Investigation of the Reaction Rates in ^{235}U, ^{238}U, and ^{209}Bi samples irradiated at the QUINTA target

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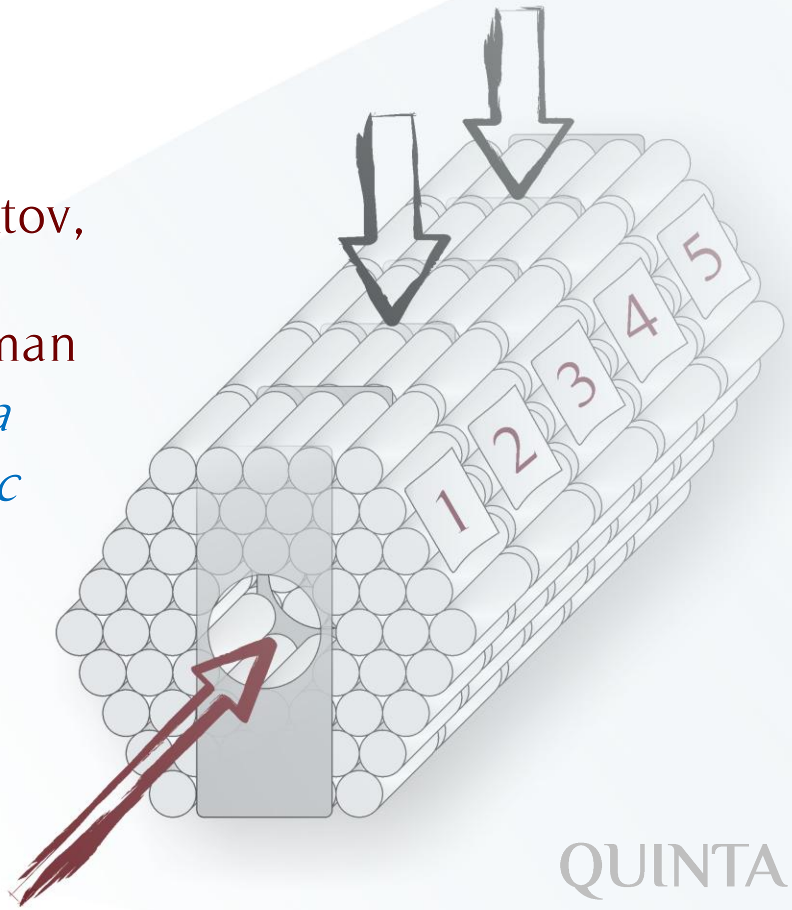
V.Chilap
CPTP «Atomenergomash», Moscow, Russia

& colleagues of the “E&T-RAW” collaboration



«Energy and Transmutation - RAW»

J.Adam, A.Baldin, A.Berlev, W.Furman, N.Gundorin, B.Gus'kov, M.Kadykov, J.Khushvaktov, Yu.Kish, Yu.Kopatch, E.Kostyuhov, I.Kudashkin, A.Makan'kin, I.Mar'in, A.Polansky, V.Pronskikh, A.Rogov, V.Schegolev, A.Solnyshkin, V.Tsupko-Sitnikov, S.Tyutyunnikov, A.Vishnevsky, N.Vladimirova, A.Wojciechowski, J.Vrzalova, L.Zavorka, M.Zeman

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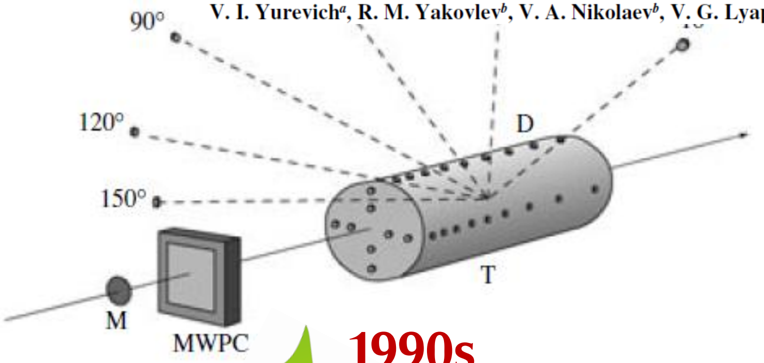
Focus

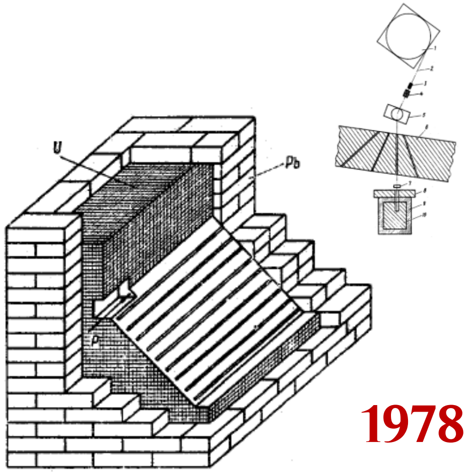
ISSN 1547-4771, Physics of Particles and Nuclei Letters, 2006, Vol. 3, No. 3, pp. 169–182. © Pleiades Publishing, Inc., 2006.
Original Russian Text © V.I. Yurevich, R.M. Yakovlev, V.A. Nikolaev, V. G. Lyapin, N.S. Amelin, 2006, published in Pis'ma v Zhurnal Fizika Elementarnykh Yadra, 2006, No. 3 (132), pp. 49–72.

Investigation of Neutron Emission in the Interaction of Relativistic Protons and Deuterons with Lead Targets

V. I. Yurevich[a], R. M. Yakovlev[b], V. A. Nikolaev[b], V. G. Lyapin[b], and N. S. Amelin[a]



1990s

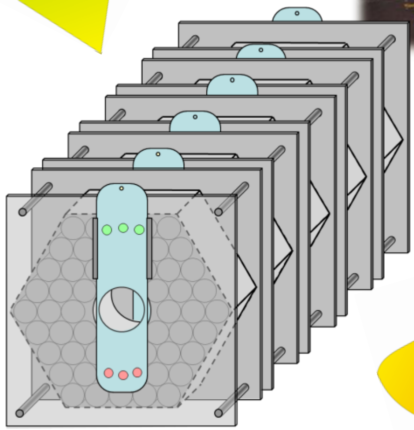


1978

NEUTRON MULTIPLICATION IN URANIUM BOMBARDED WITH 300-660-MeV PROTONS

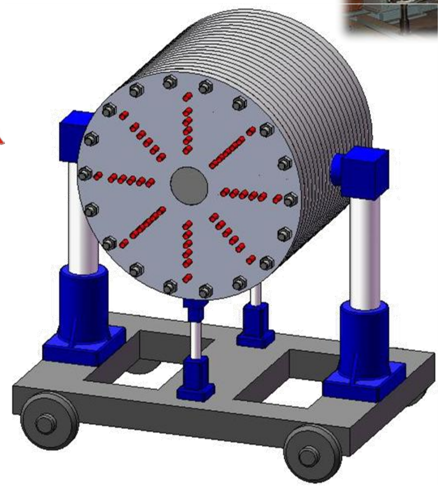
R. G. Vasil'kov, V. I. Gol'danskii, B. A. Pimenov, Yu. N. Pokotilovskii, and L. V. Chistyakov

Translated from Atomnaya Énergiya, Vol. 44, No. 4, pp. 329–335, April, 1978. April 6, 1977.



2011-2013

2015 ?



Introduction

- The key problems of the nuclear energy to be solved:
  - nuclear safety
  - spent nuclear fuel treatment
  - effective utilization of natural uranium and thorium reserves
- Subcritical Accelerator Driven Systems (ADS) represent one of possible solutions

Introduction

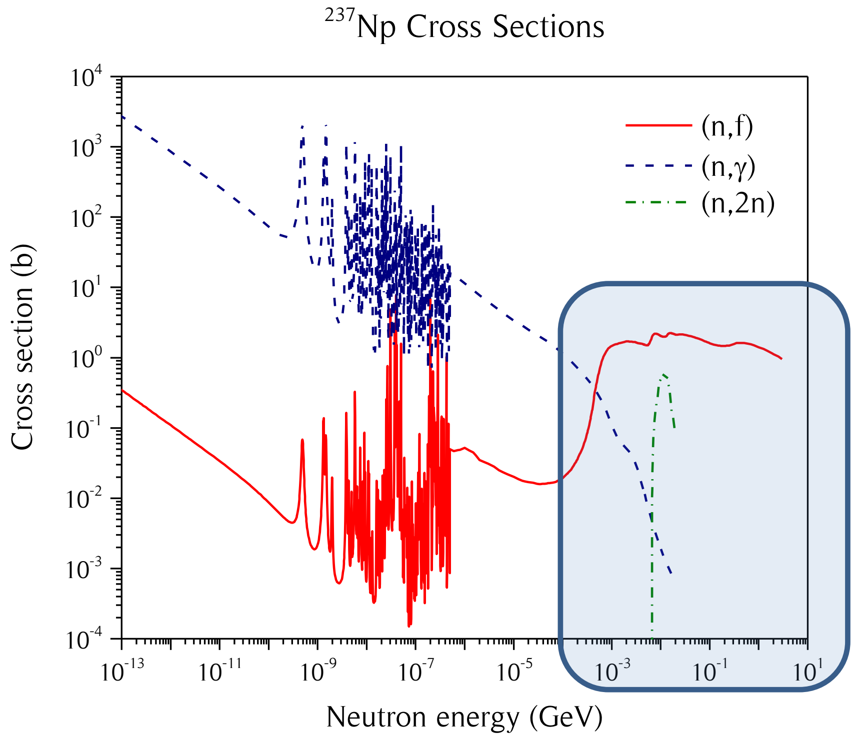
- **Different concepts and schemes in ADS research worldwide**
  - **MYRRHA project Belgium • E_p = 600 MeV**
  - **Relativistic Nuclear Technology (RNT) based on energy production and spent nuclear fuel transmutation in a hard neutron spectrum**

Energy of incident particles $E_{p,d}$ ~ 10 GeV

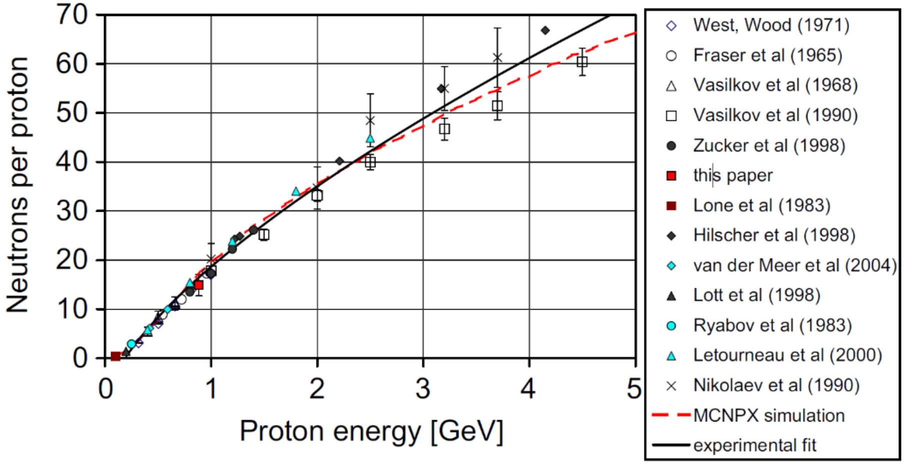
Fast neutron spectrum

- **Transmutation of long-lived fission products (FP) and actinides into short-lived or stable isotopes**

  - **~~(n,γ)~~**
  - **(n,f)**
  - **(n,xn)**



Experimental background: Beam energy



A. Krása, et al. NIM A (2010)

- ø 10 x 100 cm lead target
- compilation of experimental data + new measurement
- maximum neutron production around the beam energy 1 GeV

V.Yurevich, et al. PPN (2006)

- ø 20 x 60 cm lead target

E_d (GeV)	$< E_n >$ (MeV)	W/E_d (%)
1.03	6.5	32.6
1.98	7.9	43.9
3.76	10.4	45.7

•Kinetic energy of neutron radiation E_{kin} and mean neutron energy $< E_n >$ grow

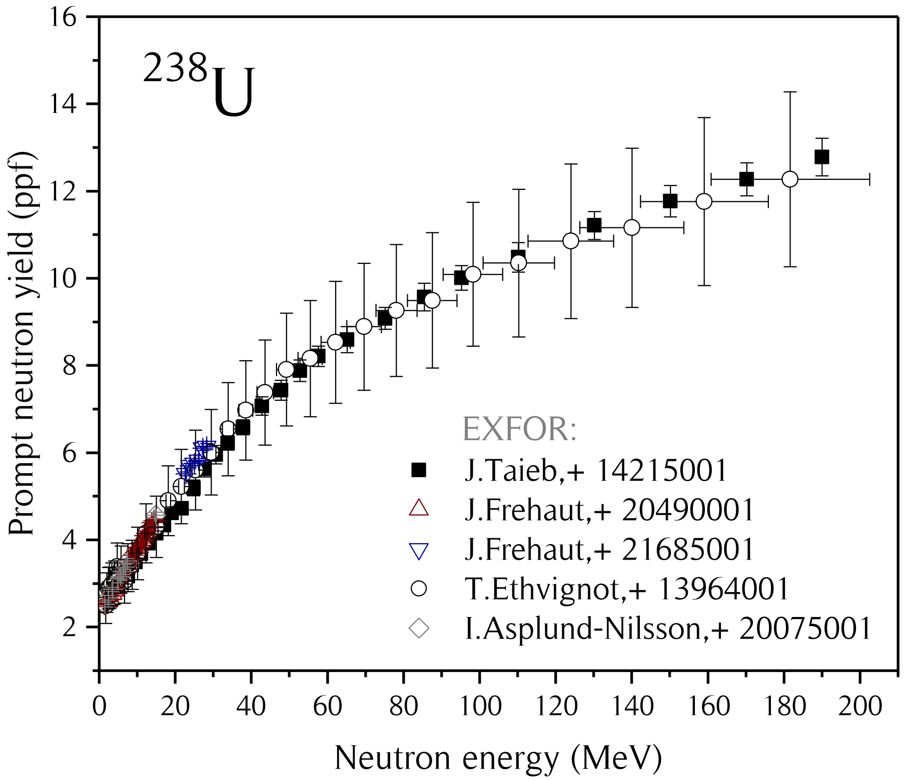
•Energy W spent on neutron production increases as well

Optimal beam energy for ADS: STILL OPEN

Neutrons at higher energies

- **Considerable increase in average multiplicity** of prompt-fission neutrons up to E_n = 200 MeV
- **Prompt-fission neutron average kinetic energy (Watt spectrum) increases as well**

(20% higher at E_n = 200 MeV)

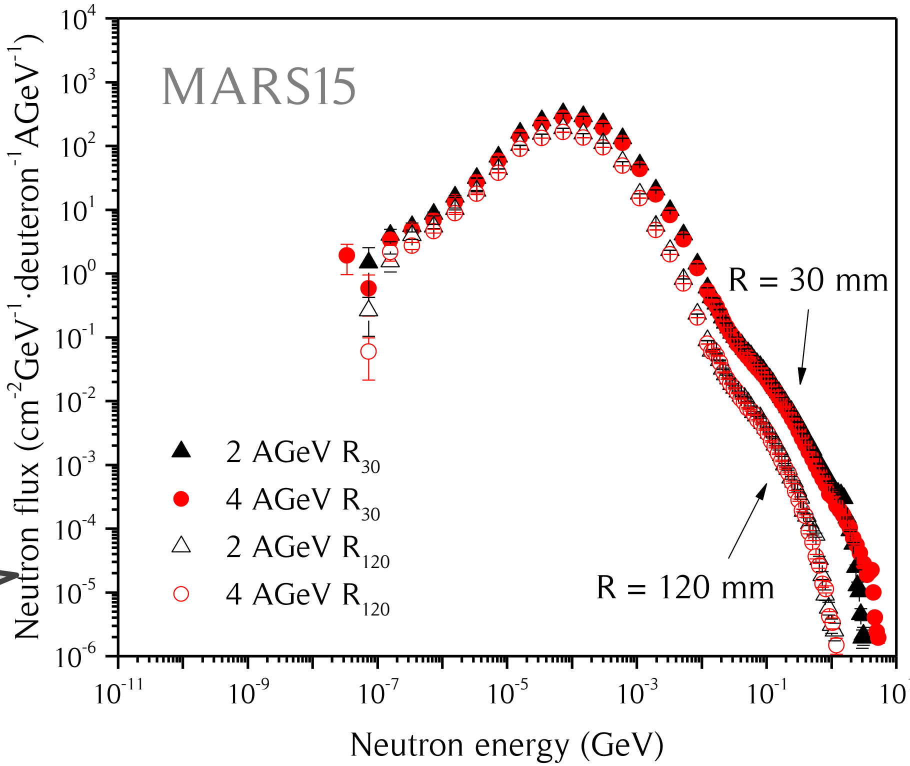


Fundamental requirement:

Maximum hard neutron spectrum

- **Increase in:**
  - Neutron multiplicity due to (n,*x*n)
  - Mean neutron energy f(E_{beam})
  - Average kinetic energy f(E_n)
  - Neutron yield f(E_n)
- **Decrease in:**
  - Neutron production per one proton above 1 GeV

- **Monte Carlo simulation tools:**

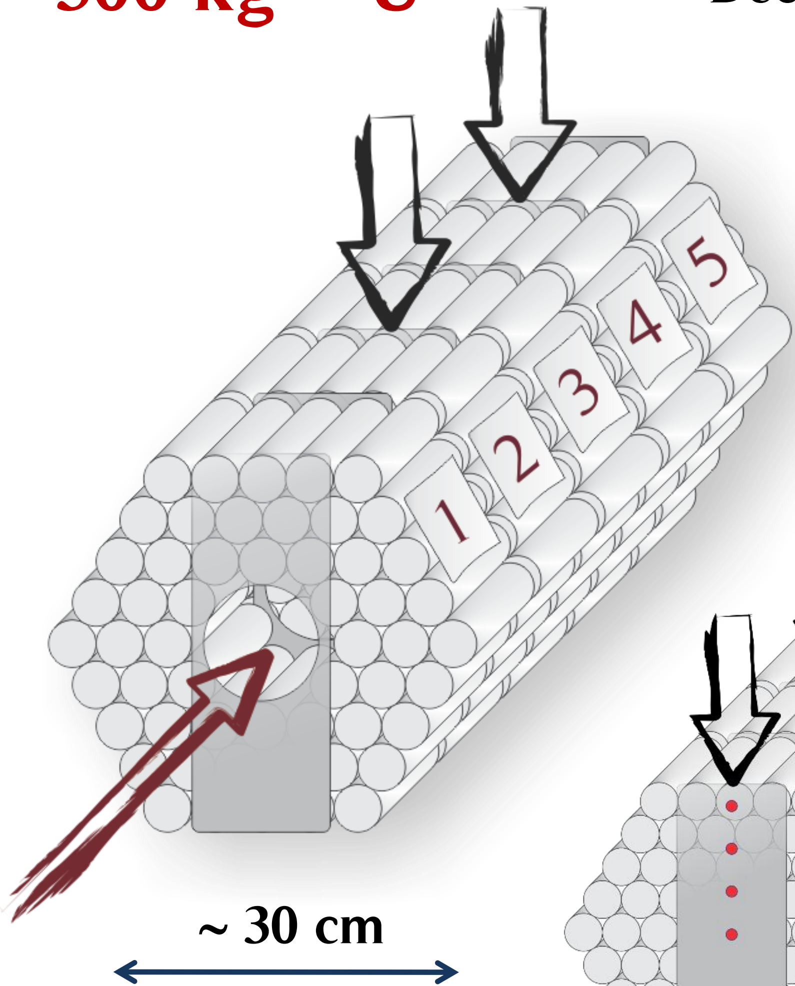


Experimental investigation at the quasi-infinite target

QUINTA target

500 kg ^{nat}U

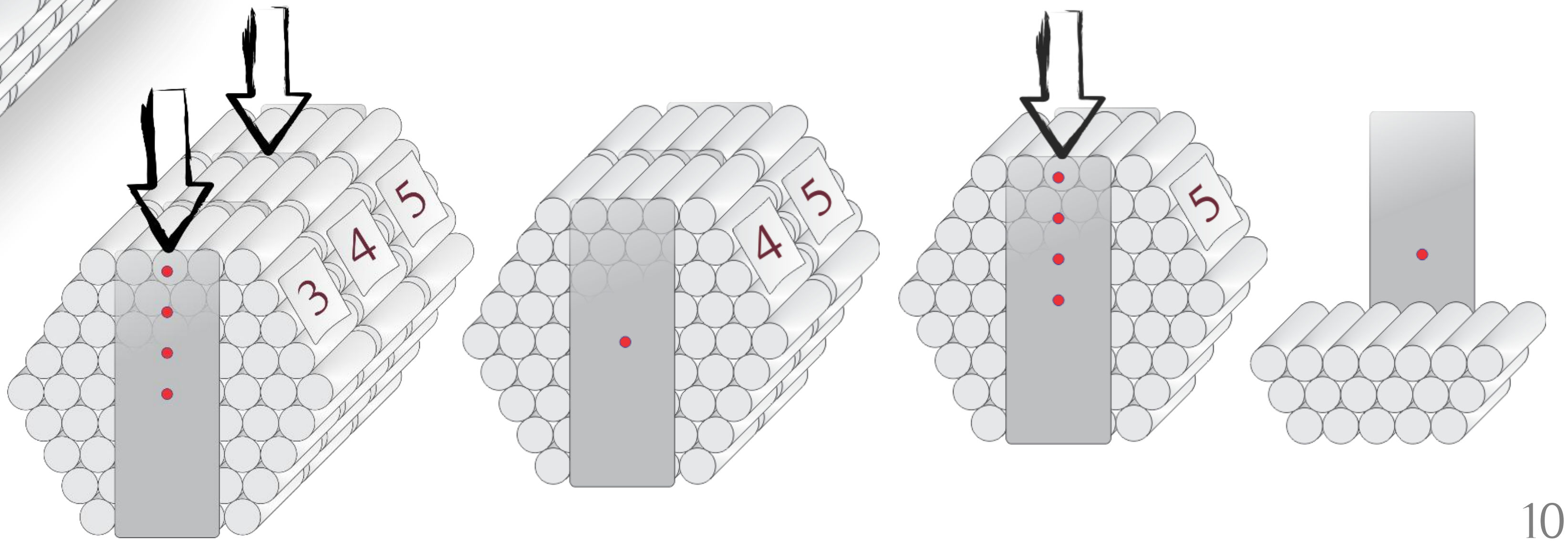
December 2013



Deuteron beam: (Al, Cu monitors)

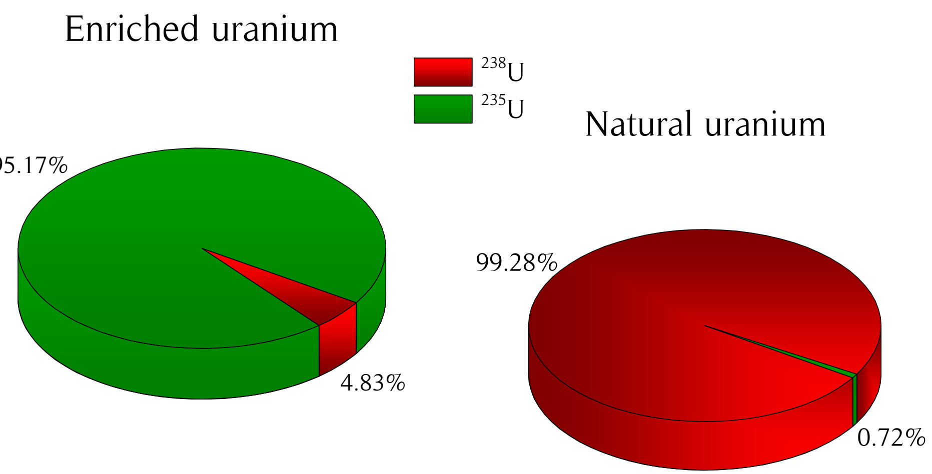
$E_d = 2$ AGeV $2.12(3)\times10^{13}$ particles

$E_d = 4$ AGeV $6.08(6)\times10^{12}$ particles

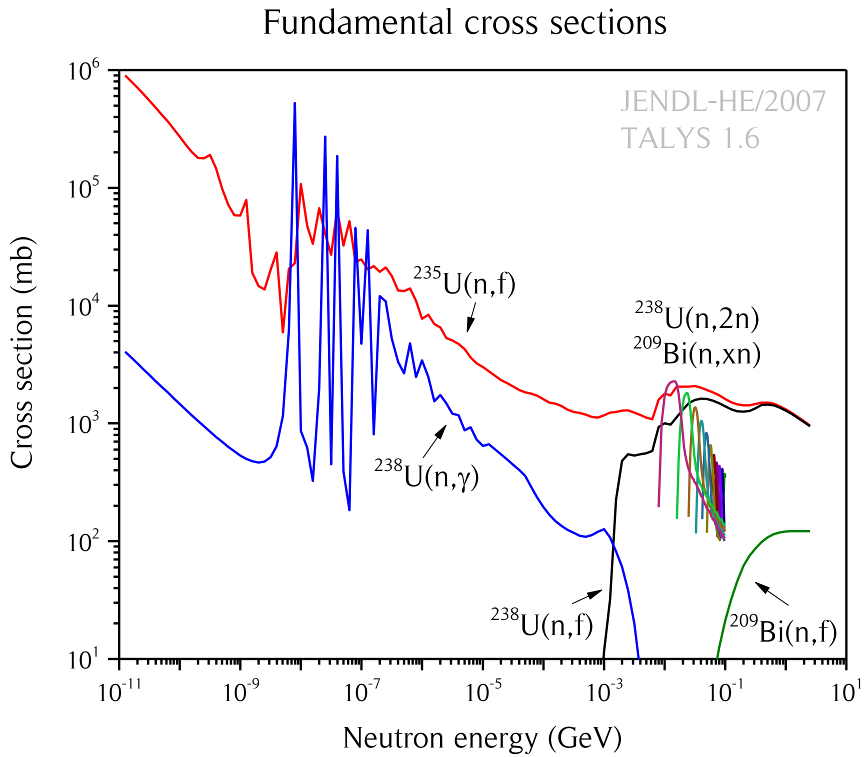


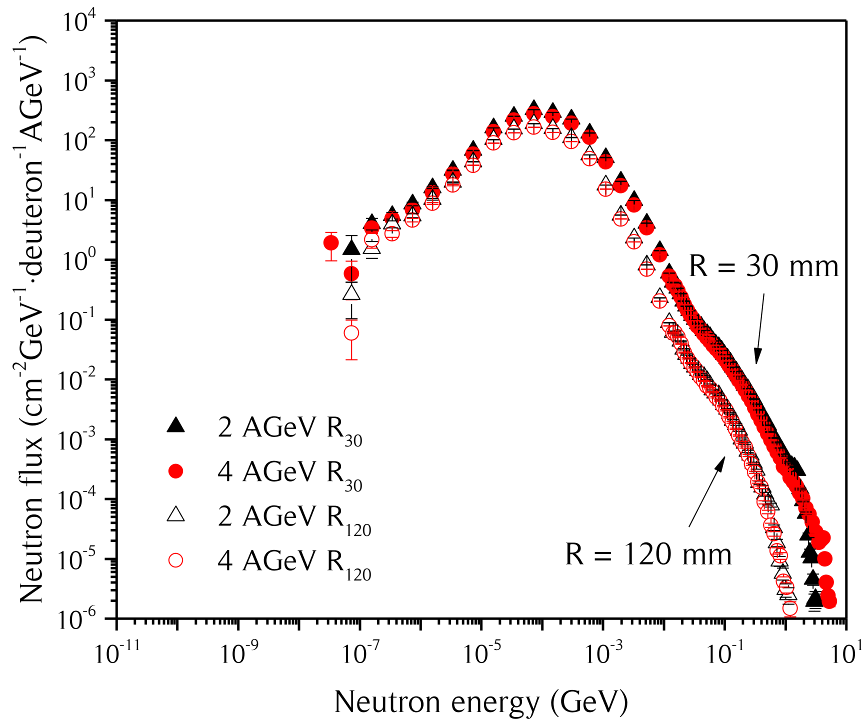
Experimental samples

- ^{209}Bi
- Natural uranium
- Enriched uranium



- ^{235}U and ^{238}U





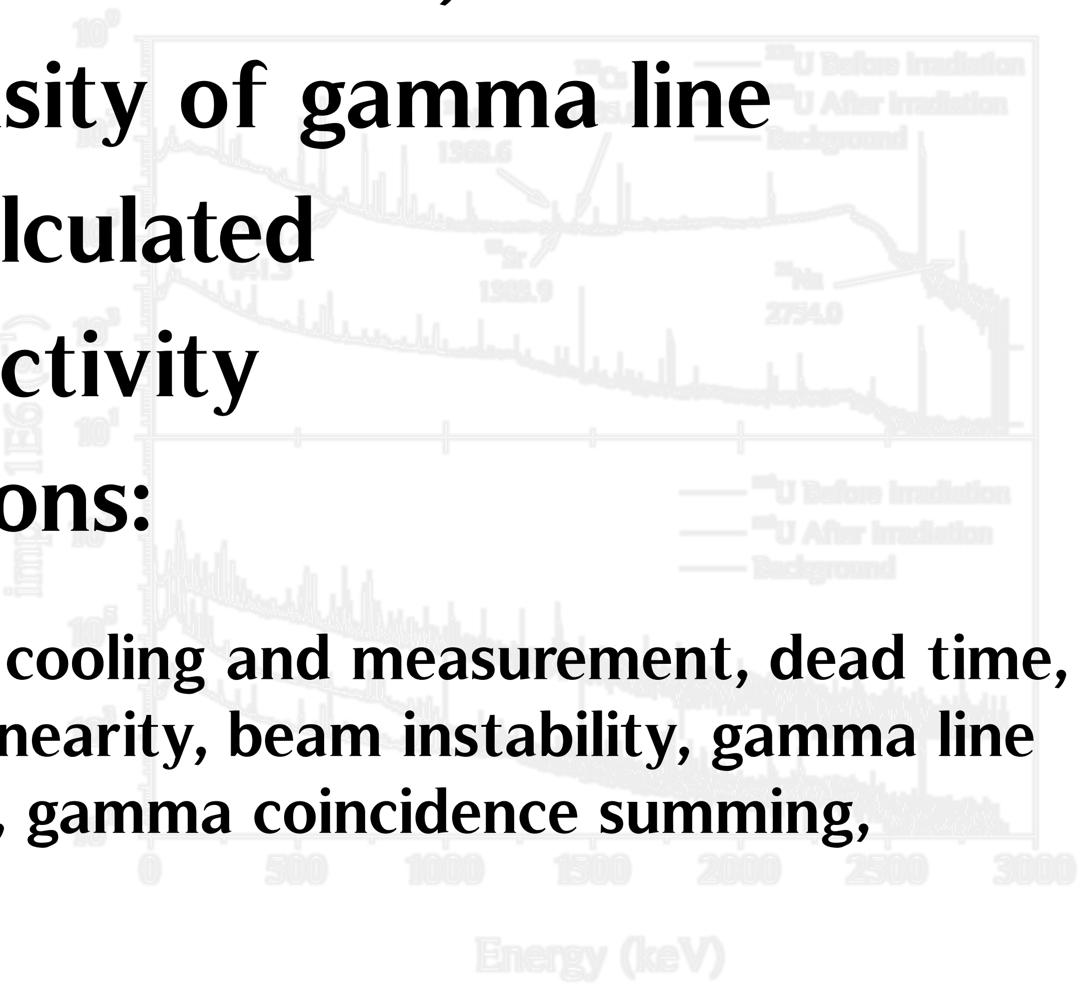
Experimental methods

- **Activation measurement technique**
- **Gamma spectroscopy with the use of HPGe detectors Canberra and ORTEC (20%, resp. 30% relative efficiency) Calibrated with standards made in 2013; FEP eff. Compared with MCNP simulation**

Isotope identification

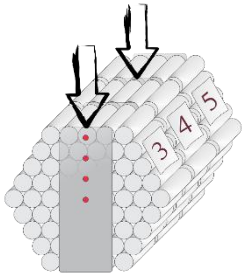
- **Half-life (≥ 6 measurements)**
- **Energy and intensity of gamma line**
- **Reaction rates calculated from measured activity**
- **Included corrections:**

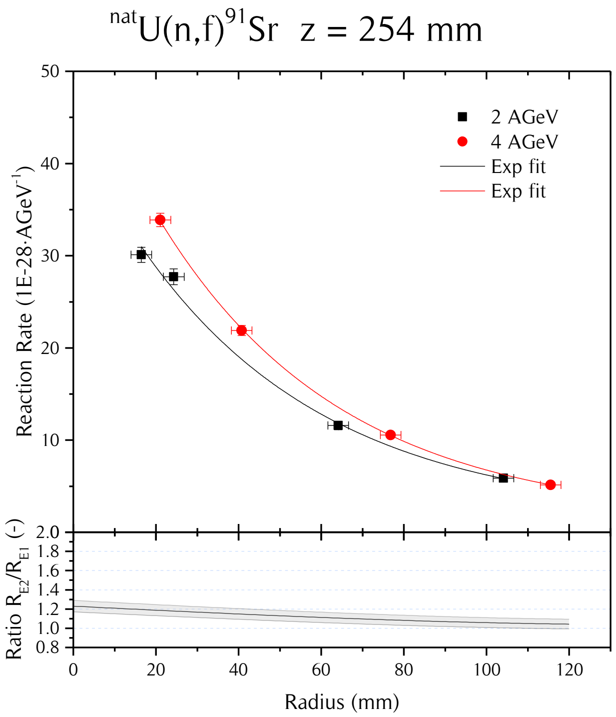
  decay during irradiation, cooling and measurement, dead time, detector efficiency, nonlinearity, beam instability, gamma line intensity, self-absorption, gamma coincidence summing, nonpoint-like source

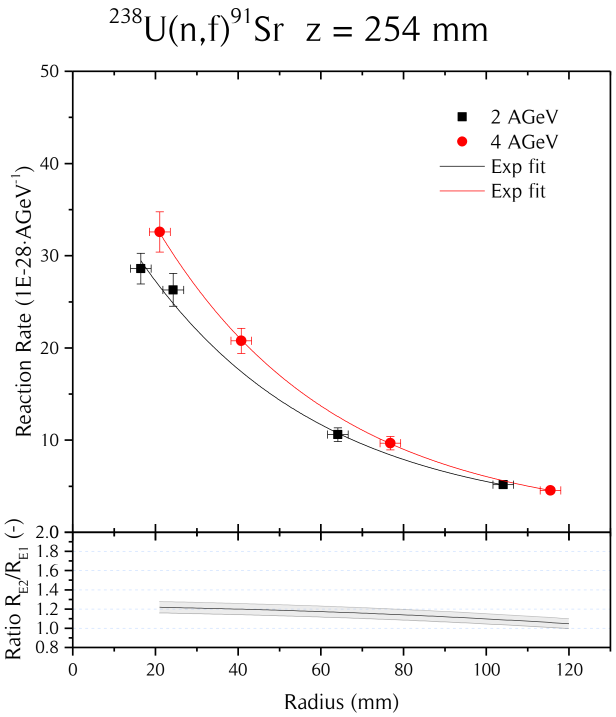


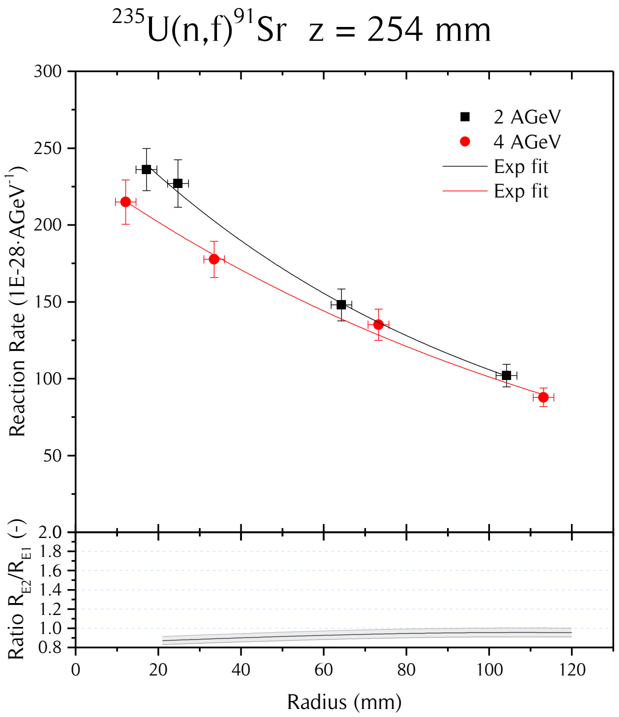
Experimental results on ^{235}U

^{91}Sr, ^{97}Zr, ^{131}I, ^{133}I, ^{135}I, ^{143}Ce, ^{112}Ag, ^{115}Cd radial production after section № 2



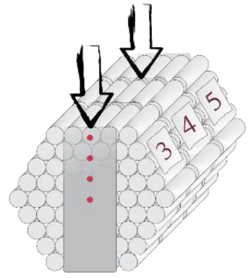


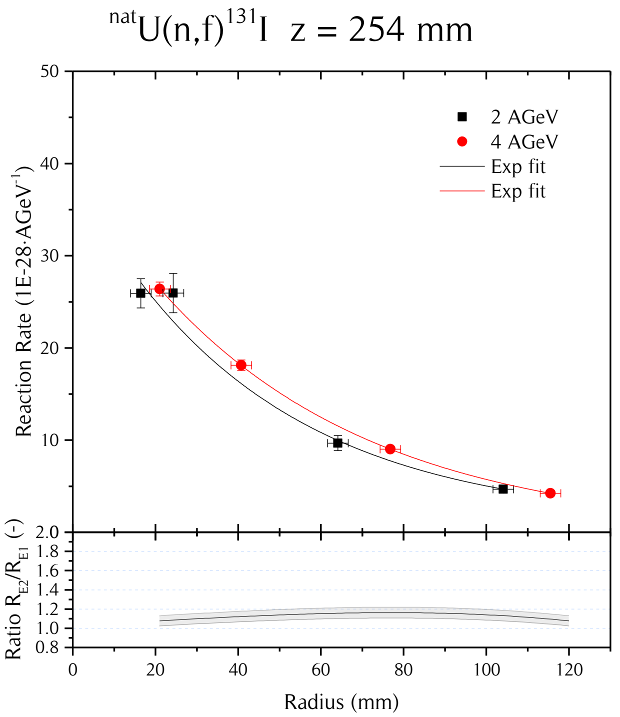


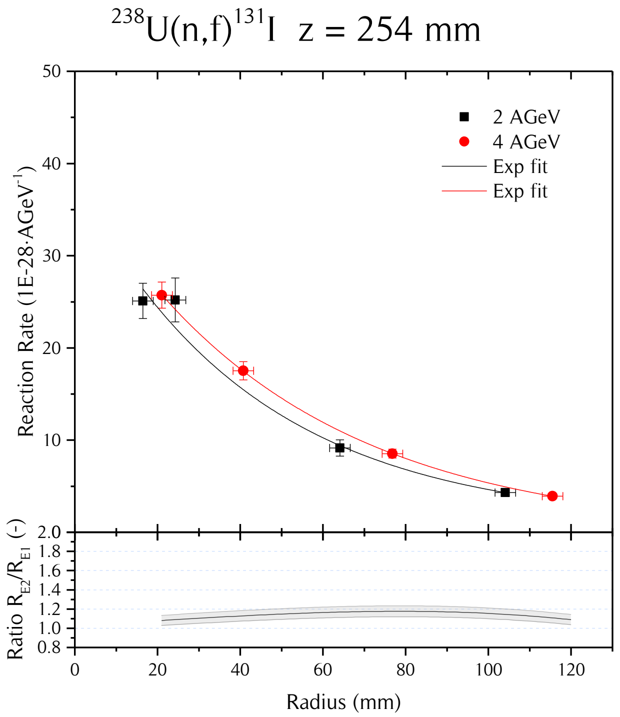


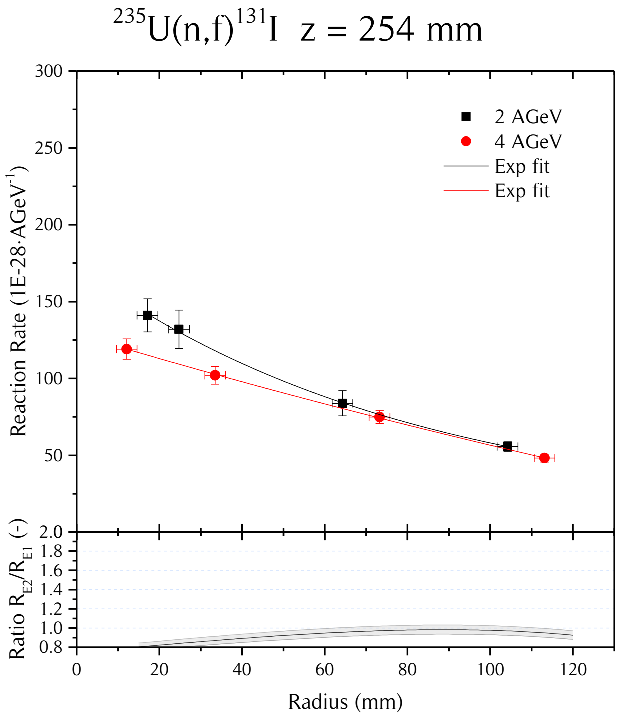
Experimental results on ^{235}U

^{91}Sr, ^{97}Zr, ^{131}I, ^{133}I, ^{135}I, ^{143}Ce, ^{112}Ag, ^{115}Cd radial production after section № 2



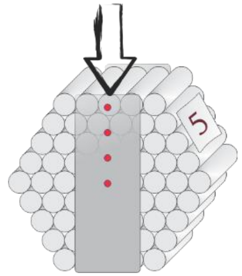




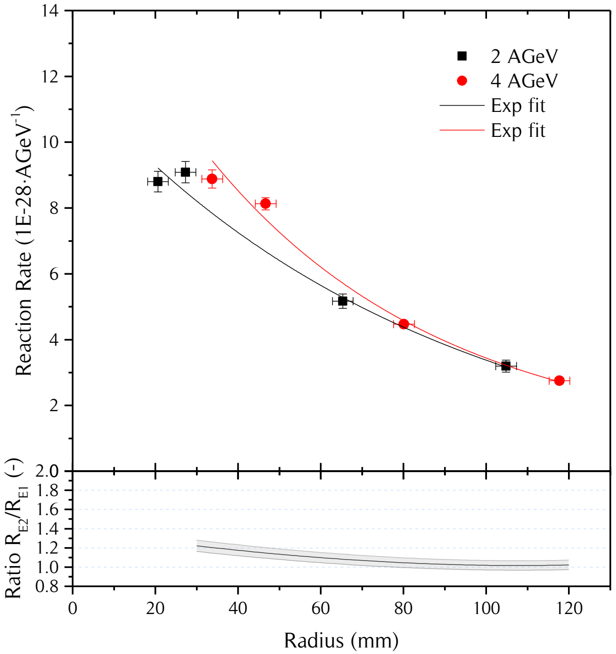


Experimental results on ^{235}U

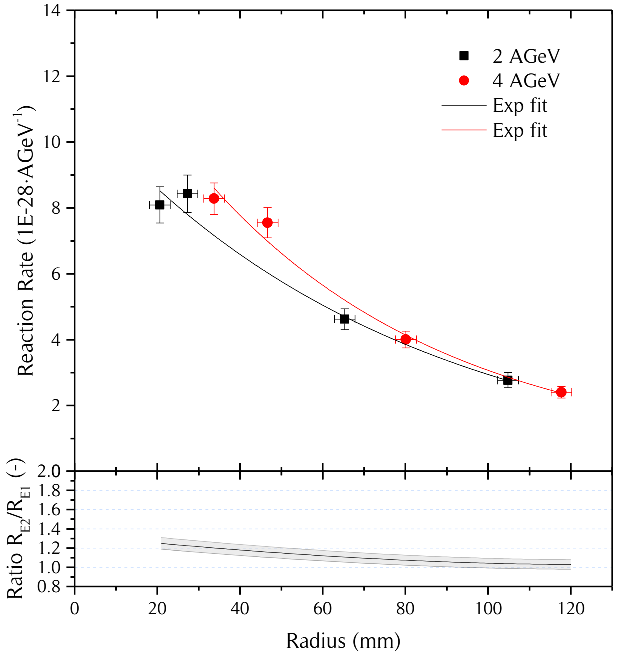
^{91}Sr, ^{97}Zr, ^{131}I, ^{133}I, ^{135}I, ^{143}Ce, ^{112}Ag, ^{115}Cd radial production after section № 4



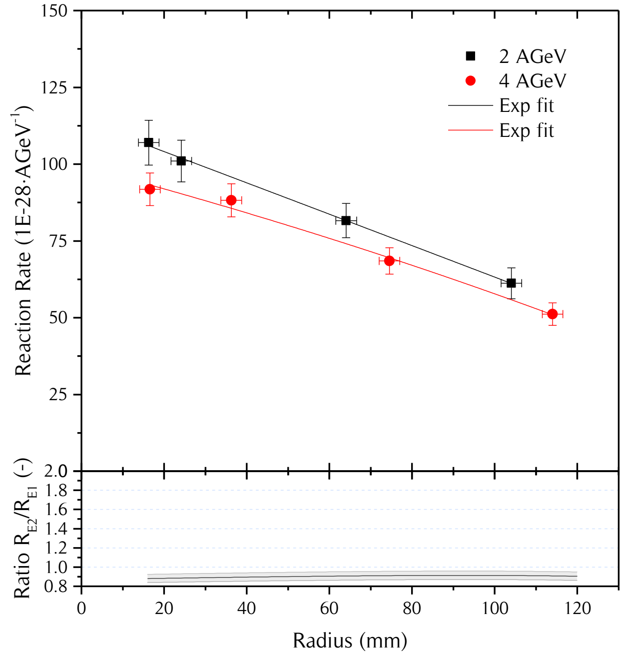
$^{nat}U(n,f)^{91}Sr$ z = 516 mm



$^{238}U(n,f)^{91}Sr$ z = 516 mm

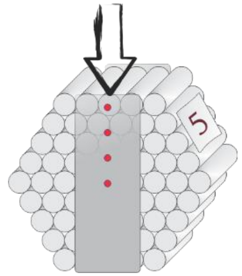


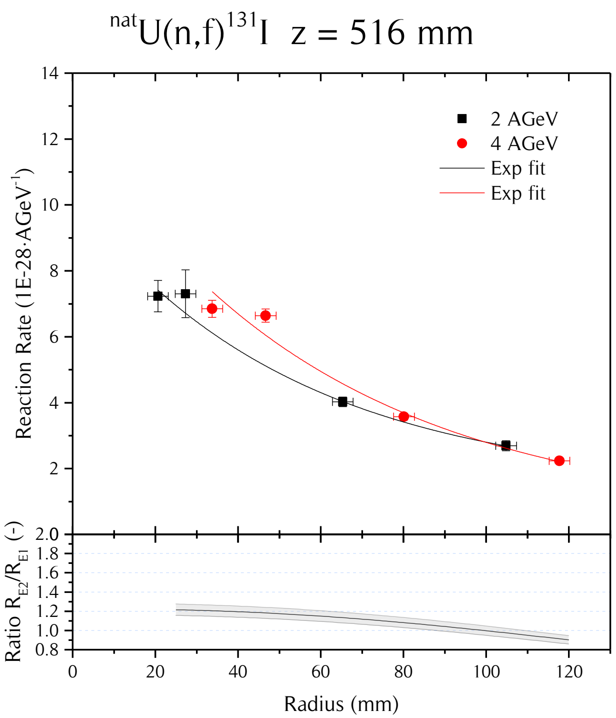
$^{235}U(n,f)^{91}Sr$ z = 516 mm

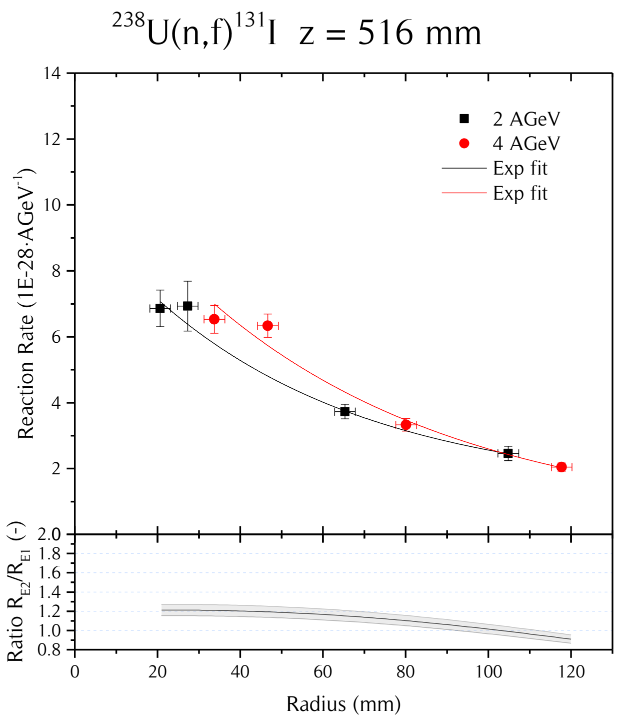


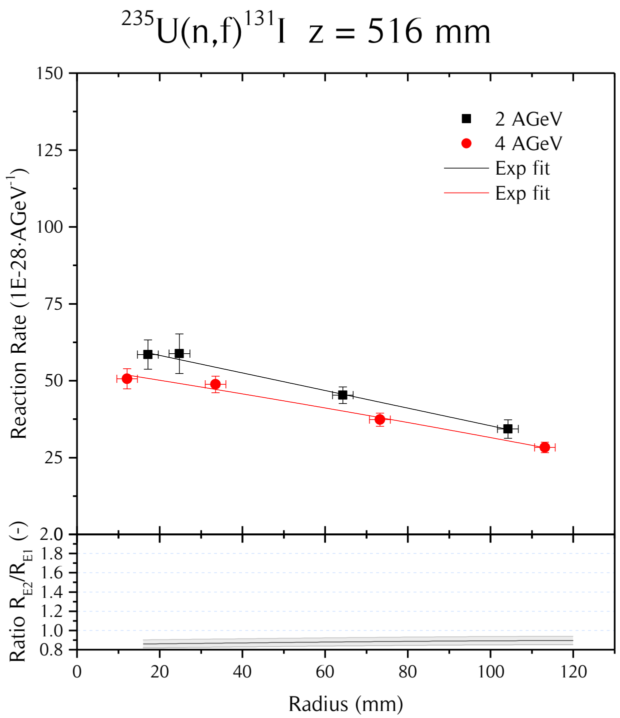
Experimental results on ^{235}U

^{91}Sr, ^{97}Zr, ^{131}I, ^{133}I, ^{135}I, ^{143}Ce, ^{112}Ag, ^{115}Cd radial production after section № 4



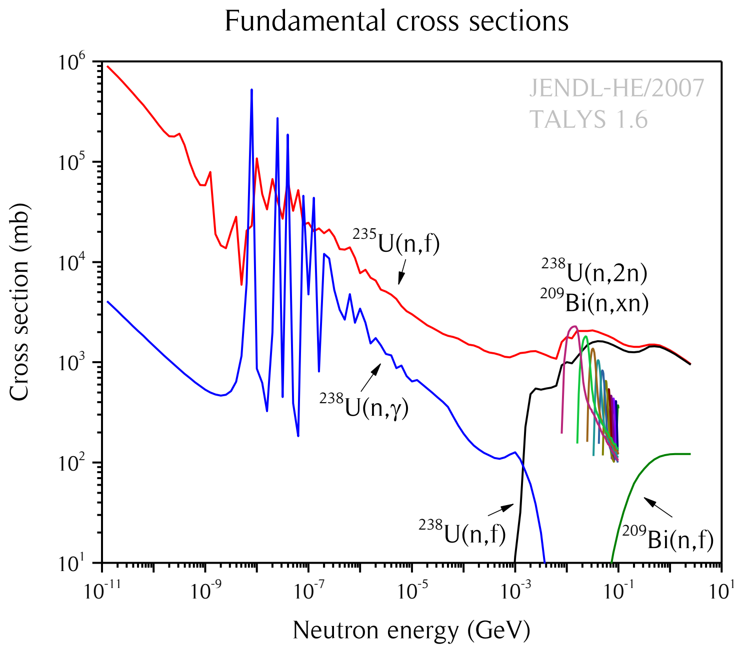


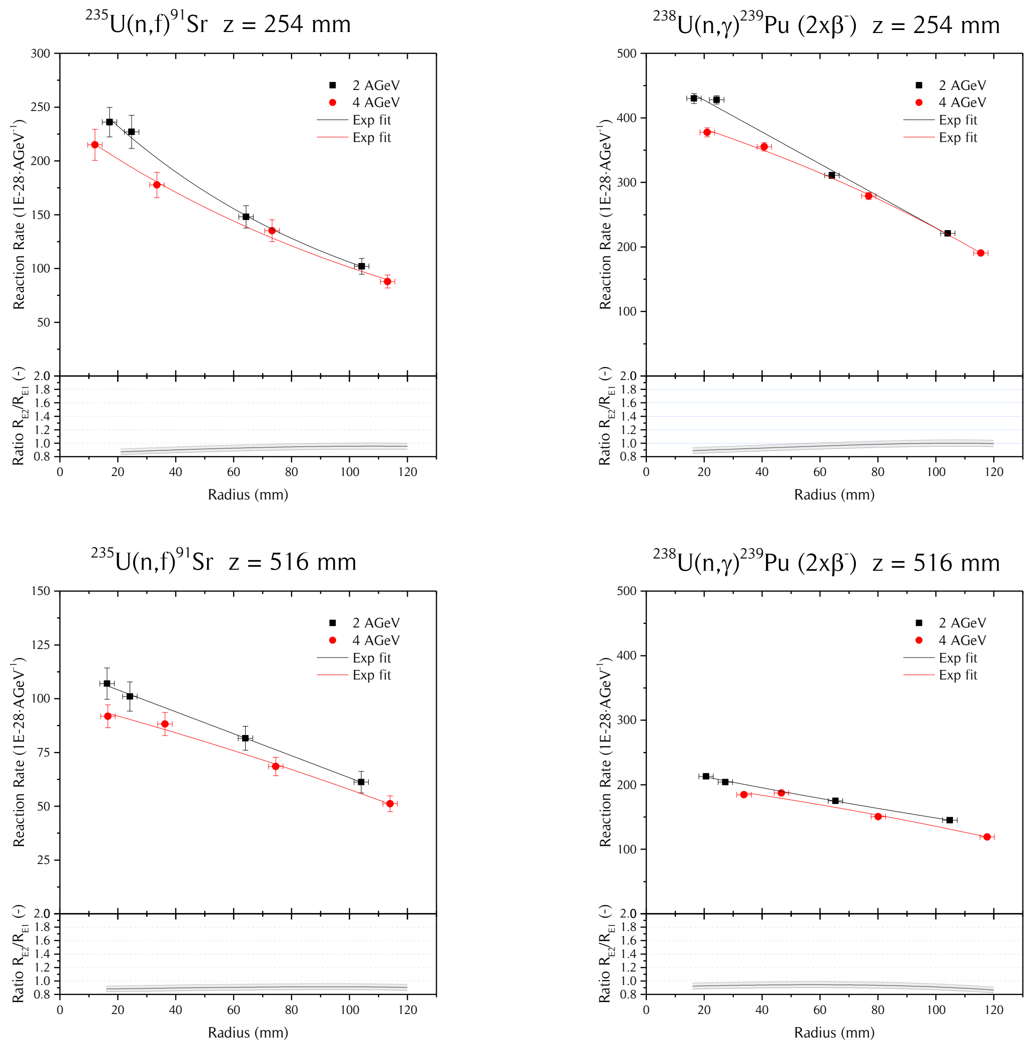




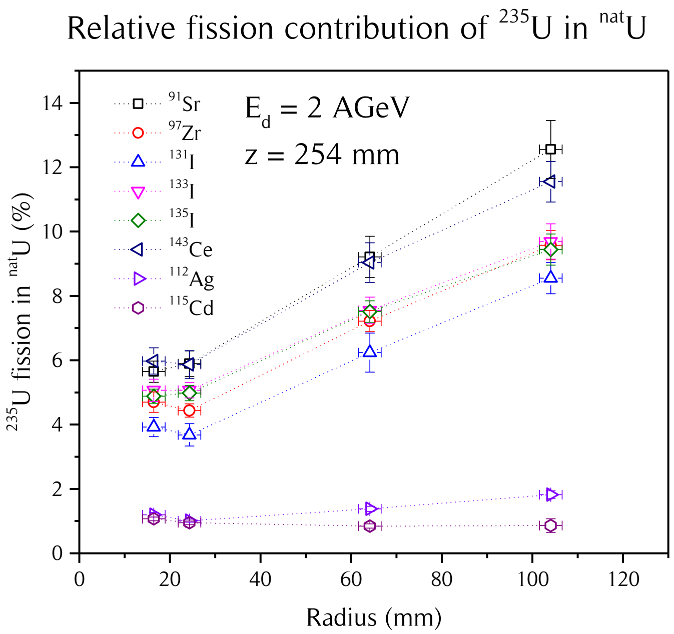
Experimental results on ^{235}U

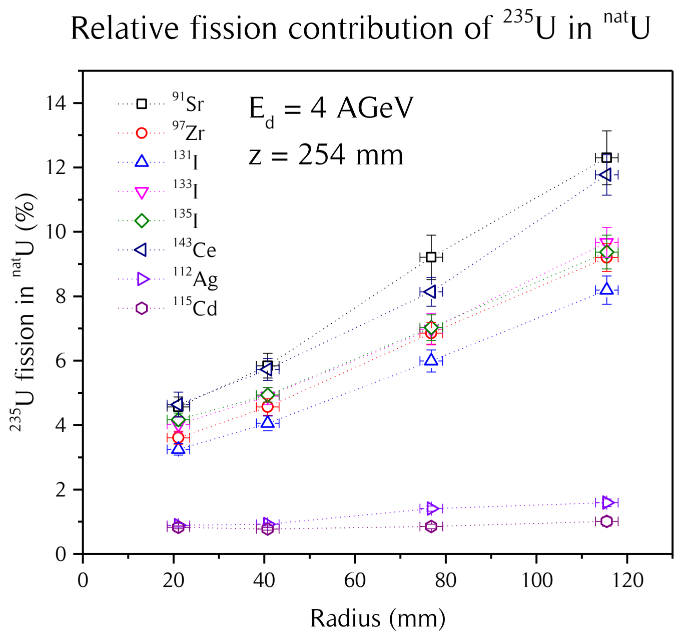
Comparison between ^{91}Sr and ^{239}Pu radial production after section № 2 and 4

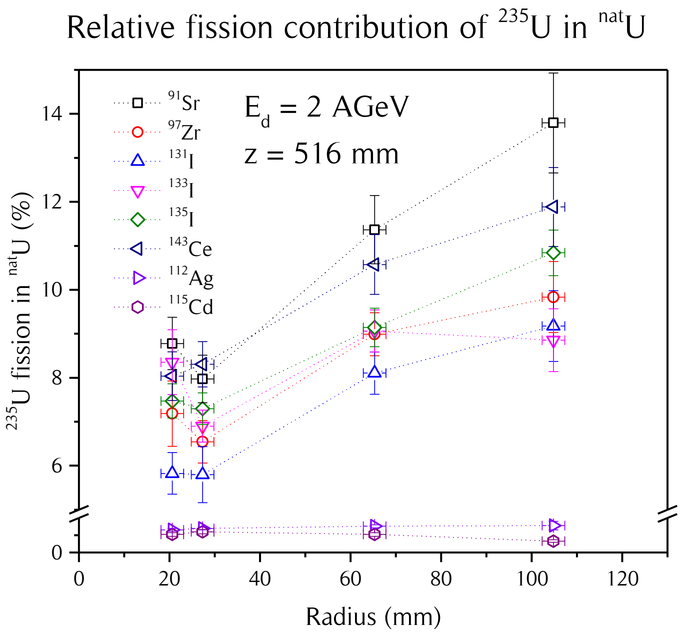


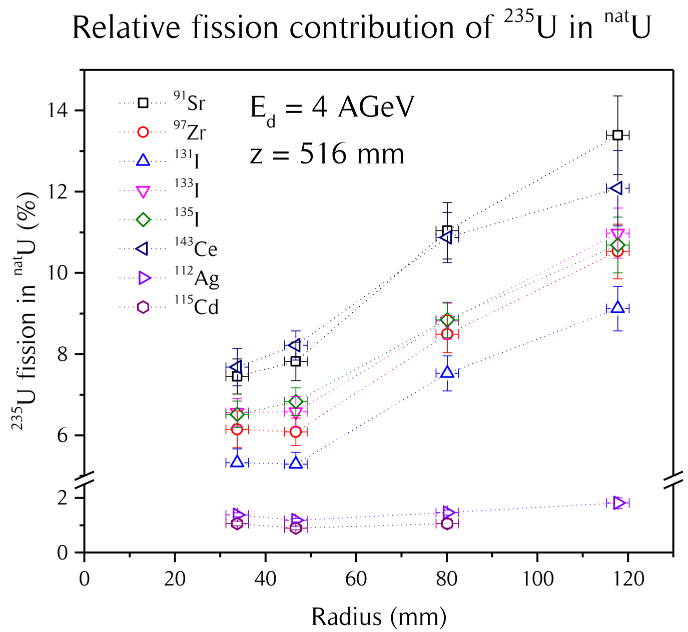


Experimental results on ^{235}U



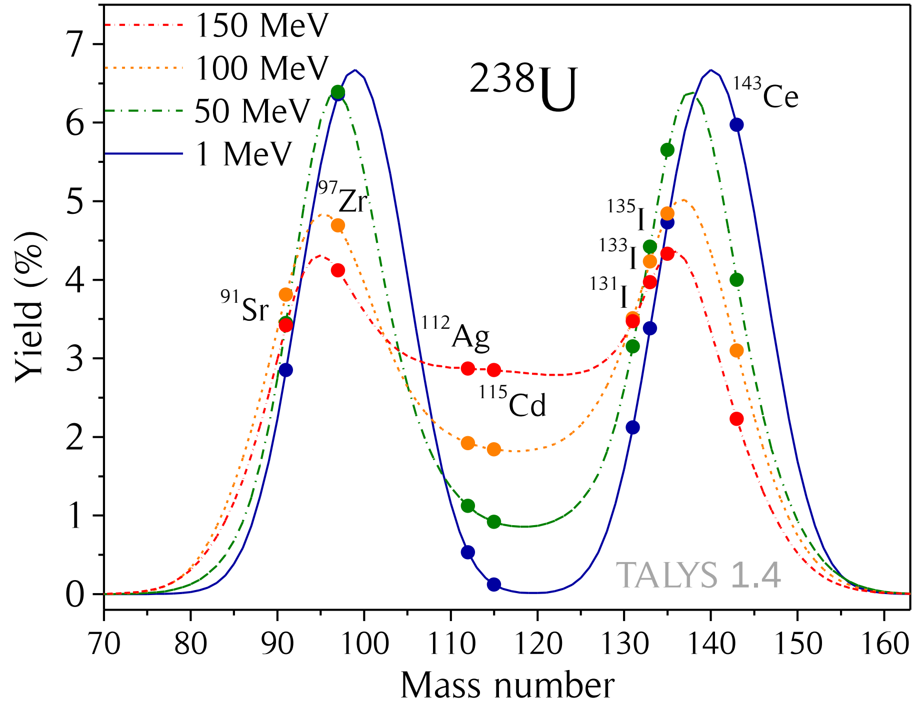


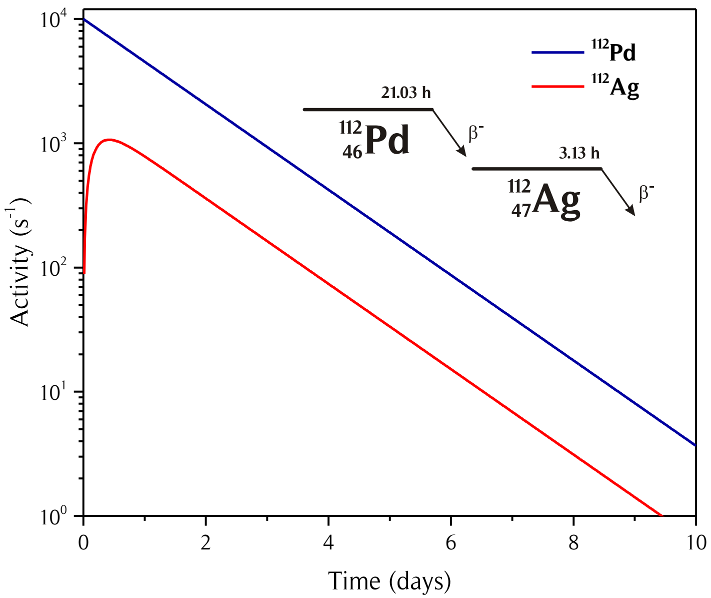




Experimental results on p-t-v

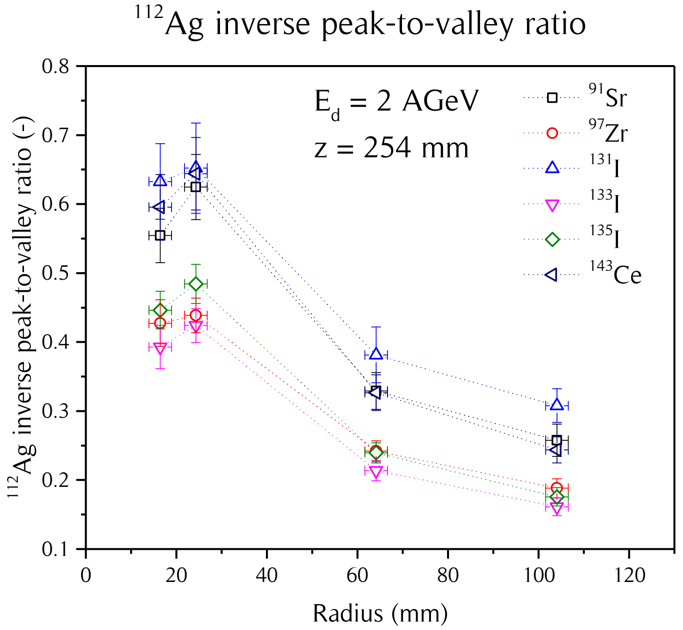
- **Mean neutron energy in dependence on mass distribution of fission products**

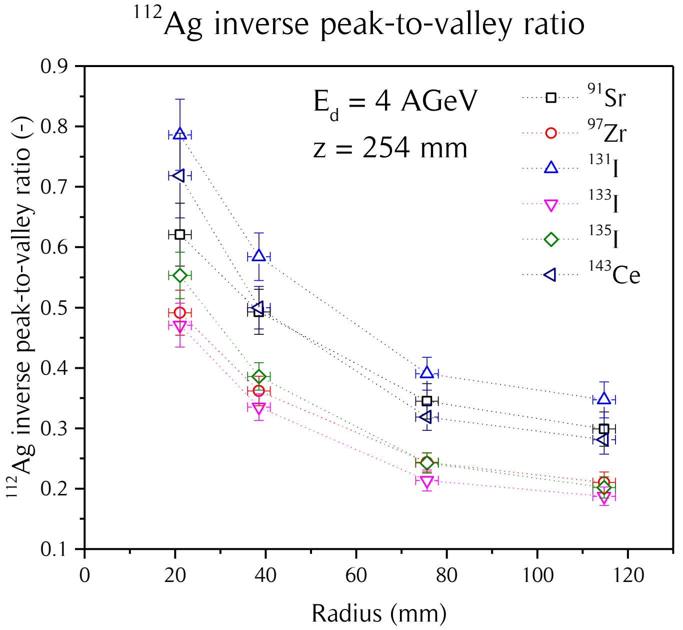


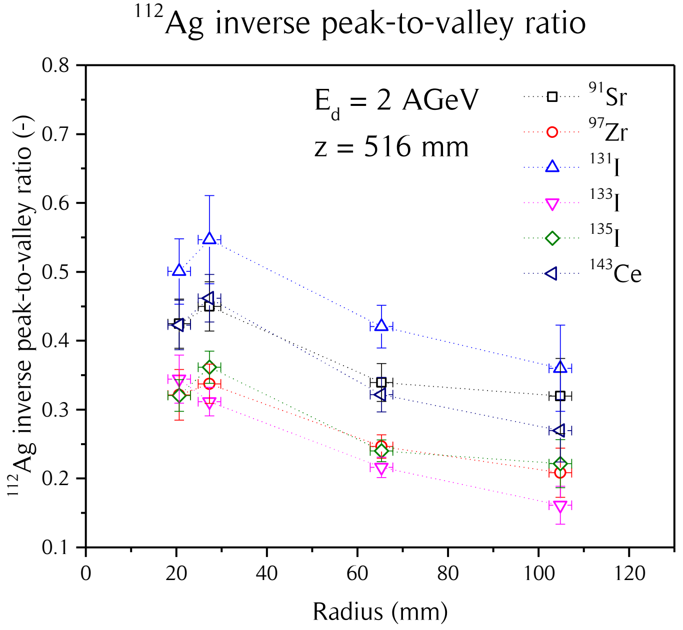


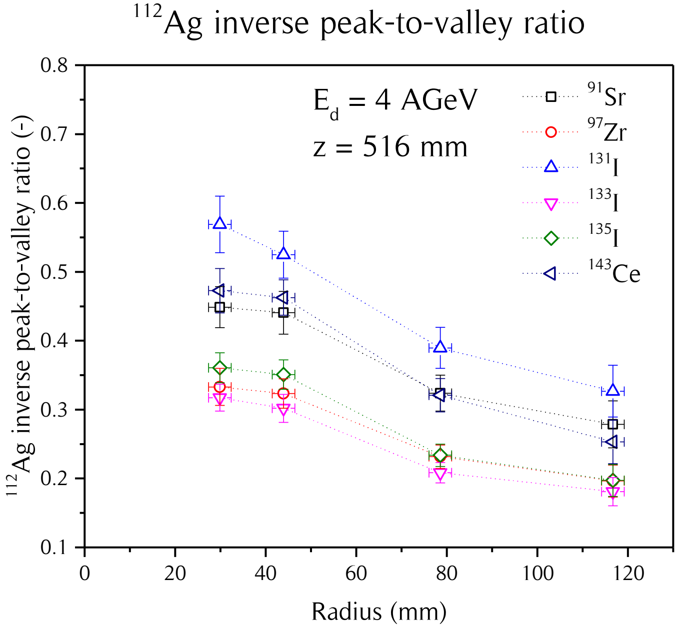
- **Inverse peak-to-valley (p-t-v) ratio for ^{238}U using ^{112}Ag, ^{115}Cd isotopes in valley**

Experimental results on p-t-v





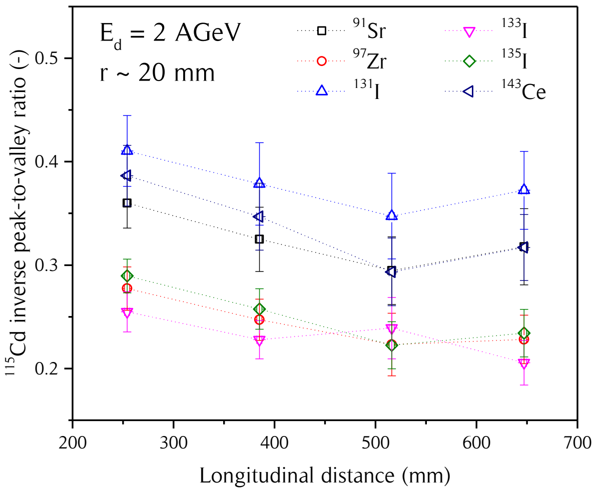




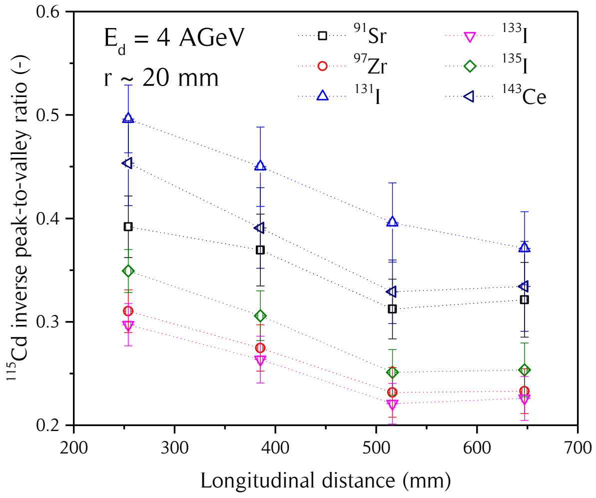
Experimental results on

axial production at $R \approx 20$ mm

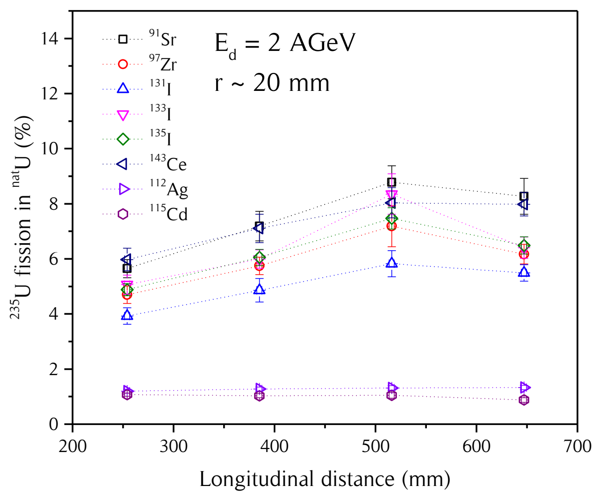
^{115}Cd inverse peak-to-valley ratio



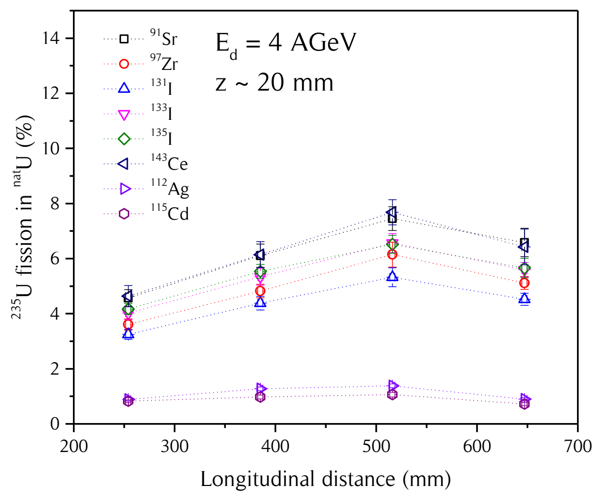
^{115}Cd inverse peak-to-valley ratio



Relative fission contribution of ^{235}U in ^{nat}U

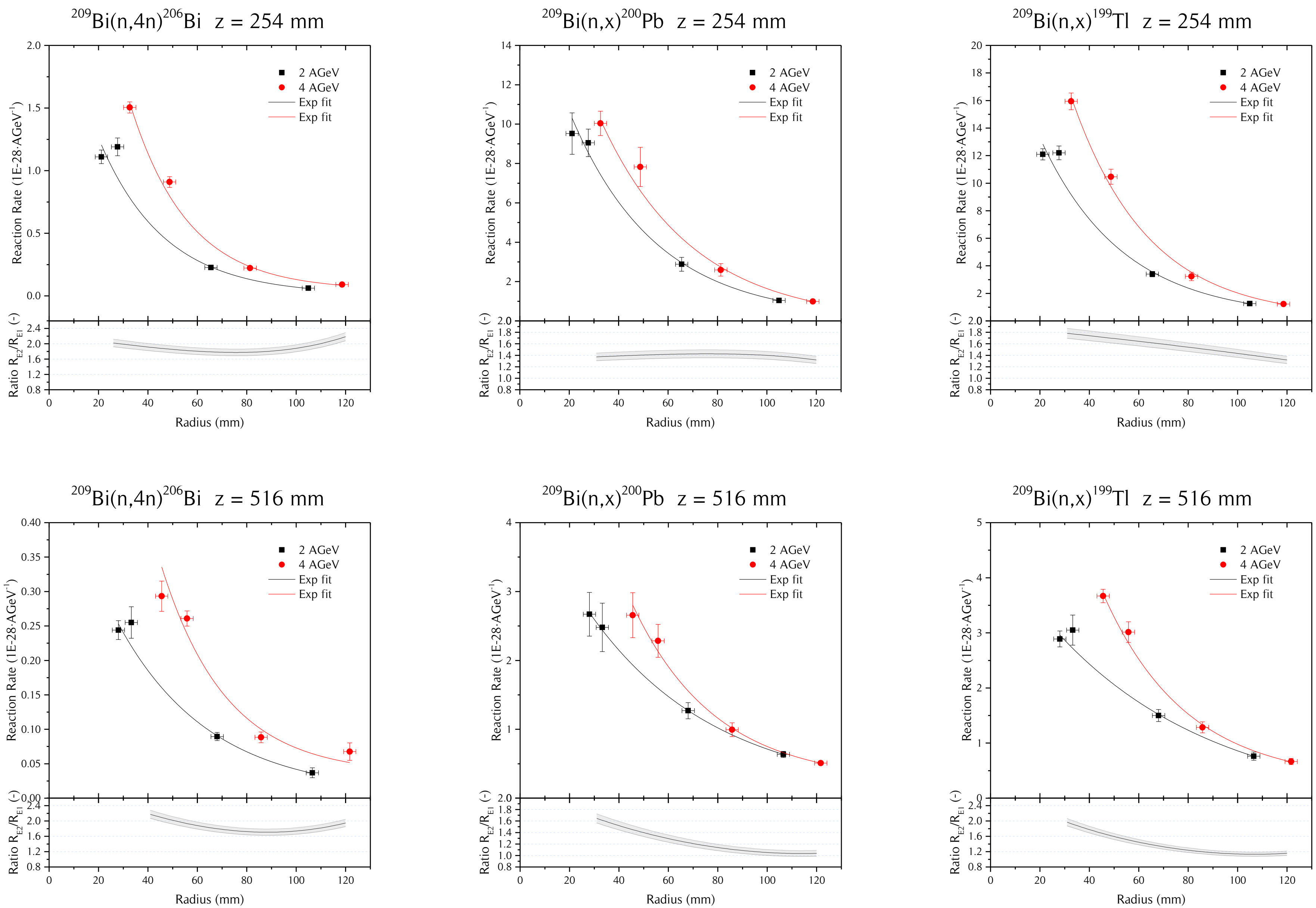


Relative fission contribution of ^{235}U in ^{nat}U



Experimental results on ^{209}Bi

No fission registered



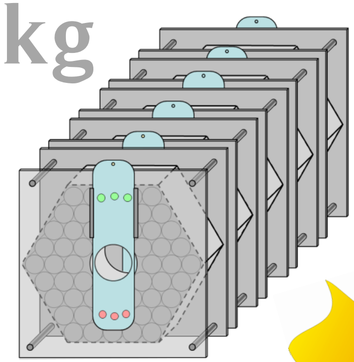
Conclusion

- Contribution of $^{235}U(n,f)$ up to approx. 15%
- Constant dependence on E_{beam} / slight increase in ^{238}U fission, decrease in ^{239}Pu production and fission of ^{235}U
- Peak-to-valley ratio corresponds to results on spatial distribution of $^{235}U(n,f)$ fission
- Increase in $^{209}Bi(n,xn)$ reaction rate $f(E_{beam})$

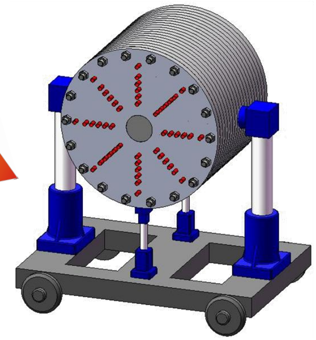
Information about the behavior of neutron spectrum inside the target

Future plans

500 kg

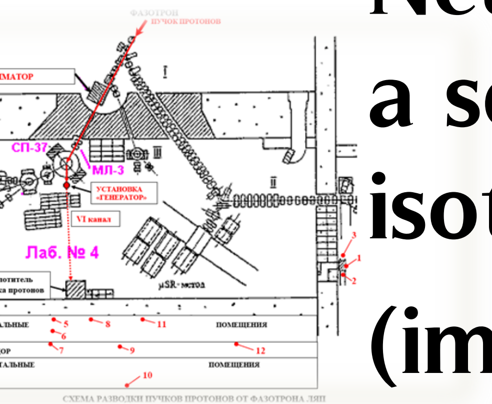


20 tons



- Experiments at BURAN (20t ^{nat}U) need to be realized in future (2015)
- QUINTA @ Phasotron E_p = 660 MeV:
  - Neutron spectrum measurements with a set of $^{235,238}U$, Bi, Au, Y, Co, Al mono-isotope activation detectors

    (improvement of measurement methods)
  - TIMEPIX Si pixelated detectors



Thank you for your attention.