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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Outline

Motivations

Experimental process

Cross sections from EXFOR data

Experimental results and comparison with the calculations
with MARS-15 and MCNPX-2.7

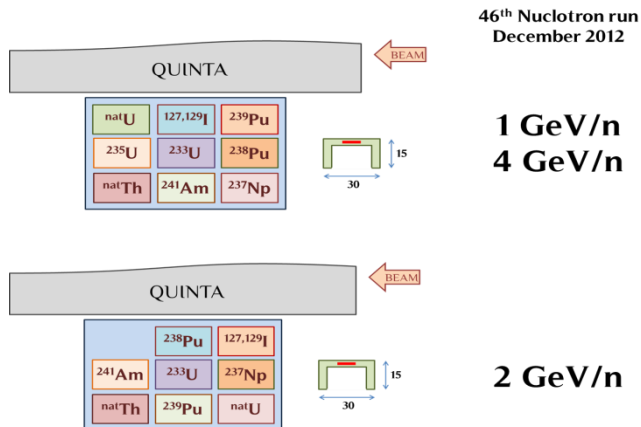Simulations by FLUKA for definition efficiency of HPGe planar detector
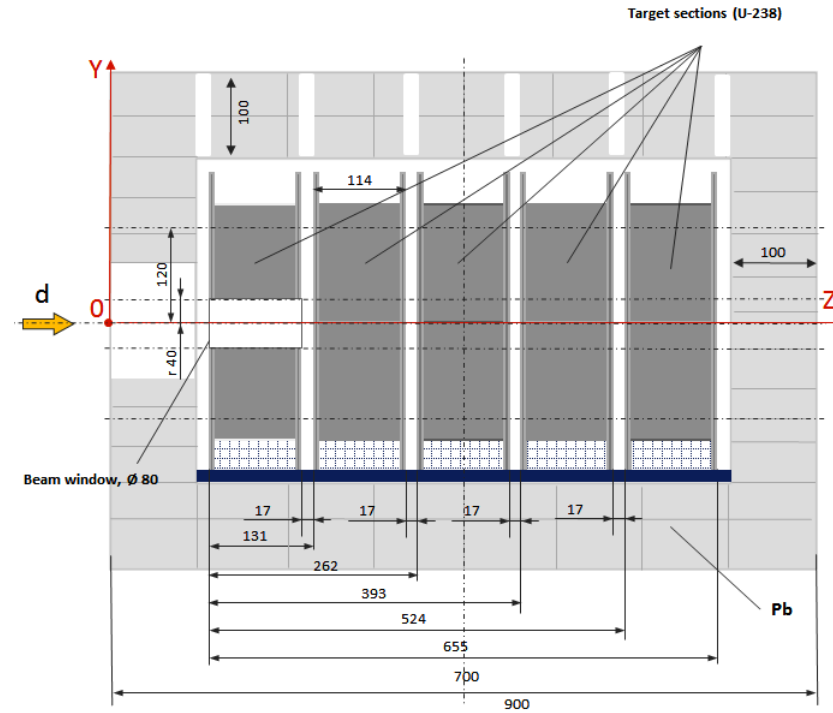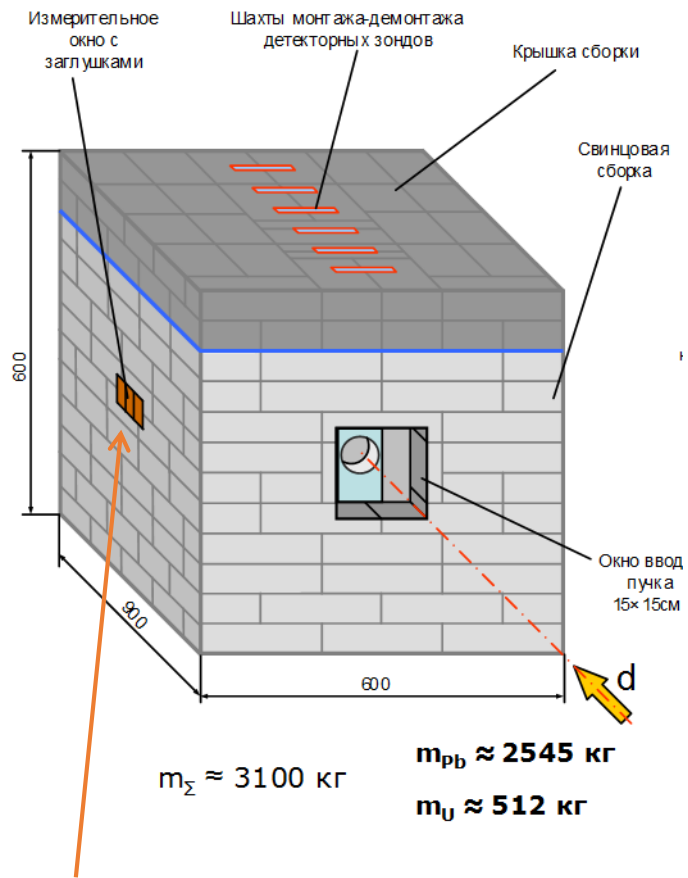
Simulations by FLUKA for experiments on the setup "QUINTA"

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»

Измерительное окно с заглушками

Шахты монтажа-демонтажа детекторных зондов

Крышка сборки

Свинцовая сборка

Окно ввод пучка 15× 15см

$m_{Pb} \approx 2545$ кг

$m_U \approx 512$ кг

$m_\Sigma \approx 3100$ кг

Target sections (U-238)

Beam window, Ø 80

Pb

100, 114, 120, r 40, 100, 17, 17, 17, 17, 131, 262, 393, 524, 655, 700, 900

46th Nuclotron run
December 2012

QUINTA

BEAM

natU	127,129I	239Pu
235U	233U	238Pu
natTh	241Am	237Np

1 GeV/n
4 GeV/n

15
30

QUINTA

BEAM

	238Pu	127,129I
241Am	233U	237Np
natTh	239Pu	natU

2 GeV/n

15
30

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

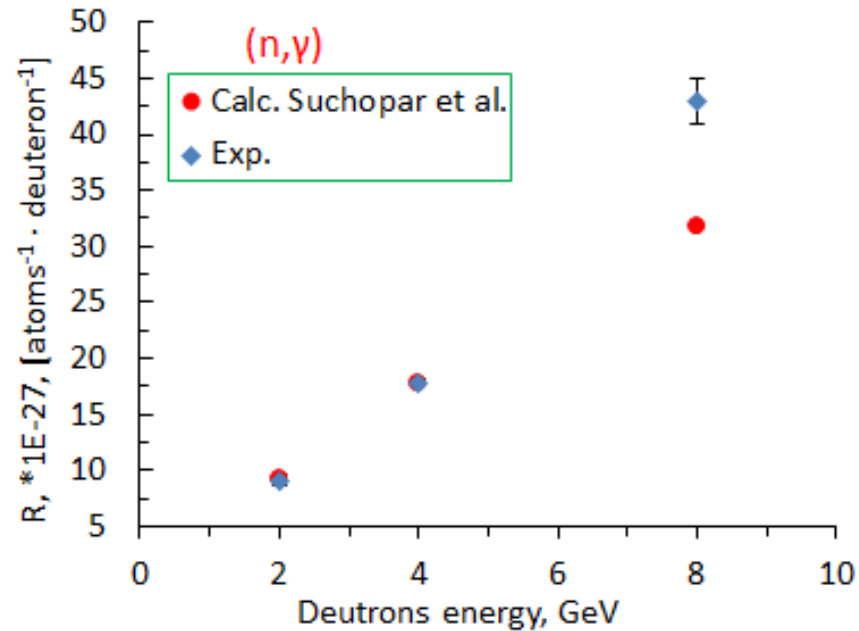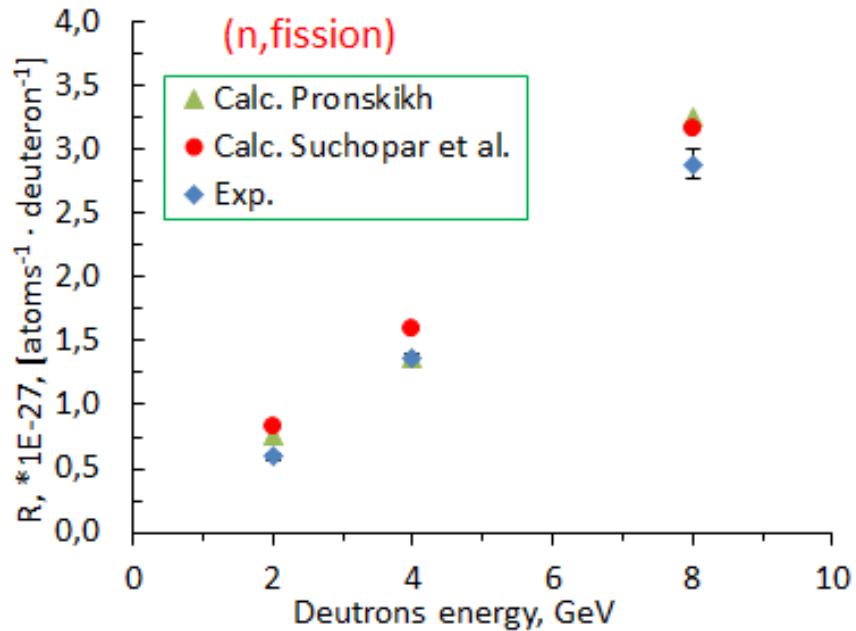Cross sections for ^{232}Th(n,g) and ^{232}Th(n,fission) reactions from EXFOR data
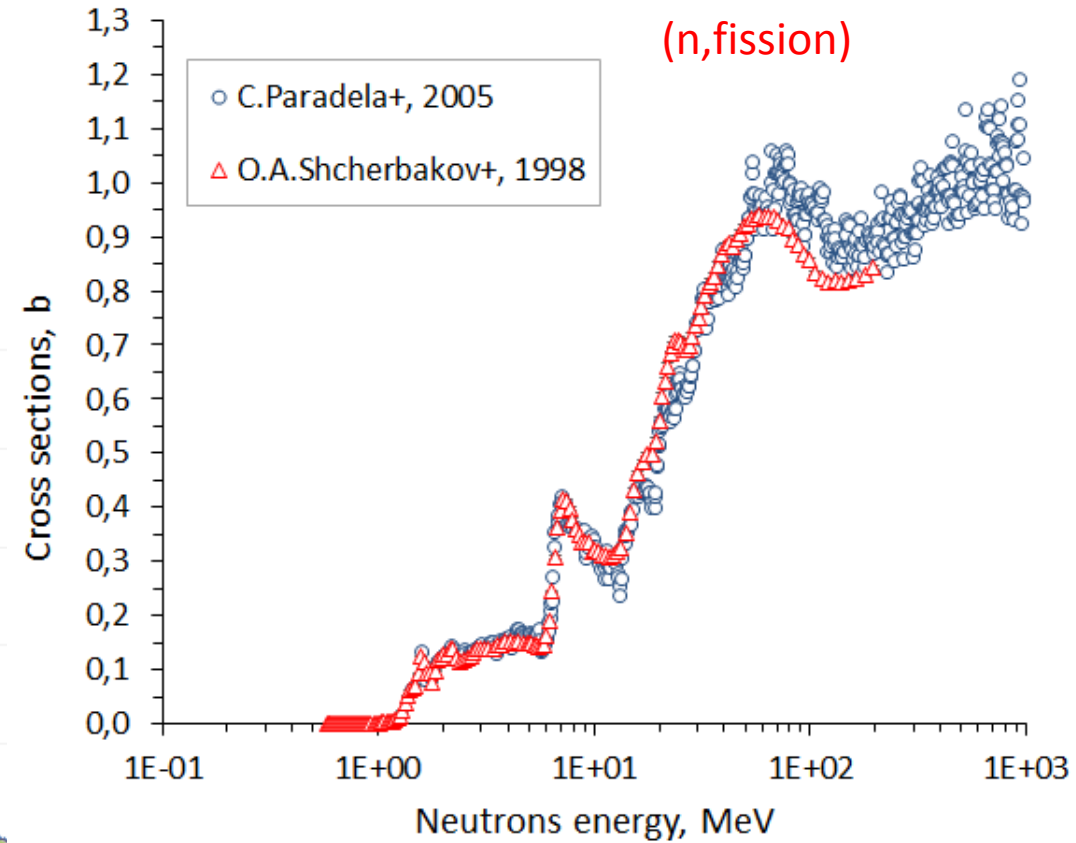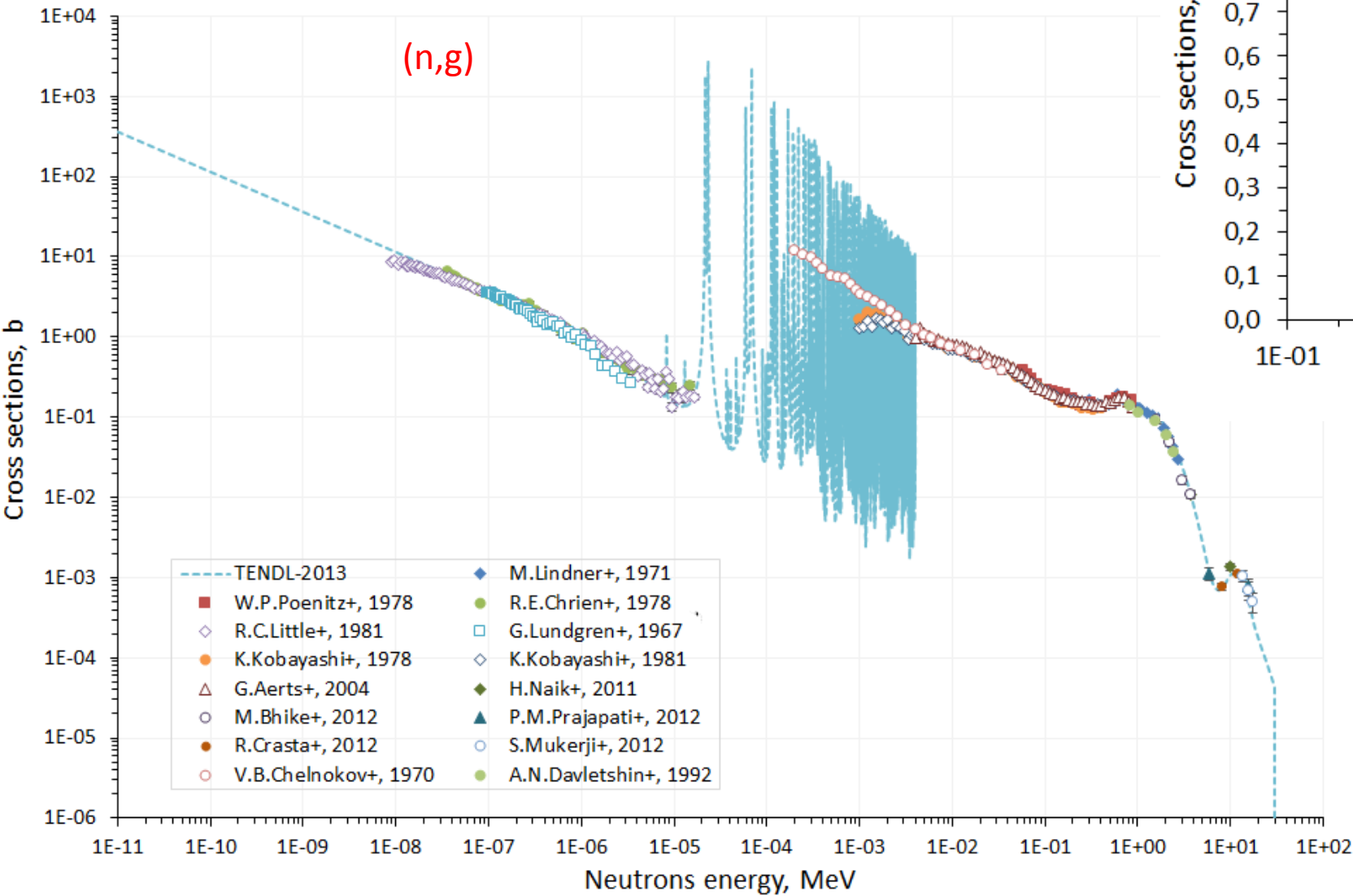
Cross sections for ^{232}Th(p,fission) and ^{232}Th(d,fission) reactions from EXFOR data
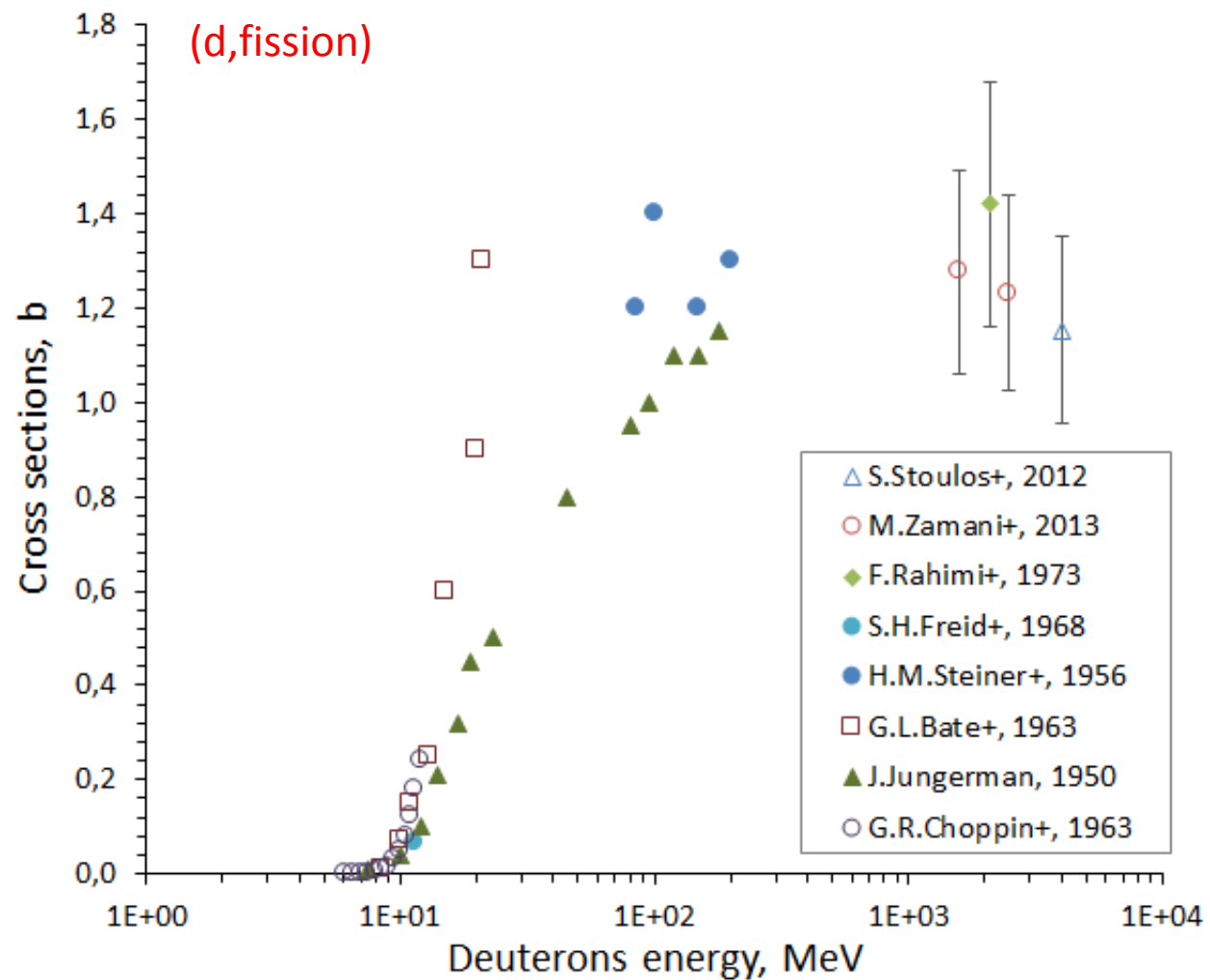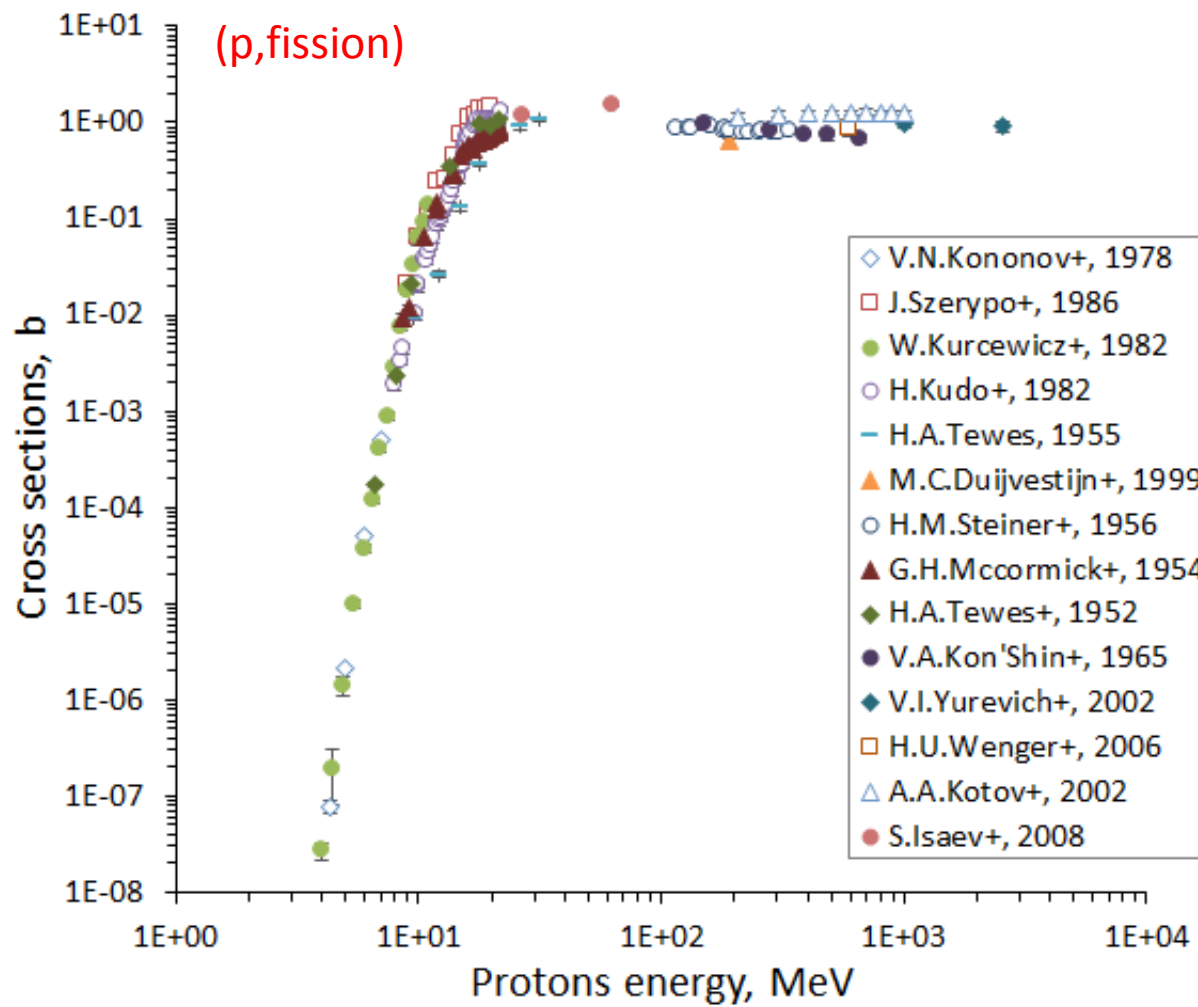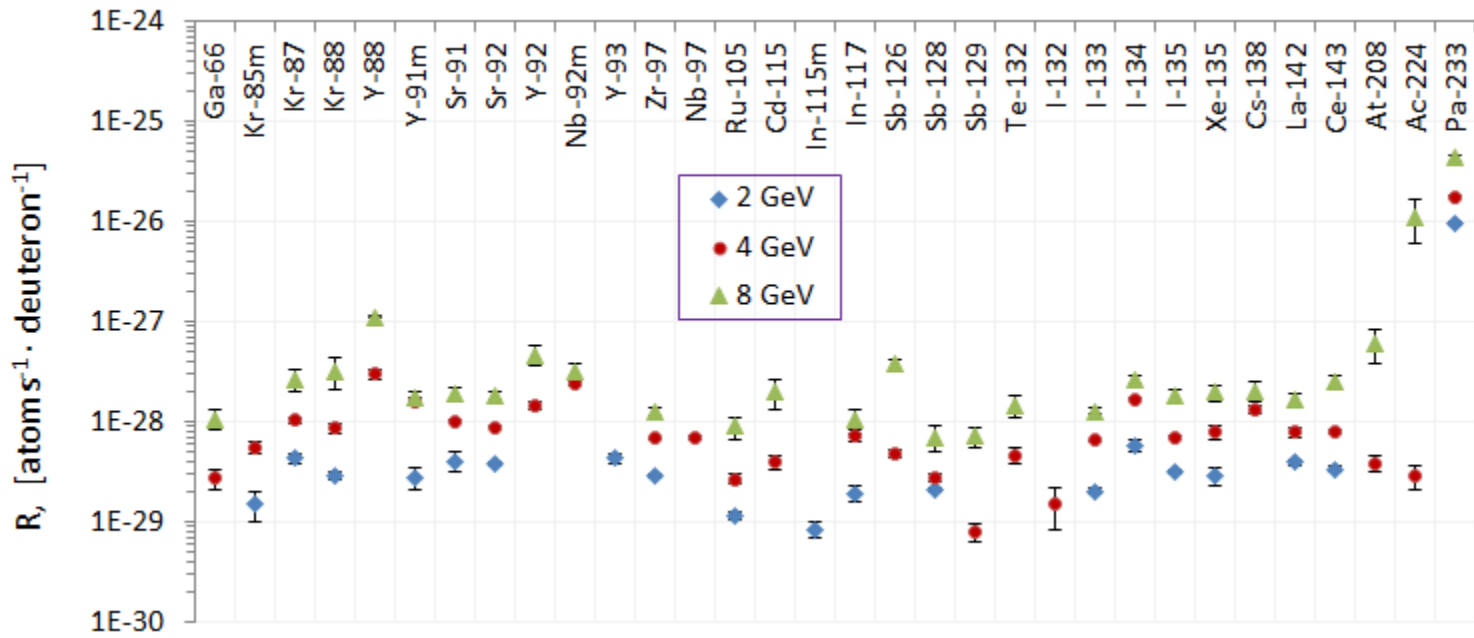
Reaction rates for residual nuclei of ^{232}Th from experiments E_d = 2,4,8 GeV, December, 2012.
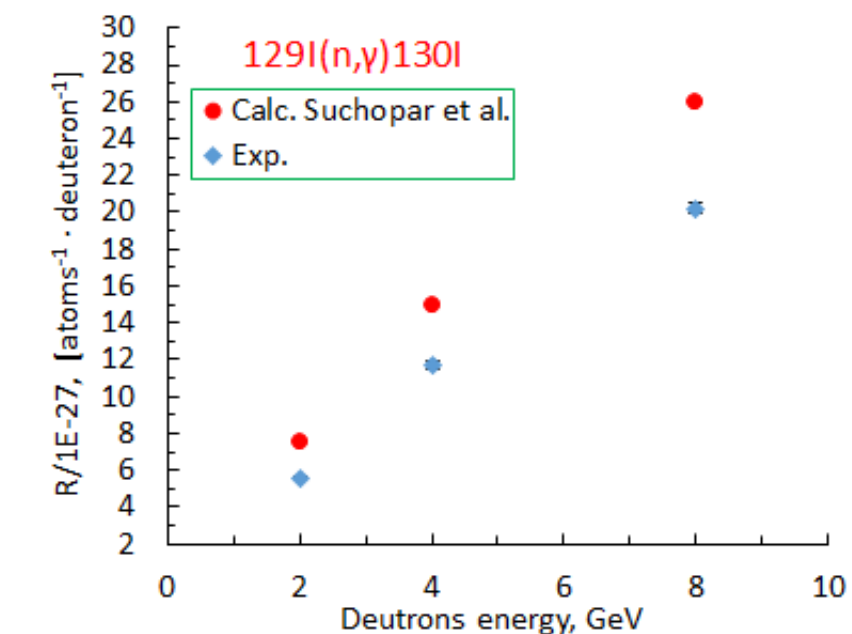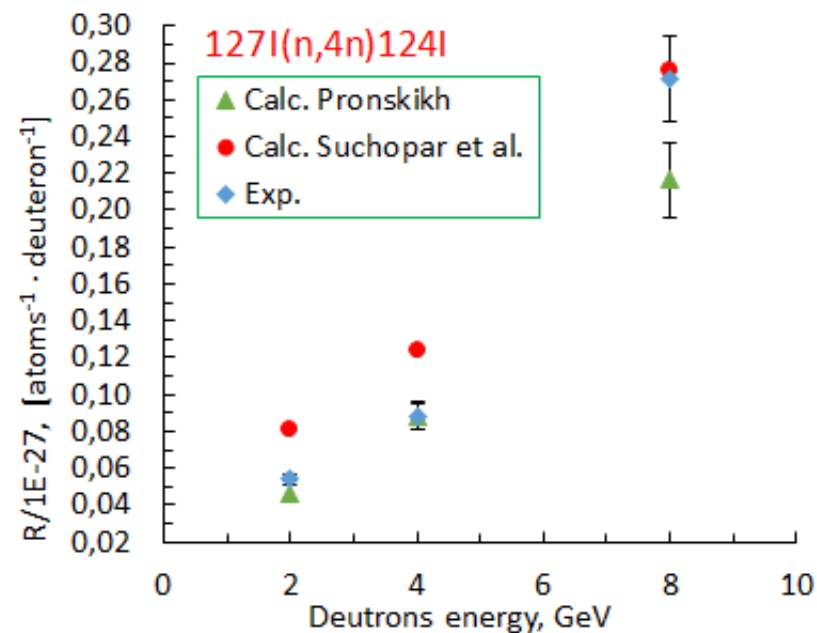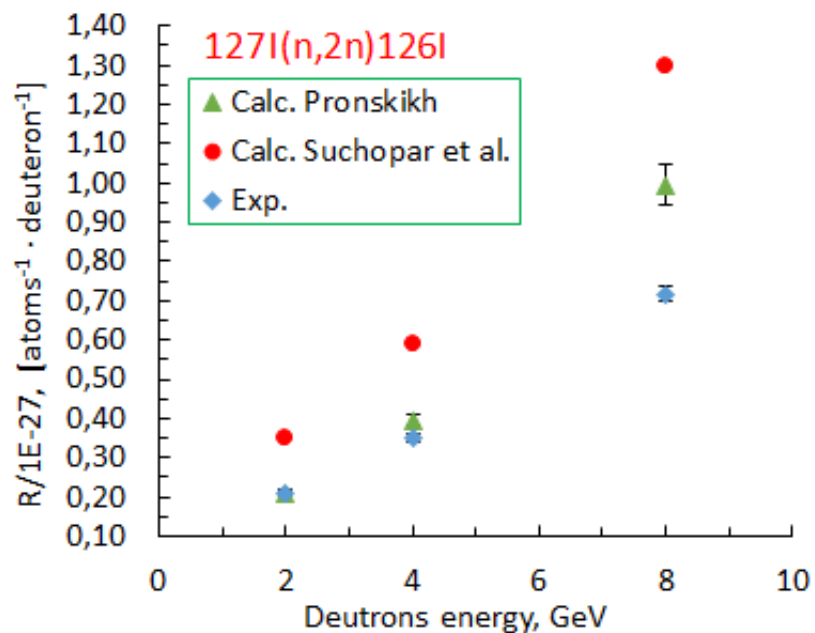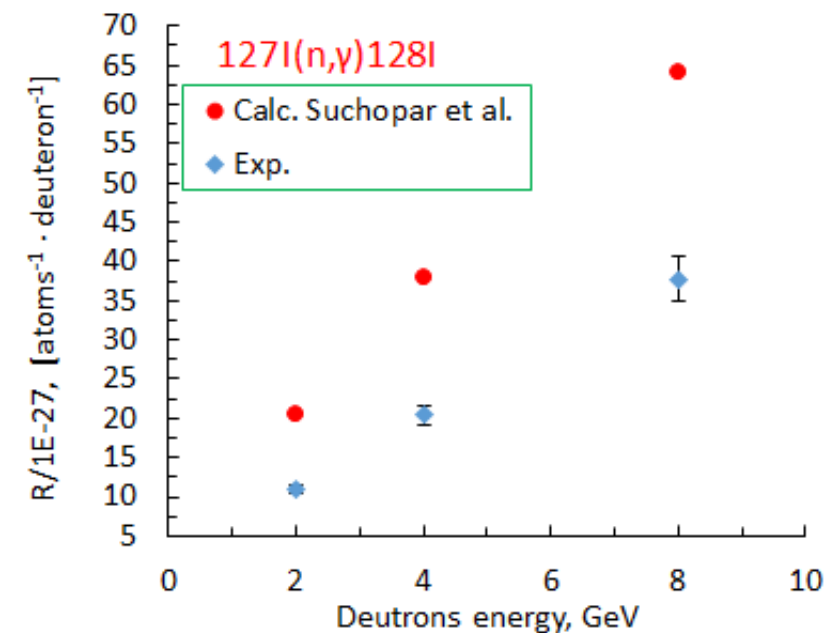("QUINTA" with Pb shields)

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)

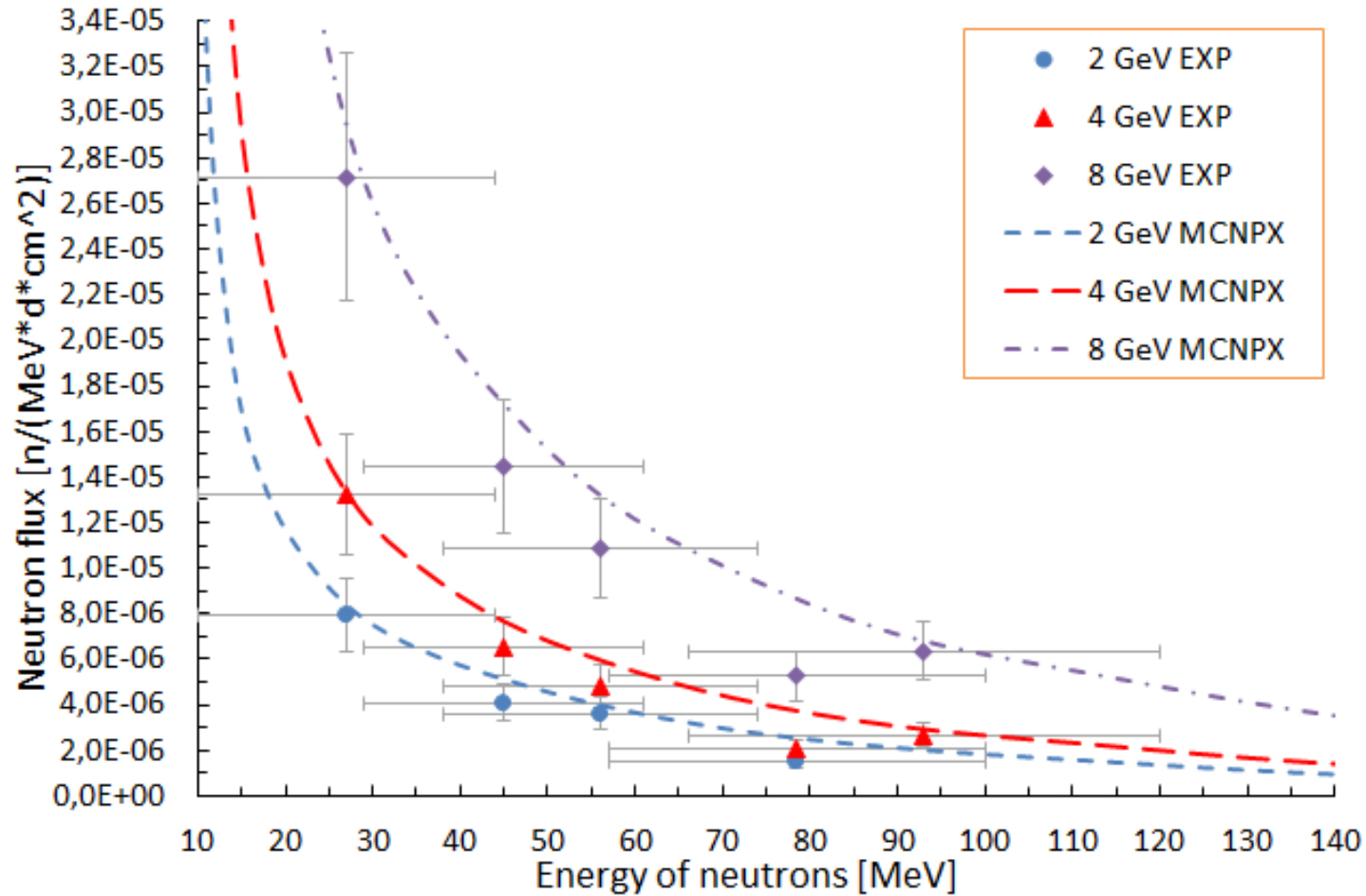# Dependence of the (n,γ), (n,xn) reactions rate of the energy deuterons in the samples ^{127}I and ^{129}I
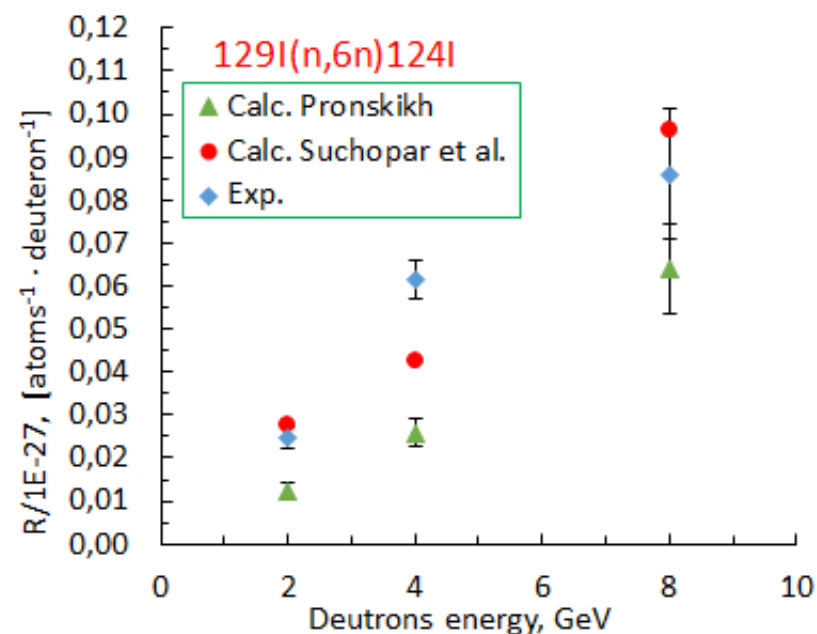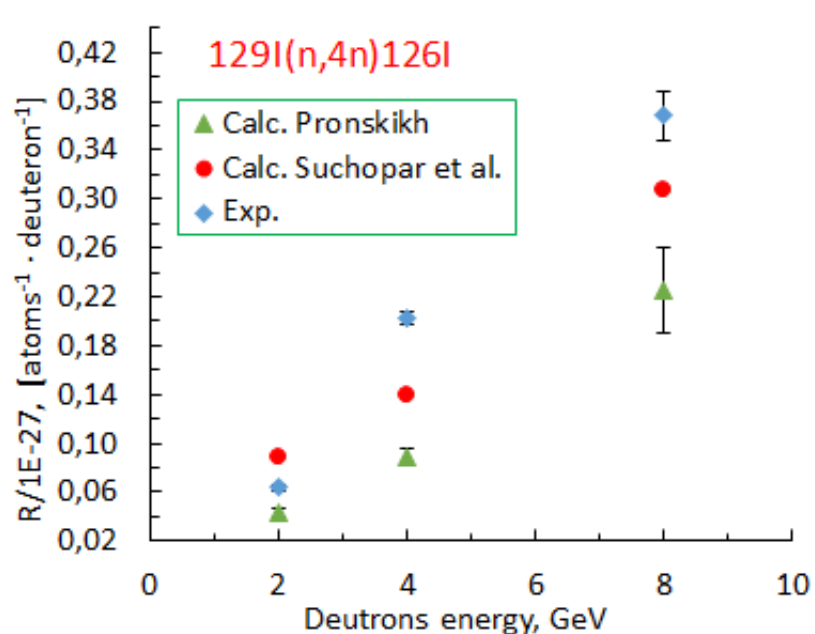
Definition of neutron fluence using ^{127}I(n,xn) reactions

0.8R – 80% of reaction rate R(exp.) (by Calc.2. neutrons in energy interval dE adding 80(5)% contribution to the reaction rate),
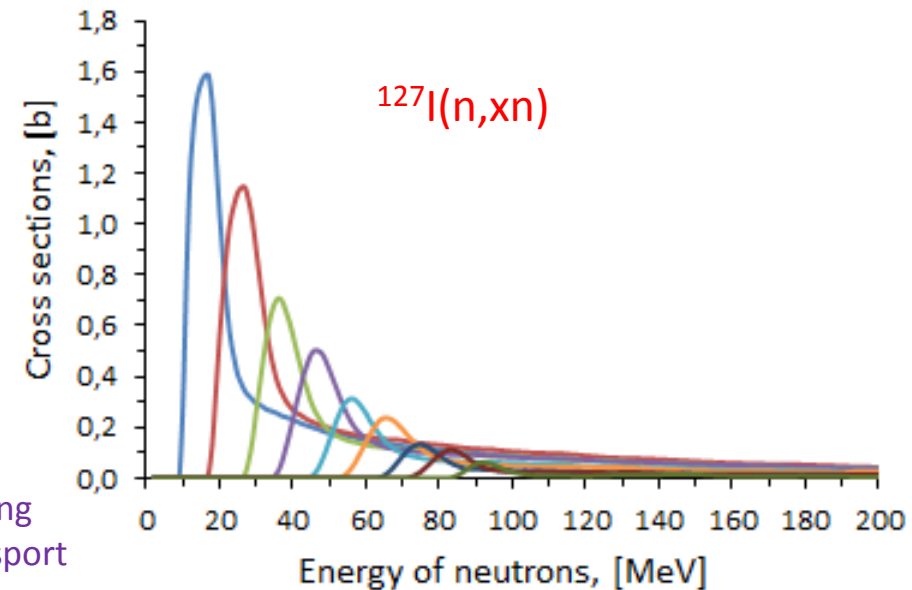σ – averaged values of reaction cross sections for energy interval dE,
F – fluence of neutrons (n/MeV·d·cm²).

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

^{127}I(n,xn)

! 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.

Flair | Input | Geometry | Run | Plot | Calculator

Cut | Copy | Paste | Select | Pan | Orbit | Info | Body | Zone | Region | ROT-DEFI | Object | Delete | Clone | Wireframe | Lock | Layer | Reload | Layout

Clipboard | Tools | Add | Select | View

Geometry of HPGe planar detector for FLUKA

Geometry

Geometry | Layers | Errors

Filter X

Type	Name
SPH	blkbody
SPH	void
RPP	Cu1
RPP	Cu2
RPP	PLEX1
RPP	PLEX2
RPP	PLEXIG3
RPP	PLEXIG4
RPP	PLEXIG5
RCC	PLASTIC
RCC	ENDCAP1
RCC	ENDCAP2
TRC	ENDCAP3
TRC	ENDCAP4
RCC	BERYLLIU
RCC	SHROUD1
RCC	SHROUD2
RCC	SHROUD3
RCC	MYLAR
RCC	COLLIMA1
RCC	COLLIMA2
RCC	COLLIMA3
RCC	COLLIMA4
RCC	COLLIMA5

Properties | Attributes

Media — Front

VOID | PLEX

Media — Top

VOID | AIR

Media — Left

AIR | VACUUM | GERMANI | COLLIMA | VOID

Media — Back

VOID | AIR | PLEX

Inp: deff.inp   x: 6.433519559   y: -5.966825945   z: 0

Efficiency of HPGe planar detector

Simulation of 100 keV gamma rays with FLUKA
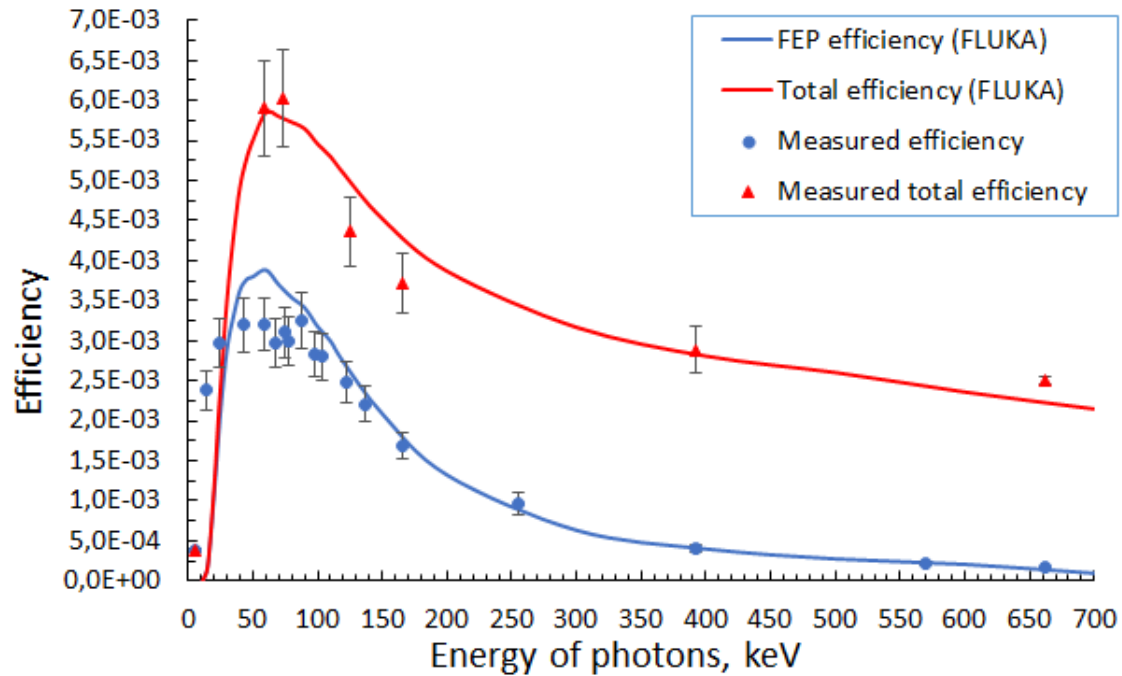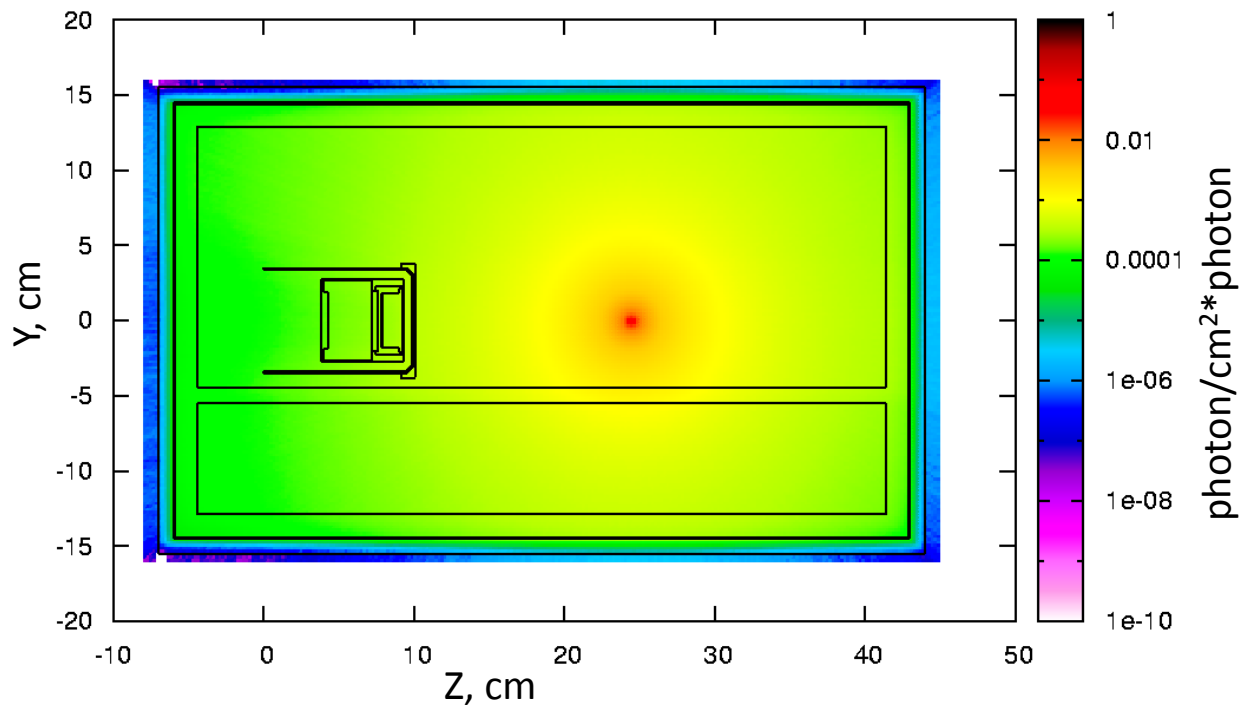
Total efficiency (exp.) is measured, using ^{55}Fe, ^{241}Am, ^{44}Ti, ^{57}Co, ^{139}Ce, ^{113}Sn and ^{137}Cs sources.

Geometry of setup "QUINTA" for FLUKA

Flair | Input | Geometry | Run | Plot

Calculator

Paste | Copy | Cut | Select | Pan | Orbit | Info | Body | Zone | Region | ROT-DEFI | Object | Delete | Clone | Visibility | Wireframe | Lock | Layer | Reload | Layout

Clipboard | Tools | Add | Select | View

<quinta>

Geometry

Geometry | Layers | Errors

Filter | X

Type	Name
SPH	blkbody
SPH	void
RCC	U231
RCC	U331
RCC	U431
RCC	U531
RCC	U232
RCC	U332
RCC	U432
RCC	U532
RCC	U133
RCC	U233
RCC	U333
RCC	U433
RCC	U533
RCC	U134
RCC	U234
RCC	U334
RCC	U434
RCC	U534
RCC	U135
RCC	U235
RCC	U335
RCC	U435

Properties | Attributes

Media (Left) — Z:-X view

Media (Back) — Front view

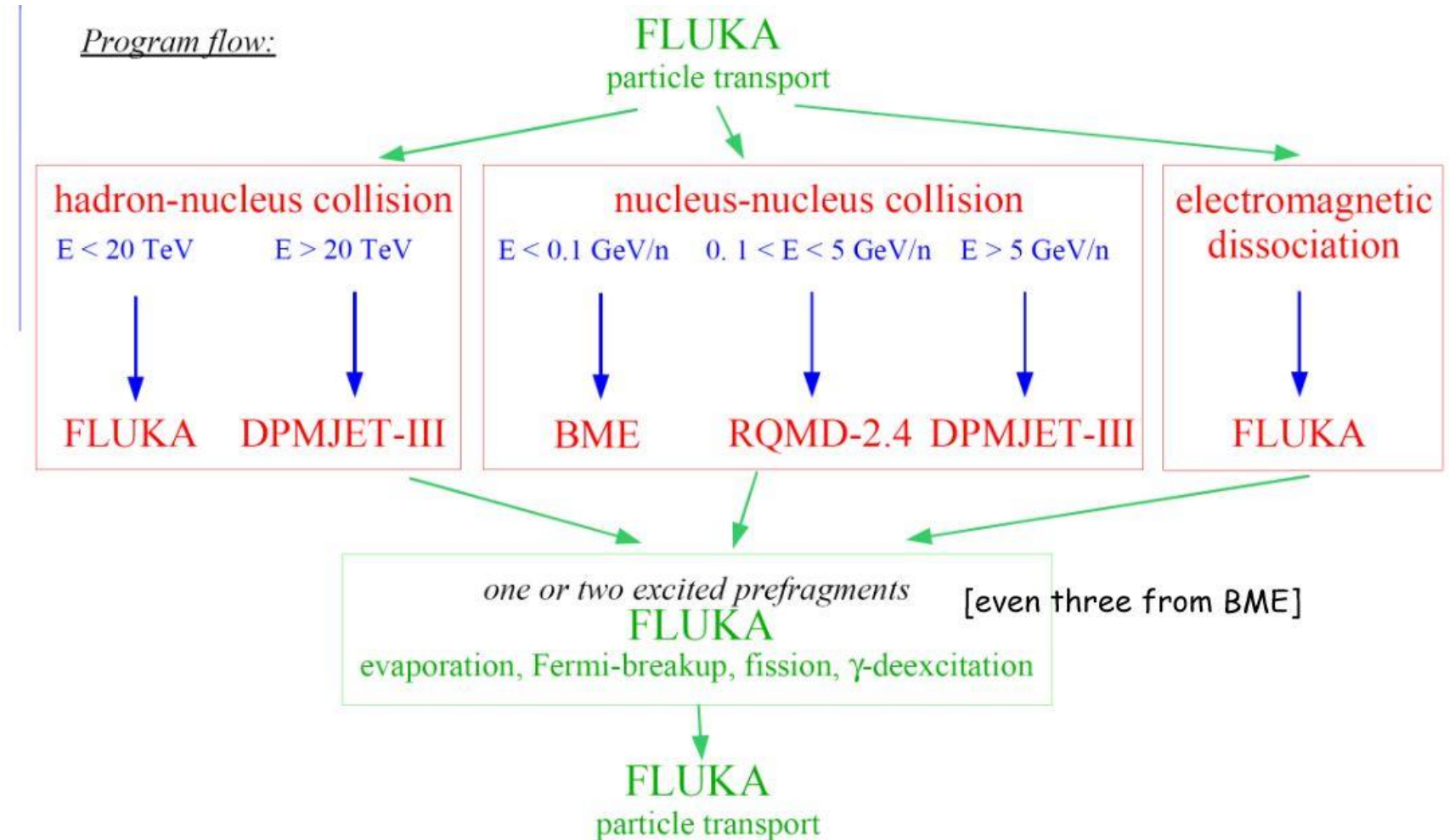Inp: quinta.inp   x: 7.4408   y: -21.15682859   z: 65.68110427

Nuclear interaction models in FLUKA

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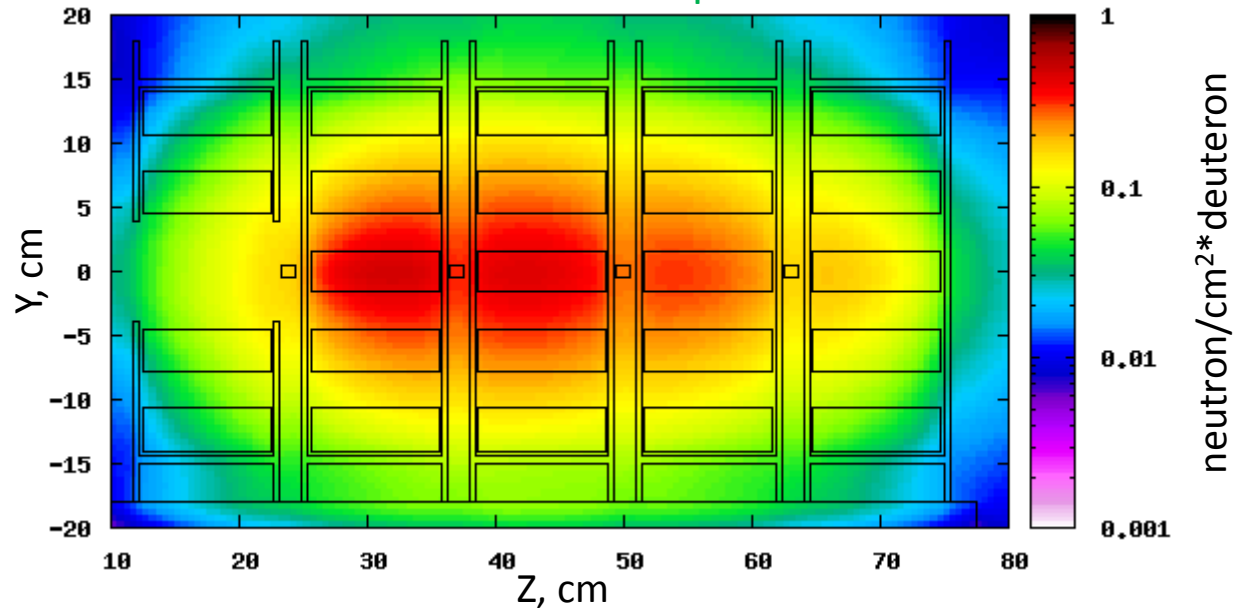Relativistic Quantum Molecular Dynamics Model (RQMD) – 0.1 GeV/n < E < 5 GeV/n
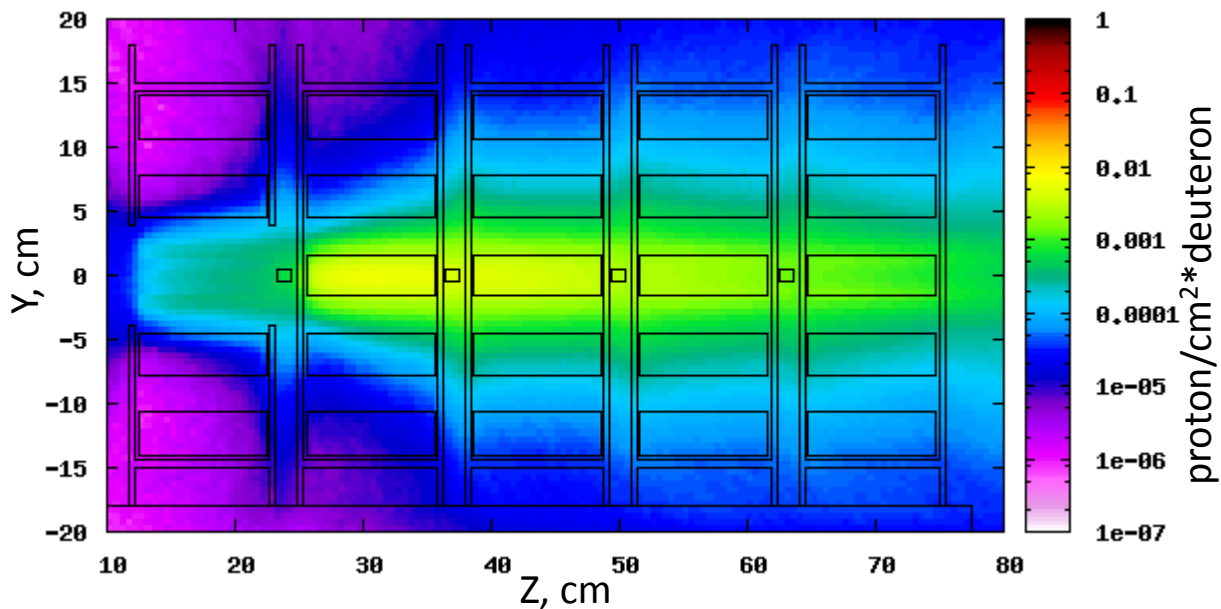Boltzmann Master Equation (BME) theory – E < 0.1 GeV/n

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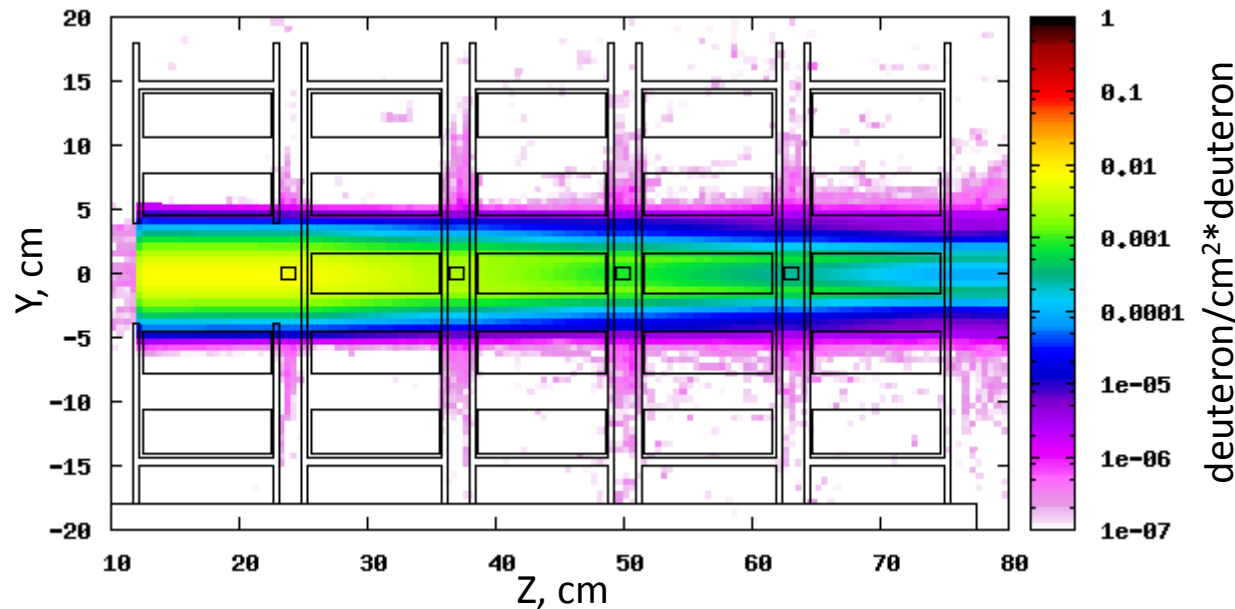("QUINTA" without Pb shields)

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.
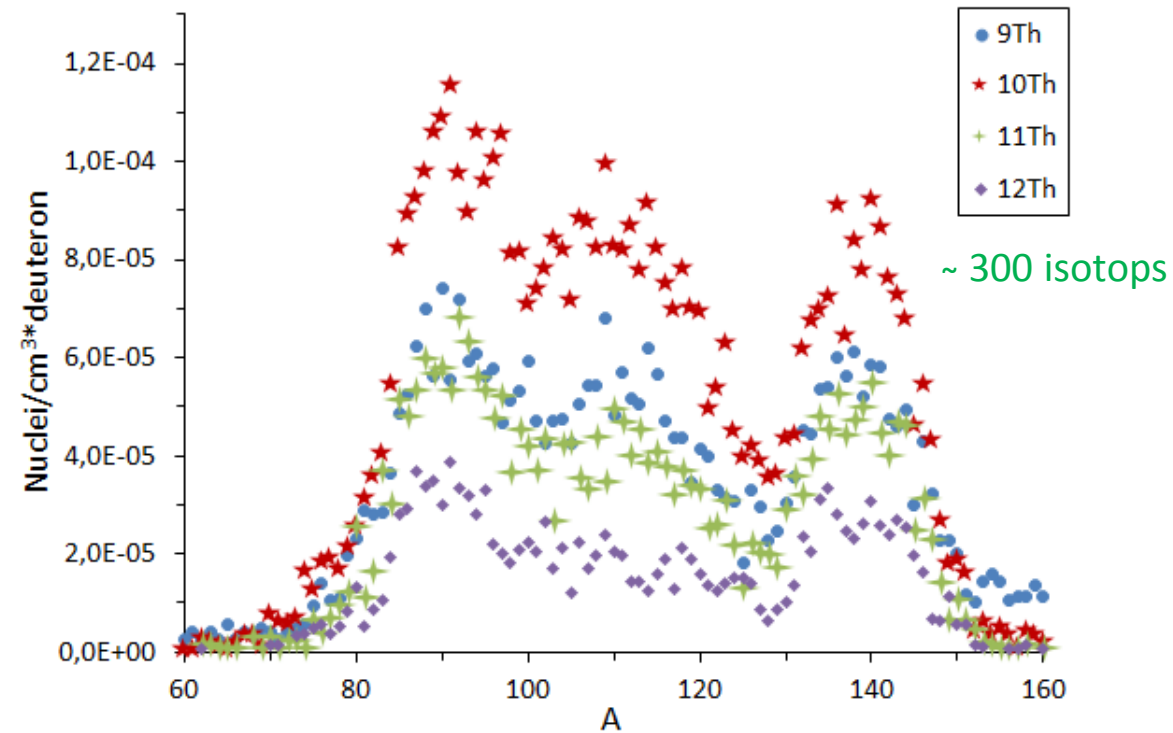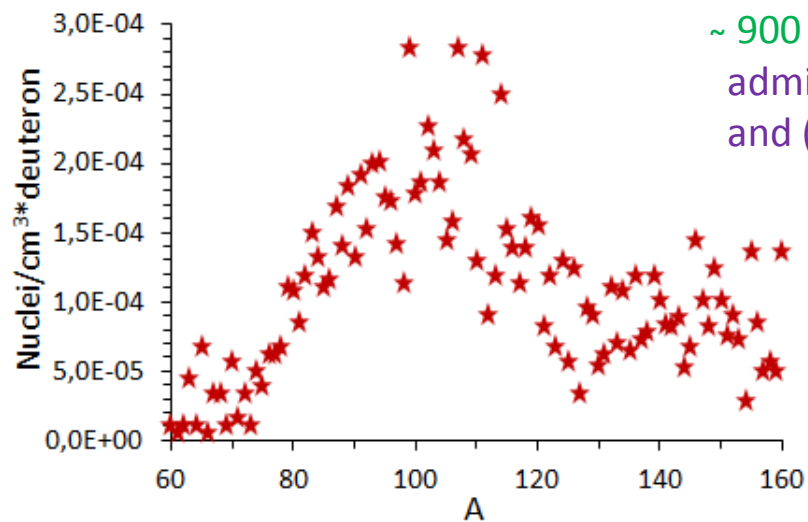("QUINTA" without Pb shields)
9Th – was placed between the first and second sections
10Th – was placed between the second and third sections
11Th – was placed between the third and fourth sections
12Th – was placed between the fourth and fifth sections

~ 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
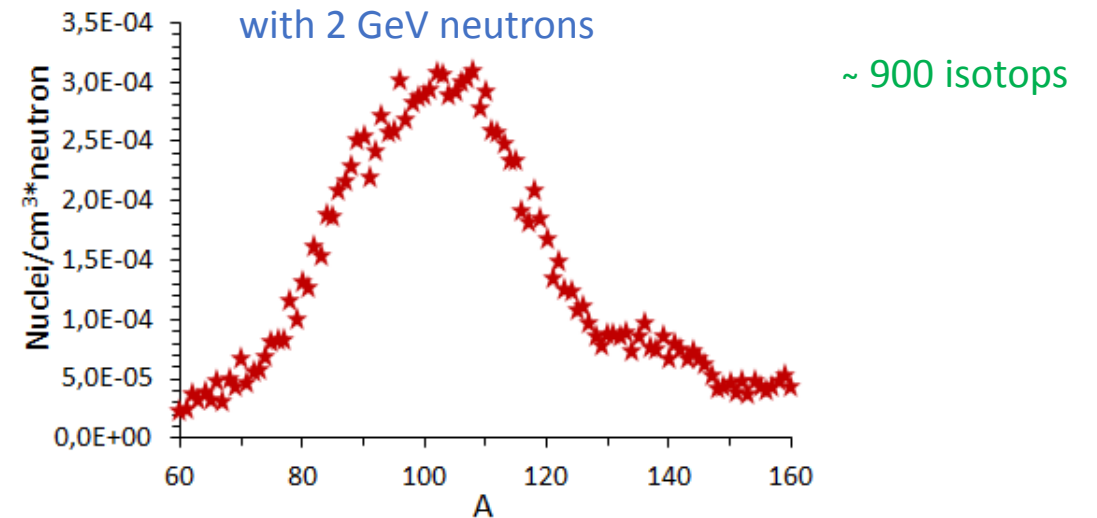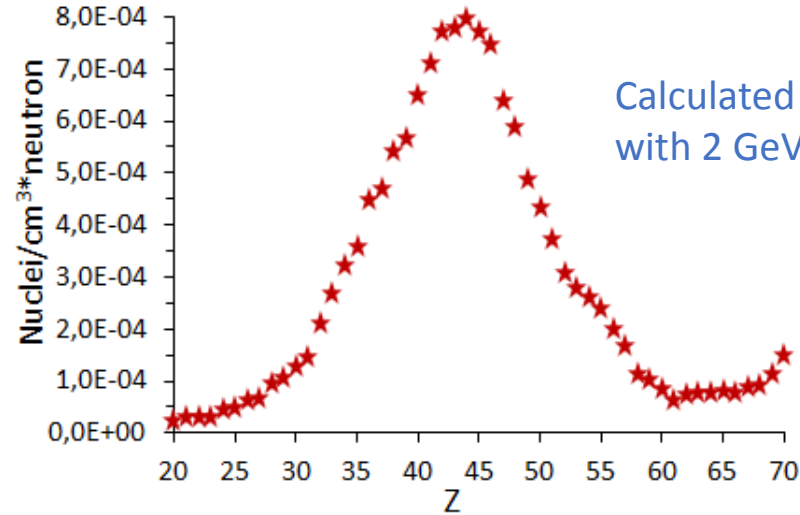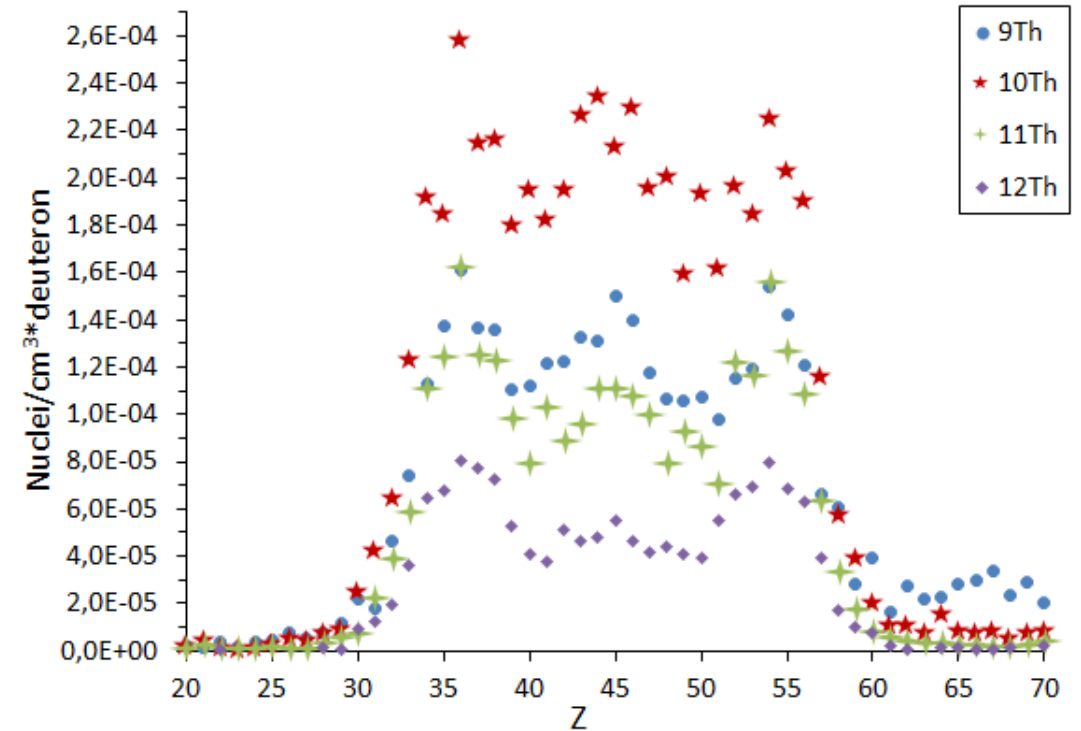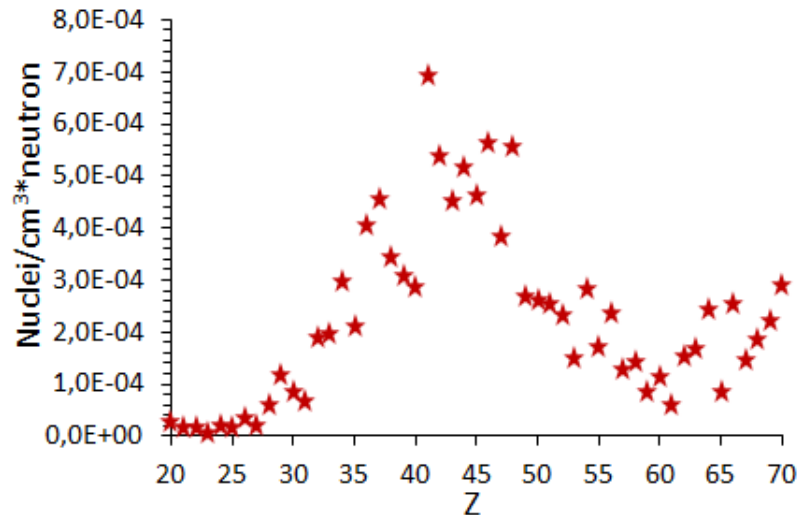10Th – was placed between the second and third sections
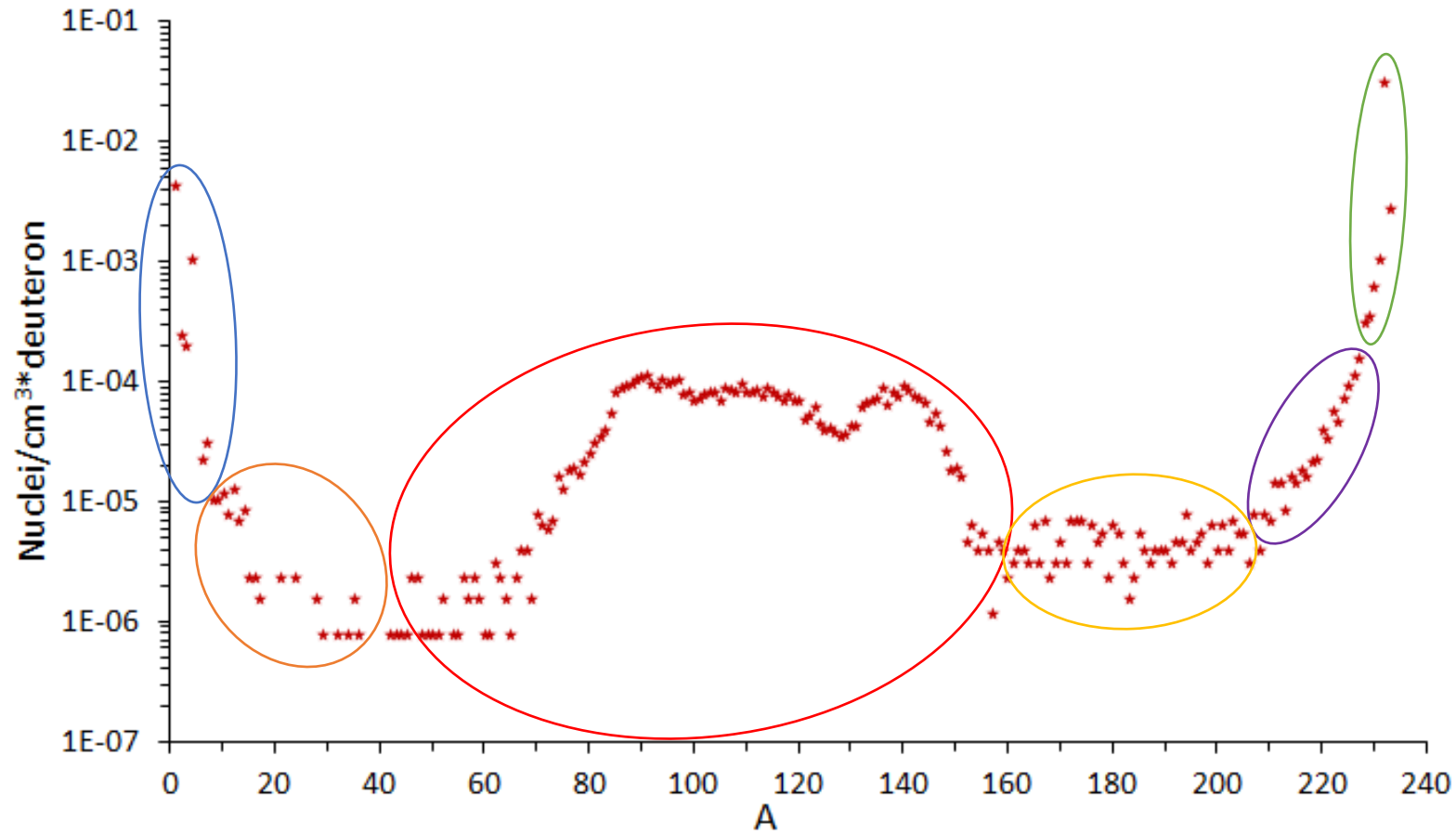11Th – was placed between the third and fourth sections
12Th – was placed between the fourth and fifth sections

Calculated fission reaction rates for ^{232}Th with 4 GeV deuterons
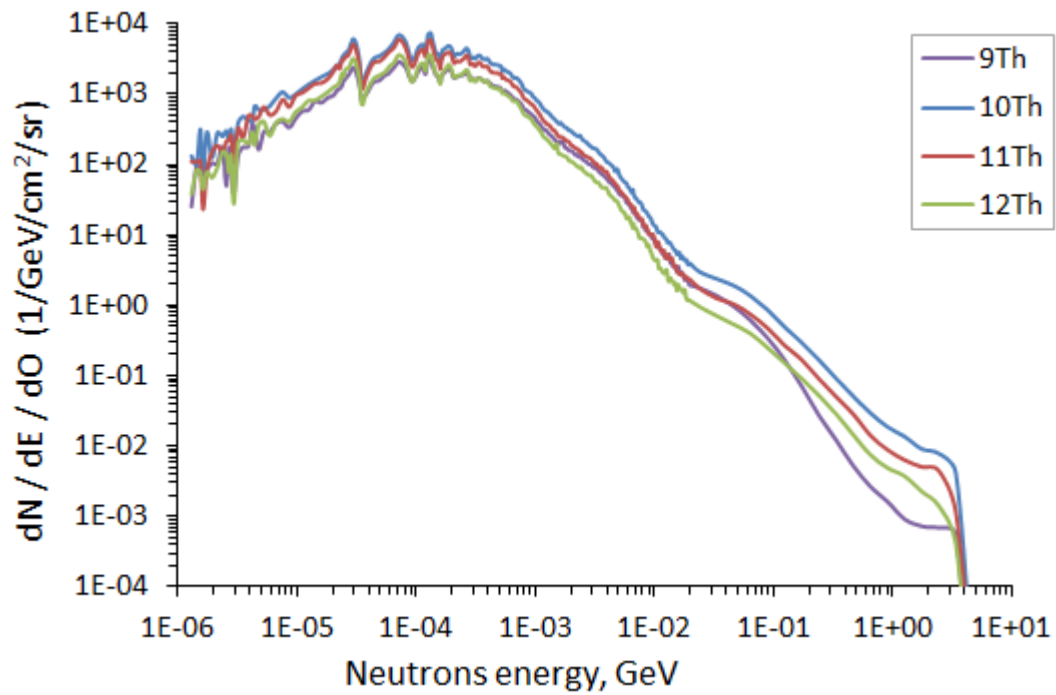
Calculated fission reaction rates for ^{232}Th with 2 GeV neutrons

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)
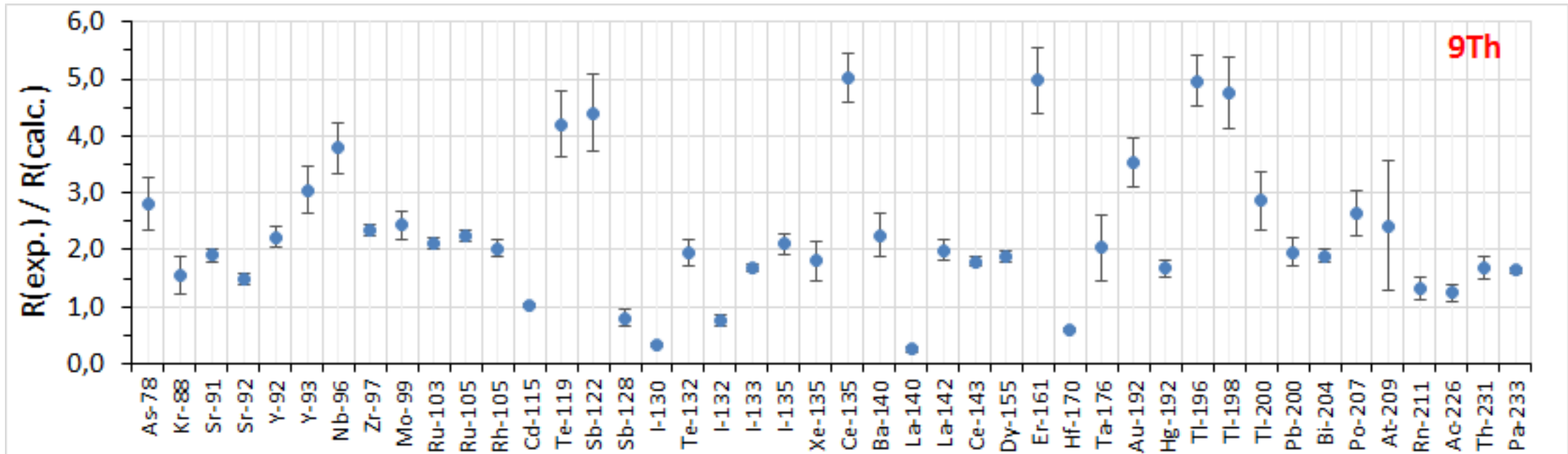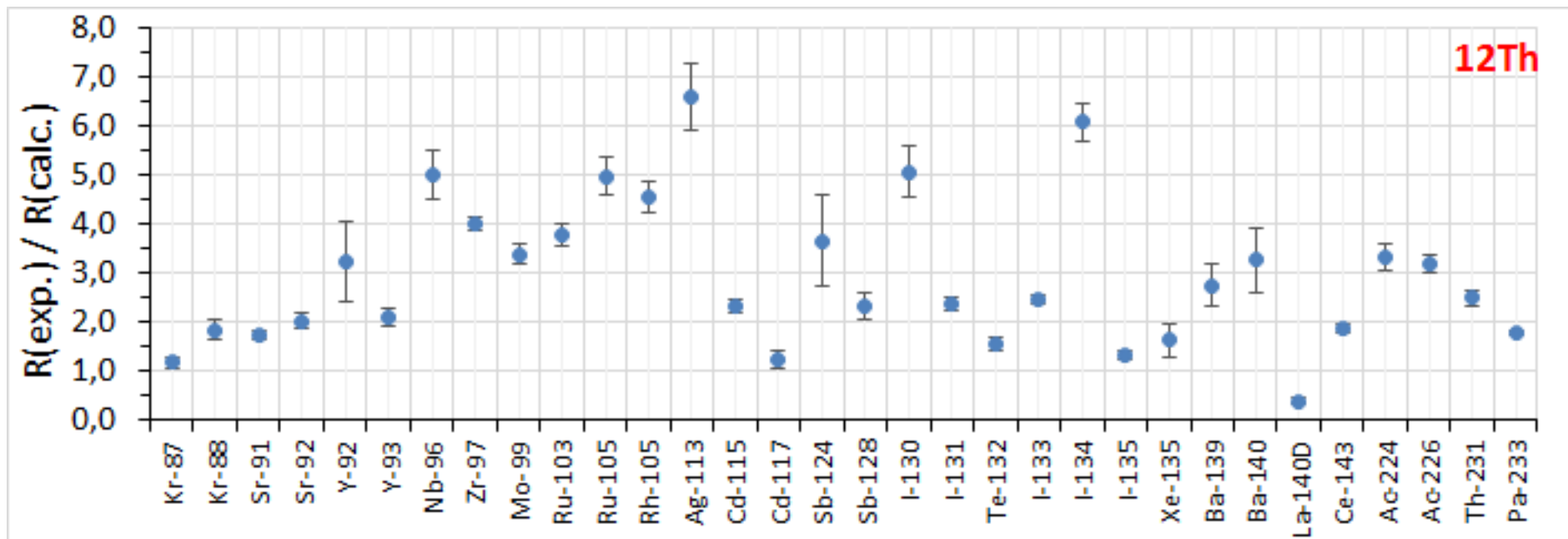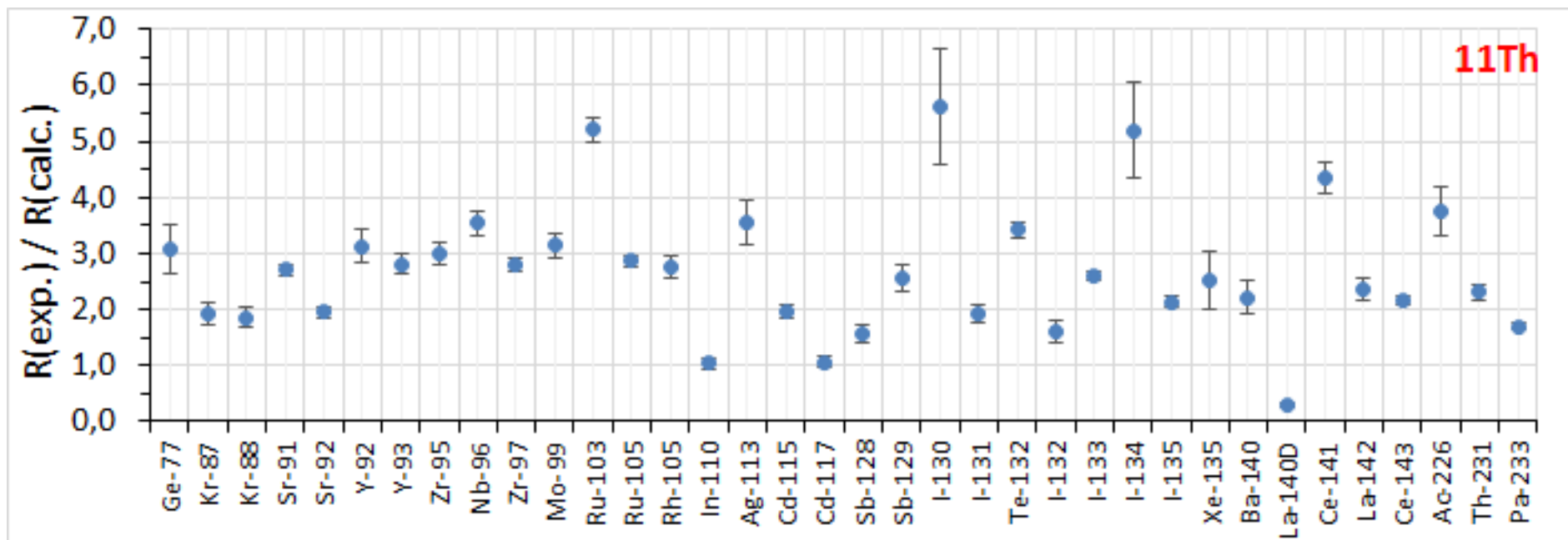
Summary

- 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 axis 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