2018 European Nuclear Physics Conference, September 2nd – 7th
Bologna, Italy, San Domenico Center

Isomers Production in ^{238}U Photofission

Cristiana Oprea[1,3], Alexandru Mihul[2,3], Ioan Oprea[1], Ion Gruia[4], Oleg D. Maslov[5], Anatoly G. Belov[5], Marina V. Gustova[5]

[1]JINR, FLNP, Dept of Exp Nucl Phys, Dubna, RF

E-mail: istina@nf.jinr.ru

[2]CERN, Genève, CMS, Switzerland

[3]Romanian National Agency for Scientific Research

[4]Faculty of Physics, University of Bucharest, RO

[5]JINR, FLNR, Dept of Actinide Research, Dubna, RF

Goal and objectives

The fission process induced by gamma quanta up to 25 MeV energy on ^{238}U was analyzed;

Experimental observables as cross sections, fragments mass distribution yields of some nuclides of interest and average prompt neutrons multiplicity characterizing ^{238}U photofission were theoretically evaluated by using TALYS-1.9 software;

Theoretical evaluations of isomer ratios using Talys possibilities supplied by own computer codes as well as experimental isomer ratios obtained at MT - 25 Microtron;

This study represents a research proposal for photofission investigations and isotopes production at the new neutron source IREN, from FLNP - JINR Dubna

Fundamental research applications

- Photofission - investigation of the configuration of fissionable system near scission point. It gives informations on: measurements of anisotropy, emitted gamma rays, fission products ground states
- Isomer Ratios (IR) $\rightarrow$spin distribution, dependence of level density on angular momentum, probabilities of radiation transitions between the levels

Applicative researches

- Photofission – important for transmutation and nuclear energy projects, new generation nuclear reactors
- Isotopes and Isomers productions for a wide range of applications in medicine, electronics, engineering

OUTLINE

INTRODUCTION

ELEMENTS OF THEORY. TALYS

RESULTS AND DISCUSSION

CONCLUSIONS

Talys codes and elements of theory. I

Codes for nuclear reaction mechanisms and nuclear structure calculations
Implemented compound, direct and pre-equilibrium processes
Wide database of nuclear data - energy levels, density levels, spins, parity, optical potential parameters for many nuclei

Photofission

Cross section -> compound processes
Mass distribution of fission fragments – evaluated in the frame of Brosa model
Density levels – Constant temperature with Fermi gas model

Isomer ratio

– It was considered a Brehmstrahlung incident gamma source (described by Kramers relation)
- Yields for IR – calculated using statistical approach based on the spins distribution (Huizenga approach)

Talys codes and elements of theory. II

Fission Cross Sections (XS) – Hauser – Feshbach Formalism

Fission XS for a given fission fragment (FF) mass

$$\sigma(A_{FF}) = \sum_{Z_{FS}, A_{FS}, E_x} \sigma_F(Z_{FS}, A_{FS}, E_x) Y(A_{FF}; Z_{FS}, A_{FS}, E_x)$$

A_{FF} = FF mass; $\sigma_F(Z_{FS}, A_{FS}, E_x)$ = cross section of fissionable system (FS)
Y (A_{FF} ;Z_{FS}, A_{FS}, E_x) = relative yield of FF with mass A_{FF} coming from a FS with mass A_{FS} and charge Z_{FS}
Z_{FS}, A_{FS} = charge and mass of FS; E_x = excitation energy

XS Production of FF with given mass (A_{FF}) and charge (Z_{FF})

$$\sigma_{prod}(Z_{FF}, A_{FF}) = \sum_{Z_{FS}, A_{FS}, E_x} \sigma_F(Z_{FS}, A_{FS}, E_x) Y(A_{FF}; Z_{FS}, A_{FS}, E_x) Y(Z_{FF}; A_{FF}, Z_{FS}, A_{FS}, E_x)$$

Y (Z_{FF} ;A_{FF} ,Z_{FS}, A_{FS}, E_x) = relative yield of FF with charge Z_{FF} and mass A_{FF} coming from a FS with mass A_{FS} and charge Z_{FS}

Talys codes and elements of theory. III

FF mass distribution

$$Y\left(A_{FF};Z_{FS},A_{FS},E_x\right)=\sum_{FM=SL,STI,STII} W_{FM}\left(Z_{FS},A_{FS},E_x\right)Y_{FM}\left(A_{FF};Z_{FS},A_{FS},E_x\right)$$

$W_{FM}\ (Z_{FS}, A_{FS}, E_x)$ = weight of fission mode (FM);
$Y_{FM}\ (A_{FF}\ ;Z_{FS}, A_{FS}, E_x)$ = mass distribution;
FM = SL = superlong; STI, II = standard I, II

FM weight

$$W_{CFM}\left(Z_{FS},A_{FS},E_X\right)=\frac{T^B_{f,CFM}}{T^B_{SL,CFM}+T^B_{STI,CFM}+T^B_{STII,CFM}}$$

CFM = SL, STI, STII; $T_{f,\ CFM}$ = transmission coefficient (Hill – Wheeler);
B = second barrier

M. C. Duijvestijn, A. J. Koning, and F. -J. Hambsch, Phys. Rev. C **64**, 014607 (2001)
A. J. Koning, S. Hilaire and M. C. Duijvestijn, TALYS-1.0., *Proceedings of the International Conference on Nuclear Data for Science and Technology*, April 22-27, 2007, Nice, France, editors O. Bersillon, F. Gunsing, E. Bauge, R. Jacqmin, and S. Leray, EDP Sciences (2008) 211-214

Isomer ratio

Isomer Ratio

$$R = \frac{Y_m}{Y_g} = \frac{\int_{E_{th}}^{E_m} N_0 \phi(E_\gamma) \sigma_m (E_\gamma) dE_\gamma}{\int_{E_{th}}^{E_m} N_0 \phi(E_\gamma) \sigma_g (E_\gamma) dE_\gamma}$$

$Y_m, Y_g =$ Yields of isomer and ground states

$E_{th}, E_m =$ Threshold maximal energy

$\phi(E_\gamma) =$ Incident gamma flux

$N_0 =$ Number of target nuclei

Incident Flux – Kramers Relation

$$\phi(E_\gamma) \sim I_c = i_b Z (E_0 - E_\gamma) E_\gamma^{-1}$$

I_c = intensity of gamma quanta
i_b = electrons beam current
E_0 = energy of accelerated electrons
Z = charge of stopping element

IR in fission

Yields of isomer and ground states are obtained using statistical approach proposed by Huizenga
Yields are proportional with the spin distribution of isomer and ground states

Spin Distribution

$$P(J) \sim (2J + 1) Exp \frac{-J(J+1)}{2(\sigma + \lambda)^2}$$

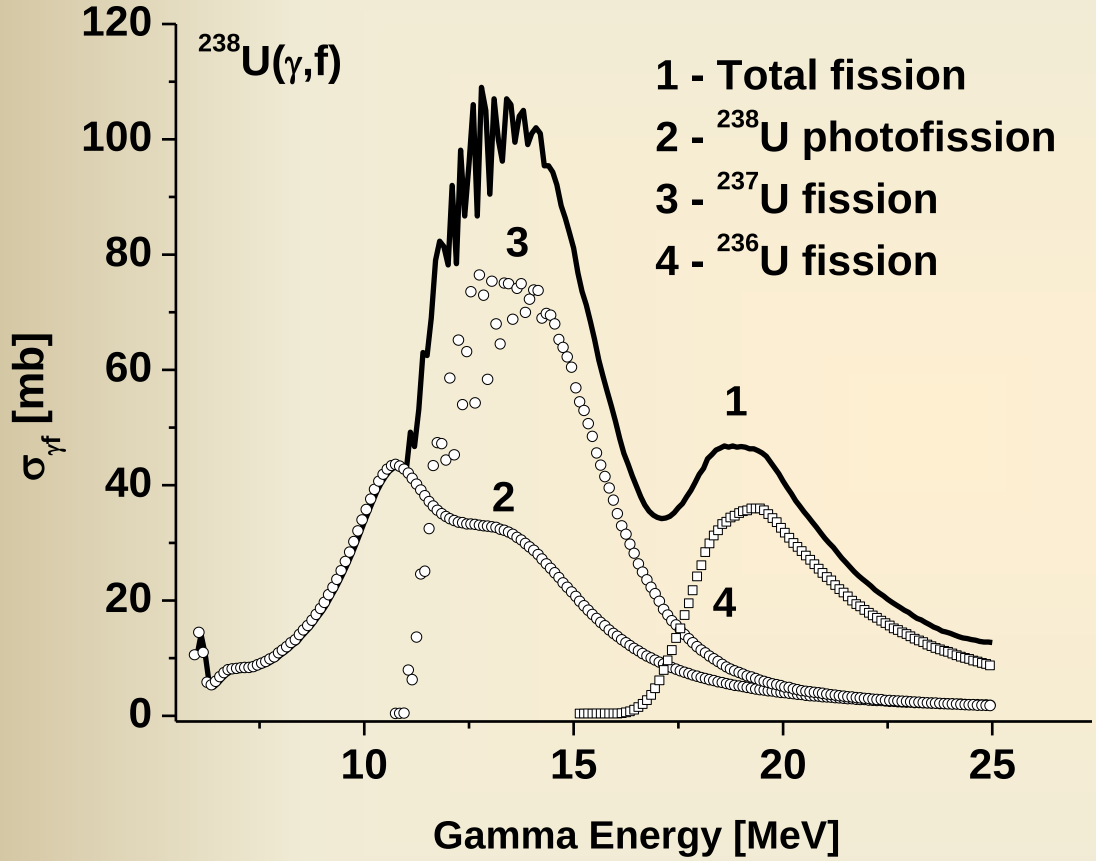
J = spin
σ, λ = parameters

J. R. Huizenga, R. Vandenbosh, Phys. Rev. **120** (1960) 1305

J. R. Huizenga, R. Vandenbosh, Phys. Rev. **120** (1960) 1313

XS. Theory

XS Talys calculation



^{238}U – photofission

Other produced fissionable nuclei are like $^{237, 236, 235}U$, ^{233}Th etc

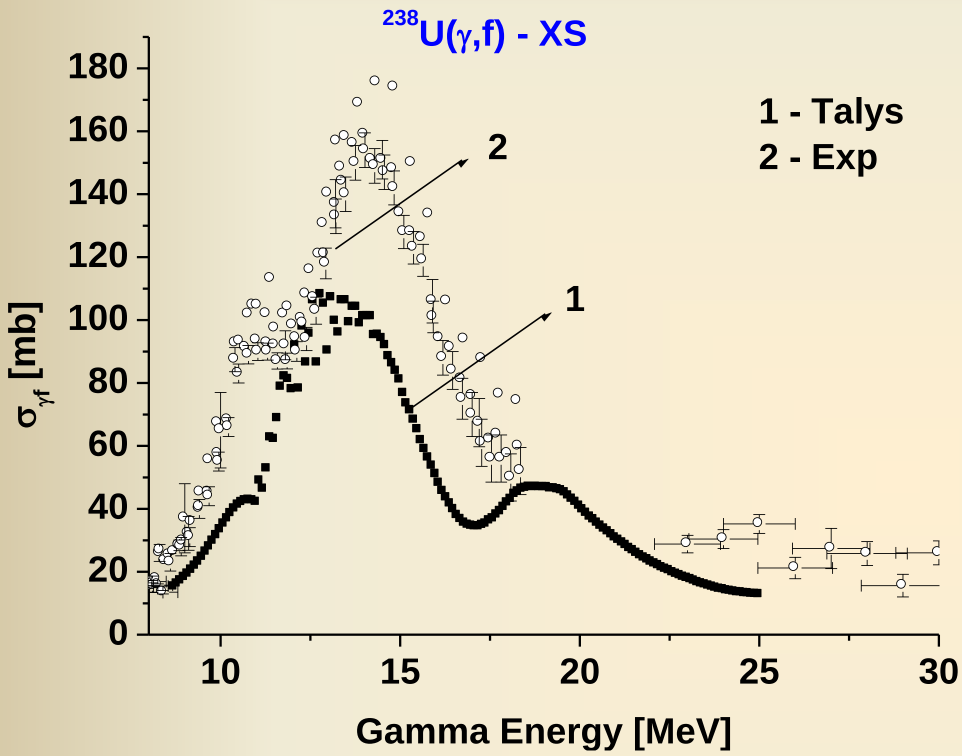
1-> 2+3+4+…

Curve 1 represents the sum of contribution of all fissionable nuclei obtained in processes like (γ,n), (γ,2n), (γ,3n), …

Fission of ^{235}U, ^{233}Th are neglected

Exclusive XS of ^{238}U photofission – typical shape for photon induced reaction in the GDR with 2 maximum characteristics for deformed nuclei

XS. Theory + Exp.

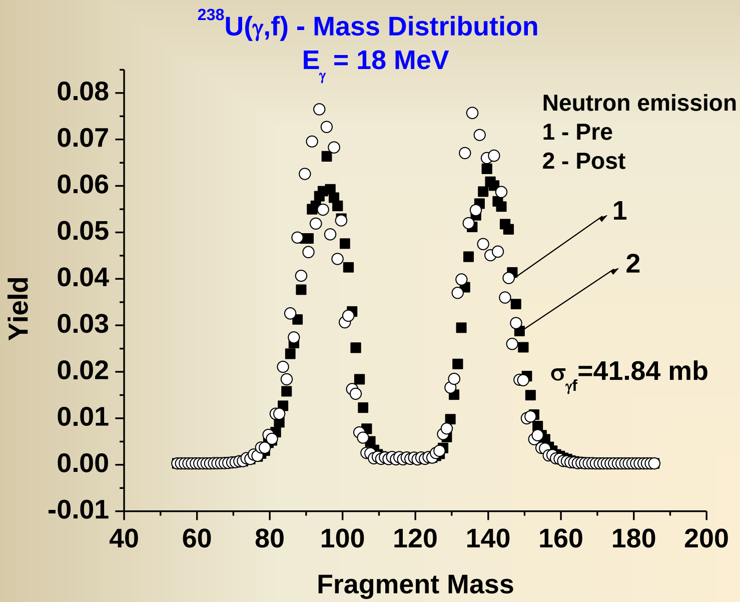


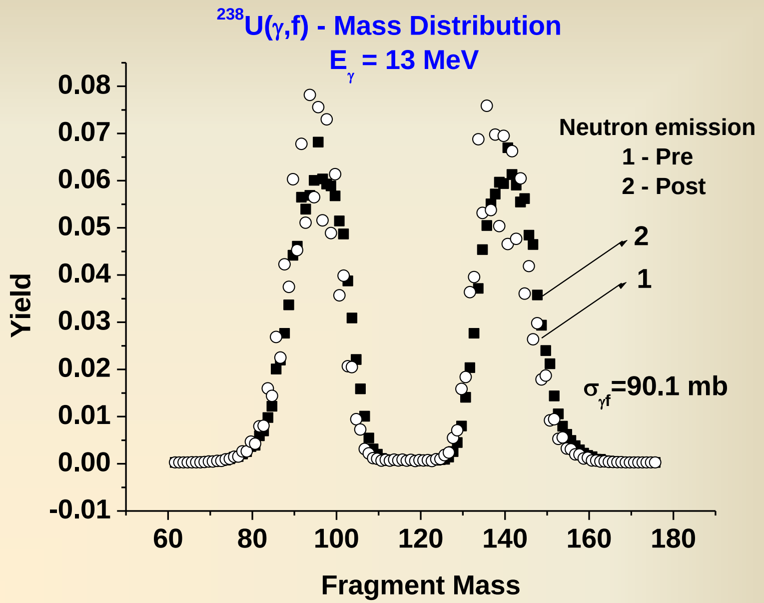
Experimental Data

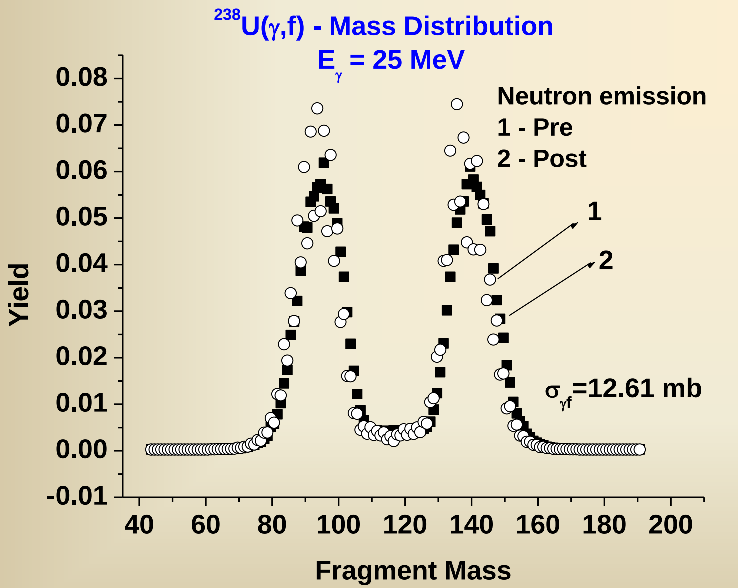
- taken from EXFOR
- Talys standard input
- data are described satisfactory
- shapes of experimental and theoretical data almost the same
- high energy part well described
- lower than 15-18 MeV there are differences

Possible explanations
- fission of some products are not counted
- need to vary the Talys input parameters

Mass distribution of fission fragments. I



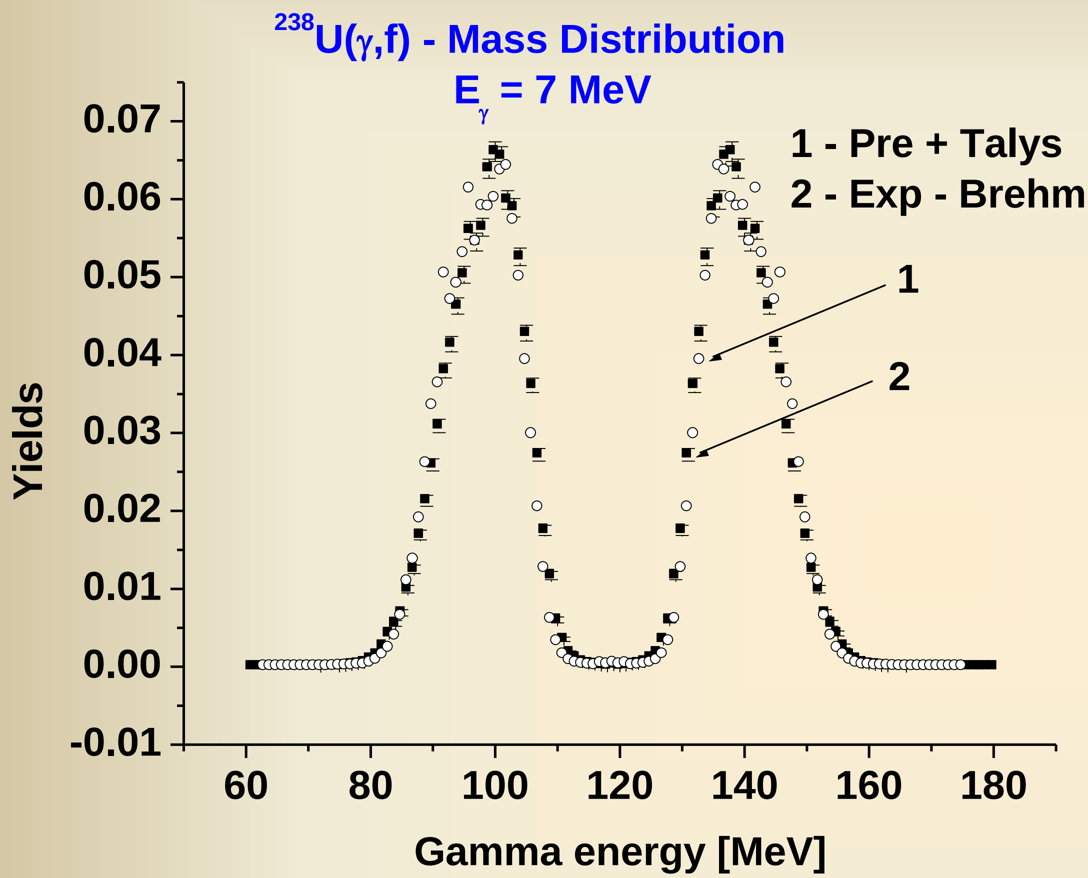




Mass Distribution

- Brosa Model
- asymmetric
- Asymmetry slowly decreases with energy

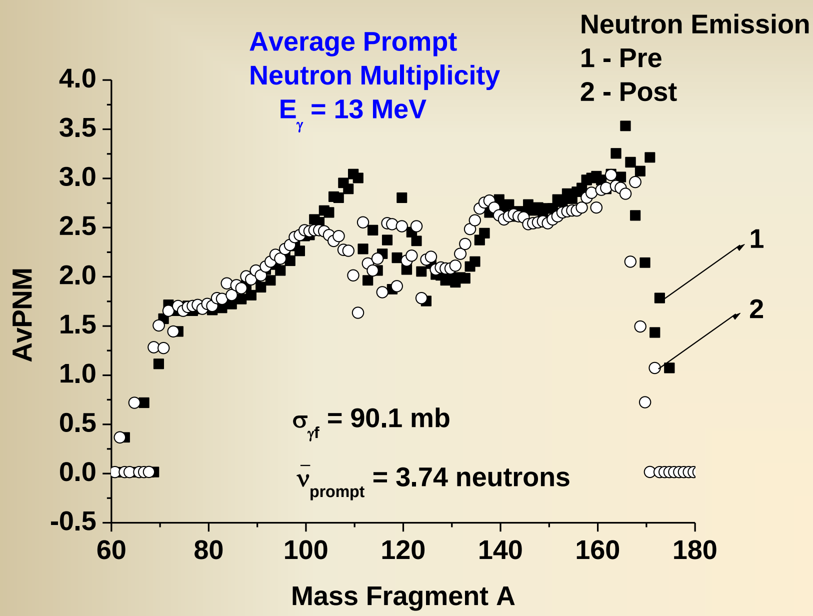
Mass distribution of fission fragments. II. Theory + Exp

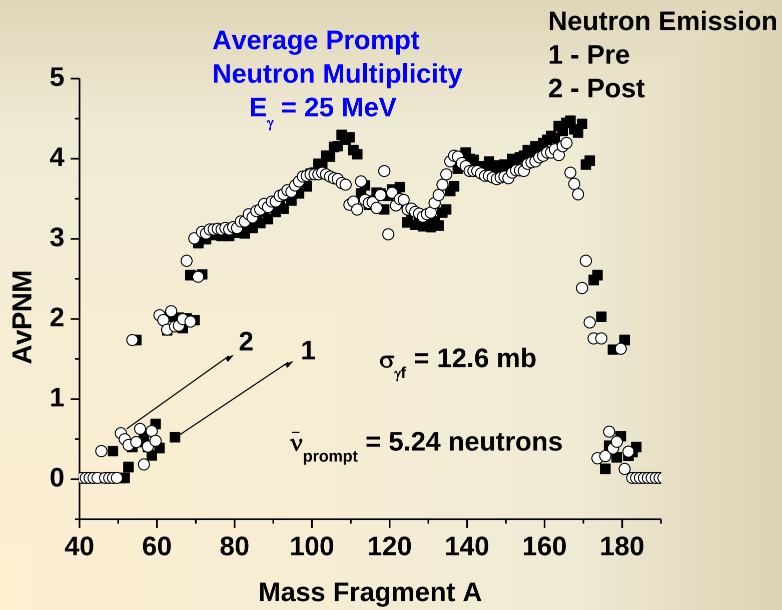


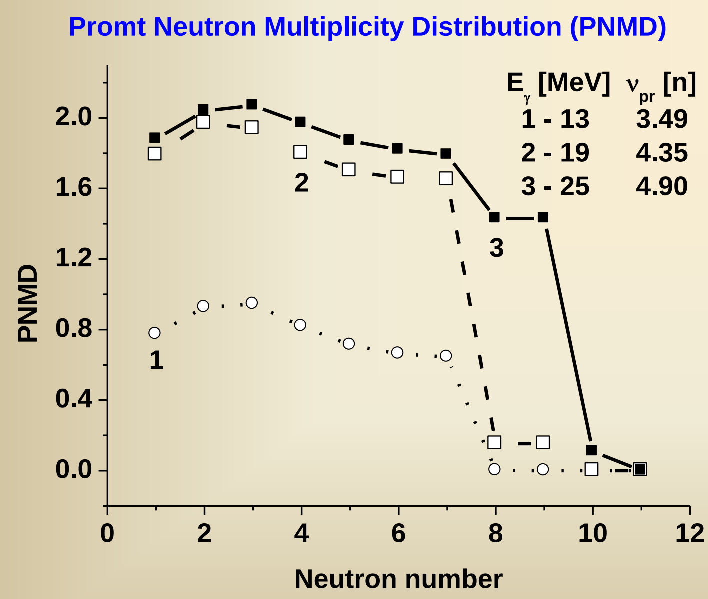
Mass distribution

Calculated with Talys before neutron emission
Compared with experimental values obtained for 8 MeV
Brehmstrahlung source

Calculated neutron emission





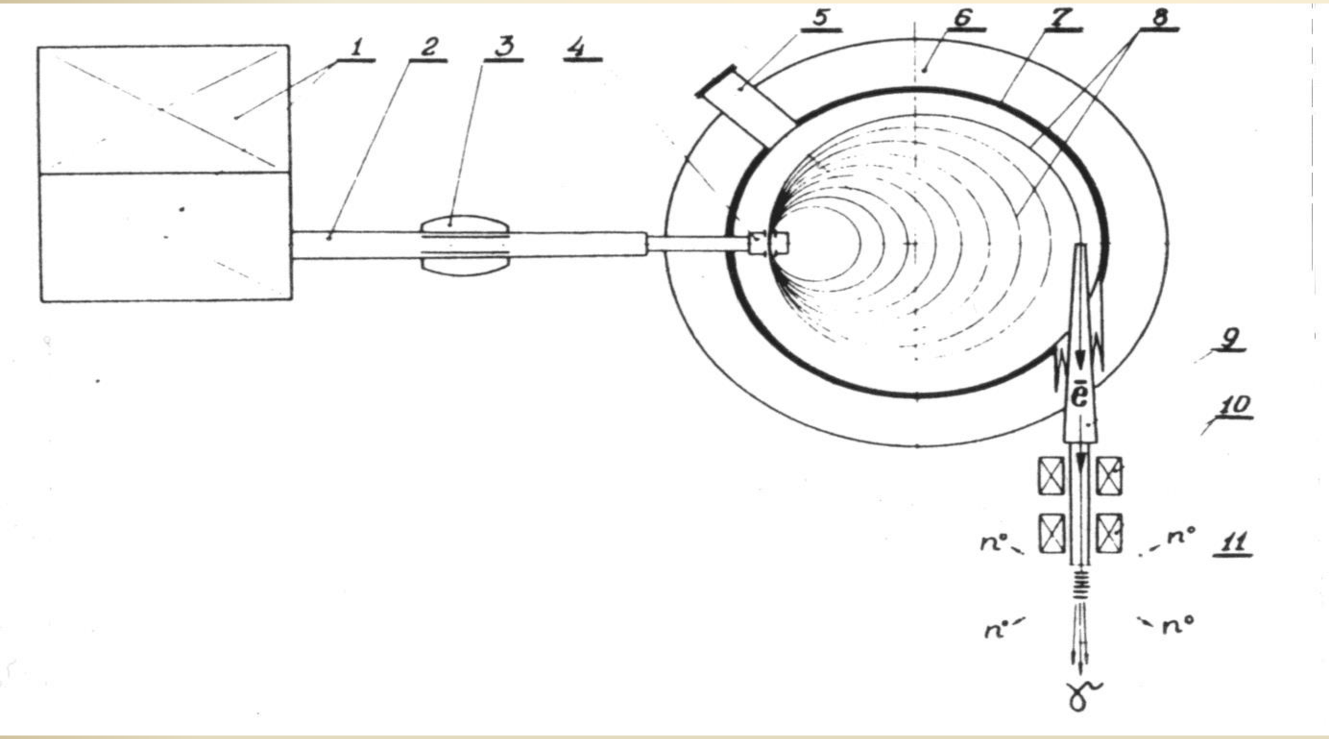


Average Prompt Neutron Multiplicity as Function of Mass and Prompt Neutron Multiplicity Distribution evaluated by Talys for different energies

Prompt neutron emission is increasing with energy

Measurements of fission products

U photofission at the compact electron accelerator – the MT-25 microtron (FLNR, JINR). The accelerated electrons are extracted from the microtron to a stopping target to produce gamma-rays or are directed into an uranium-beryllium converter to produce neutrons. The uranium-beryllium converter is placed into the middle of a graphite cube with a 120 cm side, which is the main neutron moderator. The photofission of ^{238}U sample induced by bremsstrahlungs in Giant Dipole Resonance Region of the MT-25 Microtron was performed. The maximum electron energy was 25 MeV.



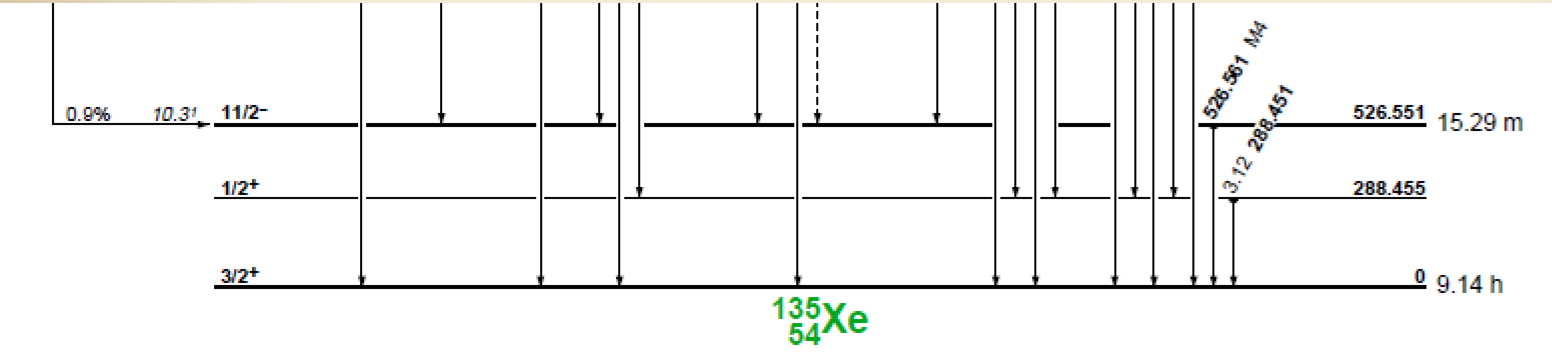
MT-25 Scheme

1-system of high frequency;
2-wave channel;
3- ferrite isolator;
4-resonator;
5- vacuum system;
6- magnet;
7-vacuum camera
8-orbits of accelerated electrons;
9-exit of electron beam;
10-magnet, focusing electron beam;
11- brake target

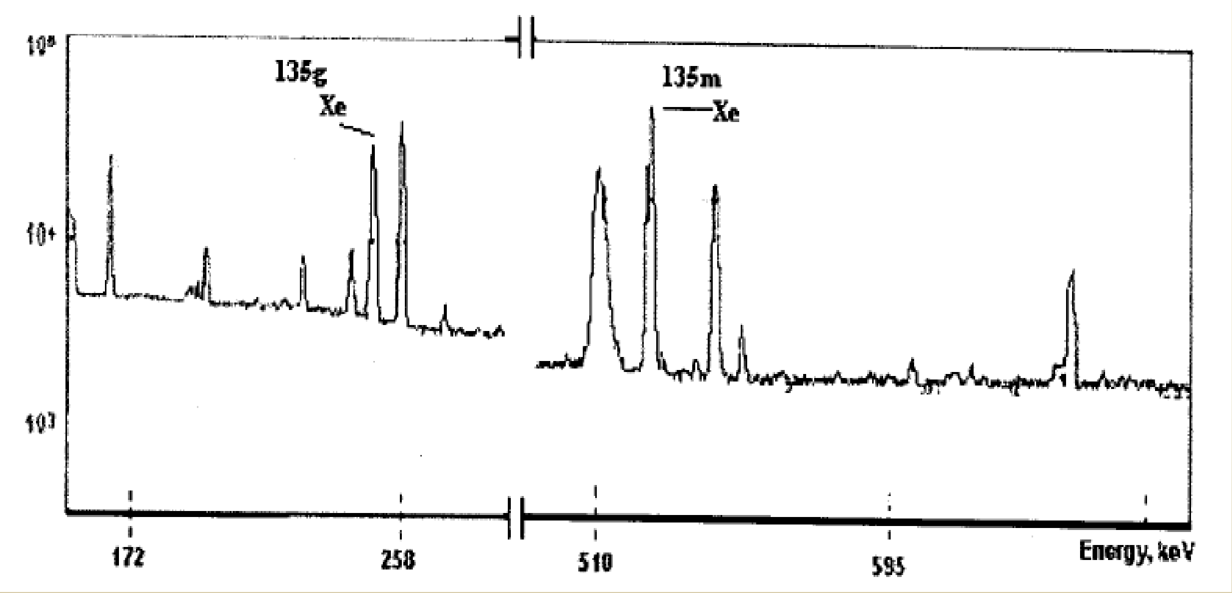
Measurements of fission products

Some of photofission fragments: ^{130}Sb, ^{132}Sb, ^{135}Xe, ^{134}I,…

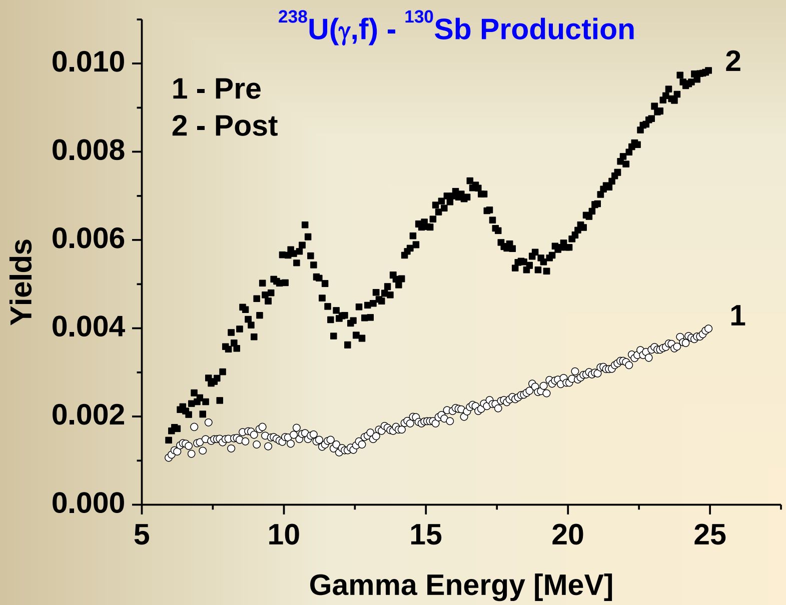
Isomer and ground levels of ^{135}Xe

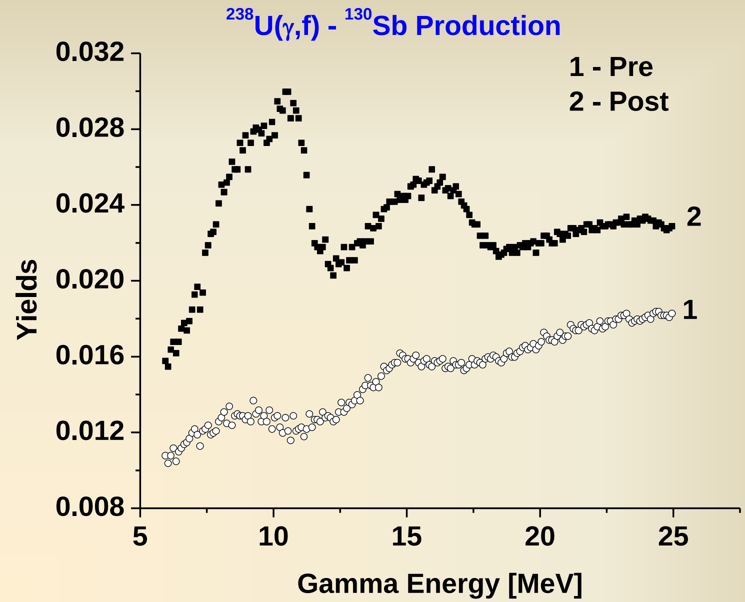


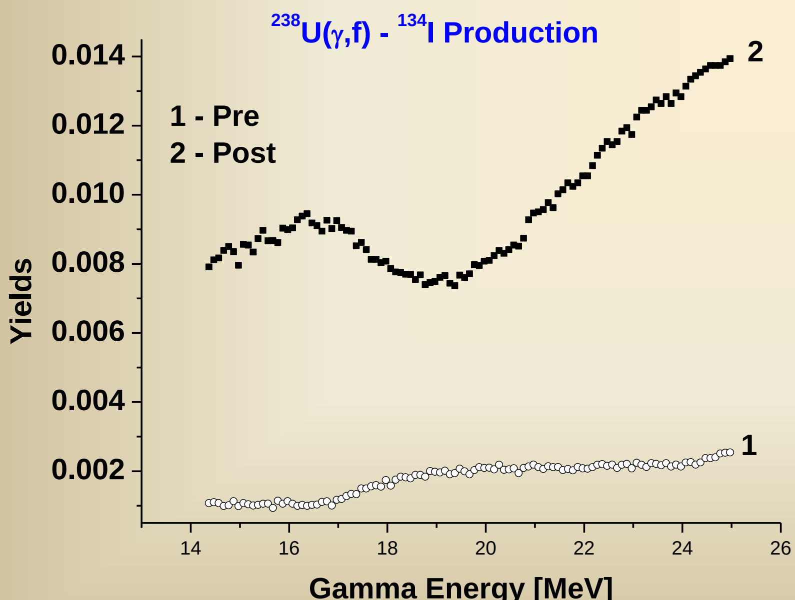
Experimental ^{135g,m}Xe spectra



Isotopes production







Talys Evaluation

Evaluations of production of isotopes ^{130}Sb, ^{132}Sb, ^{134}I before (1) and after (2) neutrons emissions are obtained with standard input For other isotopes like ^{135}Xe it is necessary to increase the precision of XS calculations

Isomer ratios. Theory + exp.

Properties of some isotopes

Elem.	Ground (g)		Isomer (m)	
	J^{Π}	τ_g	J^{Π}	τ_m
^{135}Xe	$(3/2)^+$	9.14 h	$(11/2)^-$	15.29 m
^{130}Sb	8^-	39.5 m	5^+	6.3 m

Isomer	**E_γ [MeV]**	**R^{exp}**	**R^{Talys}**
^{135}Xe	16	0.22 ± 0.03	0.43 ± 0.15
^{130}Sb	16	0.86 ± 0.15	0.95 ± 0.18
^{134}I	16	0.67 ± 0.13	-
^{132}Sb	16	0.79 ± 0.13	-

^{135}Xe diff between theory and exp

^{130}Sb – in good agreement

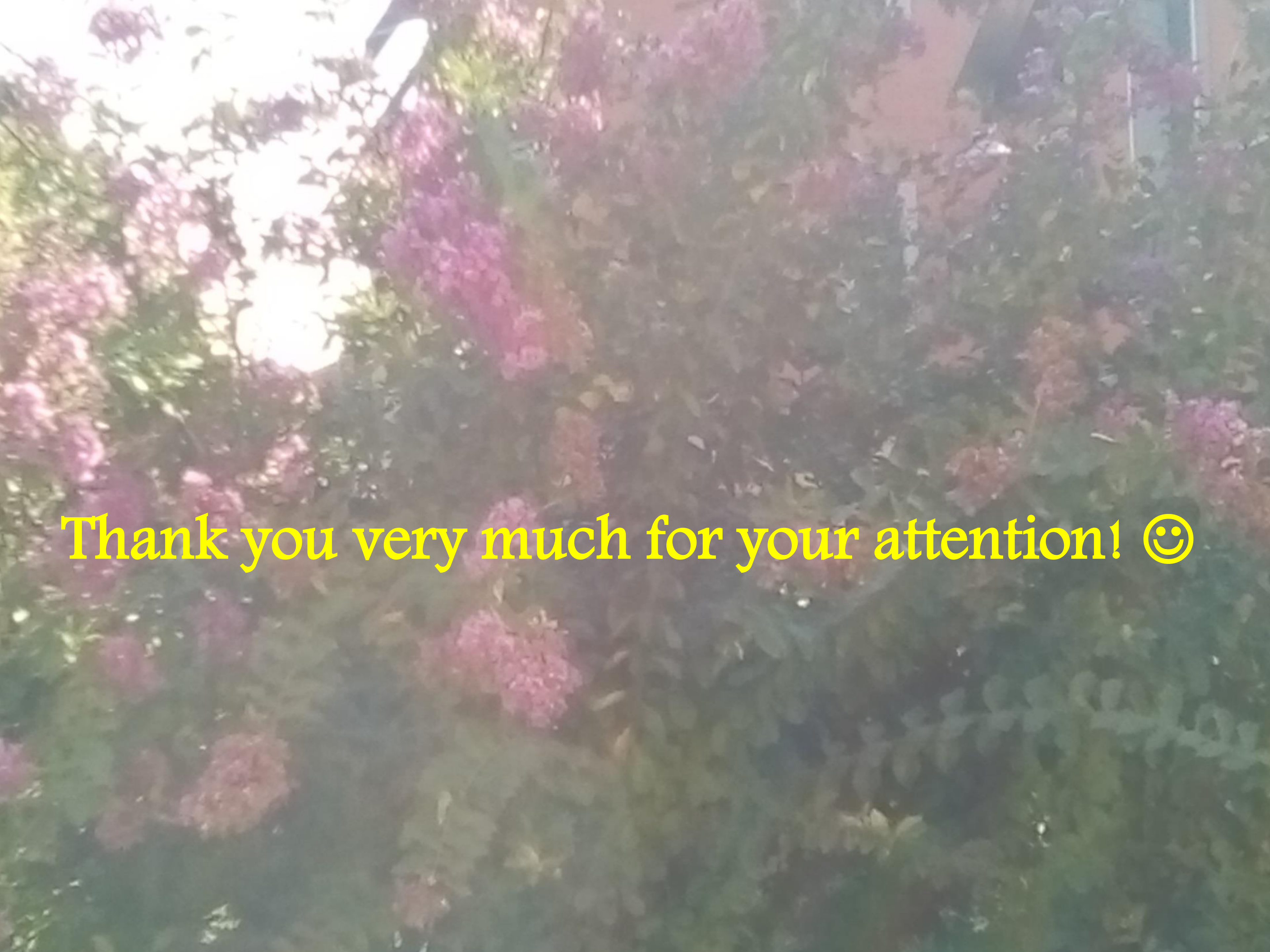
^{134}I, ^{132}Sb – future tasks

CONCLUSIONS

- Isotopes and isomers production in photofission of ^{238}U was investigated
- Cross sections, mass distributions, dependence of average prompt neutron multiplicity on fission fragment mass, isotopes production and isomer ratio were obtained for incident neutrons energy starting from 6 up to 25 MeV
- Calculations were compared with existing experimental data
- Cross section data need improvements (new data, new measurements)
- Evaluations were realized with Talys – an efficient tool of experimental data analysis

Future plans

- New experimental data from photofission of ^{238}U are planned as necessary
- Project proposals for experiment at FLNP, FLNR JINR Dubna basic facilities
- Improvement of theoretical evaluations and computer simulations


Thank you very much for your attention! ☺