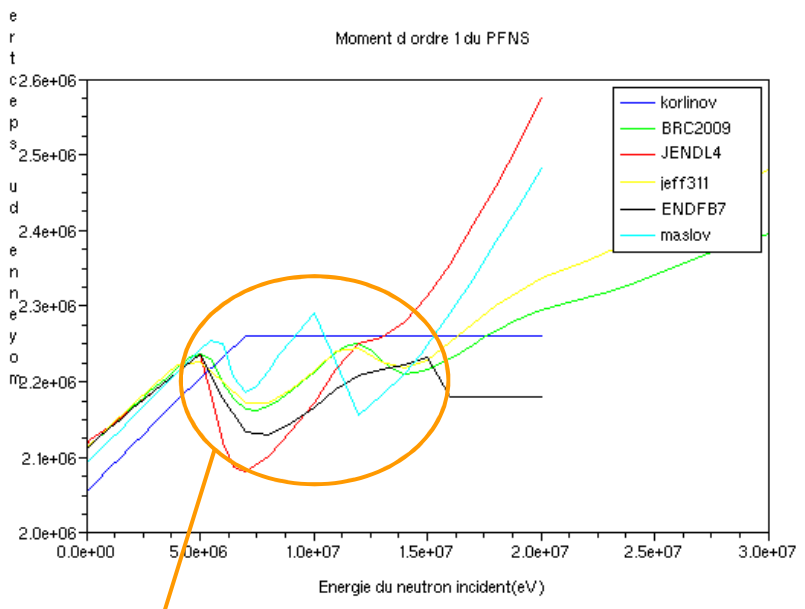
Different meshes – Maslov/Kornilov different from other evaluations

Moments : order 1 – Mean energy

JEFF-ENDF-JENDL-BRC quiet undistinguishable

MASLOV KORNILOV lower





Strange behaviour

Moments : order 2

-1,1%

énergie incidente (MeV)	BRC2009	ENDFB7	JEFF311	JENDL4	MASLOV	KORLINOV
1,00E-11	1,65	1,66	1,65	1,66	1,66	1,64
2,53E-08					1,66	
0,0005	1,65					
0,001	1,65					
0,01	1,65					
0,05					1,66	
0,1	1,66		1,66	1,67		
0,2				1,67		
0,5	1,67	1,67	1,67		1,67	1,65
0,75	1,67					
1	1,68	1,68	1,68	1,69	1,69	1,66
1,25	1,68					
1,5	1,69	1,69			1,70	1,67
1,75	1,69					
2	1,70	1,70	1,70	1,71	1,71	1,69
2,25	1,71					
2,5	1,71	1,71			1,73	1,70
2,75	1,72					
2,9					1,74	
3	1,72	1,72	1,73		1,74	1,71
3,5	1,74					
4	1,75	1,74	1,75		1,76	1,74
4,5	1,76					
5	1,77	1,77	1,77	1,78	1,79	1,76
5,5	1,77			1,80	1,80	
6	1,77	1,75	1,77	1,79	1,81	1,79
6,5	1,76			1,78	1,81	
7	1,76	1,74	1,76	1,76	1,81	1,81
7,5	1,76				1,80	
8	1,76	1,74	1,76	1,75	1,80	1,81

Difference about 1%

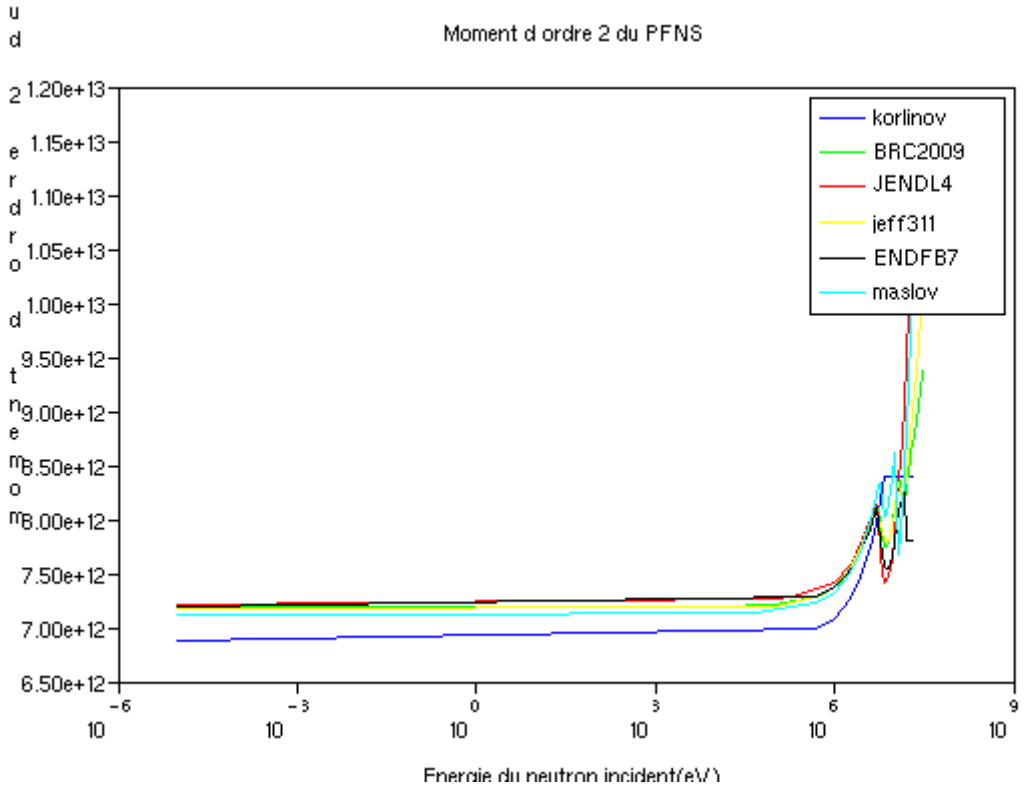
Consistency in the shape

Standard deviation : $\sigma = \sqrt{\mu_2 - \mu_1^2}$

Moments : order 2

JEFF-ENDF-JENDL-BRC quiet undistinguishable

MASLOV KORNILOV lower (because of lower mean)



EALF (ICSBEP definition)
Experiment characterization

EALF

- Energy corresponding to Average neutron Lethargy causing Fission

$$\bar{u} = \frac{\int_{u\min}^{u\max} u \times \Sigma_f(u) \times \Phi(u) \times du}{\int_{u\min}^{u\max} \Sigma_f(u) \times \Phi(u) \times du}$$

And $$\bar{E} = \frac{E_0}{e^{\bar{u}}}$$

AFGE

- Average neutron Energy causing Fission

PMF series

R. Capote list 001 – 002 – 011 – 022 – 024 - 027 – 029 - 031

EALF (MeV) 1,28 – 1,28 – 0,083 – 1,26 – 0,647 – 0,069 – 1,28 – 0,177

Serie	JEFF311		mean		ENDFB7		BRC2009		JENDL4		MASLOV		KORNILOV	
	keff	sigma	leakage	sigma	keff	sigma	keff	sigma	keff	sigma	keff	sigma	keff	sigma
PMF001	1,00046	12	0,672	0,00005	1,00004	12	1,00004	12	0,99998	12	0,99932	12	0,99767	12
PMF002	1,00433	5	0,668	0,00002	1,00420	7	1,00436	5	1,00397	5	1,00317	5	1,00162	5
PMF011	0,99707	15	0,043	0,00003	0,99730	8	0,99671	15	0,99724	15	0,99748	15	0,99690	15
PMF022	0,99810	7	0,672	0,00003	0,99784	8	0,99806	7	0,99777	7	0,99719	7	0,99583	7
PMF024	0,99982	8	0,656	0,00003	0,99969	8	0,99985	8	0,99986	8	0,99978	8	0,99878	8
PMF027	1,00131	8	0,526	0,00003	1,00101	8	1,00123	8	1,00129	8	1,00141	8	1,00131	8
PMF029	0,99747	7	0,672	0,00003	0,99713	8	0,99735	7	0,99702	7	0,99634	7	0,99483	7
PMF031	1,00333	8	0,611	0,00003	1,00330	8	1,00334	8	1,00322	8	1,00332	8	1,00270	8

Serie	JEFF311		EALF	ENDFB7		BRC2009		JENDL4		MASLOV		KORNILOV	
	keff	sigma	(MeV)	delta keff	sigma	delta keff	sigma	delta keff	sigma	delta keff	sigma	delta keff	sigma
PMF001	1,00046	12	1,280	-42	17	-42	17	-48	17	-114	17	-279	17
PMF002	1,00433	5	1,280	-13	9	3	7	-36	7	-116	7	-271	7
PMF011	0,99707	15	0,083	23	17	-36	21	17	21	41	21	-17	21
PMF022	0,99810	7	1,260	-26	11	-4	10	-33	10	-91	10	-227	10
PMF024	0,99982	8	0,647	-13	11	3	11	4	11	-4	11	-104	11
PMF027	1,00131	8	0,069	-30	11	-8	11	-2	11	10	11	0	11
PMF029	0,99747	7	1,280	-34	11	-12	10	-45	10	-113	10	-264	10
PMF031	1,00333	8	0,177	-3	11	1	11	-11	11	-1	11	-63	11

Maslov and Kornilov discrepancies : as expected by previous analysis

Different behaviour for PMF011 et PMF027,031 : water and polyethylene reflected

AFGE : lower than or close to 100 keV

PST series

Selected benchmarks : series 001, 004 and 012

TRIPOLI-4 RESULT PST

Serie	JEFF311		mean		ENDFB7		BRC2009		JENDL4		MASLOV		KORNILOV	
	keff	sigma	leakage		keff	sigma	keff	sigma	keff	sigma	keff	sigma	keff	sigma
PST001-1	1,00106	10	0	0	1,00117	10	1,00089	10	1,00089	10	1,00517	10	1,00982	10
PST001-6	1,00642	10	0	0	1,00657	10	1,00634	10	1,00632	10	1,01008	10	1,01464	10
PST004-5	0,99594	10	0	0	0,99597	10	0,99590	10	0,99583	10	0,99922	10	1,00331	10
PST012-13	1,00594	10	0,021	0,00002	1,00605	10	1,00577	10	1,00589	10	1,00644	10	1,00767	10

Serie	JEFF311		EALF	ENDFB7		BRC2009		JENDL4		MASLOV		KORNILOV	
	keff	sigma	(eV)	Delta keff	sigma	Delta keff	sigma	Delta keff	sigma	Delta keff	sigma	Delta keff	sigma
PST001-1	1,00106	10	0,089	**11**	14	**-17**	14	**-17**	14	**411**	14	**876**	14
PST001-6	1,00642	10	0,367	**15**	14	**-8**	14	**-10**	14	**366**	14	**822**	14
PST004-5	0,99594	10	0,043	**3**	14	**-4**	14	**-11**	14	**328**	14	**737**	14
PST012-13	1,00594	10	0,043	**11**	14	**-17**	14	**-5**	14	**50**	14	**173**	14

Maslov and Kornilov discrepancies : from 400 to 800 pcm for PST001,004

Behaviour different for PST012 : very low EALF, low Pu content in solution

ENDFB, BRC, JENDL very close to JEFF : around +/-20 pcm

Mockups

Mockup experiments

- Thermal spectrum : EOLE/MISTRAL-2
- Fast spectrum : MASURCA/ZONA2A

Exp.	JEFF3.1.1	MASLOV	Δk (x 10^5)	KORNILOV	Δk (x 10^5)
MISTRAL2	1,00741 (23)	1,00760 (23)	**19** (33)	1,00847 (23)	**106** (33)
ZONA2A	1,00995 (12)	1,00846 (12)	**-149** (17)	1,00685 (12)	**-310** (17)

Quiet equal for MISTRAL
Around 100 pcm maximum

PMF confirmation

Conclusion

Two spectra really different

- Maslov and Kornilov

…and the other ones quiet similar

- JEFF-3.1.1, ENDFB-7.0, JENDL-4.0 and BRC-09

→ large effects in thermal or fast spectra

Mockup experiments analysis

- MISTRAL effects different than ICSBEP ones : investigations needed
- Other libraries (ENDFB, JENDL, …) to be tested

Outlook

Short and mean term

- ICSBEP
  - other spectra (INTER)
  - other thermal spectrum experiments (no leakage, other EALFs)
- MOCKUPS (MASURCA, EOLE, ZP(P)R, BFS,…)
- Other prompt fission neutron spectra : FIFRELIN code, …, other ones?
- Interpolations : other interpolation modes (than LIN-LIN), incident energy mesh
- Neutron balance

Long term

- Deterministic calculations : ECCO/PARIS code systems
- Spectra sensitivities : PARIS for a selected set of experiments