The cross-section data from neutron activation experiments on niobium in the NPI p-7Li quasi-monoenergetic neutron field

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1. Introduction

Quasi-monoenergetic neutron source based on reaction p+Li7 is used.

Nb93 is only one stable isotope.

We used Nb foils in different experiments at 7 proton beam energies 19.8 – 37.4 MeV.

Isotopes obtained in the reactions (n,2n), (n,3n), (n,4n), (n,He3), (n,α) and (n,α2n) on Nb93 are studied using γ - spectroscopic technique.

Cross-sections for these reactions are obtained, errors and correlations are discussed.

The results are compared with predictions of EAF-2007 library.

Introduction (continued)… why Nb?

Niobium element is the important part of fusion technologies.

These data are needed to develop the dosimetry foil method for neutron spectrometry inside the test cell of IFMIF.

The cross section data for Nb for neutron energies higher than 23 MeV do not exist.

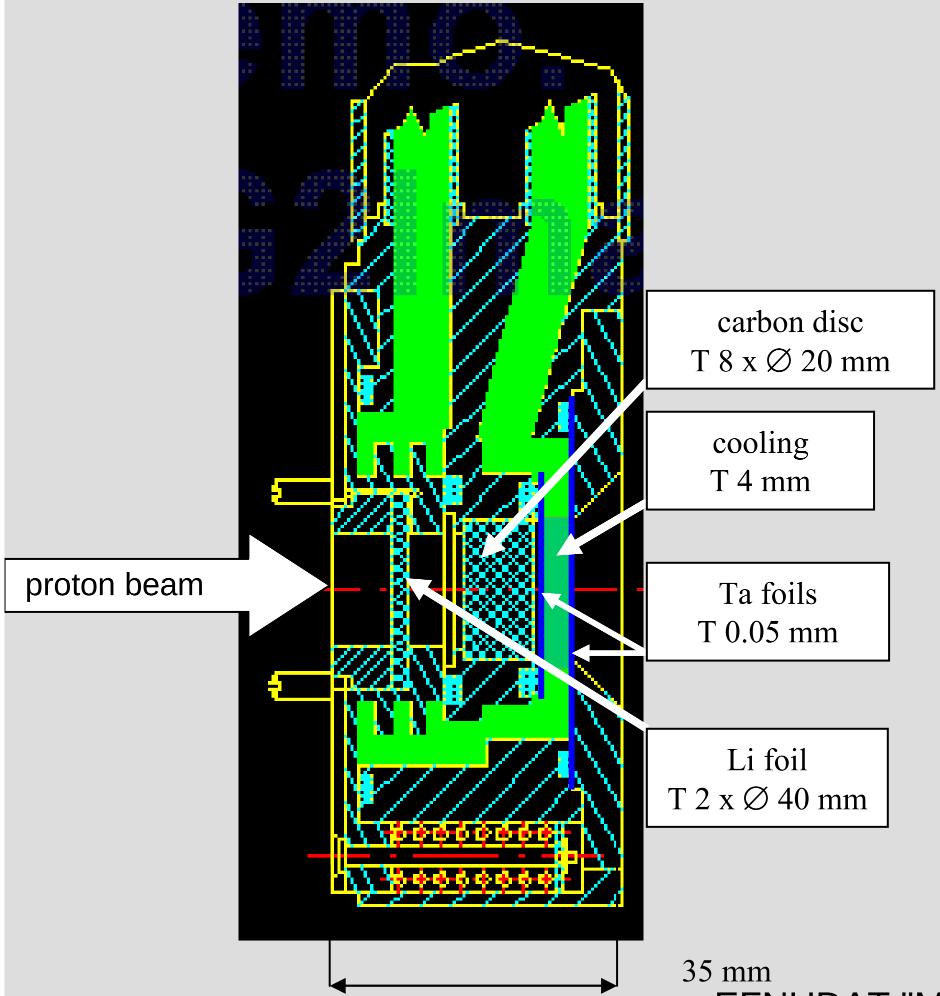
2. Experiment

Quasi-monoenergetic neutron source

■ p+^{7}Li source reaction
■ ^{7}Li(C backing) target
cooling by 5^{o}C alcohol stream
beam-power of 600 W reliably operated

■ proton beam energy range 18-38 MeV
■ flux density
~ 10^{8} n/cm^{2}/s calculated (in peak)
for 30 MeV 1 μA proton beam
at minimum t-s distance of 50 mm

Variable energy proton beam of cyclotron U 120M of NPI Řež



Irradiated foils at distances

48 mm and 88 mm from Li foil

Reactions studied on Nb93

Isotope	$T_{1/2}$	reaction	Threshold (MeV)
Nb90	14.60 h	(n,4n)	29.078
Nb91m	60.86 d	(n,3n)	16.999
Nb92m	10.15 d	(n,2n)	9.063
Y91m	49.71 m	(n,He3)	8.362
Y90m	3.19 h	(n,α)	0
Y88	106.65 d	(n,2n α)	13.554

Nb foils diam. 15 mm and weight approx. 0.75 g were irradiated at the distances of 48 and 88 mm from Li target.

Typical proton beam 3 μA, typical irradiation time 20 h
Proton beam energies 19.8, 25.1, 27.6, 30.1, 32.6, 35.0 and 37.4 MeV
Systematical analysis is possible.

Proton beam intensity vs. time is recorded and used in the analysis

Gamma spectroscopy
2 HPGe detectors of 23 and 50 % efficiencies
FWHM 1.8 keV at 1.3 MeV
Cooling times
Activated isotopes were identified on the basis of T1/2,
γ-ray energies and intensities.

Experimental results RR…. activity / 1 μC of proton beam / 1 kg

RR ~ ∫ spectrum(E) x CS(E) x d(E) → CS(E)

RR ~ ∑ spectrum(E) x CS(E) ΔE … subtraction method
In two cases we need to subtract low energy part using CS data of EAF 2007 CS library.

More neutron spectra → set of equations
matrix RR = A * CS

3. Neutron spectra

Two sets of neutron spectra

A. Spectra of Y.Uwamino et al. NIM A389 (1997)463, (for proton energies different from Y.Uwamino set the shifting procedure is used, see P.Bém et al., ND 2007 Proceedings p. 983)

- **Experimental data using TOF at the infinity**

  ! Our data are taken at closer geometry, where the geometry of the experiment (Carbon…) and angular distribution of neutrons are important

B. Spectra of S.P.Simakov et al., EFF-DOC 1093, JEFF/EFF Meeting 2009, ND2010 conference # 1450.

- **Simulated data including experimental geometry conditions (Li foil, thick C beam stopper, alcohol coolant, flanges, experimental hall). MCNPX and LA-150h proton cross sections library were used.**
- **VITAMIN J+ structure. "Energy group [17.33-19.64] MeV is too wide for mono-energy peak representation". Therefore (and based on our present day experience) the 19.8 MeV proton beam experiment was excluded from the analysis).**

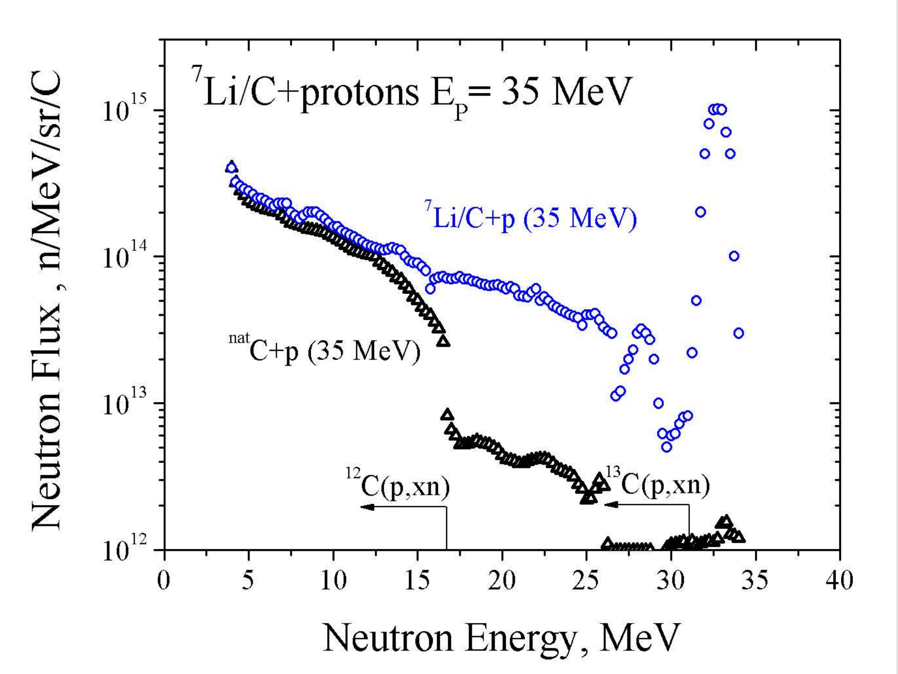
TOF

Spectra consist of

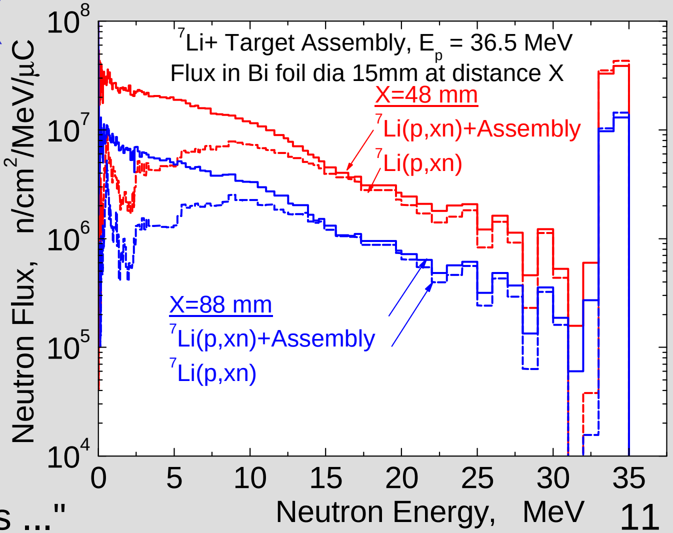
- quasi-monoenergetic part corresponding to the reactions to g.s. and 0.429 MeV state in 7Be

- low-energy tail generated
a) by reactions on 7Li leading to further excited states in 7Be and other reactions on 7Li
b) by reactions of protons on carbon stopper

- thermal neutrons – corresponding experiments were not taken into account



MCNPX



Errors to be included

Error of proton-beam current from Y.Uwamino (TOF) 10 %
Error of our proton-beam current 5 %
Estimation of the uncertainty of spectra simulation MCNPX
for quasi-monoenergetic neutrons 10 %

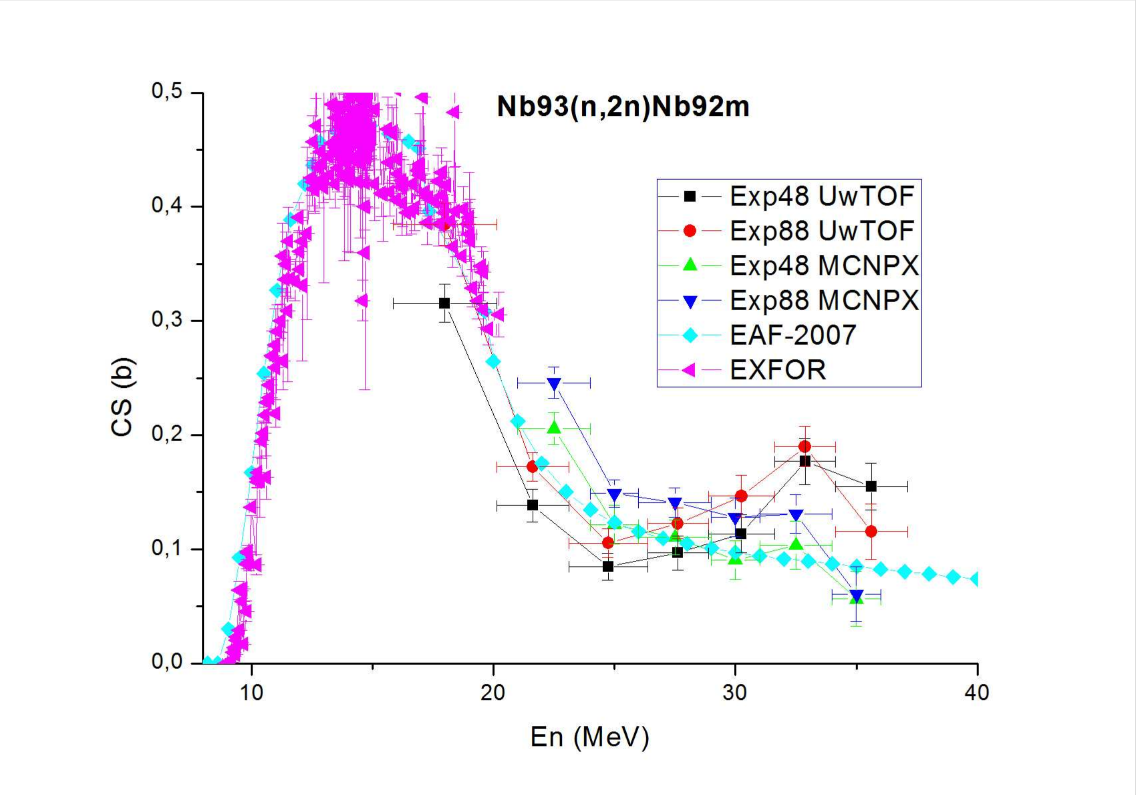
Error of activity measurement min. 3 %
The last error only is included as the error of our experimental data

The calculations of CS from the reactions (n,2n) and (n,α) need the subtraction of the low energy bump (of cross sections).
Then EAF 2007 CS library is used.
Errors of subtracted part are assumed
5 % (n,2n)
10 % (n,α)

4. Cross-sections obtained in the experiment

Results are compared with EAF-2007 CS library (VITAMIN J+), all possible reaction channels included (e.g. n,α+)

Reactions (n,2n) and (n,α), where the effect of low energy tail of the spectra is important

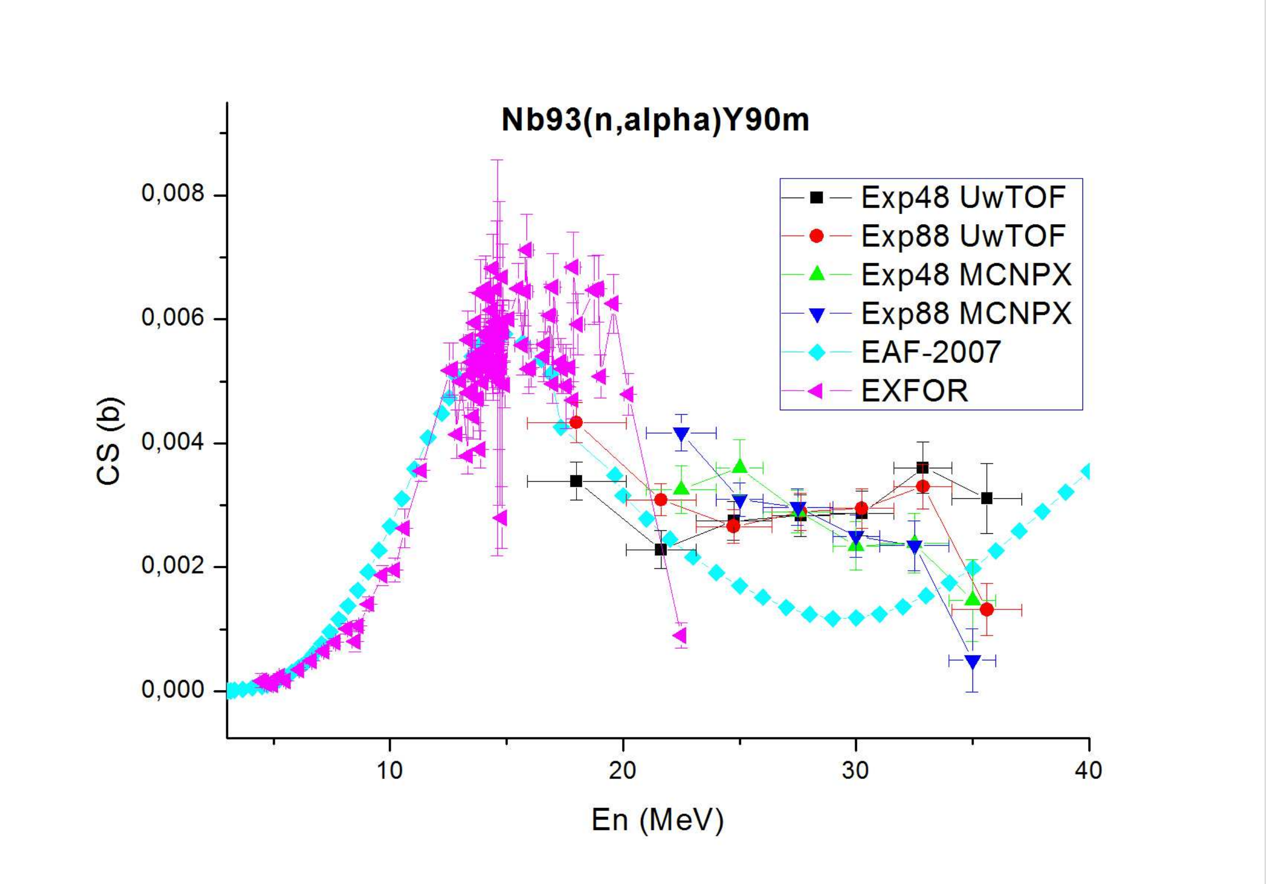


UwTOF: bump at the energies >30 MeV

MCNPX: correctly simulated geometry of the experiment

Reaction (n,α+)

EAF-2007 does not correctly describe the reaction



EAF-2007:

(n,α)

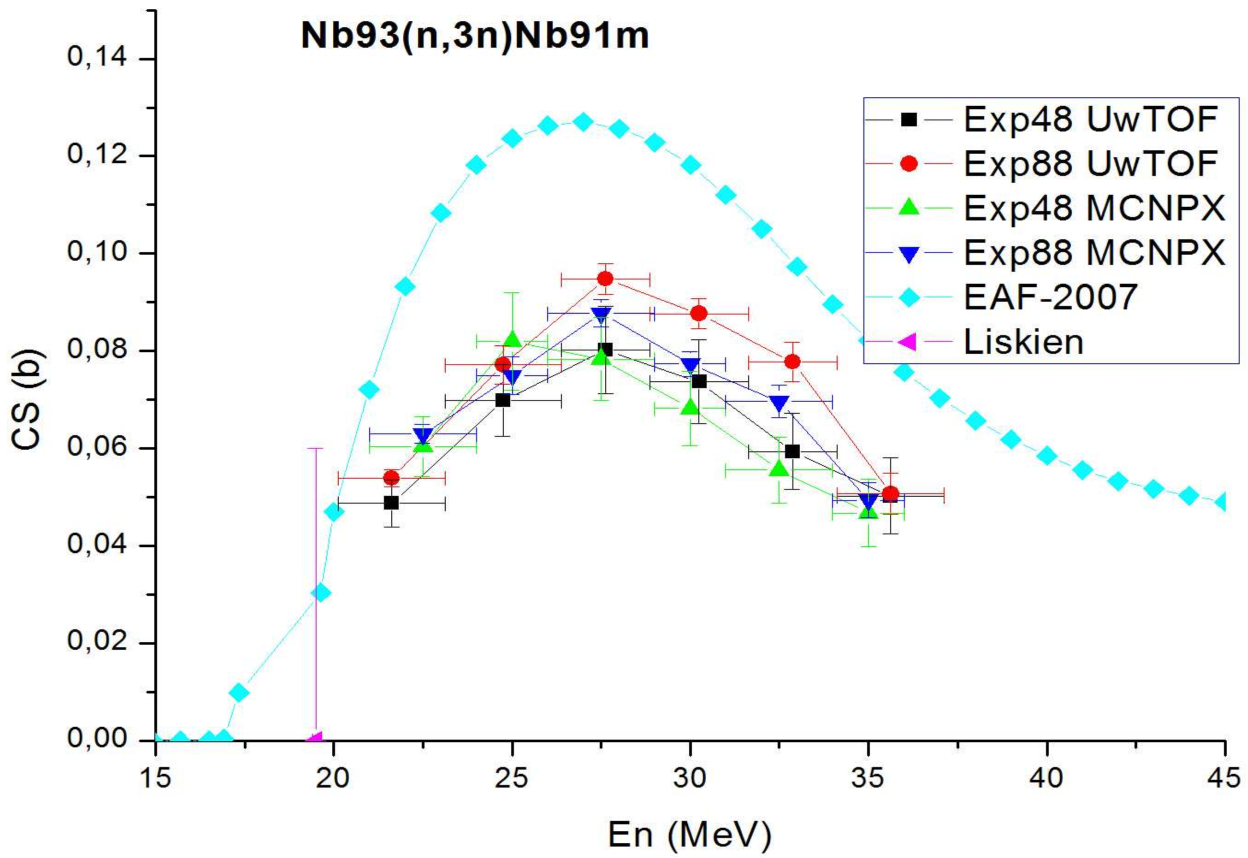
(n,2n2p)

(n,nHe3)

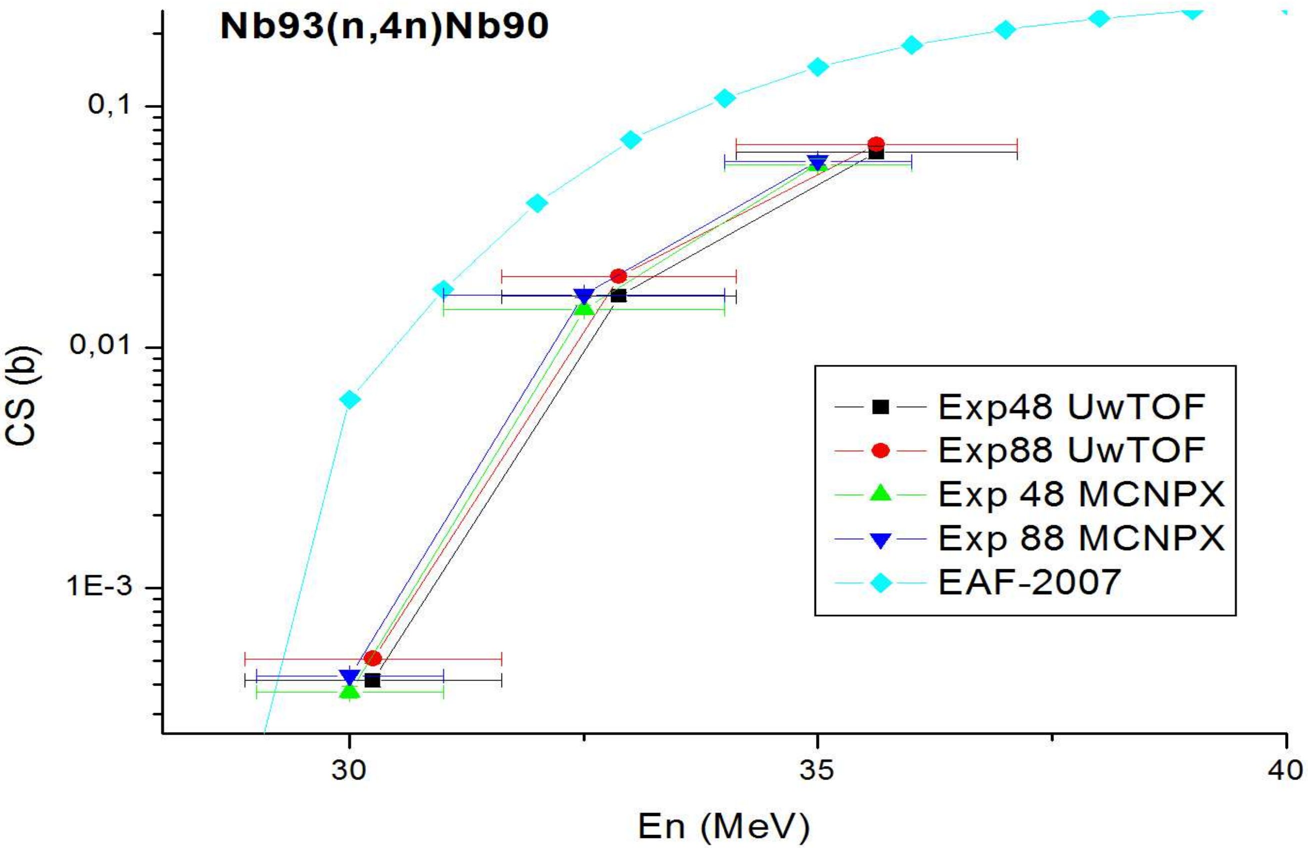
(n,npd)

(n,pt)

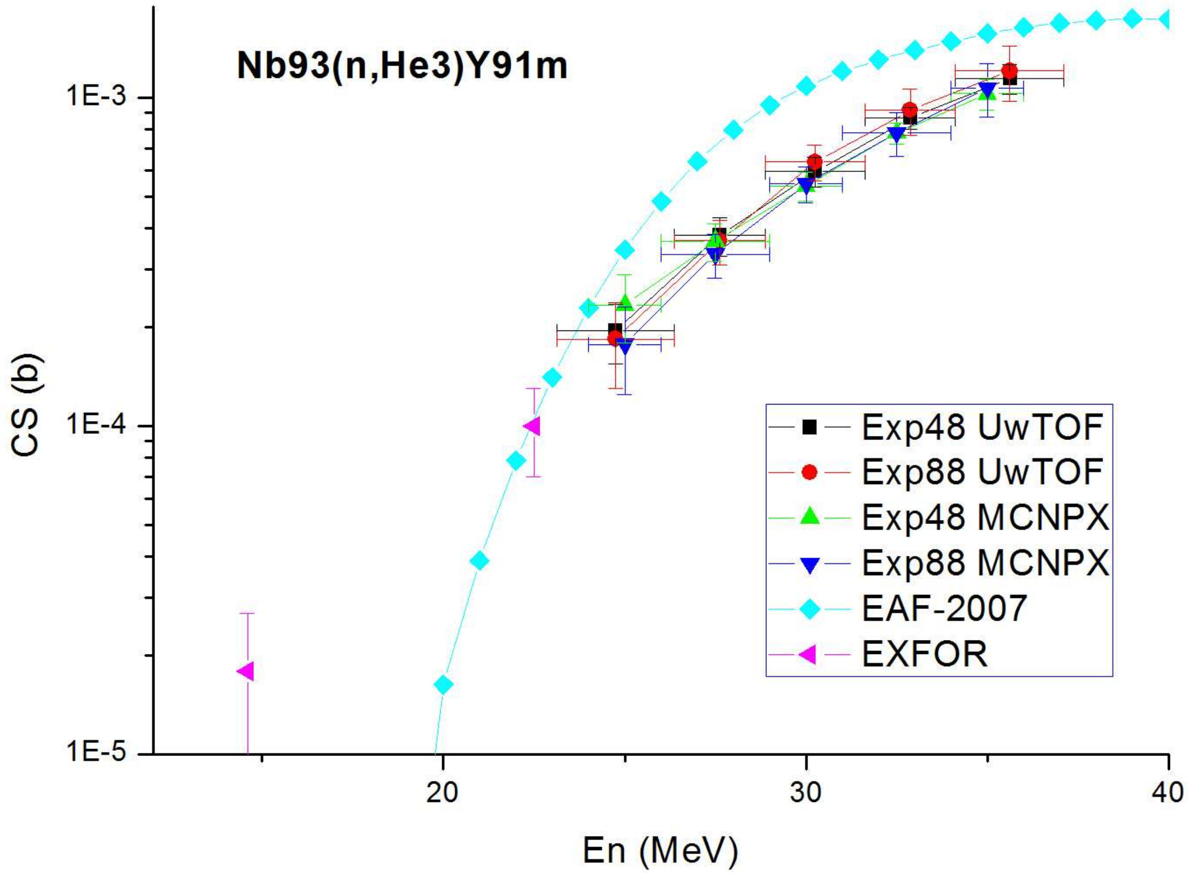
EAF-2007 overestimates CS data



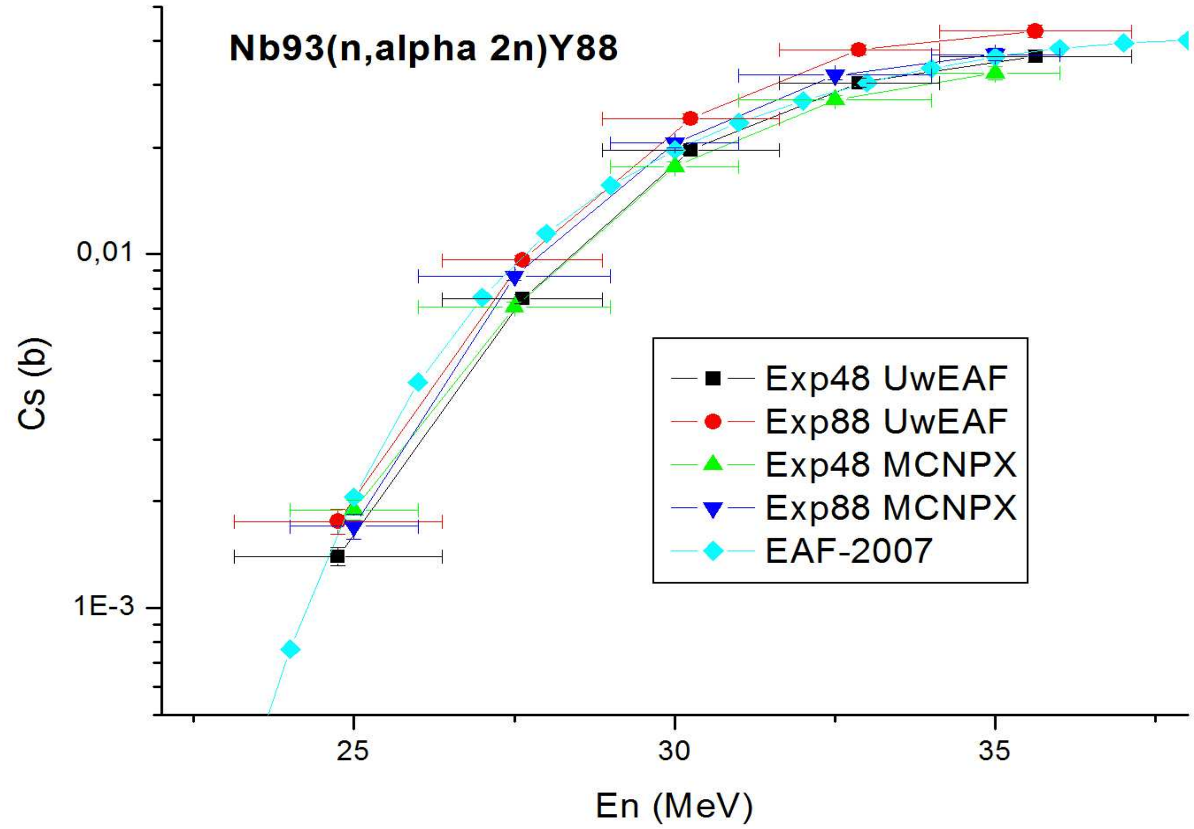
EAF-2007 overestimates CS data



EAF-2007 overestimates CS data



EAF-2007 properly describes CS data



5. Errors and correlations – some comments

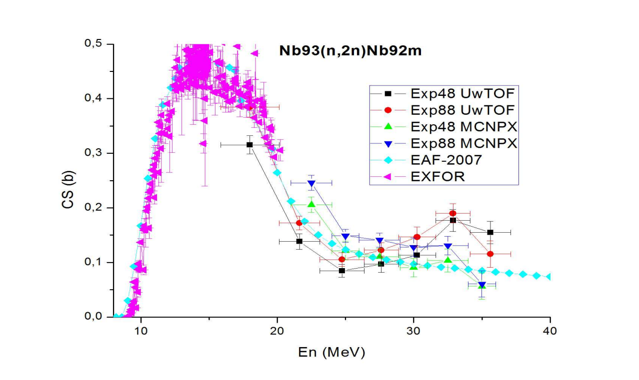
Discussed points in our error analysis:

A. Effect of subtraction of low-energy bump of CS in the reactions (n,2n) and (n,α)

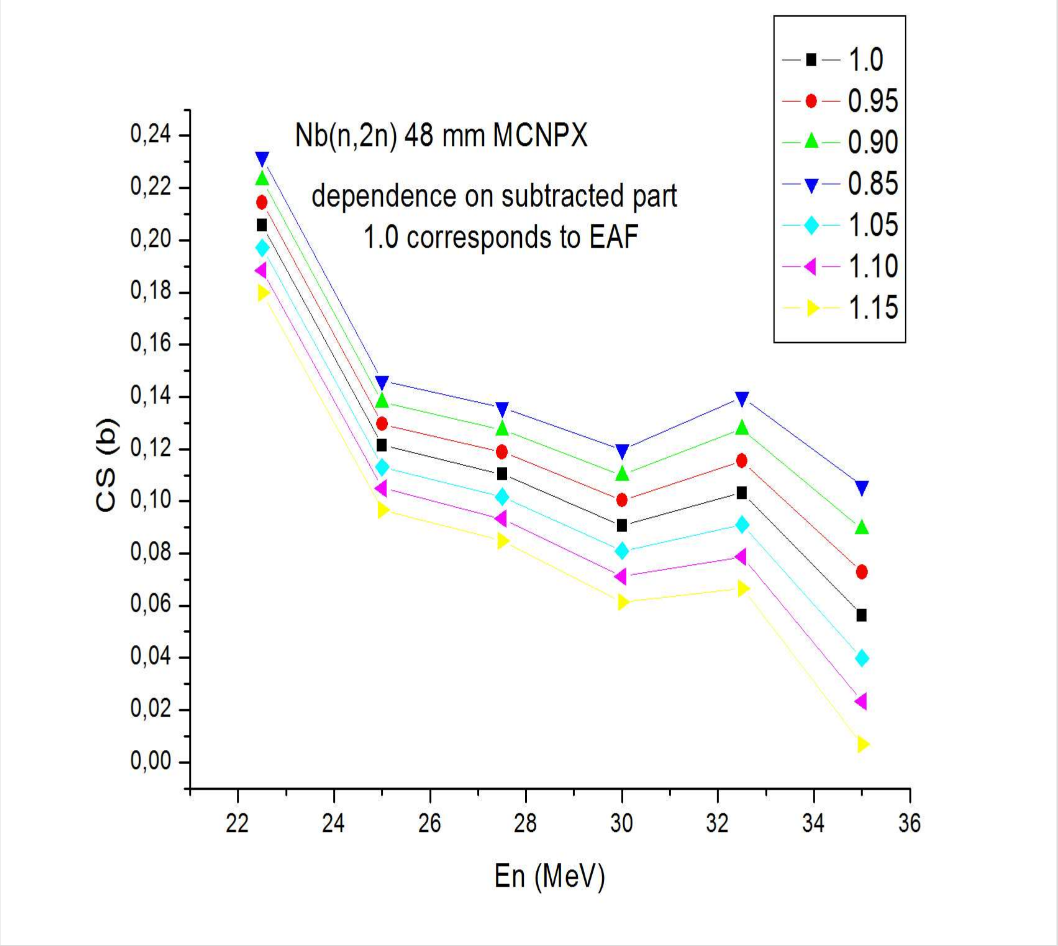
B. Effect of correlation coefficients obtained during the calculations of CS data

A. Example Nb93(n,2n)Nb92m, MCNPX, 48 mm

Assumed 5 % uncertainty of the subtracted part
M x ∫Neutr.sp.(En) x CS[EAF](En) dEn, En<our first exp. point



Dependence of CS on subtracted part (multiplication coefficient M)



-The effect of subtraction could be taken into account

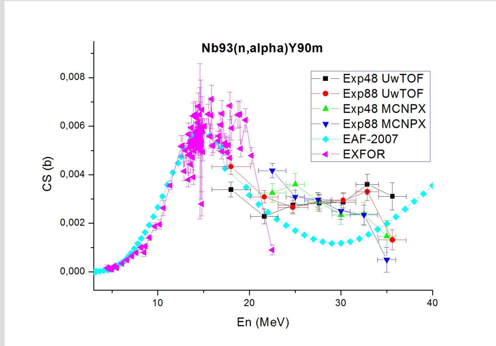
-Results for mult.coeff. 1 and others are within errors, or close to these values.

For example, En=35 MeV.

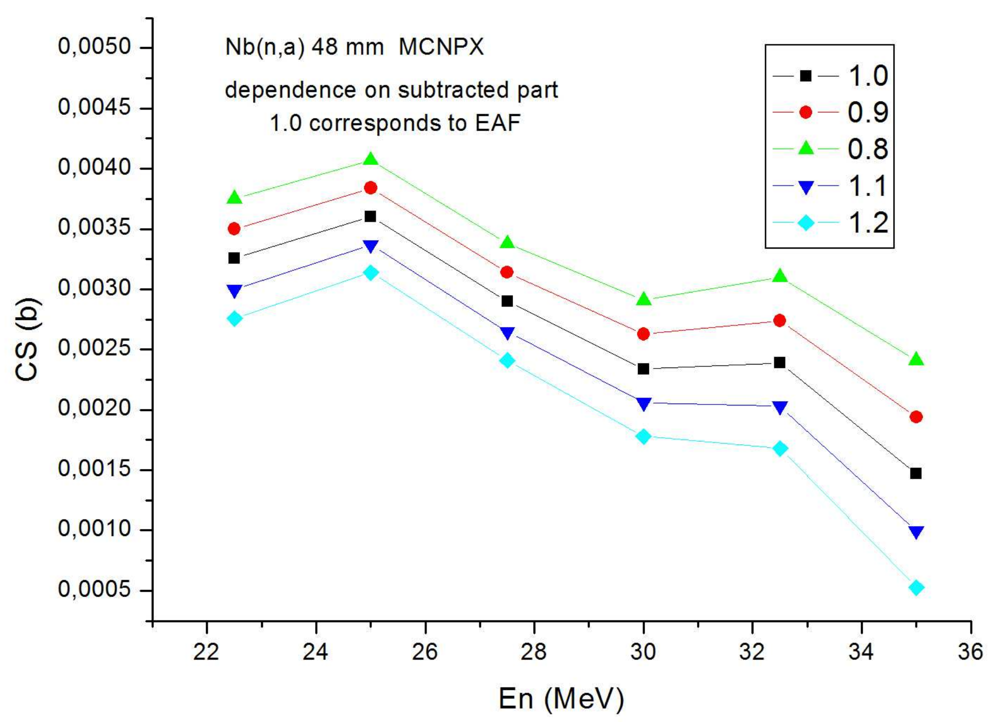
1.0 (5.64 ± 2.4) E-2
0.85 (10.6 ± 2.2) E-2
1.15 (0.68 ± 2.6) E-2

Errors not shown due to the complexity of Fig.

Example Nb93(n,α)Y90m, MCNPX, 48 mm



Assumed 10 % uncertainty of the subtracted part



Example of errors, En=35 MeV.

1.0 (1.47 ± 0.66) E-3
0.80 (2.41 ± 0.57) E-3
1.20 (0.53 ± 0.75) E-3

B. Effect of correlation coefficients obtained during the calculations of CS data (for all reactions)

RR = A * CS

Then error matrix for CS is $(A'WA)^{-1}$, W are weights of RR

Correlation coefficients

- **Negative**
- **Usually ~ -0.05 or less (in abs. values)**

- **Exception -0.258 for (n,α), MCNPX, 48 mm, first and second neutron energy.**

Test:

Error of the ratio of these values.

Without correlations 17.1 %, with correlations 19.1 %.

Error of the sum of these values.

Without correlations 8.57 %, with correlations 7.40 %.

Correlation coefficients are calculated, but their effect is (in our cases) small.

Up to now, uncertainties of beam current measurement in Řež (5 %), uncertaintes of TOF beam current measurement (10 %) and estimation of MCNPX simulation (10 %) were not taken into account.

Presentation of cross section data for databases *(preliminary).*

- **Use MCNPX simulated spectra (S.P.Simakov et al., ND2010, contribution # 1450)**
- **Calculate CS values as weighted mean value of results at 48 and 88 mm geometry.**
- **Calculate CS errors as √ (max (int.err.,ext.err.) of mean)^2 + (5 % uncertainty of Řež current)^2 + (10 % uncertainty of MCNPX simulation)^2**

6. Conclusions

- Quasi-monoenergetic high energy neutrons based on p-Li7 source are used to study neutron reactions on Nb93 target. Seven different proton beam energies were used. We presented new cross-section data for neutron energies higher than 23 MeV.

- **Results are compared with EAF-2007 library. Data on (n,2n) and (n,α 2n) reactions show that the EAF describe properly experiments. Reaction (n,α) is not correctly described. EAF-2007 overestimates reactions in cases of (n,3n), (n,4n), (n,He3) reactions.**

- **We do not need the TALYS calculation in our analysis. We need the EAF data to subtract low energy tail in the cases (n,2n) and (n,α) reactions only.**

- The sources of possible errors are analyzed.

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