Project 2253 : Investigation of the delayed neutron characteristics from the fission of compound nuclei 233Th, 234U, 235U, 244Am, 238Np, 246Cm, 233Pa, 234Pa, 239Np, 240Np at the excitation energies from 5 to 20 MeV

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- **Content**
  - **1. Aim of the project, participants, experimental technique**
  - **2. Main results obtained**
  - **3. Perspectives of the project completion**

Project 2253 : Investigation of the delayed neutron characteristics from the fission of compound nuclei 233Th, 234U, 235U, 244Am, 238Np, 246Cm, 233Pa, 234Pa, 239Np, 240Np at the excitation energies from 5 to 20 MeV

- **Project 2253 12 months, completed by 01.01.2005**
- **Project 2253.2 12 months, under way till 30.07.2007**
- **160Keuro - financing Party EU**

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- *Participants of the project:*

- *Joint Institute for Nuclear Research (JINR),*
  Frank Laboratory of Neutron Physics, Dubna
  Leader- W.I. Furman

- *State Scientific Center of Russian Federation – Institute for Physics and Power Engineering named after Acad. A.I. Leipunsky (IPPE), Nuclear Reaction Laboratory, Obninsk*
  Leader V.M. Piksaikin

- *Russian Federal Nuclear Center - Experimental Physics Institute, Nuclear and Radiation Physics Institute (VNIIEF*), Sarov
  Leader- V.A. Zavgorodny

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- *Foregn collaborators:*

- *Danas Ridikas*

  CEA Saclay – DSM/DAPNIA/SPHN, France
- *Antonio D'Angelo*

  ERG/SIEC/SISTRU ENEA/Casaccia, Italy
- *Gregory D. Spriggs*

  Lawrence Livermore National Laboratory, USA

Project 2253 : Investigation of the delayed neutron characteristics from the fission of compound nuclei 233Th, 234U, 235U, 244Am, 238Np, 246Cm, 233Pa, 234Pa, 239Np, 240Np at the excitation energies from 5 to 20 MeV

- *Facilities:*
- *JINR- the pulsed reactor IBR-2, beam line #11b, set-up "IZOMER-M" for the investigation of delayed neutron yields and decay curves from the thermal neutron induced fission of heavy nuclei.*
- *IPPE- the electrostatic accelerator EG-2.5, set-up for investigation of delayed neutron parameters in fast neutron induced fission of heavy nuclei including neutron detectors, data processing system, sample transportation system and computers for experimental data processing*
- *VNIIEF- the tandem electrostatic accelerator EGP-10 in pulsed regime, 4π-detector of neutrons, the experimental facility for the measurements of delayed neutron yields from the charged particle induced fission of heavy nuclei*

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- *Motivations*
- *Any concept of the nuclear waste transmutation or disposal will to a large extent depend on the accuracy of our knowledge of the basic nuclear data for MA.*
- *The fundamental role of delayed neutrons in the safety operation and time-dependant behavior of nuclear reactors has been well known and is now a matter of practical experience in hundreds of nuclear installations around the world.*
- *A satisfactory evaluation of the macroscopic effects of the delayed neutrons following fission in a nuclear reactor requires, among other data, an accurate knowledge of the delayed neutron data.*

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- ***Those data that of great importance to the kinetics and safety operations of nuclear reactors (including the ADS) are the absolute yield of DN (delayed neutrons), relative abundances of DN, half-lives of their precursors, and energy spectra of DN.***
- ***In spite of great efforts devoted to the investigation of delayed neutron physics, these fundamental delayed neutron characteristics of even the most common fissionable isotopes encountered in reactor systems are still insufficiently known and are now under investigation***
- ***For example, the experiments conducted at IPPE accelerators have shown that the relative abundances and half-lives of DN incorporated into ENDF/B-VI library and obtained on the basis of the summation techniques systematically deviate from appropriate experimental data***

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- ***Reactor experiments have shown that ENDF/B-VI group parameters for 235U underestimate the reactivity by 2 to 47% in the range from +0.80 to –0.80$ as compared to experimental data.***
- ***Especially large discrepancies are found for plutonium and americium isotopes. Such results point out to the need for improvement of accuracy of experimental data as a basis for evaluation.***
- ***The experimental studies of the total delayed neutron yields from neutron induced fission of 237Np made at IPPE and JINR show the prominent energy dependence of this value in the energy range above the threshold of the (n,f) reaction . This gives the definite indication that the constant value of the total DN yield accepted for the energy range from thermal to 4 MeV in the ENDF/B-VI data base for all elements must be carefully tested.***

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- ***The energy spectrum of the delayed neutrons is probably the poorest known of all input data required in the calculation of effective delayed neutron and fractions which largely determines the kinetic behavior and control margins of any fission chain reactor.***
- ***The energy spectrum of delayed neutrons incorporated in ENDF/B-VI data library is calculated using known fission charge and mass distribution and the knowledge of neutron emission probabilities and energy spectra from individual DN precursors.***
- ***However as this summation method used in deriving the DN spectra needs in serious testing.***
- ***Therefore at present the most reliable data related to the DN spectra for any fissionable spices including MA nuclides are connected with experimental determination.***

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- ***Main objective of the Project #2253***

  (including successfully completed the first stage 01.01.2004 - 31.12.2004)
  is the measurements of

- ***the total delayed neutron yields, the relative yields and half-lives of separate delayed neutron groups from the fast neutron induced fission of 232Th, 233U, 234,236U, 241,243Am***
- ***the energy spectrum of delayed neutrons from the thermal neutron induced fission of 235U and the fast neutron induced fission of 237Np,***
- ***the total delayed neutron yields from the thermal neutron induced fission of 237Np and 245Cm***
- ***the total delayed neutron yields from the proton and deuteron induced fission of 232Th and 238U in the energy range of ~10-10.5 MeV***
- ***It should be noted that the content of primary plan of the project was expanded. The additional isotopes 241Am, 235,236U and 239Pu have been added to the list of nuclides to be investigated in the frame of 2253.2 project.***

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As a result of implementation of the ISTC project #2253.2 the following experimental data have to be obtained:

- ***the total delayed neutron yields from the thermal neutron induced fission of 245Cm (JINR&VNIIEF);***
- ***the absolute total delayed neutron yields from proton and deuteron induced fission of 232Th and 238U at one energy point in the energy range from ~10 MeV to 10.5 MeV (VNIIEF);***
- ***the absolute total delayed neutron yields, relative yields and half-lives of delayed neutron groups from neutron induced fission of 236U in the energy range from ~1.0 MeV up to 5 MeV (IPPE);***
- ***the absolute total delayed neutron yields, relative yields and half-lives of delayed neutron groups from the fast neutron induced fission of 234U, 243Am (IPPE&VNIIEF);***
- ***the integral energy spectrum and spectra of separate delayed neutron groups from the fast neutron induced fission of 237Np (IPPE)***

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Main results of ISTC projects #2253
and preliminary results of the project #2253.2
(completion on 31.07.2007)

- ***TASK 1 – JINR (+ VNIIEF –active target 245Cm)***
- ***TASK 2 – VNIIEF***
- ***TASK 3 – IPPE (+ VNIIEF – targets 234U , 243Am)***

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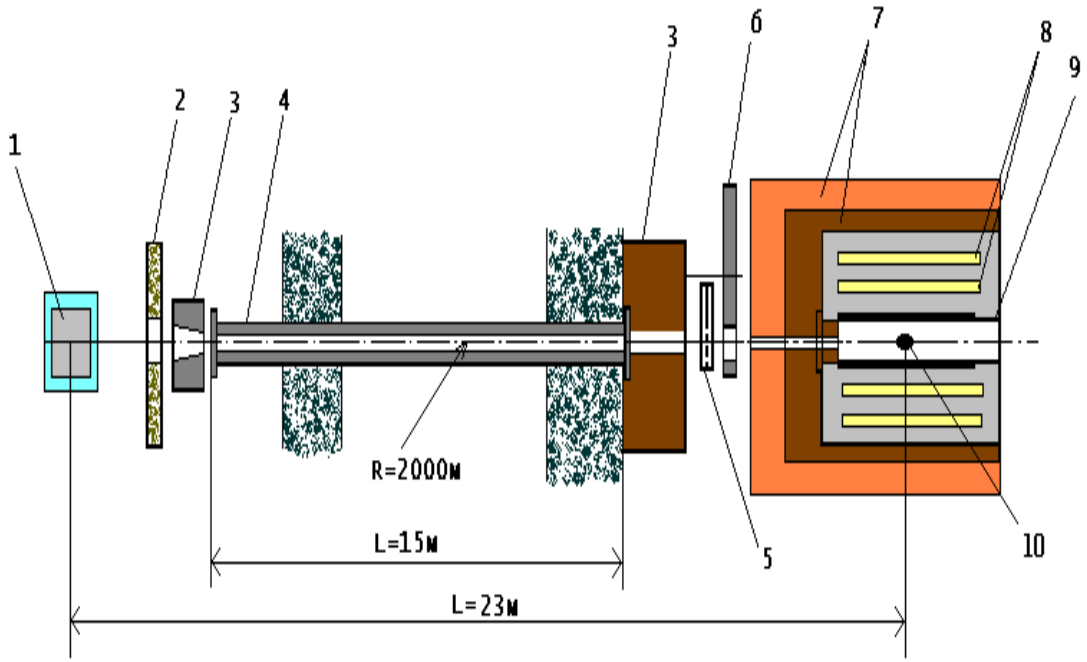
JINR

Task 1

237Np and 245Cm



Layout of **IZOMER-M facility**: 1 – IBR-2 reactor, 2, 3 – collimators, 4 – bended mirror neutron guide, 5 – Cd-shutter, 6 – chopper, 7 – detection assembly, 8 – 3He-counters, 9 – Cd-screen, 10 – sample

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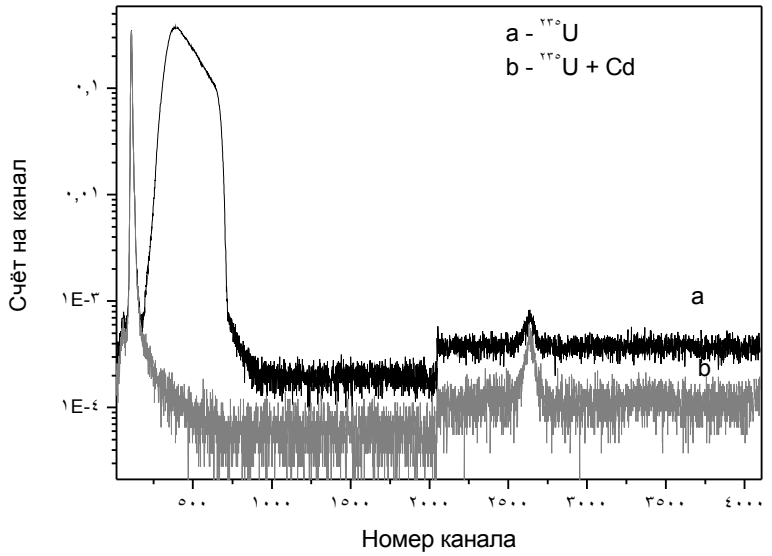
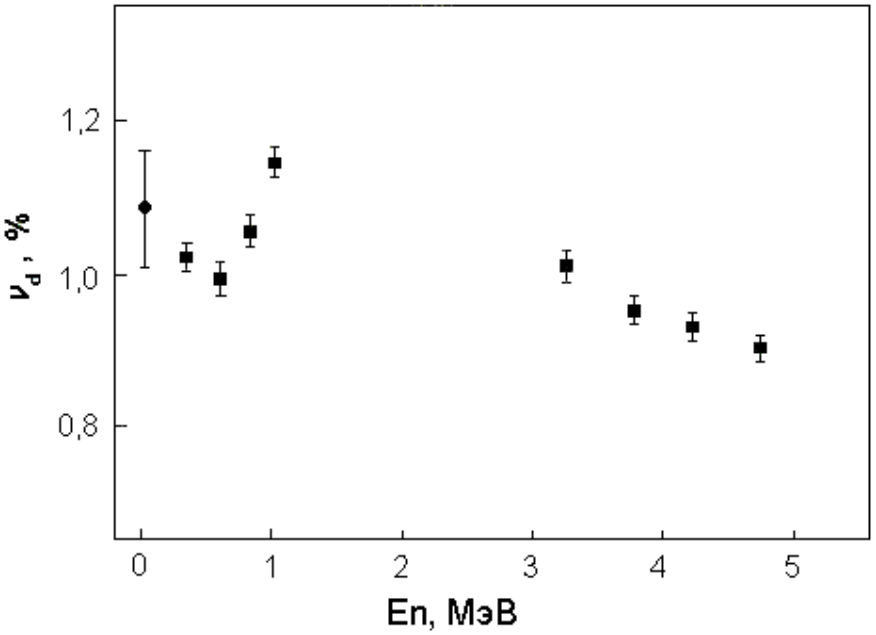
- $$N_d(t_i,t_j) = C\varepsilon_d \sum_{s=1}^{6} \frac{a_s}{\lambda_s}(1 - e^{-\lambda_s T})(e^{-\lambda_s t_i} - e^{-\lambda_s t_j})/(1 - e^{-\lambda_s \tau})$$

$$\sum_{s=1}^{6} a_s = \nu_d$$

C=N_f for one pulse



Project 2253 : Investigation of the delayed neutron characteristics from the fission of compound nuclei 233Th, 234U, 235U, 244Am, 238Np, 246Cm, 233Pa, 234Pa, 239Np, 240Np at the excitation energies from 5 to 20 MeV



Energy dependence of total DN yield for 237Np: circle JINR,Gundorin et al; squares- IPPE, Piksaikin et al.

^{237}Np

v_d=0,0110±0,0009.

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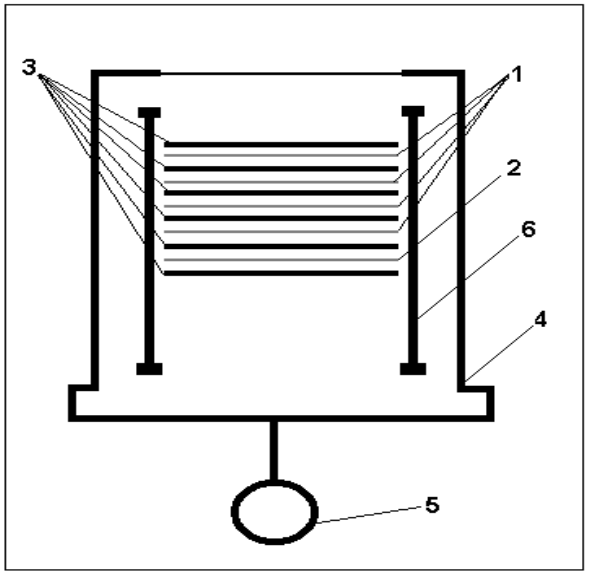

Layout of fission ionization chamber with 245Cm. 1 - Ni-anodes with isotope 245Cm, 2 - anode with isotope 235U, 3 - Ni-cathodes, 4 - framework, 5 - pressure gauge, 6 – jacket of the chamber.

^{245}Cm

JINR+VNIIEF

^{245}Cm – 95,5%
^{244}Cm – 3,8%
^{246}Cm – 0,7%
} Spontaneous fission

N_{sf} ~1000 / s
from ^{244}Cm& ^{246}Cm ⇒Active target
⇒anticoincidence

N_d (expected) ~ 20/s

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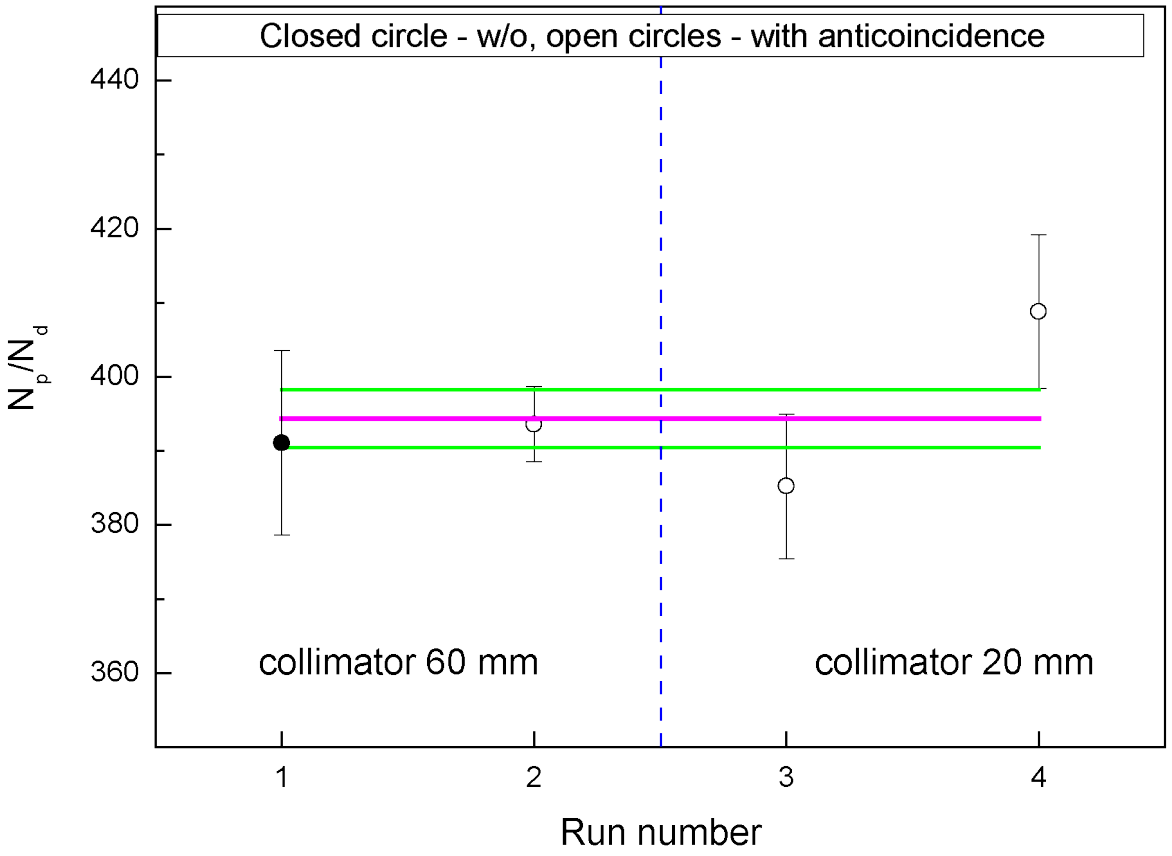
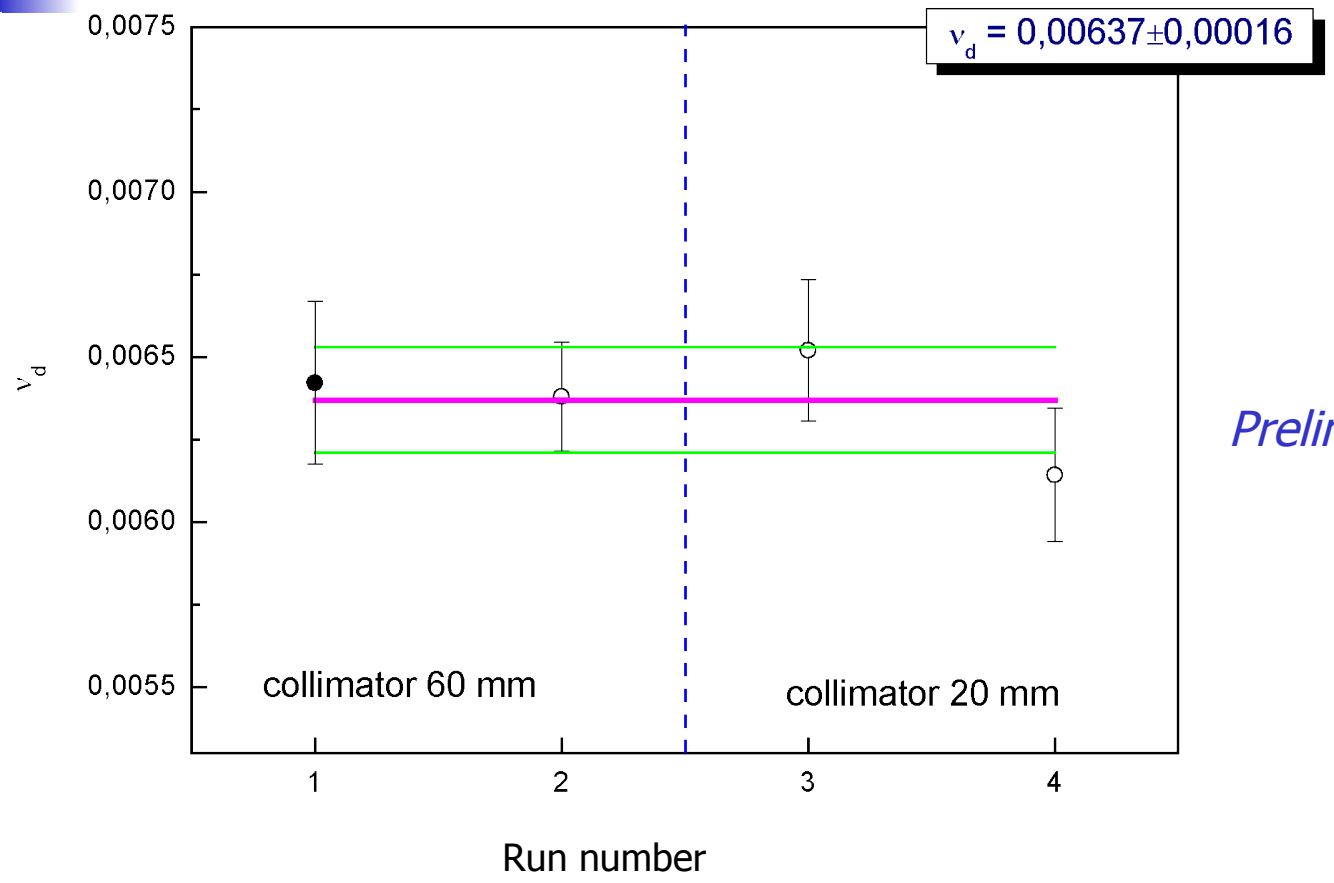


^{245}Cm

Project 2253 : Investigation of the delayed neutron characteristics from the fission of compound nuclei 233Th, 234U, 235U, 244Am, 238Np, 246Cm, 233Pa, 234Pa, 239Np, 240Np at the excitation energies from 5 to 20 MeV



^{245}Cm

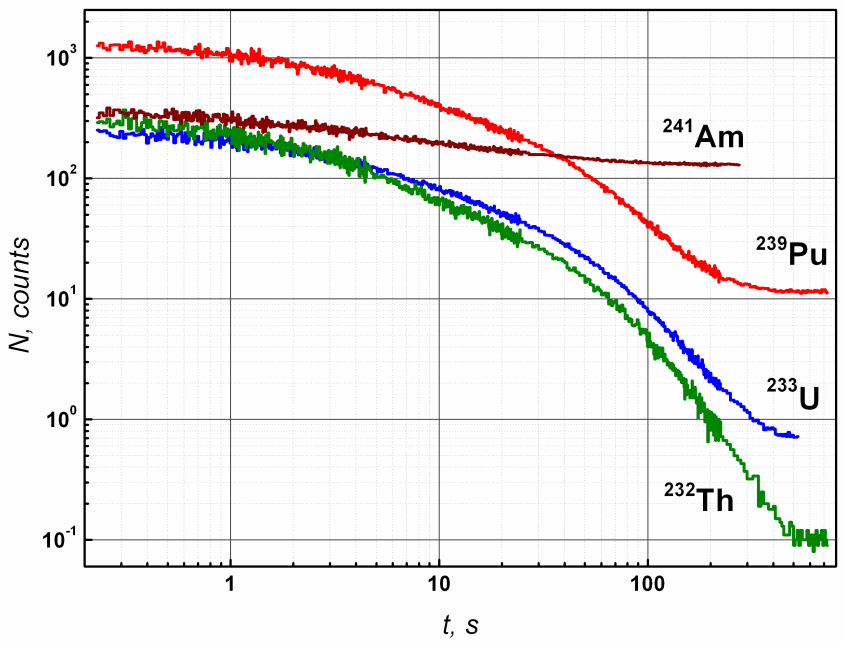
Preliminary result

Project 2253 : Investigation of the delayed neutron characteristics from the fission of compound nuclei 233Th, 234U, 235U, 244Am, 238Np, 246Cm, 233Pa, 234Pa, 239Np, 240Np at the excitation energies from 5 to 20 MeV

IPPE

Task 1

232Th, 233-236U, 237Np, 239Pu, 241,243Am



Experimental delayed neutron activity measured after the end of irradiation of 233U, 239Pu, 232Th and 241Am samples by fast neutrons

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$$N(t_k) = A \cdot \sum_{i=1}^{m} T_i \cdot \frac{a_i}{\lambda_i} \cdot (1 - e^{-\lambda_i \cdot \Delta t_k}) \cdot e^{-\lambda_i \cdot t_k} + B \cdot \Delta t_k$$

$$T_i = (1 - e^{-\lambda_i \cdot t_{irr}}) \cdot \left(\frac{n}{1 - e^{-\lambda_i \cdot T}} - e^{-\lambda_i \cdot T} \cdot \left(\frac{1 - e^{-n \cdot \lambda_i \cdot T}}{((1 - e^{-\lambda_i \cdot T})^2} \right) \right)$$

$$A = \varepsilon_n \, \sigma_f \, \varphi \, n_f \, \nu_d,$$

$$< T > = \sum_{j=1}^{6} T_j \cdot a_j \quad (\Sigma a_j = 1)$$

$$\ln[\nu_d(E_n)] = c + d \cdot \ln[< T(E_n) >]$$

$$\nu_d = \frac{\left[\sum_{t_1}^{t_2} N(t_k) - B(t_2 - t_1) \right]}{< \varepsilon_n > \cdot R_s \cdot \sum_{i=1}^{6} \left[T_i \cdot \frac{a_i}{\lambda_i} \cdot \left(e^{-\lambda_i \cdot t_1} - e^{-\lambda_i \cdot t_2} \right) \right]}$$

$$R_s = \sigma_f \varphi \, n_f$$

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E_n, MeV	Group number							<T>, s
	i	١	٢	٣	٤	٥	٦	
٠.٣٧± ٠.٠٦	a_i	٠.٠٣٧ ± ٠.٠٠١	٠.٢٩٥ ± ٠.٠٠٦	٠.٢١٢ ± ٠.٠٠٥	٠.٣١٩ ± ٠.٠٠٥	٠.١٠٣ ± ٠.٠٠٣	٠.٠٣٤ ± ٠.٠٠١	١٠.٣٦ ± ٠.١٥
	T_i	٥٢.٠٩ ± ٠.٤١	٢٢.٣٤ ± ٠.١١	٥.٢٦ ± ٠.٠٧	٢.٠٦ ± ٠.٠٤	٠.٥٤٣ ± ٠.٠١٥	٠.٢١٨ ± ٠.٠٠٦	
٠.٦٢± ٠.٠٦	a_i	٠.٠٣٧ ± ٠.٠٠١	٠.٢٩٥ ± ٠.٠٠٧	٠.٢١٧ ± ٠.٠٠٦	٠.٣٢١ ± ٠.٠٠٧	٠.٠٩٦ ± ٠.٠٠٣	٠.٠٣٤ ± ٠.٠٠١	١٠.٤٧ ± ٠.١٧
	T_i	٥٣.١٩ ± ٠.٤٩	٢٢.٤٤ ± ٠.١٢	٥.٣٠ ± ٠.٠٨	٢.٠٩ ± ٠.٠٤	٠.٥٦٨ ± ٠.٠١٩	٠.٢١٤ ± ٠.٠٠٨	
٠.٨٦± ٠.٠٦	a_i	٠.٠٣٧ ± ٠.٠٠١	٠.٢٨٩ ± ٠.٠٠٥	٠.٢١٦ ± ٠.٠٠٥	٠.٣٢٢ ± ٠.٠٠٥	٠.١٠٢ ± ٠.٠٠٣	٠.٠٣٤ ± ٠.٠٠١	١٠.٢٧ ± ٠.١٣
	T_i	٥٣.٨١ ± ٠.٤١	٢٢.١٩ ± ٠.١٠	٥.٢٥ ± ٠.٠٧	٢.٠٦ ± ٠.٠٣	٠.٥٤٧ ± ٠.٠١٦	٠.٢١٧ ± ٠.٠٠٦	
١.٠٦± ٠.٠٦	a_i	٠.٠٣٨ ± ٠.٠٠١	٠.٢٩٢ ± ٠.٠٠٤	٠.٢١٤ ± ٠.٠٠٤	٠.٣٢٠ ± ٠.٠٠٤	٠.١٠١ ± ٠.٠٠٢	٠.٠٣٥ ± ٠.٠٠١	١٠.٣٧ ± ٠.١١
	T_i	٥٣.٥١ ± ٠.٣٣	٢٢.٢٣ ± ٠.٠٩	٥.١١ ± ٠.٠٥	٢.١٥ ± ٠.٠٣	٠.٥٥٥ ± ٠.٠١٢	٠.٢١٥ ± ٠.٠٠٥	
٣.٢٧± ٠.١٤	a_i	٠.٠٣٨ ± ٠.٠٠١	٠.٢٧١ ± ٠.٠٠٧	٠.٢٢٠ ± ٠.٠٠٦	٠.٣٣٢ ± ٠.٠٠٨	٠.١٠٤ ± ٠.٠٠٣	٠.٠٣٥ ± ٠.٠٠١	١٠.٠٦ ± ٠.١٩
	T_i	٥٥.٢٩ ± ١.٤٥	٢٢.٢٣ ± ٠.٢٩	٥.١١ ± ٠.١٣	٢.١٦ ± ٠.٠٦	٠.٥٤٧ ± ٠.٠١٦	٠.٢١٦ ± ٠.٠٠٦	
٣.٨١± ٠.١١	a_i	٠.٠٣٨ ± ٠.٠٠١	٠.٢٤٧ ± ٠.٠٠٤	٠.٢٢٧ ± ٠.٠٠٤	٠.٣٤٨ ± ٠.٠٠٥	٠.١٠٥ ± ٠.٠٠٢	٠.٠٣٥ ± ٠.٠٠١	٩.٦٨ ± ٠.١١

The energy dependence of relative abundances and periods of delayed neutrons from fission of 239Pu.

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٤.٢٧± ٠.١١	a_i	٠.٠٣٨ ± ٠.٠٠١	٠.٢٤٣ ± ٠.٠٠٥	٠.٢٣٠ ± ٠.٠٠٥	٠.٣٤٨ ± ٠.٠٠٦	٠.١٠٦ ± ٠.٠٠٣	٠.٠٣٥ ± ٠.٠٠١	٩.٦٥ ± ٠.١٤
	T_i	٥٦.٦٨ ± ٠.٦٥	٢٢.٤٩ ± ٠.١٨	٥.٣١ ± ٠.٠٨	٢.١٠ ± ٠.٠٤	٠.٥٥٤ ± ٠.٠١٦	٠.٢١٧ ± ٠.٠٠٦	
٤.٨١± ٠.١٣	a_i	٠.٠٣٩ ± ٠.٠٠١	٠.٢٣٨ ± ٠.٠٠٤	٠.٢٢٨ ± ٠.٠٠٤	٠.٣٥٥ ± ٠.٠٠٥	٠.١٠٥ ± ٠.٠٠٣	٠.٠٣٥ ± ٠.٠٠١	٩.٦٢ ± ٠.١١
	T_i	٥٧.٤٩ ± ٠.٤٩	٢٢.٥٤ ± ٠.١٤	٥.٣٢ ± ٠.٠٧	٢.١٠ ± ٠.٠٣	٠.٥٥٤ ± ٠.٠١٤	٠.٢١٧ ± ٠.٠٠٥	
٤.٩٧± ٠.١٣	a_i	٠.٠٣٩ ± ٠.٠٠١	٠.٢٤٣ ± ٠.٠٠٦	٠.٢٣٢ ± ٠.٠٠٦	٠.٣٤١ ± ٠.٠٠٨	٠.١٠٩ ± ٠.٠٠٤	٠.٠٣٦ ± ٠.٠٠١	٩.٥٩ ± ٠.١٦
	T_i	٥٨.١٧ ± ٠.٦٥	٢٢.٠٤ ± ٠.١٩	٤.٩٢ ± ٠.٠٩	٢.١٧ ± ٠.٠٥	٠.٥٥٣ ± ٠.٠١٩	٠.٢١٧ ± ٠.٠٠٨	
١٥.٨ ± ٠.١	a_i	٠.٠٥٤ ± ٠.٠٠١	٠.١٨٥٧ ± ٠.٠٠٤	٠.٢٤١ ± ٠.٠٠٦	٠.٣٦٢ ± ٠.٠٠٨	٠.١١٨ ± ٠.٠٠٣	٠.٠٣٩ ± ٠.٠٠١	٨.٩٢ ± ٠.٣٤
	T_i	٥٥.٧٦ ± ٠.٦٩	٢٠.٩٧ ± ٠.٢٧	٤.٧٥ ± ٠.٠٩	٢.١٣ ± ٠.٠٥	٠.٥٦ ± ٠.٠٢	٠.٢١٥ ± ٠.٠٠٦	
١٦.٨ ± ٠.١	a_i	٠.٠٥٦ ± ٠.٠٠١	٠.٢٠٣ ± ٠.٠٠٥	٠.٢٣٤ ± ٠.٠٠٦	٠.٣٤٨ ± ٠.٠٠٨	٠.١١٩ ± ٠.٠٠٤	٠.٠٣٩ ± ٠.٠٠١	٩.١٩ ± ٠.٣٥
	T_i	٥٥.٤٤ ± ٠.٧٣	٢٠.٥٣ ± ٠.٢٦	٤.٦٨ ± ٠.٠٩	٢.١٧ ± ٠.٠٥	٠.٥٥ ± ٠.٠٢	٠.٢١٥ ± ٠.٠٠٦	
١٧.٩ ± ٠.١	a_i	٠.٠٥٦ ± ٠.٠٠١	٠.٢٢٩ ± ٠.٠٠٦	٠.٢٣٣ ± ٠.٠٠٦	٠.٣١٨ ± ٠.٠٠٧	٠.١٢٤ ± ٠.٠٠٤	٠.٠٤٠ ± ٠.٠٠١	٩.٨٠ ± ٠.٣٨
	T_i	٥١.٦٢ ± ٠.٧٢	٢١.٥٤ ± ٠.٢٦	٥.٠٤ ± ٠.١٠	٢.٢٨ ± ٠.٠٦	٠.٥٣ ± ٠.٠٢	٠.٢١٧ ± ٠.٠٠٦	

Project 2253 : Investigation of the delayed neutron characteristics from the fission of compound nuclei 233Th, 234U, 235U, 244Am, 238Np, 246Cm, 233Pa, 234Pa, 239Np, 240Np at the excitation energies from 5 to 20 MeV

Correlations matrix of delayed neutron group parameters related to 0.37 MeV neutron induced fission of 239Pu.

	a_1	T_1	a_2	T_2	a_3	T_3	a_4	T_4	a_5	T_5	a_6	T_6
a_1	١											
T_1	٠	١										
a_2	٠	٠.١٧٧	١									
T_2	٠	-٠.١٨	٠.٠٩	١								
a_3	٠	٠.٢٦	٠.٤١	٠.٣٣	١							
T_3	٠	-٠.١٣	-٠.١٦	٠.٦٥	-٠.٢٢	١						
a_4	٠	٠.٤٣	٠.٦	٠.٤٥	-٠.٠٧	٠.٥١	١					
T_4	٠	٠.٠٨	٠.١٤	٠.٠١	-٠.٤٦	٠.٠	٠.١٢	١				
a_5	٠	٠.٠٨	٠.١١	٠.٠٦	٠.٠٢	٠.٠٣	-٠.٠٥	٠.١٩	١			
T_5	٠	٠.٠٤	٠.٠٦	٠.٠٥	٠.٠١	٠.٠٥	-٠.٠٧	٠.٠٩	٠	١		
a_6	٠	٠.٠١	٠.٠٢	٠.٠١	٠	٠	٠	٠.٠٣	-٠.٠١	٠	١	
T_6	٠	٠.٠١	٠.٠٢	٠.٠١	٠	٠	٠	٠.٠٤	-٠.٠١	٠	٠	١

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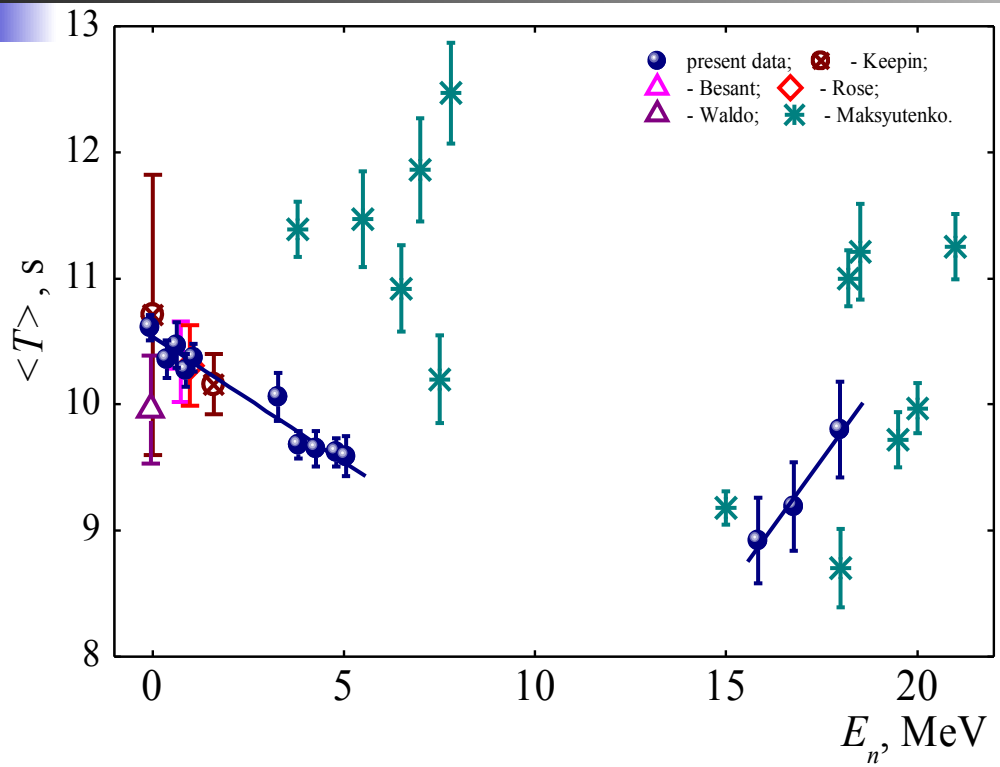

^{239}Pu

The energy dependence of average half-life of delayed neutron precursors from neutron induced fission of 239Pu

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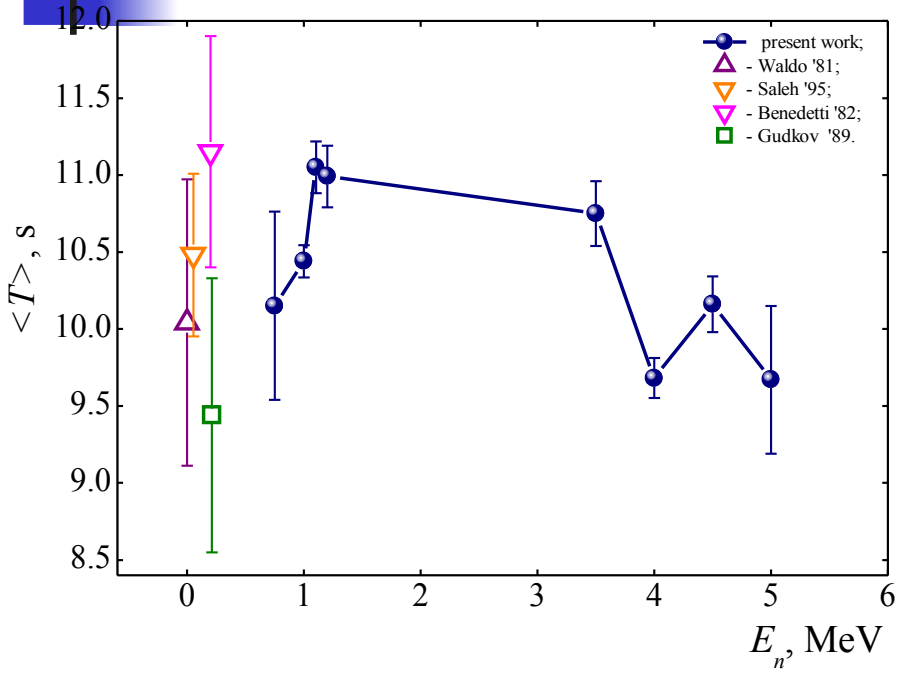

The energy dependence of average half-life of delayed neutron precursors from neutron induced fission of 241Am

^{241}Am

(*Obtained for the first time*)

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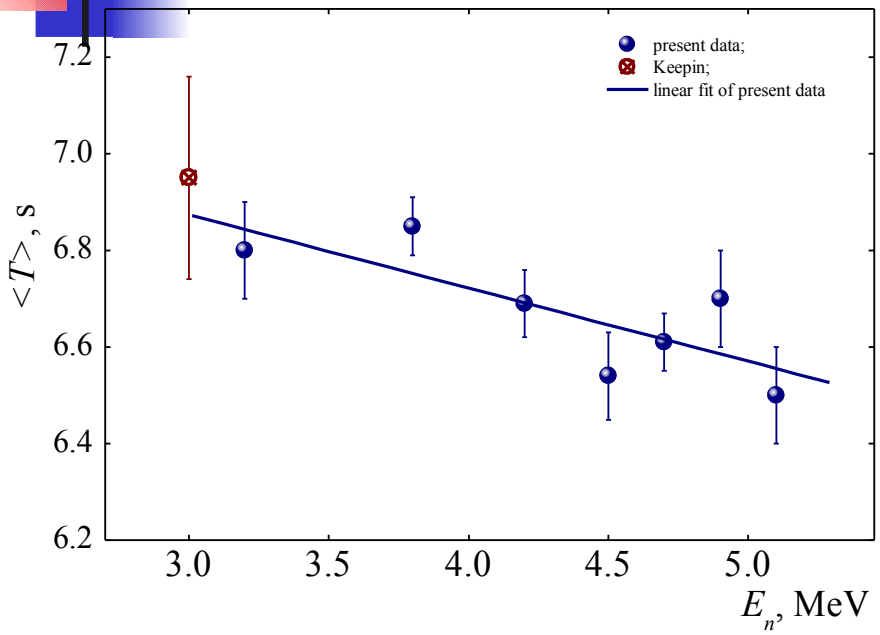

The energy dependence of average half-life of delayed neutron precursors from neutron induced fission of 232Th

^{232}Th

(Obtained for the first time)

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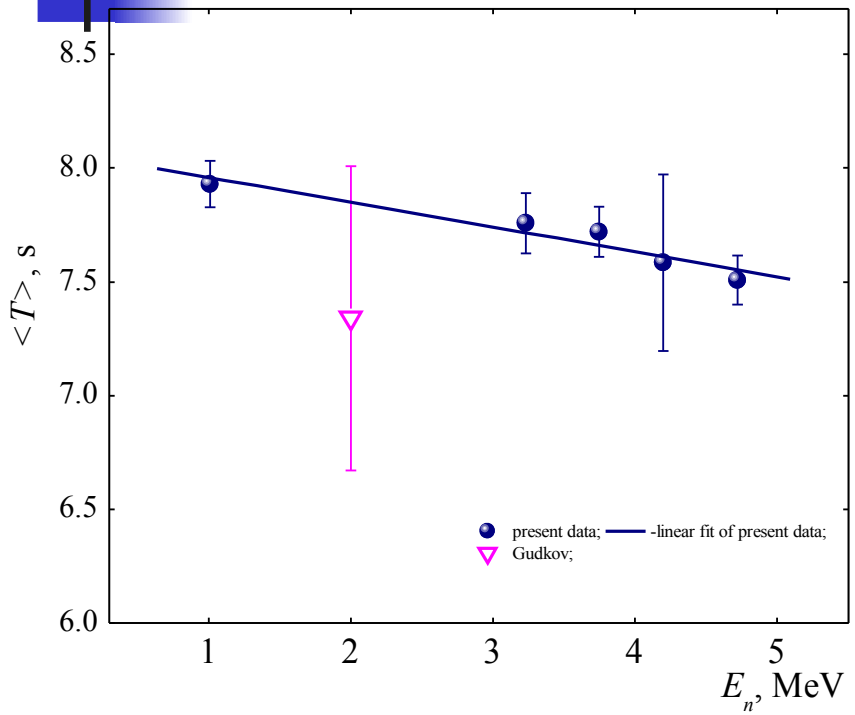

The energy dependence of average half-life of delayed neutron precursors from neutron induced fission of 236U

^{236}U

(*Obtained for the first time*)

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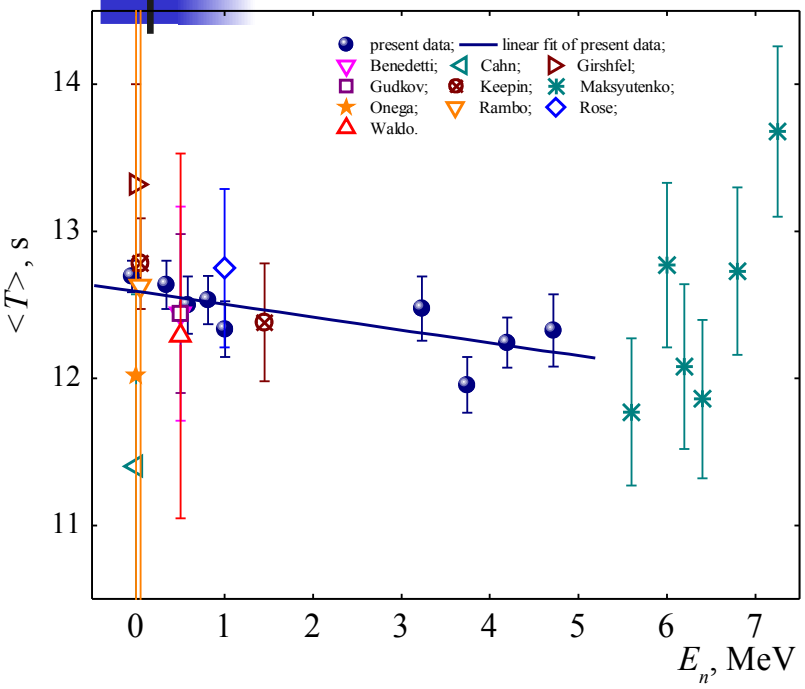
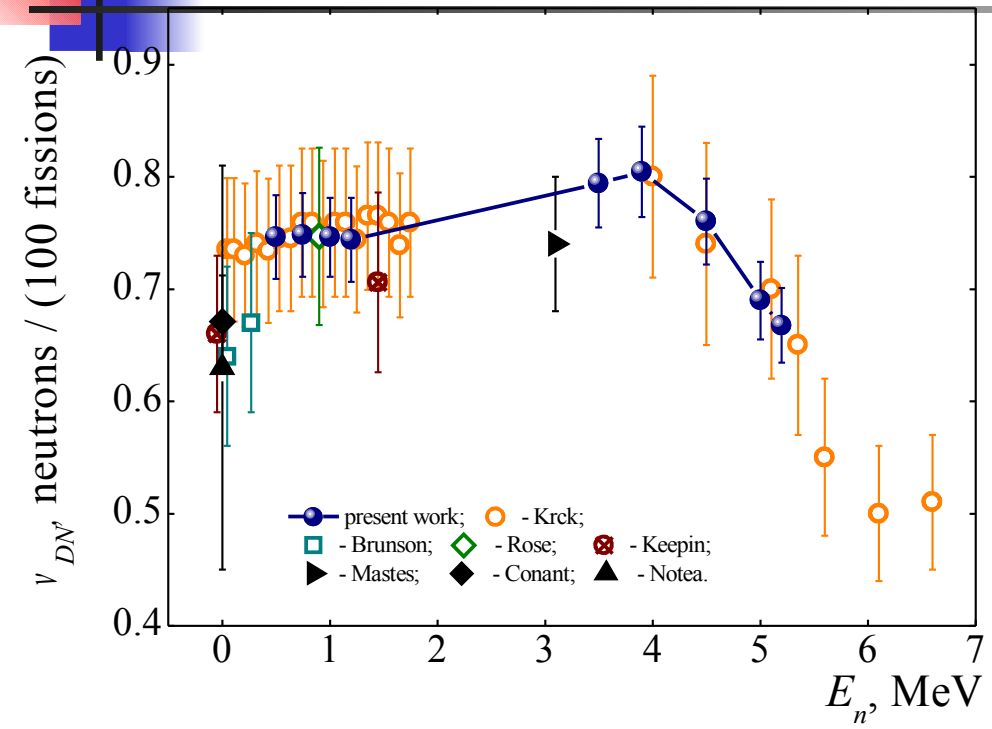


^{233}U

The energy dependence of average half-life of delayed neutron precursors from neutron induced fission of 233U

Project 2253 : Investigation of the delayed neutron characteristics from the fission of compound nuclei 233Th, 234U, 235U, 244Am, 238Np, 246Cm, 233Pa, 234Pa, 239Np, 240Np at the excitation energies from 5 to 20 MeV

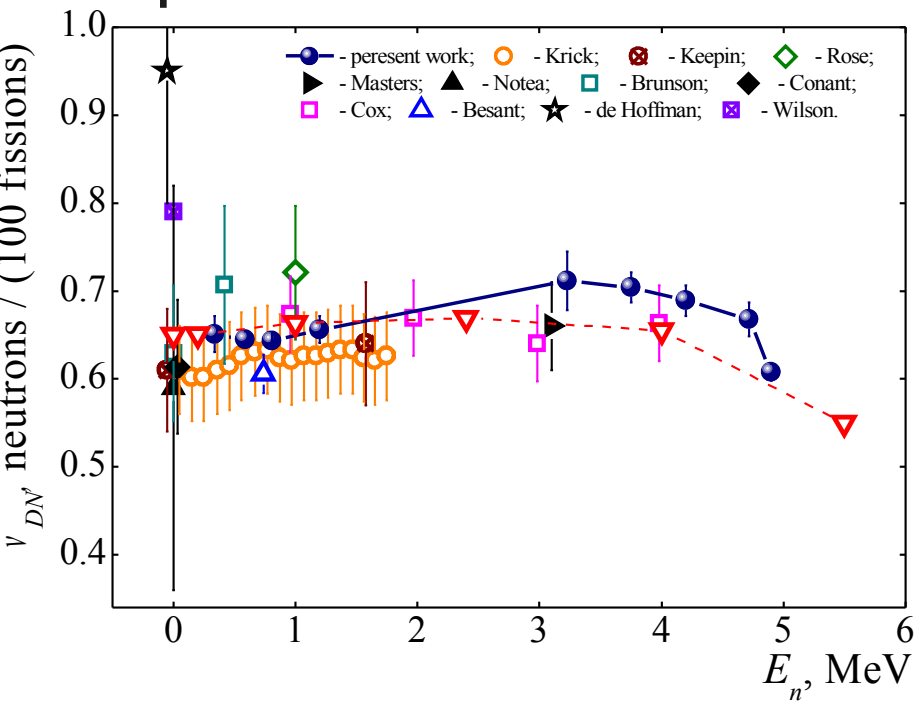


^{233}U

$$\nu_d = \frac{\left[\sum_{t_1}^{t_2} N(t_k) - B(t_2 - t_1)\right]}{\langle \varepsilon_n \rangle \cdot R_s \cdot \sum_{i=1}^{6} \left[T_i \cdot \frac{a_i}{\lambda_i} \cdot \left(e^{-\lambda_i \cdot t_1} - e^{-\lambda_i \cdot t_2}\right)\right]}$$

The energy dependence of the total delayed neutron yield from fission of 233U

Project 2253 : Investigation of the delayed neutron characteristics from the fission of compound nuclei 233Th, 234U, 235U, 244Am, 238Np, 246Cm, 233Pa, 234Pa, 239Np, 240Np at the excitation energies from 5 to 20 MeV



^{239}Pu

The energy dependence of the total delayed neutron yield from fission of 239Pu

(*Open up triangles – the latest evaluation by D'Angelo, Rowlands and Fort*)

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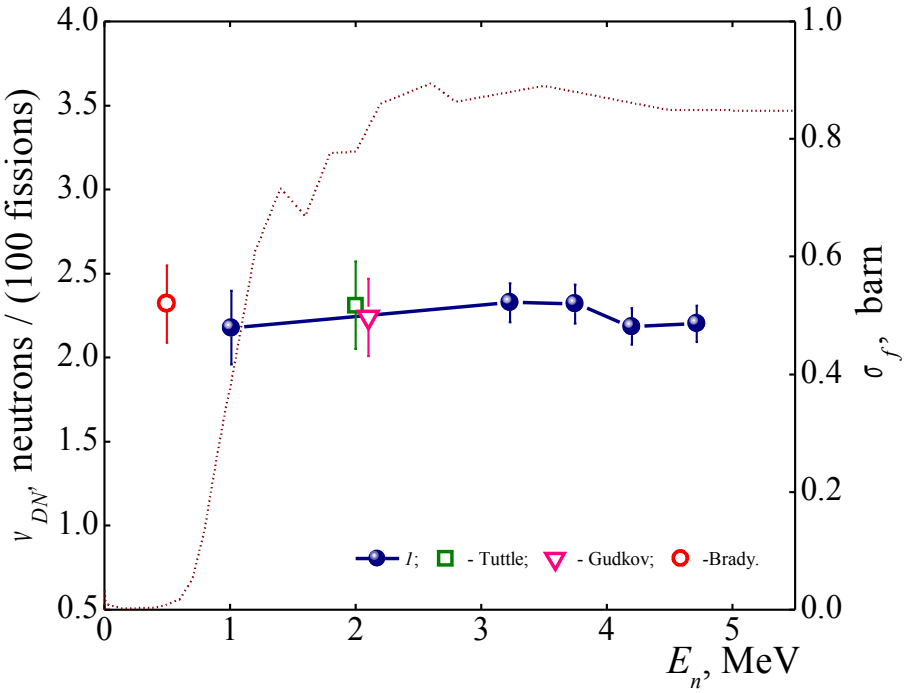


^{233}U

The energy dependence of the total delayed neutron yield from neutron induced fission of 233U

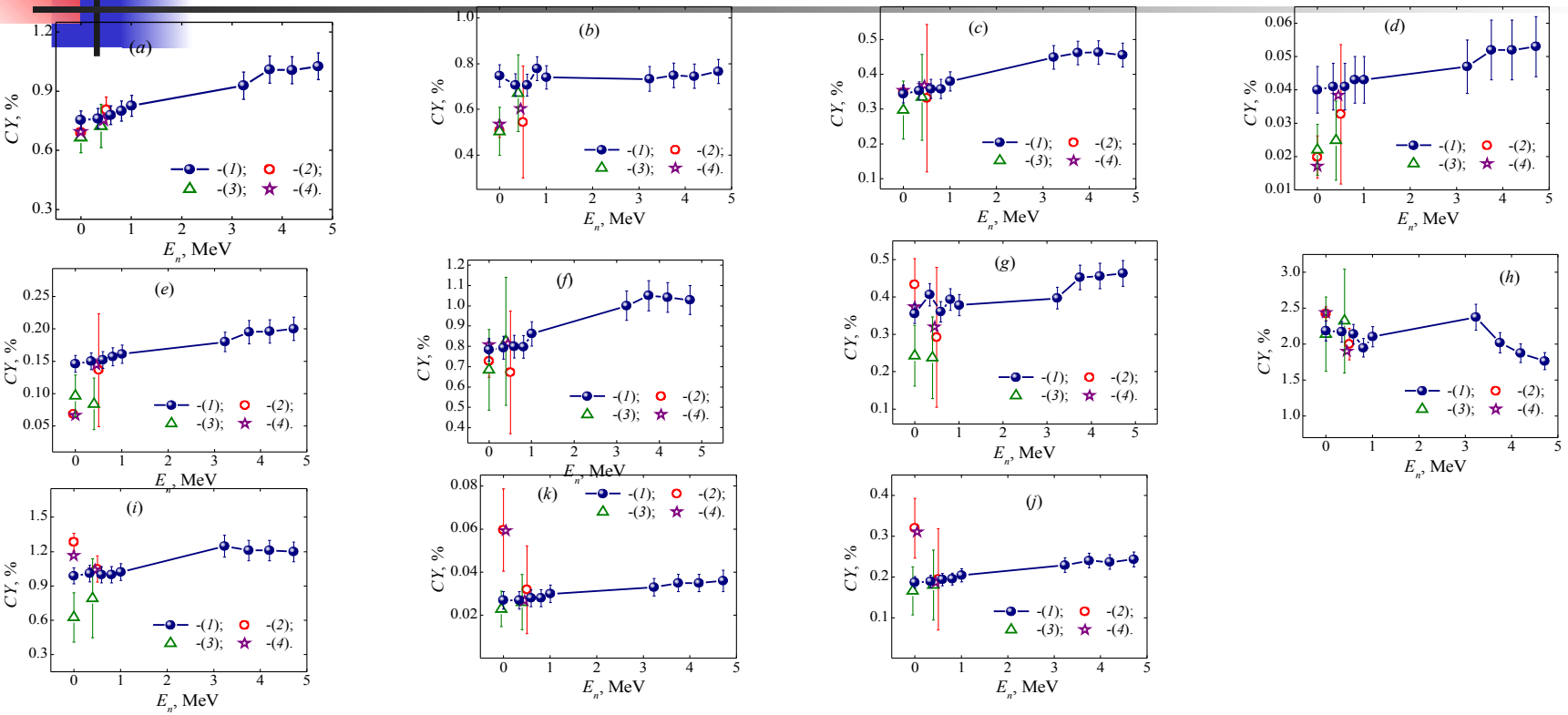
Project 2253 : Investigation of the delayed neutron characteristics from the fission of compound nuclei 233Th, 234U, 235U, 244Am, 238Np, 246Cm, 233Pa, 234Pa, 239Np, 240Np at the excitation energies from 5 to 20 MeV

- ***Fractional cumulative yield:***

$$FCY(A,Z) = \frac{Y_d(A,Z)}{P_n(A,Z)Y(A)} \cdot \nu_d$$

- ***Y(A) – the chain yields (from literature) ,***
- ***$Y_d(A,Z)$ [<=>a_i]– the relative abundance of delayed neutrons (obtained in this experiment)***
- ***$P_n(A,Z)$ - the delayed neutron emission probability corresponding to precursor (A,Z) (from literature),***
- ***ν_d – the total delayed neutron yield per one fission (obtained in this experiment).***
- ***Cumulative yields CY is related to FCY(A,Z) by expression CY(A,Z) = FCY(A,Z)* Y(A)***

Project 2253 : Investigation of the delayed neutron characteristics from the fission of compound nuclei 233Th, 234U, 235U, 244Am, 238Np, 246Cm, 233Pa, 234Pa, 239Np, 240Np at the excitation energies from 5 to 20 MeV



Energy dependence of cumulative yields of fission products 87Br(a), 88Br(b), 89Br(c), 91Br(d), 93Kr(e), 94Rb(f), 95Rb(g), 137I(h), 138I(i), 139I(j), and 140I(k) from neutron induced fission of 239Pu. (1-present data, 2-ENDF/B, 3- JEF, 4- JENDL)

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- *Fractional independent yield FIY(A,Z) determines charge distribution for any isobaric A chain:*

$$FIY = \frac{1}{\sqrt{2 \cdot \pi \cdot \sigma^{2}}} \cdot \exp\left[- \frac{1}{2 \cdot \sigma^{2}} \cdot \left(Z - Z_{P} \right)^{2} \right]$$

- *Taking into account a relation of FCY and FIY it's possible to estimate the most probable charge in given isobaric chain:*

$$FCY = \sum_{0}^{Z} (FIY)_{n} = \frac{1}{\sigma \cdot \sqrt{2 \cdot \pi}} \cdot \int_{-\infty}^{(Z+1/2)} \exp\left[\frac{-(n - Z_{P})^{2}}{2 \cdot \sigma^{2}} \right] dn = \frac{Y_{m}}{2} \cdot \left\{ 1 + f\left[(Z - Z_{P} + \frac{1}{2}) \Big/ \sigma \right] \right\}$$

$$f[X] = \frac{1}{\sqrt{2 \cdot \pi}} \cdot \int_{-X}^{X} \exp\left[\frac{-\alpha^{2}}{2} \right] d\alpha$$

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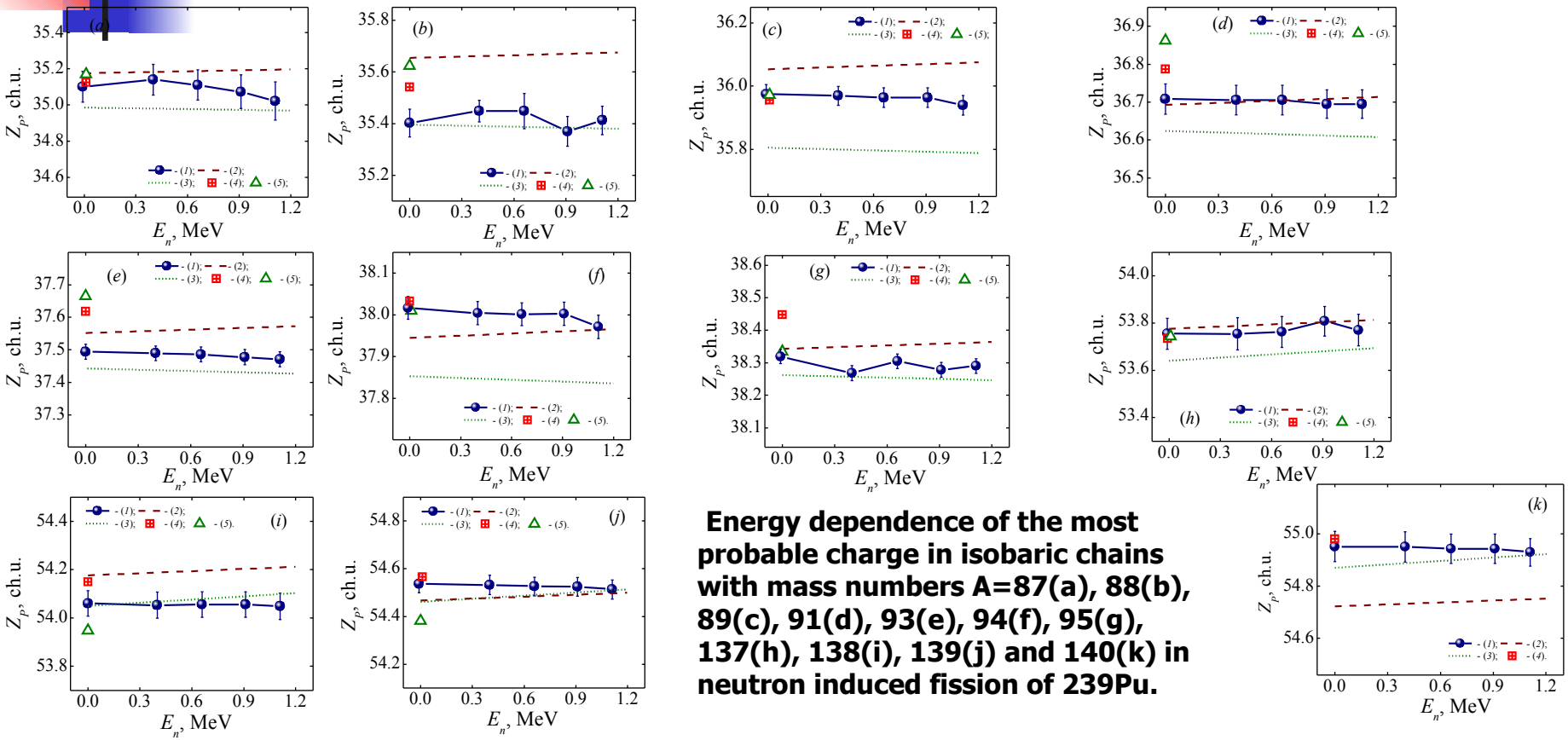

Energy dependence of the most probable charge in isobaric chains with mass numbers A=87(a), 88(b), 89(c), 91(d), 93(e), 94(f), 95(g), 137(h), 138(i), 139(j) and 140(k) in neutron induced fission of 239Pu.

(1- present data, 2- Nethaway, 3- Wahl-evaluation, 4- Waldo, 5- Wahl's experimental data).

Project 2253 : Investigation of the delayed neutron characteristics from the fission of compound nuclei 233Th, 234U, 235U, 244Am, 238Np, 246Cm, 233Pa, 234Pa, 239Np, 240Np at the excitation energies from 5 to 20 MeV

- ***List of published papers and reports***

- *1. V. Roshchenko, V. Piksaikin, S. Isaev and A. Goverdovski, "Energy dependence of nuclear charge distribution in neutron induced fission of Z-even nuclei." // Physical Review C (2006) v. 74, p.014607(1-11). http://dx.doi.org/10.1103/PhysRevC.74.014607*
- *2. V. Piksaikin, V. Roshchenko, S. Isaev, L. Kazakov, G. Korolev, Yu. Balakshev, A. Goverdovski, "Cumulative yields and average half-life of delayed neutron precursors from neutron induced fission of 233U", // Proc. of 12-th Int. Seminar on Interaction of Neutrons with Nuclei, Dubna, Russia, 26-29 May 2004, pp. 342 – 353.*
- *3. V. Roshchenko, V. Piksaikin, S. Isaev, A. Goverdovski, "Nuclear charge distribution in neutron induced fission of Z-even nuclei", // Proc. of 12-th Int. Seminar on Interaction of Neutrons with Nuclei, Dubna, Russia, 26-29 May 2004, pp. 354 – 370.*
- *4. V. Roshchenko, V. Piksaikin, L. Kazakov, G. Korolev, "Relative abundances of delayed neutrons and half-lives of their precursors from neutron induced fission of 239Pu in the incident neutron energy range 14.2-17.9 MeV." // Atomic energy (2006), (Accepted for publishing)*
- *5. V. Piksaikin, V. Roshchenko, G. Korolev, "Relative abundances of delayed neutrons and half-lives of their precursors from neutron induced fission of 238U in the incident neutron energy range 14.2–17.9 MeV." // Atomic energy (2006), (Accepted for publishing)*
- *6. V. Piksaikin, N. Semenova, V. Mil'shin, V. Roshchenko and G. Korolev, "A method and setup for studying the energy dependence of delayed neutron characteristics in nuclear fission induced by neutrons from the T(p, n), D(d, n), and T(d, n) reactions." // Instruments and Experimental Techniques (2006) №5, p. 765-777 http://dx.doi.org/10.1134/S0020441206060030*
- *7. V. Piksaikin, V. Roshchenko and G. Korolev, "A method for determining the intensity of concomitant neutron source D(d, n)3He when studying the characteristics of delayed neutrons from nuclear fission induced by neutrons from reaction T(d, n)4He." // Instruments and Experimental Techniques (2006) №5, p. 778-784 http://dx.doi.org/10.1134/S0020441206060042*
- *8. V. Piksaikin, V. Roshchenko, G. Korolev, Total yields, relative abundances and periods of delayed neutrons from neutron-induced fission of 233U, 236U, 239Pu, and 241Am. // accepted for presentation at International Conference on Nuclear Data for Science and Technology, 22-27 April, Nice, France, 2007.*
- *9. N. A. Gundorin, K. V. Zhdanova, V. E. Zhuchko, L. B. Pikelner,N. V. Rebrova, I. M. Salamatin, V. I. Smirnov, V. I. Furman Measurement of delayed neutron yield from thermal neutron induced fission of 237Np, Phys. Atomic Nuclei, 2007, in press*

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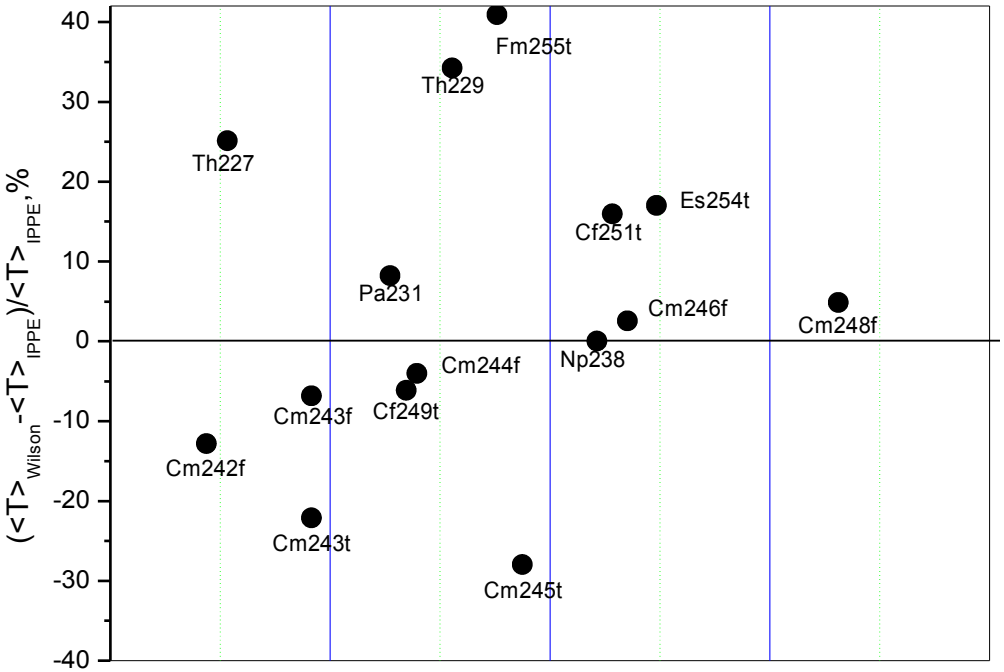
- ***Perspectives of the project 2253/2 completion***

- ***Task 1 – measurements are practically completed***
- ***Task 2 – all planned target are produced, measurements at EGP-10 have to be performed***
- ***Task 3 – all remaining measurements will be made***

- ***All planned papers will be presented for publication***

Project 2253 : Investigation of the delayed neutron characteristics from the fission of compound nuclei 233Th, 234U, 235U, 244Am, 238Np, 246Cm, 233Pa, 234Pa, 239Np, 240Np at the excitation energies from 5 to 20 MeV

(<*T*>Wilson-<*T*>IPPE)/ <*T*>IPPE,



Perspectives for future measurements

(mainly on the basis of IPPE, Obninsk)