Criticality experiments and benchmarks for validation of cross sections: the neptunium case

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Neptunium 237

1. Abundant waste produced in present thermal nuclear reactors.
2. $T_{1/2} = 2$ My.
3. Candidate for incineration in fast neutron reactors.
4. Burning ^{237}Np needs a better knowledge of neutronic properties (neutron cross sections(XS)).

Motivation

$^{237}Np/^{235}U$

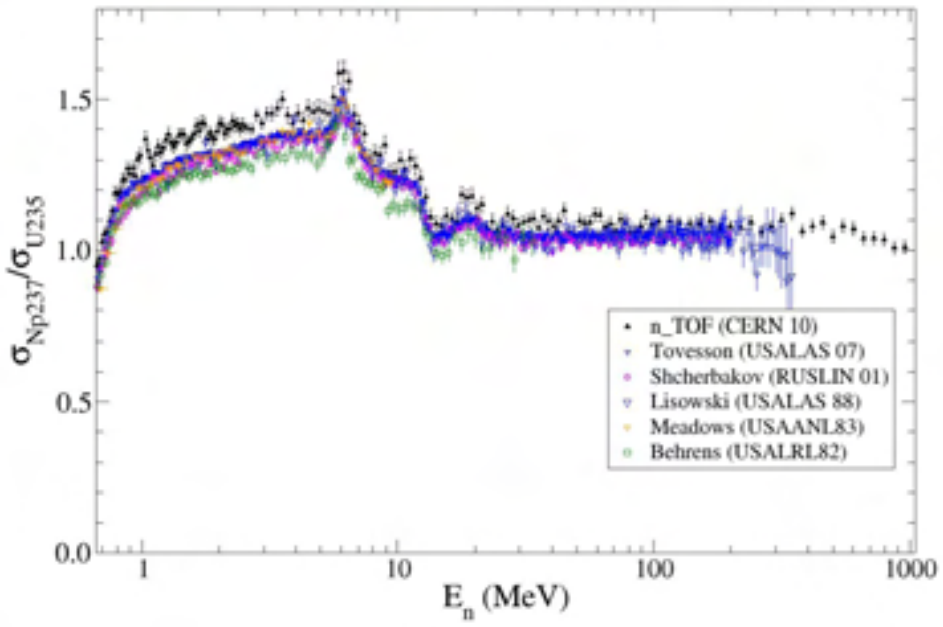


Figure : Ref: C. Paradela et al, Phys. Rev. C82 (2010), 034601. Although most of the measurements are in agreement with each others, the last data obtained at the CERN n_TOF facility are about 5% to 6% higher than the others beyond 1 MeV.

^{237}Np status

However! Several previous measurements are not independent.

ENDF-B7.0 based on Tovesson measurement(2008).

2. Tovesson's one normalised to ENDF-B6.8 at 14 MeV.
3. ENDF-B6.8 based on Lisowski's measurement(1988).
4. Lisowski normalized to Meadows (1983) between 1 and 10 MeV
5. n_TOF measurement consistent with data at 14 MeV within the experimental uncertainty of 4%

Verification of ^{237}Np cross section is necessary

Verification of ^{237}Np Cross Section

1. ^{237}Np+^{235}U Sphere critical model is critical experiment measurement performed in Los Alamos and proposed as a benchmark for neutron transport simulations
2. ^{235}U retains 86% of the mass, criticality is still sensitive to fission of ^{237}Np. (0.3% uncertainty)
3. $K_{eff} = 1.0019 \pm 0.0036$ (experimental value)

Los Alamos Experiment

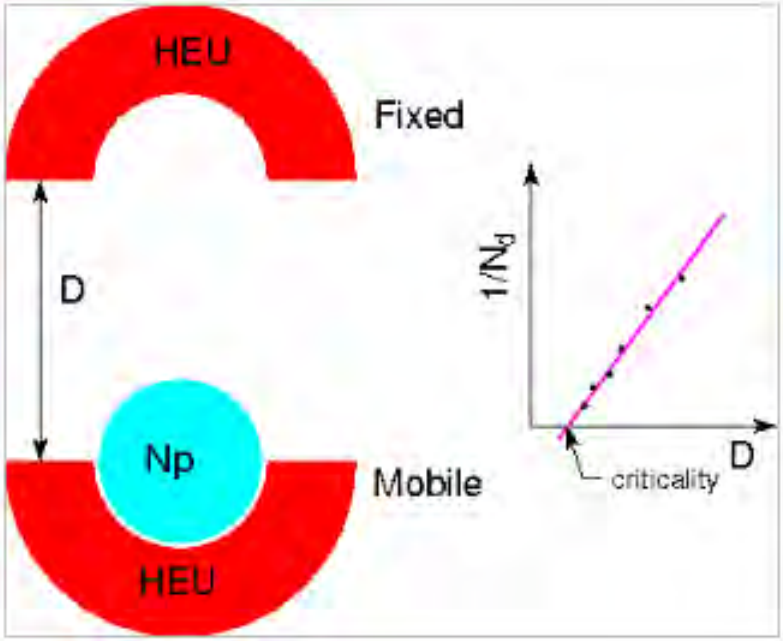
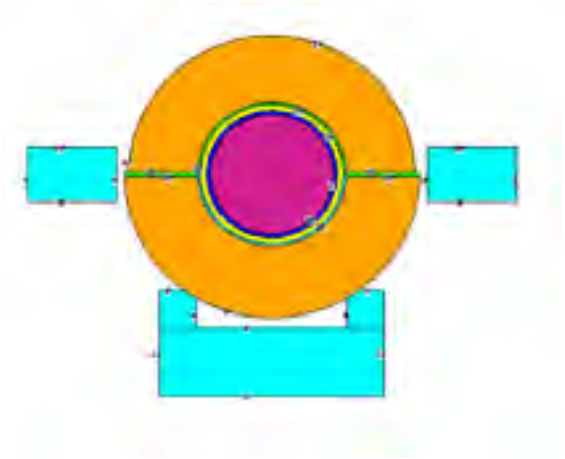


Figure : a neutron source inside Np, (K_{eff}: Mutiplicatif factor)

$N = 1 + K_{eff} + K_{eff}^2 + K_{eff}^3 + ... = \frac{1}{1-K_{eff}}$; $N_d = \frac{\epsilon}{1-K_{eff}}$

Final result: $K_{eff} = 1.0019 \pm 0.0036$

Simulation with MCNP5/MURE



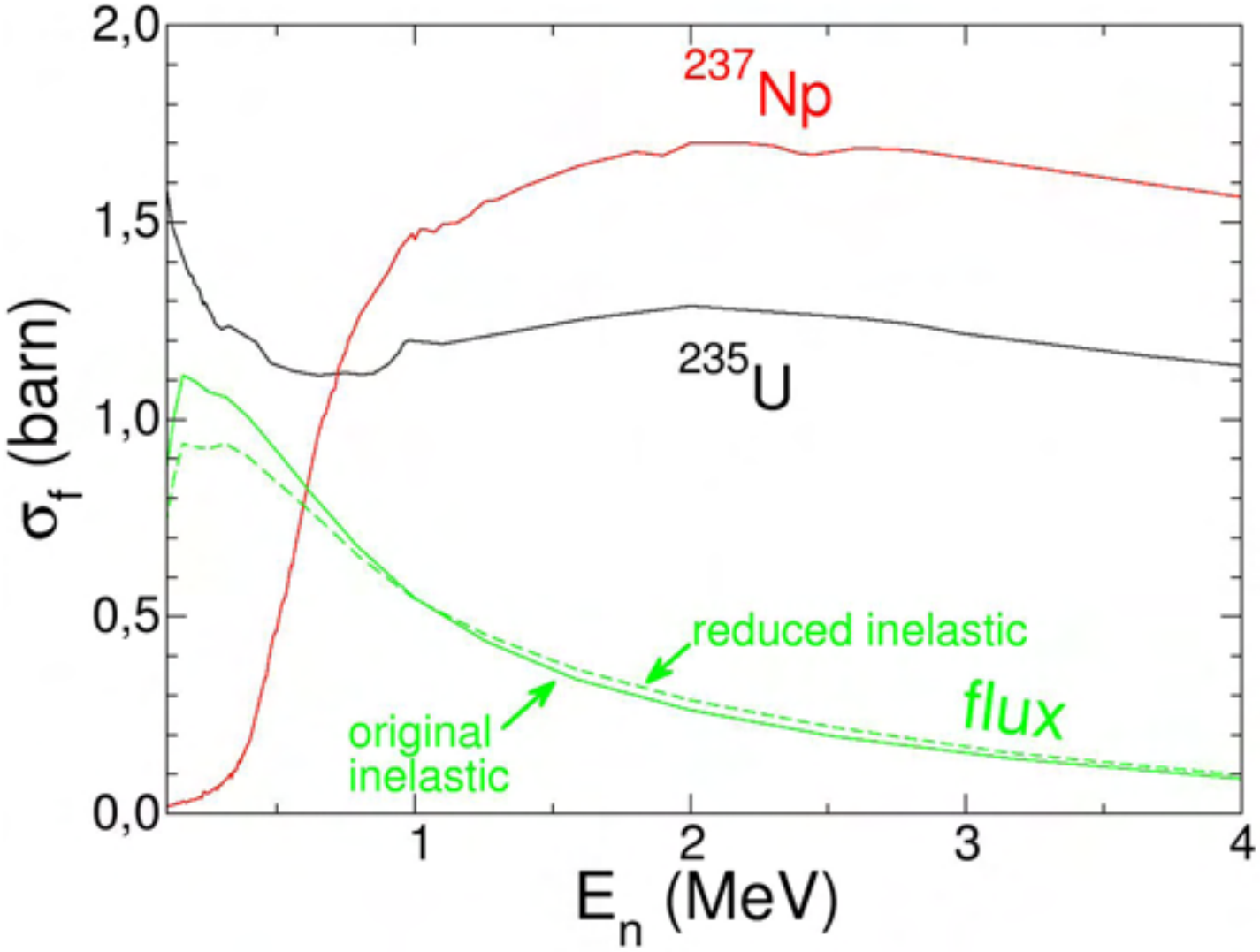
Our work:

- Compute the same Benchmark with same conditions. ($K_{eff} = 0.9942$ (exp-2σ))
- ———————————————
- Substitute nTOF Np XS in place of the evaluated data ENDF/B-7.0's one.
- Result: criticality increased $K_{eff} = 1.0043$ (exp+0.8σ) .

^{237}Np fission XS could be higher than previous measurements.

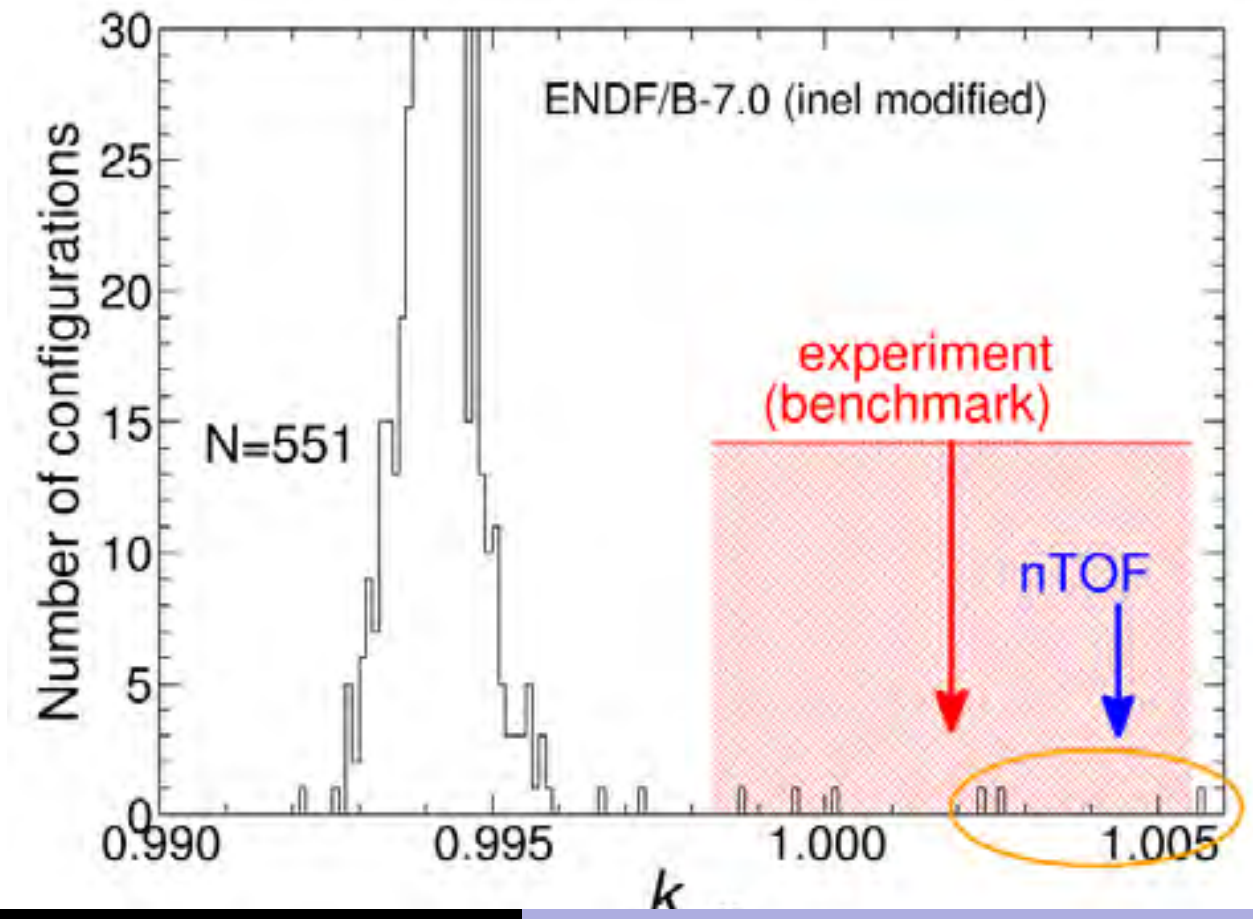
^{235}U inelastic cross section

Inelastic cross section



Criticality distribution the generated configurations

Random variation of XS for excitation of the ^{235}U levels.
Criticality of ^{235}U sphere benchmark should remain invariant:
(selection among the generated XS configurations)



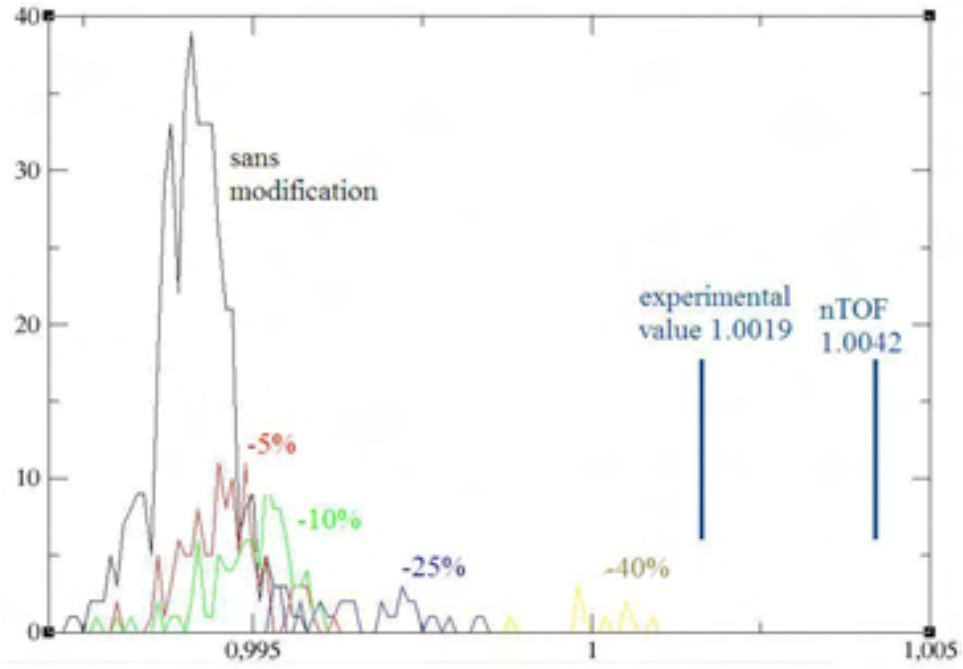


Figure : Criticality according to the continuum reduction

- Continuum (MT=91), bears most of the effect on criticality.
- Variation of criticality by the modification of MT=91, to get closer to the experimental value

Is 40% reduction of the continuum inelastic compatible with existed measurements (Knitter and Batchelor)?

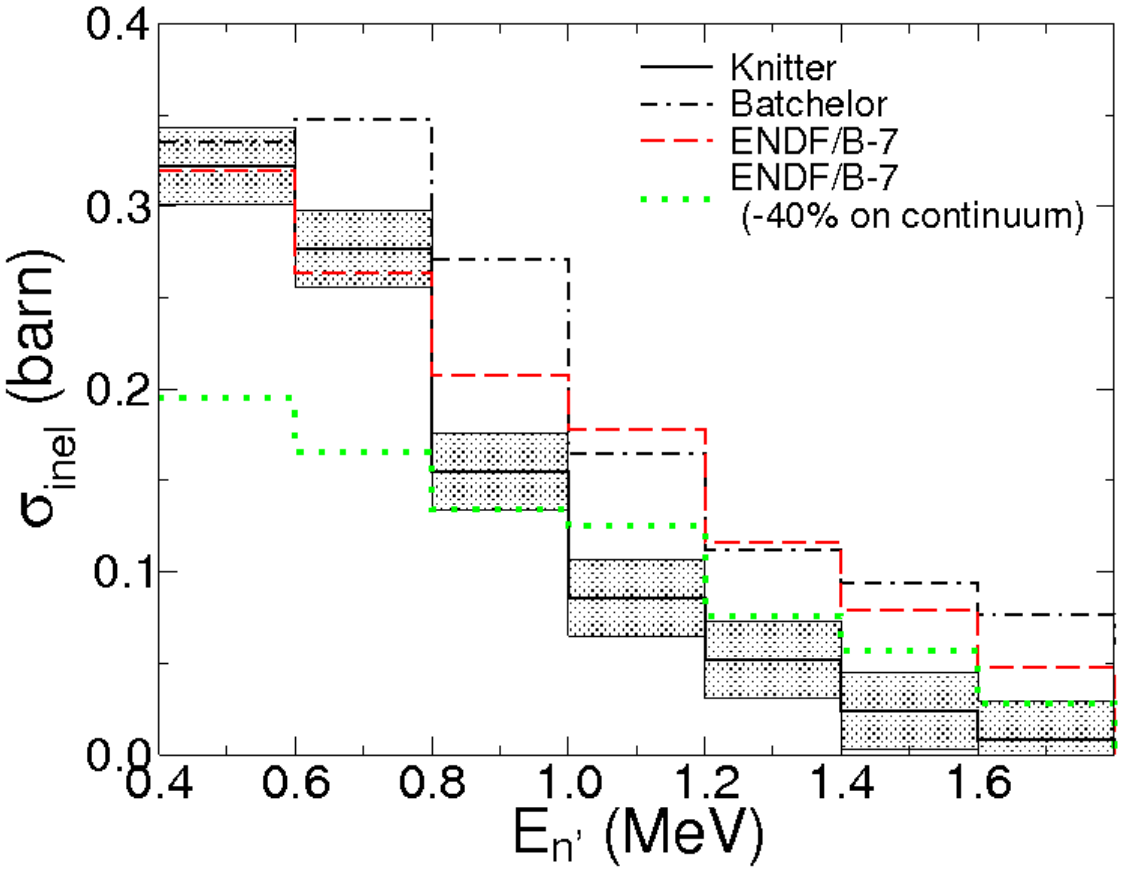
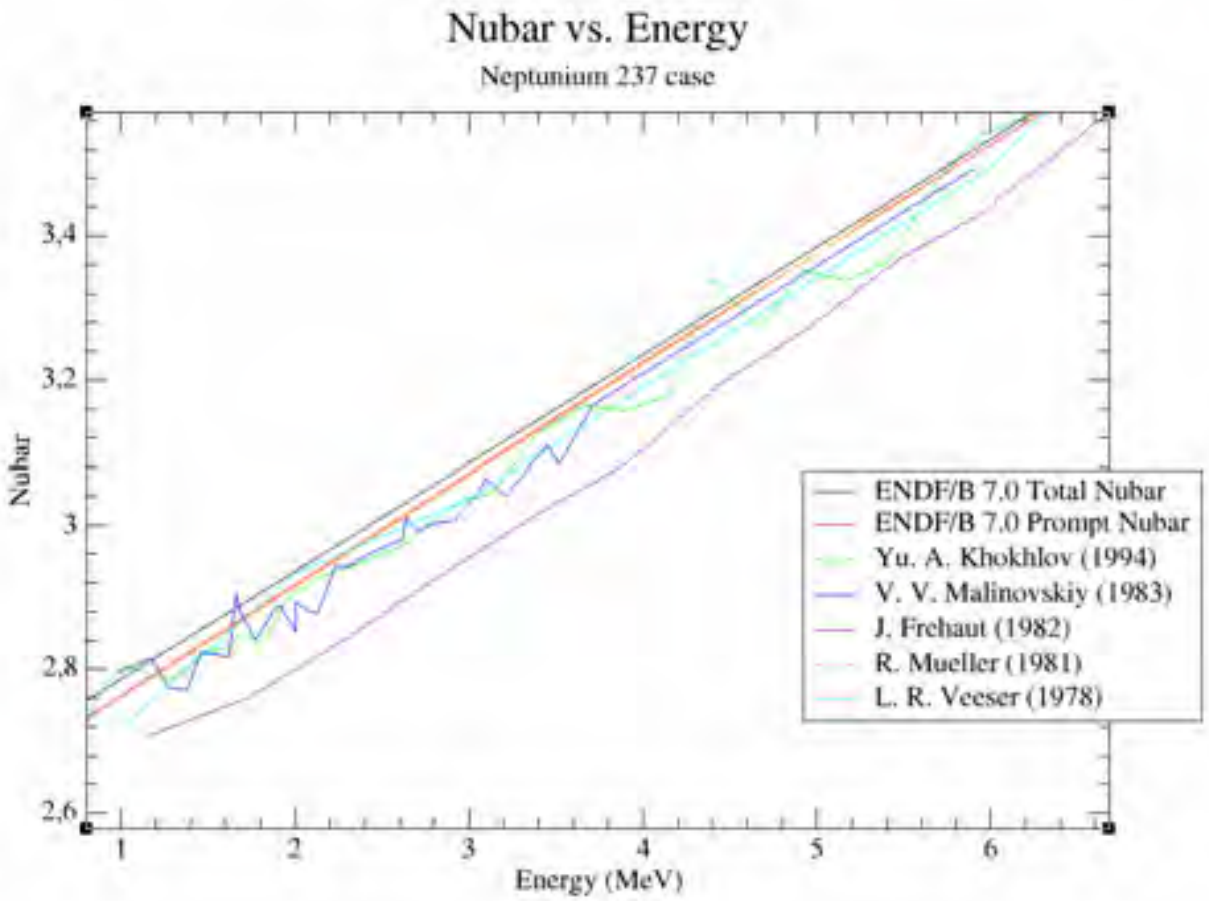


Figure : Comparison between experimental inelastic cross section measured for ^{235}U and ENDF/B-7.0, versus the outgoing neutron energy.

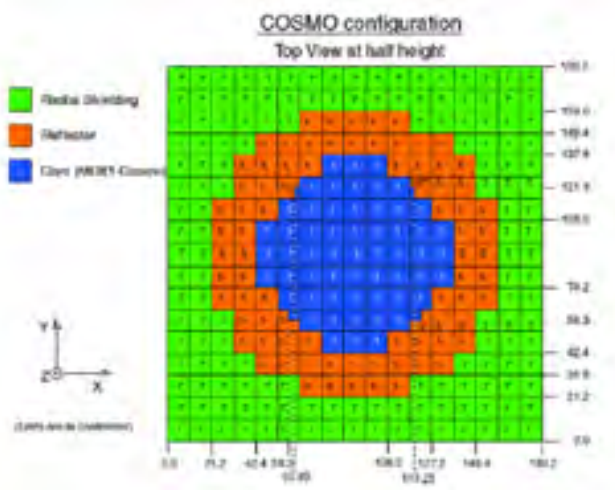
Nubar



3% increase on $\bar{\nu}$ of ^{237} =Np gives 0.76% variation of criticality.

The ^{237}Np criticality experiment seems to support the n_TOF data. Now, we compare the ^{237}Np fission rate under different neutron fields.

Reaction Rate: GODIVA, MASURCA



$$R_f(E) = \frac{\sum_i \Phi(E_i) \times \sigma(E_i)_{237Np}}{\sum_i \Phi(E_i) \times \sigma(E_i)_{235U}}$$

Set-up	R_f(exp)	R_f(calc-ENDF/B-7	R_f(calc-nT
GODIVA(HMF001-002)	0.85	0.83	0.88
MASURKA(COSMO)	0.285	0.284	0.299

Table : The Experimental measurement lies between n_TOF and ENDF/B-7.0 data for GODIVA. However, ENDF/B-7.0 seems to be more consistent with MASURCA reaction rate.

Neutron spectrum from ^{252}Cf

Calculated spectrum-averaged cross section is compared to measured integral benchmarks in ^{252}Cf spontaneous fission neutron field.

$$< \sigma >= \frac{\int W(E)\sigma(E)dE}{\int W(E)dE}$$

	calc $< \sigma > (b)$	exp$< \sigma > (b)$
^{235}U(n, f)	1.225	1.21 ± 0.014
^{237}Np(ENDFB7)	1.357	1.361 ± 0.022
^{237}Np(n_TOF)	1.431	1.361 ± 0.022

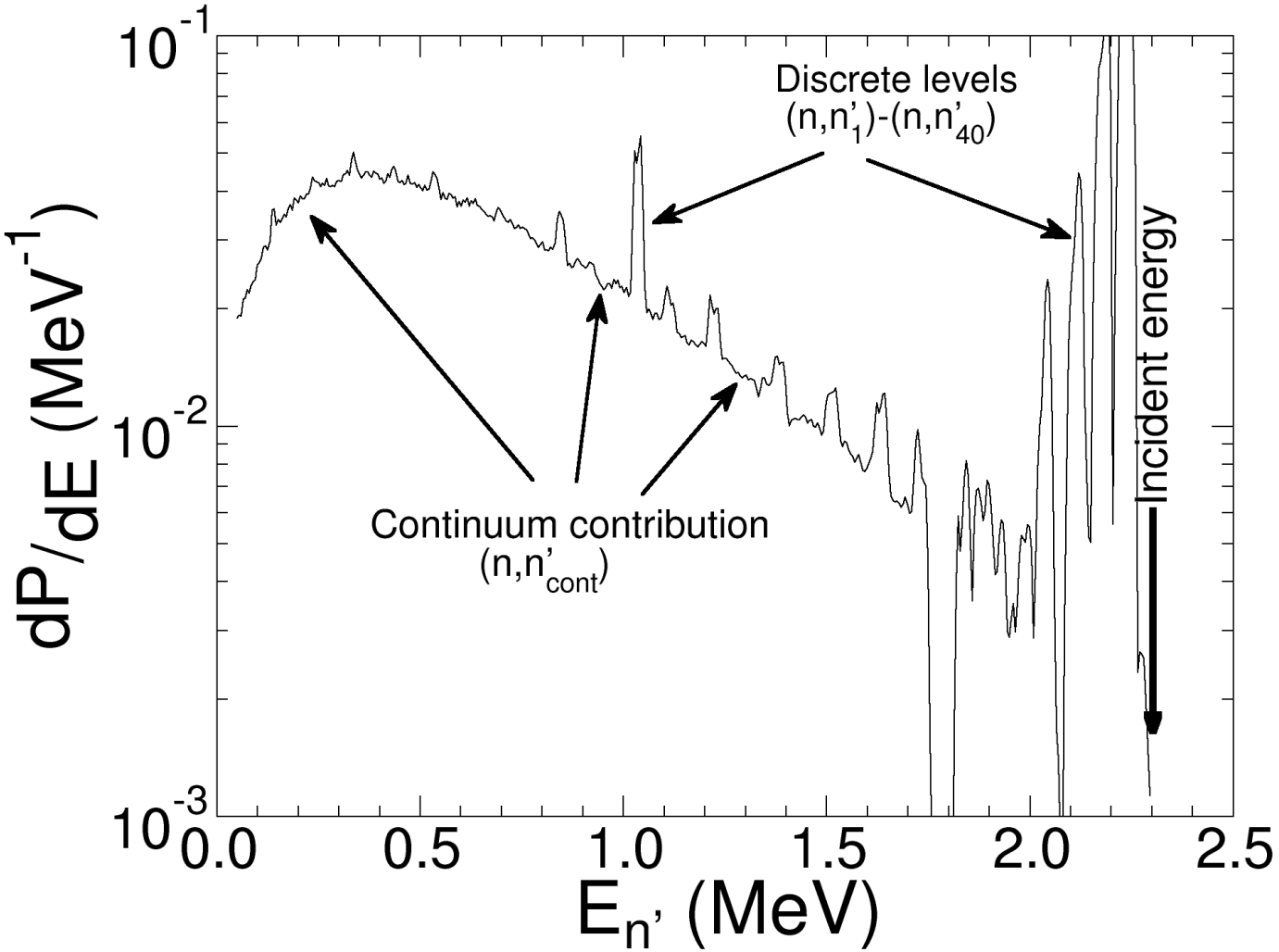
The table shows that n_TOF fission cross section is 5% higher than the experimental value.

Conclusion

1. We used the ^{237}Np critical benchmark to test the validity of the ^{237}Np fission cross section
2. The Keff predicted using the n_TOF cross section, slightly exceeds the experimental value, it is much closer to the benchmark value
3. (n,n') cross section in ^{235}U doesn't explain the discrepancy. because the -40% configuration is strongly discrepant with experimental data.
4. the discrepancy can't be ascribed to the ^{237}Np $\bar{\nu}$
5. Integral fission rate experiments do not agree completely with n_TOF experiment data
6. New measurements for confirmation of ^{237}Np fission cross section are desired. .

THANK YOU!

ANNEXE


Discrete levels
(n,n'1)-(n,n'40)
Continuum contribution
(n,n'cont)
Incident energy
dP/dE (MeV-1)
En' (MeV)
10-1
10-2
10-3
0.0
0.5
1.0
1.5
2.0
2.5

E_n-$E_{n'}$ (MeV)	E_n=1.9 MeV		E_n=2.3 MeV	
	Exp $\sigma_{inel} \pm \Delta\sigma_{inel}$	ENDF/B-7	Exp $\sigma_{inel} \pm \Delta\sigma_{inel}$	ENDF/B-7
0.5 - 0.7	0.046±0.022	0.087	0.008±0.022	0.048
0.7 - 0.9	0.113±0.022	0.147	0.024±0.022	0.078
0.9 - 1.1	0.213±0.022	0.205	0.052±0.022	0.115
1.1 - 1.3	0.294±0.022	0.290	0.086±0.022	0.178
1.3 - 1.5	0.267±0.022	0.320	0.155±0.022	0.207
1.5 - 1.7			0.277±0.022	0.264
1.7 - 1.9			0.322±0.022	0.319