Study of secondary neutron interactions with ^{232}Th, ^{129}I, and ^{127}I nuclei with the uranium assembly "QUINTA" at 2, 4, and 8 GeV deuteron beams of the JINR Nuclotron accelerator

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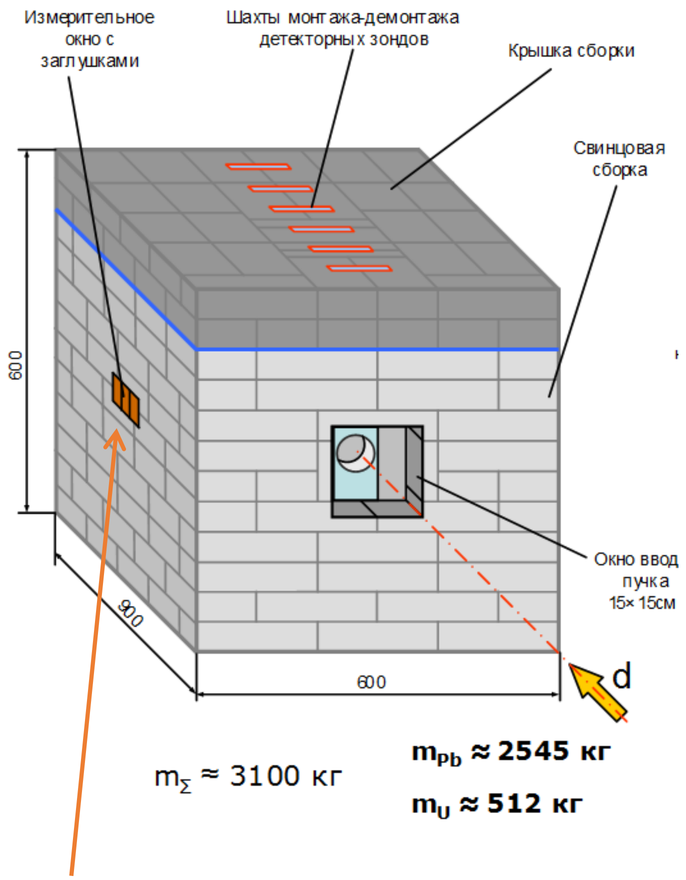
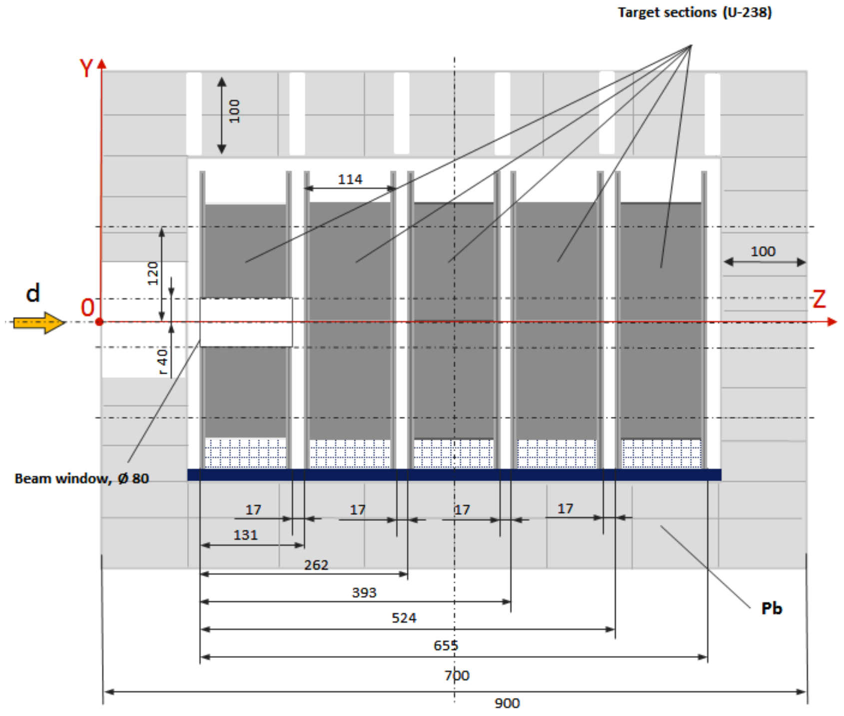
Summary

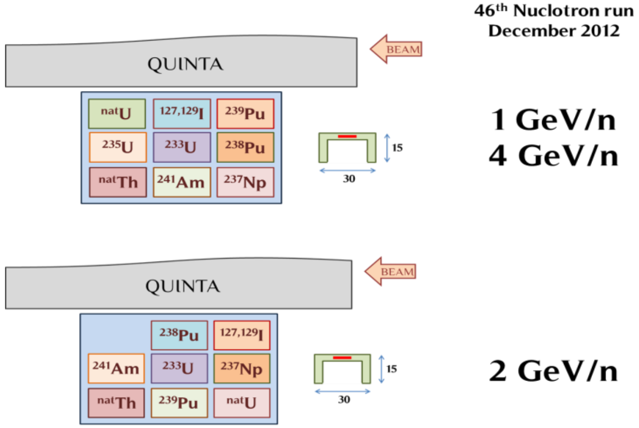
Motivations

The ADS-related research has long been attracting attention of the international scientific community primarily due to societal concerns with the problem of the long-lived radioactive waste storage and the proposals of subcritical nuclear power plant concepts based on the uranium-thorium cycle, and controlled by high-energy particle accelerators (Accelerator Driven Subcritical systems)

Experimental setup «Quinta»

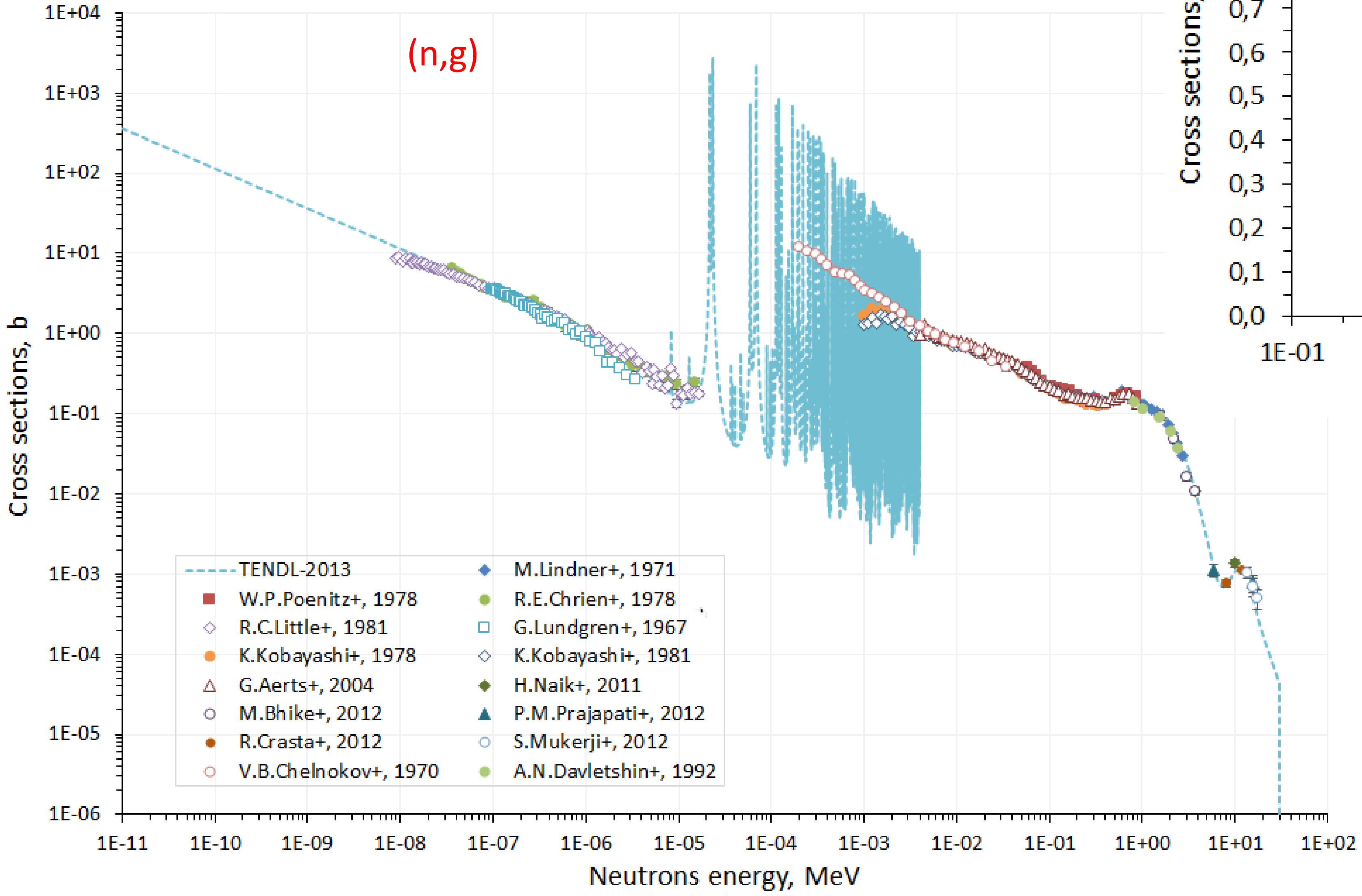


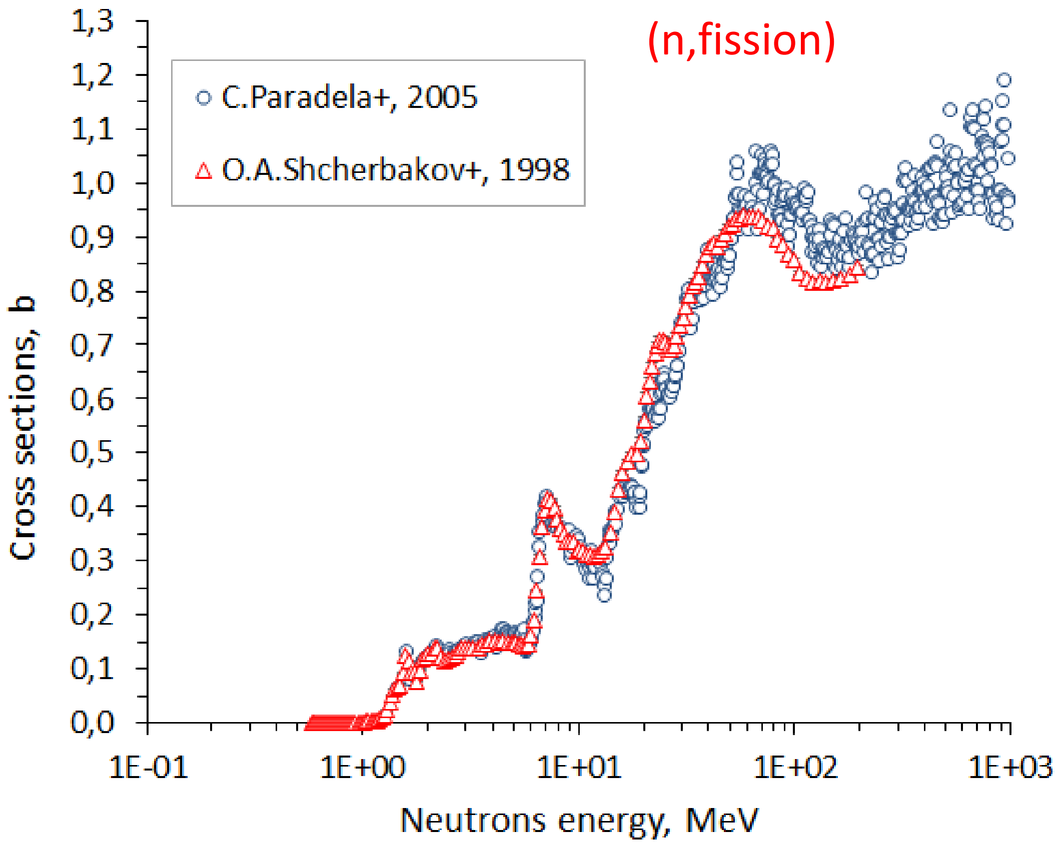




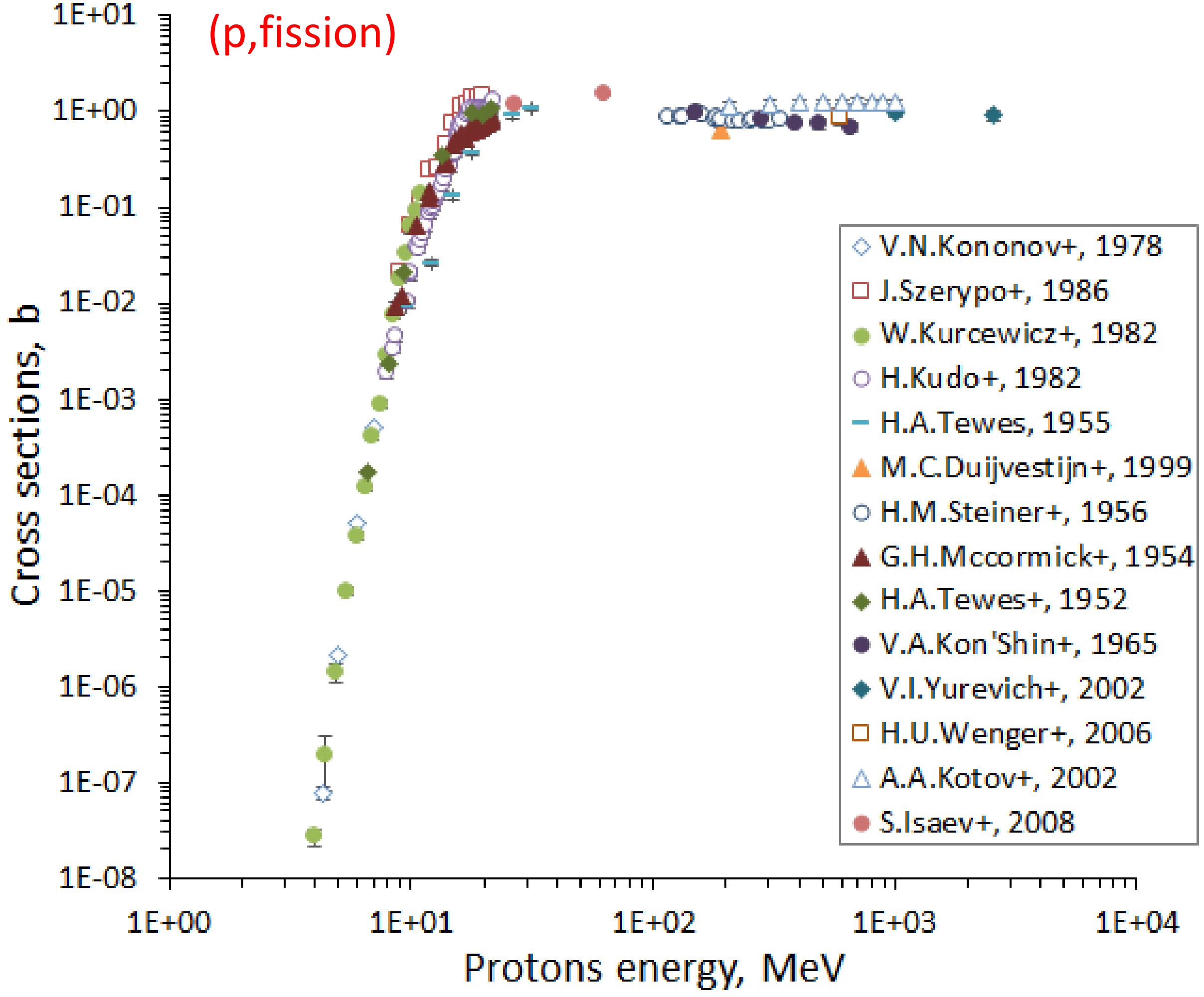
Data on the irradiation conditions and characteristics of the samples Th-232			
Energy of deuterons, GeV	2	4	8
Irradiation time, min.	376	561	970
Integral flux of deuterons	3.02(10)E+13	2.73(10)E+13	9.10(40)E+12
Samples	Th-232	Th-232	Th-232
Mass, g.	0.975	1.000	0.249
Diameter of samples, sm	1.3	1.3	1.3

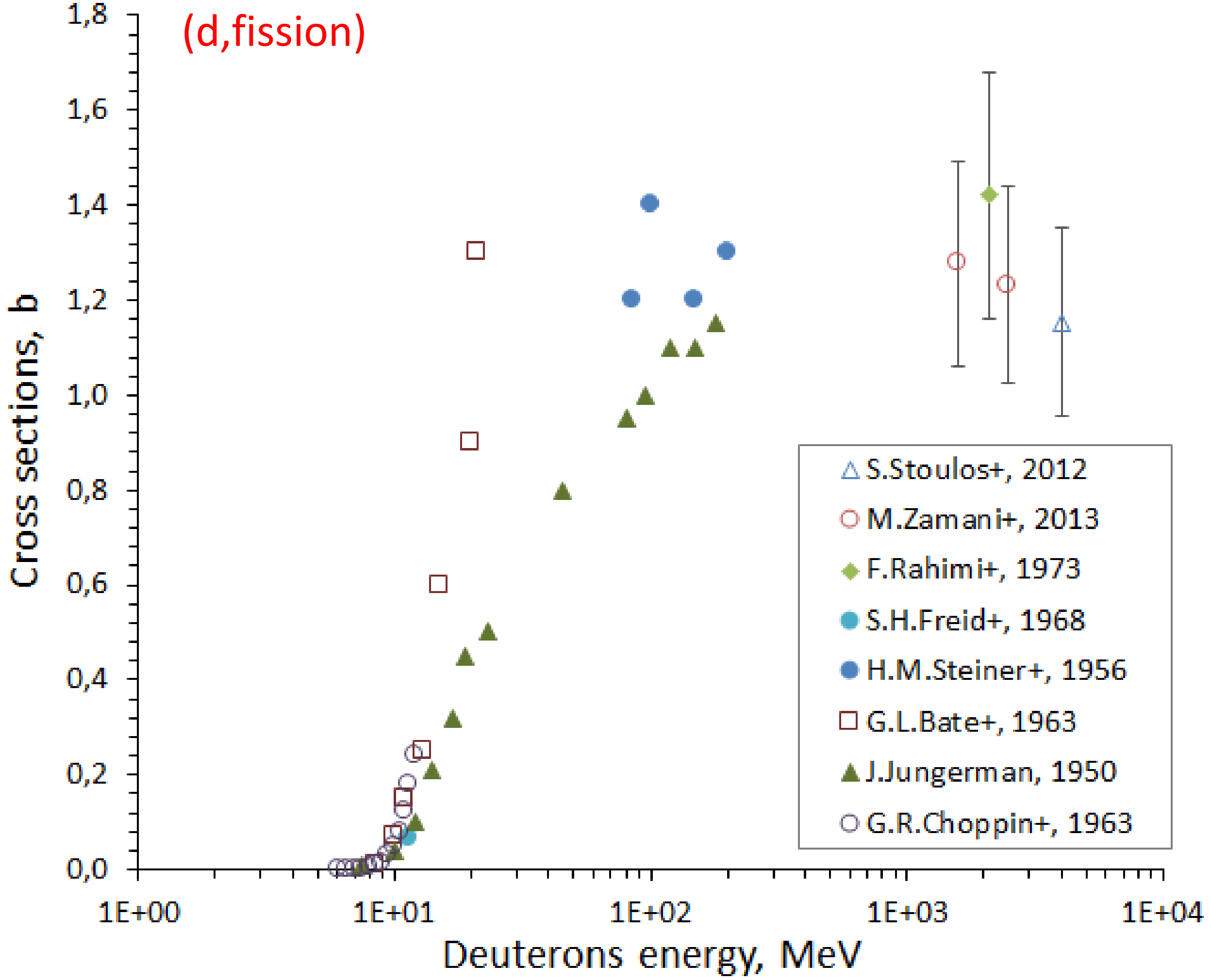
Cross sections for $^{232}Th(n,g)$ and $^{232}Th(n,fission)$ reactions from EXFOR data

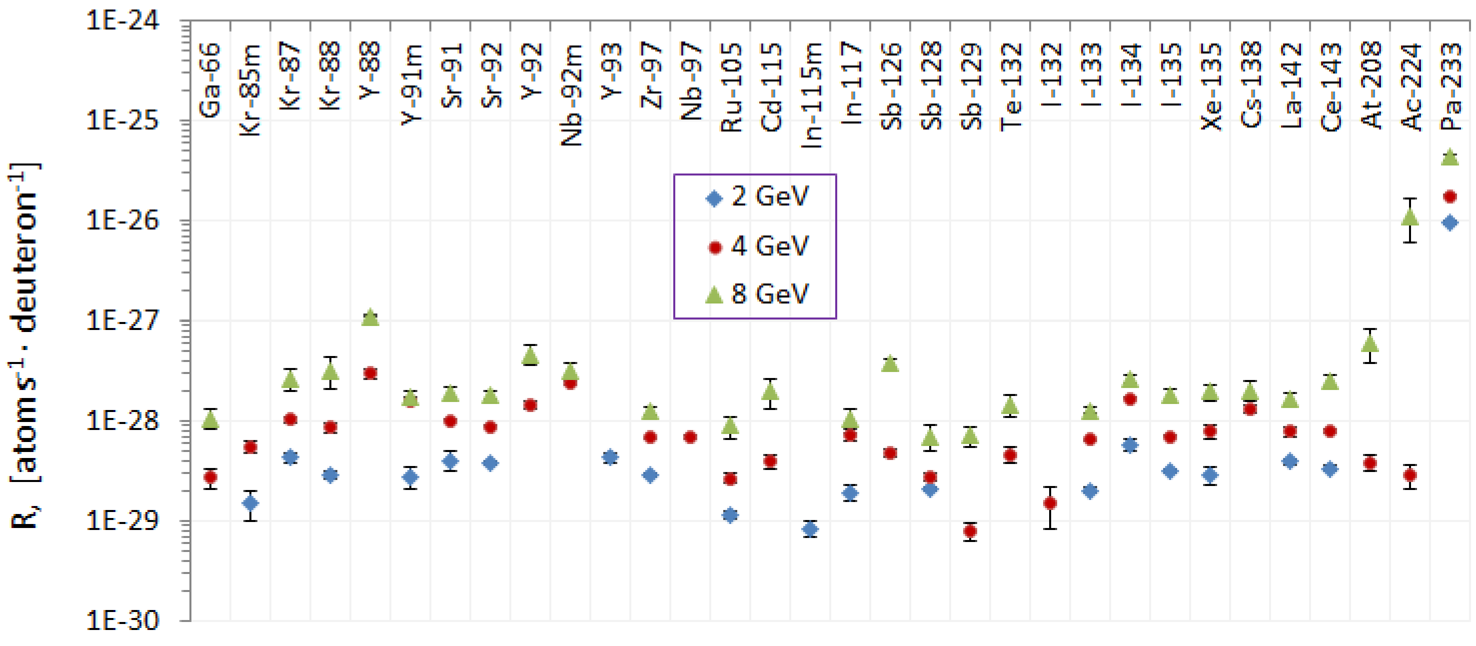




Cross sections for $^{232}Th(p,fission)$ and $^{232}Th(d,fission)$ reactions from EXFOR data

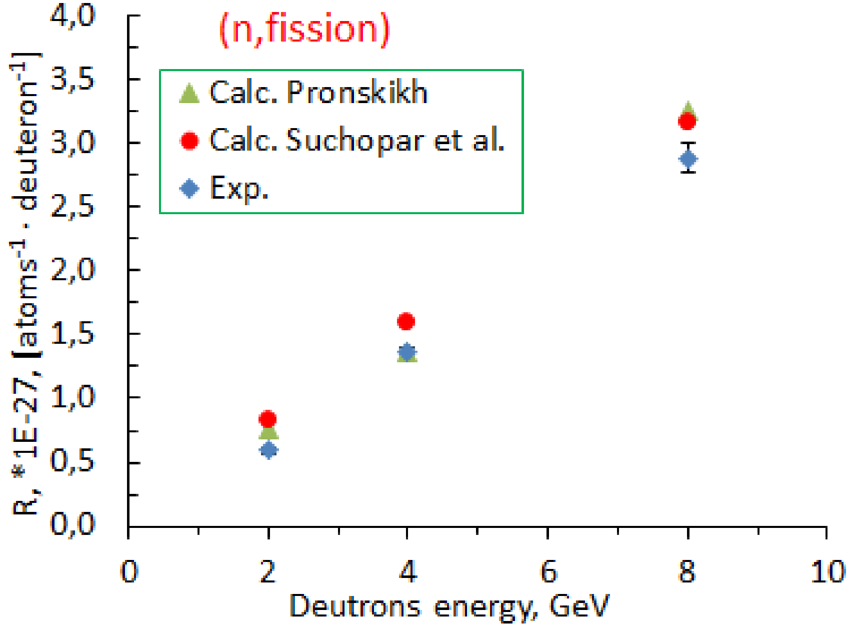


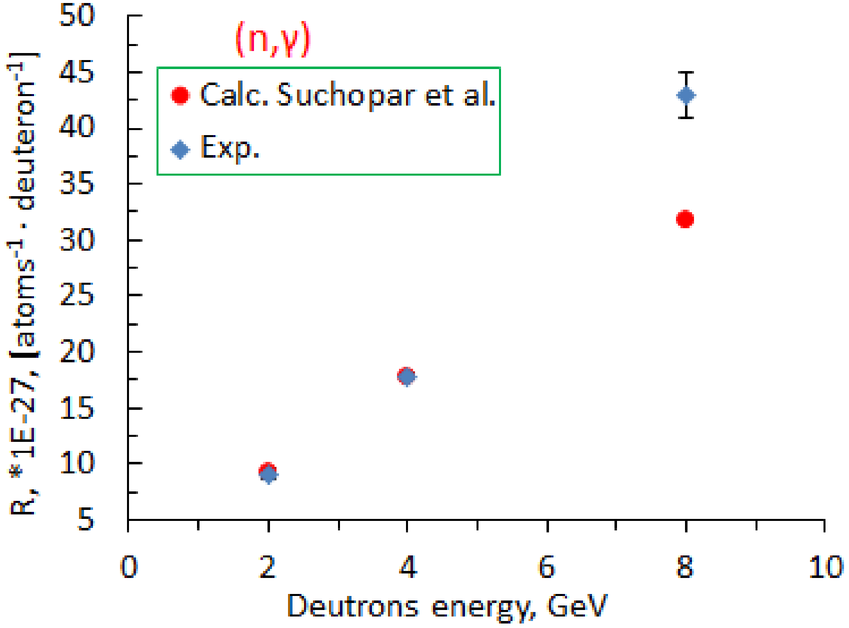




Reaction rates for residual nuclei of ^{232}Th from experiments E_d = 2,4,8 GeV, December, 2012.
("QUINTA" with Pb shields)

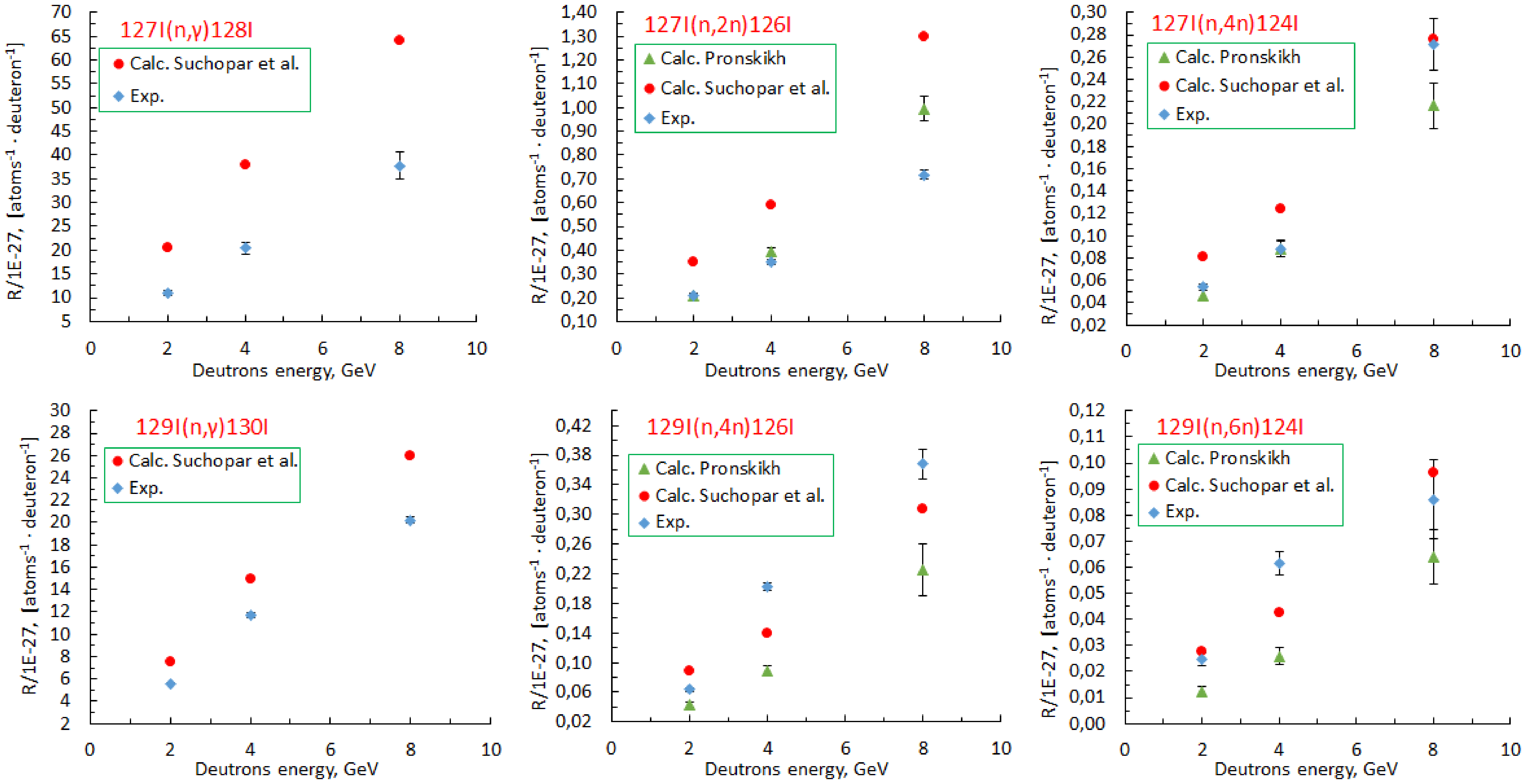
Dependence of reaction rates on the deuteron energy for ^{232}Th(n,fission) and ^{232}Th(n,γ) reactions





Calc. Pronskikh is calculated by MARS-15,
Calc. Suchopar is calculated by MCNPX-2.7 + TENDL(TALYS)

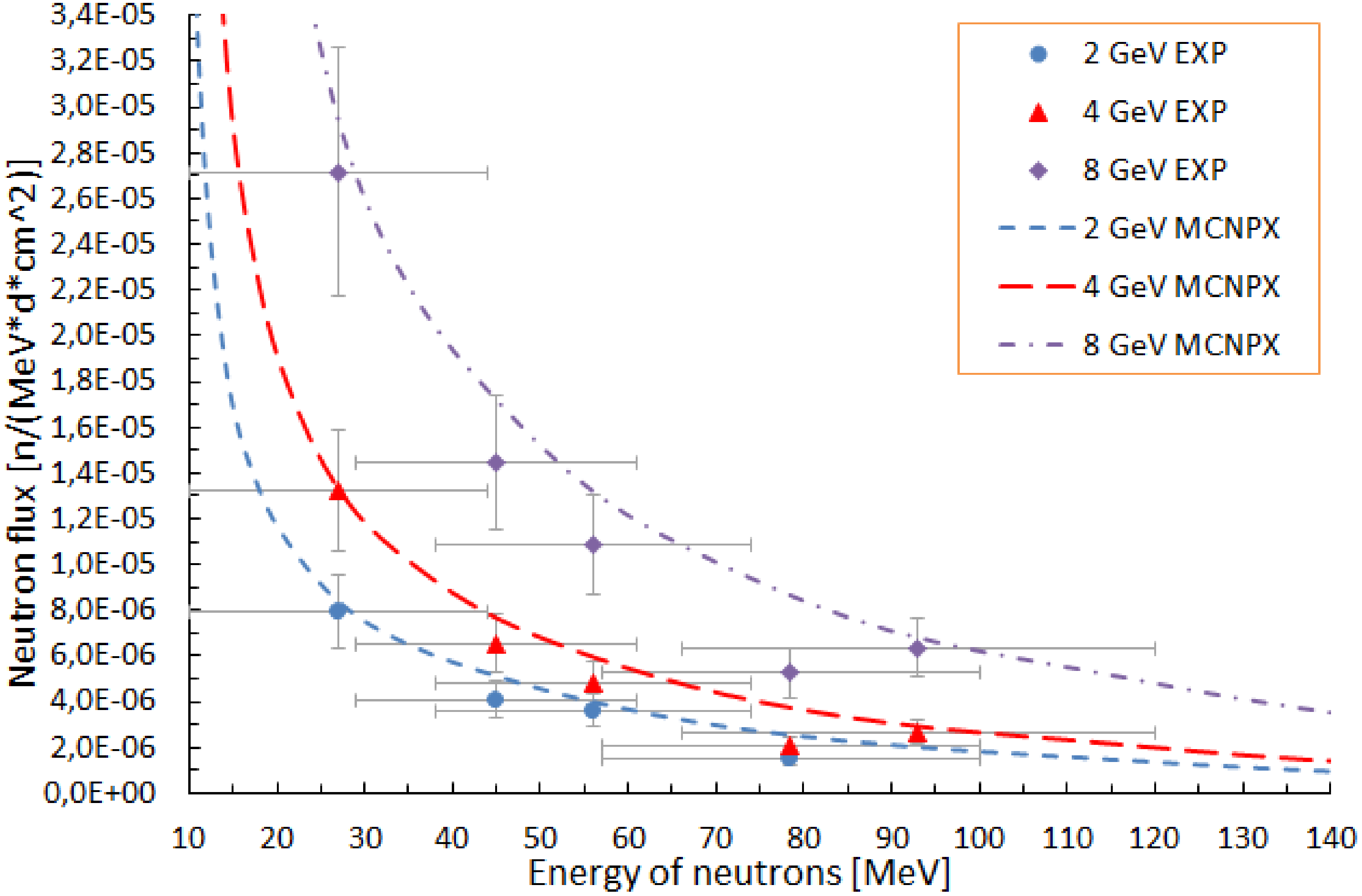
Dependence of the (n,γ), (n,xn) reactions rate of the energy deuterons in the samples ^{127}I and ^{129}I

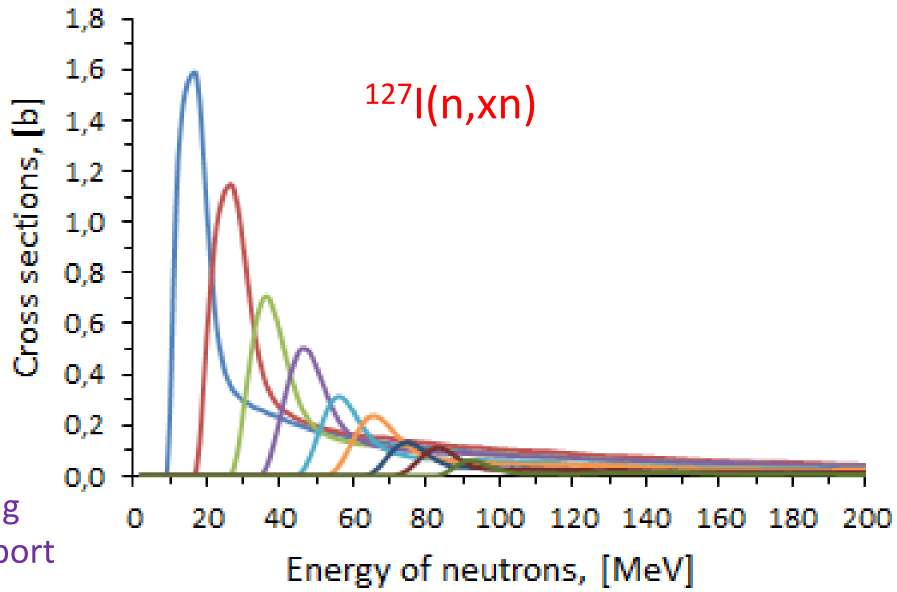


Definition of neutron fluence using $^{127}I(n,xn)$ reactions

0.8R – 80% of reaction rate R(exp.) (by Calc.2. neutrons in energy interval dE adding 80(5)% contribution to the reaction rate),
σ – averaged values of reaction cross sections for energy interval dE,
F – fluence of neutrons (n/MeV·d·cm^2).

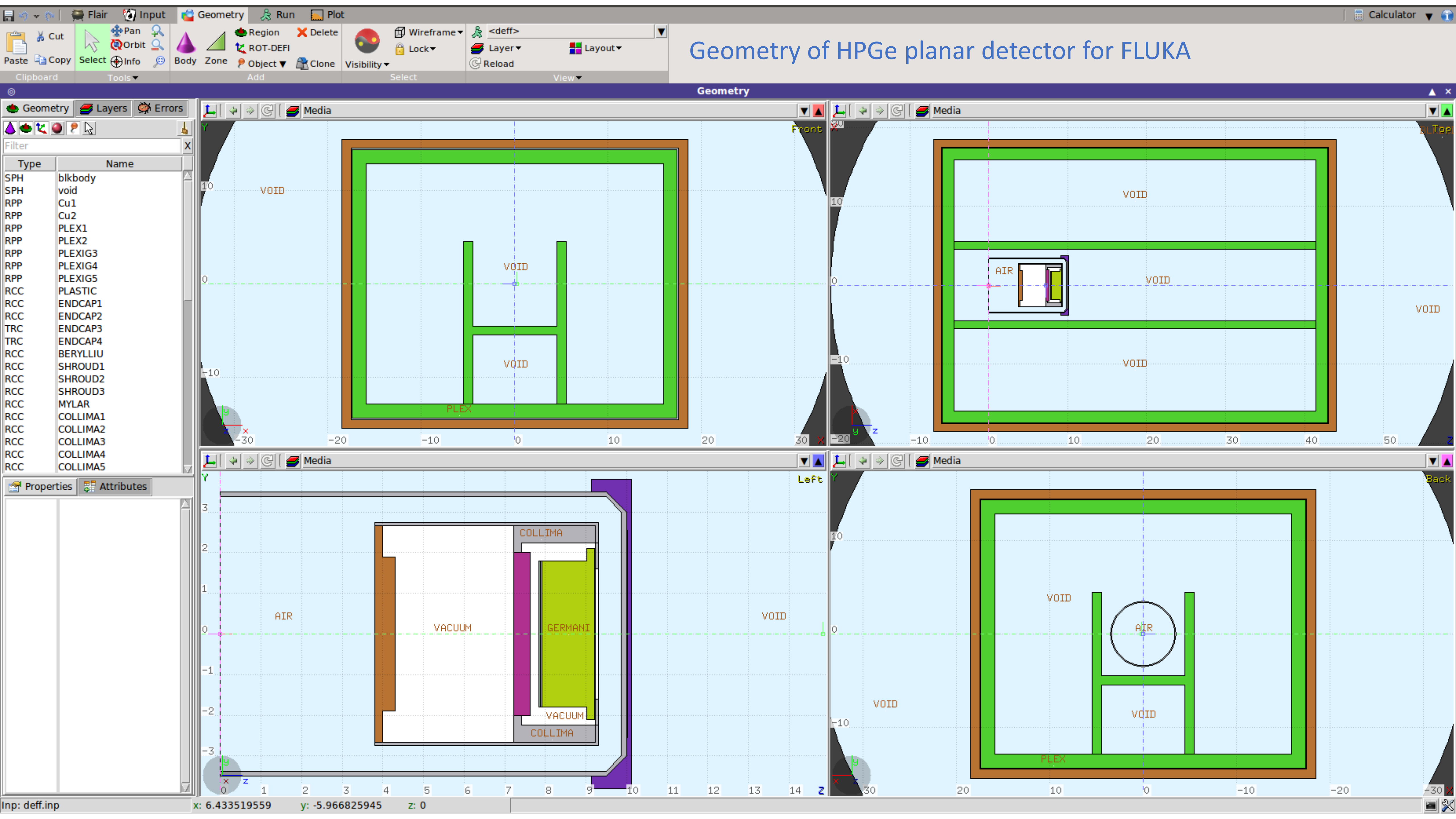
Nuclear reactions	0.8R	dE (MeV)	σ (b)	F
2 GeV				
$^{127}I(n,8n)^{120}I$				
$^{127}I(n,7n)^{121}I$	7.15(29)E-30	57 – 100	0.110	1.51(30)E-6
$^{127}I(n,5n)^{123}I$	3.16(13)E-29	38 – 73	0.249	3.63(73)E-6
$^{127}I(n,4n)^{124}I$	4.40(18)E-29	29 – 61	0.337	4.08(82)E-6
$^{127}I(n,2n)^{126}I$	1.68(6)E-28	10 – 44	0.621	8.0(16)E-6
4 GeV				
$^{127}I(n,8n)^{120}I$	7.20(64)E-30	66 – 120	0.050	2.65(53)E-6
$^{127}I(n,7n)^{121}I$	9.84(48)E-30	57 – 100	0.110	2.07(41)E-6
$^{127}I(n,5n)^{123}I$	4.18(22)E-29	38 – 73	0.249	4.80(96)E-6
$^{127}I(n,4n)^{124}I$	7.07(57)E-29	29 – 61	0.337	6.6(13)E-6
$^{127}I(n,2n)^{126}I$	2.80(7)E-28	10 – 44	0.621	1.33(26)E-5
8 GeV				
$^{127}I(n,8n)^{120}I$	1.73(14)E-29	66 – 120	0.050	6.4(13)E-6
$^{127}I(n,7n)^{121}I$	2.49(16)E-29	57 – 100	0.110	5.2(10)E-6
$^{127}I(n,5n)^{123}I$	9.44(56)E-29	38 – 73	0.249	1.08(22)E-5
$^{127}I(n,4n)^{124}I$	1.56(8)E-28	29 – 61	0.337	1.45(29)E-5
$^{127}I(n,2n)^{126}I$	5.74(16)E-28	10 – 44	0.621	2.72(54)E-5



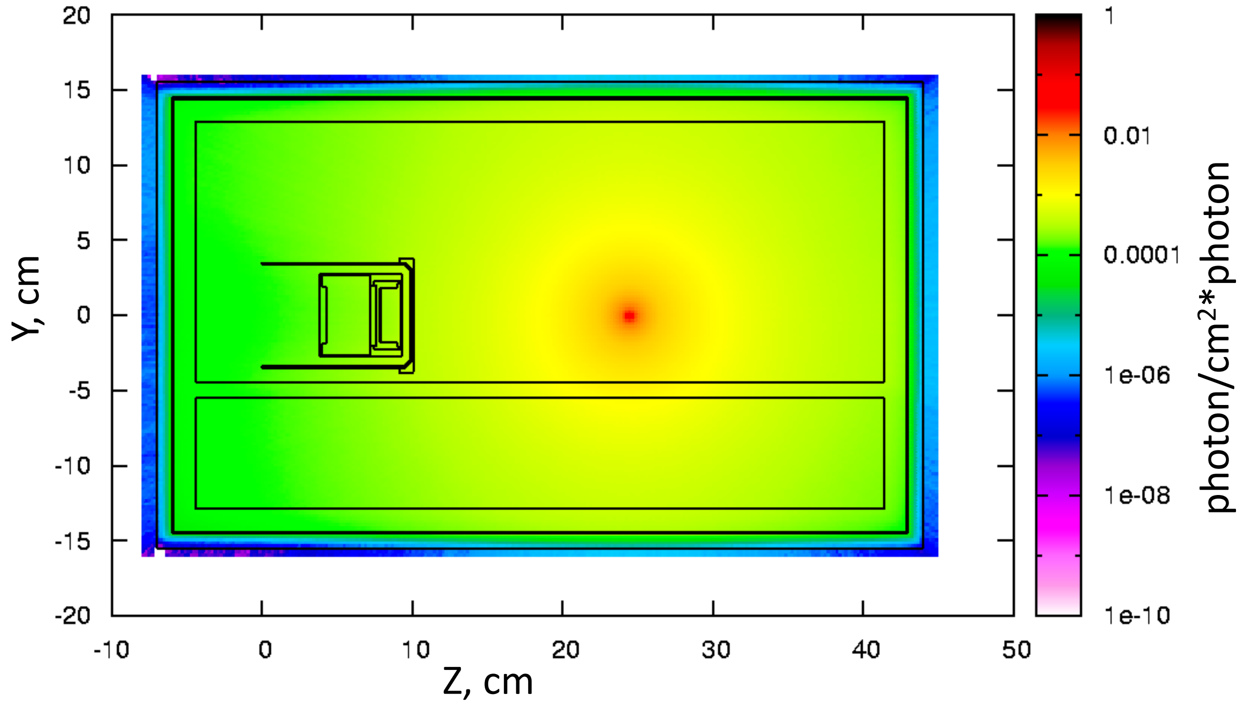


! We couldn't defined of neutron fluence using $^{129}I(n,xn)$ reactions because, have uncertainties depending on the mass of ^{129}I in the samples I129b(4GeV) and I129c(8GeV), according to our estimates on the passport of the sample I129c(8GeV) mass of ^{129}I showed to 30(5)% less.

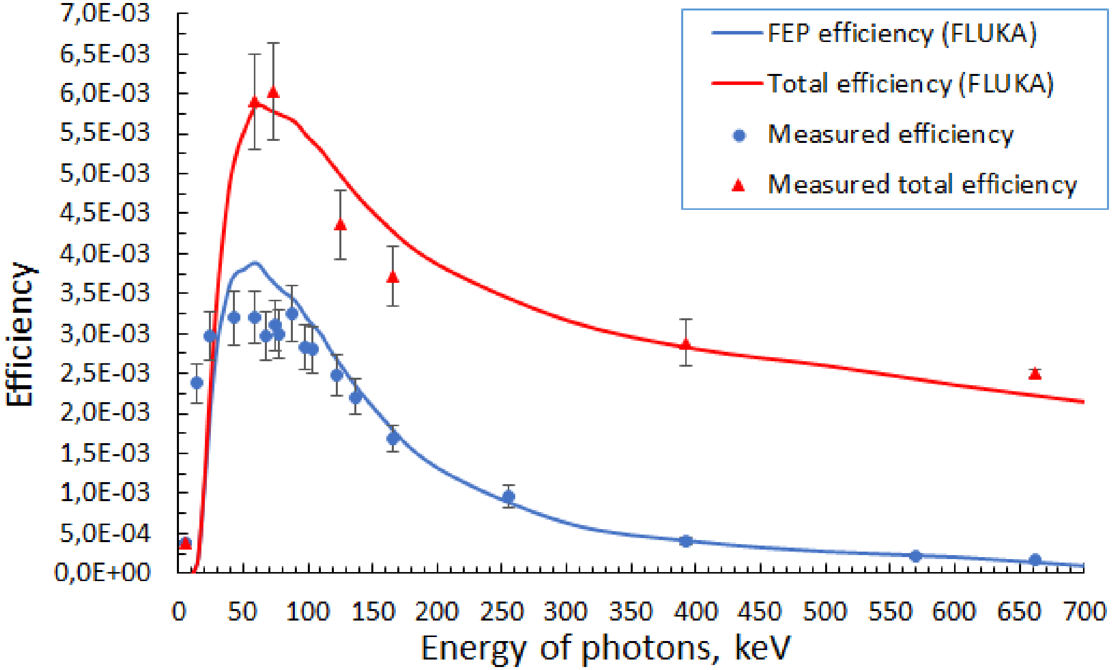
Geometry of HPGe planar detector for FLUKA



Efficiency of HPGe planar detector

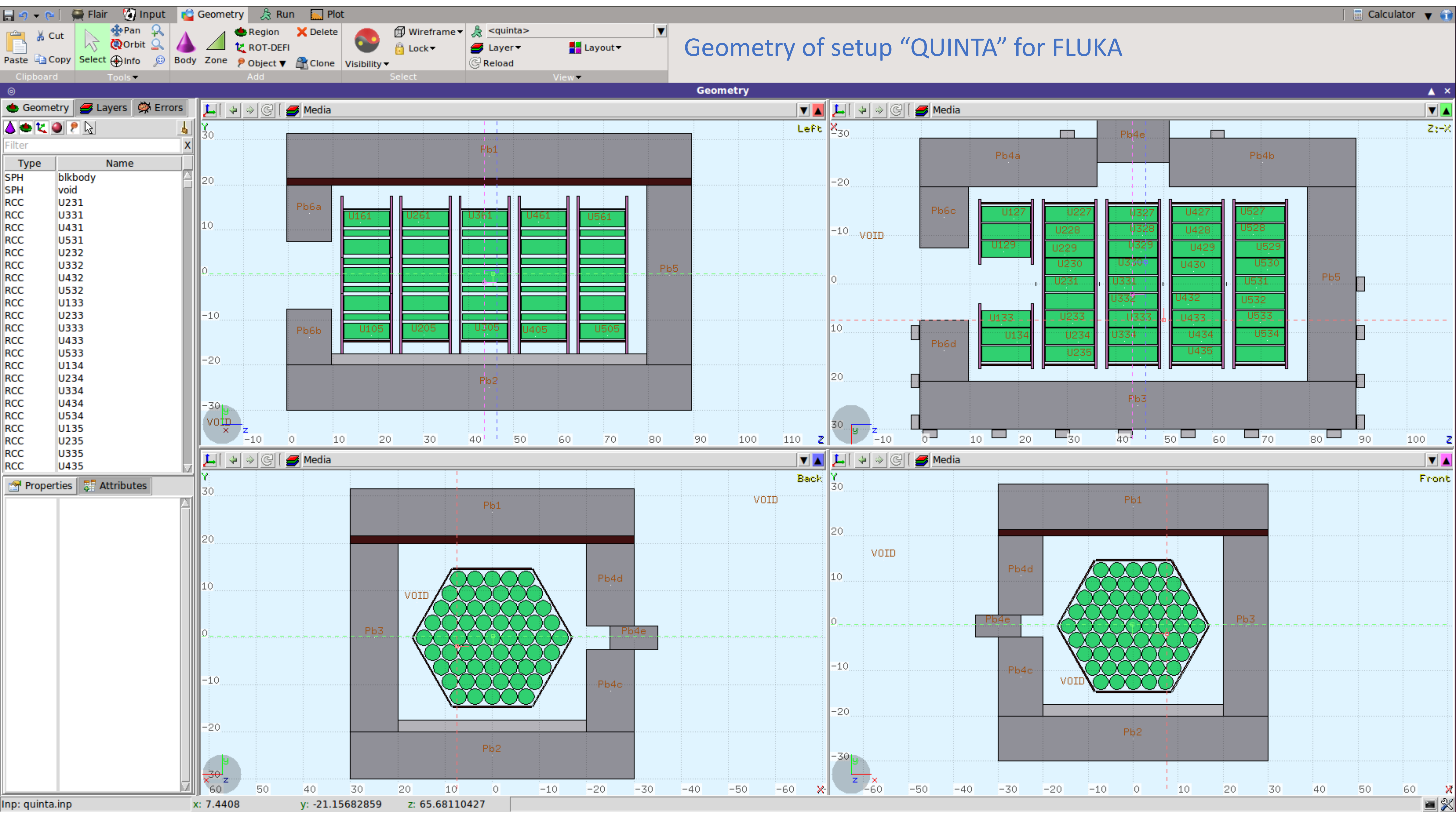


Simulation of 100 keV gamma rays with FLUKA



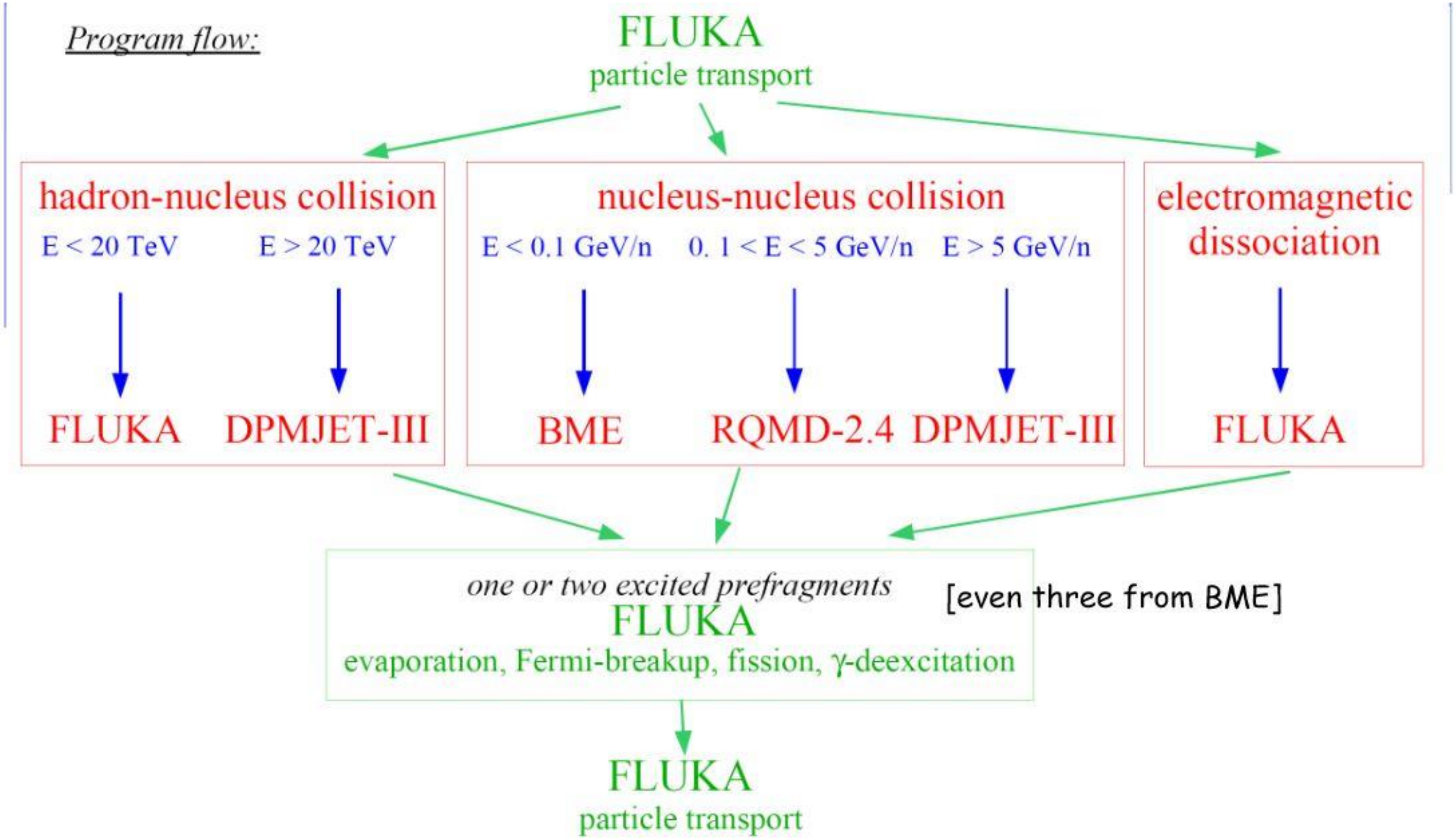
Total efficiency (exp.) is measured, using ^{55}Fe, ^{241}Am, ^{44}Ti, ^{57}Co, ^{139}Ce, ^{113}Sn and ^{137}Cs sources.

Geometry of setup “QUINTA” for FLUKA



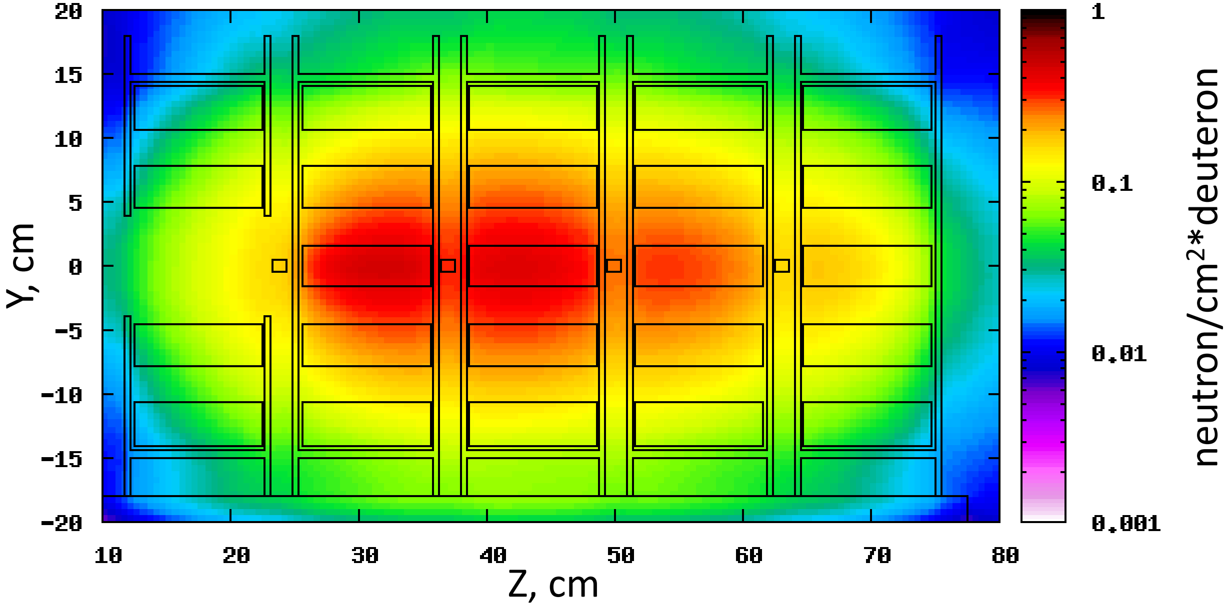
Nuclear interaction models in FLUKA

Dual Parton Model (DPM) – E > 5 GeV/n
Relativistic Quantum Molecular Dynamics Model (RQMD) – 0.1 GeV/n < E < 5 GeV/n
Boltzmann Master Equation (BME) theory – E < 0.1 GeV/n

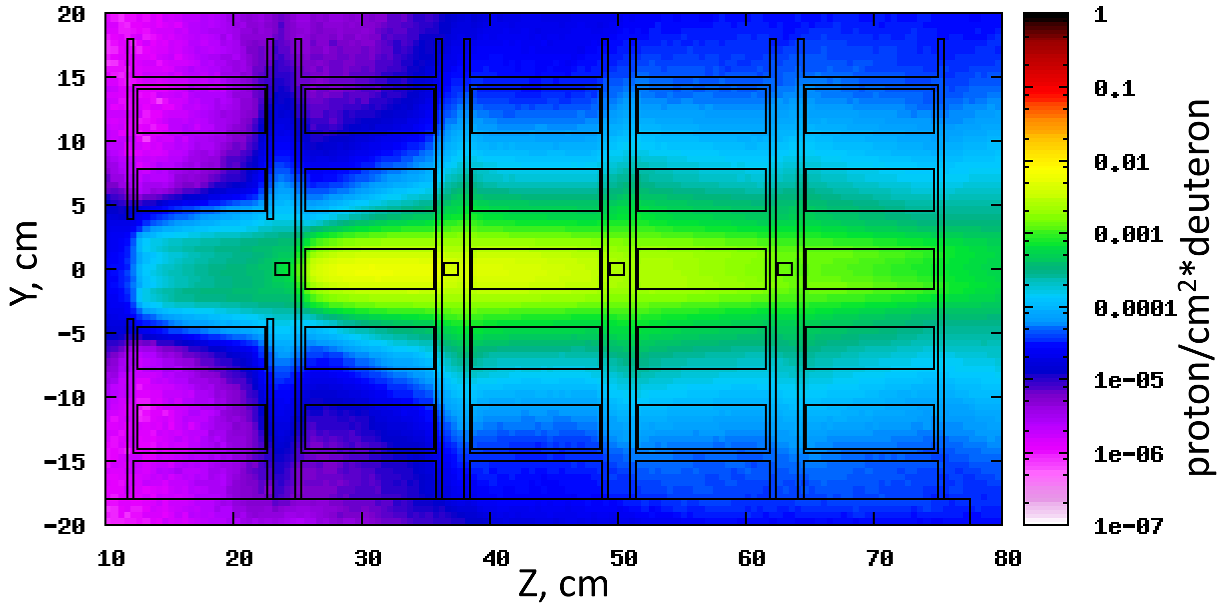


Some results of simulations for experiment
E_d = 6 GeV, March, 2011.
("QUINTA" without Pb shields)

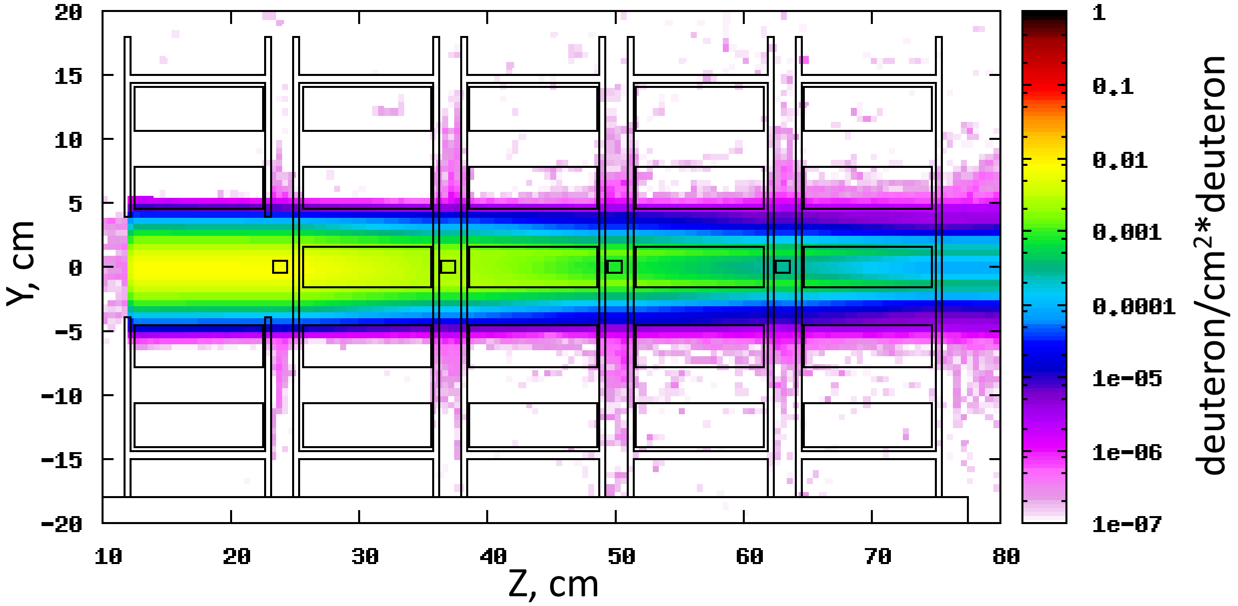
Neutrons on the setup "QUINTA"



Protons on the setup "QUINTA"

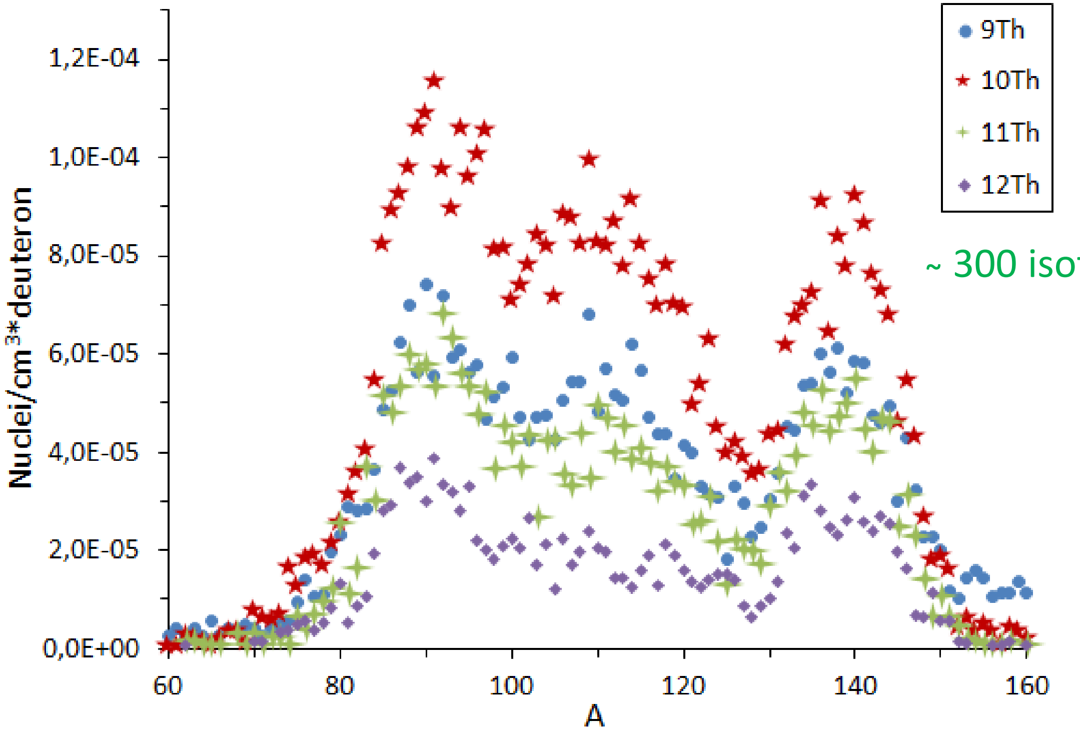


Deuterons on the setup "QUINTA"



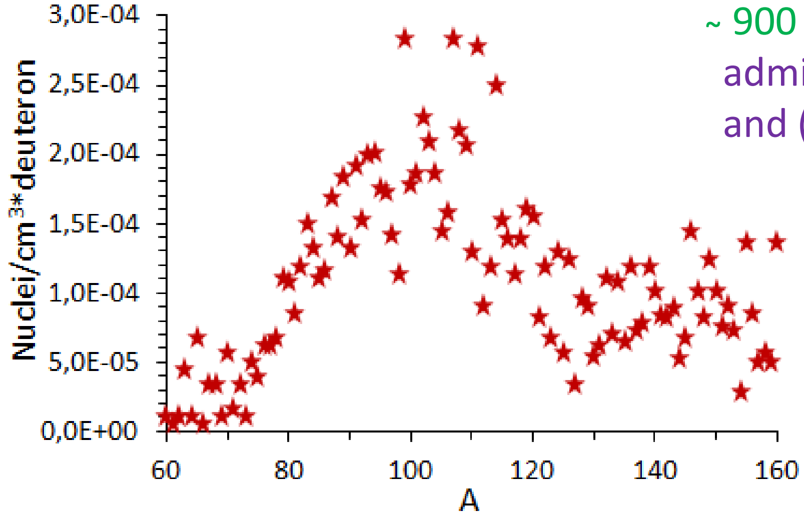
Dependence of calculated reaction rates on the mass of residual nuclei in the samples ^{232}Th

E_d = 6 GeV, March, 2011.
("QUINTA" without Pb shields)
9Th – was placed between the first and second sections
10Th – was placed between the second and third sections
11Th – was placed between the third and fourth sections
12Th – was placed between the fourth and fifth sections



~ 300 isotops

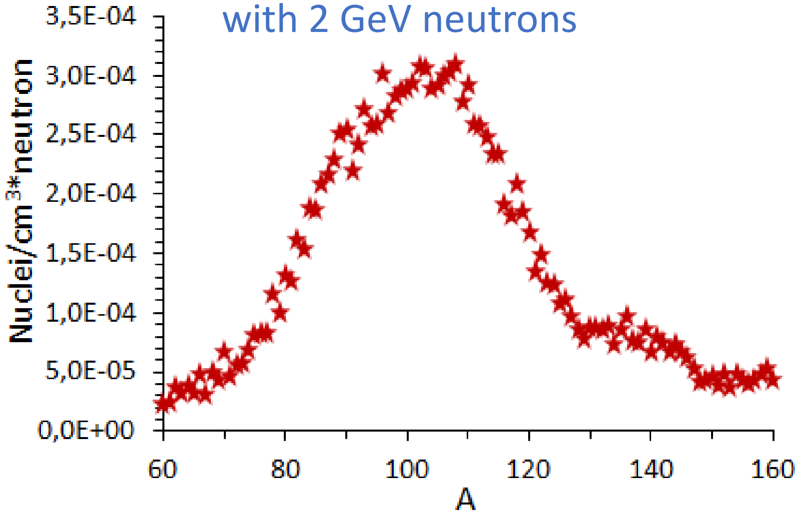
Calculated fission reaction rates for ^{232}Th with 4 GeV deuterons



~ 900 isotops
admixtures from (n,fission) and (p,fission)

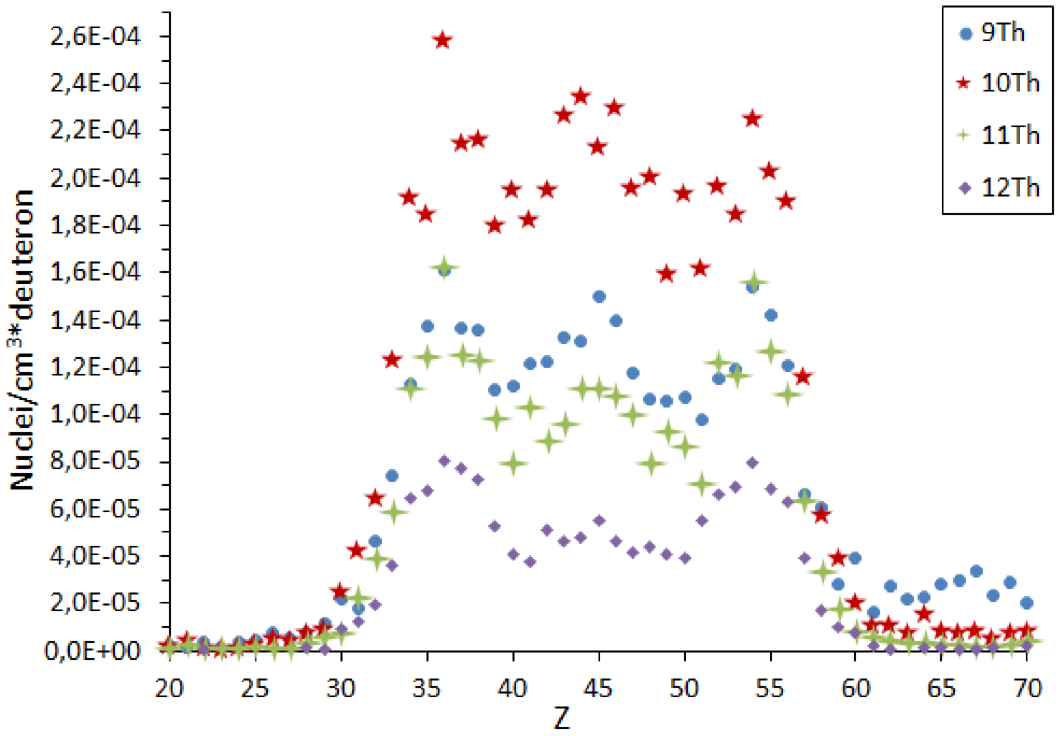
Calculated fission reaction rates for ^{232}Th with 2 GeV neutrons

~ 900 isotops

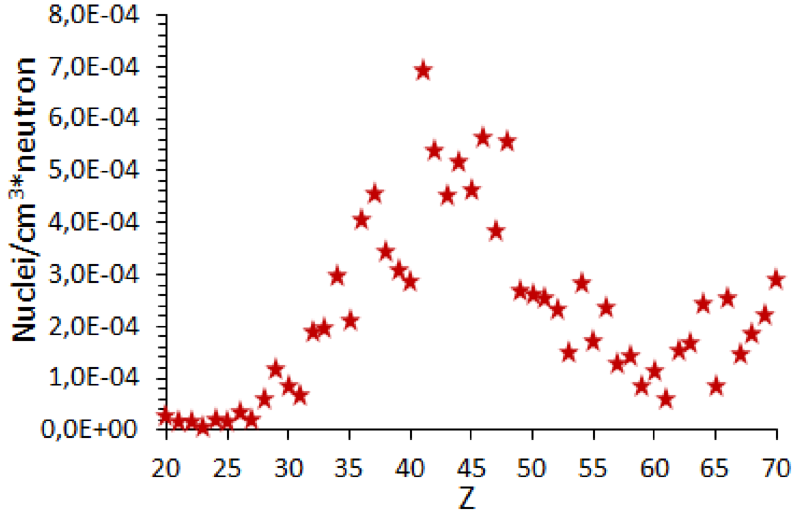


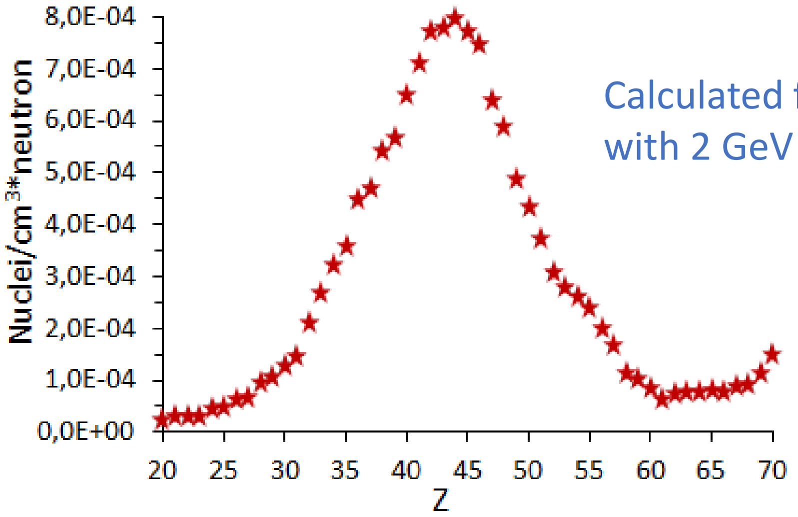
Dependence of calculated reaction rates on the charge of residual nuclei in the samples ^{232}Th

E_d = 6 GeV, March, 2011.
("QUINTA" without Pb shields)
9Th – was placed between the first and second sections
10Th – was placed between the second and third sections
11Th – was placed between the third and fourth sections
12Th – was placed between the fourth and fifth sections



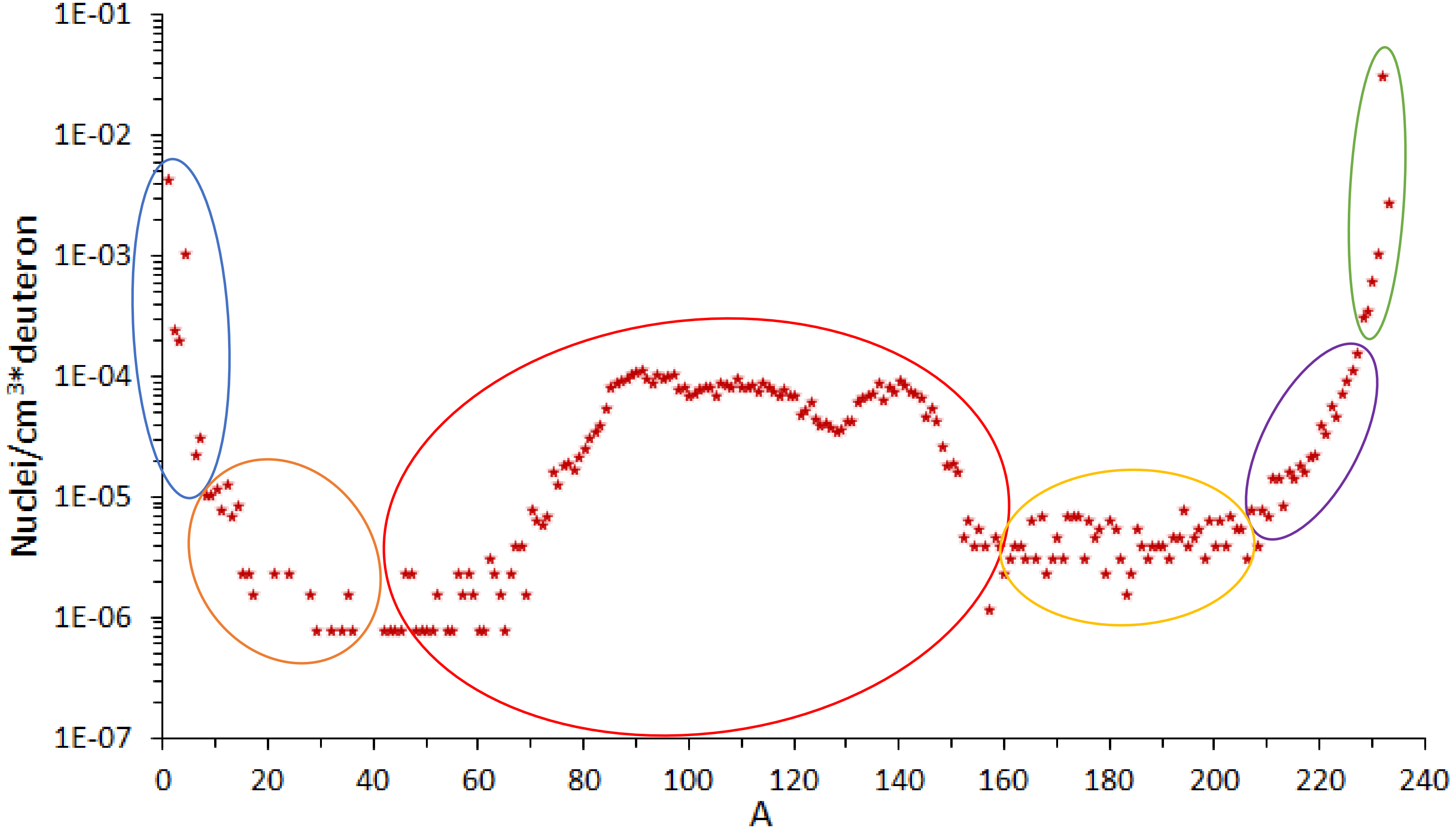
Calculated fission reaction rates for ^{232}Th with 4 GeV deuterons



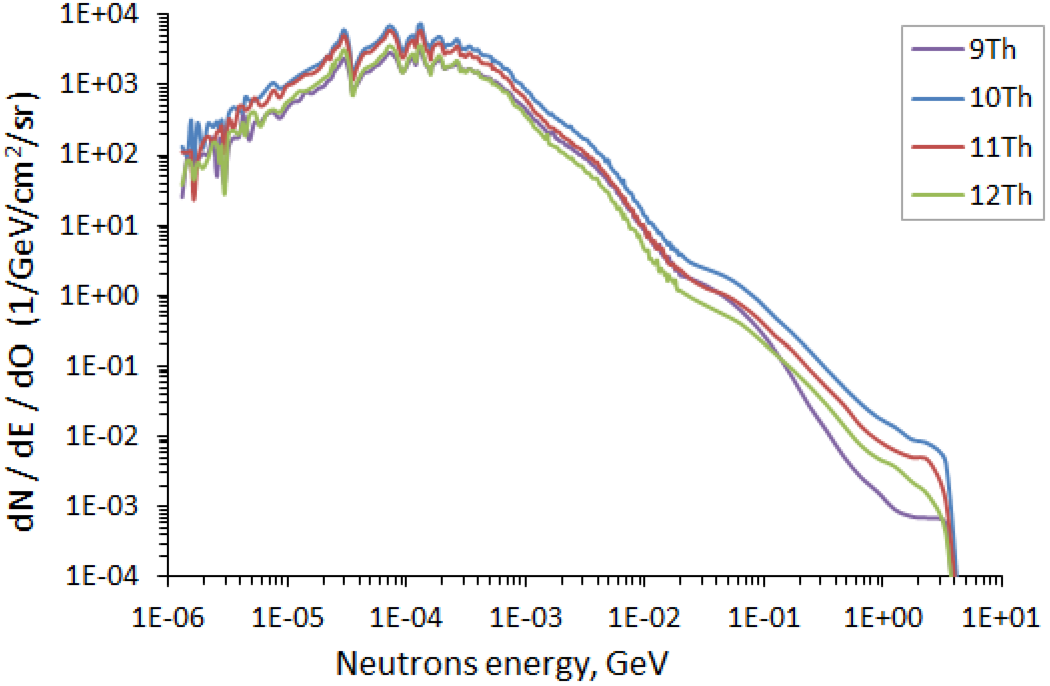


Calculated fission reaction rates for ^{232}Th with 2 GeV neutrons

Dependence of calculated reaction rates on the mass of residual nuclei in the sample ^{232}Th (10Th)

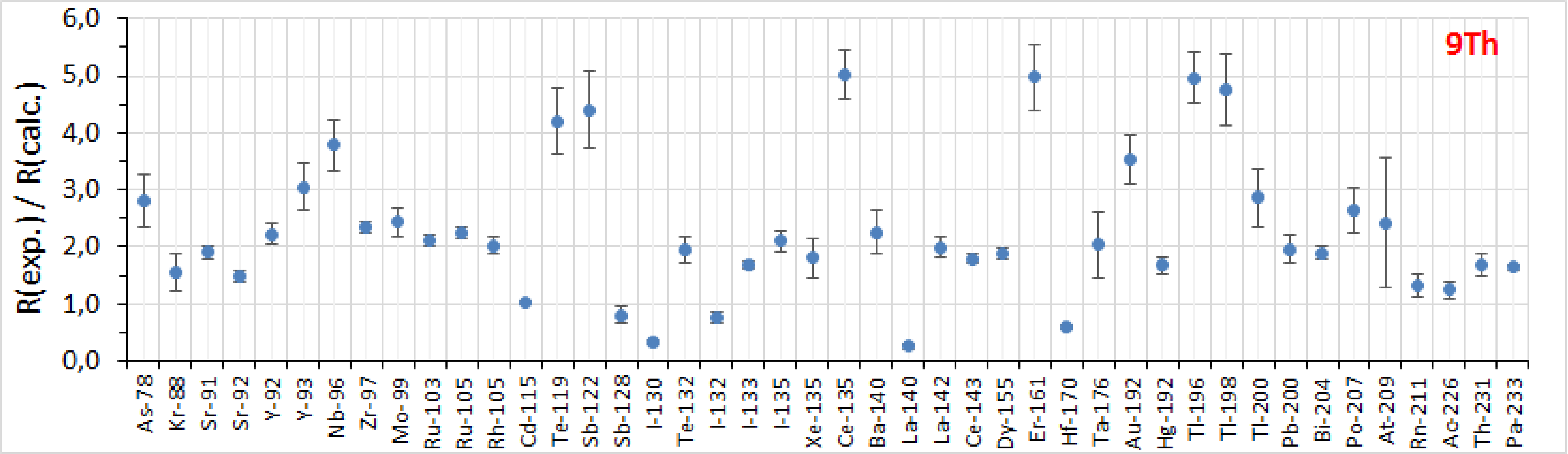


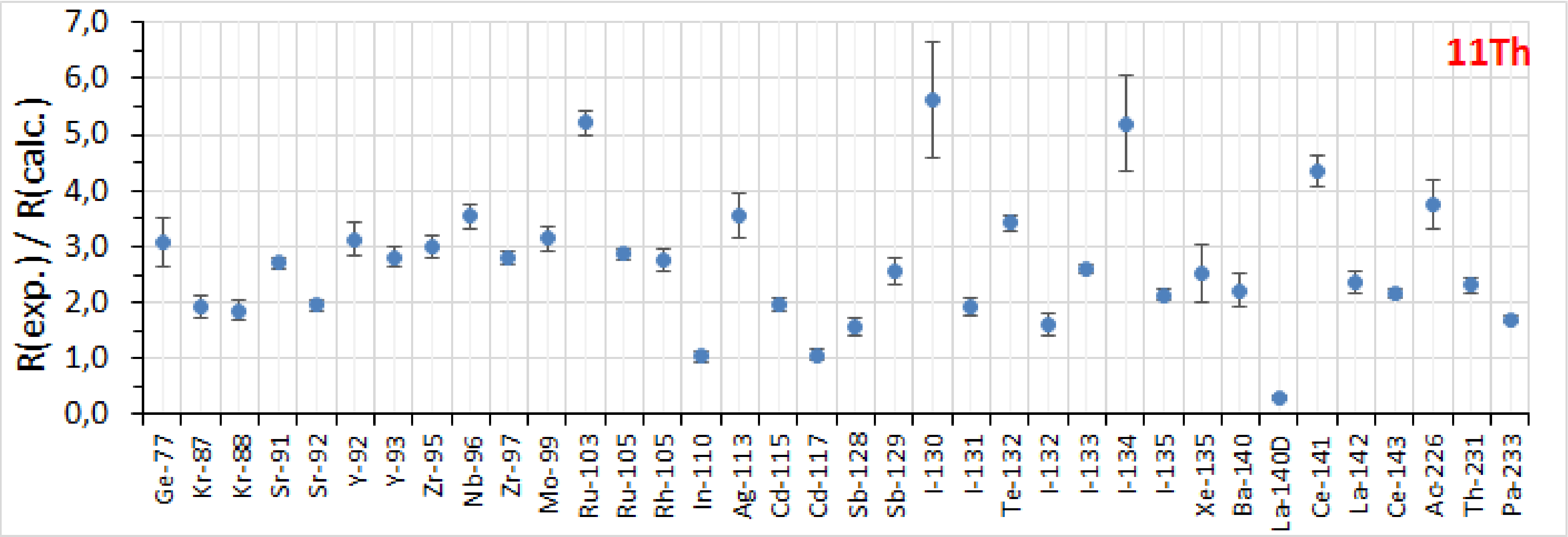
- Evaporation products
- Fragmentation products
- Low and high energy fission products
- Deep spallation products
- Spallation products
- Quasi-elastic products

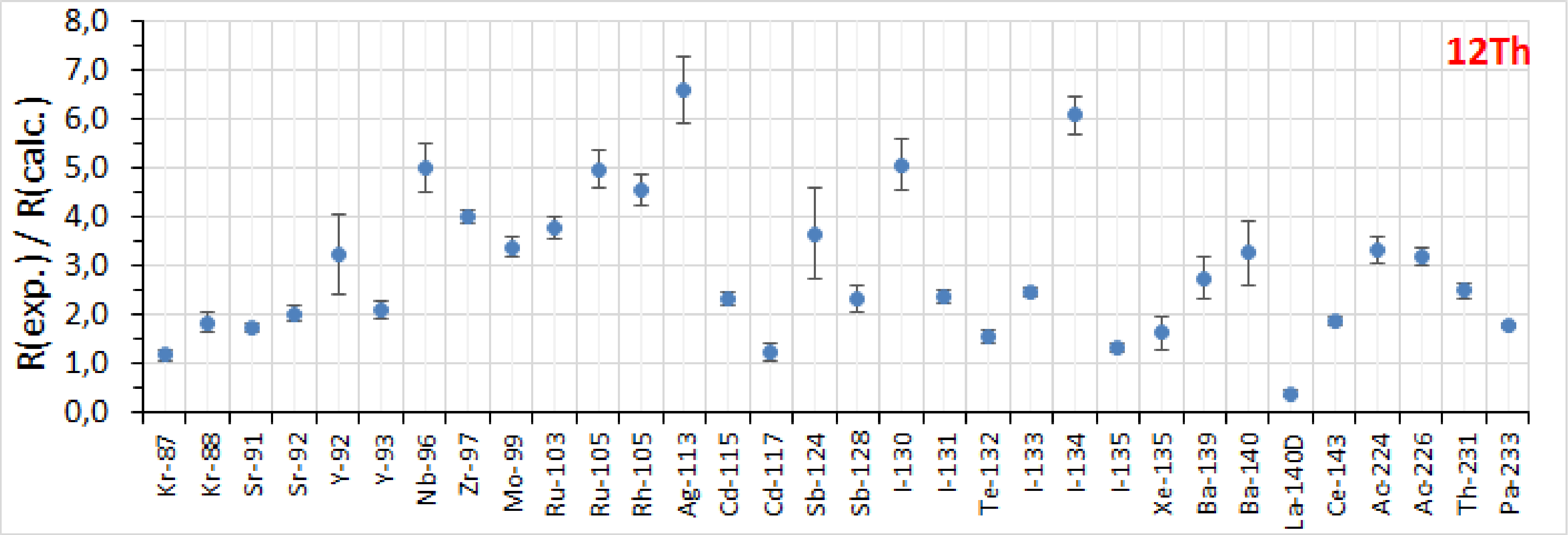


Neutron fluence $d^2\Phi/dEd\Omega$ in the setup “QUINTA” at the beam axis (calculated by FLUKA)

Ratio of the experimental reaction rate to the calculations (Exp./Calc.) by FLUKA for some of residual nuclei in the sample ^{232}Th (9Th)







Ratio of the experimental reaction rate to the calculations (Exp./Calc.) by FLUKA for some of residual nuclei in the samples ^{232}Th (11Th and 12Th)

Summary

- The experimental data obtained in the study of the interaction of secondary neutrons with ^{232}Th, ^{129}I, ^{127}I nuclei at the "QUINTA" show a proportional increase in the values of reaction rate with increasing energy of deuterons, for almost all produced nuclei.

- The experimental results were compared with Monte Carlo simulations performed with the MCNPX2.7 and MARS15 code. Ratios of experimental and calculated rates of (n,γ), (n,xn) and (n,fission) reactions are in the range 0.5 – 2.4.

- Ratios of experimental and calculated with FLUKA reaction rates for residual nuclei of ^{232}Th samples (irradiated on the central axes of "QUINTA", P1, P3 and P4) are in the range 0.3 – 6.6.

- Defined fluence of neutrons (10 – 120 MeV) by ^{127}I(n,xn) reactions in good agreement with calculated by MCNPX 2.7.

Thanks for your attention