FISSION OF ^{236}Pu BY FAST NEUTRONS

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ABSTRACT. Plutonium isotopes are produced in nuclear reactors by neutron-induced fission of ^{235,238}U nuclei and, by (n,2n), (γ,n) processes of Neptunium isotopes. Among the Plutonium isotopes, ^{236}Pu nucleus is a trace element of interest for studies of the environmental impact of fuel cycles. Development of a new type of fast neutron nuclear reactions destined for scientific researches based on ^{237}Np fuel, implies the analysis of the influence of different fission products such as ^{236}Pu. Fission variables of fast neutron-induced of ^{236}Pu nucleus like cross-sections, fission fragments mass and charge distributions, emitted neutron spectra, isotope production of interest for applications in medicine, electronics and nuclear technology were investigated. The contribution of different reaction mechanisms to fission and production of 236Pu was examined. In the incident, emergent fission channels, level density and Wood-Saxon potential parameters were extracted. Experimental data from the literature were compared with theoretical evaluations of fission observables. It is necessary to note that in the case of fast neutron-induced fission of ^{236}Pu nucleus there are very few experimental data regarding fission observables and therefore their evaluation is of great importance for both fundamental and applicative researches.

1. INTRODUCTION

Fundamental Researches

Fission - investigation of the configuration of fissionable ^{236}Pu nucleus near scission point. It gives information on: measurements of anisotropy, emitted gamma rays, fission products ground states

Applicative Researches

236Pu fission – 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 etc

2. GOAL AND OBJECTIVES

Fission process induced by fast neutrons up to 15 MeV energy on ^{236}Pu was analyzed;

Experimental observables as cross sections, fragments mass distribution, yields of some nuclides of interest and average prompt neutron multiplicity characterizing ^{236}Pu fission were theoretically evaluated by using TALYS-1.9 software;

This study represents a research proposal for fast neutrons and photofission investigations and isotope production at the neutron source based experimental facilities.

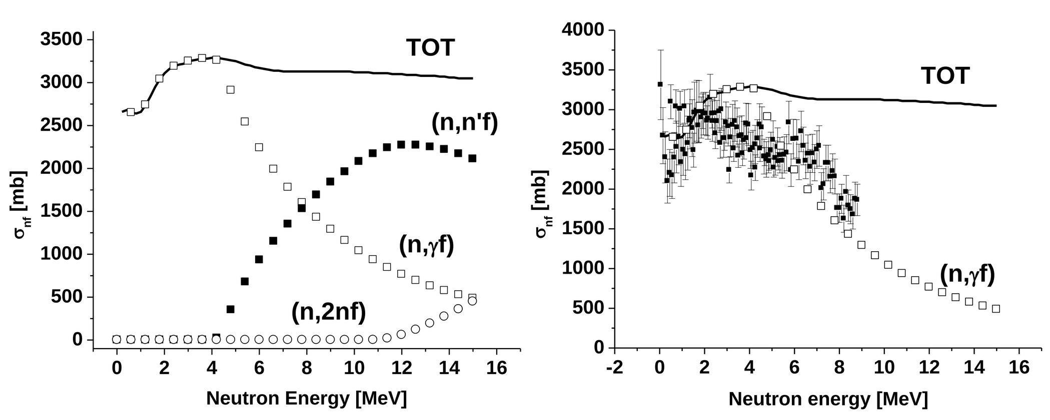
3. CODES AND ELEMENTS OF THEORY

Evaluations of fission variables were realized mainly with Talys software and author's calculation codes. In the mentioned programs are implemented most of the nuclear reaction mechanisms, together with a large database containing spin, parity, energy of nuclear levels, parameters of nuclear states density and of optical nuclear potential (Wood-Saxon) with volume (V), surface (d) and spin-orbit (SO) components respectively, each with real and imaginary part. Compound processes are described by Hauser-Feshbach formalism, direct mechanism by Distorted-Wave-Born-Approximation (DWBA) and pre-equilibrium one by two-component exciton model]. Protons induced fission can be described by compound processes in the frame of statistical model of nuclear reactions. In this formalism, cross section is

$$\sigma_{ab} = \frac{T_a T_b}{\sum_c T_c} W_{ab}$$

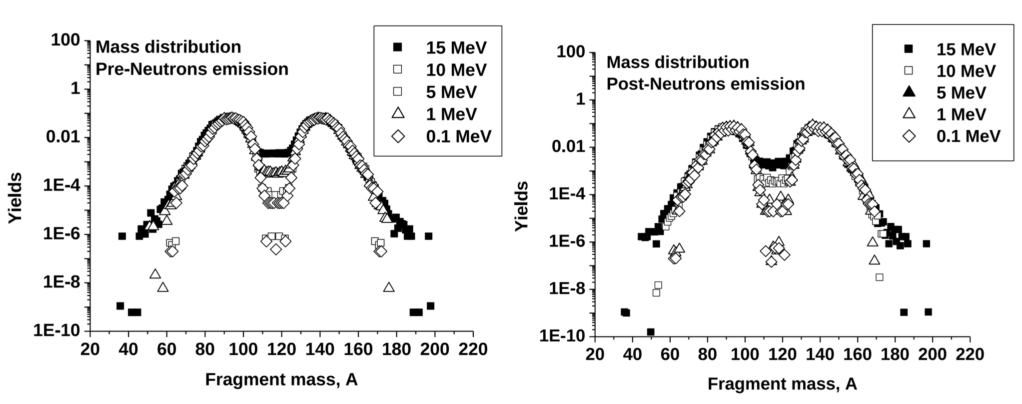
4. RESULTS AND DISCUSSIONS. CROSS SECTION

Total Fission XS – Talys + Experimental Data



Experimental and Theoretical Data - compared in an energy interval up to 15 MeV
- Contribution of other fissionable nuclei are given
- Experimental data are described approximately well by our calculations – (n,γf) channel described well in **EXFOR**

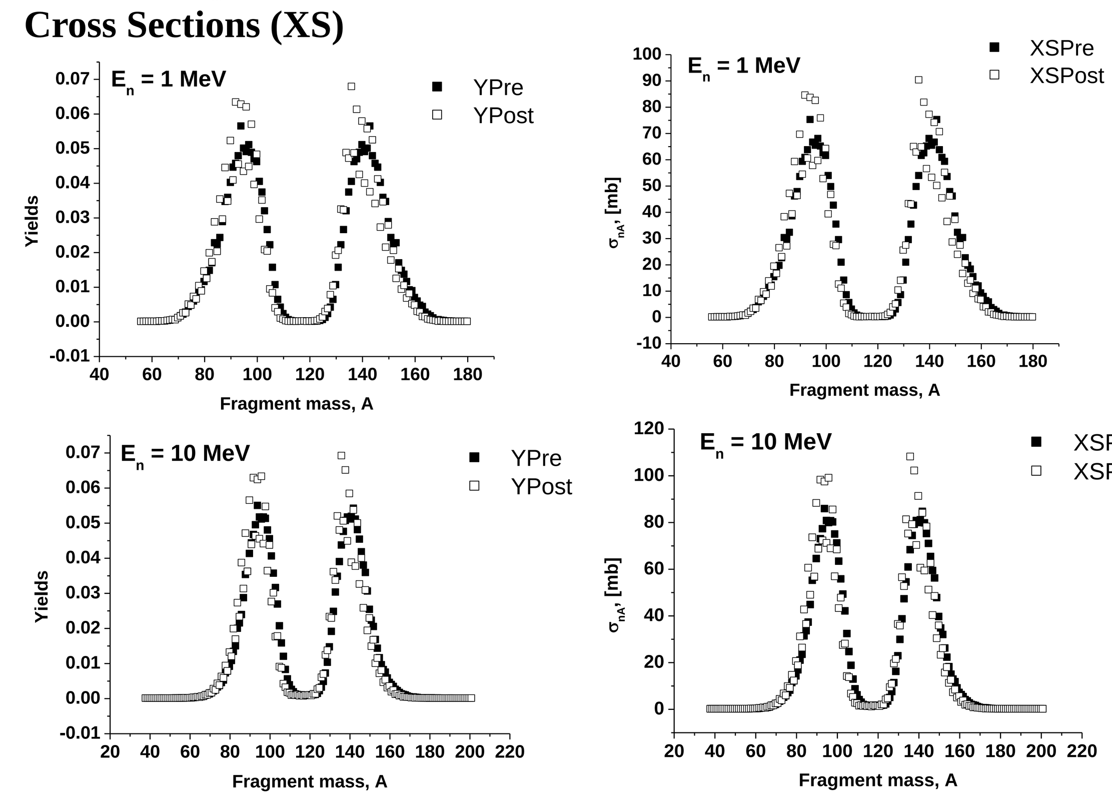
Fission Fragment (FF) Mass Distribution (MD)



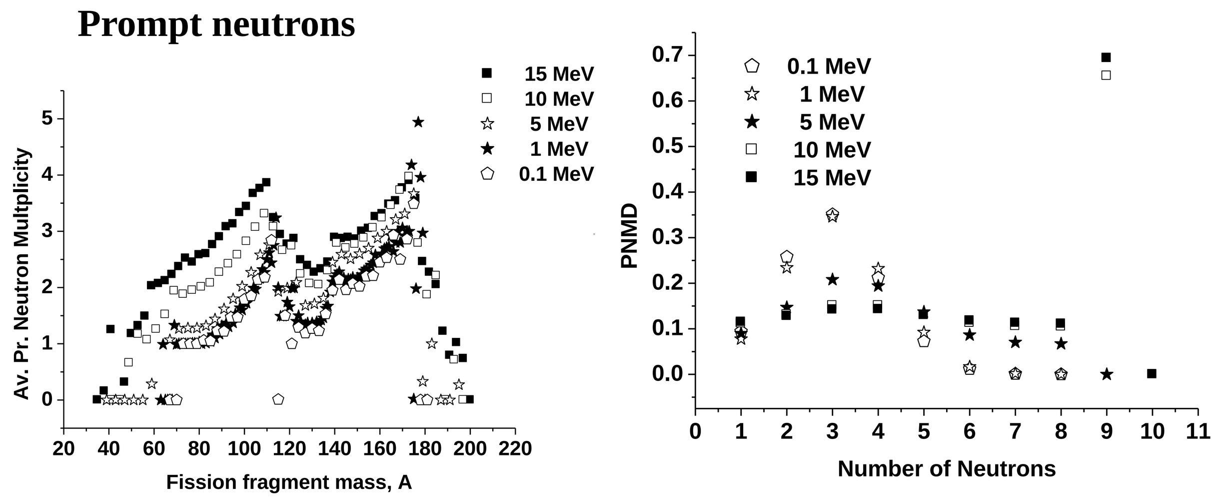
MD for All Energy Intervals

- Pre and Post Neutron Emission
- The relative yields are not sensible at the maxim point
- With the increasing of the energy more nuclei are produced
- With the increasing of the energy MD becomes more symmetric

Fission Fragment Mass Distribution FF-MD. Yields (Y). Cross Sections (XS)



Prompt neutrons



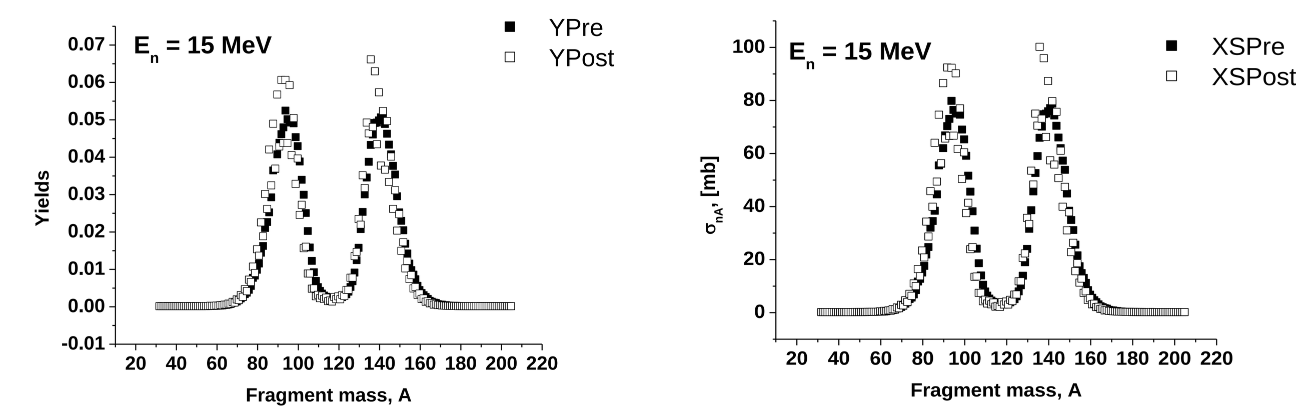
Average nubar_promt

En(MeV)	nubar_prompt
15	4.64913
10	4.20279
05	3.73621
01	3.08377
0.1	2.95052

APNM – (Averaged Prompt Neutron Multiplicity)
- Number of Emitted Neutrons as Function of FF Mass is increasing in both cases
- Because fission at equal masses has very low probability APNM has low value also
- At equal FF mass number of emitted neutrons is decreasing (Like MD and XS)

PNMD (Prompt Neutron Multiplicity)
– increasing with neutron incident energy but limited by excitation energy

Fission Fragment (FF). Y And XS – 15 MeV



Relative Yields of FF Mass for FN / From 0.1 up to 15 MeV / Pre and Post Neutron Emission / By increasing of the incident energy the number of produced nuclei is increasing / the magnitude of MD is slowly increasing

With the increasing of the incident energy the number of produced nuclei is increasing
- The MD becomes more symmetric by increasing incident neutron energy
- XS is slowly decreasing with increasing of incident energies

Isotope Production

In fission process a large number of artificial nuclei are produced which are of a great interest in many applications

Talys allows to calculate the fission yields for many isotopes

Results of some isotopes of interest like ^{99}Mo, ^{131}I and ^{133}Xe are obtained

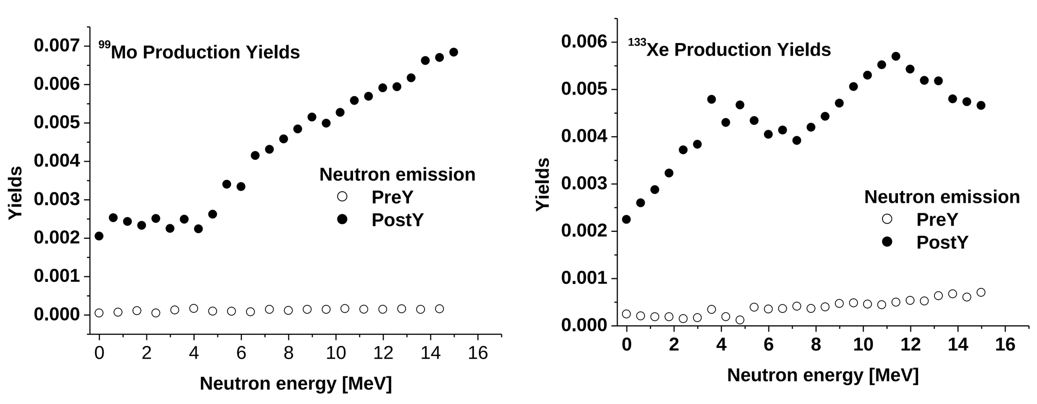
^{99}Mo – very important for medicine in cancer therapy

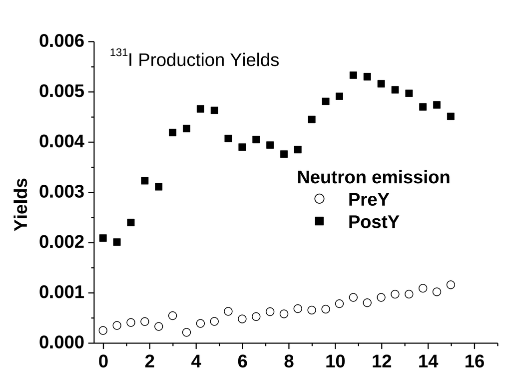
^{131}I – major fission product of Uranium and Plutonium
- important in radiobiological protection, nuclear medicine and industry as tracer

^{133}Xe – for medicine applications

^{135}Xe – important in nuclear reactor technology – a high neutron absorption ~ 2 x 10^{6} b

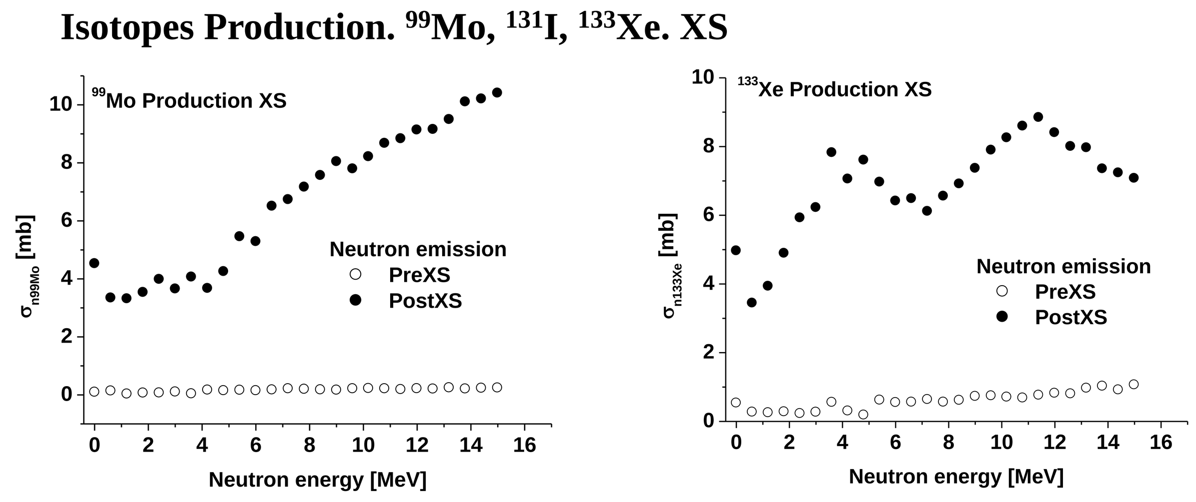
Isotopes Production. ^{99}Mo, ^{131}I, ^{133}Xe. Relative Yields

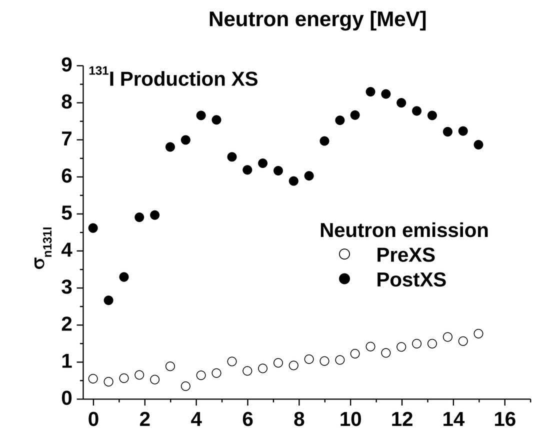




Relative yields of ^{99}Mo, ^{131}I and ^{133}Xe
- With a standard input of Talys these yields are not obtained because they are very low
- it was necessary to increase the precision of calculation by a new computer program in order to obtain evaluation which by Talys default are neglected
- it is opening the possibility to investigate isomer ratios obtained in ^{236}Pu fission

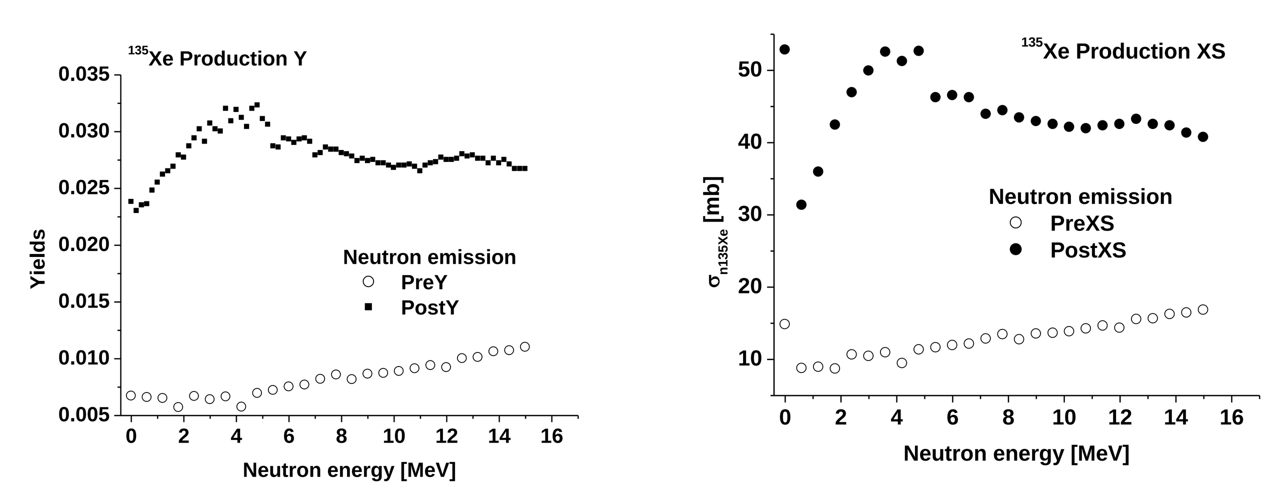
Isotopes Production. ^{99}Mo, ^{131}I, ^{133}Xe. XS





XS Production of ^{99}Mo, ^{131}I and ^{133}Xe as Function of Incident Energy
-XS obtained by increasing Talys precision calculation
- XS for ^{99}Mo are larger than in the case of ^{238,235,233}U (previous author's calculations)

Isotopes Production. ^{135}Xe. Yields and XS



^{135}Xe – neutron absorber -> reactor technology
- ^{135}Xe major fission product
- Yields and XS are with order of magnitude higher then ^{99}Mo, ^{131}I and ^{133}Xe
Relative yields and XS production + parameters of potential and levels density variation obtained with default Talys precision
Analogue XS were obtained for a large number of isotopes

Isotope Production. Talys input data

Fission calculations
n+^{236}Pu – double humped barrier

First barrier
Height: 5.1 MeV; Width: 0.7 MeV
Type of axiality: axial symmetry

Second barrier
Height: 5.15 MeV; Width: 0.5 MeV
Type of axiality: left: right asymmetry

Fission model – chosen experimental fission barrier (Maslov)

Fission model yields – Brosa

Level density model – Constant temperature + Fermi gas

Isotope Production. Talys input data

Optical model parameters – n+^{236}Pu incident channel
Wood – Saxon Potential

Central	U[MeV]	r[fm]	a[fm^{-1}]
Real	46.53	1.245	0.660
Imaginary	0.10	1.248	0.594
Surface			
Real	0	0	0
Imaginary	2.78	1.208	0.614
Spin-Orbit			
Real	5.67	1.121	0.590
Imaginary	-0.01	1.121	0.590

In the evaluation
30 discrete levels for target nucleus
10 discrete levels for residual nucleus
5 excited rotation levels

5. CONCLUSIONS

- Observables of fast neutron induced fission process on ^{236}Pu was investigated;
- Cross sections, mass distributions, dependence of average prompt neutron multiplicity on fission fragment mass, isotope production were obtained for incident neutron energy starting from slow up to 15 MeV;
- Cross sections and yields of a large number of isotopes produced in ^{236}Pu(n,f) process, were calculated;
- Calculations were compared with the few existing experimental data. They were well correlated;
- Cross sections well described for fast neutrons;
- The calculations will be extended for cross sections of slow neutron reactions.

Future plans

- New experimental data on fast neutrons fission of ^{236}Pu are planned as necessary
- Project proposals for experiment are in preparation
- Improvement of theoretical evaluations and computer simulations

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