Spallation Neutron Source at the 1 GeV Synchrocyclotron of PNPI

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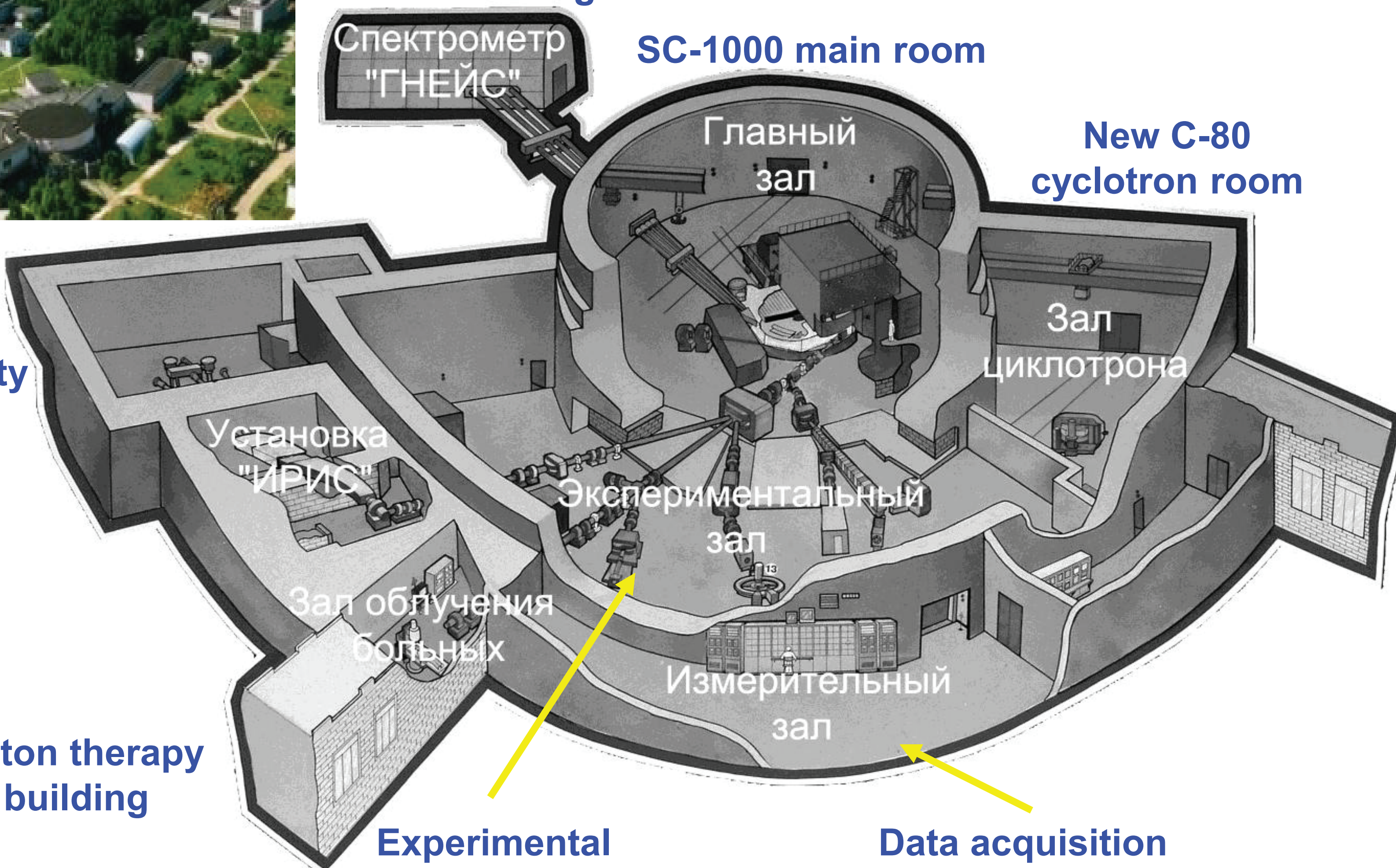
RuPAC-2016, Peterhof, St. Petersburg, 21-25 November, 2016

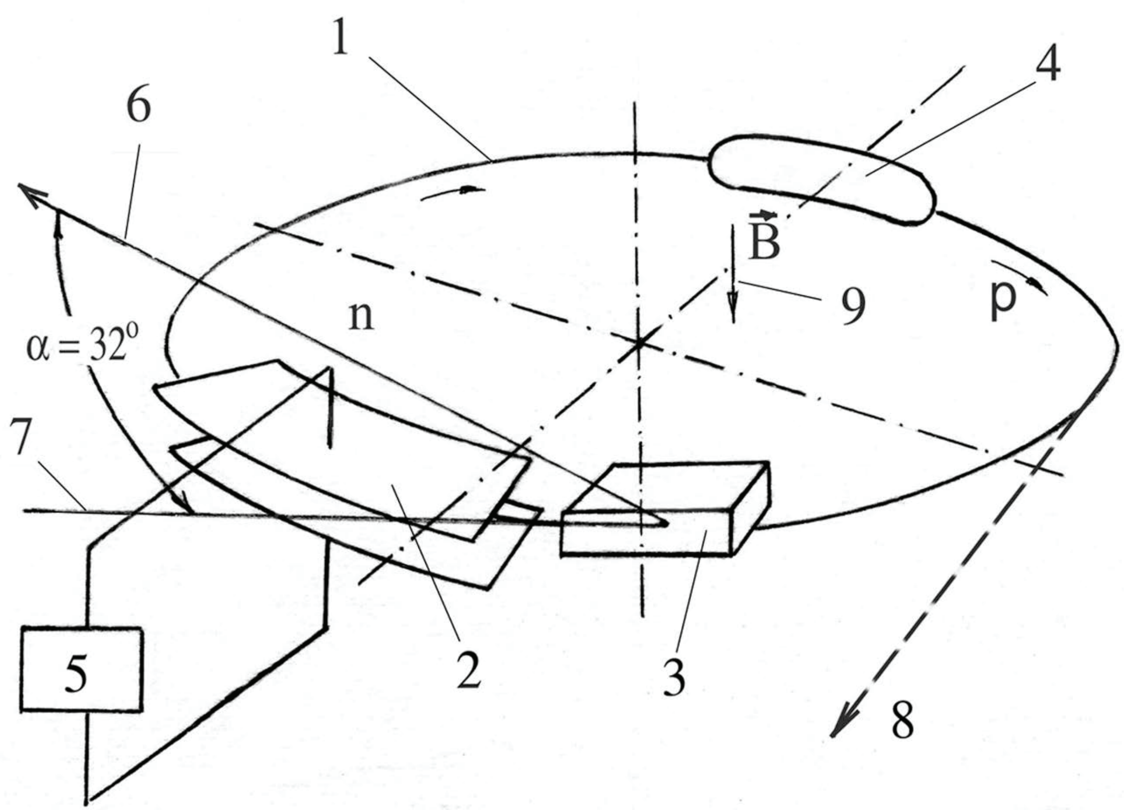
WEZMH01

1 GeV proton synchrocyclotron SC-1000 of the PNPI
(in operation since 1970)

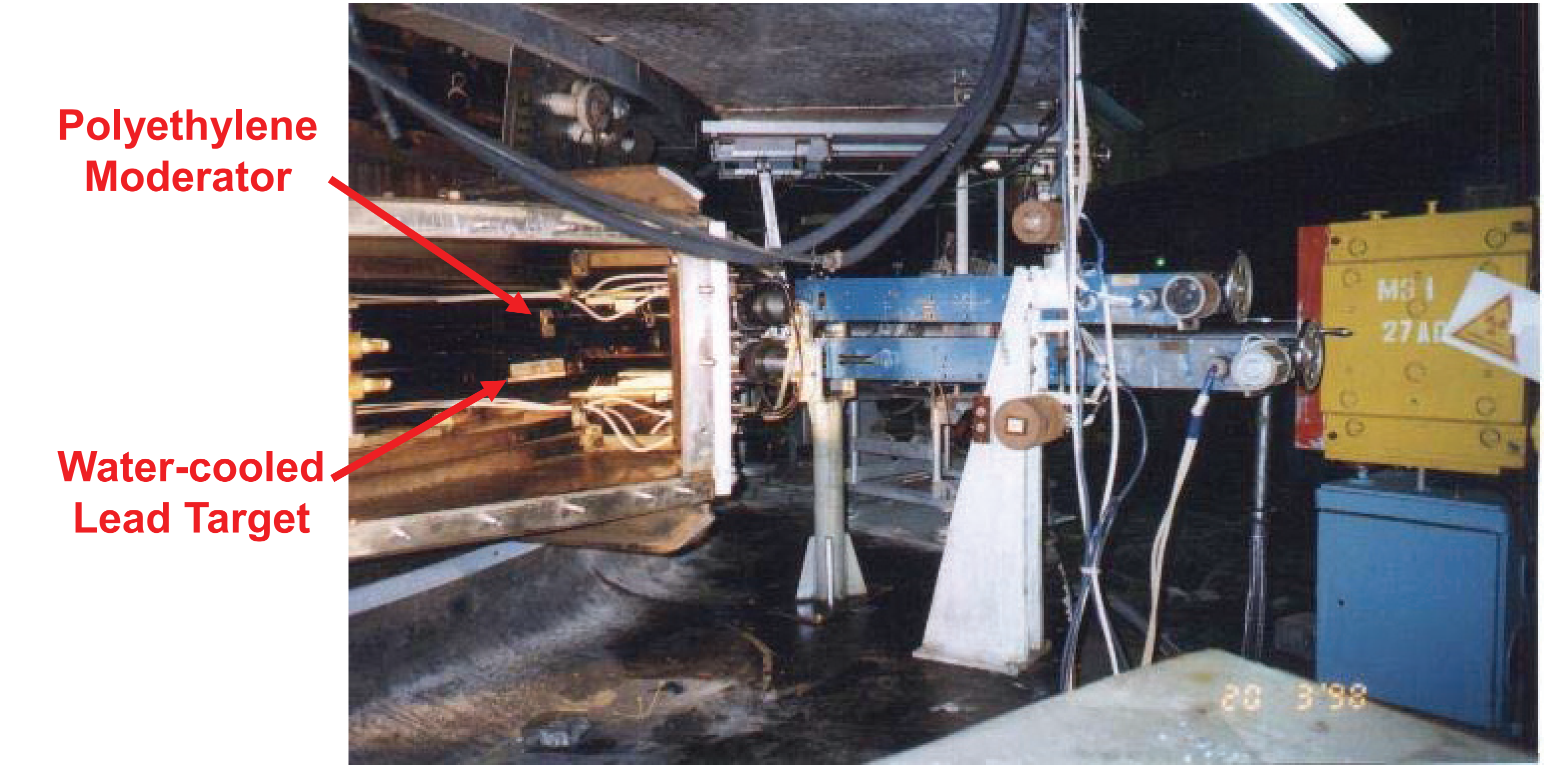


Synchrocyclotron SC-1000	
Proton energy	1 GeV
Internal proton beam current	$\leq 3\ \mu A$
Repetition rate	40–60 Hz

Schematic diagram of the pulsed neutron source GNEIS

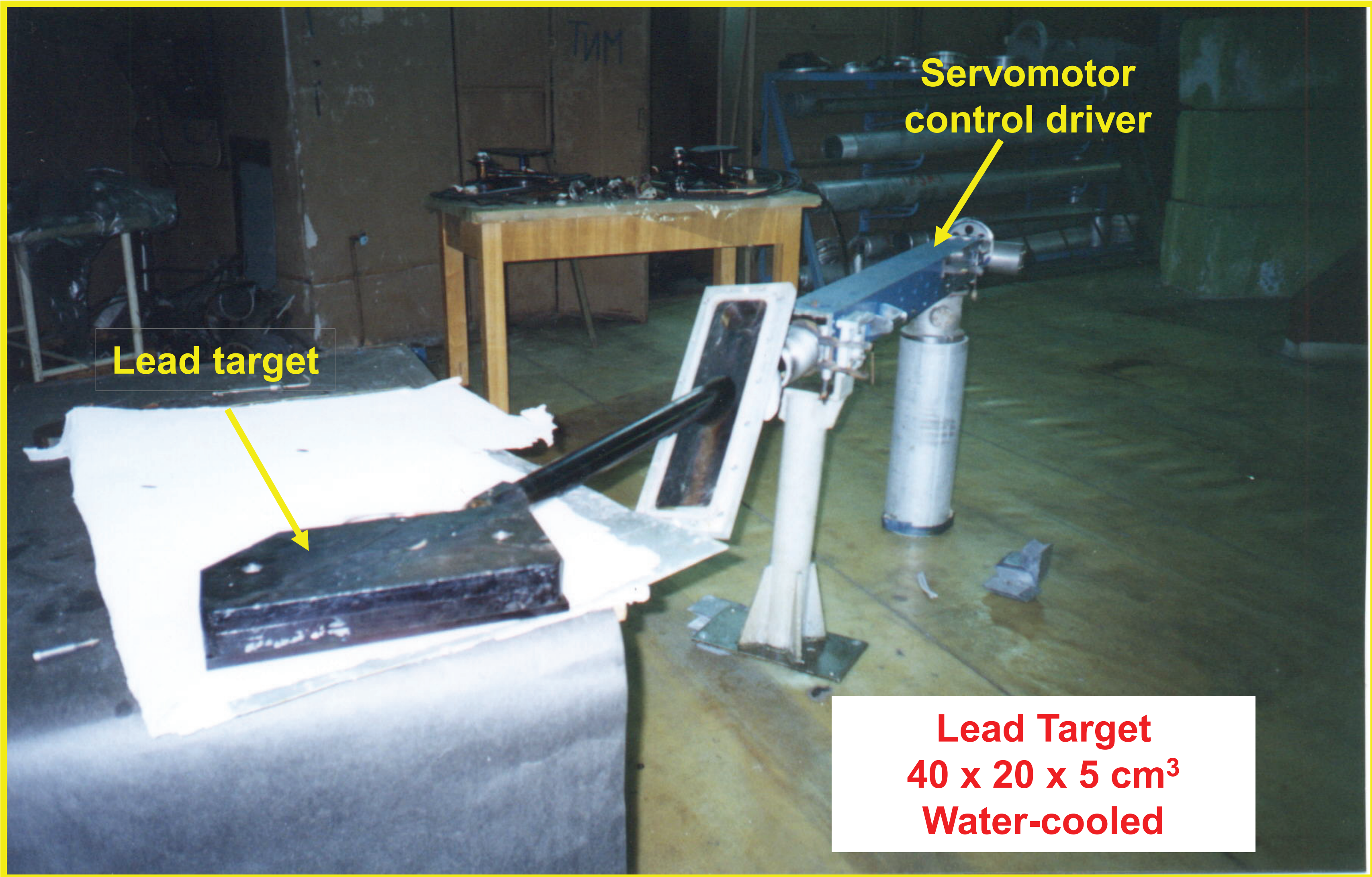


1. "Final" orbit of 1-GeV protons
2. Electrostatic deflector plates
3. Neutron-producing target
4. Proton bunch
5. Power supply and deflector control unit
6. Neutron beam axis
7. Direction of the tangent to the proton orbit
8. Direction of the beam axis of protons extracted from the accelerator for external beams
9. Direction of the magnetic field in the accelerator

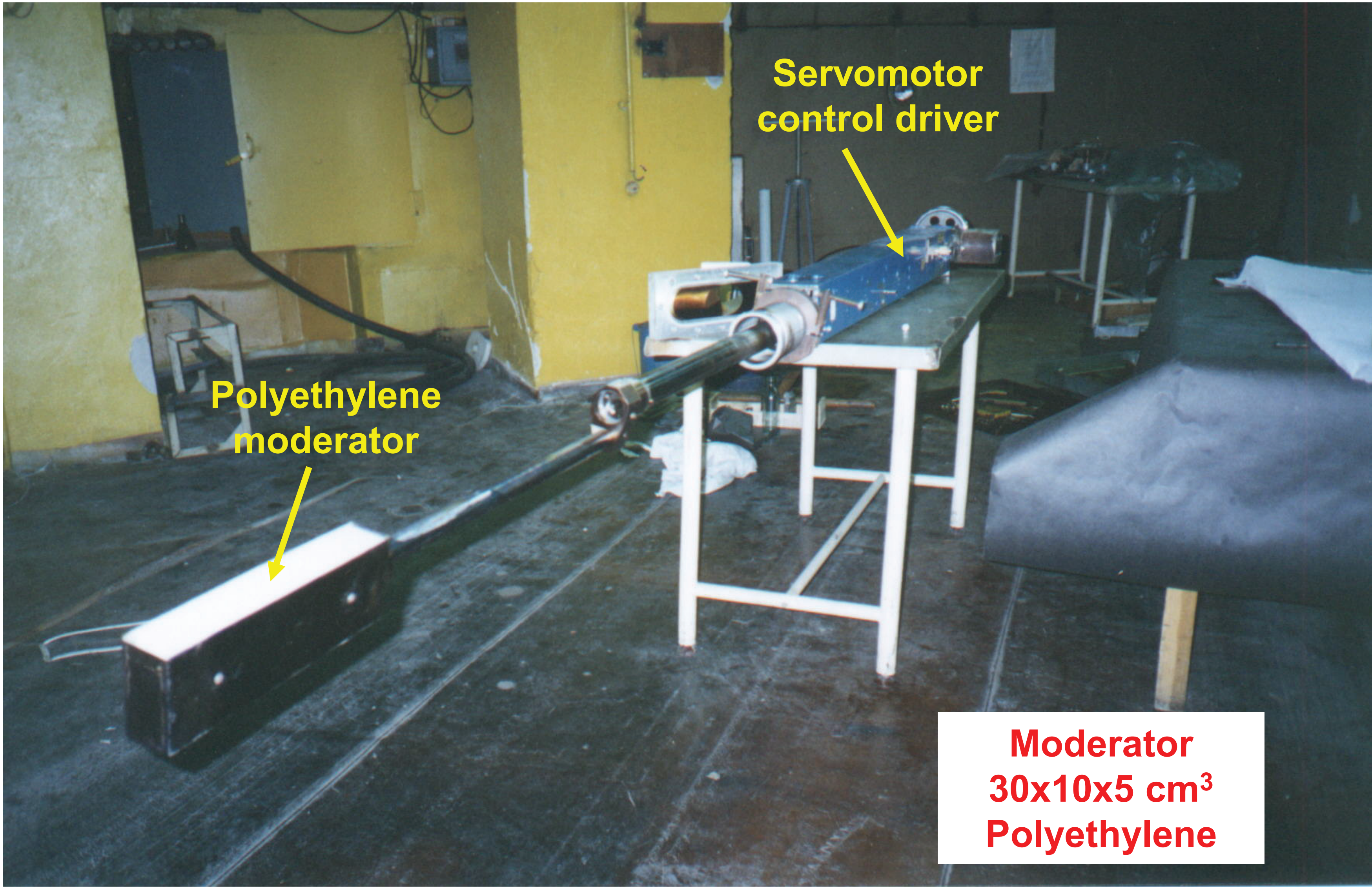


Pulsed neutron source	
Average fast neutron intensity	≤ $3 \cdot 10^{14}$ n/s
Duration of fast neutron pulse	~ 10 ns
Repetition rate	≤ 50 Hz
Neutron energy range	Thermal – 1000 MeV
Type of neutron spectrum Beam #1-4 (En < 0.1 MeV)	$1/E^{\alpha}$, α=0.75-0.95
Type of neutron spectrum Beam #5 (En > 0.1 MeV)	“spallation”

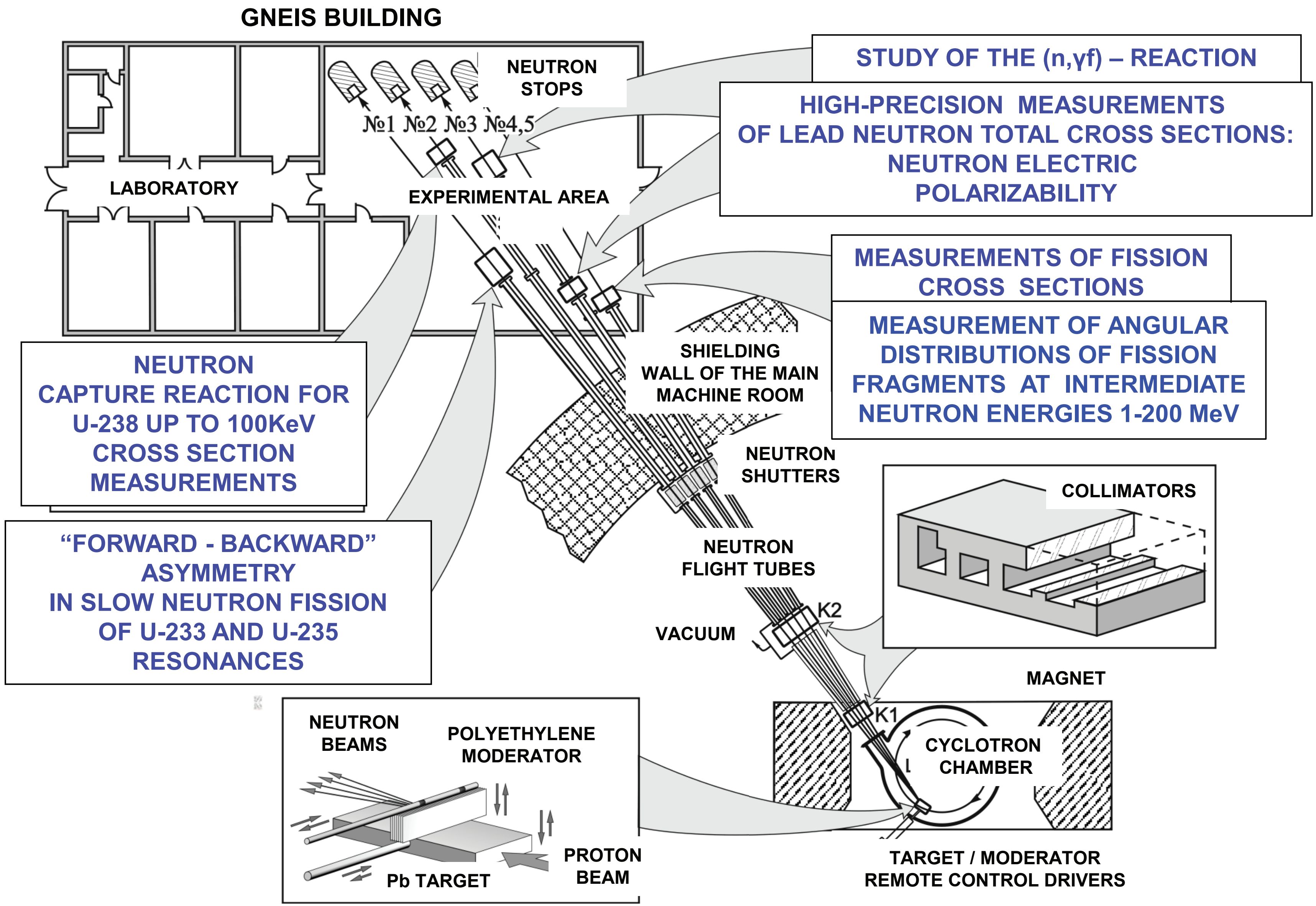
Water-cooled lead target of the GNEIS neutron source



Polyethylene moderator of the GNEIS neutron source



GNEIS NEUTRON TOF-SPECTROMETER (since 1975)



Description of the GNEIS neutron source and TOF-spectrometer
NIM A242 (1985) 121-133

Nuclear Instruments and Methods in Physics Research A242 (1985) 121–133 121
North-Holland, Amsterdam

NEUTRON TIME-OF-FLIGHT SPECTROMETER GNEIS AT THE GATCHINA 1 GeV PROTON SYNCHROCYCLOTRON

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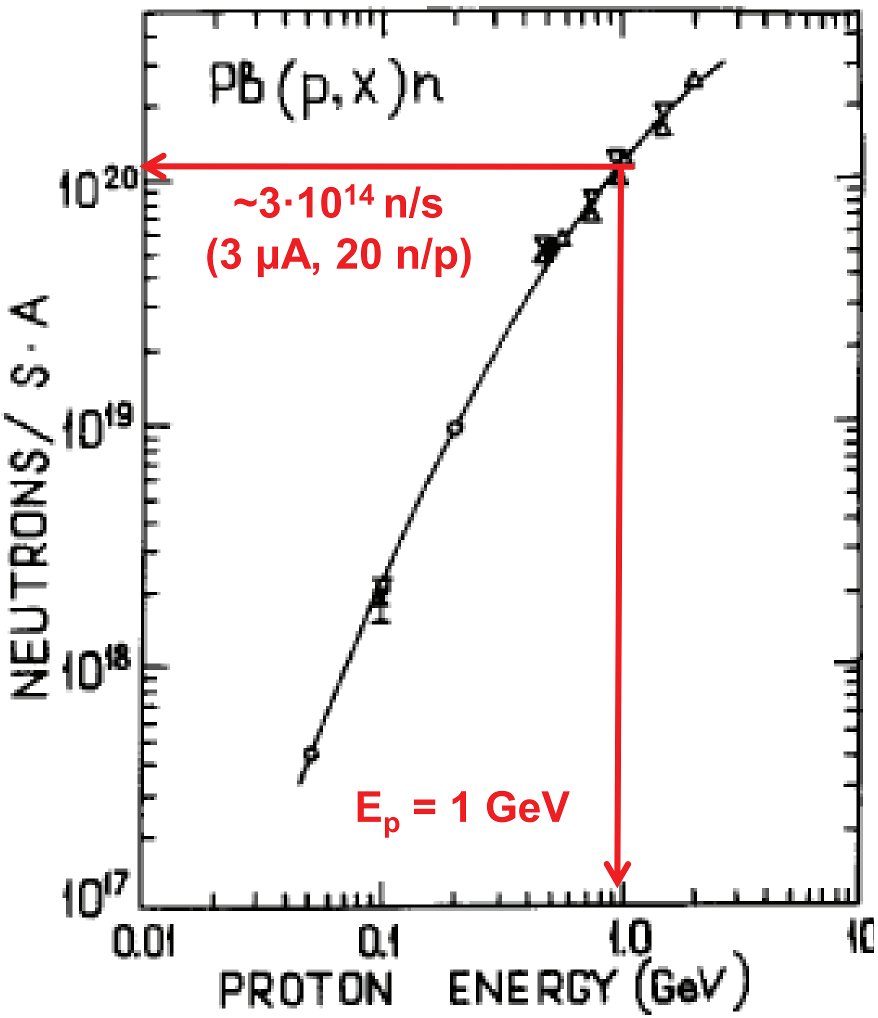
Received 9 March 1985 and in revised form 31 July 1985

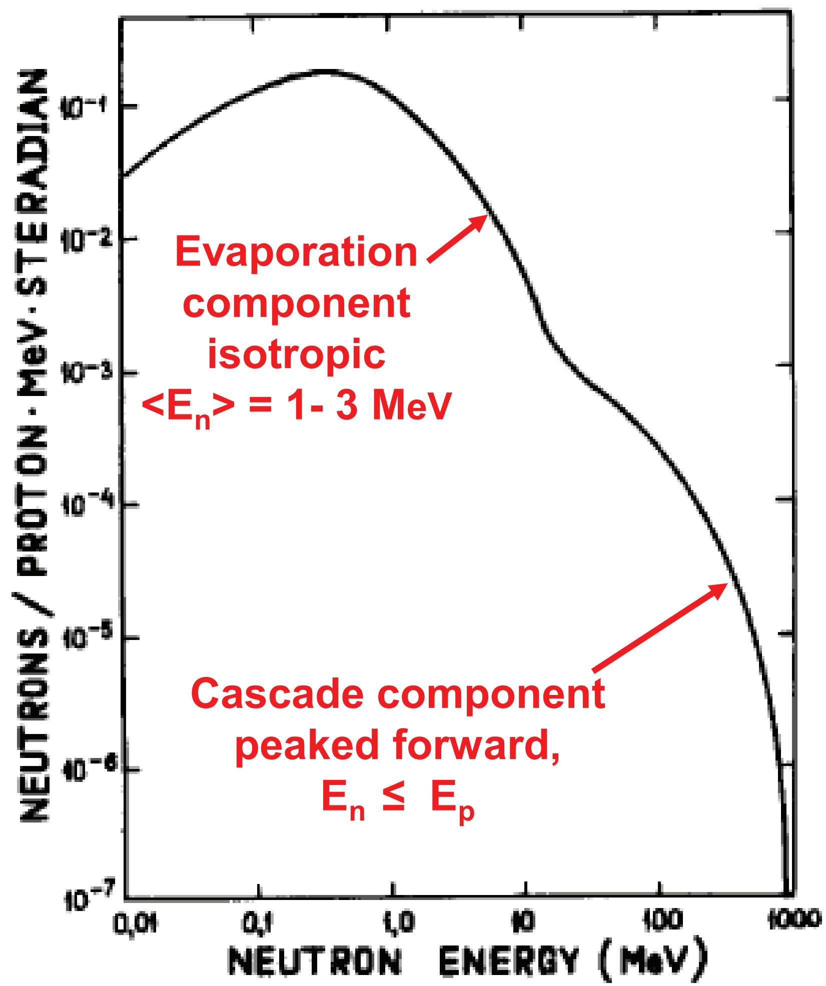
A description of GNEIS – the Gatchina neutron time-of-flight spectrometer at the 1 GeV proton synchrocyclotron – is given together with its basic parameters, as well as a comparison with other modern pulsed neutron source facilities. The integral neutron yield from a lead target is 3×10^{14} n/s. The spectrometer has five flight paths and a data acquisition system equipped with a few autonomous measuring stations. Some results of the (n, γf) experiments and neutron capture cross section measurements are presented to illustrate the facility's performance.

4π total neutron yield from bombardment of lead target with protons

Neutron spectrum for Pb-target : Ø15cm, length 30cm, Ep = 800 MeV

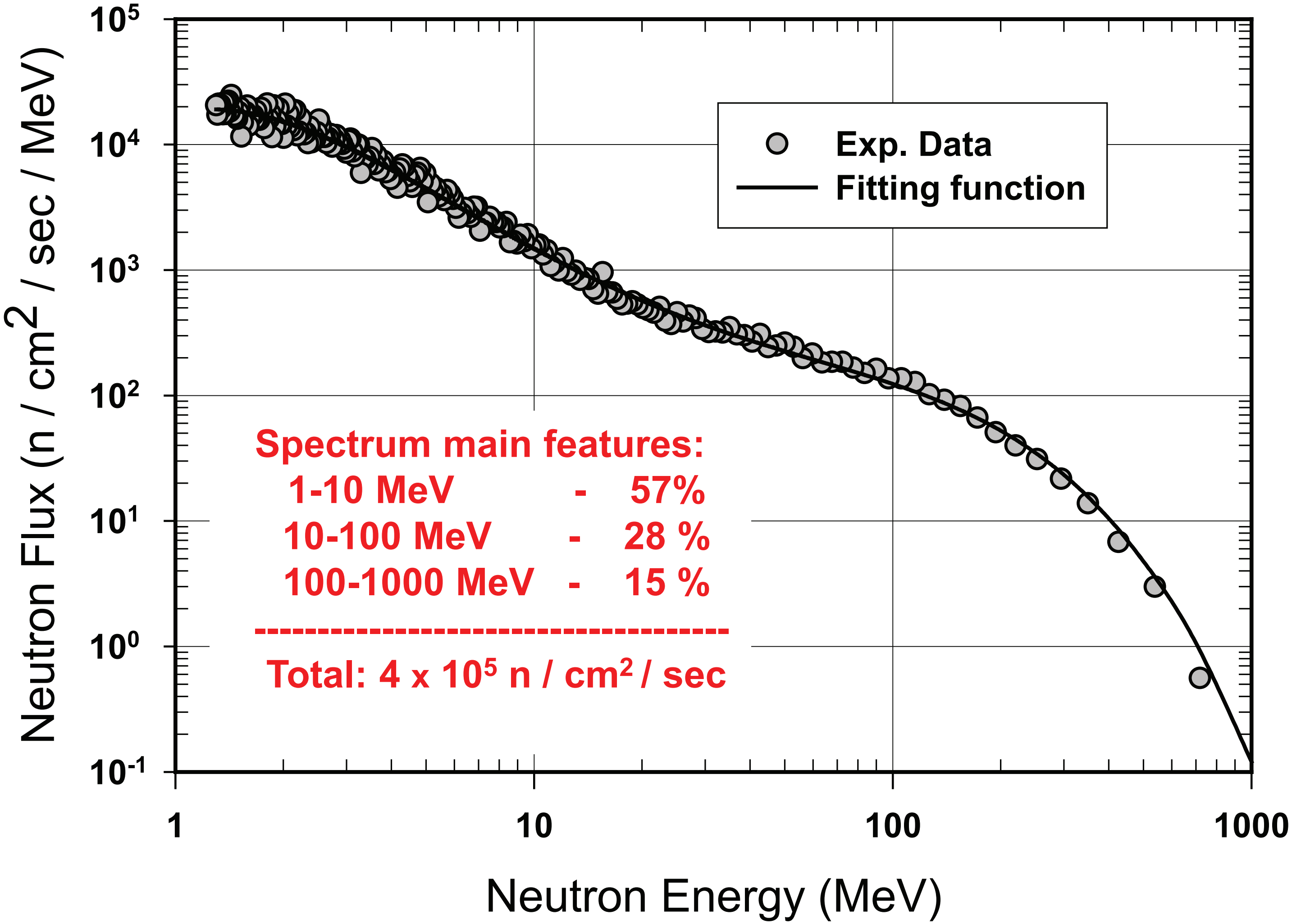


G. Bartholomew, ICANS-V (1981)



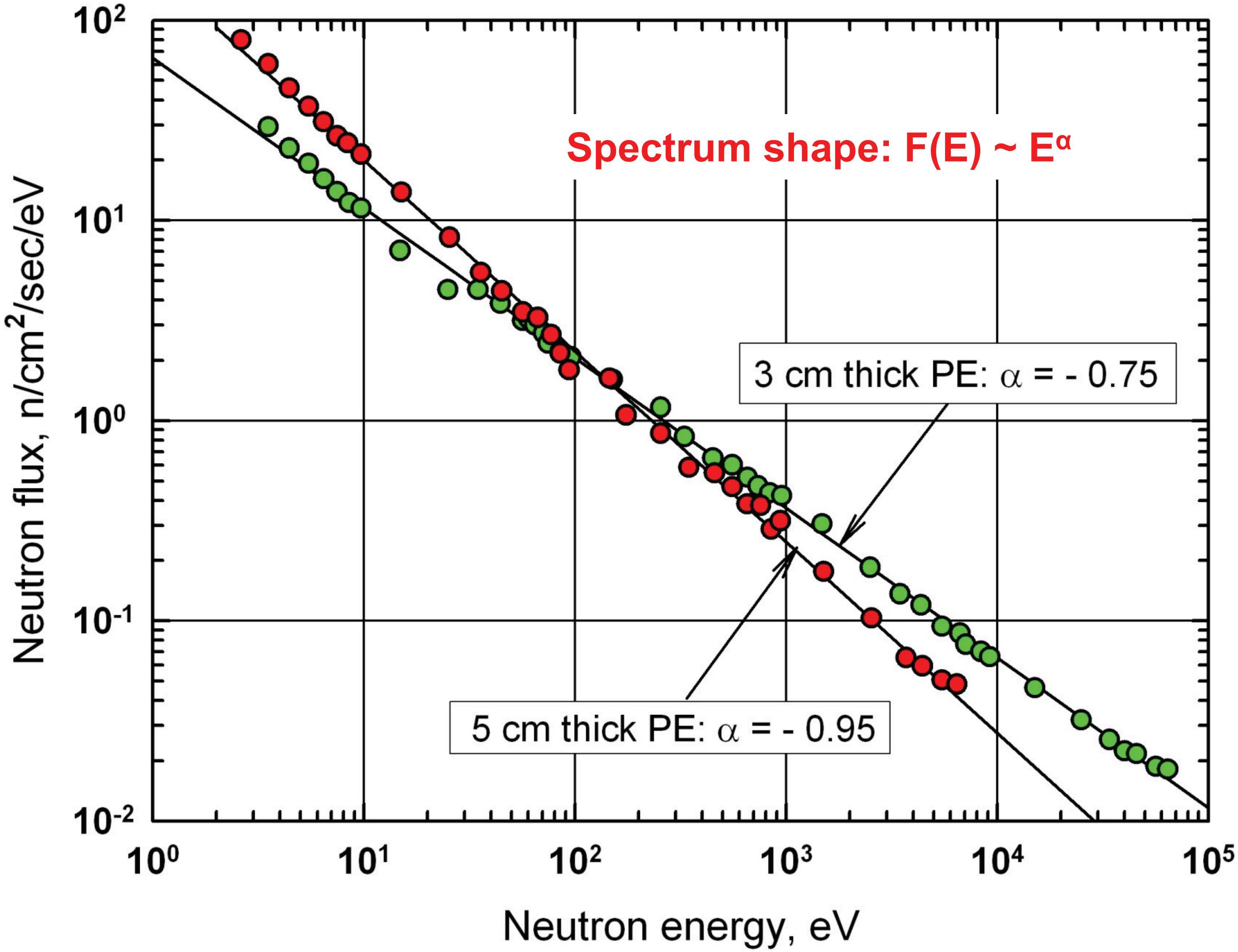
J. Carpenter, NIM (1977)

Non-moderated neutron spectrum of the GNEIS



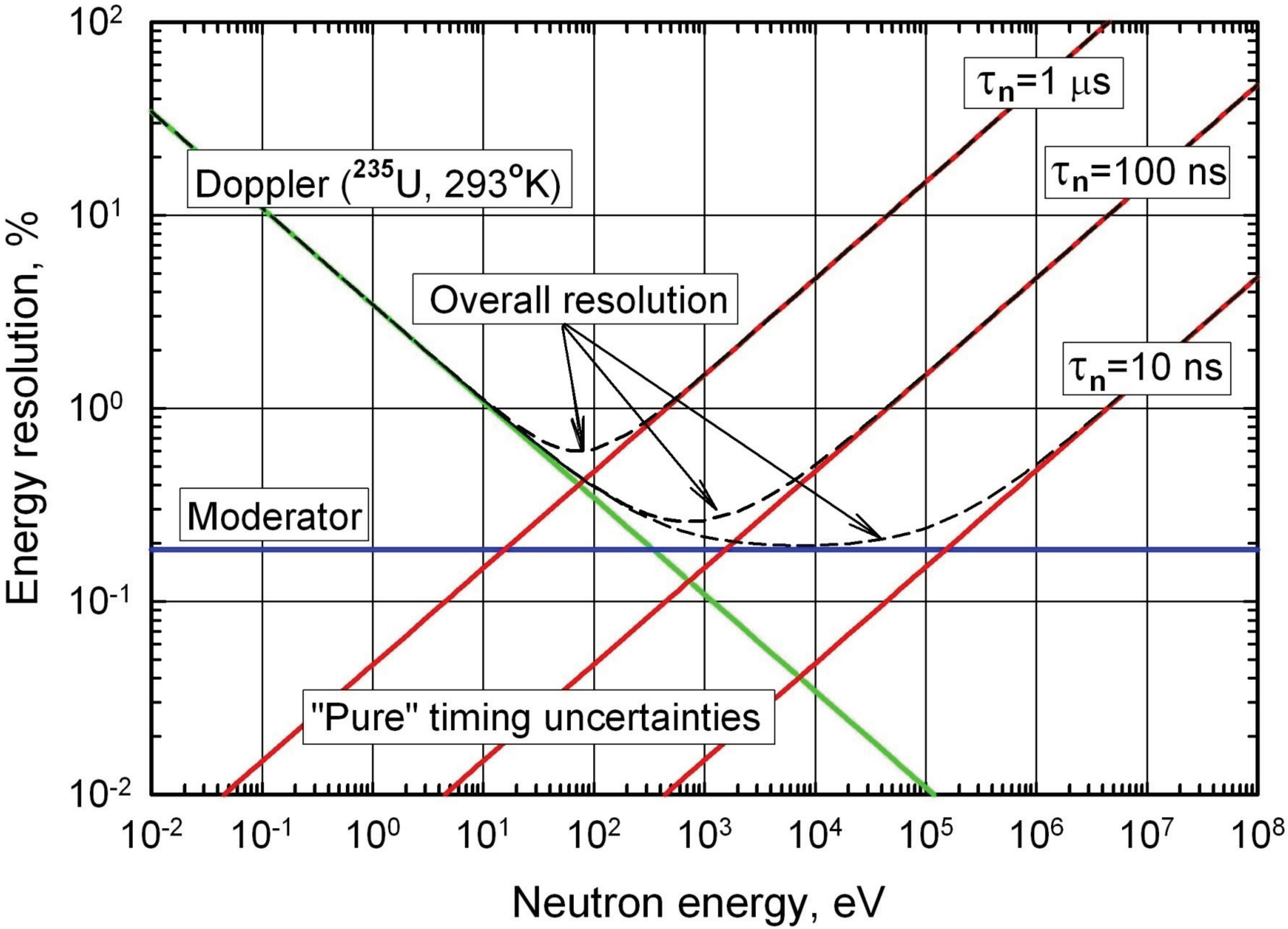
Measurement: beam #5, 36.5 m flight path, 10^{14}n/s neutron yield, neutron detector – fission ionization chamber with ^{235}U target

Moderated neutron spectra of the GNEIS



Measurement: beam #3, 40m flight path, 10^{14} n/s average neutron yield, neutron detector – ^{10}B radiator + NaI(Tl) detector

Energy resolution of the TOF- spectrometer GNEIS



Calculation parameters: 40m flight path length, 5cm thick PE-moderator
10ns fast neutron pulse width

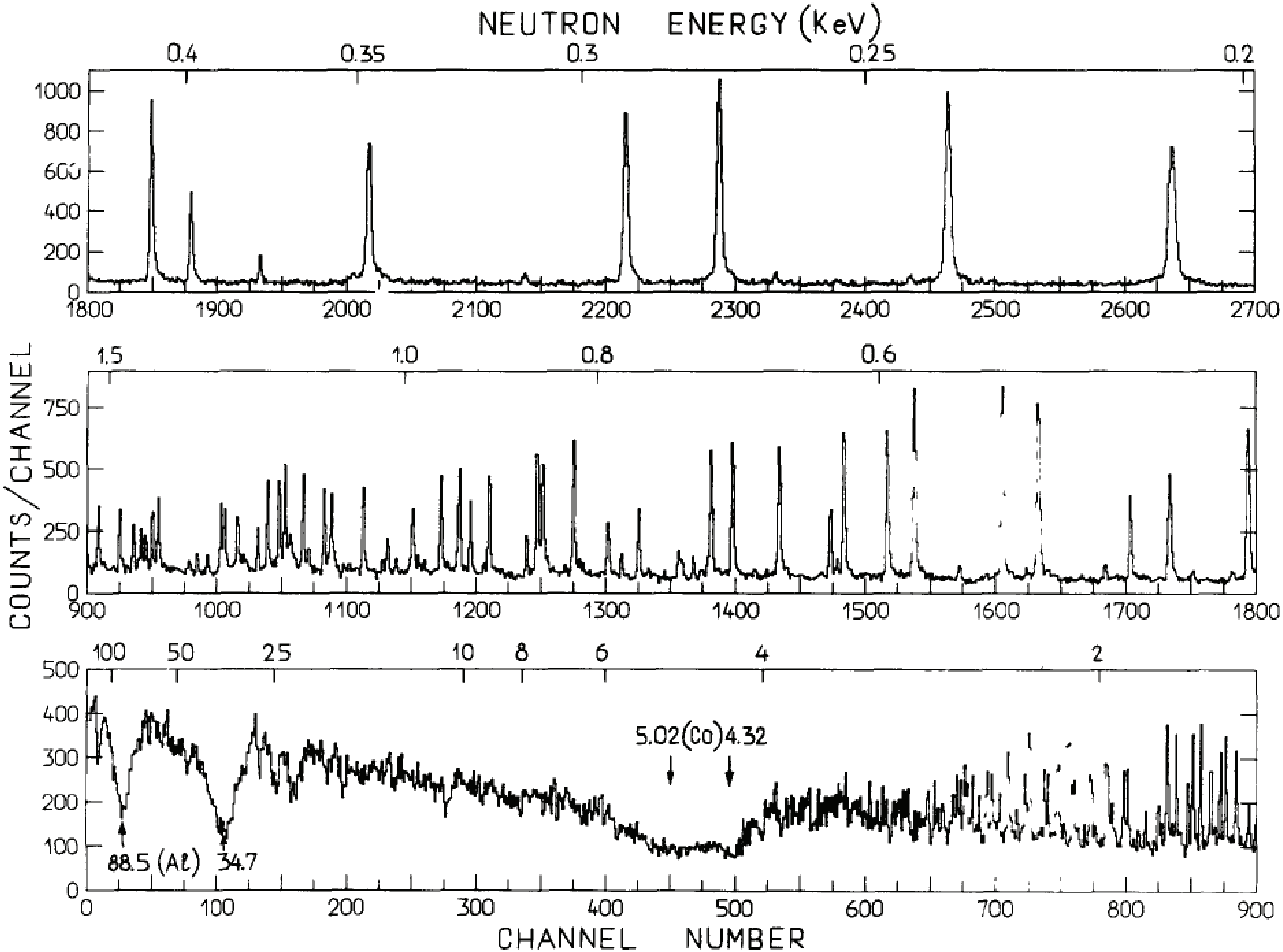


Fig. 17. Time-of-flight spectrum of the relative yield of ^{238}U resonance neutron capture between 0.2 and 100 keV. Data of a 2 h run, C_6D_6 detector, 80 ns channel width.

QUALITY CRITERION USED FOR COMPARISON OF THE PULSED NEUTRON SOURCES AND TOF-FACILITIES

For two TOF-facilities **F1** and **F2**:

- having pulsed neutron sources with **similar spectra**,
- average neutron intensities $\langle I_n \rangle_1$ and $\langle I_n \rangle_2$,
- neutron pulse widths Δt_1 and Δt_2,
- flight path lengths L_1 and L_2,
- in a case of **equal energy resolution**, i.e.

$$\frac{\Delta t_1}{L_1} = \frac{\Delta t_2}{L_2} \qquad \Delta E / E = 2.78 \cdot 10^{-2} E^{1/2} (\Delta t / L),$$

Counting rates N_1 and N_2 ratio in channels corresponding to the same neutron energy will be:

$$\frac{N_1}{N_2} = \left(\frac{\langle I_n \rangle_1}{\Delta t_1^2} \right) \Big/ \left(\frac{\langle I_n \rangle_2}{\Delta t_2^2} \right)$$

COMPARISON OF THE NEUTRON SOURCE GNEIS WITH OTHER TOF FACILITIES

Neutron source (laboratory)	$\langle I_n \rangle$, 10^{15} n/s	Δt, ns	Q, 10^{30} n/s³	Number of instruments for nuclear physics experiments
ORELA (ORNL, USA)	0.13	2-30	0.14*)	5 (total, partial cross sections)
GELINA (IRMM, Belgium)	0.025	1	25	5 (total, partial cross sections)
LANSCE (LANL, USA)	10	1-125	0.64*)	8 (total, partial cross sections) + ICE House test facility
n_TOF (CERN, Switzerland)	0.4	10	4	6 (total, capture, fission, scattering,(n,α))
IREN (JINR, Dubna, project)	1.0	400	0.0062	3 (total, partial cross sections)
GNEIS (PNPI, Gatchina)	0.3	10	3	3 (total, capture, fission) + ISNP/GNEIS test facility

<In> - average intensity of neutrons emitted in 4π solid angle

Δt - neutron pulse width

$Q = \langle I_n \rangle / (\Delta t)^2$ - quality coefficient of the neutron source

***) - present value corresponds to maximum pulse width**

«ФИЗИКА ЭЛЕМЕНТАРНЫХ ЧАСТИЦ И АТОМНОГО ЯДРА»,
1990, ТОМ 21, ВЫП. 2

Soviet Journal of Particles and Nuclei, 21 (2), March-April 1990, p.177

EXPERIMENTAL INVESTIGATIONS OF THE (n,γf) - REACTION

ЭКСПЕРИМЕНТАЛЬНЫЕ ИССЛЕДОВАНИЯ (*n*, γ*f*)-РЕАКЦИИ

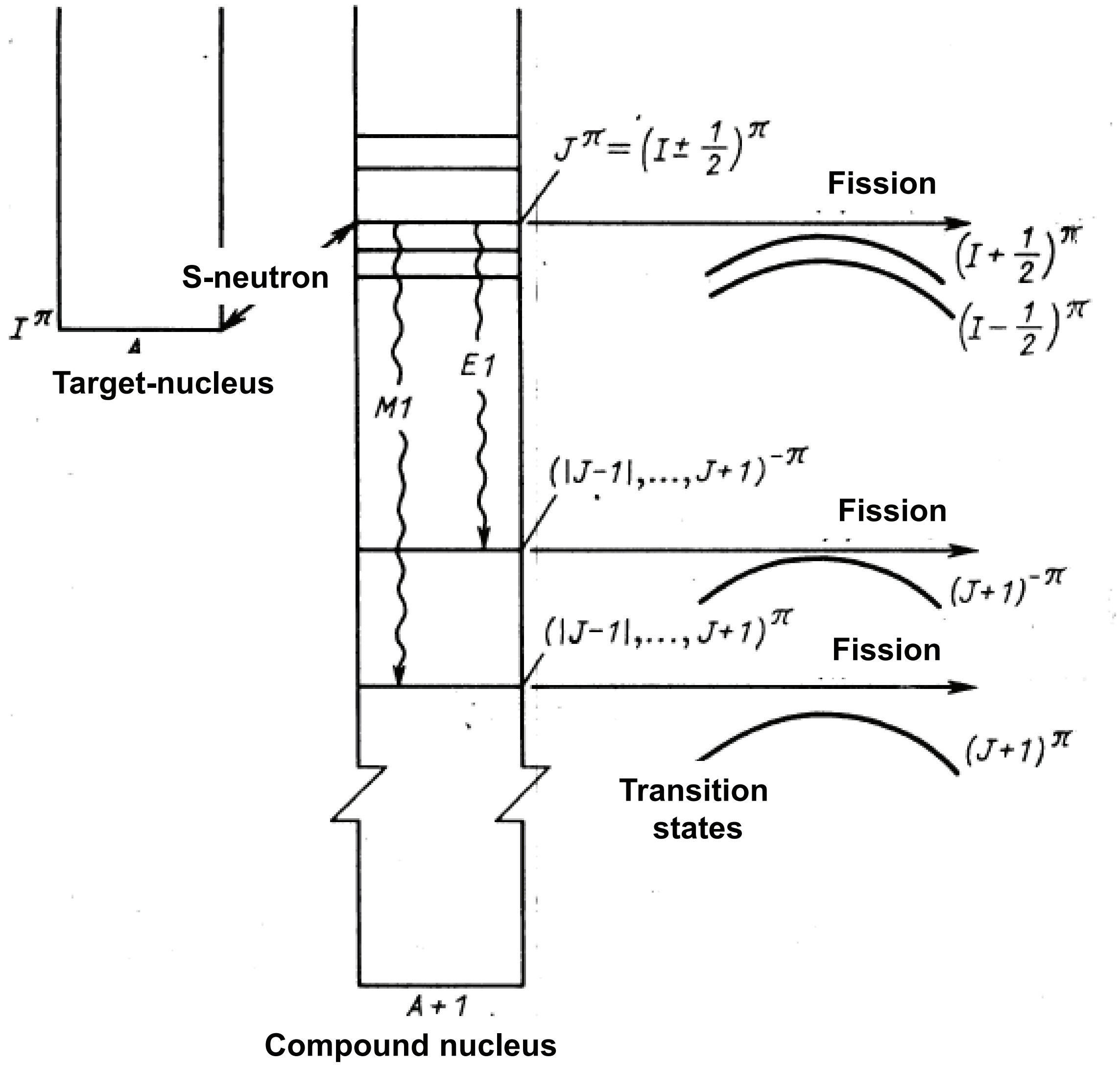
О. А. Щербаков

Ленинградский институт ядерной физики им. Б. П. Константинова
АН СССР, Гатчина

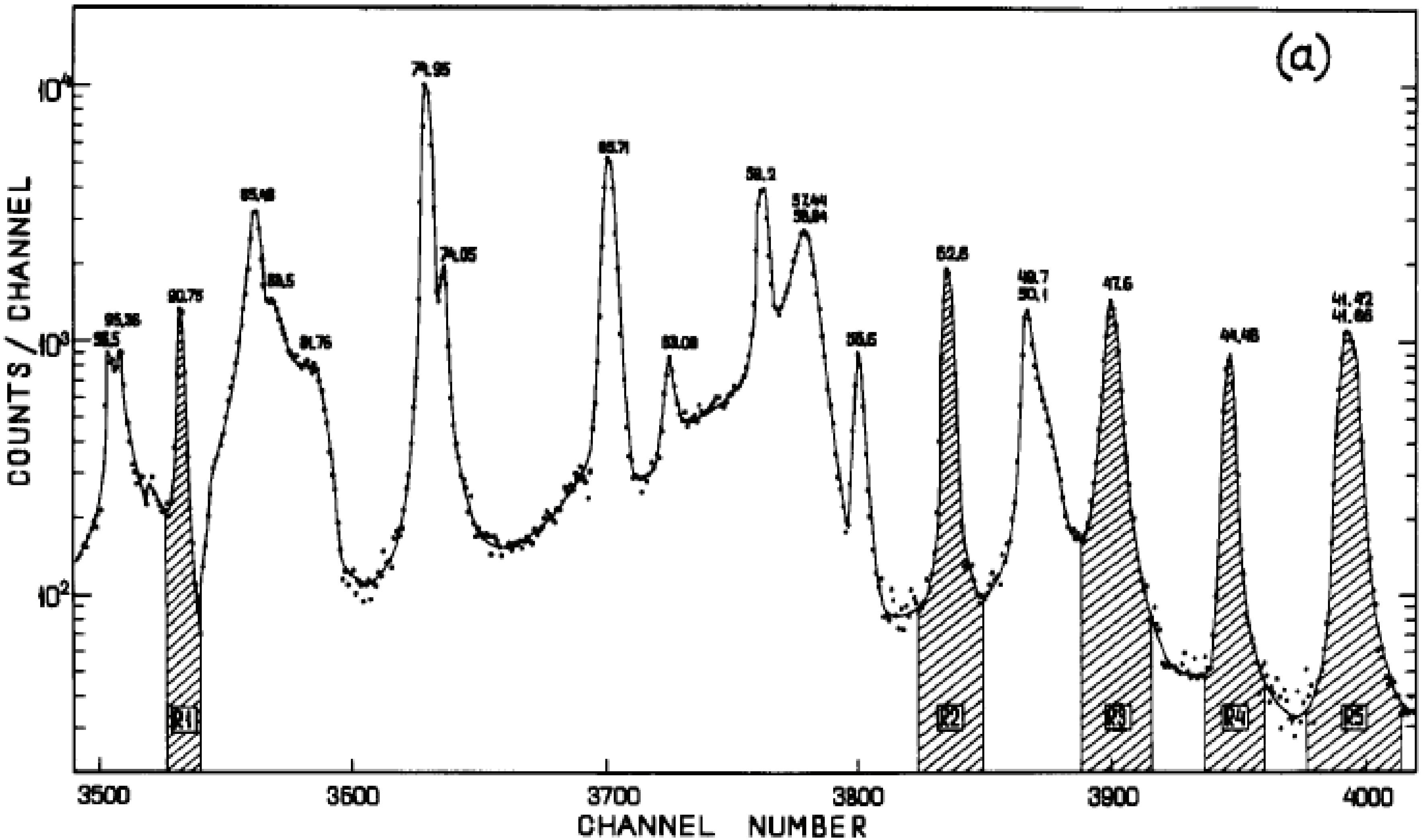
Дан обзор экспериментальных методов и результатов исследований (*n*, γ*f*)-реакции. Приведены также теоретические оценки вероятности этой реакции для некоторых тяжелых ядер.

Experimental methods and results of (*n*, γ*f*)-reaction studies are reviewed, as well as the theoretical evaluations of the probability of this reaction for some heavy nuclei.

Scheme of the (n,γf)-reaction



TOF-spectrum for fission fragments of ^{239}Pu



Data of a 4.5h run, 80ns channel width. Total weight of ^{239}Pu in fission chamber - 0.8 g.
Fission γ-ray spectra were measured for resonances R1, R2, …, R5.

Variations of fission γ-ray multiplicity in resonances of ^{235}U and ^{239}Pu

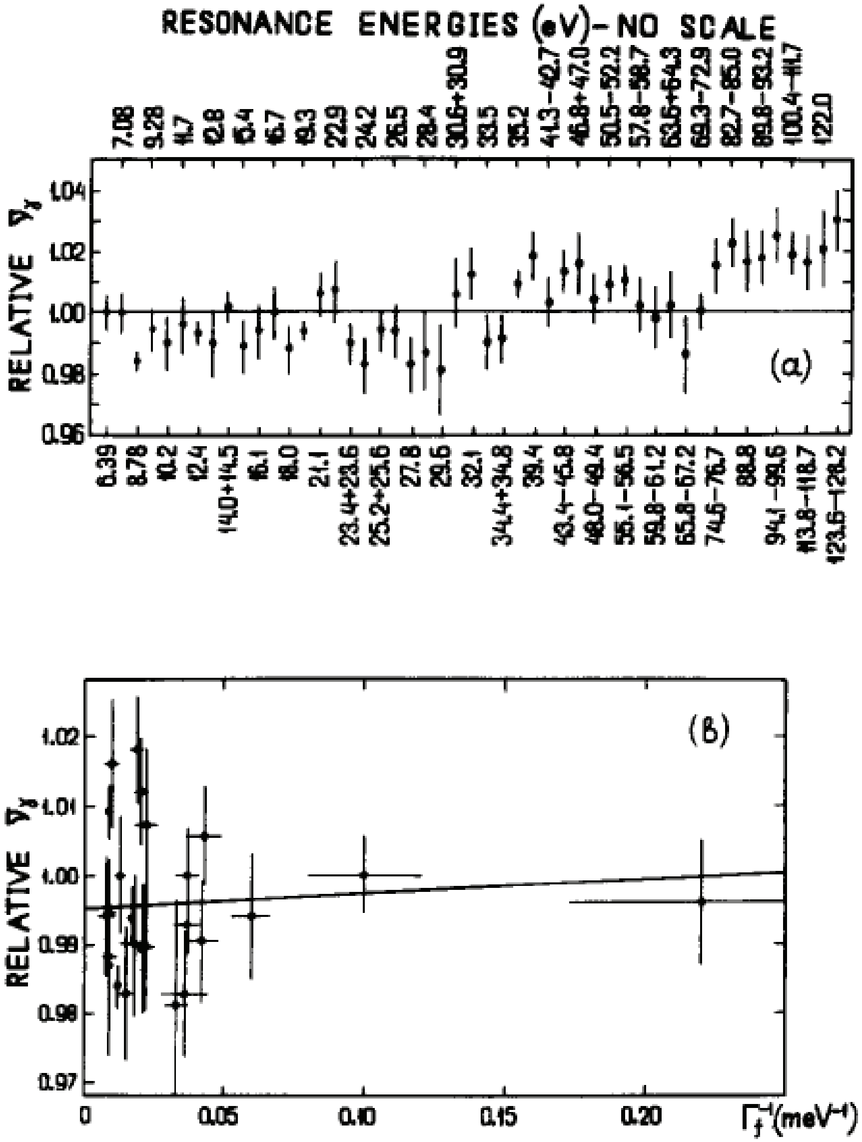


Fig. 11. Relative fission γ-rays multiplicity of ^{235}U [24]. (a) Multiplicity variations. (b) Correlation between the multiplicity variations and Γ_f^{-1} for the 4^- resonances.

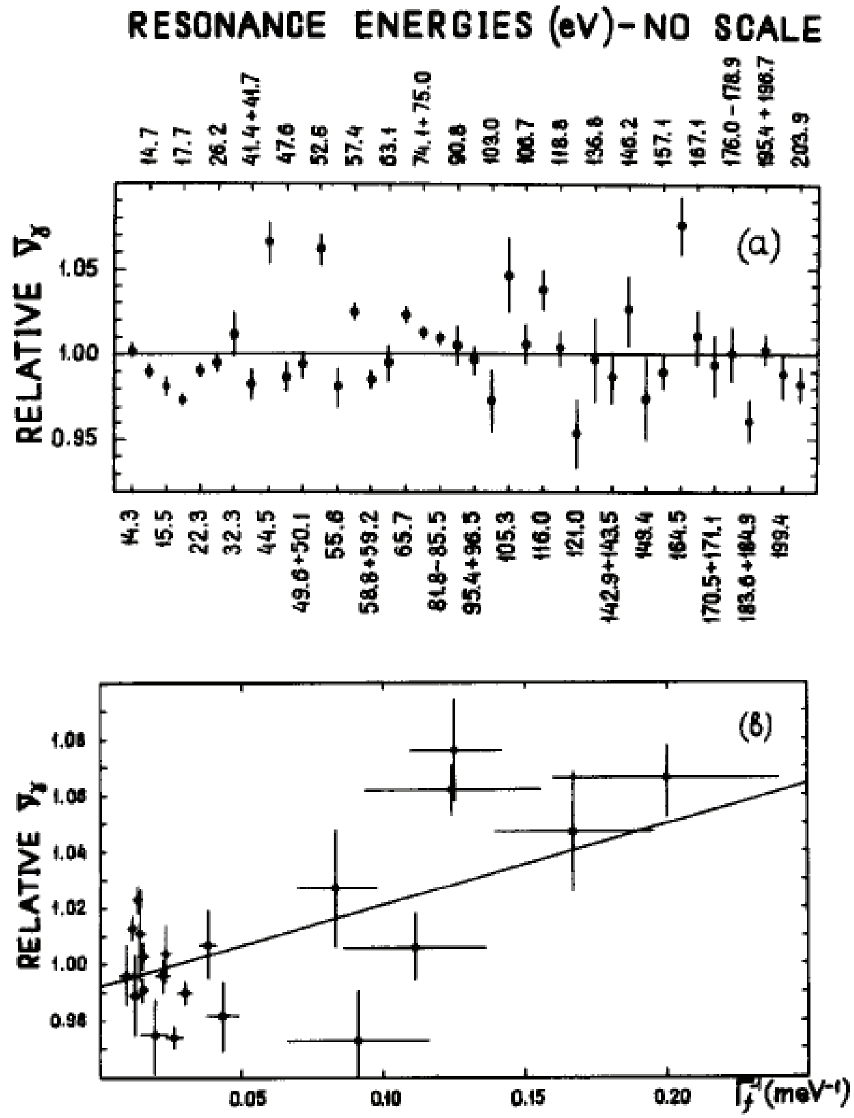
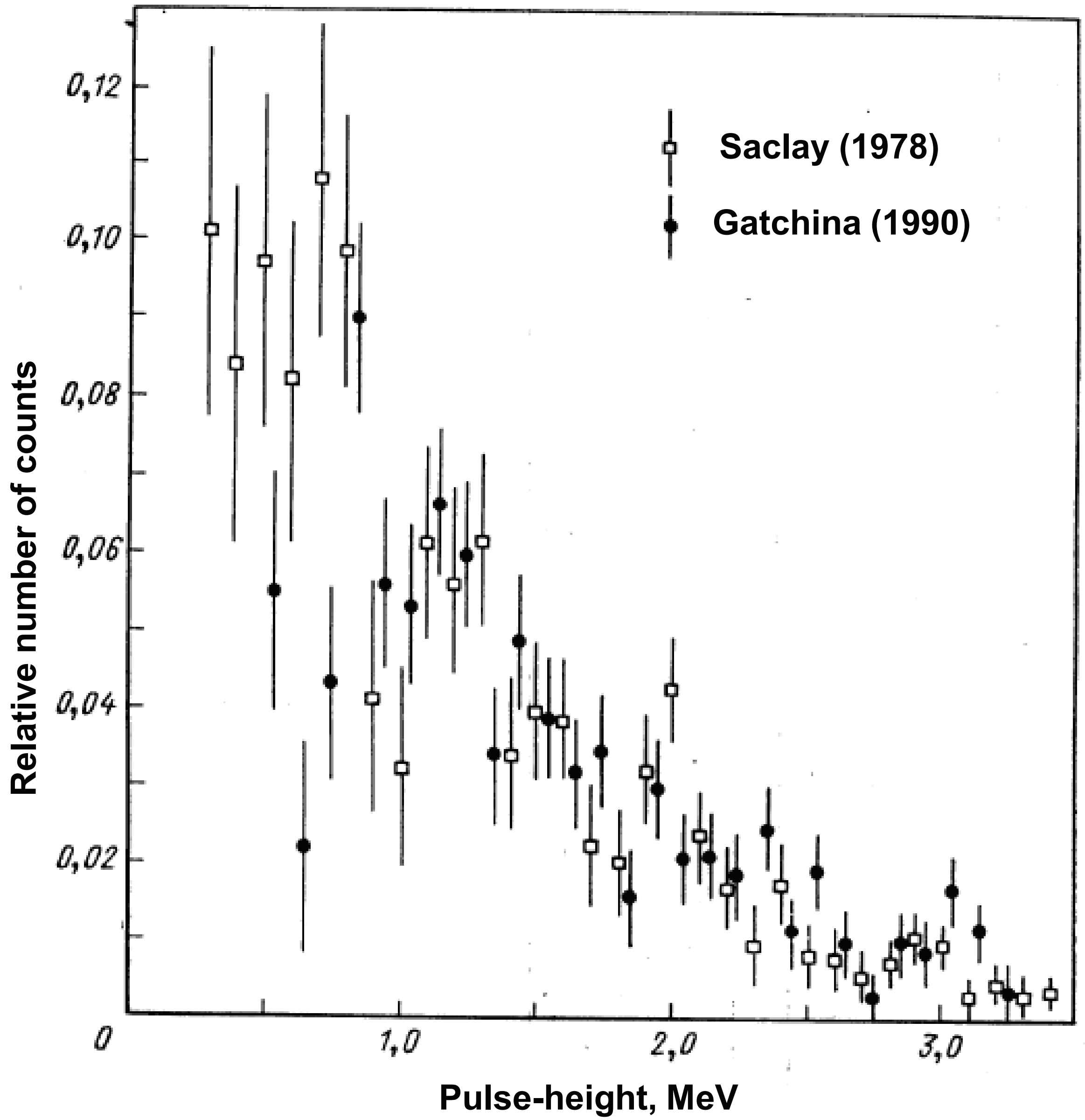


Fig. 12 Relative fission γ-ray multiplicity of ^{239}Pu [25]. (a) Multiplicity variations. (b) Correlation between the multiplicity variations and Γ_f^{-1} for the 1^+ resonances.



Prefission γ-ray spectrum from (n, γf)-reaction for ^{239}Pu.

Properties of p resonances in the fission of ^{235}U by neutrons with energies of 1–136 eV

A. M. Gagarskiĭ, S. P. Golosovskaya, A. B. Laptev, G. A. Petrov, A. K. Petukhov, Yu. S. Pleva, V. E. Sokolov, and O. A. Shcherbakov
B. P. Konstantinov Institute of Nuclear Physics, Academy of Sciences of the USSR, 188350, Gatchina

(Submitted 8 May 1991)
Pis'ma Zh. Eksp. Teor. Fiz. **54**, No. 1, 9–12 (10 July 1991)

The P-even front–back asymmetry in the emission of the fission fragments of ^{235}U, with respect to the direction of the neutron momentum, has been measured for the first time. Irregularities due to p resonances are observed on the energy dependence of the asymmetry coefficient α_{nf}^{fb}. The effective parameters of the strongest p resonances are determined.

As a result of interference of s- and p-resonances, in a vicinity of p-resonance it is observed a following angular distribution of fission fragments:

$$W(\theta) = 1 + \alpha_{nf}^{fb}(\vec{p}_n \cdot \vec{p}_f),$$

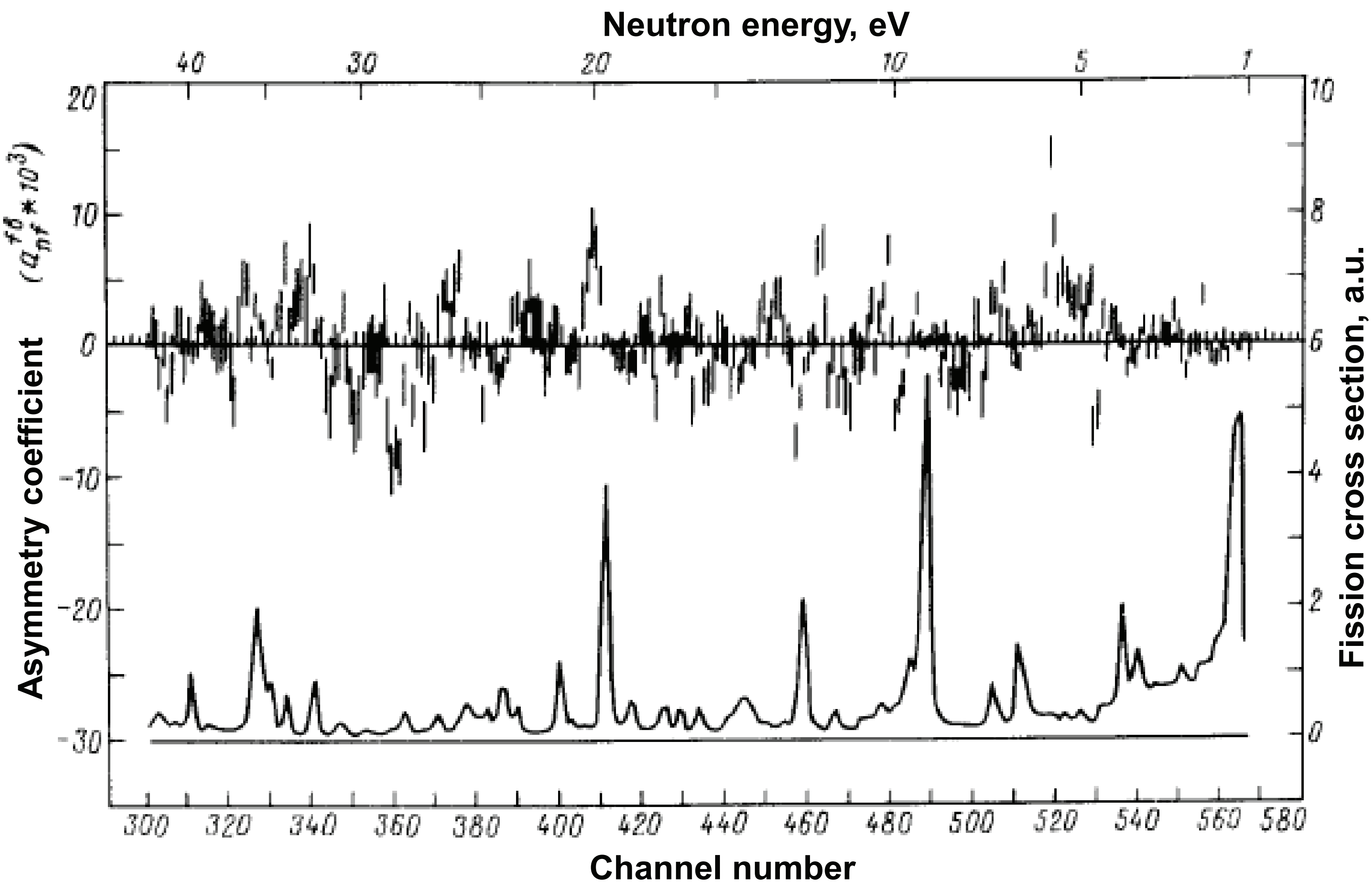
In a case of simple two-level approximation :

$$\alpha_{fb}^{nf} \sim Q_{sp}\sqrt{\frac{\Gamma_p^n \Gamma_p^f}{\Gamma_s^n \Gamma_s^f}} \mathrm{Re}\left\{ \frac{E - E_s + \frac{i\Gamma_s}{2}}{E - E_p + \frac{i\Gamma_p}{2}} \exp(i\Delta\varphi_{sp}) \right\}.$$

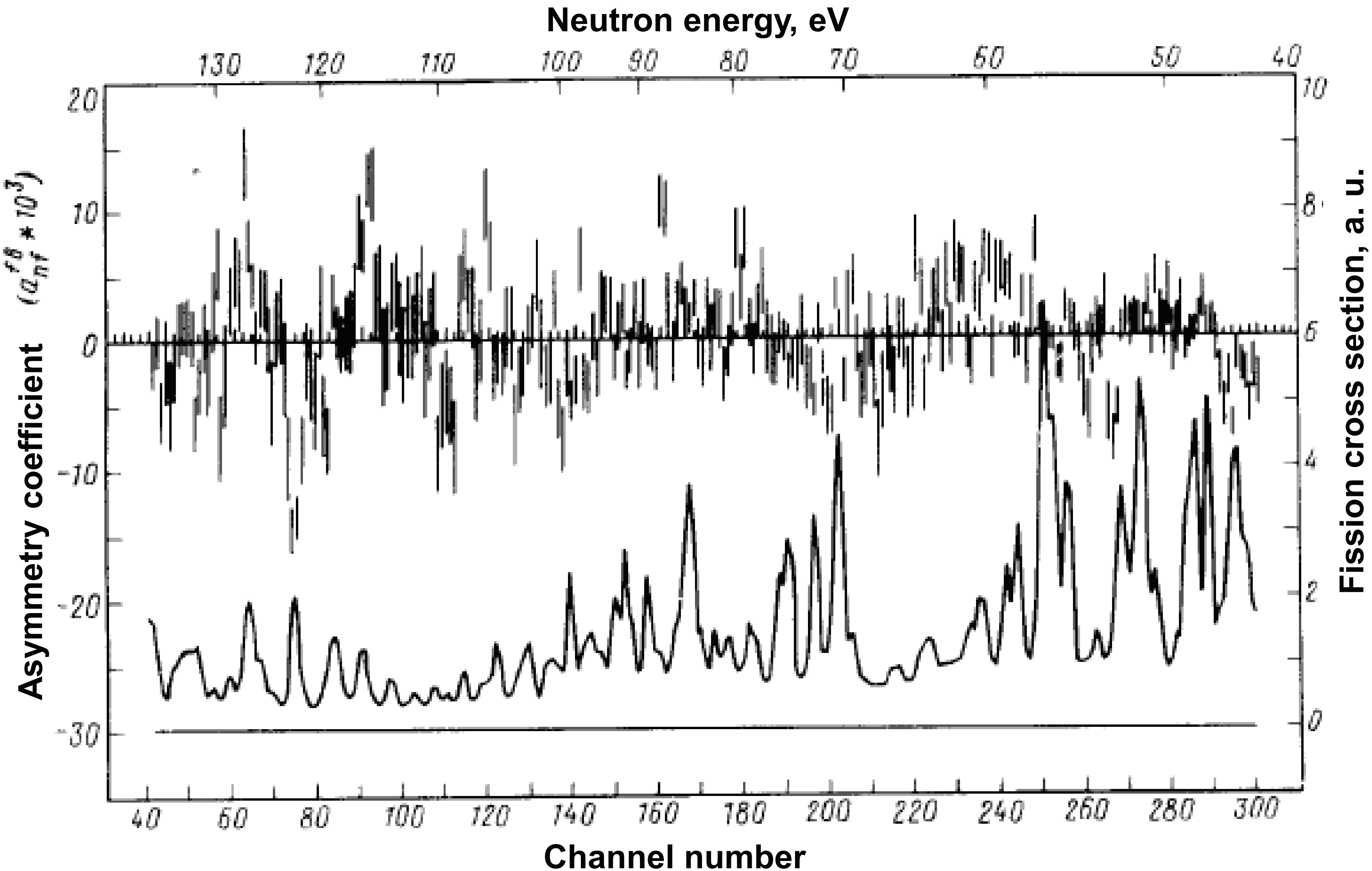
where: p_n and p_f – neutron and light fragment moments, respectively;

$Q_{sp} = \frac{Q(J_s, J_P, j, K, I)}{2J_s+1}$ - spin-factor; $\Delta\varphi_{sp}$ – phase difference;

$\Gamma_{s,p}^{n,f}$ - neutron and fission widths for s- and p-resonances, respectively.



Neutron energy, eV
40
30
20
10
5
1
20
10
0
-10
-20
-30
10
8
6
4
2
0
Asymmetry coefficient
Fission cross section, a.u.
300
320
340
360
380
400
420
440
460
480
500
520
540
560
580
Channel number



Neutron energy, eV
130
120
110
100
90
80
70
60
50
40
20
10
0
-10
-20
-30
10
8
6
4
2
0
Asymmetry coefficient
$(a_{nf}^{fB} * 10^3)$
Fission cross section, a. u.
40
60
80
100
120
140
160
180
200
220
240
260
280
300
Channel number

TABLE I. Effective parameters of the fit of the p resonances.

N	$Q^2_{sp}\Gamma^{n1}_p$, meV	E_p, eV	Γ_p, meV	$\Delta\varphi_s$, rad	χ^2
1	$21,7 \pm 31,9$	$1,70 \pm 0,05$	50 ± 30	$0,8 \pm 0,2$	$1,2 \pm 0,3$
2	$6,4 \pm 1,1$	$5,70 \pm 0,05$	160 ± 30	$2,9 \pm 0,1$	$1,0 \pm 0,2$
3	$1,3 \pm 0,4$	$9,90 \pm 0,05$	130 ± 50	$2,4 \pm 0,2$	$1,0 \pm 0,3$
4	$3,0 \pm 0,9$	$12,9 \pm 0,1$	240 ± 50	$1,9 \pm 0,2$	$1,1 \pm 0,4$
5	$1,2 \pm 0,5$	$20,1 \pm 0,1$	190 ± 50	$1,9 \pm 0,2$	$0,9 \pm 0,3$
6	$0,7 \pm 0,3$	$28,5 \pm 0,2$	300 ± 100	$1,4 \pm 0,4$	$1,5 \pm 0,3$
7	$17,1 \pm 6,9$	$32,05 \pm 0,05$	90 ± 30	$1,9 \pm 0,3$	$1,6 \pm 0,3$
8	$1,1 \pm 0,6$	$36,4 \pm 0,1$	180 ± 80	$2,2 \pm 0,3$	$1,5 \pm 0,3$
9	$3,2 \pm 1,3$	$45,8 \pm 0,1$	190 ± 50	$1,6 \pm 0,3$	$1,1 \pm 0,3$
10	$2,2 \pm 1,0$	$52,8 \pm 0,2$	800 ± 200	$2,3 \pm 0,3$	$0,7 \pm 0,4$
11	$7,5 \pm 3,4$	$70,75 \pm 0,15$	550 ± 150	$2,0 \pm 0,2$	$1,2 \pm 0,4$
12	$2,0 \pm 1,1$	$79,6 \pm 0,1$	200 ± 90	$0,9 \pm 0,3$	$1,1 \pm 0,3$
13	$1,8 \pm 1,3$	$87,35 \pm 0,05$	180 ± 120	$0,2 \pm 0,3$	$1,1 \pm 0,3$
14	$1,9 \pm 1,2$	$115,7 \pm 0,1$	130 ± 60	$0,2 \pm 0,5$	$0,6 \pm 0,3$
15	$5,8 \pm 4,7$	$121,8 \pm 0,1$	130 ± 30	$0,7 \pm 0,5$	$0,6 \pm 0,3$
16	$1,4 \pm 0,8$	$126,8 \pm 0,2$	260 ± 170	$0,8 \pm 0,6$	$1,0 \pm 0,3$

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Neutron Total Cross Sections of ^{204}Pb, ^{206}Pb, ^{207}Pb and ^{208}Pb and the Neutron Electric Polarizability

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The neutron total cross sections have been measured for lead isotopes ^{208}Pb, ^{206}Pb and ^{207}Pb in the range from 1 eV to 20 keV and for ^{204}Pb in the range from 1 eV to 100 eV using the time-of-flight facility GNEIS in Gatchina. An accuracy of the measured neutron total cross section ($\Delta\sigma/\sigma$) is about 10^{-3} for ^{208}Pb, 10^{-2} for ^{206}Pb and ^{207}Pb, $5 \cdot 10^{-2}$ for ^{204}Pb. An estimated value of the neutron electric polarizability from analysis of total cross section of ^{208}Pb is $\alpha_n = (2.4 \pm 1.1) \cdot 10^{-3}$ fm^3.

The electric polarizability α_n is one of the characteristics of the neutron as an elementary particle and determines the induced electric dipole moment *d* in the external electric field *E*:

$$d = \alpha_n \cdot E.$$

In Coulomb field, the interaction potential due to neutron electric polarizability α_n is given by

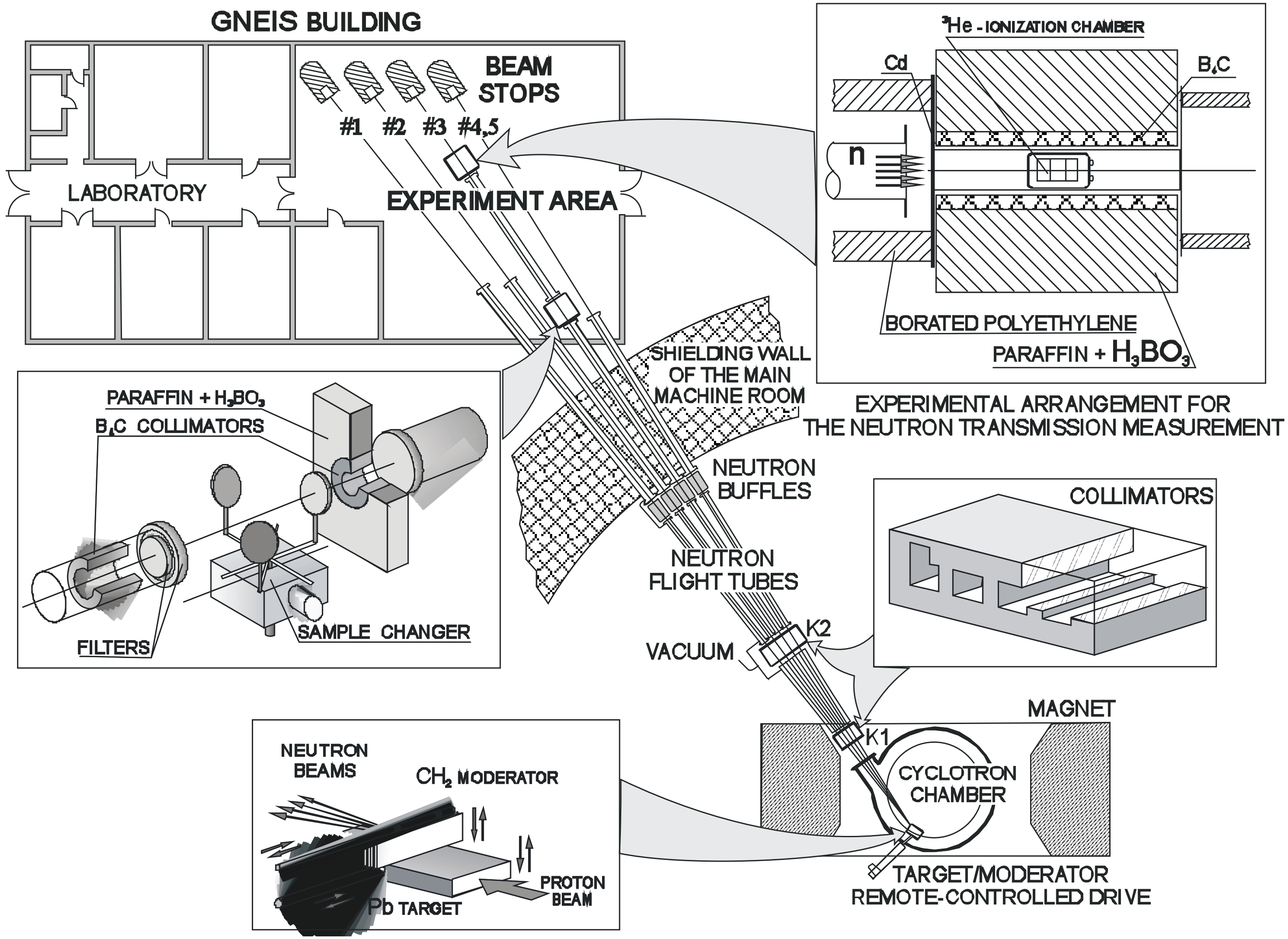
$$V = - 1/2 \cdot \alpha_n Z^2 e^2 / r^4$$

and it adds to the neutron-nucleus interaction potential. That leads to several additional terms in the total cross section. A main term has linear dependence on *k* (or), where *k* is the wave number:

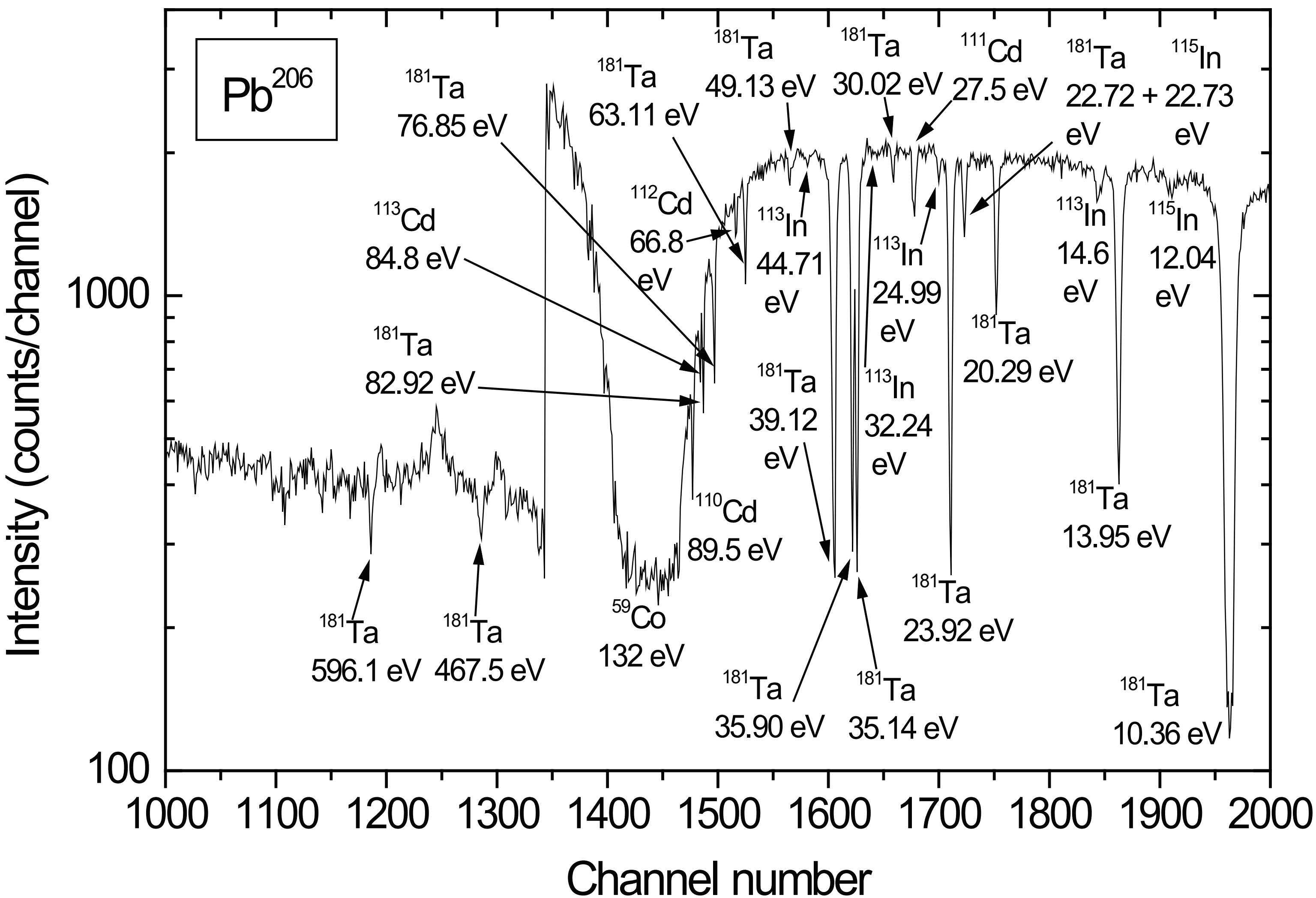
$$\sigma_p \approx 10^{-4} \cdot \alpha_n \cdot \sqrt{E_n} \text{ barn},$$

here α_n is in 10^{-3} Fm^3 units, E_n is in eV.

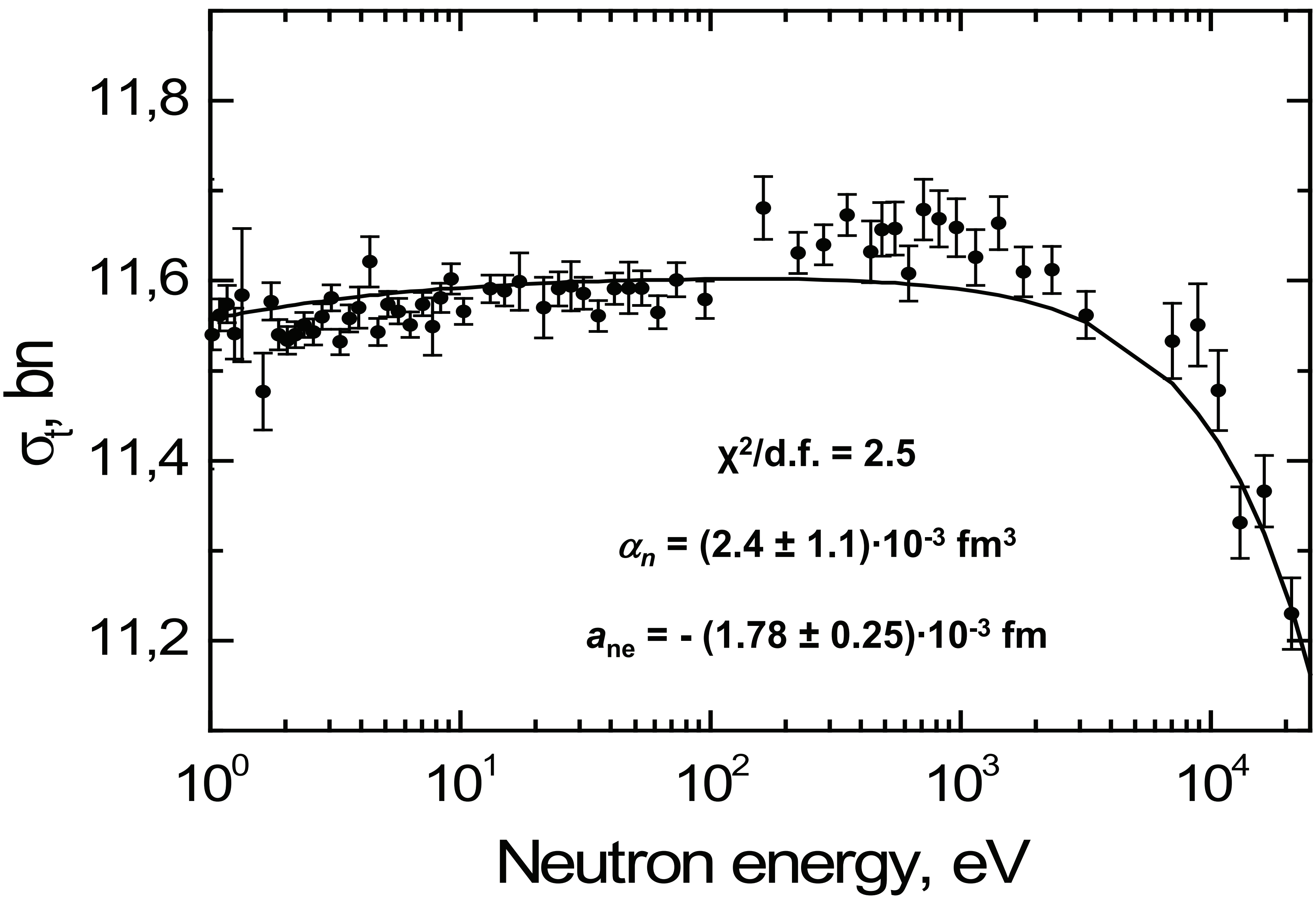
General layout of the spectrometer GNEIS and experimental arrangement for transmission measurements



TOF-spectrum for neutron transmission of ^{206}Pb



Fitting results for ^{208}Pb



Measurement of the neutron-induced fission cross sections of ^{233}U, ^{238}U, ^{232}Th, ^{237}Np, ^{239}Pu, ^{240}Pu, ^{243}Am, ^{nat}Pb, ^{nat}W and ^{209}Bi relative to ^{235}U in the energy range 1-200 MeV

[1] Petersburg Nuclear Physics Institute, Russia

[2] V.G. Khlopin Radium Institute, Russia

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Journal of NUCLEAR SCIENCE and TECHNOLOGY, Supplement 2, p. 230–233 (August 2002)

Neutron-Induced Fission of ^{233}U, ^{238}U, ^{232}Th, ^{239}Pu, ^{237}Np, ^{nat}Pb and ^{209}Bi Relative to ^{235}U in the Energy Range 1-200 MeV

Oleg SHCHERBAKOV[1,*], Andrei DONETS[2], Alexander EVDOKIMOV[2], Alexander FOMICHEV[2]
Tokio FUKAHORI[3], Akira HASEGAWA[3], Alexander LAPTEV[1], Vladimir MASLOV[4],
Guennady PETROV[1], Sergei SOLOVIEV[2], Yuri TUBOLTSEV[5] and Alexander VOROBYEV[1]

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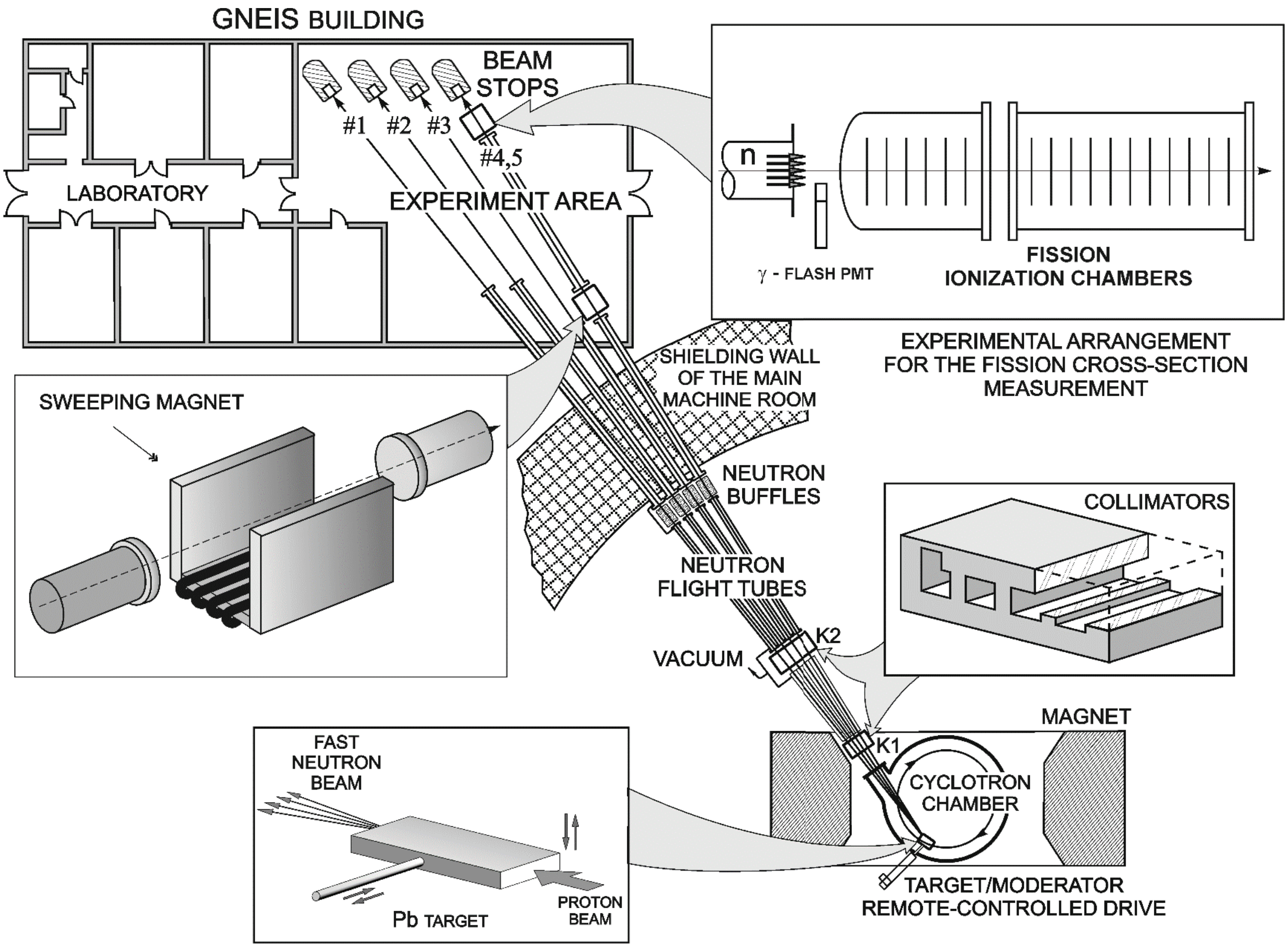
Fission cross section ratios of ^{233}U, ^{238}U, ^{232}Th, ^{239}Pu, ^{237}Np, natural Pb and ^{209}Bi to ^{235}U have been measured in a wide energy range of incident neutrons from 1 MeV to 200 MeV using a time-of-flight technique at the neutron spectrometer GNEIS based on the 1-GeV proton synchrocyclotron of PNPI. For actinide targets, the threshold cross section method and evaluated data below 14 MeV were used for normalization of the shape measurement data, while the evaluated and recommended fission cross sections of ^{235}U were used to convert the ratio data to absolute fission cross sections. For Pb and Bi targets, an absolute normalization of the measured cross section ratios has been done using the thickness of the targets and detection efficiencies.

Measurements of the fission cross sections at intermediate neutron energies 1 – 200 MeV



FISSION CROSS SECTION OF ^{237}Np - GNEIS (2001)

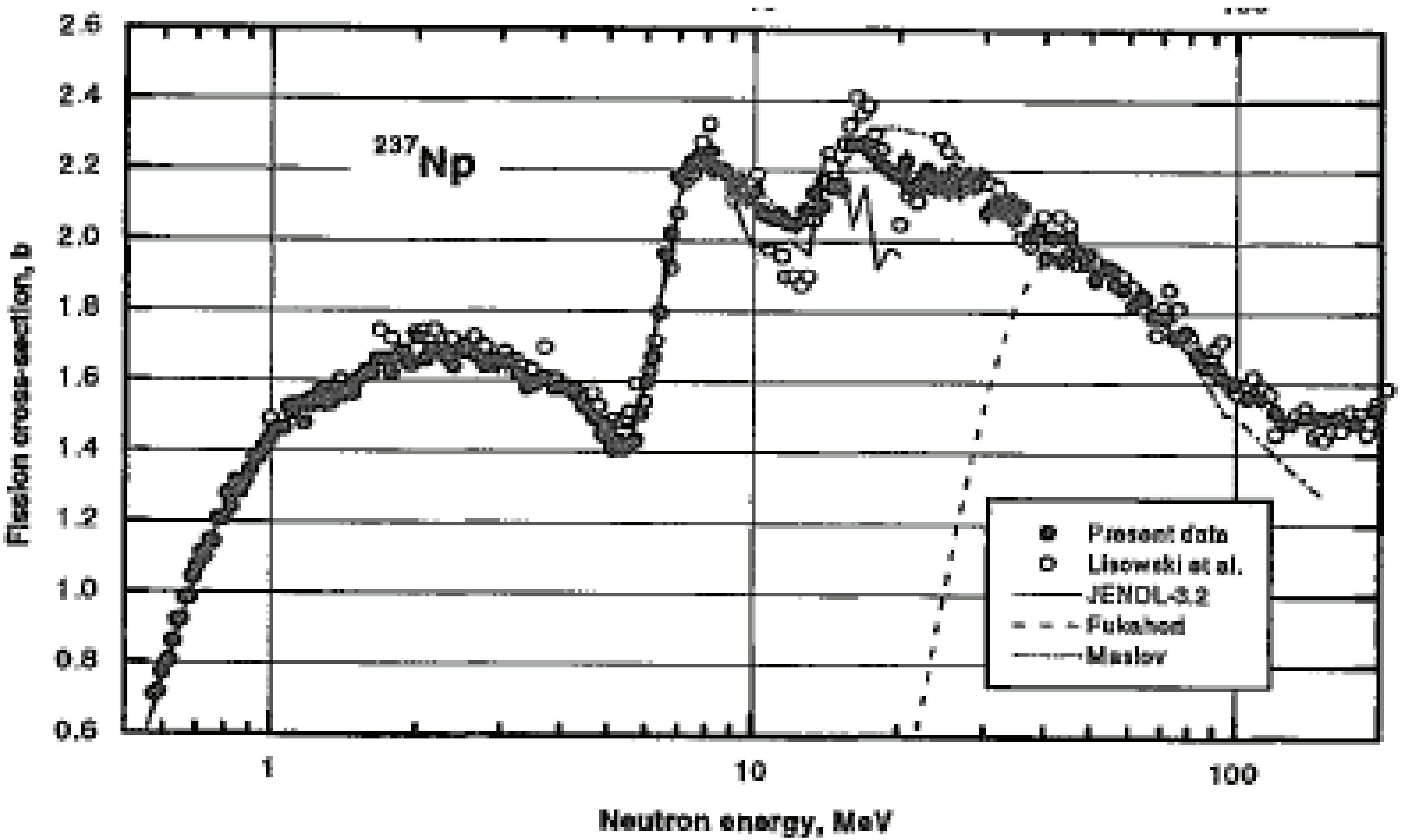
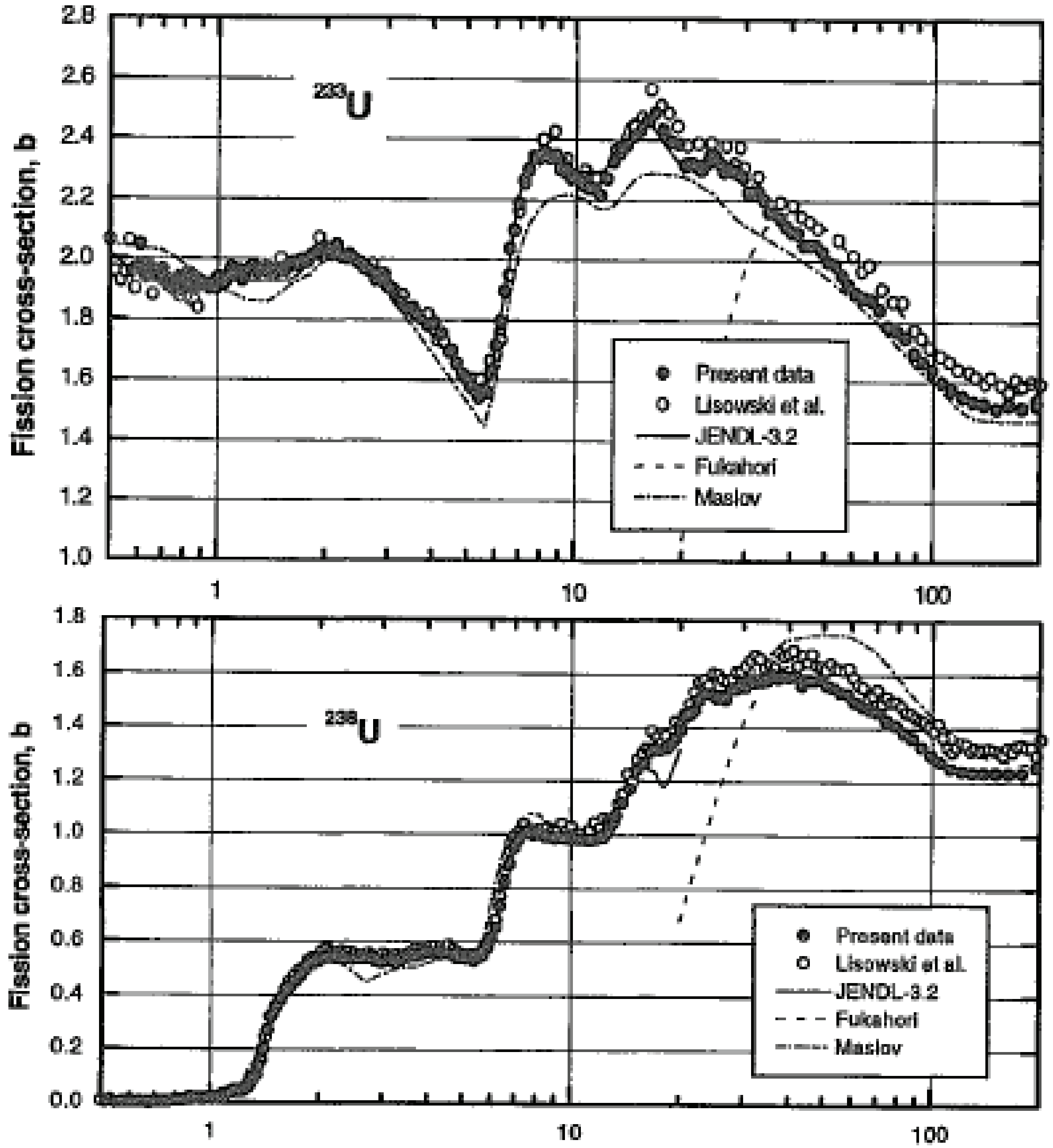
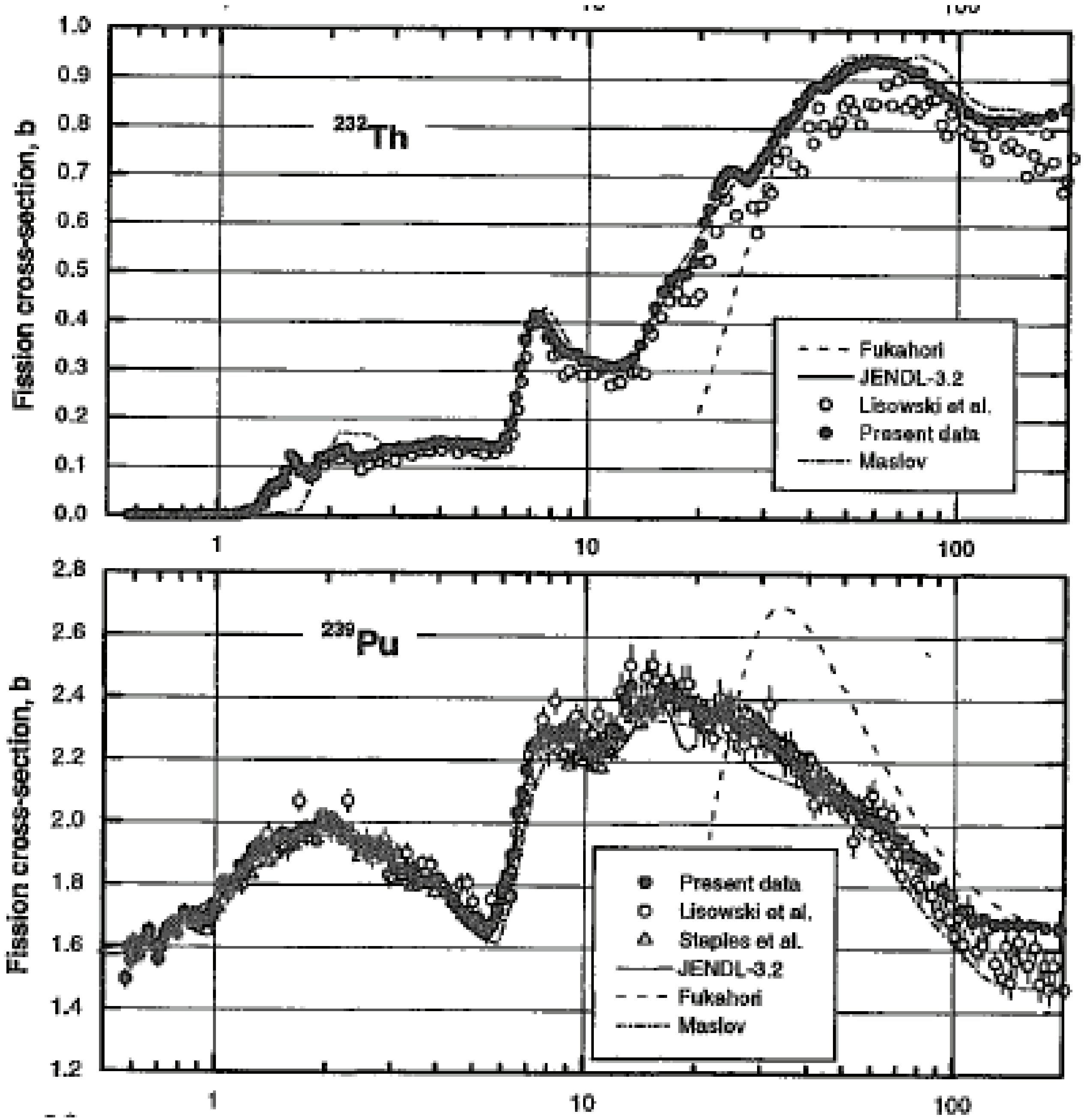


Fig. 4 Fission cross section of ^{233}U, ^{238}U, ^{232}Th, ^{239}Pu and ^{237}Np in the energy range up to 200 MeV

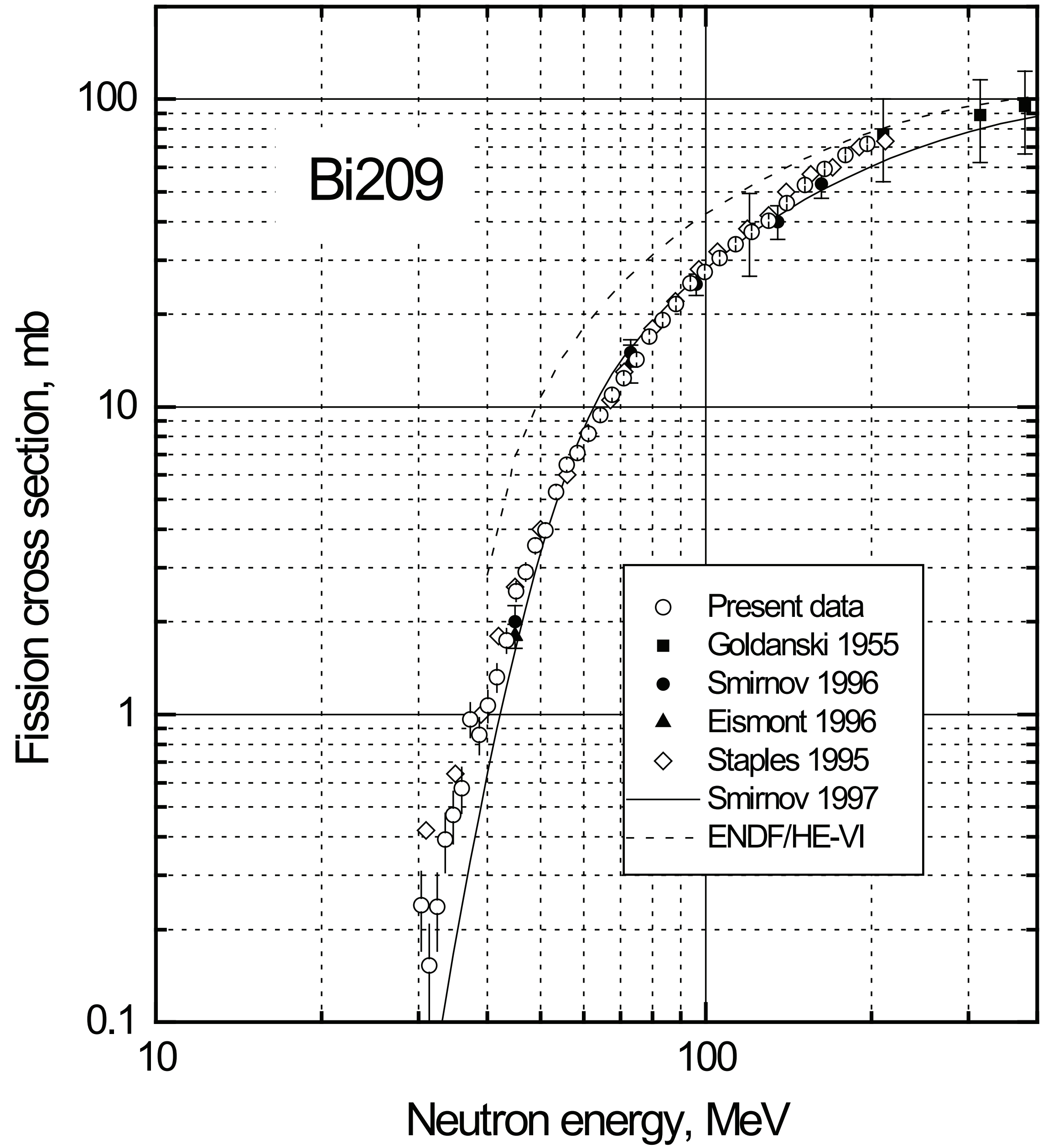
FISSION CROSS SECTIONS OF ^{233}U and ^{238}U - GNEIS (2001)



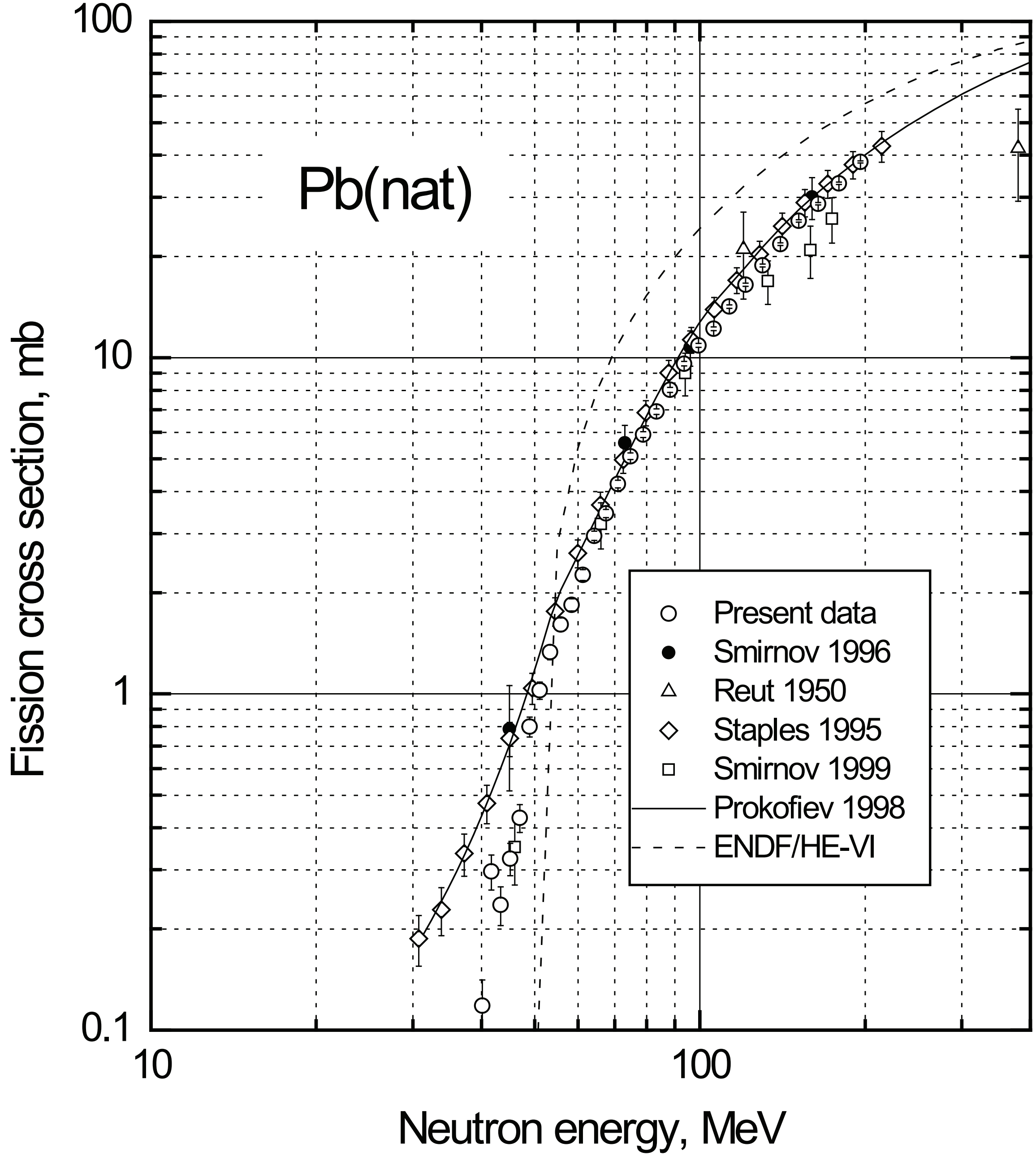
FISSION CROSS SECTIONS OF ^{232}Th and ^{239}Pu - GNEIS (2001)



FISSION CROSS SECTION OF ^{209}Bi - GNEIS (2001)



FISSION CROSS SECTION OF ^{nat}Pb - GNEIS (2001)



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FIELDS, PARTICLES, AND NUCLEI

Anisotropy of the Fission Fragments from Neutron-Induced Fission in Intermediate Energy Range 1–200 MeV[1]

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Angular distributions of fission fragments from the neutron-induced fission of ^{232}Th, ^{235}U, and ^{238}U have been measured in the energy range 1-200 MeV at the neutron time-of-flight (TOF) spectrometer GNEIS using position sensitive multiwire proportional counters as fission fragment detector. A short description of the experimental equipment and measurement procedure is given. The anisotropy of fission fragments deduced from the data on measured angular distributions is presented in comparison with experimental data of other authors.

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Angular Distributions and Anisotropy of the Fragments from Neutron-Induced Fission of ^{233}U and ^{209}Bi in the Intermediate Energy Range of 1–200 MeV[1]

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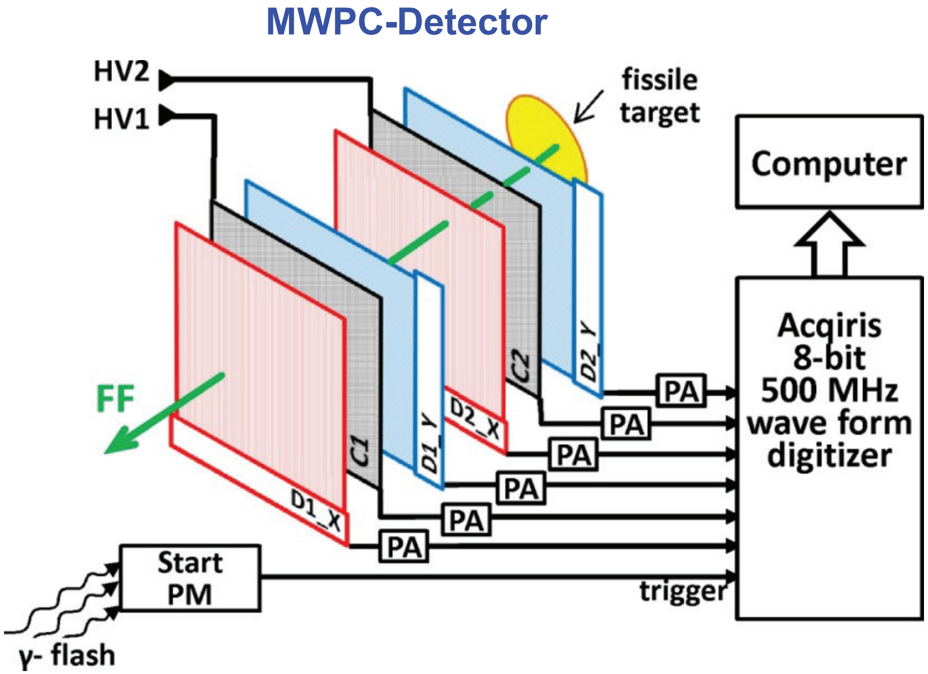
Received June 30, 2016; in final form, August 3, 2016

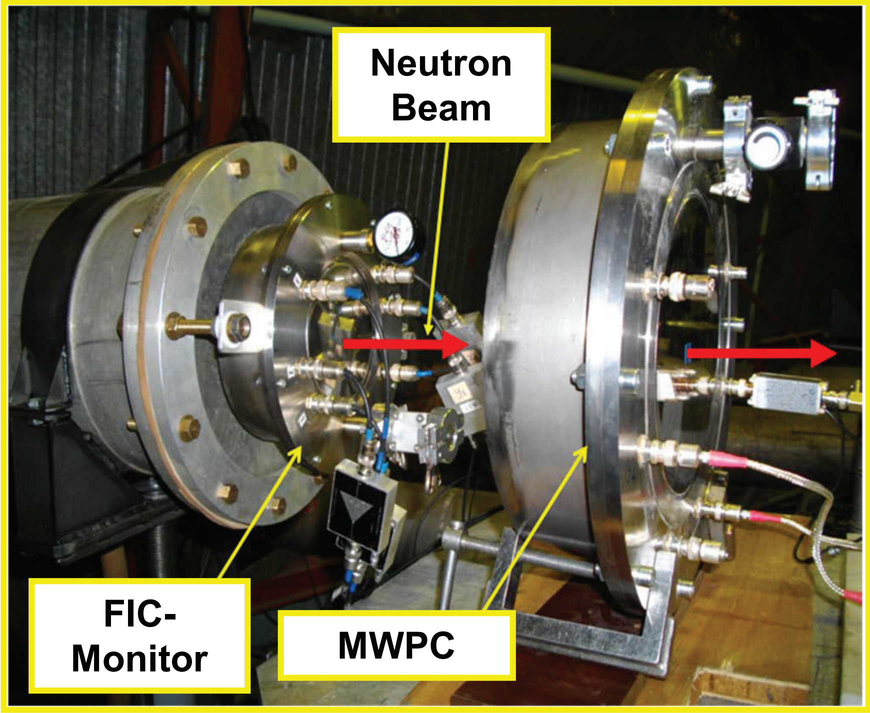
New results of the neutron-induced fission experiments carried out at the neutron time-of-flight spectrometer GNEIS of the PNPI are given. Angular distributions of fission fragments from the neutron-induced fission of ^{233}U and ^{209}Bi nuclei have been measured in the energy range 1–200 MeV using position sensitive multiwire proportional counters as fission fragment detector. The recent improvements of the measurement and data processing procedures are described. The data on anisotropy of fission fragments deduced from the measured angular distributions are presented in comparison with the experimental data of other authors.

DOI: 10.1134/S002136401618003X

Measurement of the fission fragment distributions and anisotropy in neutron-induced fission at intermediate energies 1-200 MeV (2014-2016)

Experimental setup



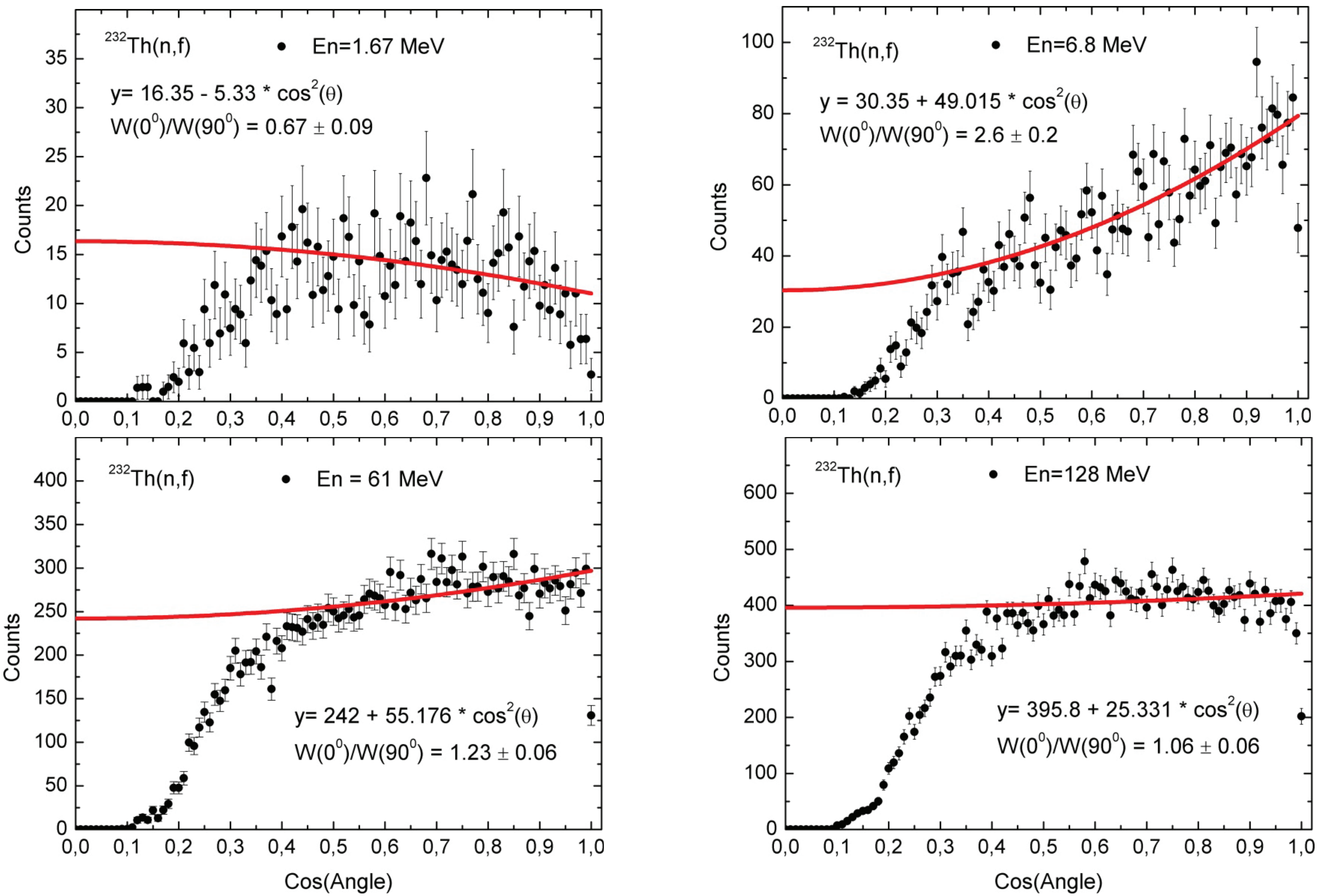


Motivation

Data on angular distributions of fission fragments are needed for development of nuclear fission theory, for processing of the experimental data on fission cross sections and development of evaluated nuclear data libraries at intermediate and high energies which are necessary for construction of modern power and research nuclear facilities (reactors, accelerators, etc.).

At present, experimental data on fission fragment angular distributions (anisotropy) in the energy range E_n> 20 MeV are very scarce and limited in accuracy, and practically absent for E_n> 100 MeV.

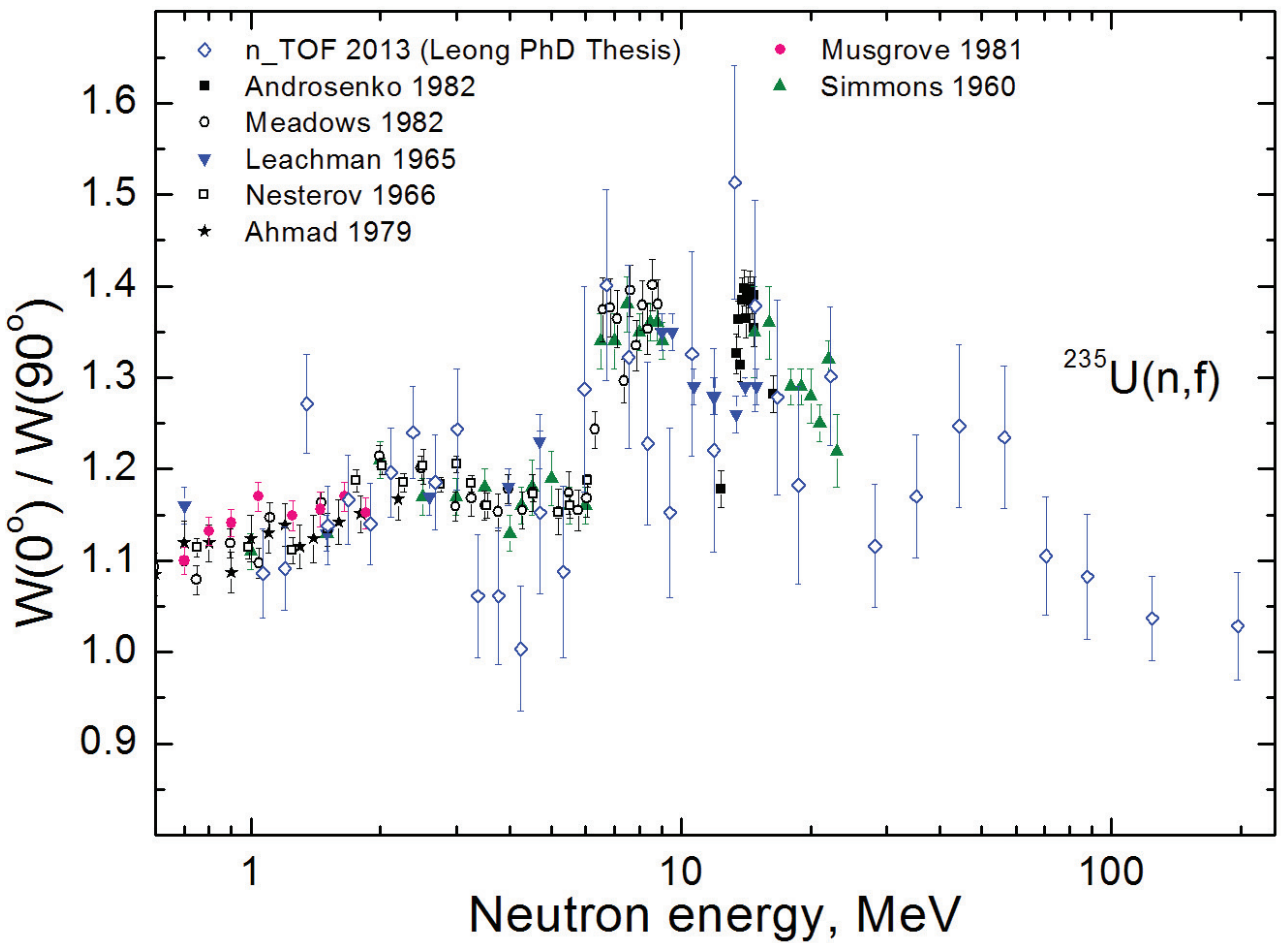
Measurement of the fission fragment distributions and anisotropy in neutron-induced fission at intermediate energies 1-200 MeV



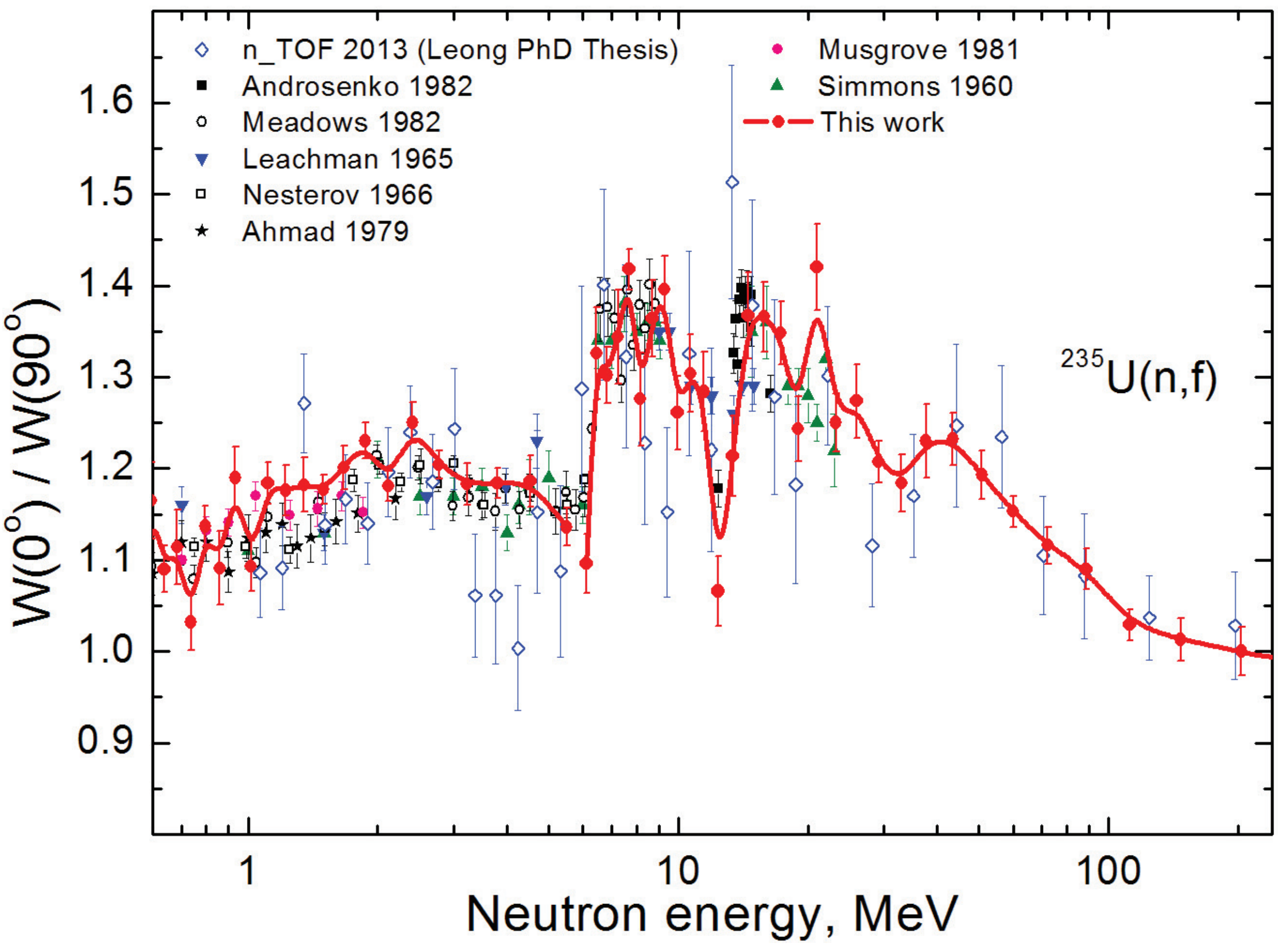
$$W(\theta) \sim 1 + A\cos^2\theta \qquad \frac{W(0^o)}{W(90^o)} = A + 1$$

Cos θ fitting range was 0.42– 0.98

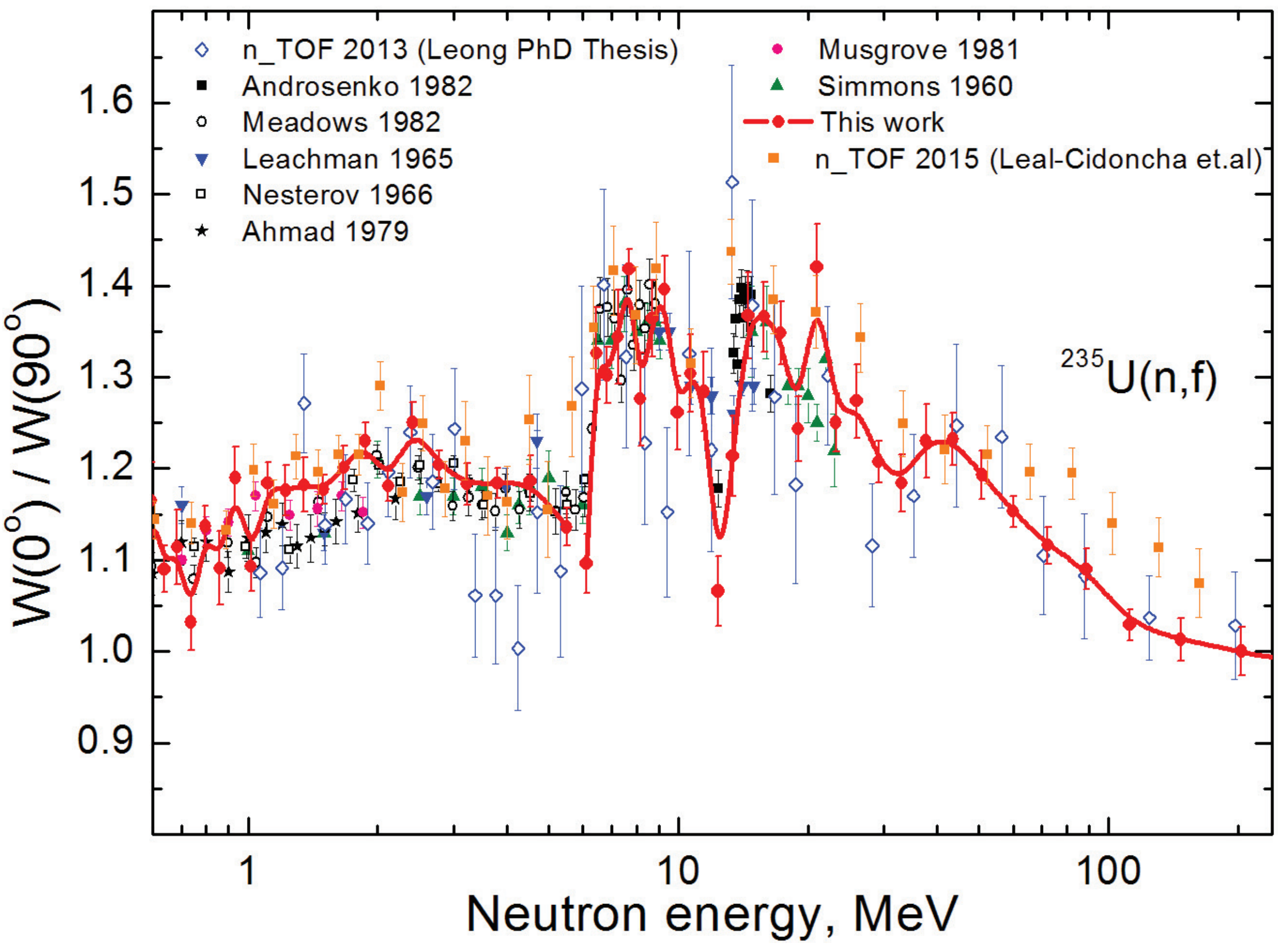
Anisotropy of ^{235}U fission fragments



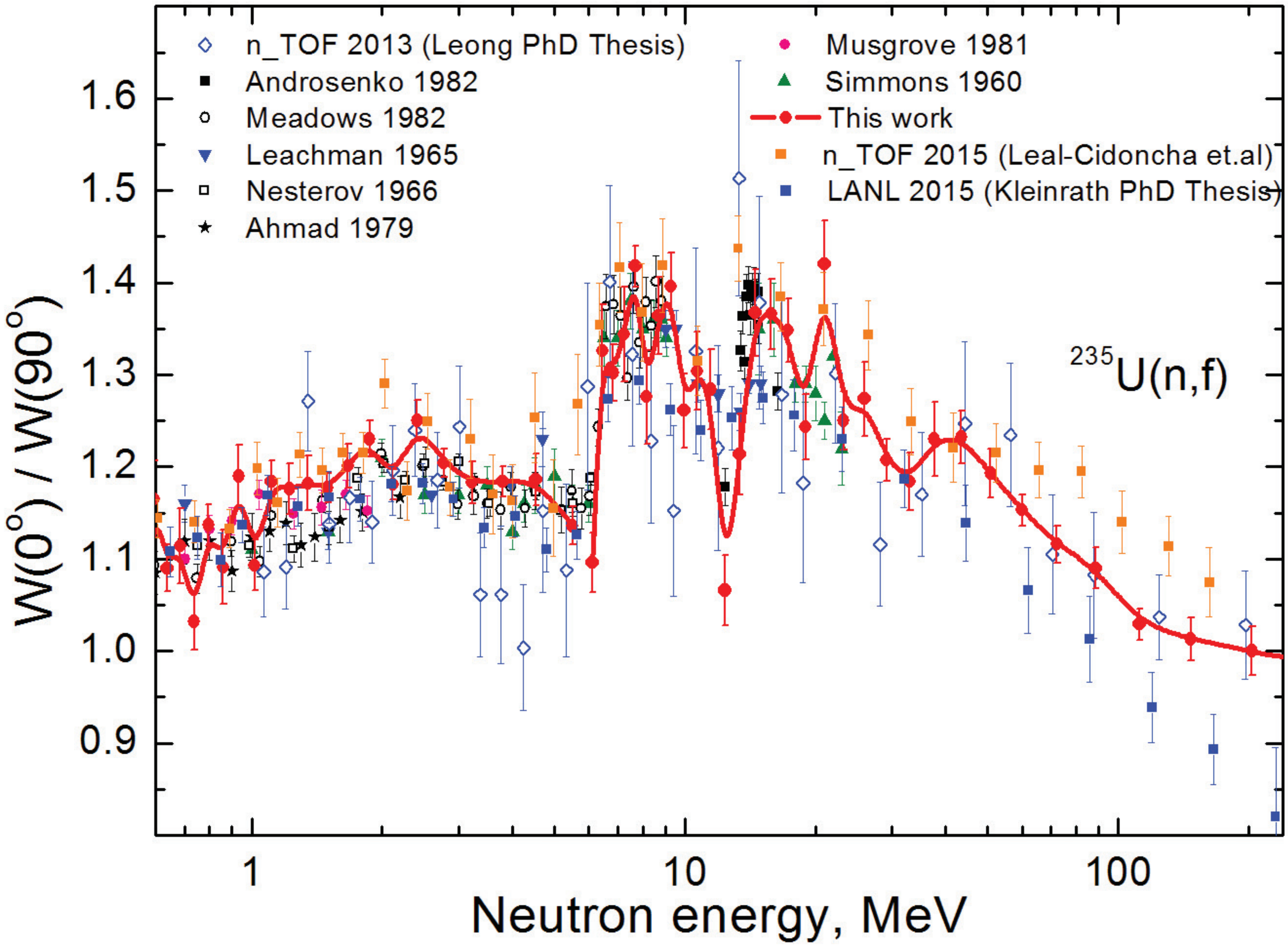
Anisotropy of ^{235}U fission fragments



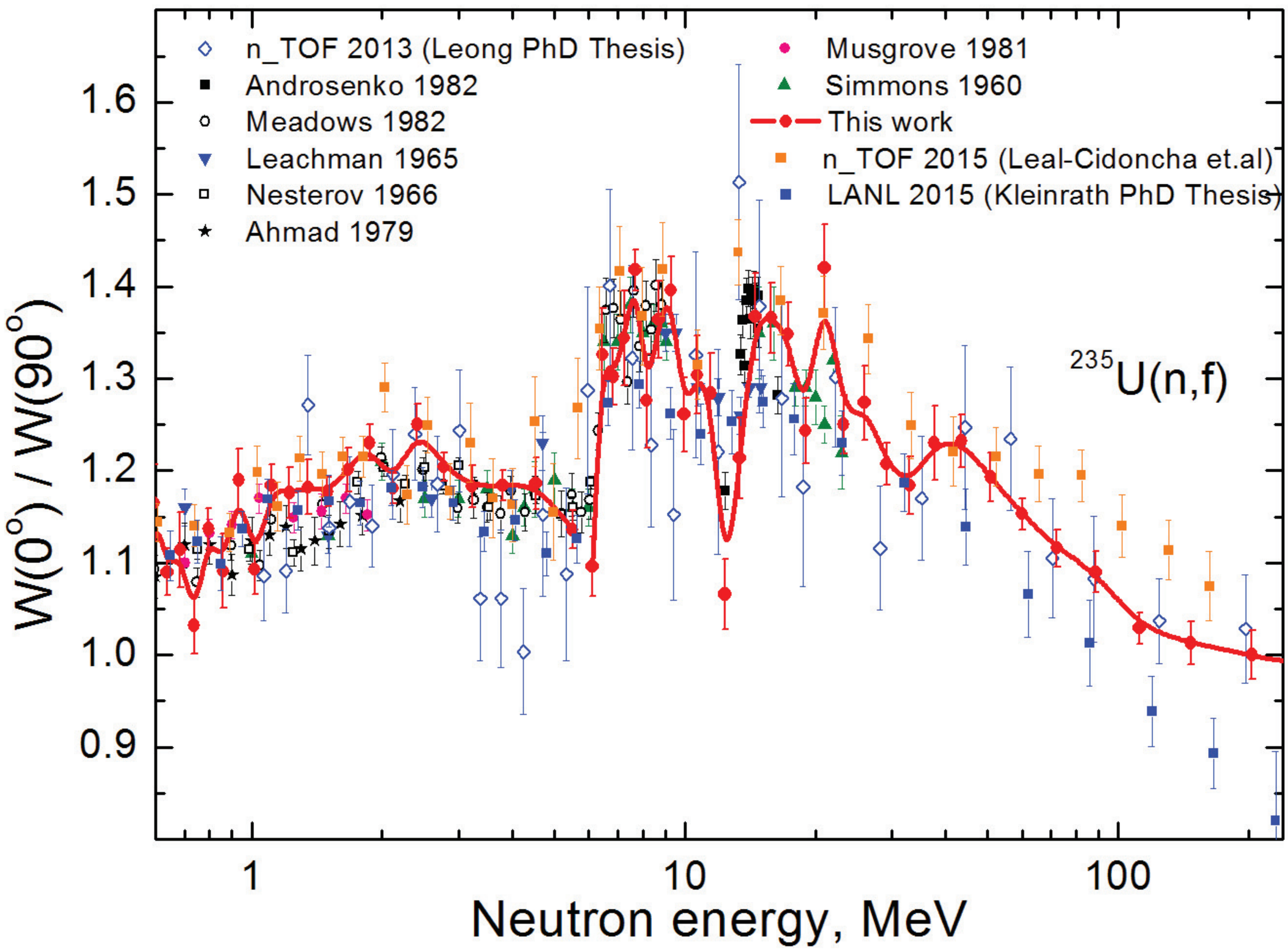
Anisotropy of ^{235}U fission fragments



Anisotropy of ^{235}U fission fragments

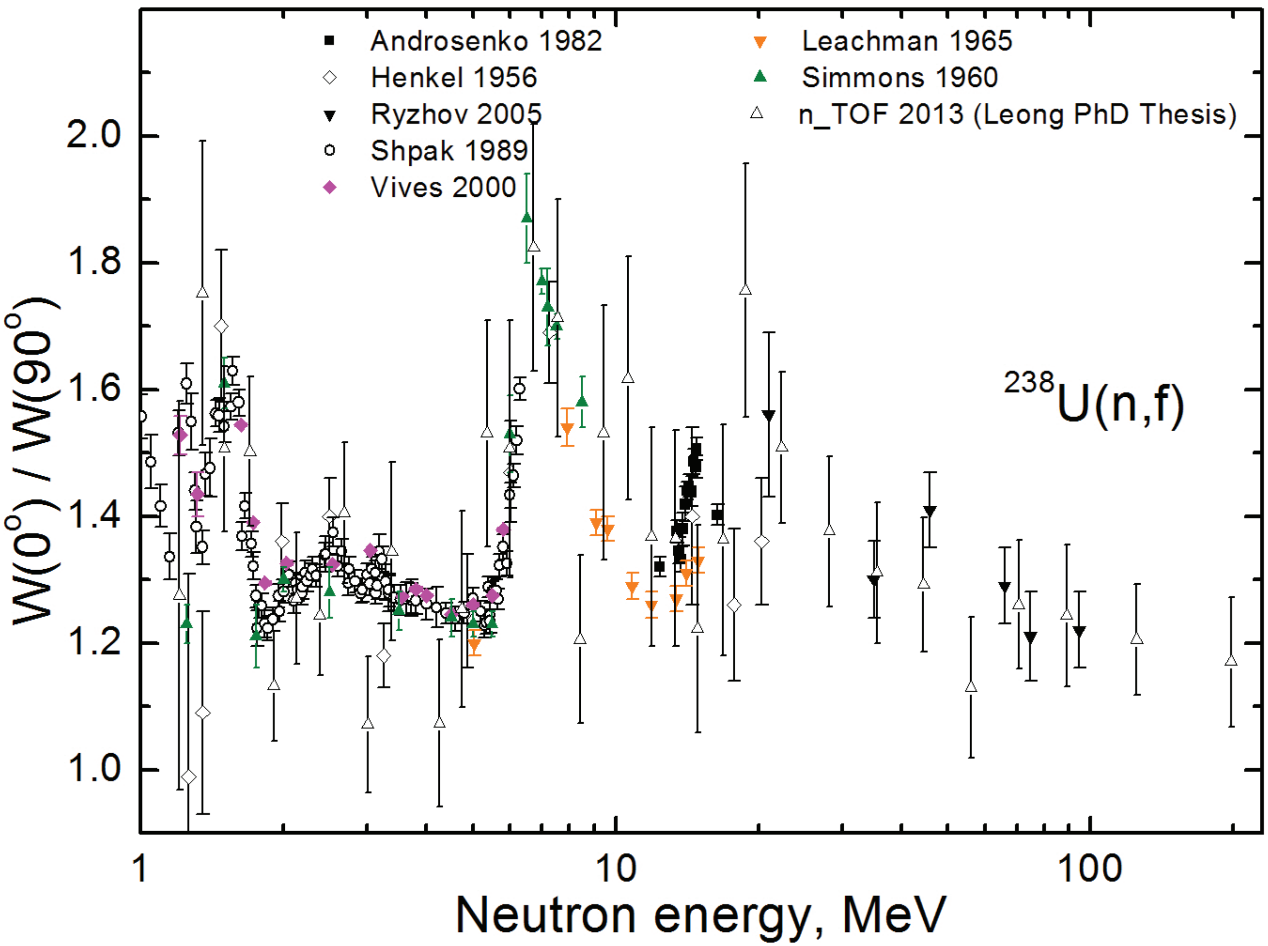


Anisotropy of ^{235}U fission fragments

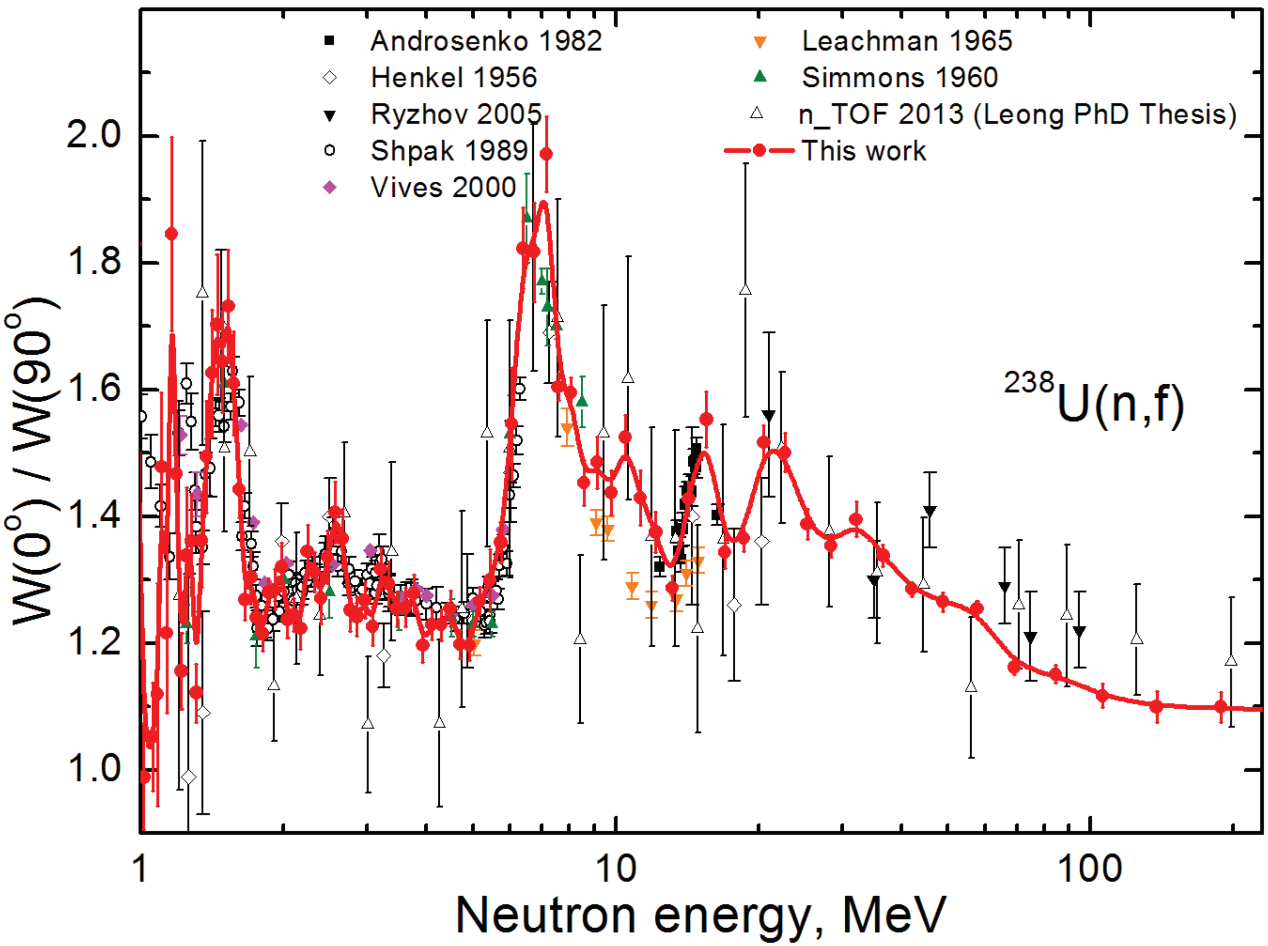


- ✓ **Above 50 MeV there is disagreement between these results and those recently obtained by Kleinrath (WNR, LANSCE) and Leal-Cidoncha et.al (n_TOF, CERN).**

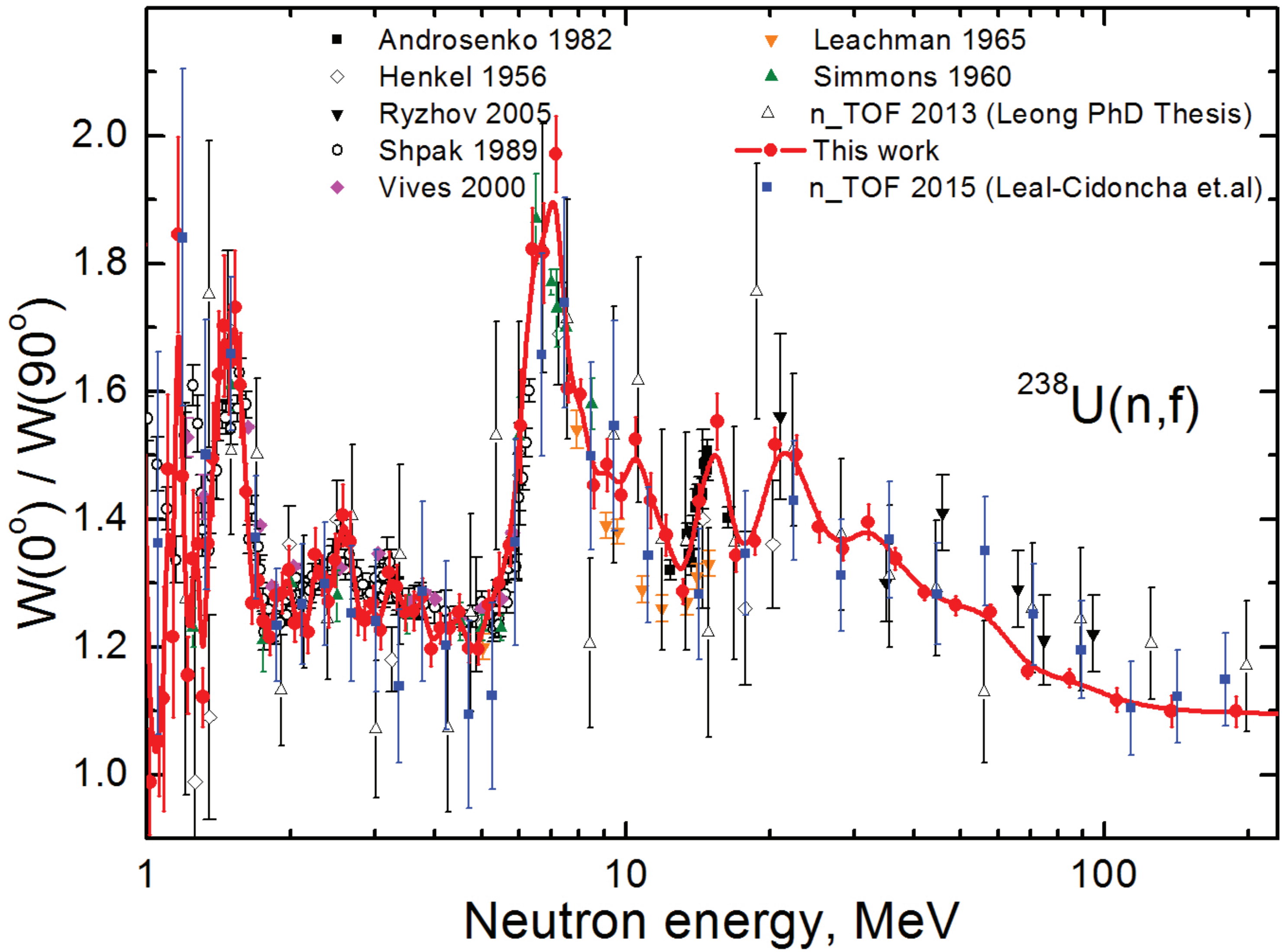
Anisotropy of ^{238}U fission fragments



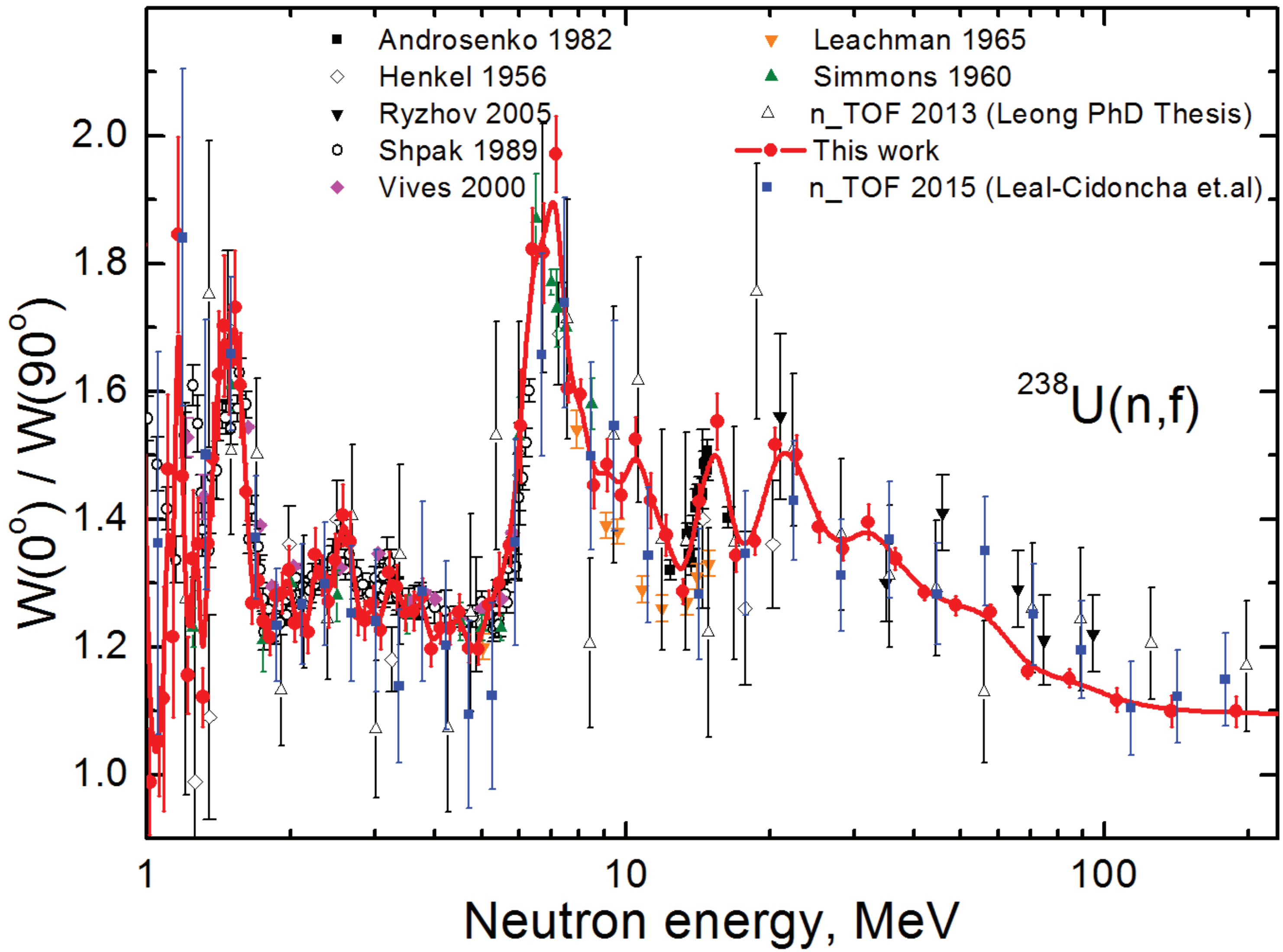
Anisotropy of ^{238}U fission fragments



Anisotropy of ^{238}U fission fragments

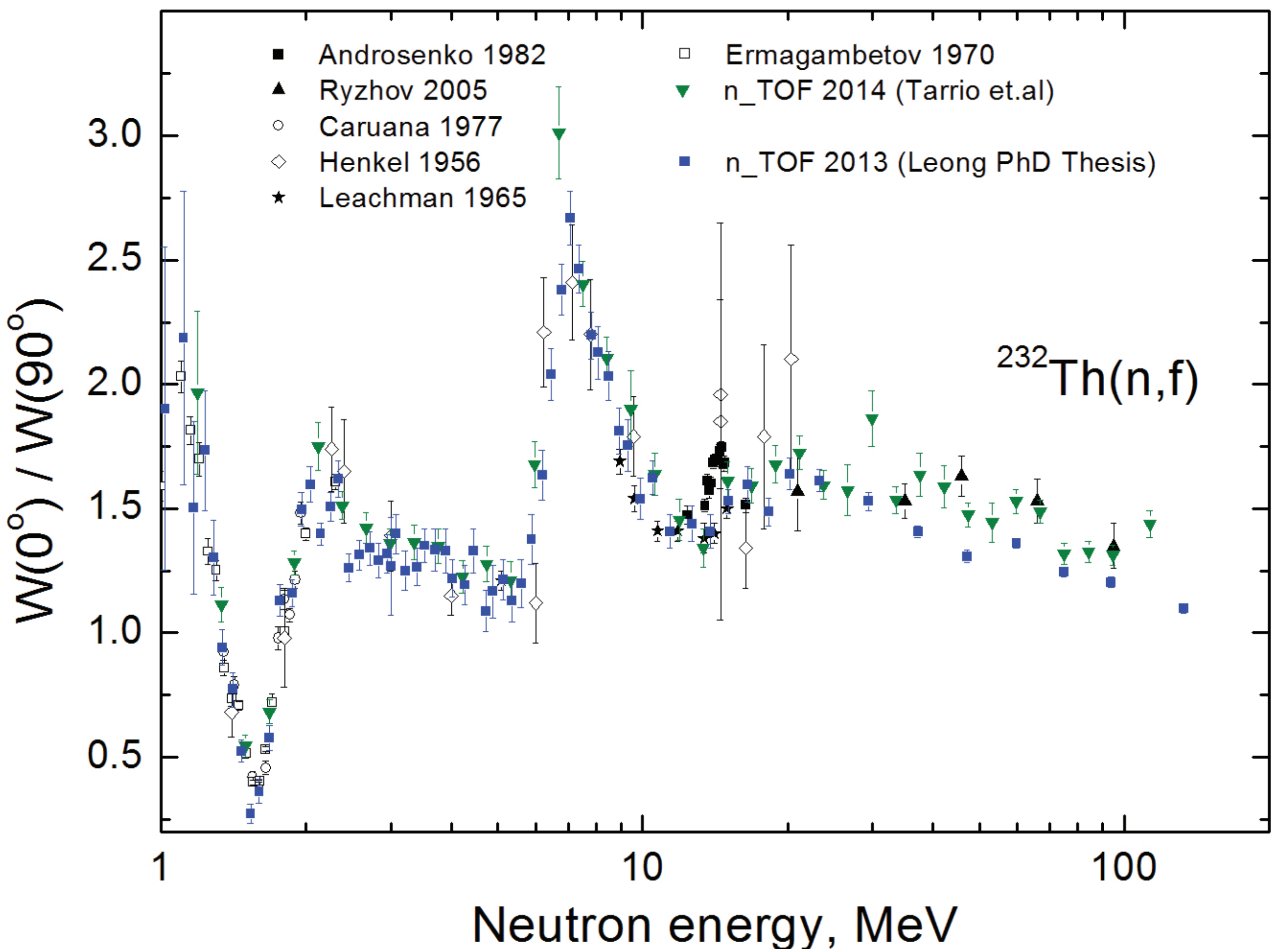


Anisotropy of ^{238}U fission fragments

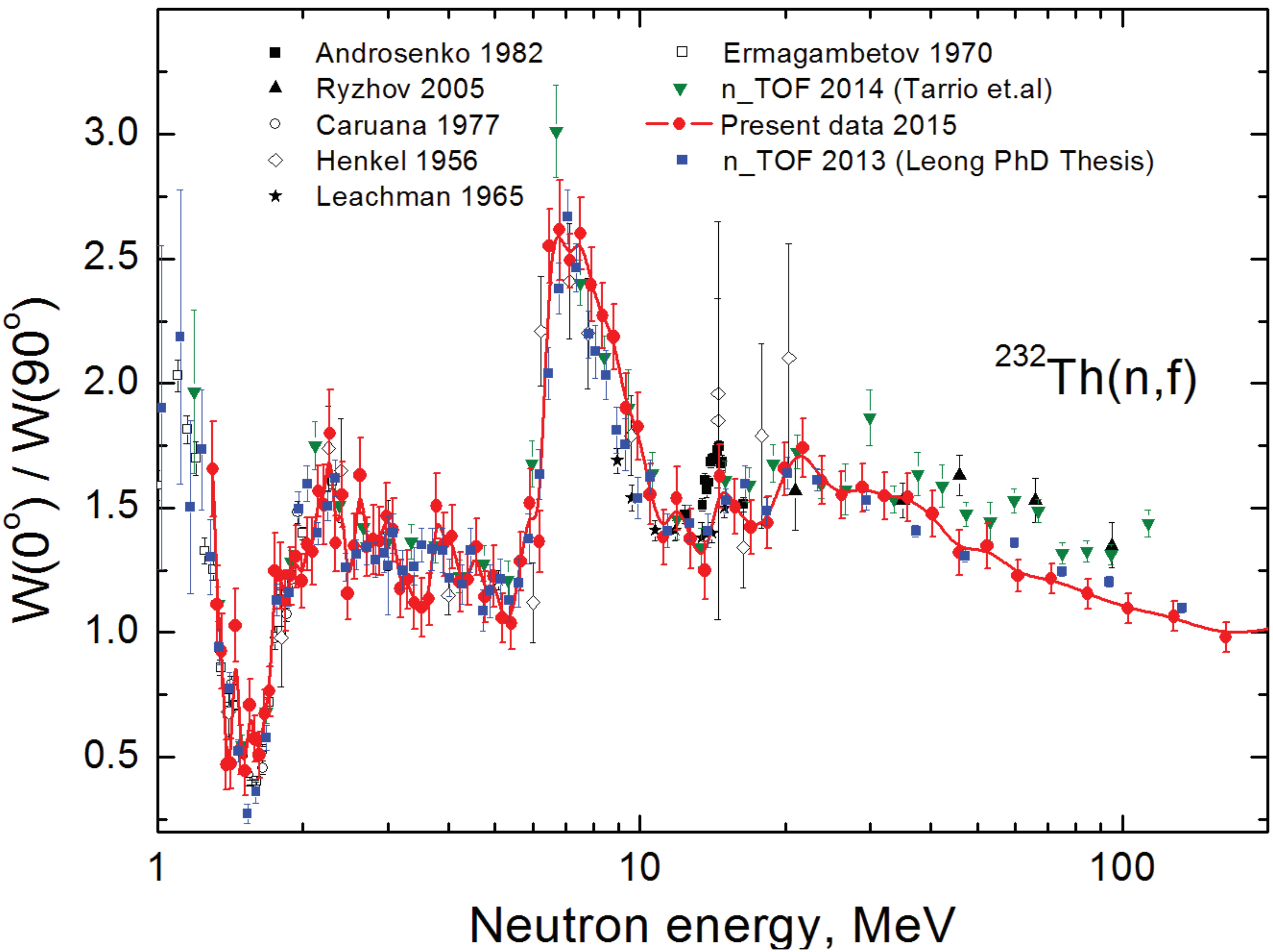


- ✓ **Above 20 MeV the uncertainties of our data are much smaller than those presented by Ryzhov et.al (TSL, Uppsala) and Leong, Leal-Cidoncha et.al (n_TOF, CERN).**

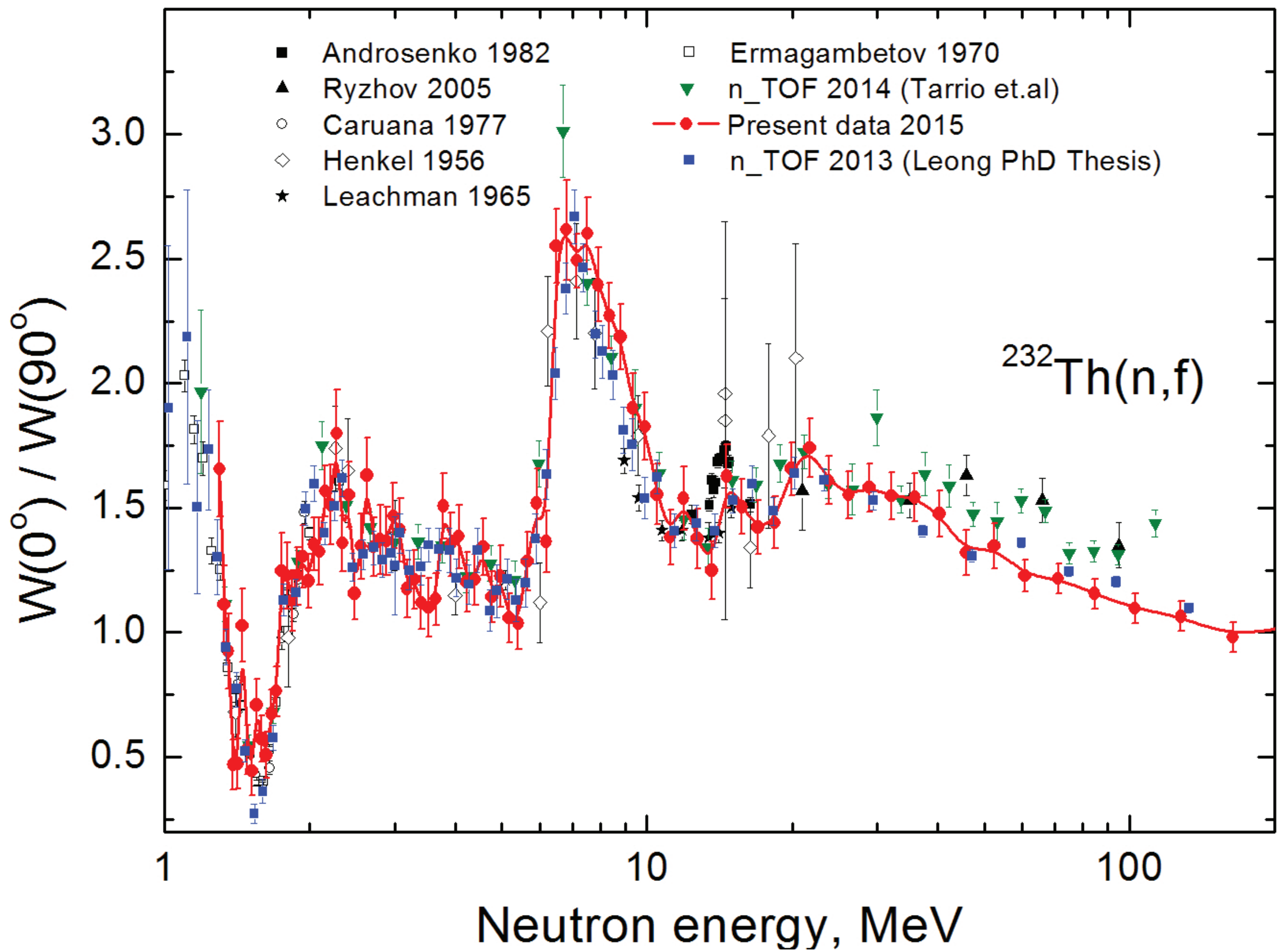
Anisotropy of ^{232}Th fission fragments



Anisotropy of ^{232}Th fission fragments

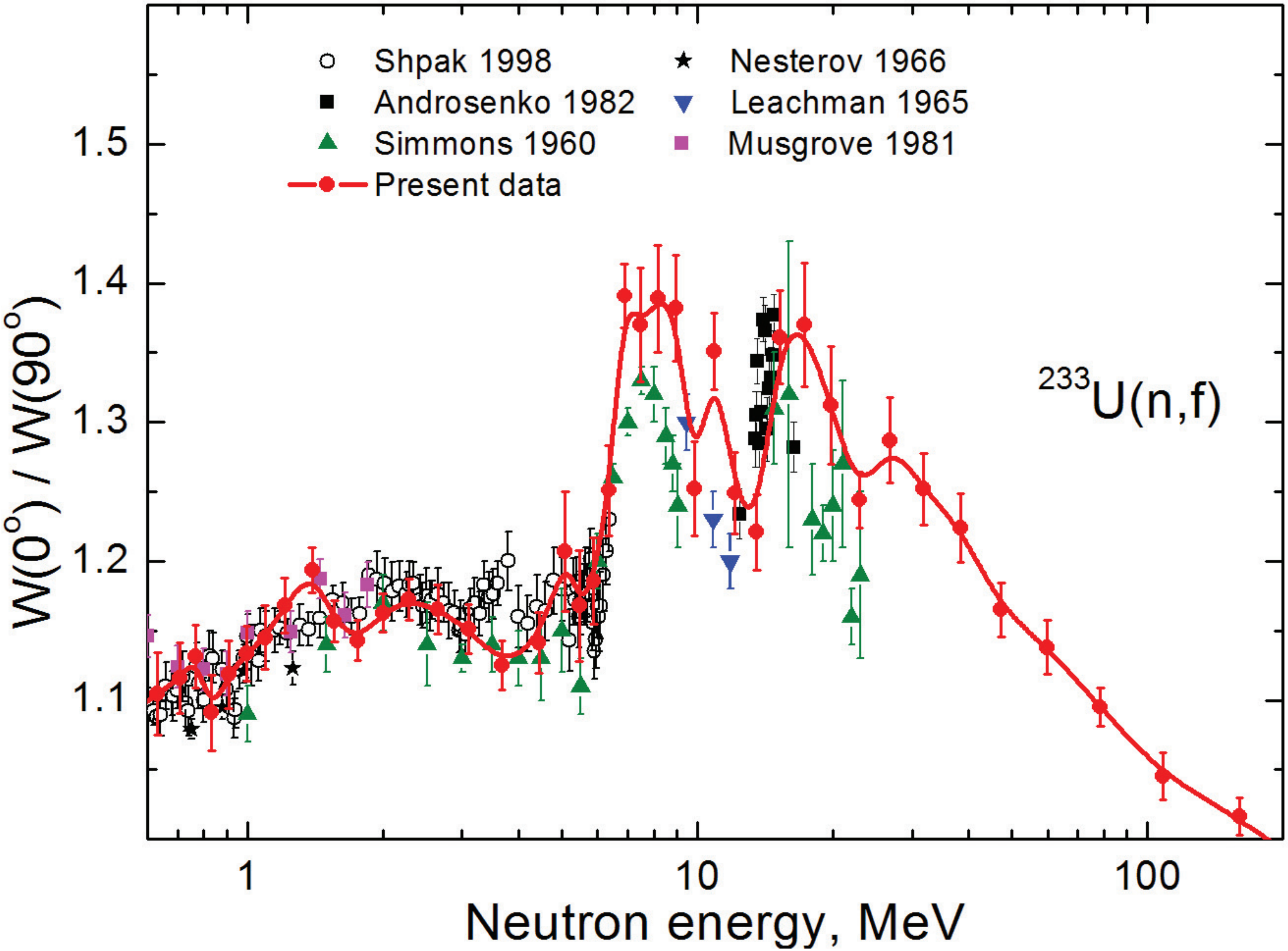


Anisotropy of ^{232}Th fission fragments



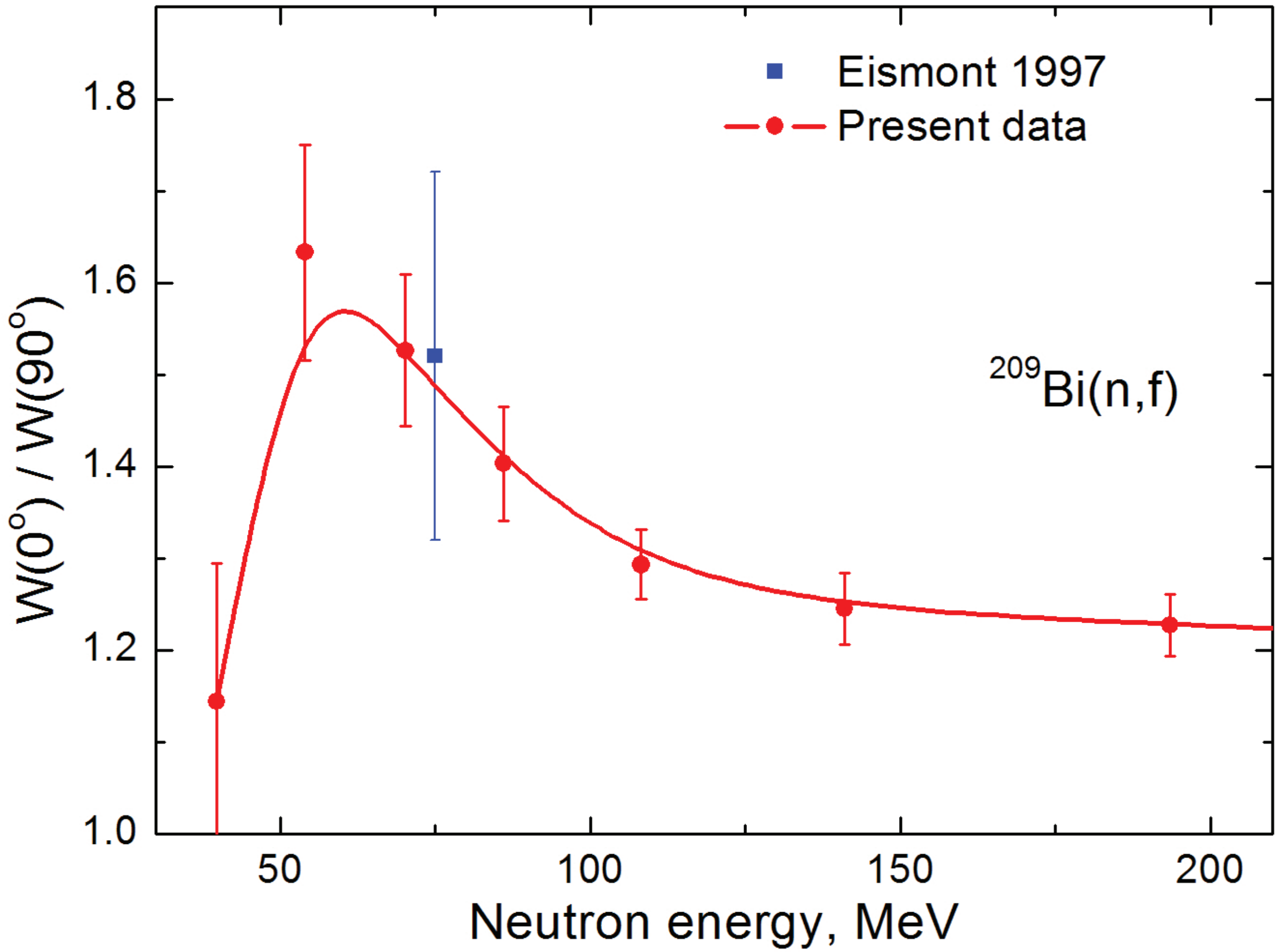
- ✓ Above 40 MeV our data agree with results given by Leong (n_TOF, CERN) and differ substantially from the data presented by Ryzhov et.al (TSL, Uppsala) and Tarrio et.al (n_TOF, CERN).

Anisotropy of ^{233}U fission fragments



✓ **Presently, there is only our data in the neutron energy range above 24 MeV.**

Anisotropy of ^{209}Bi fission fragments



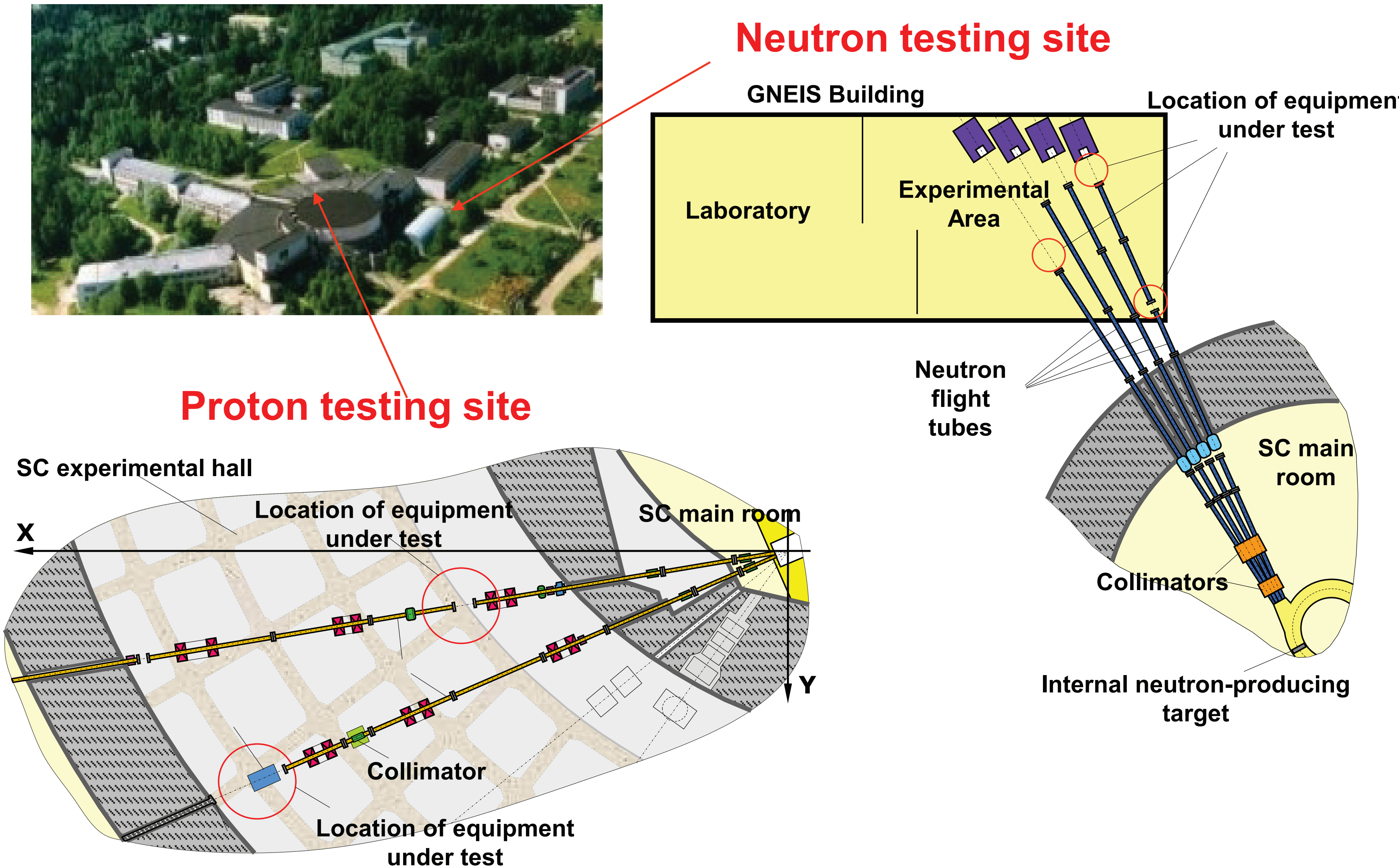
- ✓ **There is no other data except our data. Our data agree with previous result by Eismont et.al (RI+TSL) at 75 MeV.**
- ✓ **There is a maximum of the anisotropy at ~50 MeV equal to ~1.6 followed by descend with increasing neutron energy. At 200 MeV the anisotropy is about 1.2.**

Neutron test facility at the GeV synchrocyclotron of PNPI for radiation resistance testing of avionic and space electronics

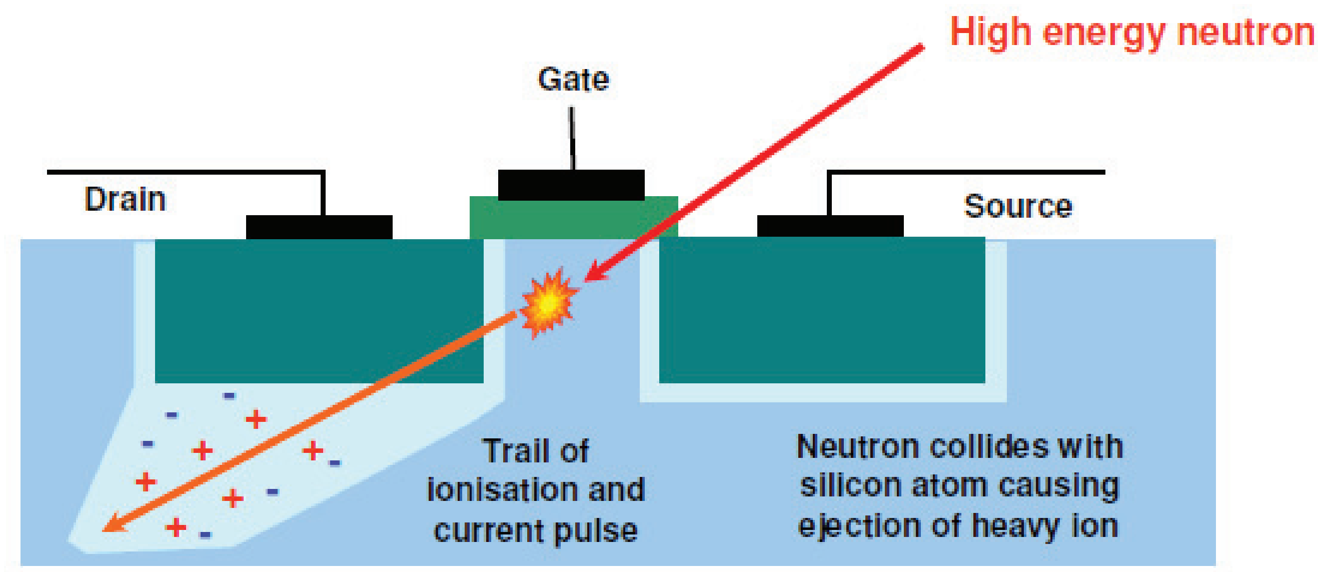
ROSCOSMOS Test Facilities of the Branch of Joint Stock Company "United Rocket and Space Corporation" - Institute of Space Device Engineering (Moscow) at B.P. Konstantinov Petersburg Nuclear Physics Institute (Gatchina) of the National Research Center "Kurchatov Institute"

	IS SC - 1000	IS OP - 1000	ISNP/GNEIS
Conditions	Atmosphere	Atmosphere	Atmosphere
Particles	Protons	Protons	Neutrons
Energy, MeV	1000	60 - 1000	1 - 1000
Flux, particles/$cm^2 \cdot s$	10^5 - 10^8	10^5 - 10^8	$\leq 4 \cdot 10^5$
Irradiation area, mm	Ø ≥ 25	Ø ≥ 25	Ø 50 – 100
Uniformity, %	≤ 10	≤ 10	≤ 10
Status	In operation (1998)	In operation (2015)	In operation (2010)

TESTING OF ELECTRONIC EQUIPMENT AT THE PNPI PROTON AND NEUTRON BEAMS



NEUTRON-INDUCED SOFT ERROR TESTING
of Electronic Components Used for
Terrestrial, Avionic and Space Equipment

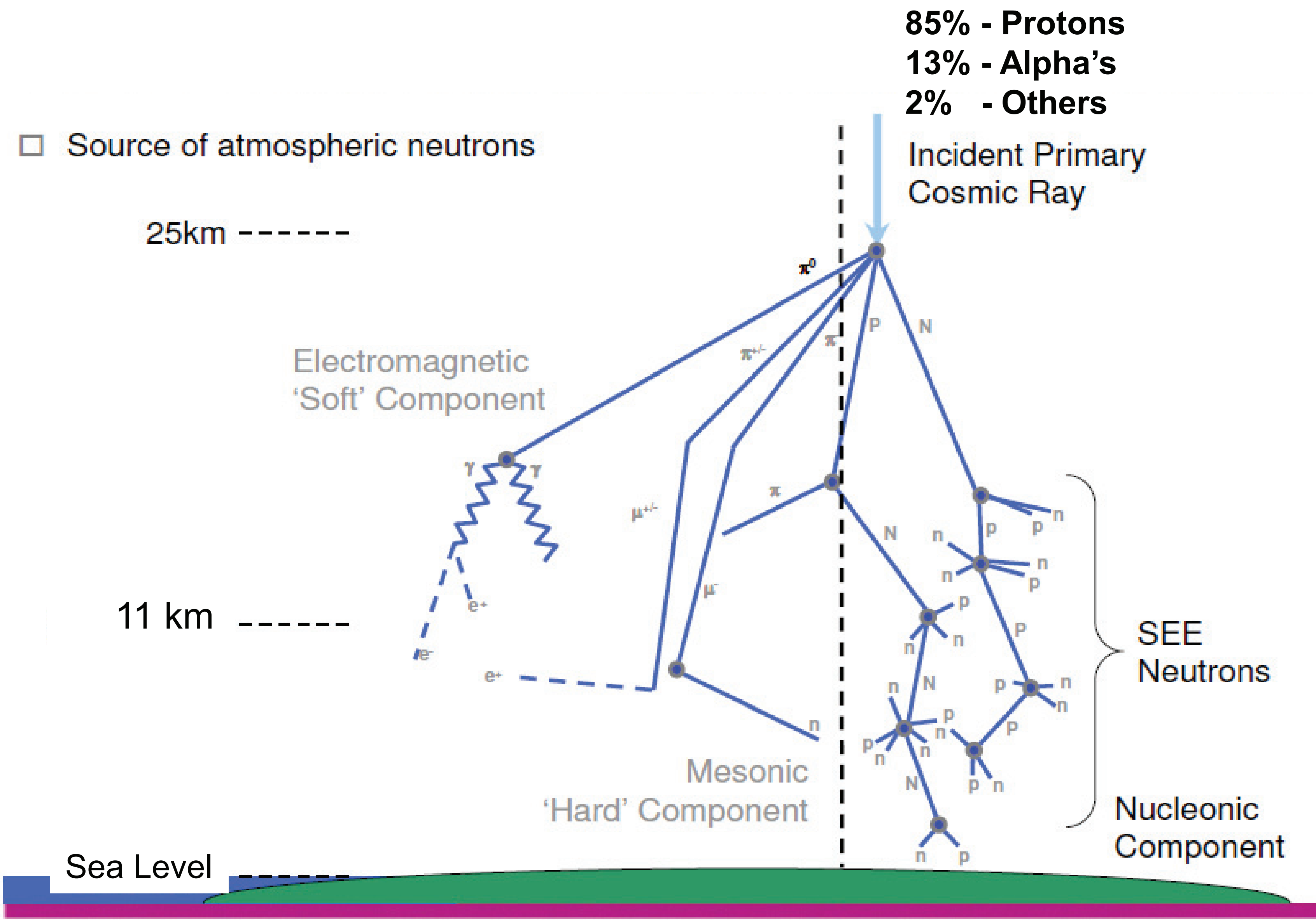


What are Single Event Effects and why are they important?

Single Event Effects are created when an energetic particle (proton, <u>neutron, alpha,</u> heavy ion) generates enough charge (so-called <u>critical charge</u>) to upset the function of integrated circuit

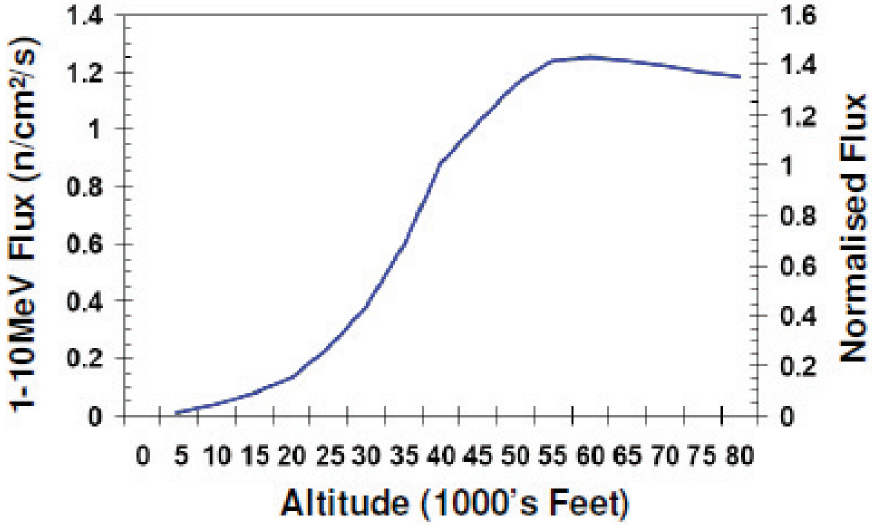
<u>S</u>ingle <u>E</u>vent <u>E</u>ffect – SEE - Эффекты одиночных событий

NEUTRON COMPONENT OF COSMIC RAYS



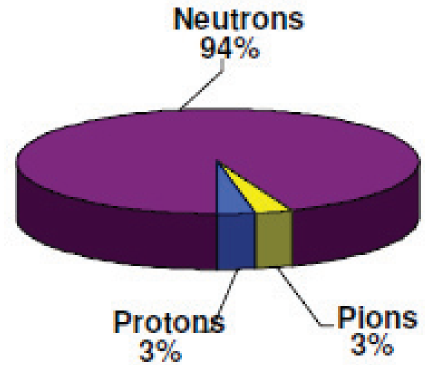
NEUTRON COMPONENT OF COSMIC RAYS

- Intensity and Composition with Altitude
  - ~ 300x Sea Level at flight altitudes

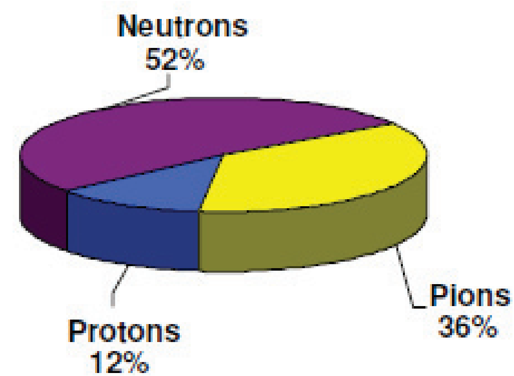


Source: Boeing Radiation Effects Lab

1000 Feet = 304.8 m



Sea Level



32,000 Feet

Source: JF Zilegler IBM J Res Dev 40, 19-40, (1996)

INTERNATIONAL STANDARD (by JEDEC)

Альянс предприятий электронной промышленности (Electronics Industries Alliance), до октября 1997 г. назывался Electronics Industries Association. Профессиональная организация в США, разрабатывающая электрические и функциональные стандарты с идентификатором RS (Recommended Standards). Самый известный из её стандартов - RS-232C.

В 1958 году в США Ассоциацией предприятий электронной промышленности был создан Объединённый инженерный совет по электронным устройствам (Joint Electronic Device Engineering Council - JEDEC).

В настоящее время JEDEC является мировым лидером по разработке открытых стандартов в микроэлектронной промышленности.
JEDEC насчитывает более 3000 членов, представляющих около 300 компаний.

JEDEC STANDARD

Measurement and Reporting of Alpha Particles and Terrestrial Cosmic Ray-Induced Soft Errors in Semiconductor Devices

JESD89

AUGUST 2001

JEDEC SOLID STATE TECHNOLOGY ASSOCIATION

JEDEC

EIA Electronic Industries Alliance

JESD89A (2006)
STANDARD TERRESTRIAL NEUTRON SPECTRUM

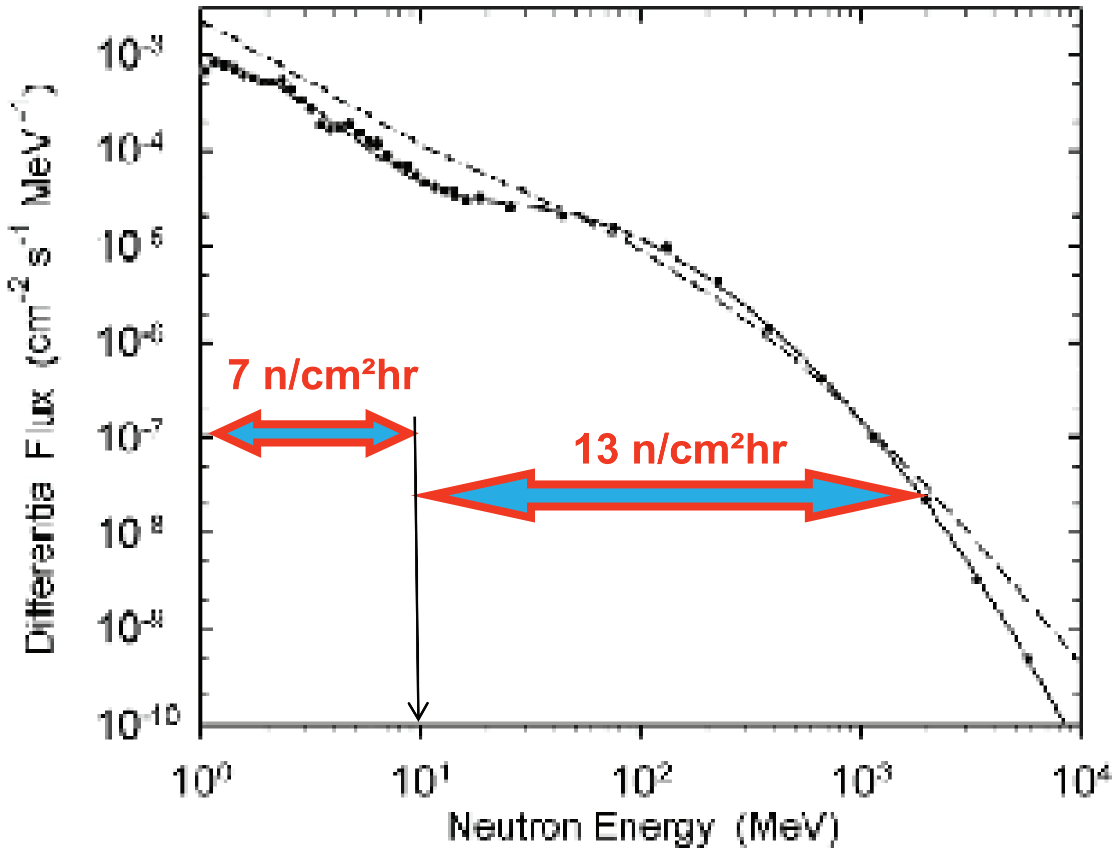
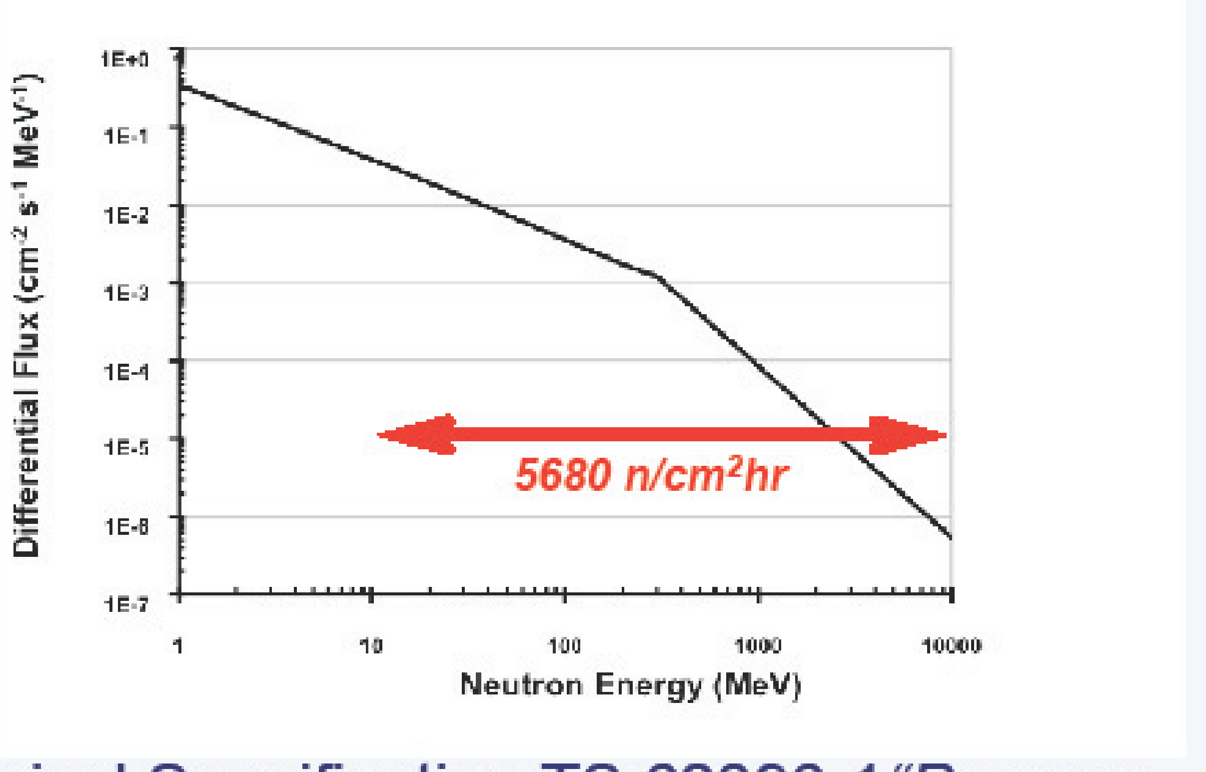


Figure A.2.1 — The differential flux of cosmic-ray-induced neutrons as a function neutron energy under reference conditions (sea level, New York City, mid-level so activity, outdoors). The data points are the reference spectrum, the solid curve is analytic fit to the reference spectrum, and the dashed curve is the model from previous version of this standard, JESD89 (2001).

AVIONIC NEUTRON SPECTRUM AT 12 Km



- IEC Technical Specification TS 62396-1 *"Process Management for Avionics - Atmospheric Radiation Effects"*
- 400x more intense than terrestrial levels

FACILITIES FOR RADIATION TESTING WITH ATMOSPHERIC – LIKE NEUTRON SPECTRUM

- Los Alamos National Laboratory, New Mexico, USA
  - Weapons Neutron Research Facility
  - ICE House 'Irradiation of Chips and Electronics'
- Tri-University Meson Facility, Vancouver, Canada
  - Neutron Irradiation Facility
- Uppsala University, Sweden
  - Theodor Svedberg Laboratory
  - ANITA Irradiation facility
- Vesuvio, ISIS at the Rutherford Appleton Lab., Oxfordshire, UK
  Neutron Irradiation Facility
- Research Center for Nuclear Physics at Osaka University (RCNP), Japan
- Petersburg Nuclear Physics Institute, Gatchina
  ISNP/GNEIS Neutron Irradiation Facility

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Original Russian Text © N.K. Abrosimov, L.A. Vaishnene, A.S. Vorob'ev, E.M. Ivanov, G.F. Mikheev, G.A. Ryabov, M.G. Tverskoi, O.A. Shcherbakov, 2010, published in Pribory i Tekhnika Eksperimenta, 2010, No. 4, pp. 5–12.

NUCLEAR EXPERIMENTAL TECHNIQUES

Development and Experimental Study of the Neutron Beam at the Synchrocyclotron of the Petersburg Nuclear Physics Institute for Radiation Tests of Electronic Components

N. K. Abrosimov, L. A. Vaishnene, A. S. Vorob'ev, E. M. Ivanov, G. F. Mikheev, G. A. Ryabov, M. G. Tverskoi, and O. A. Shcherbakov

Petersburg Nuclear Physics Institute, Russian Academy of Sciences, Orlova roshcha, Gatchina, Leningrad oblast, 188300 Russia
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Received December 2, 2009

Abstract—A neutron beam with an energy spectrum resembling that of atmospheric neutron radiation has been developed at the 1000-MeV synchrocyclotron of the Petersburg Nuclear Physics Institute. The beam is intended for testing the radiation resistance of electronics and meets the requirements of the JEDEC international standard. The only test facility in which the neutron spectrum is close to the standard in the energy range of 0.1–750 MeV has been developed at the Los Alamos National Laboratory on the basis the LAMPF linear proton accelerator and used by aviation and space companies of the United States, Europe, and Asia to test their electronic equipment. In contrast to the test facilities in Los Alamos and Uppsala (Sweden), the method of neutron production on an internal accelerator target is used by the Petersburg Nuclear Physics Institute. The development of the neutron beam and the test facility extends considerably the experimental potential of radiation research and can act as a basis for establishing a unique center for radiation tests of aviation and space electronic equipment in compliance with the requirements of international standards.

DOI: 10.1134/S0020441210040019

ISNP/GNEIS Facility in Gatchina for Neutron Testing With Atmospheric-Like Spectrum

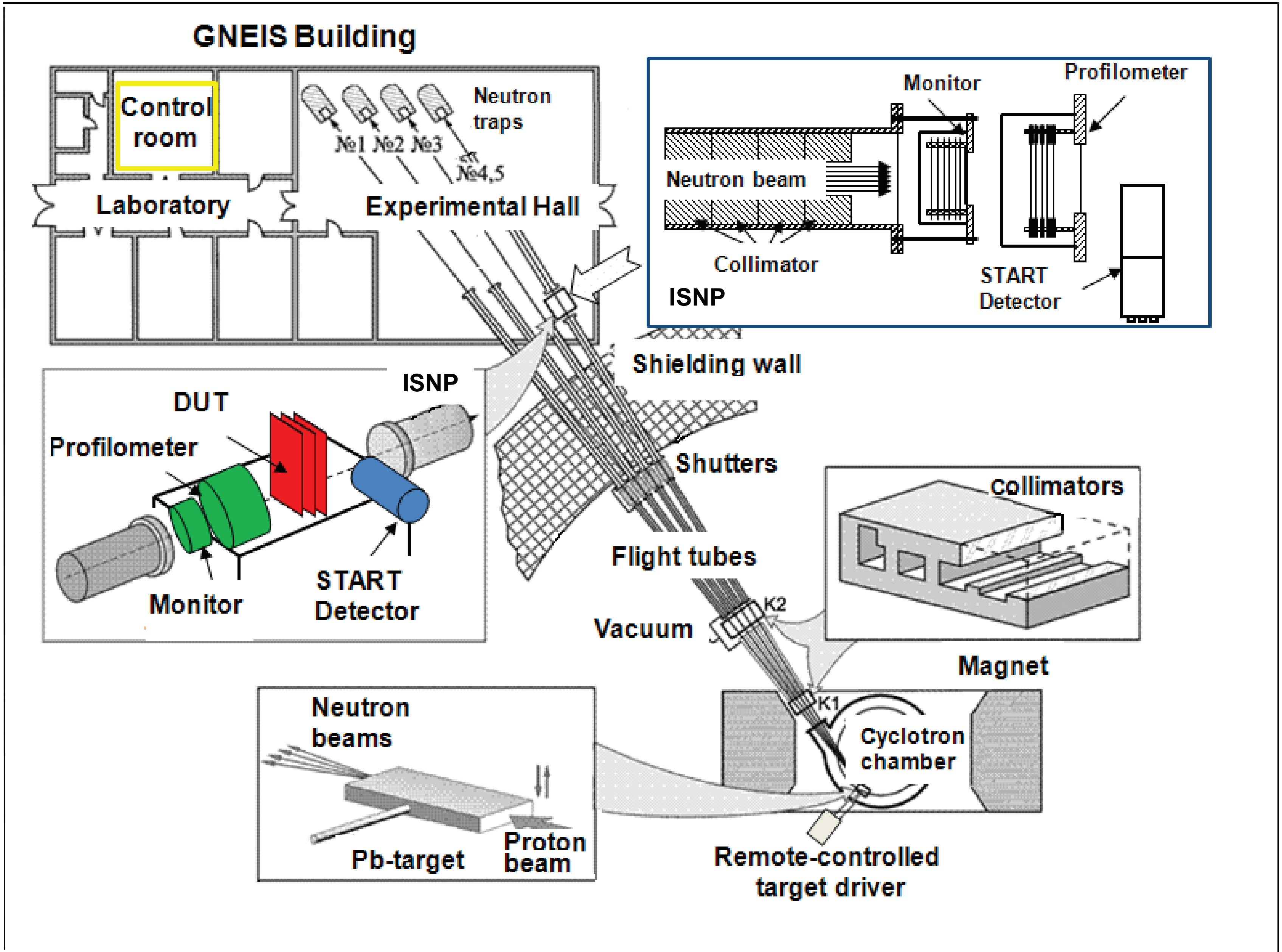
Oleg A. Shcherbakov, Alexander S. Vorobyev, Alexei M. Gagarski, Larisa A. Vaishnene, Evgeni M. Ivanov, Vasily S. Anashin, *Senior Member, IEEE*, Linaris R. Bakirov, and Aleksandr E. Koziukov, *Member, IEEE*

***Abstract*—A description of the testing facility ISNP with spectrum resembling that of terrestrial neutron radiation developed at the PNPI (Gatchina) is given. A broad spectrum (1–1000 MeV) spallation neutron source of the facility with a neutron flux of $4 \cdot 10^5$ n/(cm^2·s) is used for accelerated soft error testing. High-quality collimation of the neutron beam in conjunction with the TOF-technique enables to carry out precise and reliable monitoring of the neutron beam. The results of recent tests carried out at the ISNP by the Branch of JSC "URSC" - "ISDE" (Moscow) are presented.**

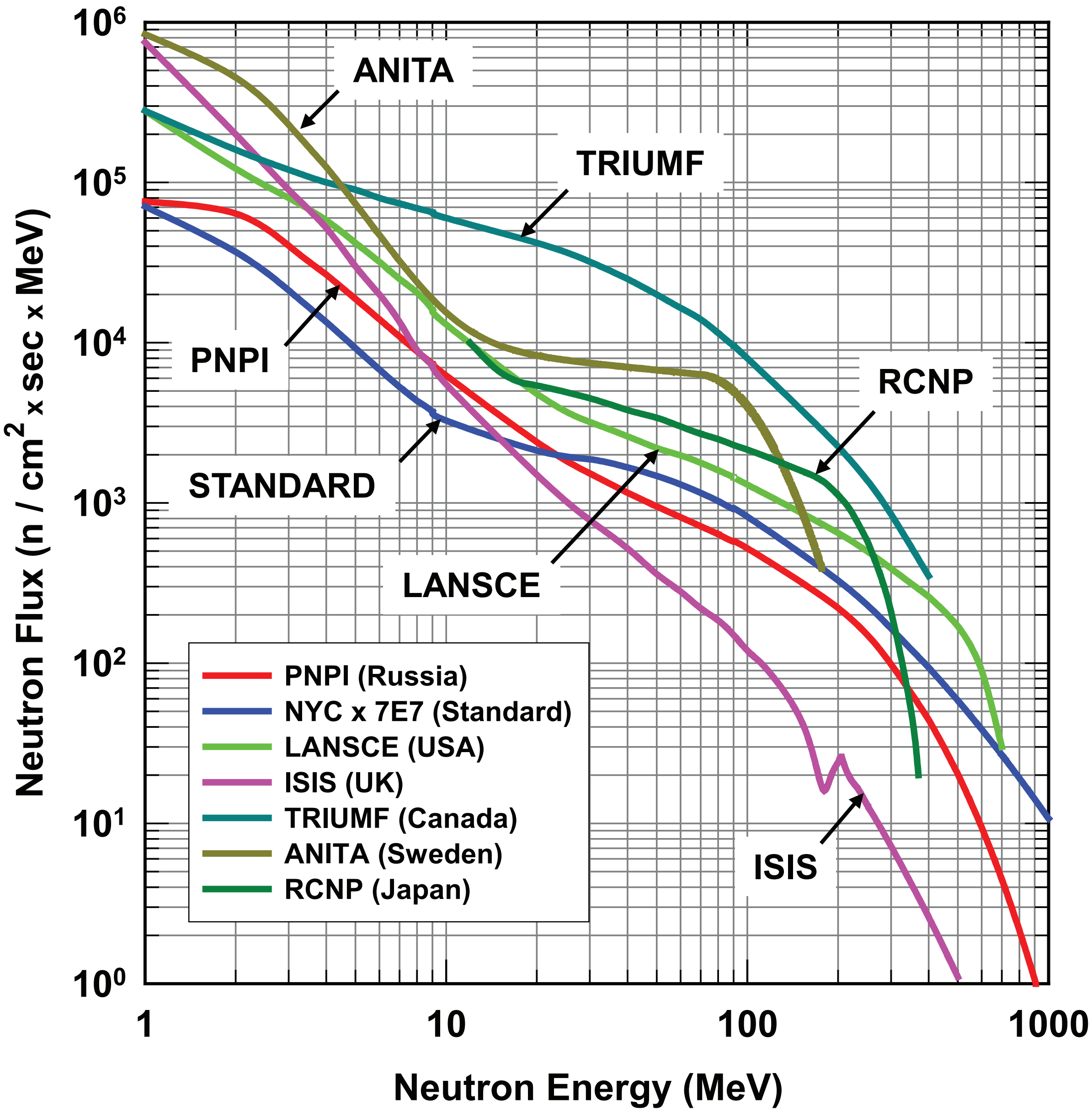
II. Description of the ISNP

The ISNP facility was developed at the neutron time-of-flight spectrometer GNEIS (Fig. 1) based on the 1000 MeV proton synchrocyclotron of the PNPI [2]. The spectrometer was constructed to study neutron-nucleus interactions using the TOF technique at neutron energies ranging from $\sim 10^{-2}$ eV to several hundreds of MeV. The lead target located inside the accelerator vacuum chamber produces short (of width ~10 ns)

General View of the GNEIS and ISNP/GNEIS Test Facility



Comparison of Broad Spectrum Neutron Sources



How to Compare Various Broad Neutron Spectrum Test Facilities?

Acceleration Factor - Definition

$$A = \frac{\int_{E_{\min}}^{\infty} \phi_{acc}(E)\,dE}{\int_{E_{\min}}^{\infty} \phi_{jedec/iec}(E)\,dE}$$

where E_{min} = 10MeV as specified in JEDEC and IEC

$\Phi_{acc}(E)$ - differential neutron flux from the test facility

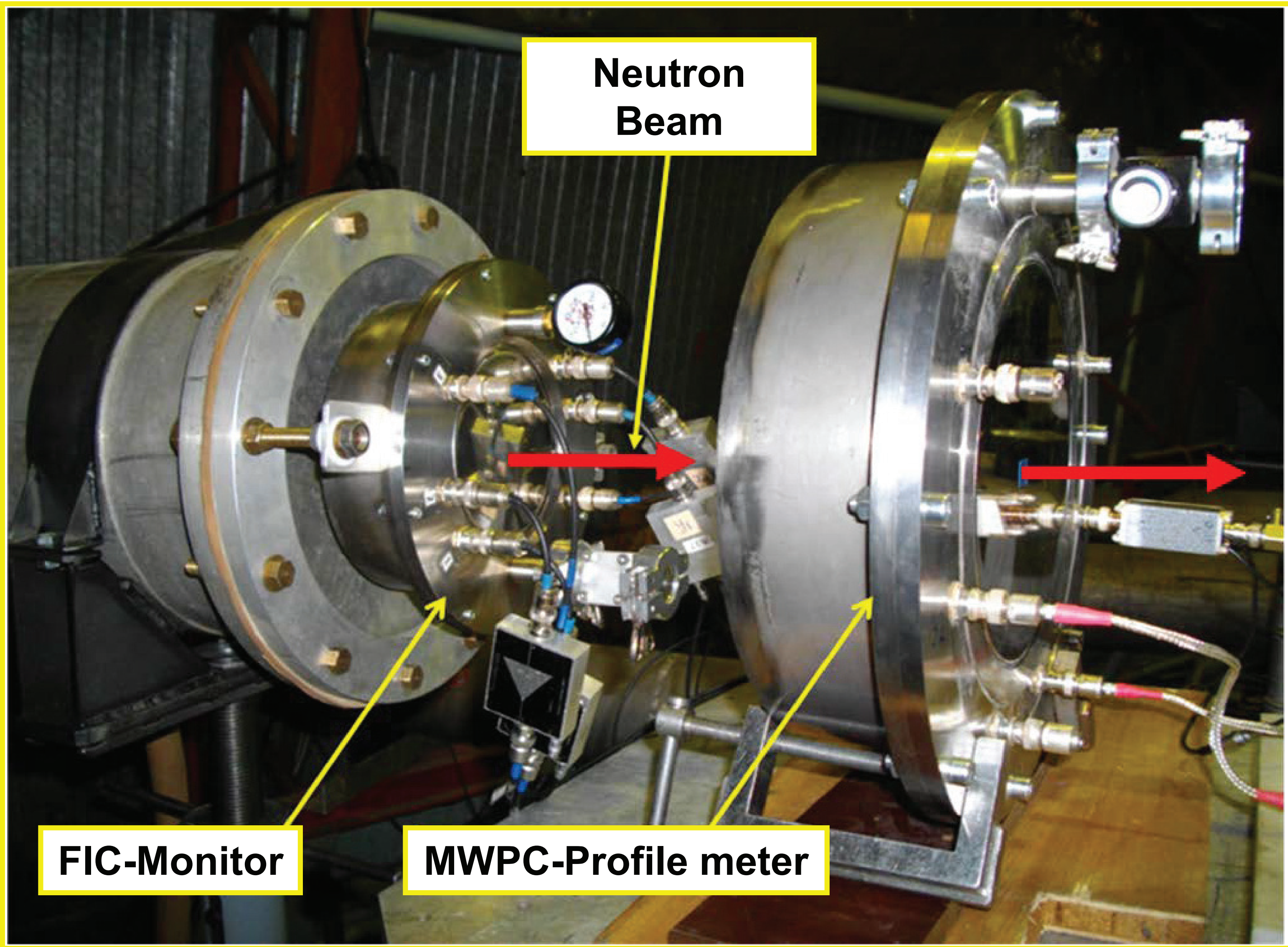
$\Phi_{jedec/iec}(E)$ – differential terrestrial (standard) neutron flux

Acceleration Factors of Broad Neutron Spectrum Facilities

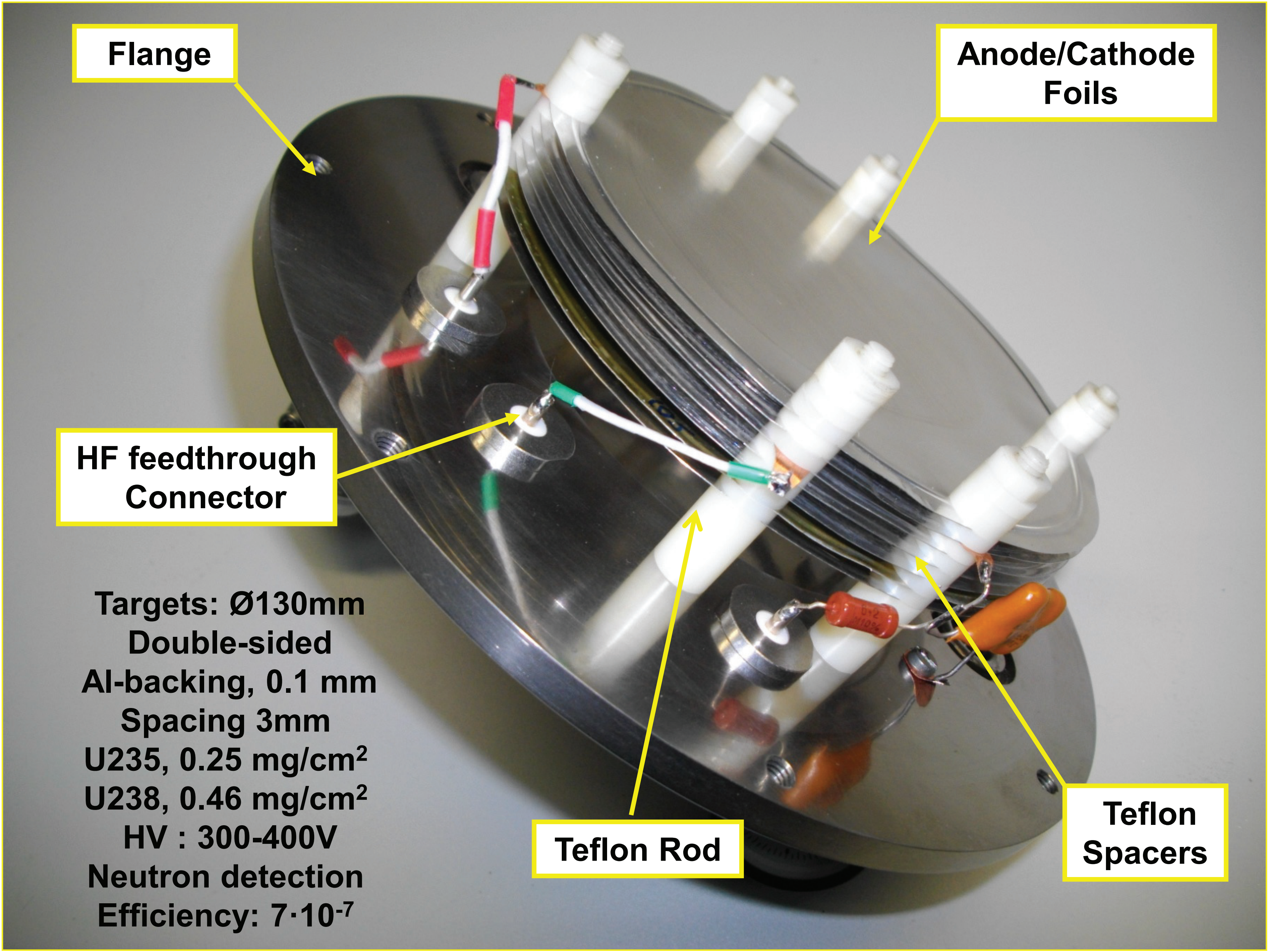
Facility (location, particle energy, target material)	Acceleration factor*)
ISNP/GNEIS (PNPI, Gatchina, Russia, 1000 MeV, lead)	$4.6 \cdot 10^7$
LANSCE (Ice House, Los Alamos, USA, 800 MeV, tungsten)	$1.3 \cdot 10^8$
ANITA (TSL, Uppsala, Sweden, 180 MeV, tungsten)	$2.7 \cdot 10^8$
RCNP (Osaka University, Japan, 400 MeV, lead)	$1.8 \cdot 10^8$
TRIUMF (NIF, UBC, Vancouver, Canada, 500 MeV, aluminum)	$7.6 \cdot 10^8$
ISIS (VESUVIO, RAL, Chilton, UK, 800 MeV, tungsten/tantalum)	$1.5 \cdot 10^7$

*) Exact acceleration factor vary due to tuning of the accelerator facility

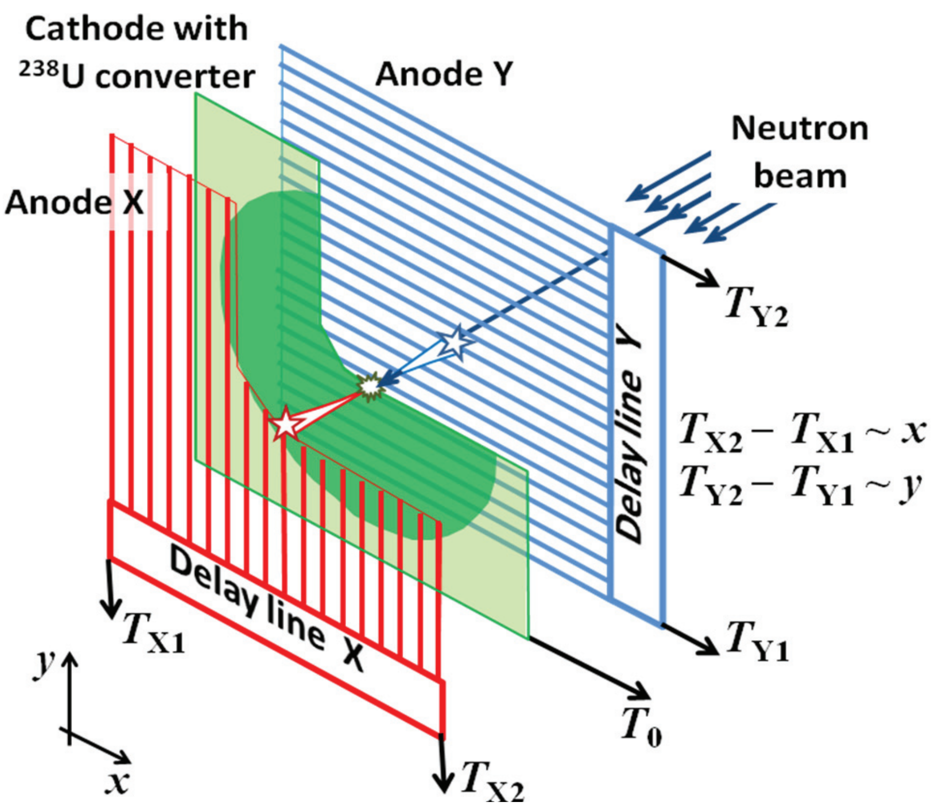
Devices Used at the PNPI Test facility for Characterization of the Neutron Beam



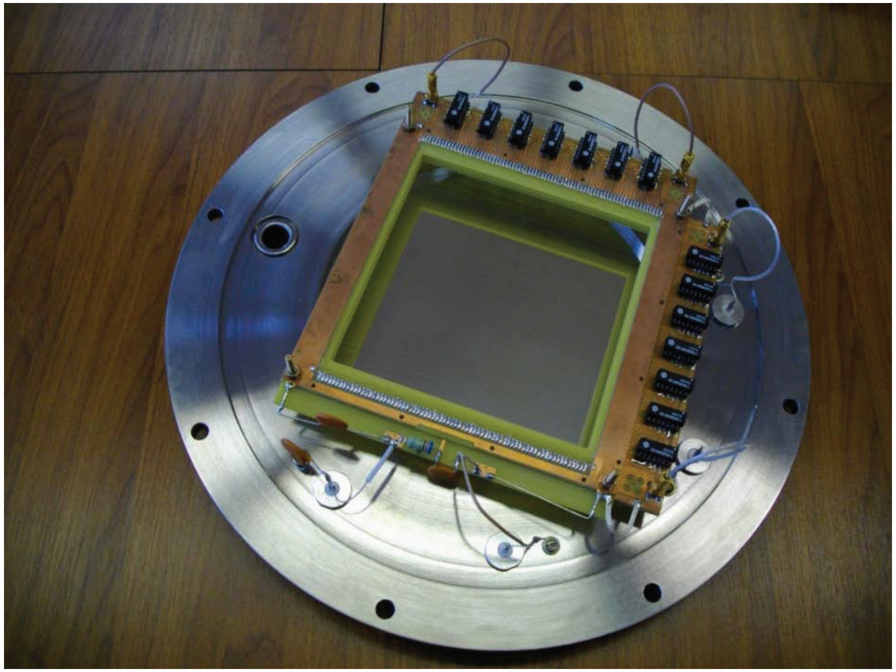
Internal structure of the neutron beam monitor FIC with U-235 and U-238 targets



MWPC – Neutron beam profile meter (position sensitive MultiWire Proportional Counter)

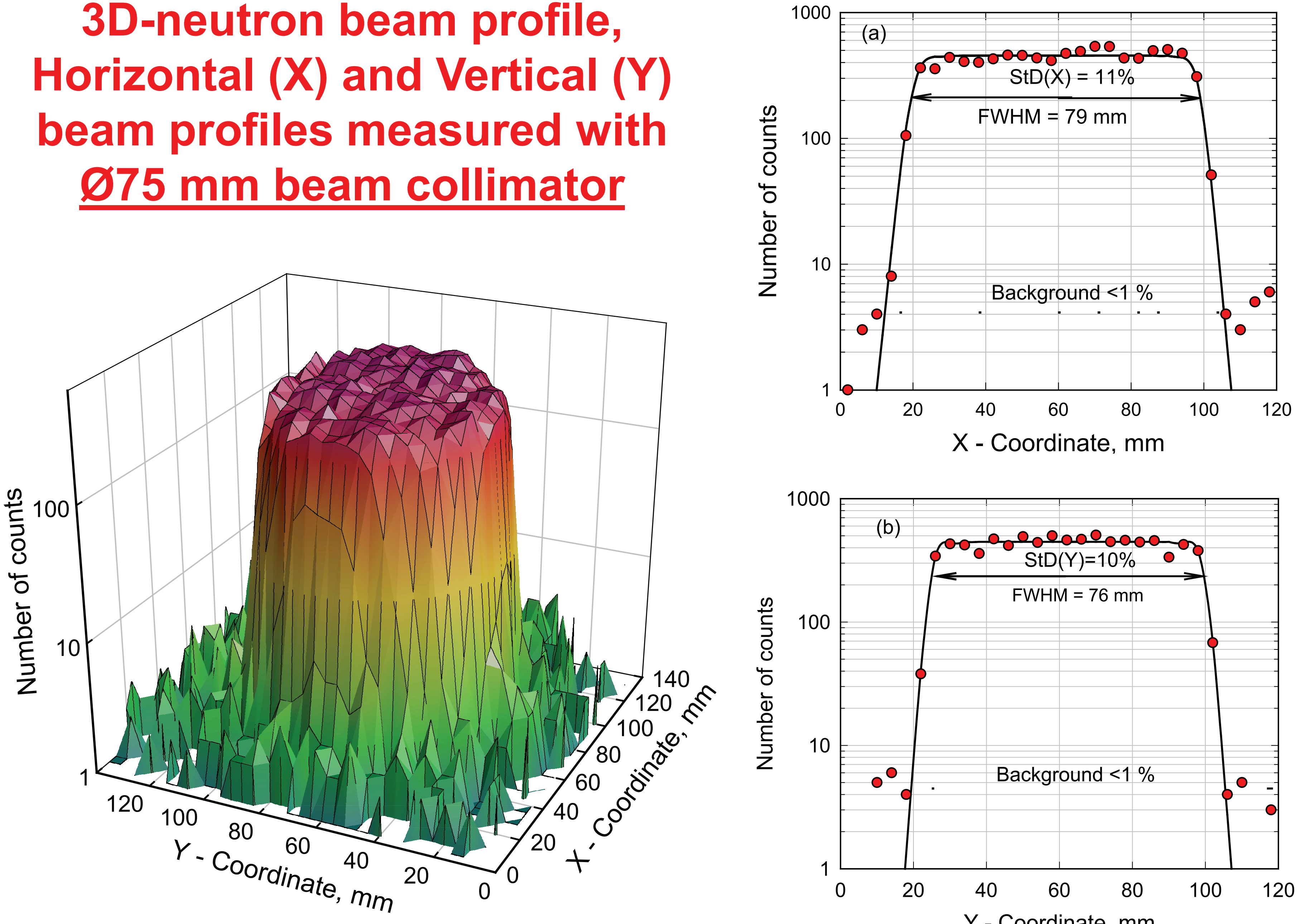


Size: 140 x 140 mm²
Neutron detection efficiency: $3 \cdot 10^{-7}$
Spatial resolution:
2 mm < FWHM < 4 mm

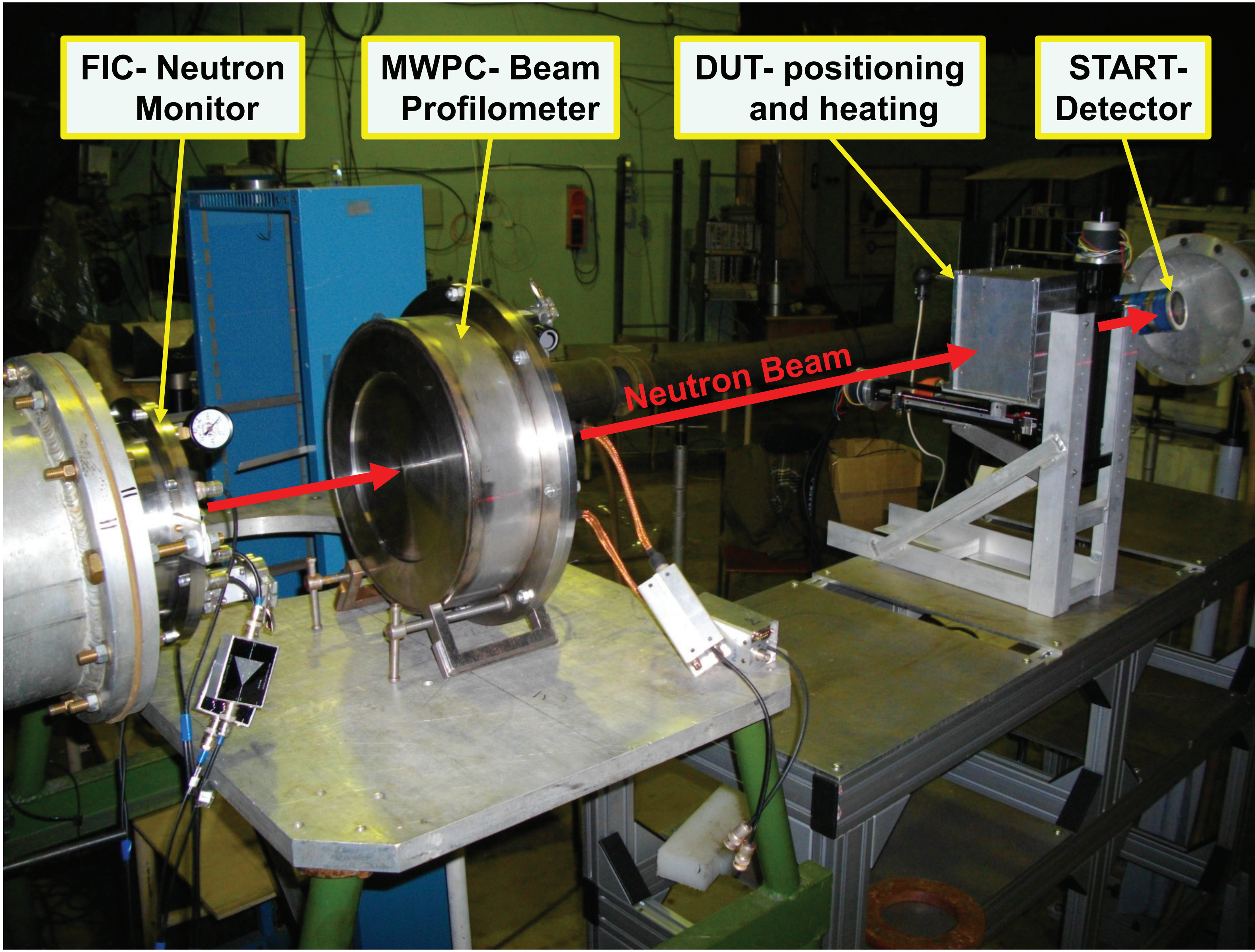


Anodes: 140 gilded W-wires, Ø25μm, 1 mm step on 3mm thick fiberglass plastic frame
Cathode: 150 μg/cm² thick ^{238}U converter on aluminized 2 μg thick Mylar film
Working Gas: isobutene (iC_4H_{10}), 6-7 Torr
Data read-out: delay lines, 2 ns/step

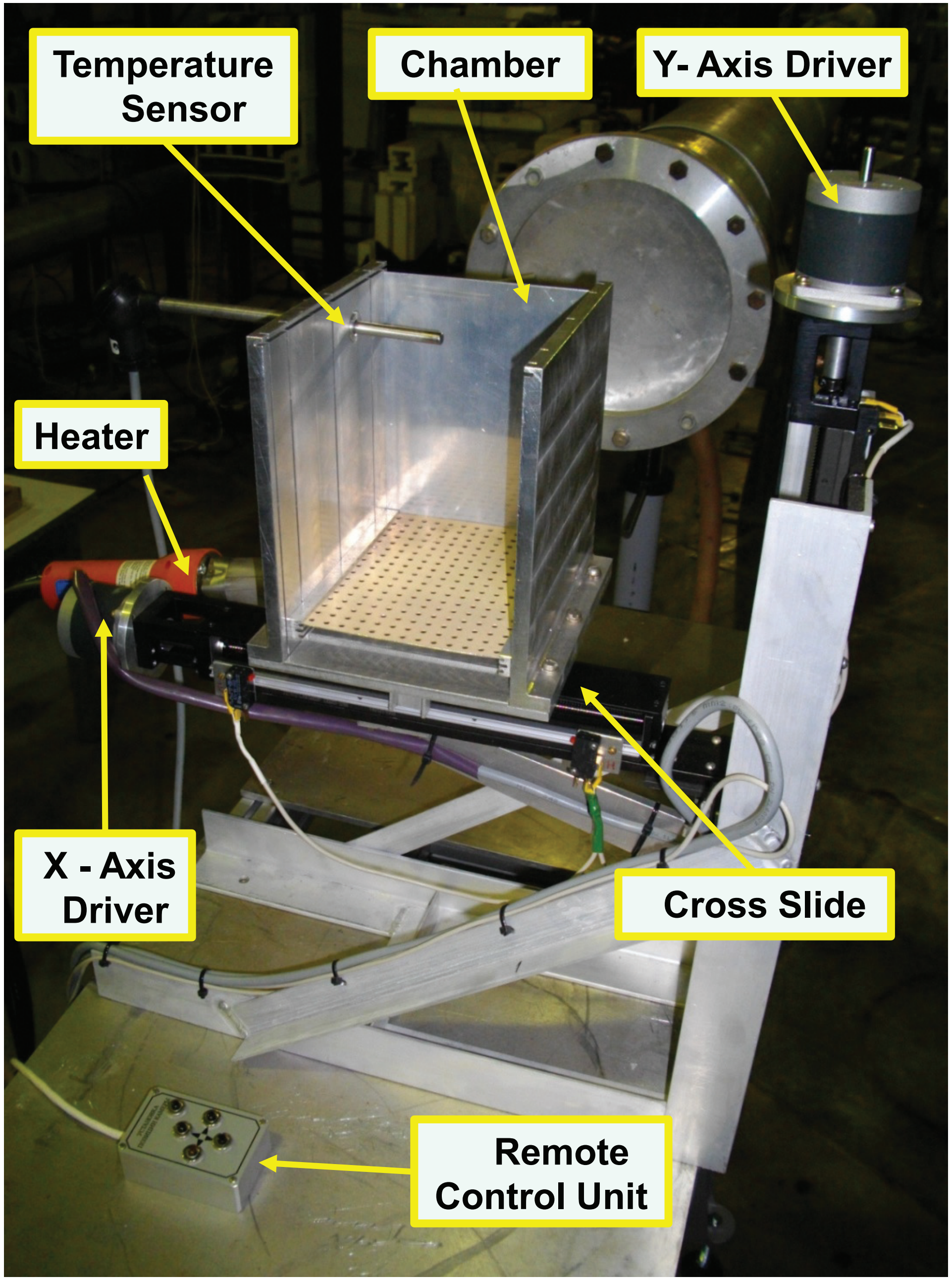
3D-neutron beam profile, Horizontal (X) and Vertical (Y) beam profiles measured with Ø75 mm beam collimator



Neutron Testing Facility ISNP/GNEIS (2015)



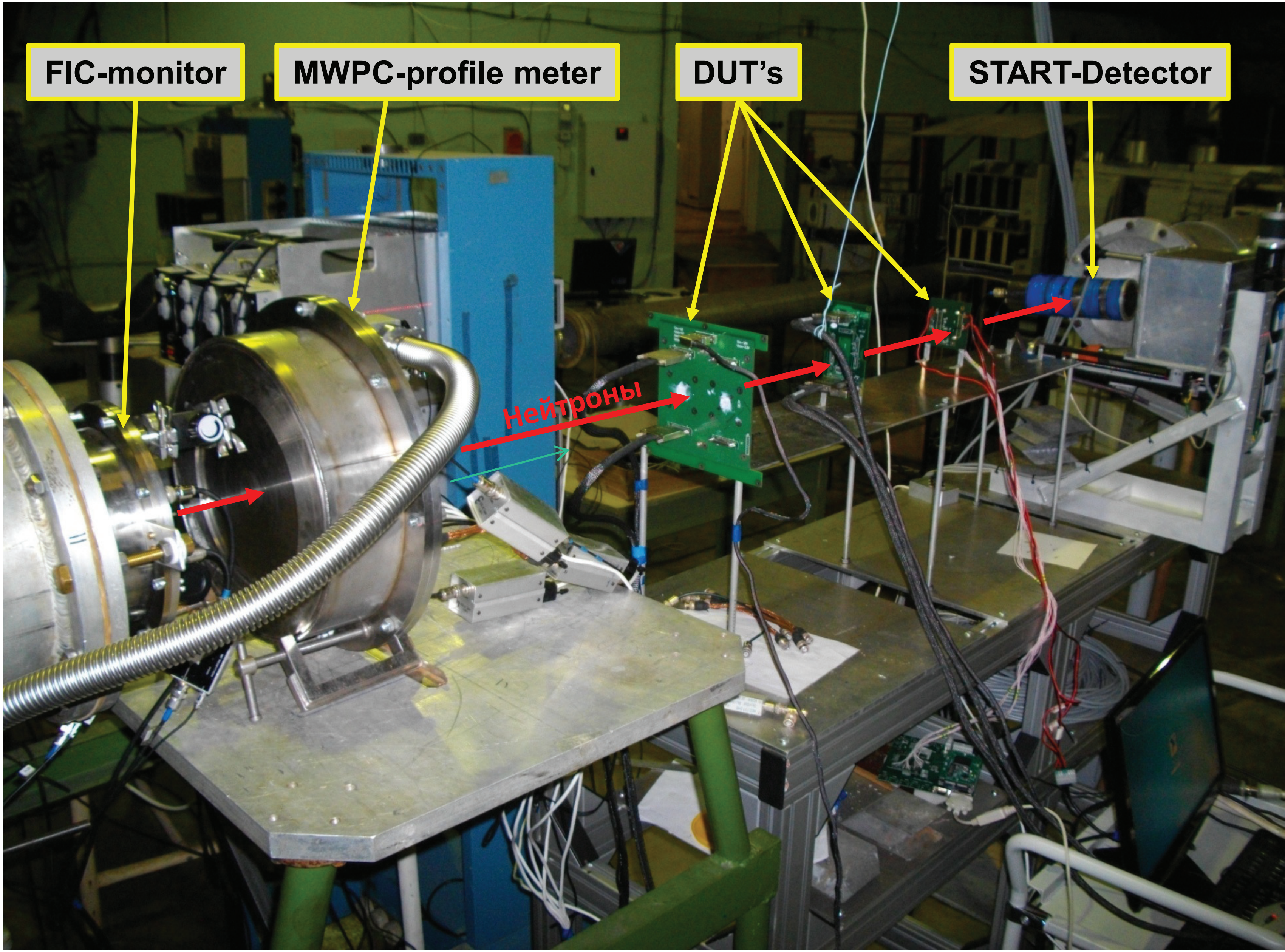
System for DUT (Device Under Test) Positioning and Heating



DUT enclosed in the Heating Chamber can be:

- **heated, temperature range $20^0C – 130^0C$**
- **max. heating / cooling time 300 sec (closed chamber) 600 sec (upper cover removed)**
- **moved along X-Y axes, max. displacement range 200 mm**
- **max. DUT dimensions 150 mm x 150 mm**
- **Distant Computer control**

Neutron Testing Facility at GNEIS (October, 2015)

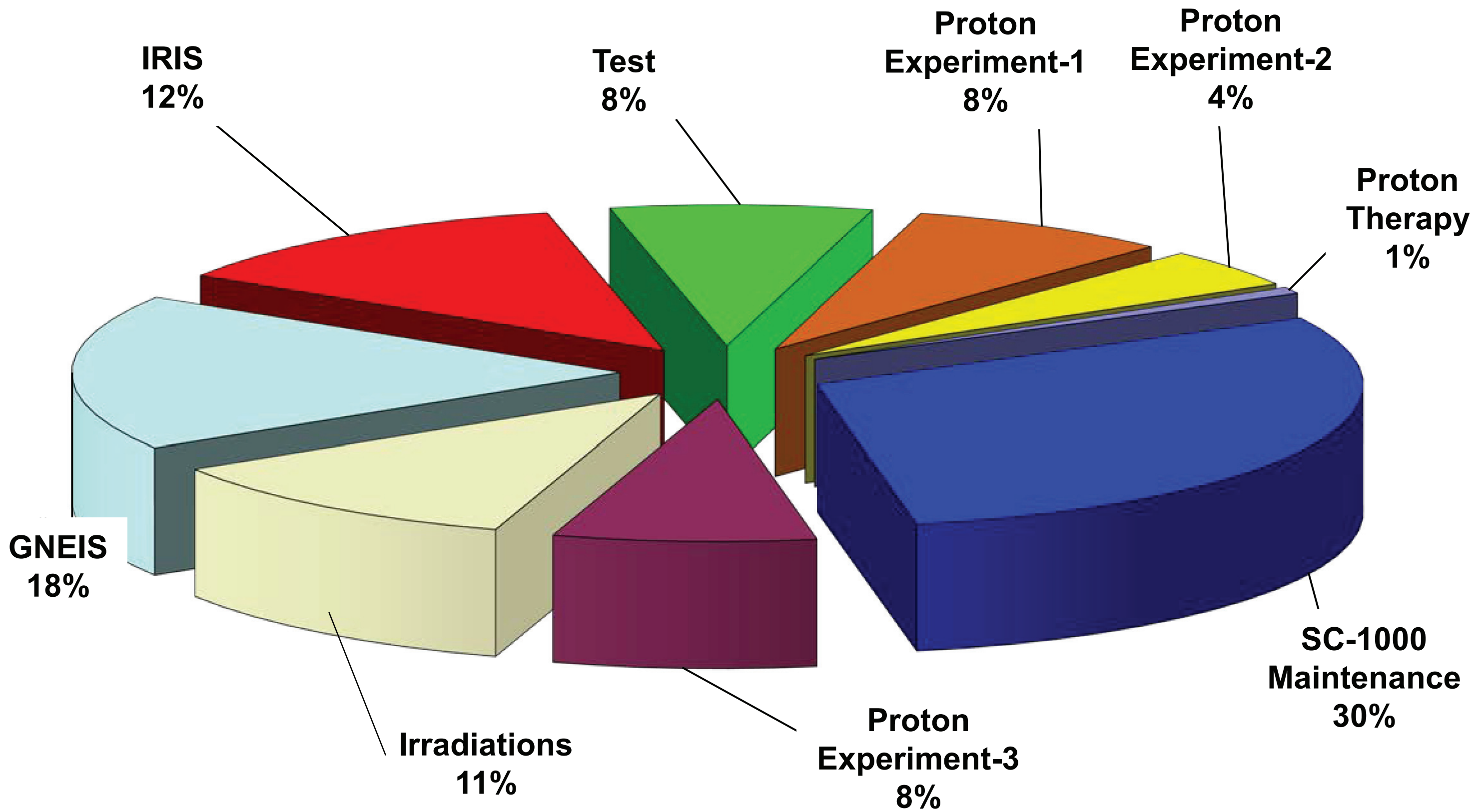


Example of the tests of 6 types of commercial Cypress SRAMs carried out at the ISNP/GNEIS facility

Device type	Process (nm)	Size (bit)	Fluence*) (n/cm^2)	σ_{seu} (cm^2 / bit)
CY7C1021BN - 15ZSXE	250	1 M	$2.0\cdot10^{9}$	$2.3 \cdot 10^{-14}$
CY62256NLL - 55SNXI	90	256 K	$9.2\cdot10^{9}$	$1.5 \cdot 10^{-14}$
UT6264CPCL - 70LL	350	64 K	$1.7\cdot10^{10}$	$3.3 \cdot 10^{-14}$
CY61248ELL - 45ZSXA	90	4 M	$1.0\cdot10^{9}$	$2.3 \cdot 10^{-13}$
CY7C1049CV33 - 12ZSXA	150	4 M	$5.0\cdot10^{8}$	$2.0 \cdot 10^{-14}$
CY7C1049DV33 - 10ZSXI	90	4 M	$6.6\cdot10^{8}$	$7.9 \cdot 10^{-15}$

*) Data presented correspond to neutron fluence in the energy range 10-1000 MeV

Annual operation of the SC-1000
November 2014 – November 2015



Total machine time: 1844 h

SUMMARY

- pulsed spallation neutron source / TOF-spectrometer GNEIS based on the 1 GeV proton synchrocyclotron of PNPI after more than 40 years of operation still is a powerful neutron facility suitable for high-level investigations in basic nuclear physics and applied research;

- high average neutron intensity of $3 \cdot 10^{14}$ n/s and short neutron pulse of 10 ns enable to carry out neutron TOF- measurements in a wide energy range from thermal up to hundreds MeV and high energy resolution;

- unique neutron testing facility ISNP/GNEIS with atmospheric-like neutron spectrum in the energy range 1-1000 MeV and neutron flux of $4 \cdot 10^{5}$ n/cm$^{2}\cdot$sec enables to carry out accelerated SEE-tests of electronic components used in space and avionic equipment;

- GNEIS facility is open for cooperative research for users both from Russia and abroad.


Welcome to GNEIS in Gatchina!


Thank you very much for attention!