Fission Cross Section Measurements at Intermediate Energies

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OBJECTIVE:

-To carry out precise measurements of the neutron- and proton-induced fission cross-sections of long-lived actinides and some stable heavy nuclei in wide energy range.

MOTIVATION:

-A long standing need in information about fission of heavy nuclei induced by the particles at intermediate energies for many applications:

accelerator-driven transmutation of nuclear waste, especially actinides;

energy generation;

peaceful use of weapon plutonium, *etc*.

-Tasks of fundamental physics.

-The existing differences among the data of different measurements amount up to 30 % that is outside the quoted experimental errors for the most part.

1997-2000 *ISTC Project # 609*

Neutron induced fission cross-sections of ^{233}U, ^{238}U, ^{232}Th, ^{239}Pu, ^{237}Np, ^{nat}Pb and ^{209}Bi in neutron energy range from 1 MeV to 200 MeV have been measured at GNEIS facility

About 900 points

Reference:

O. Shcherbakov, A. Donets, A. Evdokimov , A. Fomichev, T. Fukahori, A. Hasegawa, A. Laptev, V. Maslov, G. Petrov, S. Soloviev, Yu. Tuboltsev and A. Vorobyev, *J. Nucl. Sci. Tech.*, Suppl. 2, 230 (2002)

EXFOR file numbers are 41429 and 41430

2001-2004 *ISTC Project # 1971*

Neutron induced fission cross-sections of ^{240}Pu, ^{243}Am, ^{nat}W and ^{209}Bi in neutron energy range from 1 MeV to 200 MeV have been measured at GNEIS facility

About 400 points

References:

A.B. Laptev, A.Yu. Donets, A.V. Fomichev, A.A. Fomichev, R.C. Haight, O.A. Shcherbakov, S.M. Soloviev, Yu.V. Tuboltsev and A. Vorobyev, *Nucl. Phys. A* **734S**, E45 (2004).

A.B. Laptev, A.Yu. Donets, V.N. Dushin, A.V. Fomichev, A.A. Fomichev, R.C. Haight, O.A. Shcherbakov, S.M. Soloviev, Yu.V. Tuboltsev and A. Vorobyev, Report at the *Int. Conf. on Nucl. Data for Sci. and Tech. (ND2004)*, Santa Fe, NM, USA, Sept. 26-Oct. 1, 2004.

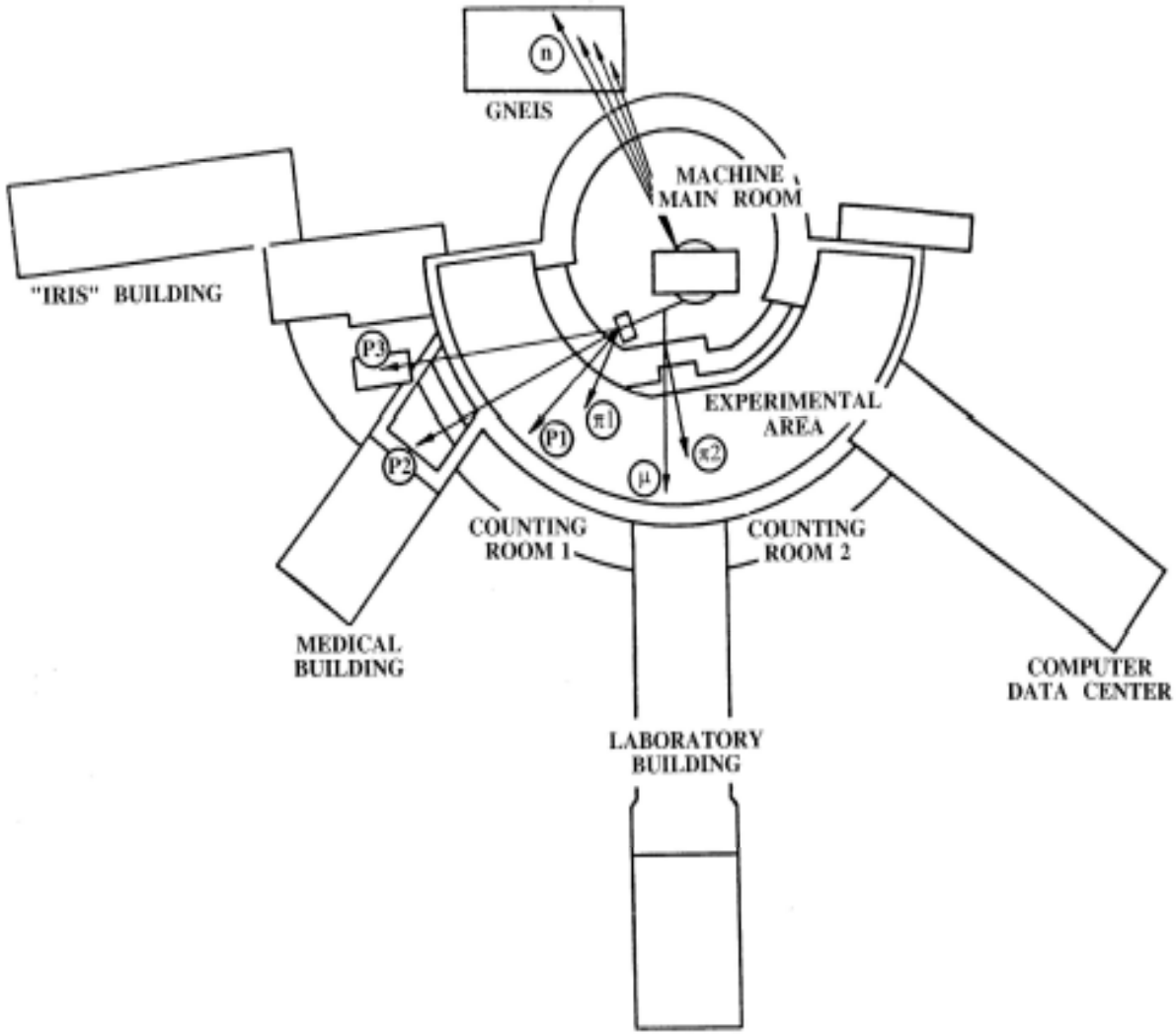
2000-2003 *ISTC Project # 1405*

Proton induced fission cross-sections of ^{233}U, ^{238}U, ^{235}U, ^{232}Th, ^{239}Pu, ^{237}Np, ^{nat}Pb and ^{209}Bi in proton energy range from 200 MeV to 1000 MeV at 100 MeV intervals have been measured at PNPI proton synchrocyclotron

Reference:

A. Kotov, Yu. Gavrikov, L. Vaishnene, V. Vovchenko, V. Poliakov, O. Fedorov, T. Fukahori, Yu. Chestnov and A. Shchetkovskiy,
Report at the *XVI Int. Workshop on Physics of Nuclear Fission*, IPPE, Obninsk, Russia, October 7-10, 2003.
It is available at web by URL *http://nucleus.ru/fission2003/*

General layout of the PNPI synchrocyclotron



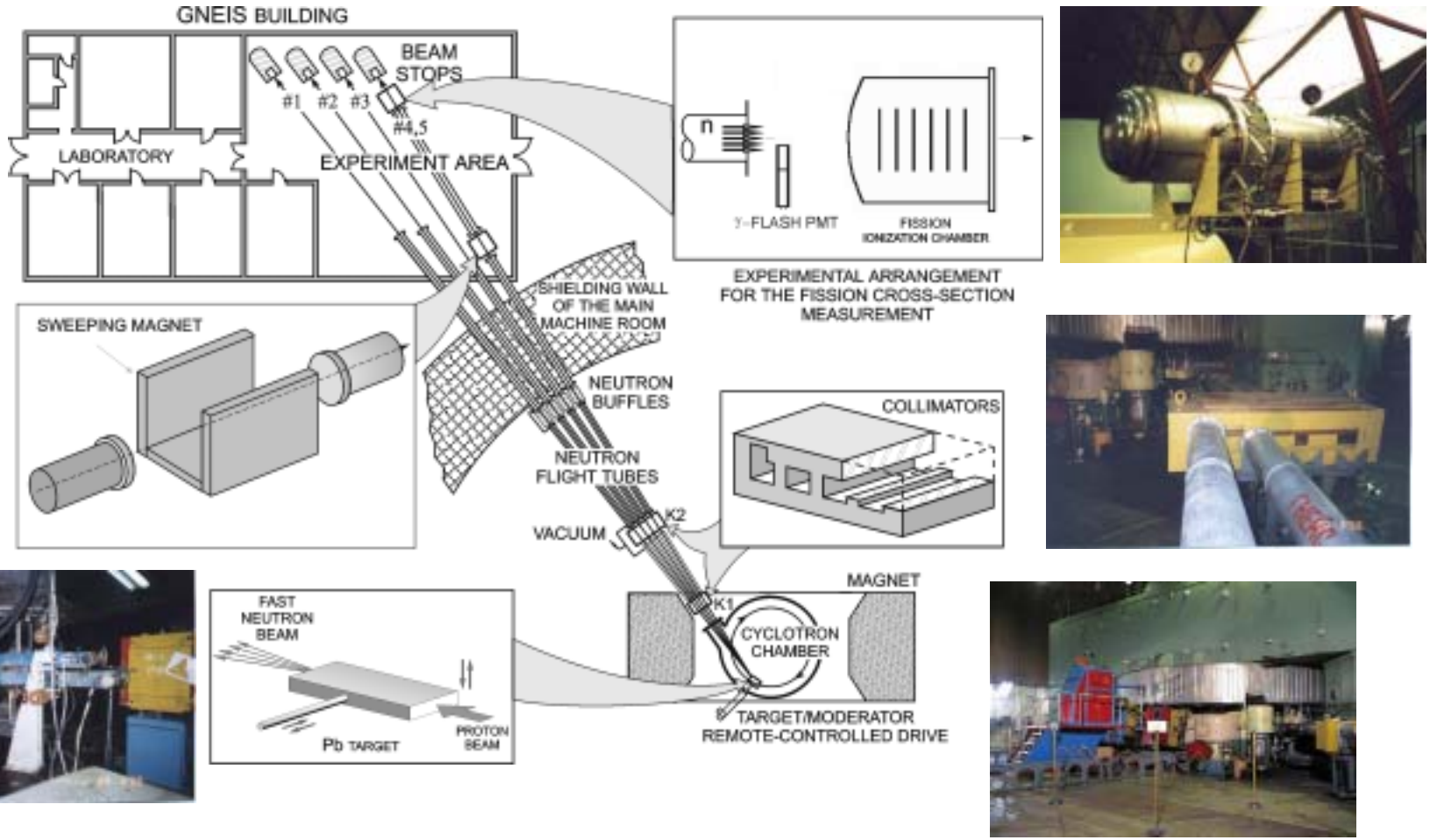
PNPI synchrocyclotron

PNPI SYNCHROCYCLOTRON

general information:

- Diameter of the magnet pole pieces……	685 cm
- Width of the gap between poles..……	50 cm
- Magnet weight……	8,000 t
- Electric power supplied……	1 MWt
- Frequency range……	30 – 13 MHz
- Accelerating voltage……	10 kV
- Repetition rate……	40-60 Hz
- Internal beam intensity……	< 3 μ A
- Extraction coefficient……	30 %
- Duty cycle coefficient……	50 %

General layout of the Gatchina neutron time-of-flight spectrometer GNEIS and experimental arrangement for fission cross-section measurements



Pulsed neutron source:

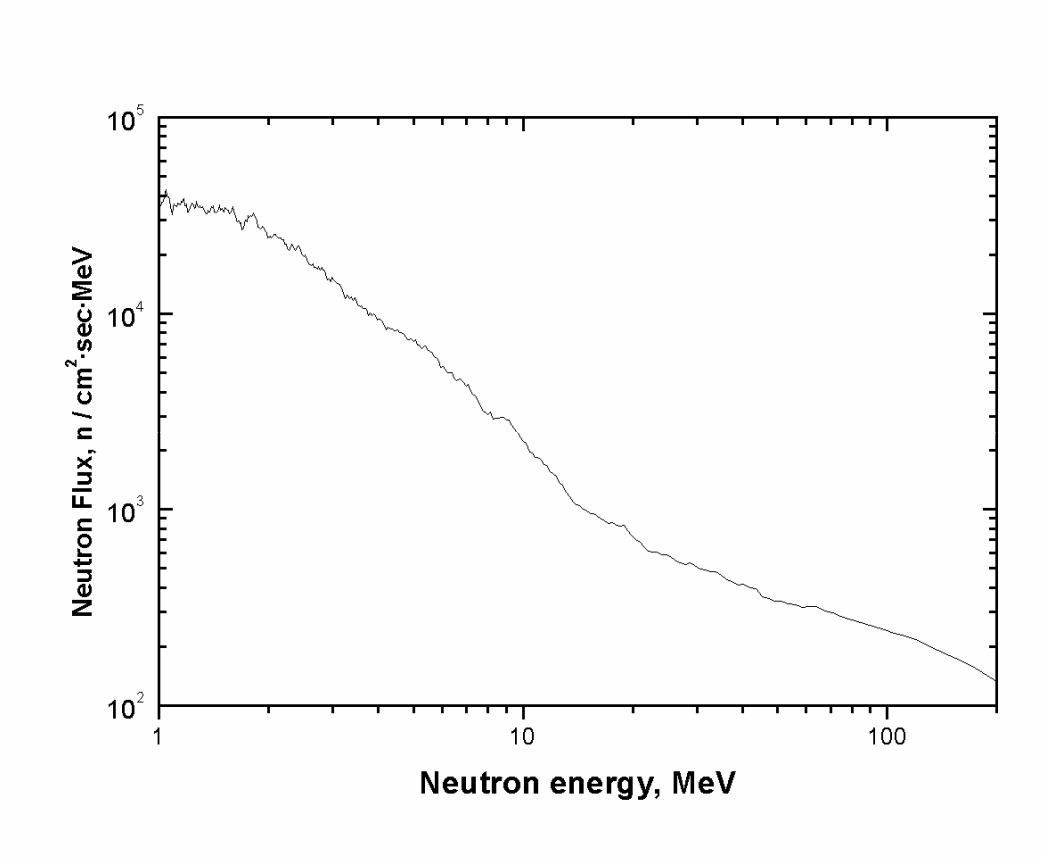
- average fast neutron intensity…… ~ $3 \cdot 10^{14}$ n/s
- duration of the fast neutron pulse…… ~ 10 ns
- repetition rate …… < 50 Hz
- internal water-cooled rectangular lead target …… 40 cm × 20 cm × 5 cm
- rectangular polyethylene moderator…… 30 cm × 10 cm × 5 cm

Spectrometer:

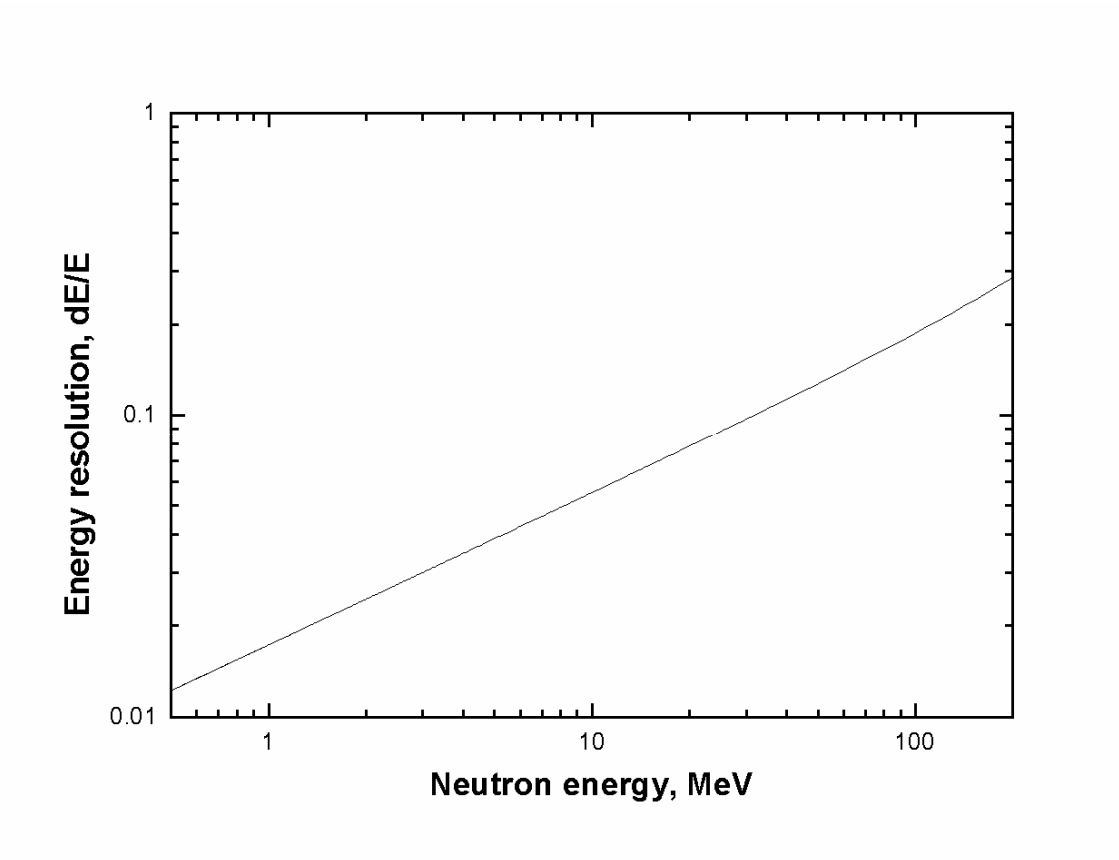
- number of evacuated flight paths …… 5
  (one beam #5 looking at the target and
  others #1-4 looking at the moderator)
- length of flight paths …… 35 – 50 m
- experimental area (GNEIS building) …… 45 × 30 m^2

Reference: N.K. Abrosimov et al., Nucl.Inst.Meth. A242 (1985) 121
Internet URL: *http://hepd.pnpi.spb.ru/~gneis*

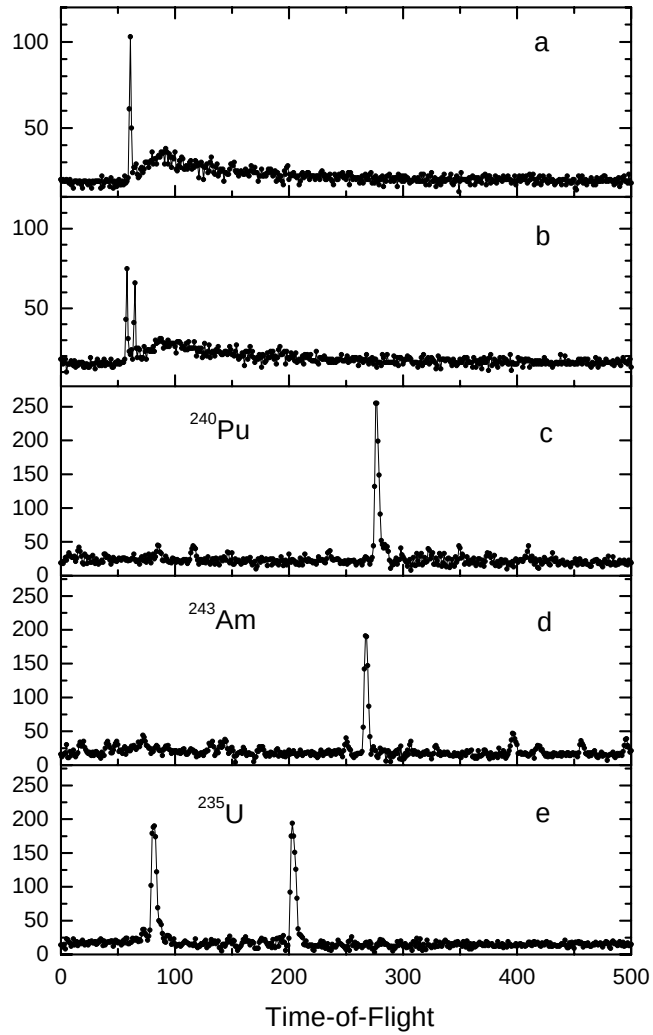
The neutron flux at the 48.5-m flight path normalized to a value of 1 μA of the proton beam on the neutron-producing target



Neutron energy resolution for the flight path length 48.5 m



Examples of gamma flash detector (*a* and *b*) and fission chamber signal

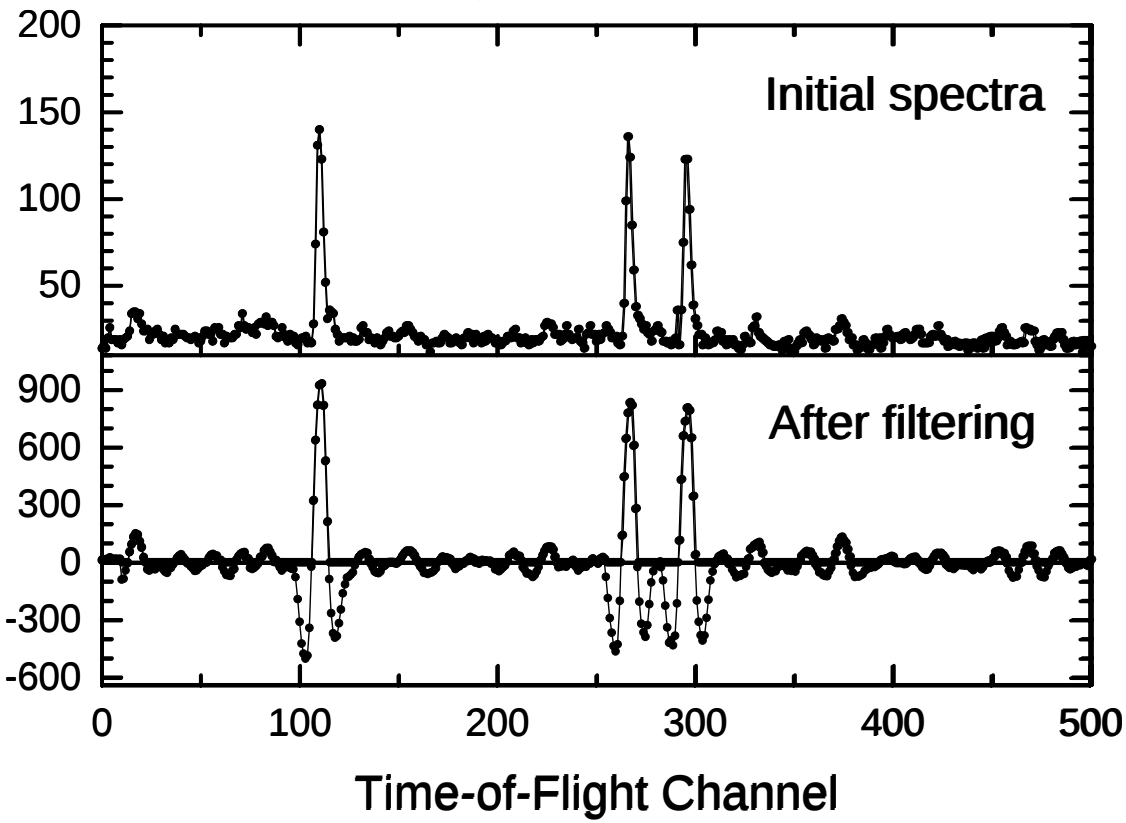


Signal identification has been made by a method of digital filtering:

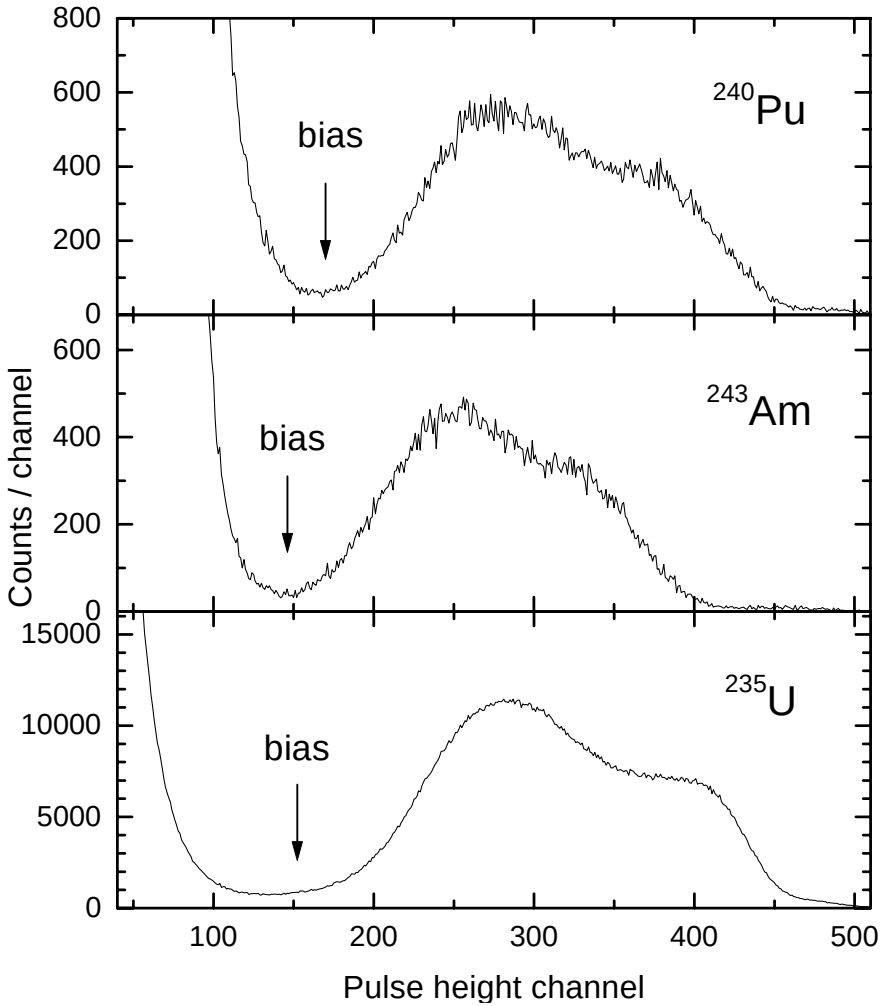
$$y'(i) = \sum_{j=i-n}^{i+n} \{2y(j) - y[j-(2n+1)] - y[j+(2n+1)]\}$$

$y(i)$ – initial data in TOF channel ***i***

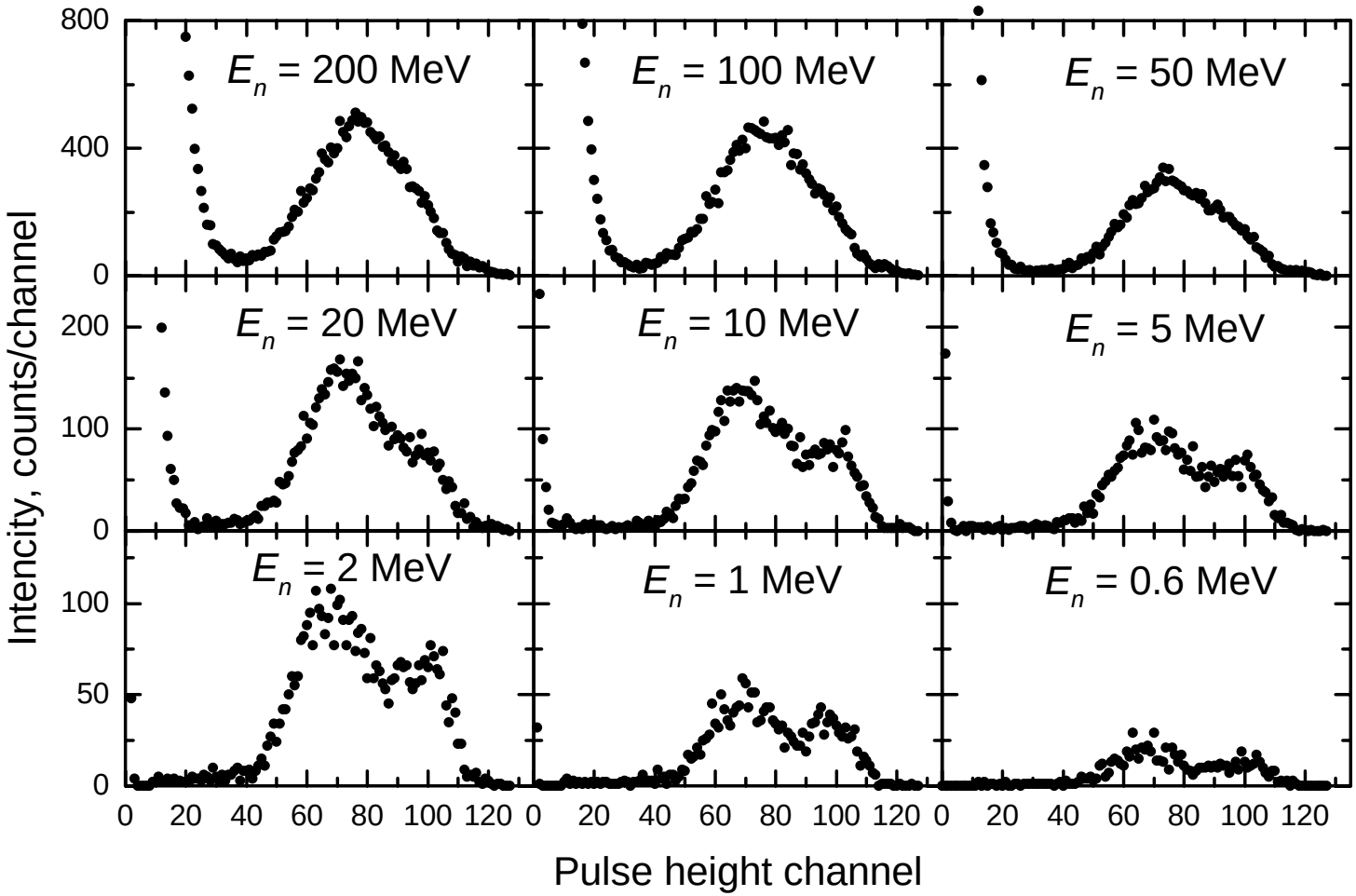
$y'(i)$ – filtered data in TOF channel ***i***



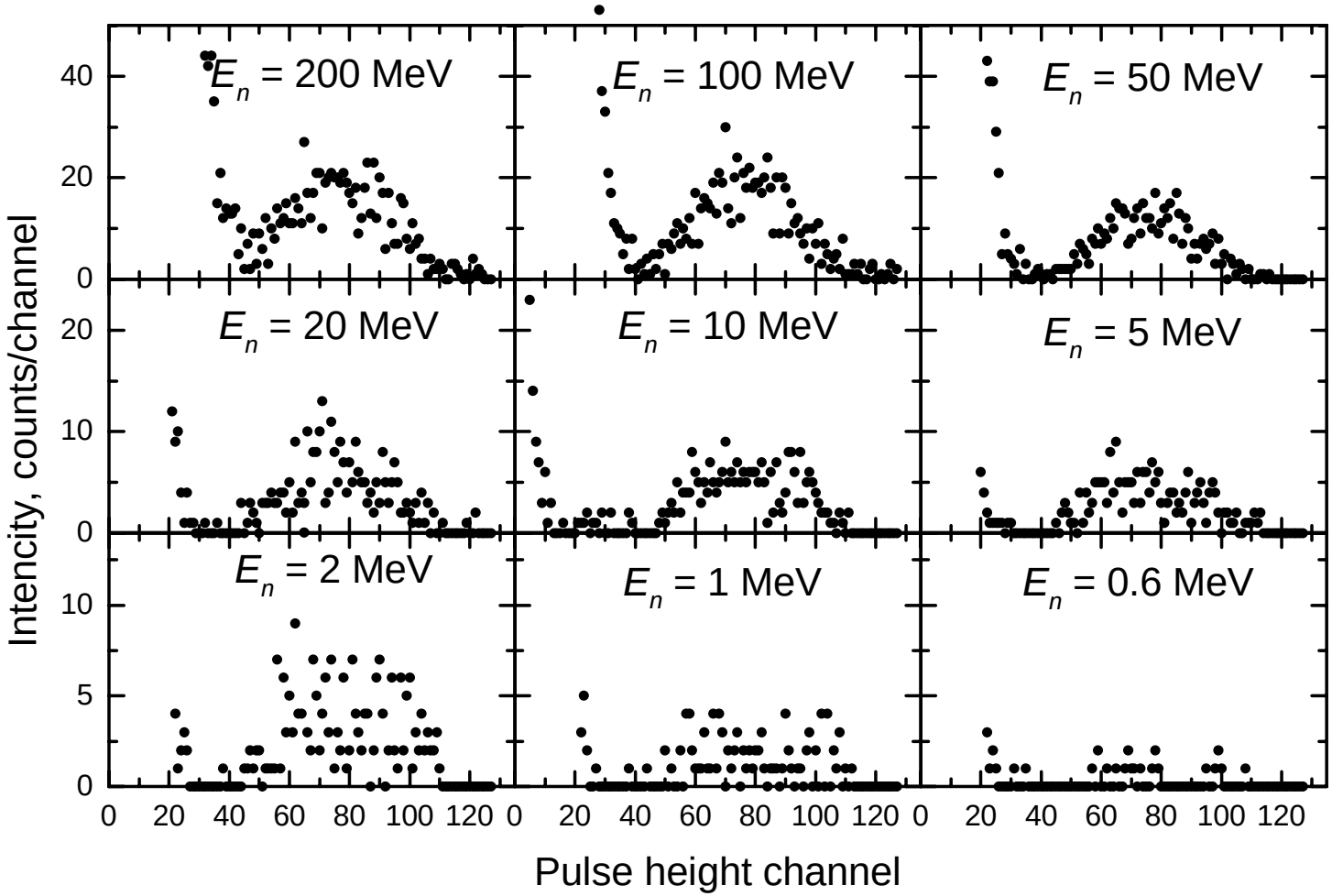
Average pulse height spectra observed in the neutron energy range 0.5 – 200 MeV



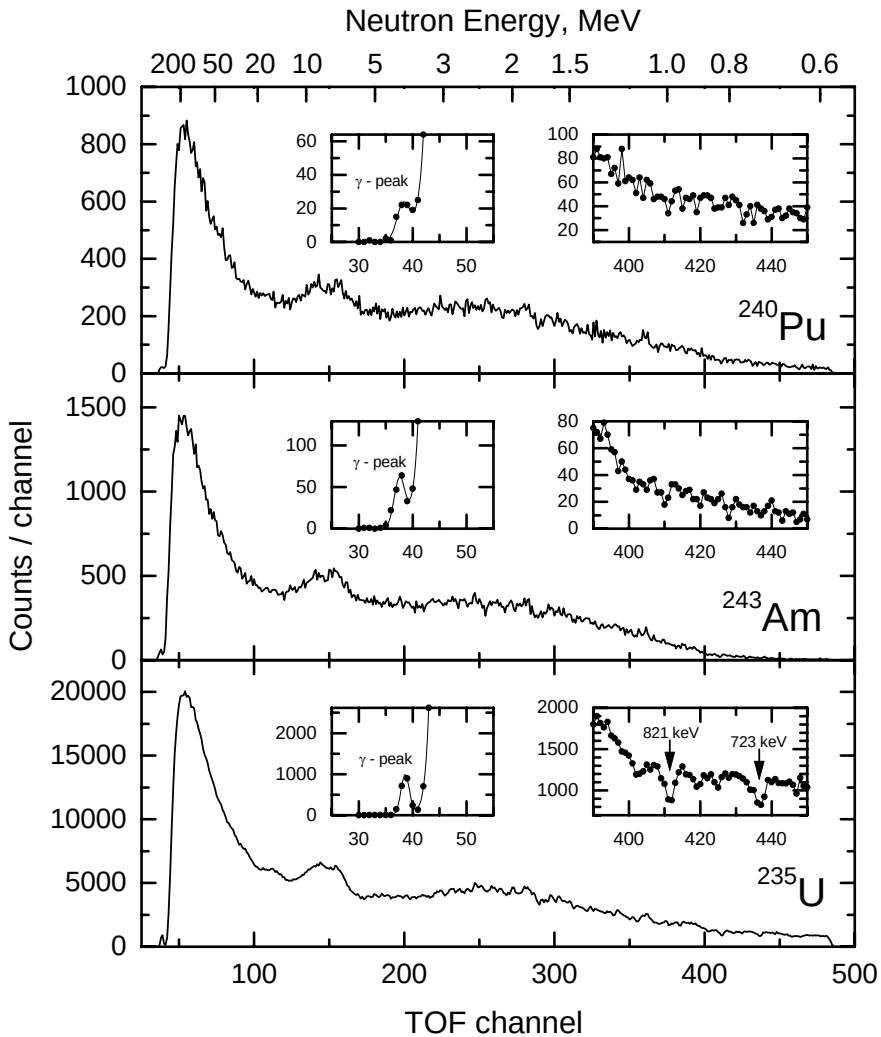
Pulse height spectra observed at different neutron energies for ^{235}U



Pulse height spectra observed at different neutron energies for ^{240}Pu



Time-of-flight spectra (10 ns channel width) observed after background subtraction

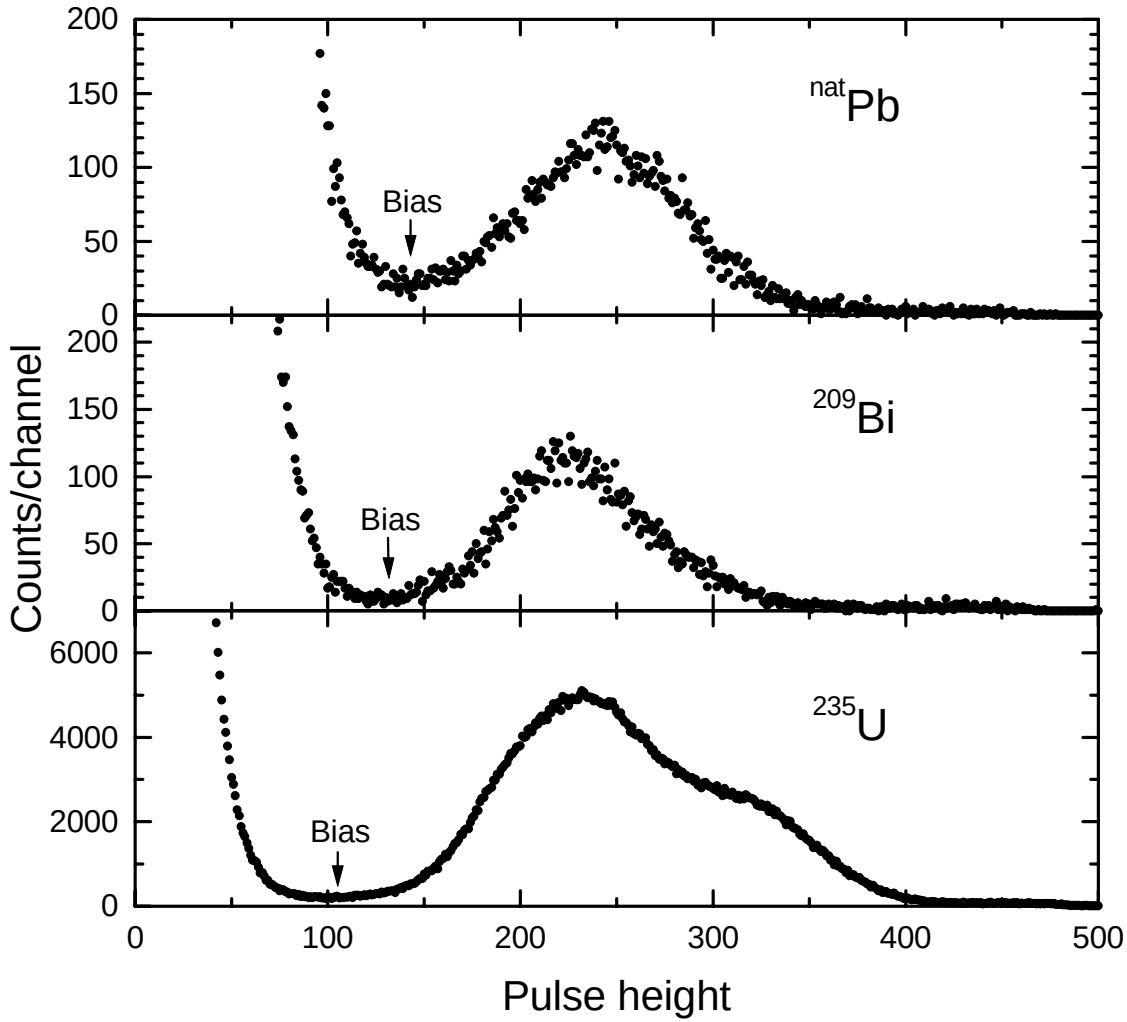


The *TOF vs energy* calibration have been used:

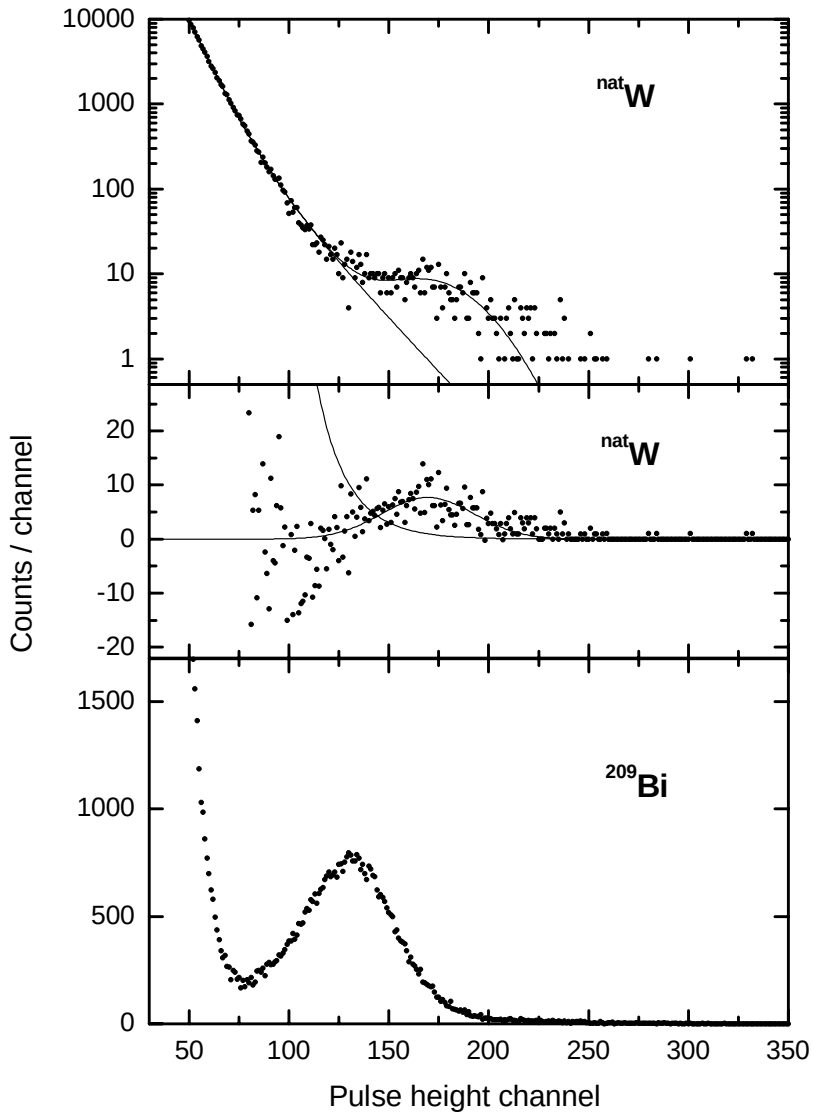
-a position of the lead total cross-section resonances;
-a true time-zero of the scale from the position of the gamma-flash peak.

An accuracy of this calibration is $\pm$ 0.03 %

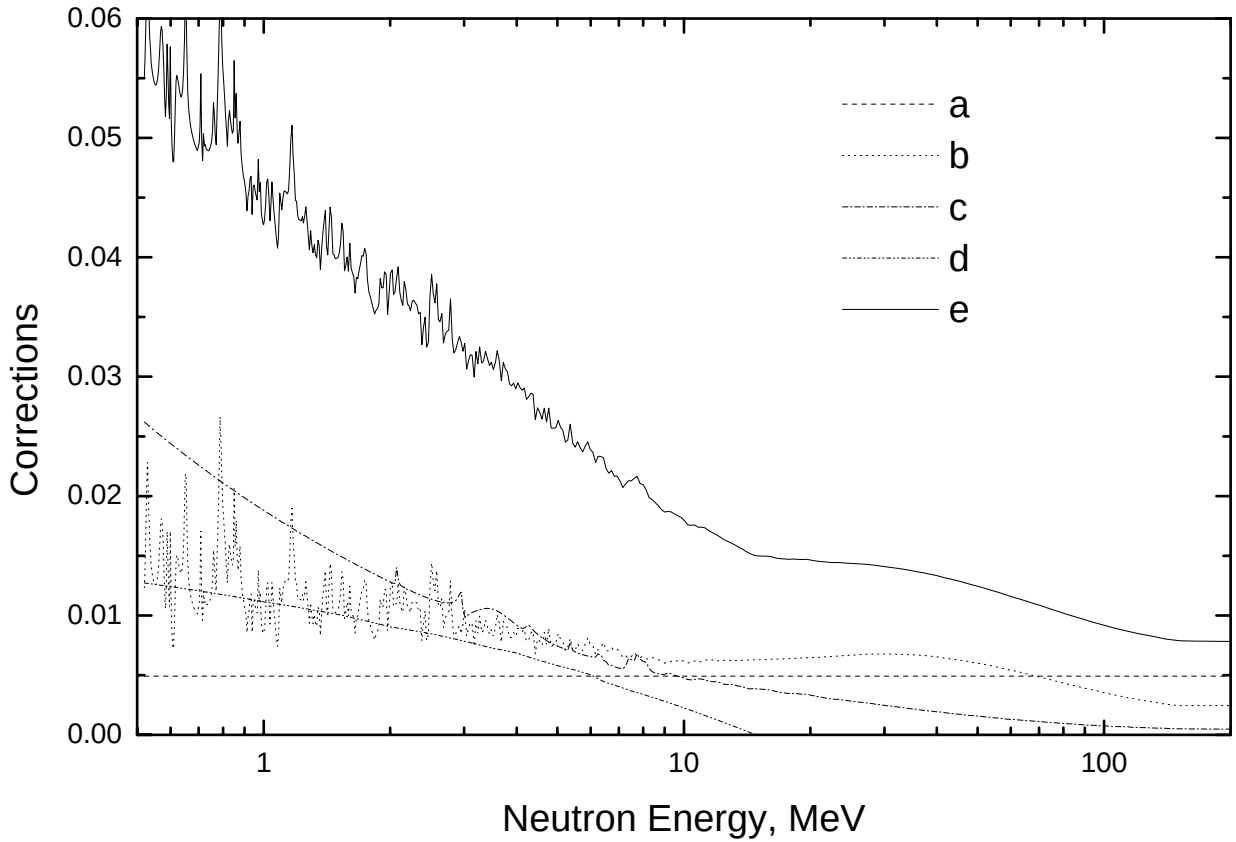
Pulse height spectra observed for one of ^{nat}Pb, ^{209}Bi and ^{235}U targets for the neutron energy range 25 – 200 MeV (Pb, Bi) and 0.5 – 200 MeV (^{235}U)



Average pulse height spectra observed for W and Bi targets

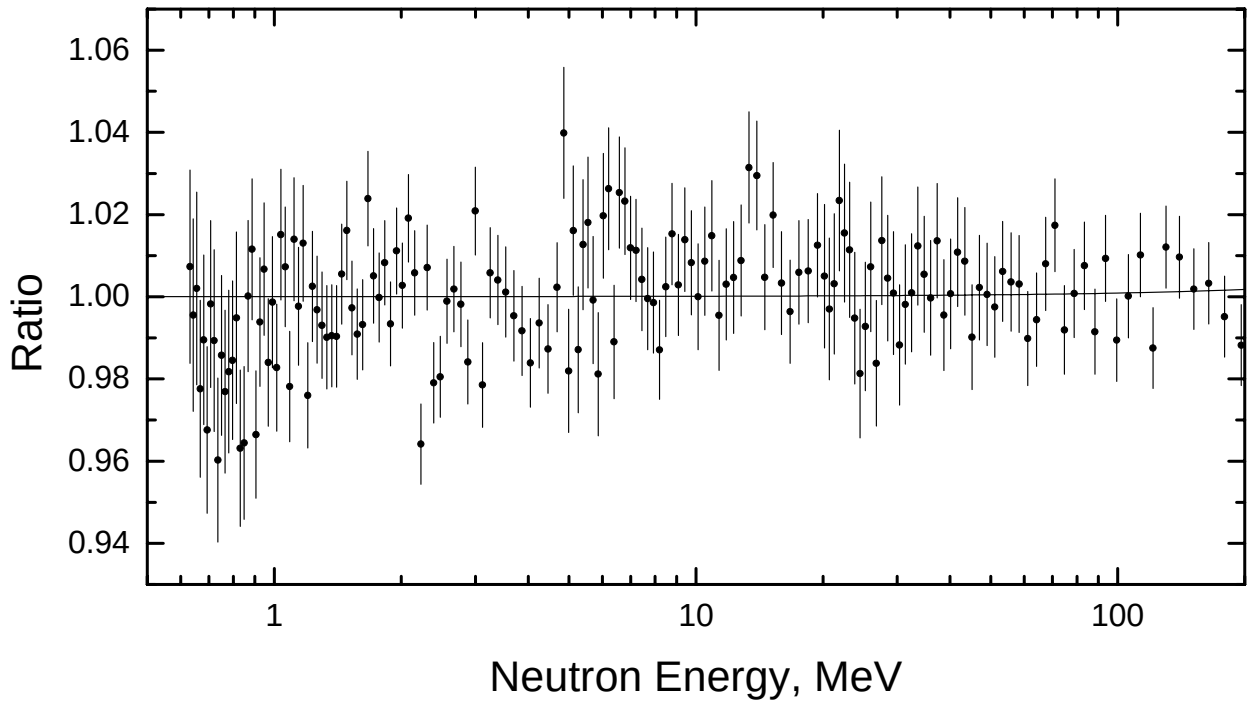


Corrections due to neutron flux attenuation in case of ^{240}Pu



(**a**) - different flight path length of the of ^{240}Pu and of ^{235}U targets; (**b** and **c**) - absorption and scattering in the backing foil material (Al) and working gas (methane); (**d**) - fragment losses in the targets, neutron momentum transfer and angular anisotropy of fission fragments; (**e**) - total correction.

Ratio of the TOF-spectra for two ^{235}U targets (ΔL = 200 mm)

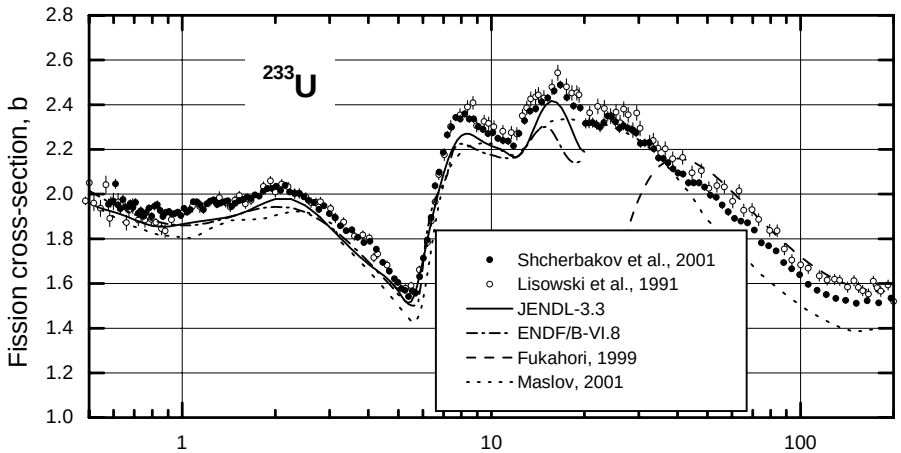


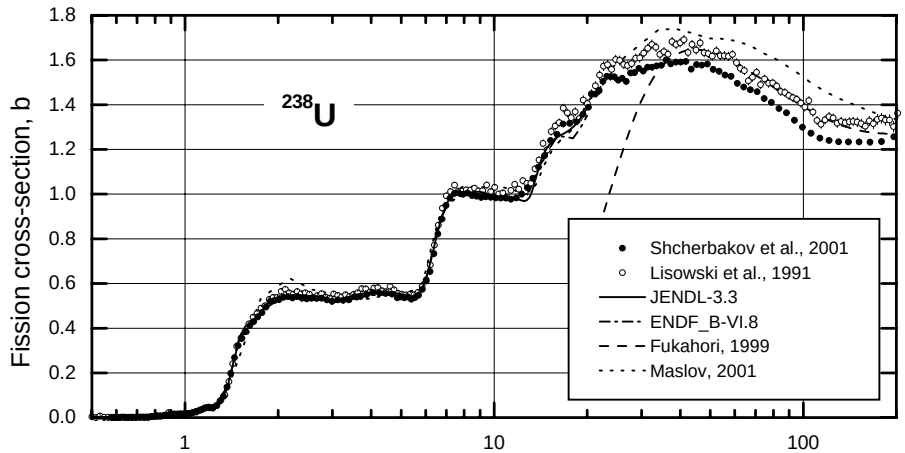
Linear fit

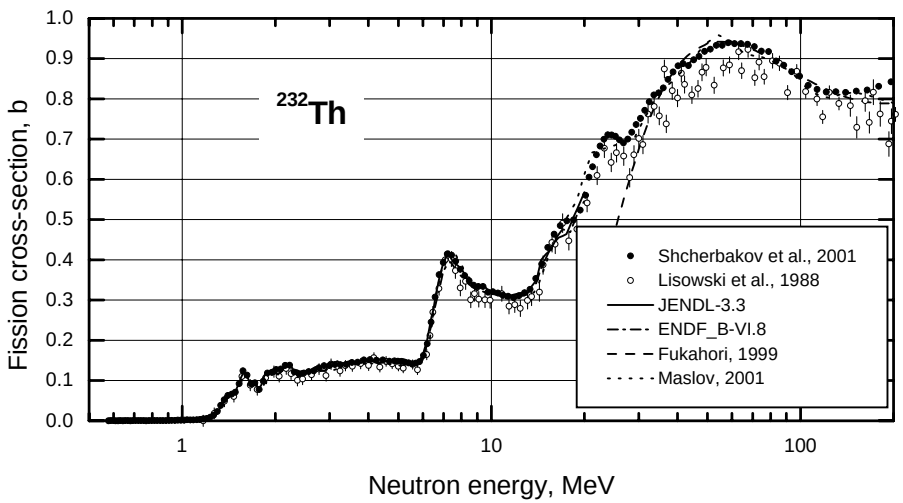
$R(E) = a \cdot E + b$

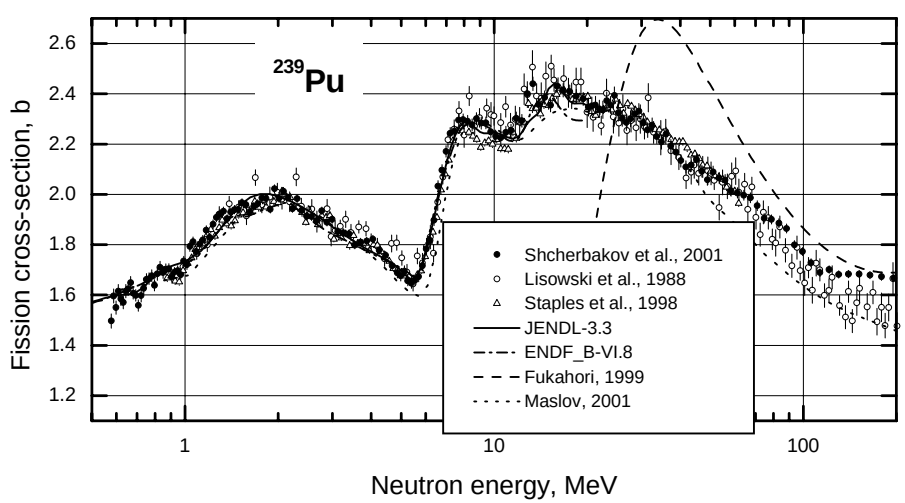
$a = (0.88 \pm 2.34) \cdot 10^{-5}$

Fission cross-section of ^{233}U, ^{238}U, ^{232}Th and ^{239}Pu measured by Shcherbakov *et al*. (2001) in comparison with other data and evaluations

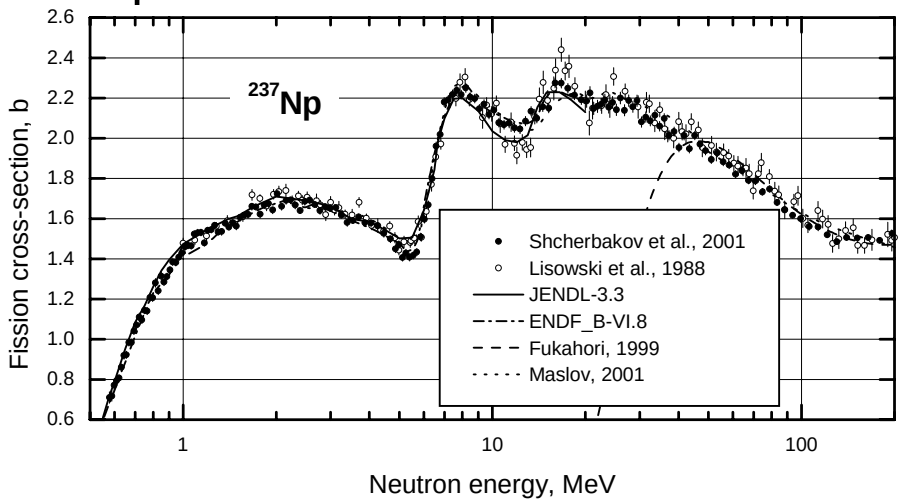




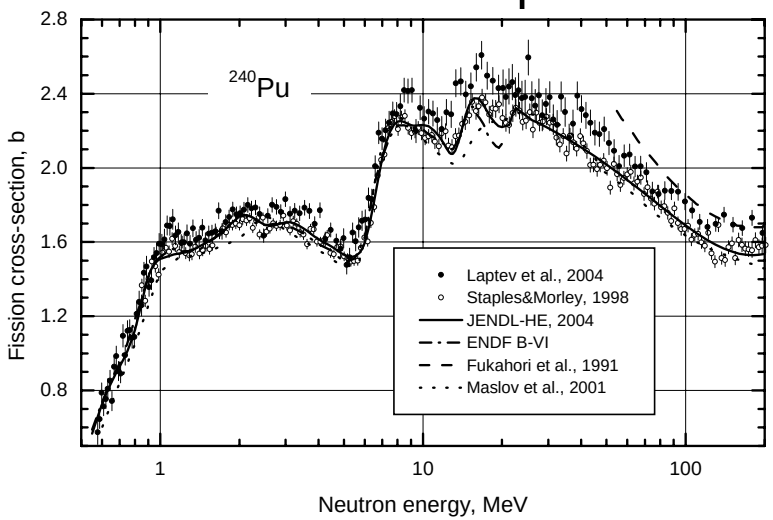


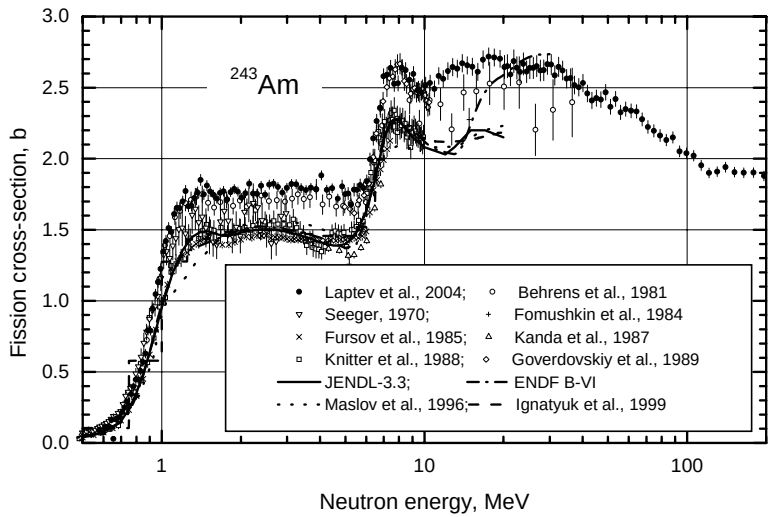


Fission cross-section of ^{237}Np measured by Shcherbakov *et al*. (2001) in comparison with other data and evaluations

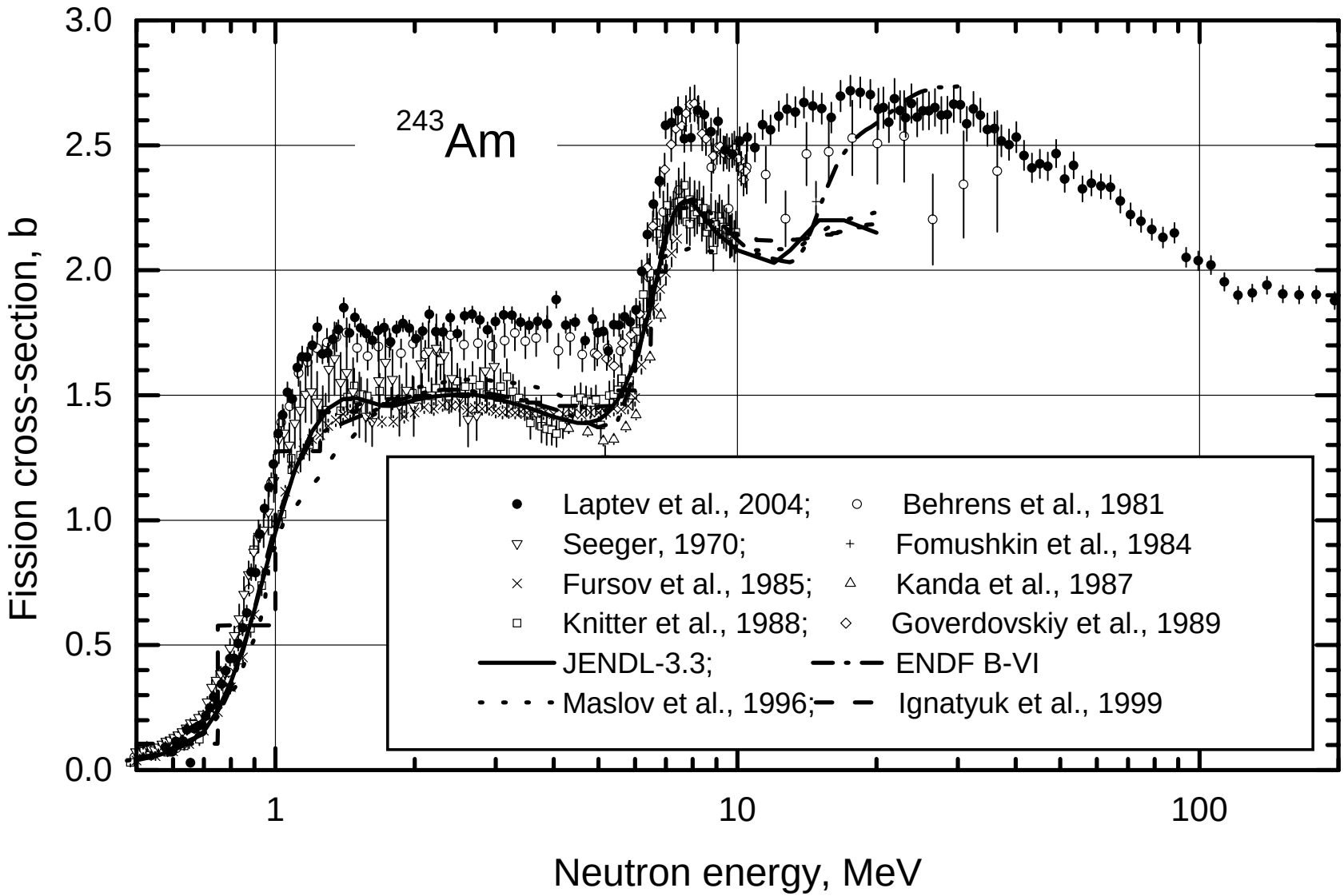


Fission cross-section of ^{240}Pu and ^{243}Am measured by Laptev *et al*. (2004) in comparison with other data and evaluations

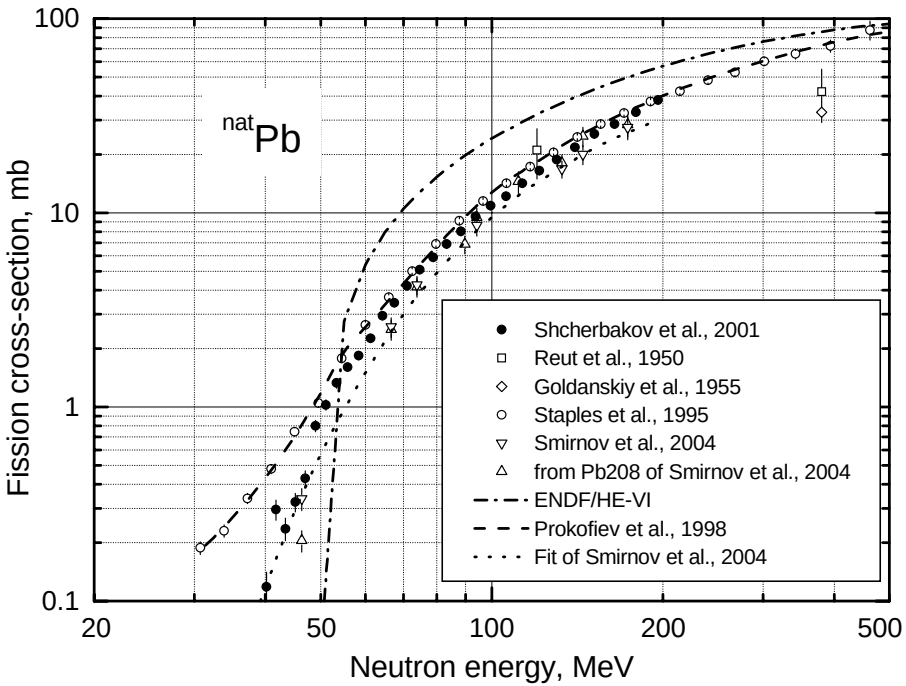


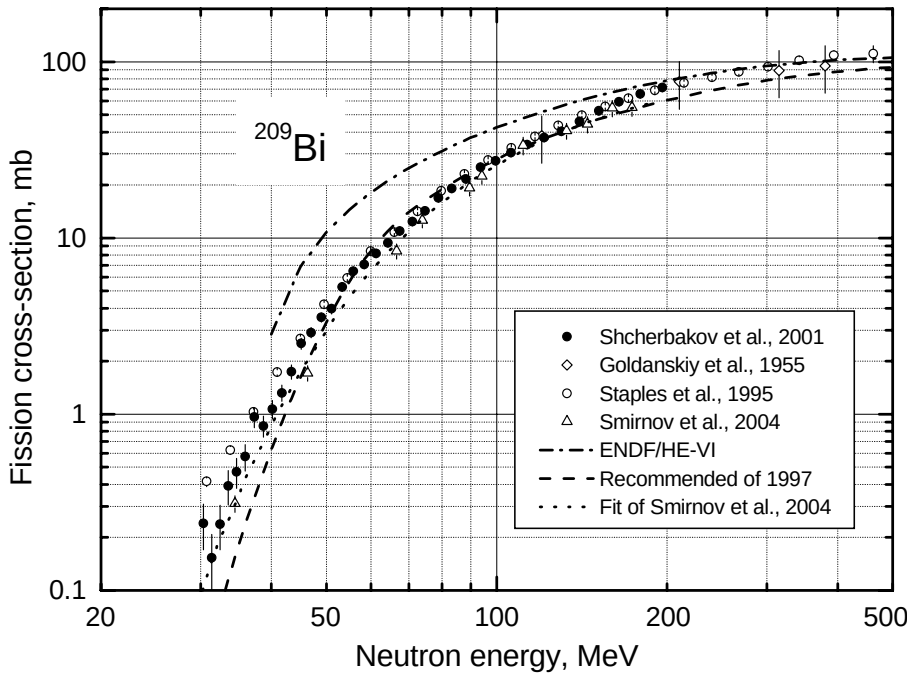


Fission cross-section of ^{243}Am measured by Laptev *et al*. (2004) in comparison with other data and evaluations

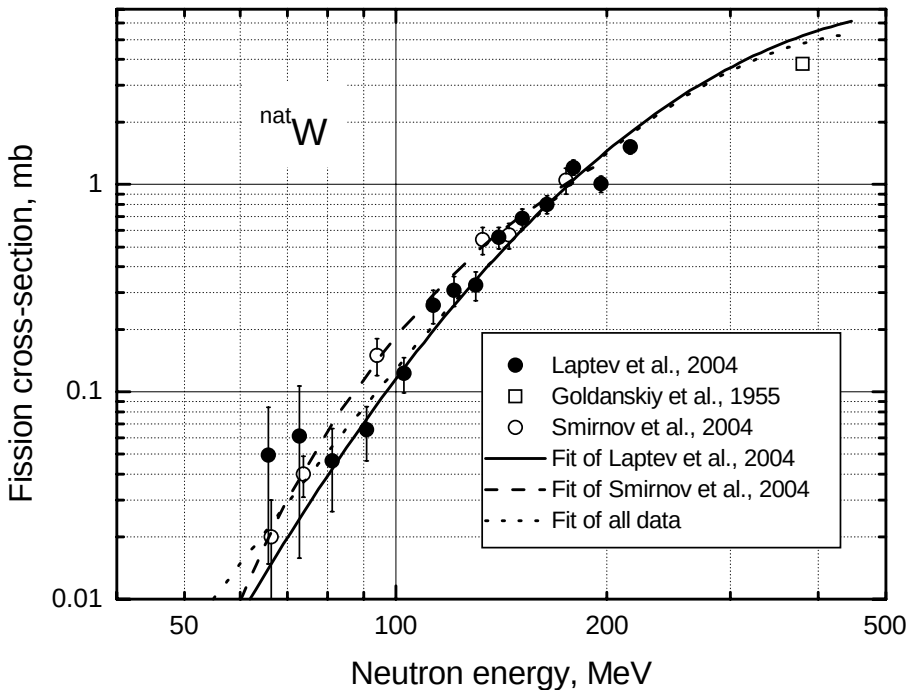


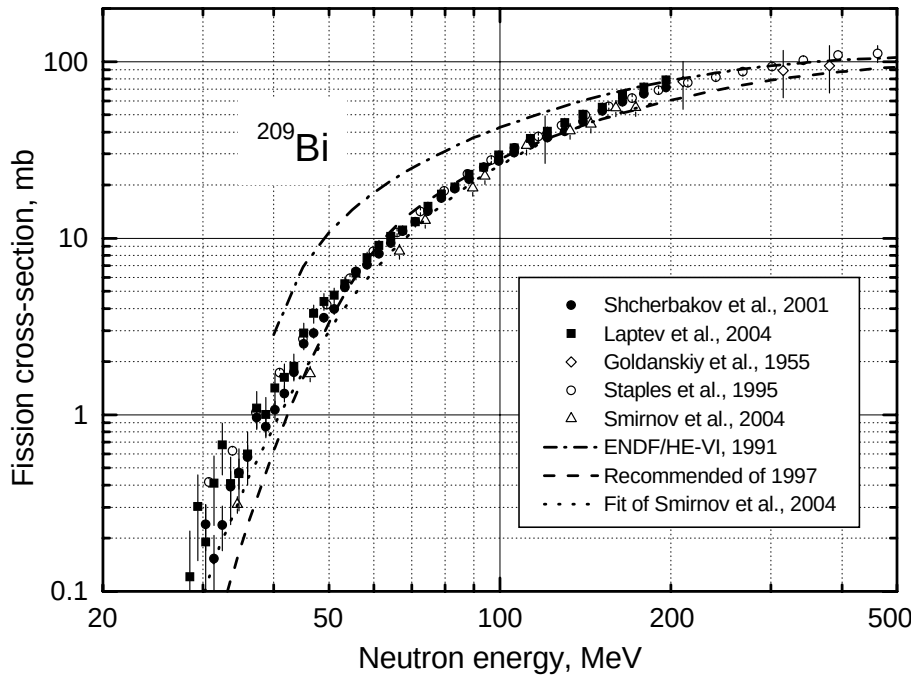
Fission cross-section of ^{nat}Pb and ^{209}Bi measured by Shcherbakov *et al*. (2001) in comparison with other data and evaluations



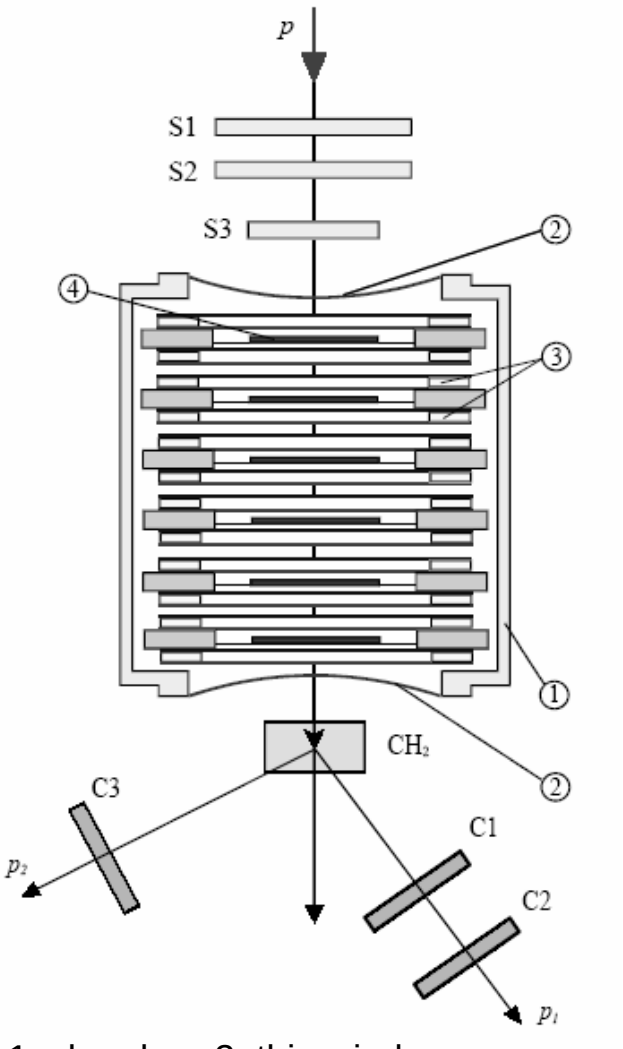


Fission cross-section of ^{nat}W and ^{209}Bi measured by Laptev *et al*. (2004) in comparison with other data and evaluations





Experimental set-up for proton-induced fission cross-section measurements of Kotov *et al*. (2003)



1. chamber; 2. thin windows;
3. PPAC's; 4. target.

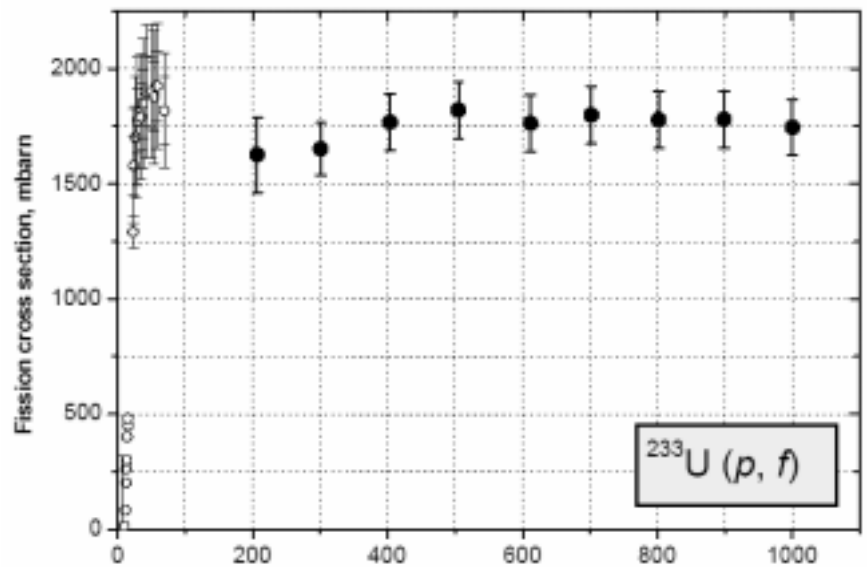
SPECIFICATION:

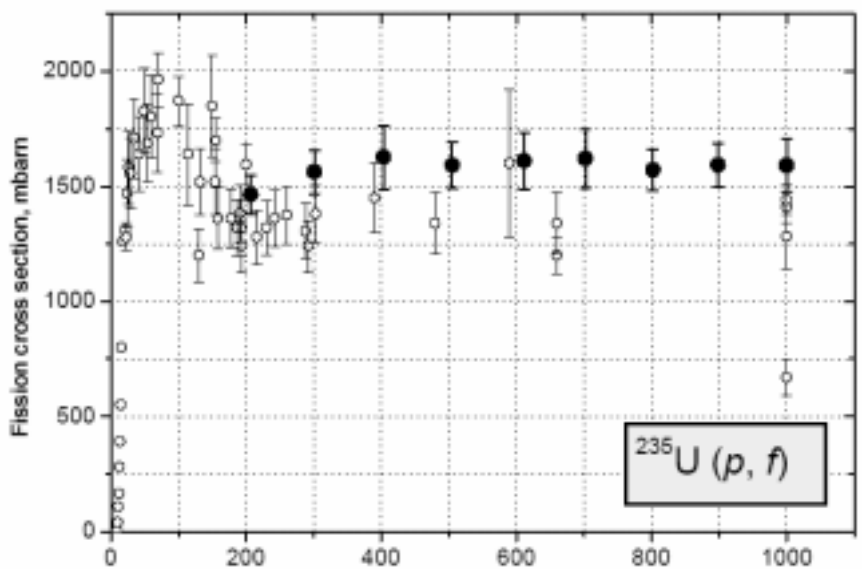
- both fission fragments registration in coincidence by two parallel plate avalanche counters;
- a large solid angle acceptance about 10 sr for fission fragment;
- 100% efficiency for fission fragments;
- good resolution fission events from events produced by other nuclear reactions;
- the proton beam monitoring:
  - at low beam intensity (~10^5 p/s) by direct count of scintillation telescopes;
  - at high beam intensity (~10^7 p/s) by registration of *pp*−elastic scattering on the CH_2 target;
- copper degrader to obtain proton energy variation.

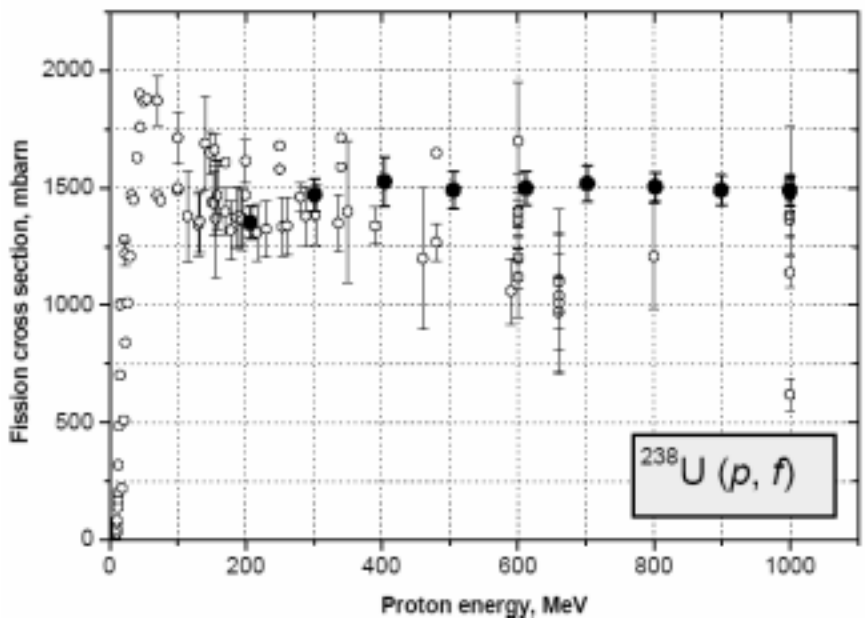
CORRECTIONS FOR:

- solid angle acceptance of fission fragment;
- inefficiency of the proton monitor;
- a probability of two ore more protons appearance in the single bunch;
- an anisotropy of fission fragments and their energy losses in target.

Proton-induced fission cross-sections of ^{233}U, ^{235}U and ^{238}U measured by Kotov *et al*. (2003) in comparison with other data







Summary

- Neutron-induced fission cross-sections of actinide nuclei ^{233}U, ^{238}U, ^{232}Th, ^{239}Pu, ^{237}Np, ^{240}Pu and ^{243}Am and sub-actinide nuclei ^{nat}Pb, ^{209}Bi and ^{nat}W have been measured in neutron energy range from 1 MeV to 200 MeV in two experiments at GNEIS facility.

- The fission cross-section of ^{243}Am in the neutron energy range from 40 MeV to 200 MeV has been measured for the first time.

- The neutron-induced fission cross-section of ^{nat}W has been measured for the first time with a "white" neutron source.

- Statistical accuracy of measured fission cross-sections of actinides ^{233}U, ^{238}U, ^{232}Th, ^{239}Pu and ^{237}Np is less than 1%, that of actinides ^{240}Pu and ^{243}Am is about 2%, that of sub-actinides ^{nat}Pb and ^{209}Bi varies from about 5% at 60 MeV to 1.5% at 200 MeV and that of ^{nat}W varies from 19% at 100 MeV to 7% at 200 MeV .

- Detailed analysis of systematic errors has been done.

- In general, in the overlapping energy regions (below 20 MeV) our data are in reasonable agreement with previous data obtained mainly at electron linacs.

- There is a significant disagreement between data of Shcherbakov *et al*. (2001) and that of Lisowski *et al*. for ^{233}U, ^{238}U, ^{239}Pu and ^{232}Th above 20 MeV while for ^{237}Np both data sets are not in contradiction.

- There is some disagreement between data of Laptev *et al*. (2004) and that of Staples and Morley for ^{240}Pu above 40 MeV. On our opinion, most of the differences are in normalization rather than shape.

- For ^{243}Am data of Laptev *et al*. (2004) shows a good agreement with that of Behrens *et al.* and Goverdovskiy *et al*., there are significant disagreements between previous data sets.

- The libraries' evaluations, theoretical calculations of Maslov *et al*. and evaluation of Ignatyuk *et al*. correspond other data sets rather than Laptev *et al*. in case of ^{243}Am. Normalization of data of Laptev *et al*. for ^{243}Am to libraries' 14 MeV value withdraws this disagreement.

- There is a good agreement between data of Shcherbakov *et al*. for ^{nat}Pb and ^{209}Bi and previous data.

- There is generally good agreement between data of Laptev *et al*. for ^{nat}W and those of Smirnov *et al*., except for a possible discrepancy in the 90-100 MeV region.

- Measured fission cross-section of ^{209}Bi by Laptev *et al*. reproduces very carefully that measured in frame previous experiment of Shcherbakov *et al*.

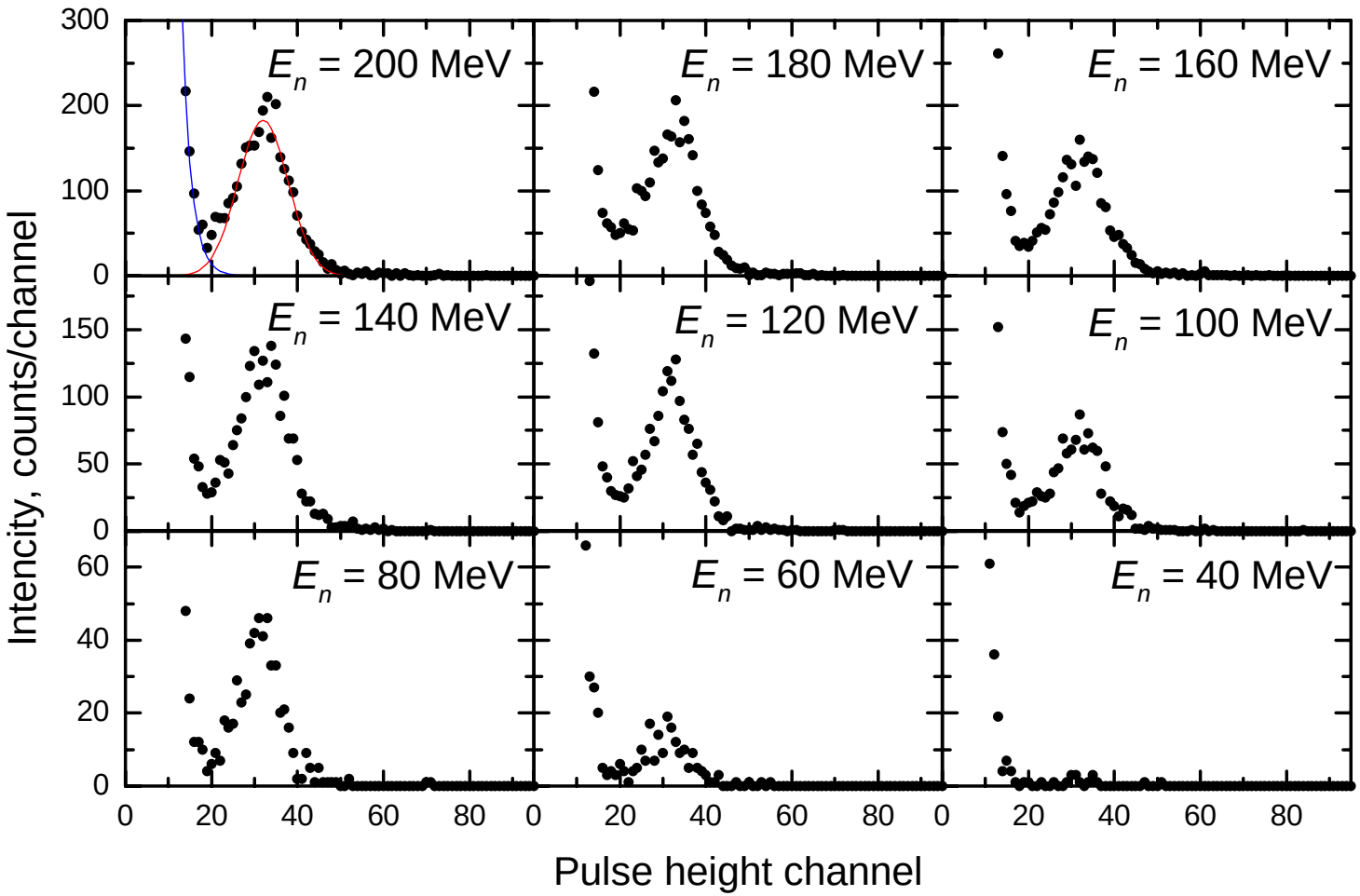
- Proton-induced fission cross-sections of actinide nuclei ^{233}U, ^{235}U, ^{238}U, ^{232}Th, ^{239}Pu and ^{237}Np and sub-actinide nuclei ^{nat}Pb and ^{209}Bi have been measured in proton energy range from 200 MeV to 1000 MeV at PNPI proton synchrocyclotron by Kotov *et al*. (2003). Results of measurements in case of ^{233}U, ^{235}U and ^{238}U are presented.

- A statistical accuracy of the measured fission cross section by Kotov *et al*. was better than 1.5%, the overall accuracy was better than 10%.

- The cross sections for proton induced fission of ^{233}U in the energy range 200-1000 MeV was obtained by Kotov *et al*. for the first time.

- According to opinion of Kotov *et al*., their results for ^{238}U in the energy range from 300 to 900 MeV do not agree with a majority of the early-obtained data.

Pulse height spectra observed at different neutron energies for ^{209}Bi



Pulse height spectra observed at different neutron energies for ^{nat}W