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Comparative sensitivity study of some criticality safety benchmark experiments using JEFF3.1.2, JEFF3.2T and ENDF/B-VII.1

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Outline of the work

- This work was aimed at understanding the effect of the nuclear data used on the calculated value of the multiplication factor for criticality safety calculations.

- This is important to evaluate the Upper Safety Limit of criticality safety calculations and the uncertainties associated with the nuclear data libraries.

- The methodology used will first be presented and then, the results obtained will be discussed isotope per isotope.

Purpose of the work

- As one can see , for the same input, the result of the calculations can be very different :

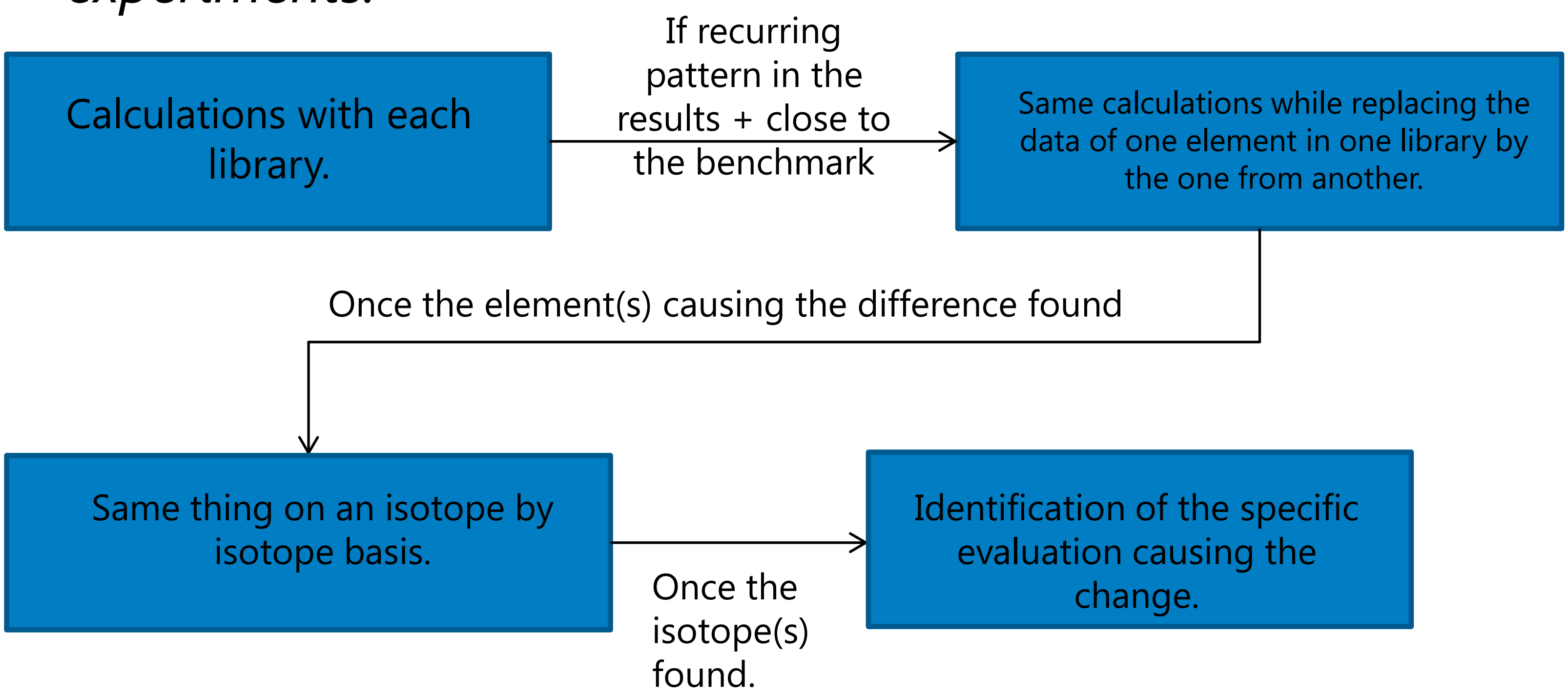
	Experimental value	ENDF/B-VII.1	JEFF 3.1.2	JEFF 3.2t	JENDL
Sphere of HEU reflected by steel	0,999 ± 0,0015	0,99256 ± 0,00036	1,00332 ± 0,00035	0,99827 ± 0,00034	1,00121 ± 0,00036

k_{eff} vs the library used

- This may cause some problems during the conception of installations, such as over/under sizing or lack of adequate protection.
- Three nuclear data libraries were compared : JEFF3.1.2, JEFF3.2T and ENDF/B-VII.1
- MCNP code for the Kcode calculation and tallies

Methodology used

- A set of experiments featuring different combinations of fissile material, moderator and reflector was selected in the *International handbook of evaluated criticality safety benchmark experiments.*



Used methodology (continued)

- To identify the data responsible of the change, the evaluation of the cross sections of several reactions (fission, capture, scattering…) were compared for each library. Then some hypothesis about the cause of the change were formulated and confirmed or infirmed using a perturbative functionality of MCNP code.

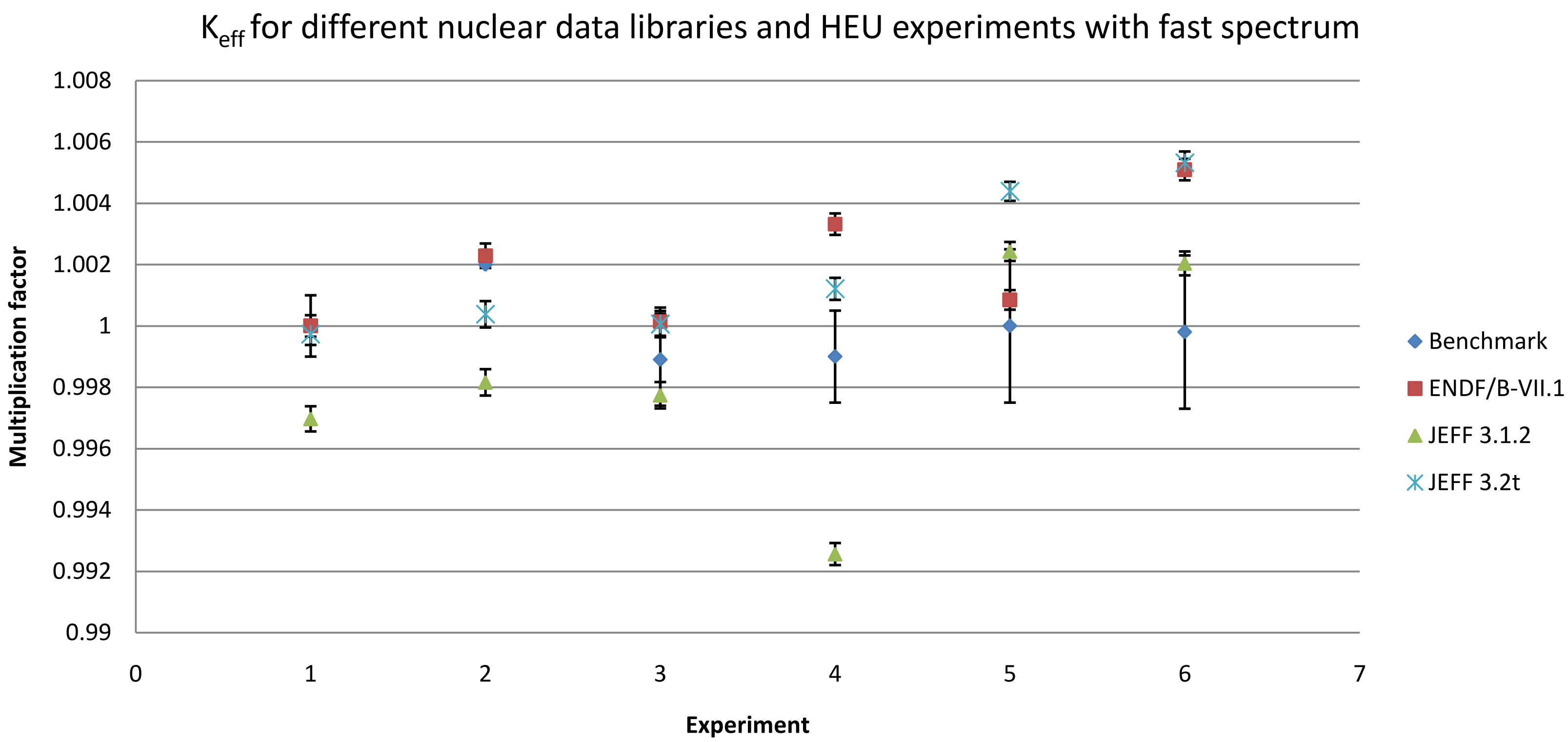
- Several nuclides were identified this way : ^{235}U, ^{239}Pu, ^{240}Pu, ^{208}Pb, ^{54}Fe, ^{56}Fe, ^{57}Fe. Among those nuclides, lead and uranium were the one which triggered the biggest changes.

Experiments for Uranium with fast spectrum

N°	Exp	Description
1	HEU-MET-FAST-001	Bare Sphere
2	HEU-MET-FAST-004	Water reflected sphere
3	HEU-MET-FAST-011	Polyethylene reflected sphere
4	HEU-MET-FAST-013	Steel reflected sphere
5	HEU-MET-FAST-027	Lead reflected sphere
6	HEU-MET-FAST-061	Cylindrical assembly with graphite

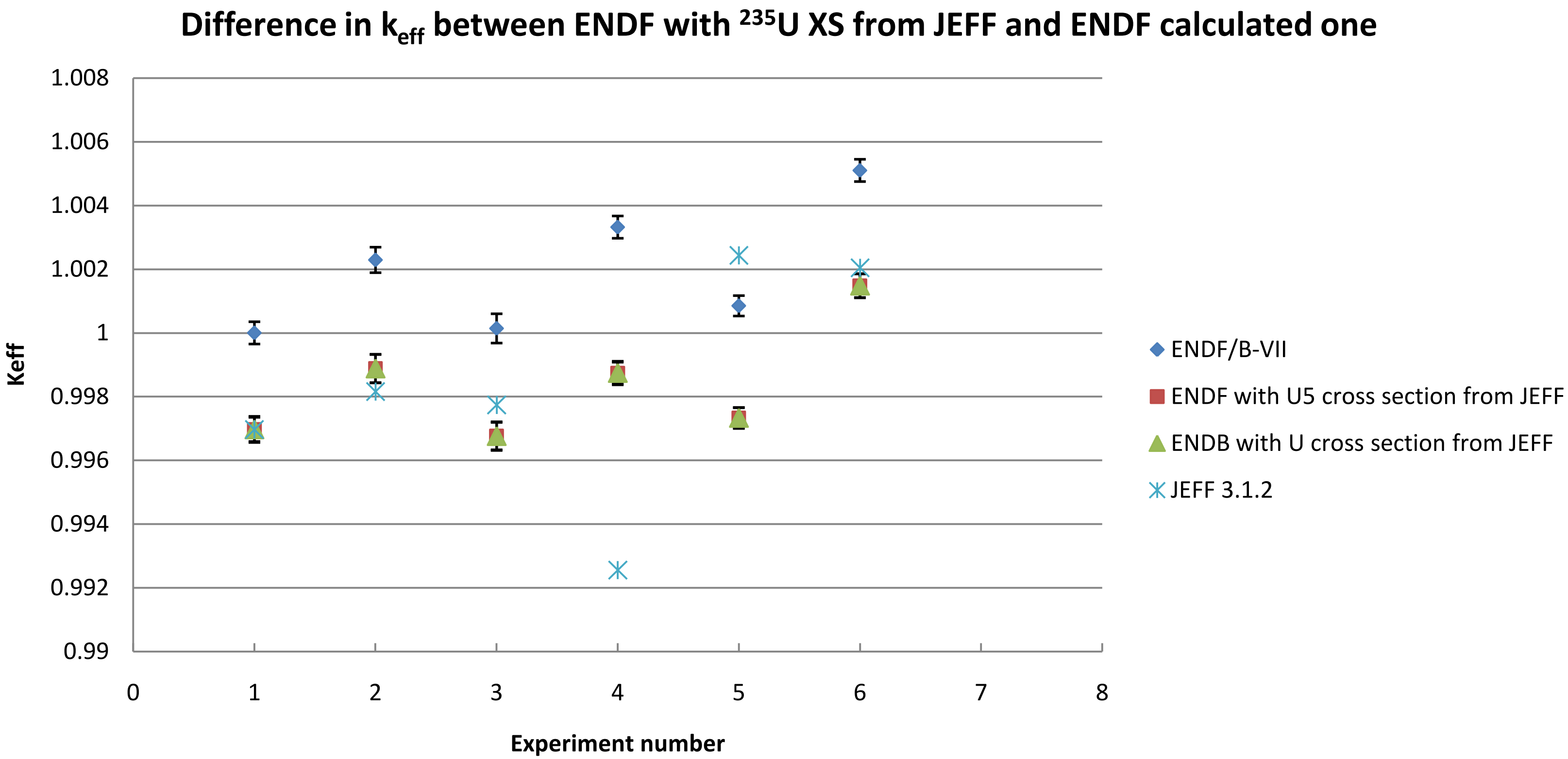
Table 1 : Experiments used for calculations on Uranium with fast spectrum

Results for Uranium



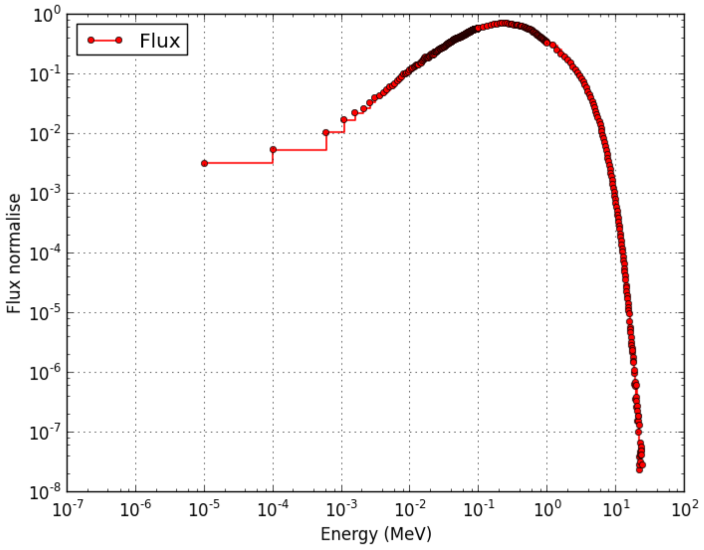
- ENDF results are relatively close to the results from the benchmark on the average and
- they are superior to the JEFF 3.1.2 results, except for experiment n°5 (with Lead as reflector).
- The JEFF 3.2t results are also always superior to the JEFF 3.1.2 results

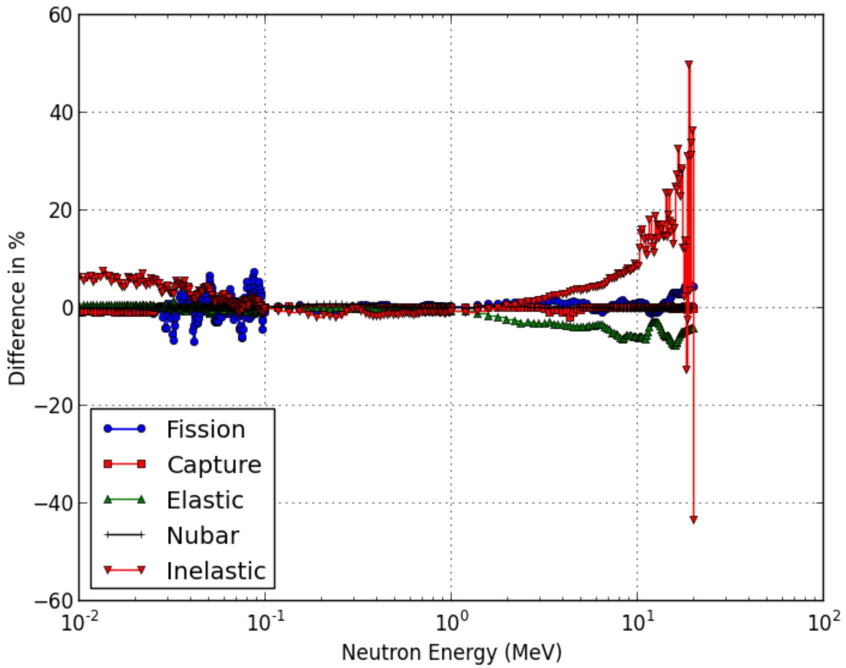
Results for uranium, ENDF/B-VII et JEFF 3.1.2



- Uranium alone is responsible for the changes observed between the two calculations especially ^{235}U
- This is not visible in experiment 4 and 5 because of the presence of respectively lead and iron which also have an effect on the multiplication factor.

Results for Uranium, ENDF/B-VII et JEFF 3.1.2 (HEU bare sphere experiment)





With the perturbation card in MCNP code, Two evaluations are important here : the fission cross section and the inelastic scattering cross section of ^{235}U.

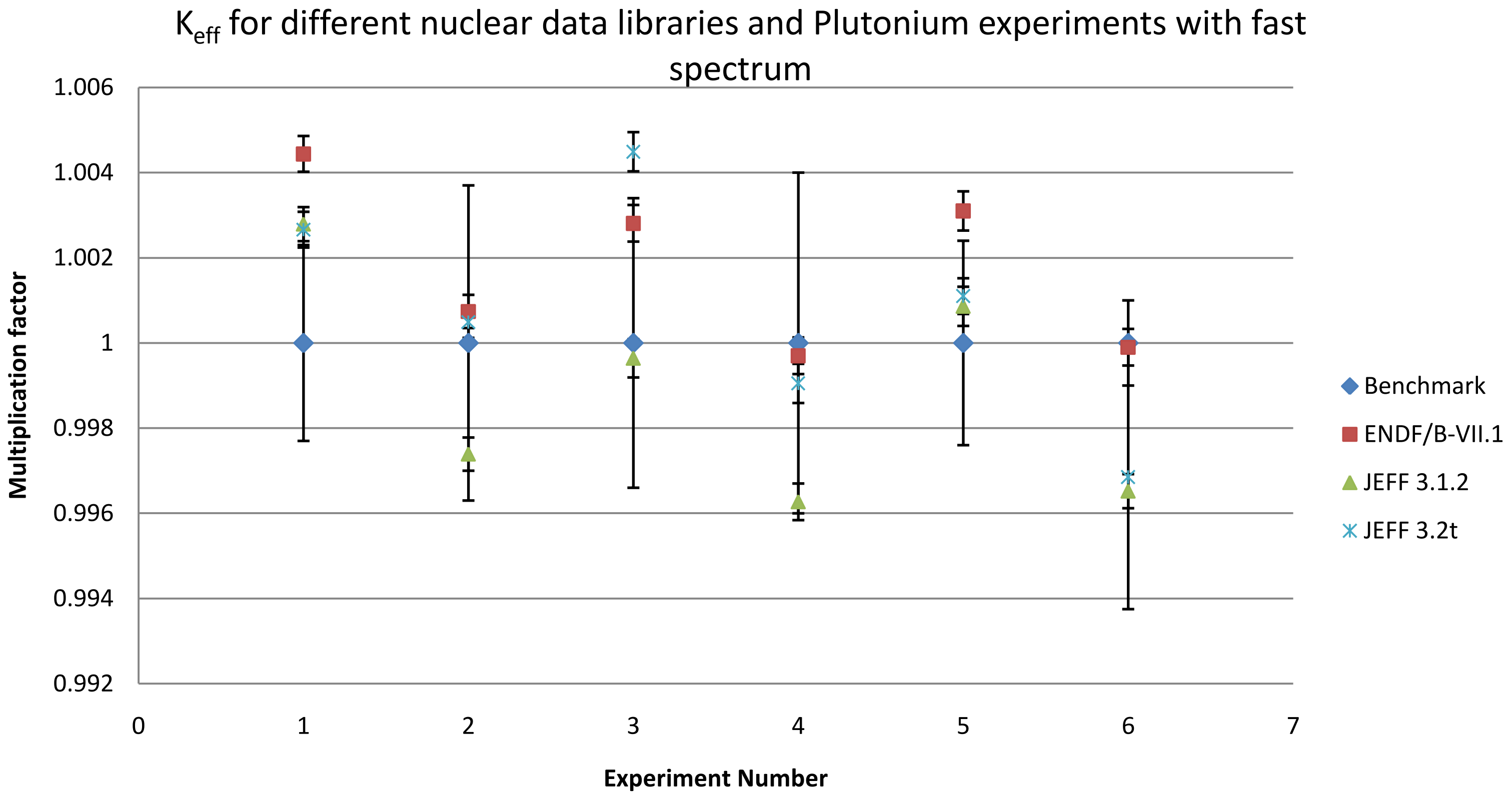
Reaction	Energy Range	Change	Effect (pcm)
Fission	1-11 MeV	2%	674
Fission	20-100 keV	-8%	7
Inelastic	5-11 MeV	-5%	-330
Elastic	1-11 MeV	20%	5

Results for uranium and JEFF 3.2t

	Experiment	ENDF-JEFF3.2t	JEFF3.1.2-JEFF3.2t	ENDF-JEFF3.1.2
1	HEU-MET-FAST-001 Bare Sphere	27	-276	303
2	HEU-MET-FAST-004 3D	191	-222	413
3	HEU-MET-FAST-011	8	-232	240
4	HEU-MET-FAST-013	211	-865	1076
5	HEU-MET-FAST-027	-354	-196	-158
6	HEU-MET-FAST-061	-22	-328	306

- With the new version of JEFF library (JEFF3.2T) , there is an improvement compared to the previous one
- There is a constant difference between the JEFF3.1.2 value and the JEFF3.2T value.

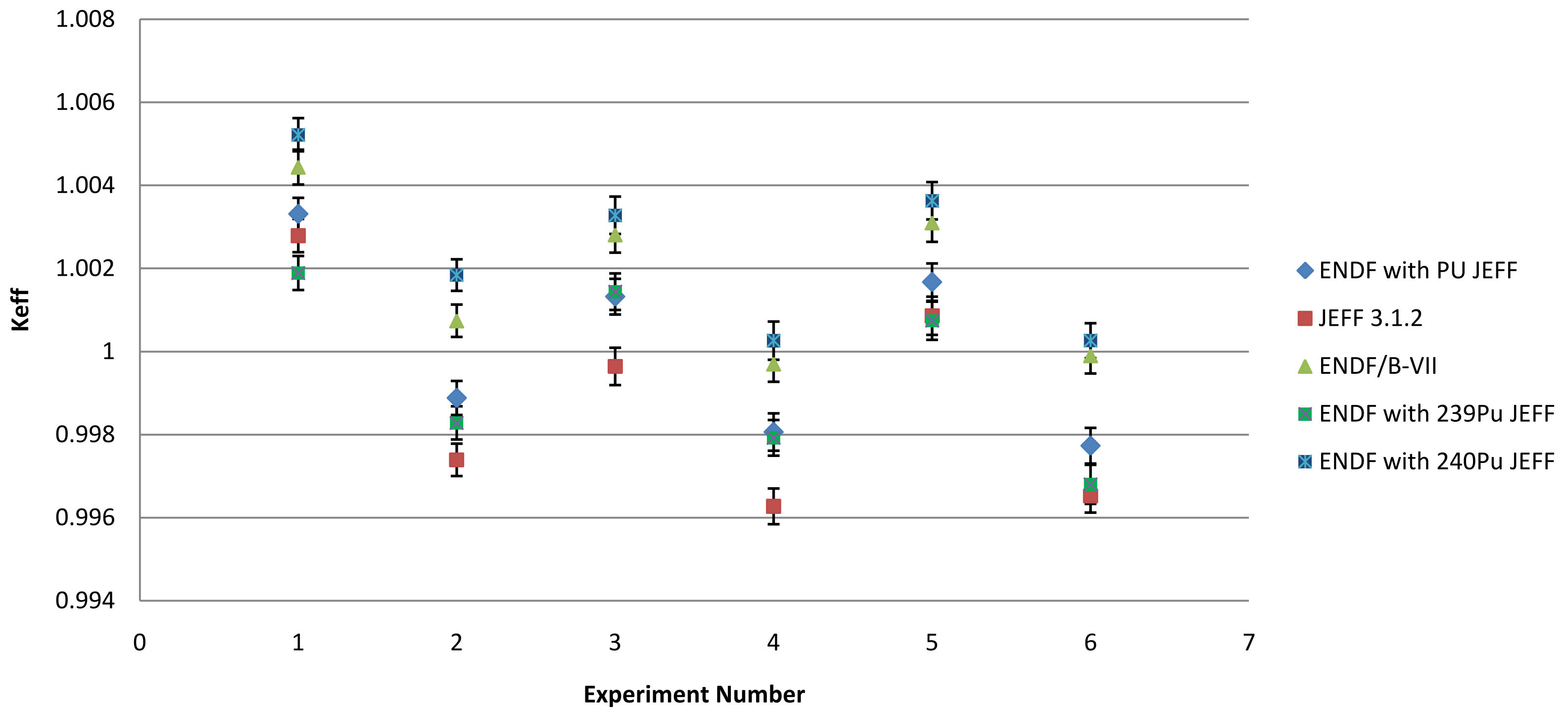
Results for Plutonium with Fast spectrum



- The JEFF 3.1.2 calculation result is always smaller than the ENDF calculation results.
- There is no clear pattern for the JEFF3.2T values

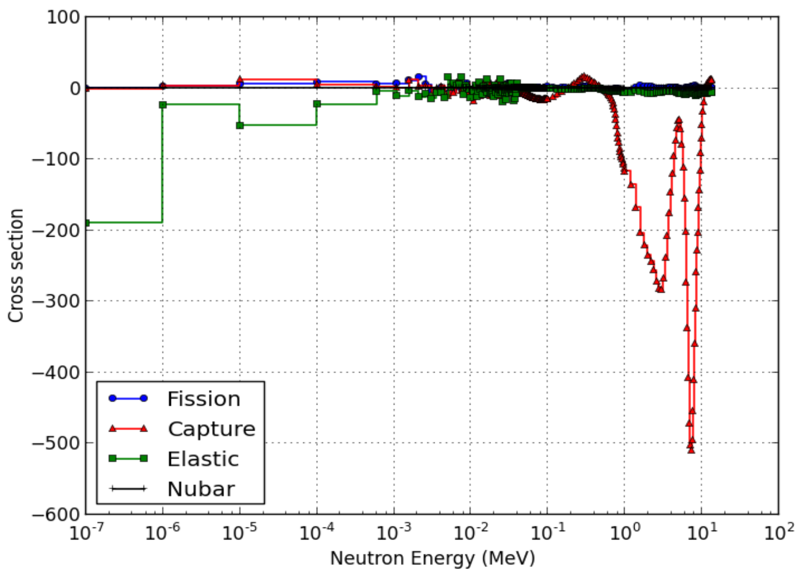
Results for plutonium, ENDF/B-VII and JEFF 3.1.2

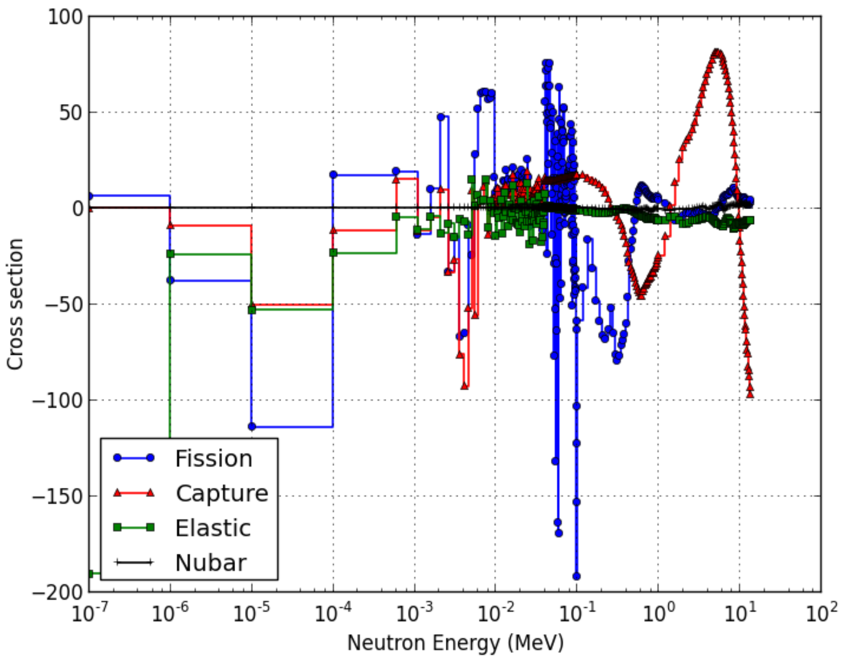
Effect of ^{239}Pu and ^{240}Pu cross section evaluation on the keff



- An average decrease of 120 pcm of k_{eff} value due to the change of ^{239}Pu cross section from JEFF library
- Replacing the ^{240}Pu in the same way leads to an average increase of 80 pcm for k_{eff} value .

Results for plutonium, ENDF/B-VII and JEFF 3.1.2





Experiment PU-MET-FAST-037 (flooded array of plutonium cylinders)

Higher **^{239}Pu** capture cross section in JEFF library could explain the decrease in k_{eff} value (<u>in the left side</u>)

Higher **^{240}Pu** capture cross section in ENDF library could explain the increase in k_{eff} value (<u>in the right side</u>)

Results for plutonium, ENDF/B-VII and JEFF 3.1.2

Nuclide	Reaction	Energy Range	Change	Effect (pcm)
^{239}Pu	Capture	1-20 MeV	-300%	116
^{239}Pu	Elastic	100 Mev-1kev	-50%	123
^{239}Pu	Fission	1-10 Mev	+1%	318
^{240}Pu	Elastic	100 mev-1kev	-50%	3
^{240}Pu	Capture	2-9 MeV	50%	-2
^{240}Pu	Capture	0,2-1 MeV	-25%	10
^{240}Pu	Fission	0,1-0,5 MeV	-50%	-174
^{240}Pu	Fission	1-10 MeV	10%	35
^{240}Pu	Capture	10-100 keV	+50%	22
^{240}Pu	Capture	100 Mev – 1kev	+50%	227
^{240}Pu	Fission	1-10 keV	25%	1

- Based on perturbation calculation, some evaluations are important here:
  - fission cross section of ^{239}Pu
  - elastic cross section of ^{239}Pu
  - fission and capture cross section of ^{240}Pu

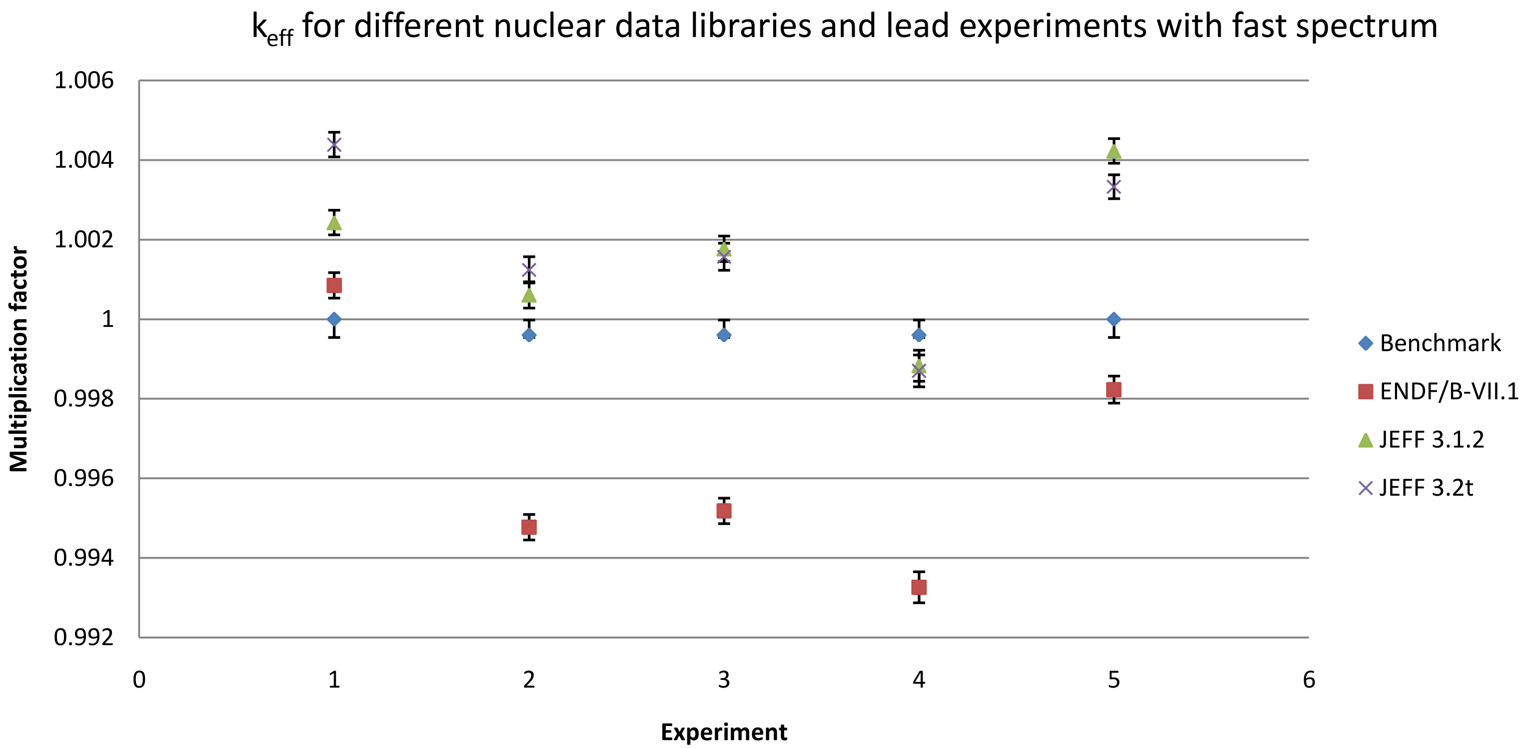
And to a lesser extent, capture cross section of ^{239}Pu.

Experiments with Lead

N°	Exp	Description
1	HEU-MET-FAST-027	Lead reflected sphere
2	HEU-MET-FAST-064,1	Lead reflected cylinder
3	HEU-MET-FAST-064,2	Lead reflected cylinder
4	HEU-MET-FAST-064,3	Lead reflected cylinder
5	PU-MET-FAST-035	Lead reflected sphere

Table 2 : Experiments used for calculations on lead with fast spectrum

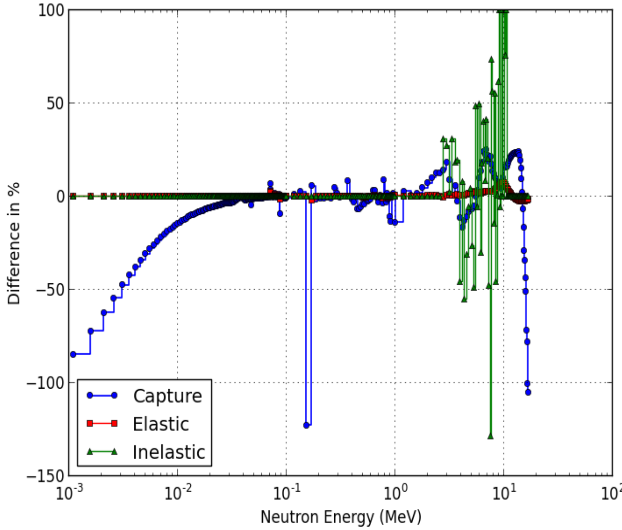
Results for lead



- There is some kind of hierarchy for the lead related calculations for all the experiments with Lead
- JEFF 3.2t results are higher than JEFF 3.1.2 one , which are much higher than ENDF results

Results for lead, ENDF/B-VII.1 and JEFF 3.1.2

All changes in pcm	HMF-27	PMF-35	HMF-64.1	HMF-64.2	HMF-64.3
Difference JEFF3.1.2-ENDF	158	600	584	659	557
Change due to ^{204}Pb	0	0	0	0	13
Change due to ^{206}Pb	27	33	57	79	64
Change due to ^{207}Pb	70	39	64	67	32
Change due to ^{208}Pb	417	713	998	996	980
Overall change due to Pb	418	723	1001	978	1017



Cross section difference (%) for ^{208}Pb

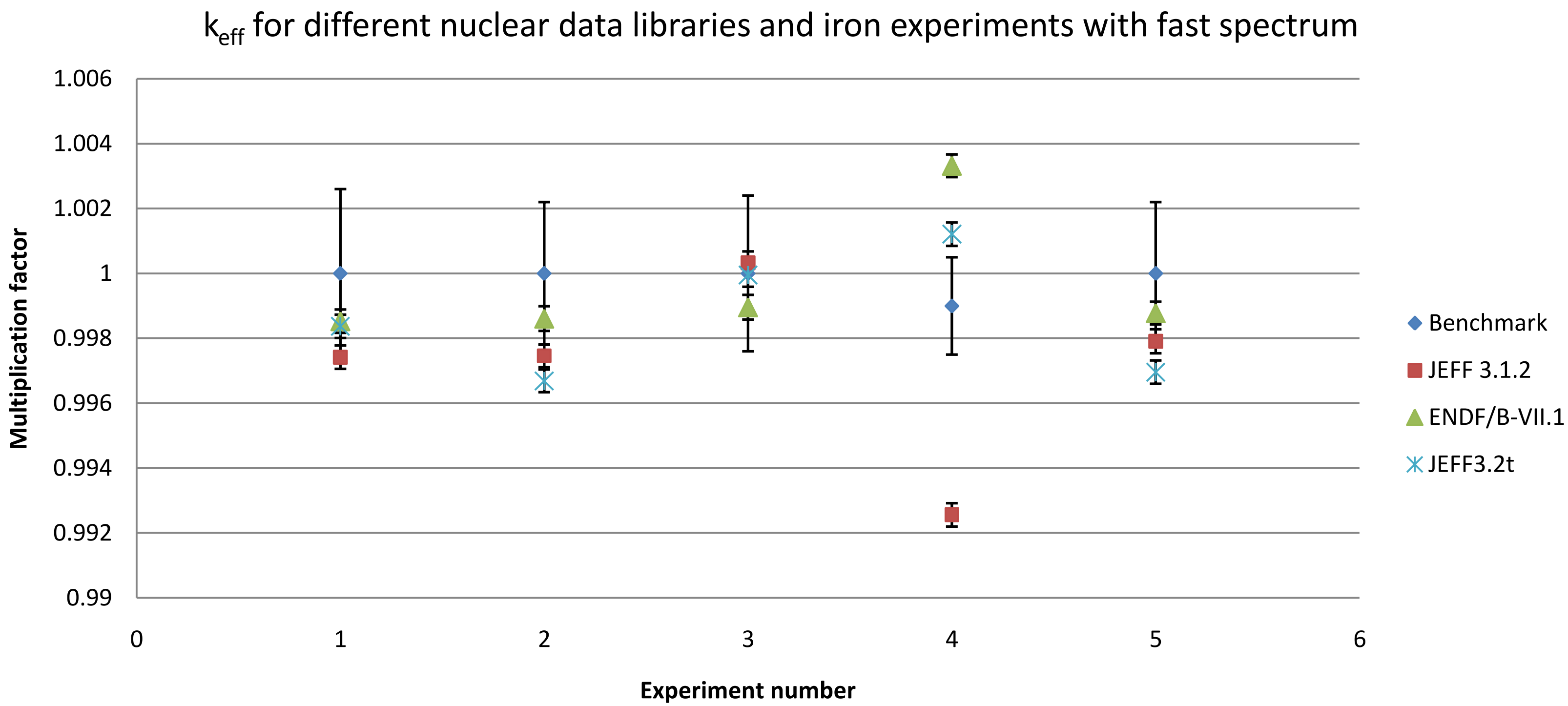
- ^{208}Pb is the isotope responsible for most of the changes
- An average increase of 700 pcm due to the lead evaluation
- No significant change with perturbation test: no origin of this sensitivity
- The same conclusion for JEFF-3.2T evaluation: the difference is slightly smaller: an average change of 520 pcm

Results for iron: Experiments

N°	Exp	Description
1	PU-MET-FAST-026	Steel reflected sphere
2	PU-MET-FAST-025	Steel reflected sphere
3	PU-MET-FAST-028	Steel reflected sphere
4	HEU-MET-FAST-013	Steel reflected sphere
5	PU-MET-FAST-032	Steel reflected sphere

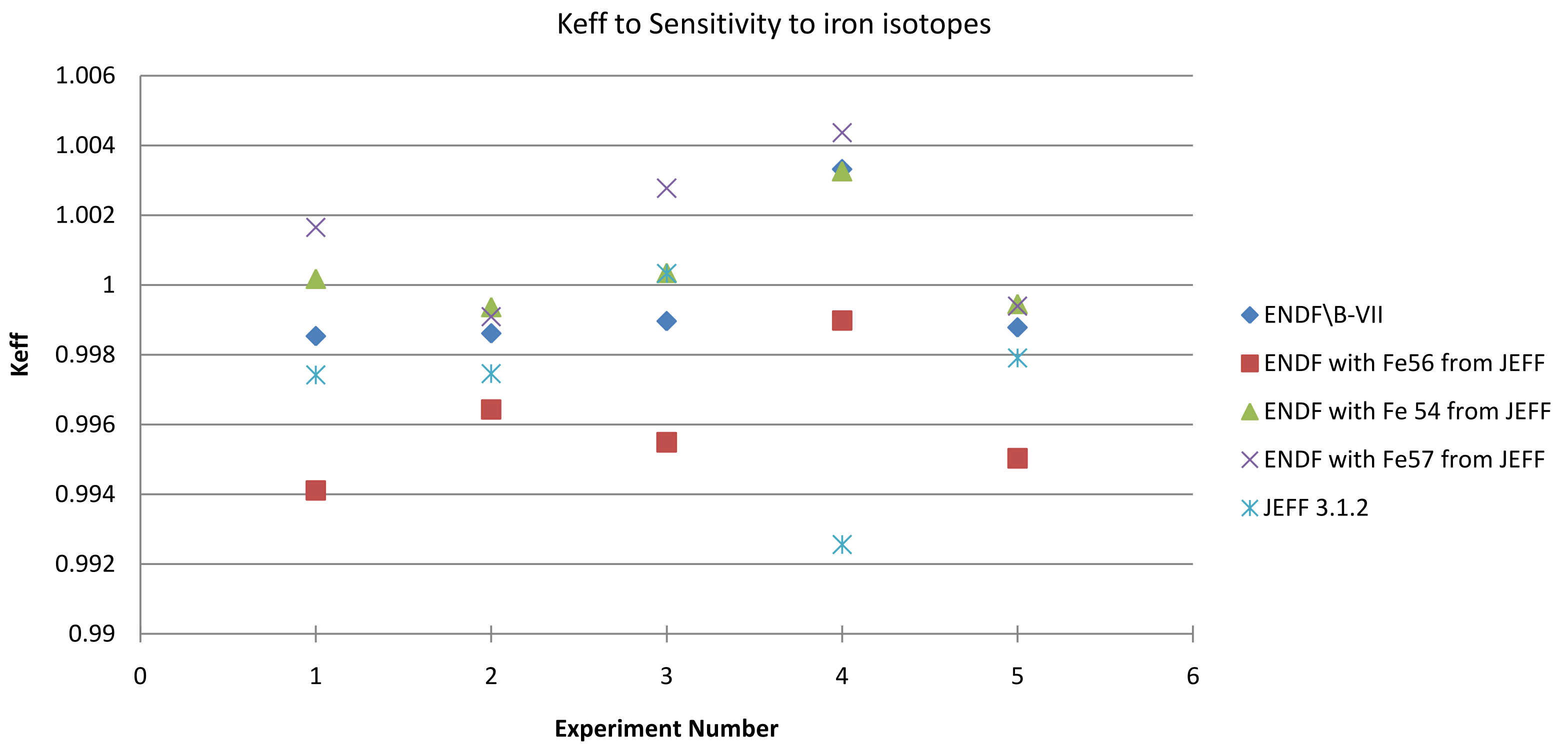
Experiments used for calculations on iron and fast neutrons

Results for iron



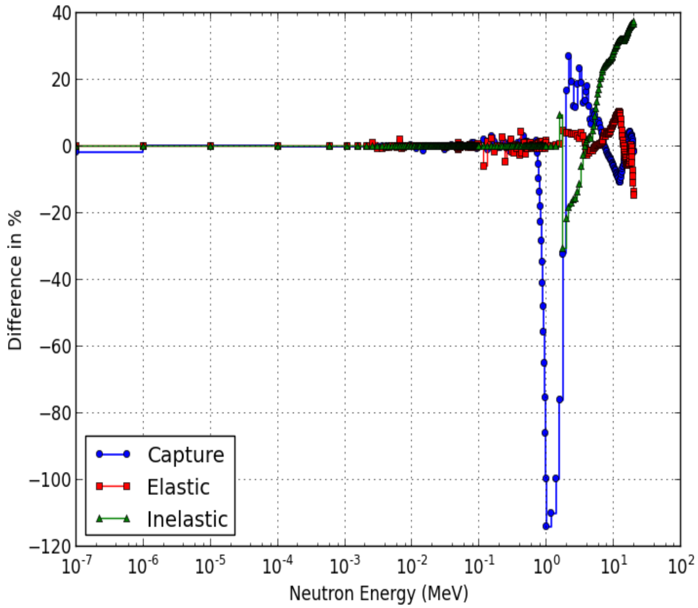
- ENDF and JEFF 3.1.2 results are relatively close for almost all experiments
- With further investigation, there are changes due to isotopes ^{54}Fe, ^{56}Fe and ^{57}Fe which compensate each other.

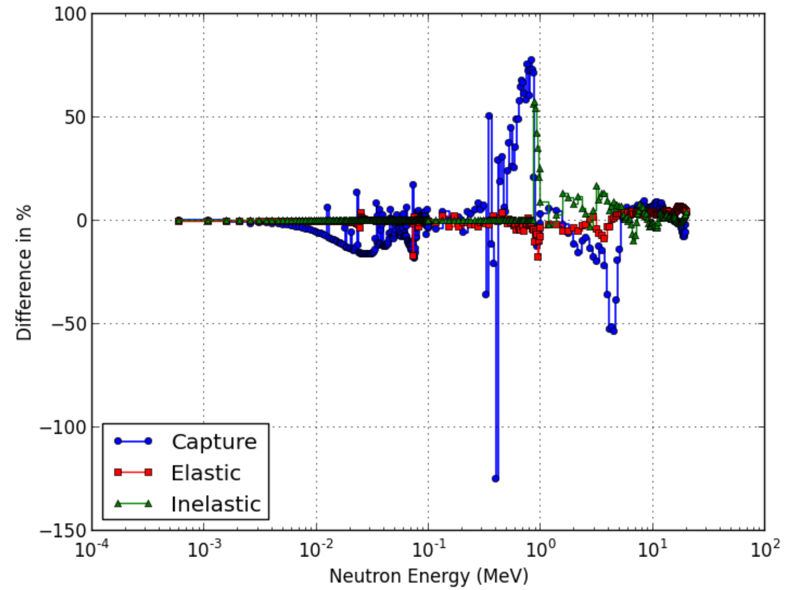
Results for iron, ENDF/B-VII and JEFF 3.1.2



- ^{54}Fe cross section from JEFF library led to a change of -80 pcm compared to the ENDF value
- ^{56}Fe cross section from JEFF library led to change of 360 pcm and that ^{57}Fe led to a change of -180 pcm.

Results for iron, ENDF/B-VII and JEFF 3.1.2





No possible coherent explanation from reaction rates:

Cross section differences of ^{54}Fe and ^{56}Fe do not have a constant behavior in the range of 0.1 to 20MeV

No conclusion from the perturbation tool of MCNP code

Results for iron

Nuclide	Reaction	Energy Range	Change	Effect (pcm)
^{54}Fe	Capture	0,8-2 MeV	-50%	0
^{54}Fe	Capture	2-8 MeV	20%	-38
^{54}Fe	Capture	8-12 MeV	-10%	-23
^{54}Fe	Inelastic	3-12 MeV	20%	-7
^{56}Fe	Inelastic	2-3 MeV	-20%	-9
^{56}Fe	Capture	2-8 MeV	-25%	3
^{56}Fe	Capture	0,4-1 MeV	50%	-24
^{56}Fe	Capture	10-100 keV	-20%	2
^{57}Fe	Capture	10-100 keV	-200%	0
^{57}Fe	Capture	0,2 -2 MeV	50%	-50
^{57}Fe	Elastic	0,1-1 Mev	-300%	0
^{57}Fe	Elastic	0,1 ev-1keV	100%	0

As one can see here, no conclusion can be drawn from the plotted cross sections and the pertubative calculations.

For JEFF 3.2t, the same results were found than for JEFF 3.1.2, which is consistent with the fact that no reevaluation was performed on the iron data for JEFF 3.2t.

As for lead, no explanation could have been found for the changes due to iron isotopes, which has to be linked with the absence of change in the scattering law with the MCNP PERT card.

Conclusion

- Several sensitivities to nuclear data evaluations were found in this study.
- For fissile material, the main one was to the fission cross section of ^{235}U, followed by fission cross section of ^{240}Pu and ^{239}Pu.

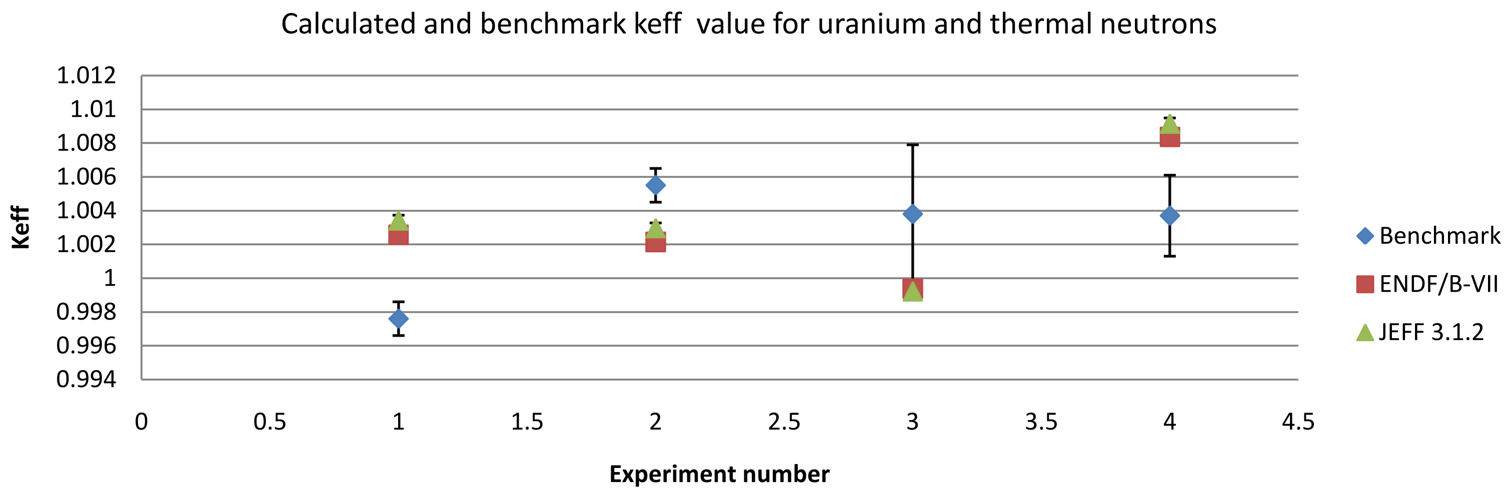
- For non fissile material, namely lead and iron, no explanation could have been found, even though there were important changes due to the library used. The best hypothesis is the scattering law, but this needs to be tested.

- Several improvements toward convergence of the results from ENDF and JEFF have been achieved between JEFF3.1.2 and JEFF3.2T.

N°	Exp	k_{exp}	Δk_{exp}	k_{jeff}	Δk_{jeff}	k_{endf}	Δk_{endf}	Description
1	PU-MET-FAST-031	1,00000	0,0023	1,00279	0,00040	1,00444	0,00042	Polyethylene reflected sphere
2	PU-MET-FAST-037 Case 5	1,00000	0,00370	0,99739	0,00039	1,00074	0,00039	Flooded array of cylinders
3	PU-MET-FAST-037 Case 10	1,00000	0,00340	0,99964	0,00045	1,00281	0,00043	Flooded array of cylinders
4	PU-MET-FAST-037 Case 12	1,00000	0,00400	0,99627	0,00043	0,99970	0,00043	Flooded array of cylinders
5	Pu-MET-FAST-027	1,00000	0,0024	1,00086	0,00046	1,0031	0,00046	Polyethylene reflected sphere
6	PU-MET-FAST-011	1,00000	0,00100	0,99652	0,00040	0,99990	0,00043	water reflected sphere

Experiments used for calculations on Plutonium and fast neutrons

Results for thermal neutrons



All changes in pcm	HMT-32.1	HMT-32.2	HMT-018	HMT-031
Difference ENDF-JEFF	-85	-79	-27	-82
Change due to ^{235}U	-15	14	83	68
Change due to ^{238}U	5	-32	32	50
Change due to ^{234}U	-5	12	0	25
Overall change due to U	-19	52	101	33

No differences were found between ENDF/B-VII and JEFF 3.1.2 results for thermal neutrons. I checked this was not due to some changes compensating each other, but such was not the case. For JEFF3.2T, no pattern was found.