Analysis of spatial distribution of the (n,f)^{nat}U, (n,γ)^{nat}U, (n,xn)^{nat}U reaction rates in the massive (512 kg) natural uranium target assembly QUINTA induced by irradiation with deuterons with energies in the range (1 – 8) GeV and a beam of carbon nuclei with energies 24 and 48 GeV

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Contents

Simulations of Quinta set-up

MCNPX 27.e, Data tables - ENDF70

Nuclear models used for simulations:

1) ISABEL – ABLA – LAQGSM

2) CEM2K

3) INCL4 – ABLA

4) The pre-equilibrium stage is considered.

5) **Cross section for reactions (n,f)^{238,235}U (E_n>20MeV) and charged particles inducing fission**

6) **Calculations of neutron induced reactions in uranium cylinders**

(n,f)^{238}U, (n,f)^{235}U, (n,2n)^{238}U and (n,γ)^{238}U for incident neutron energy En<20MeV and En>20MeV

7) **Estimation of charge particles induced fission, multiplicity constant and additional neutrons**

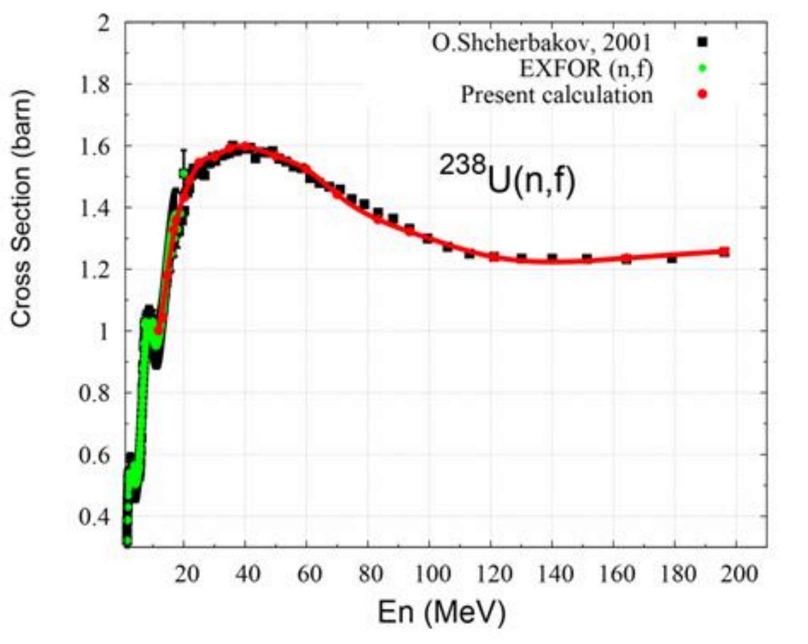
Restrictions of MCNPX 2.7e

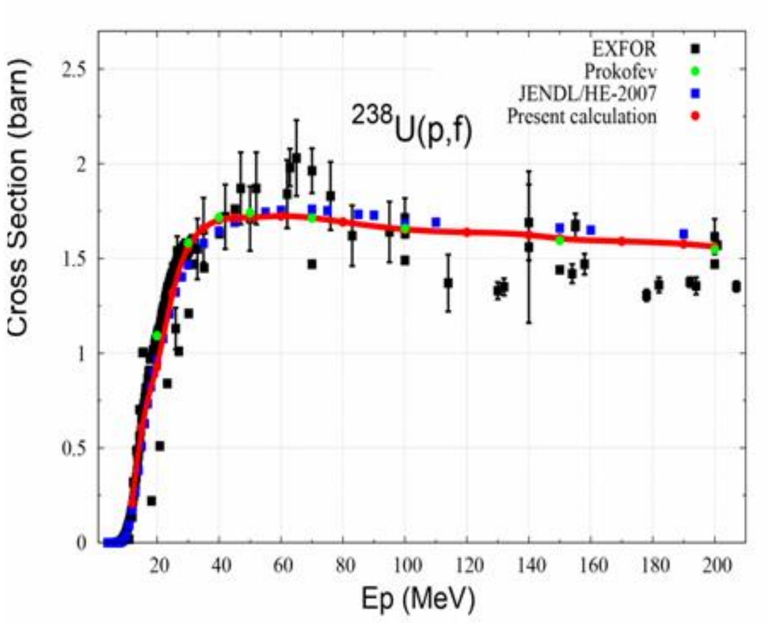
1) Does not calculate the reaction (n,f) for incident neutron energy n>20MeV.

2) Does not calculate charged particles induced fission.

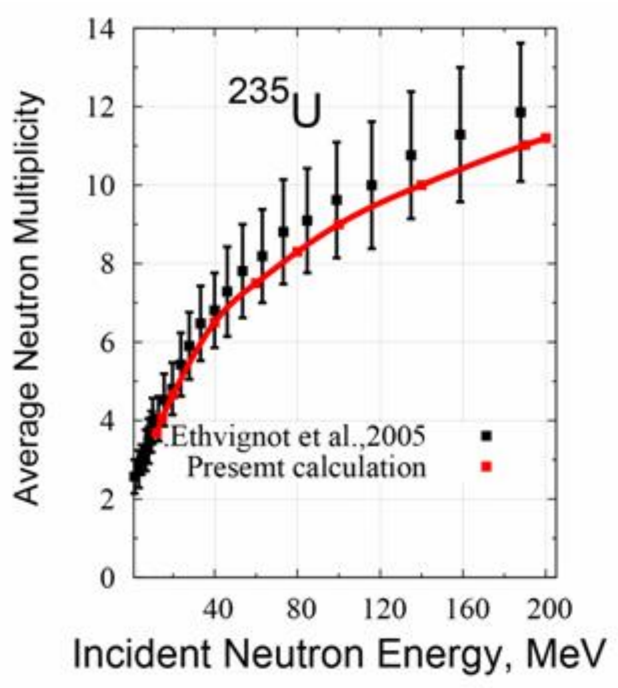
3) Does not transport and interact neutrons coming from the above two process.

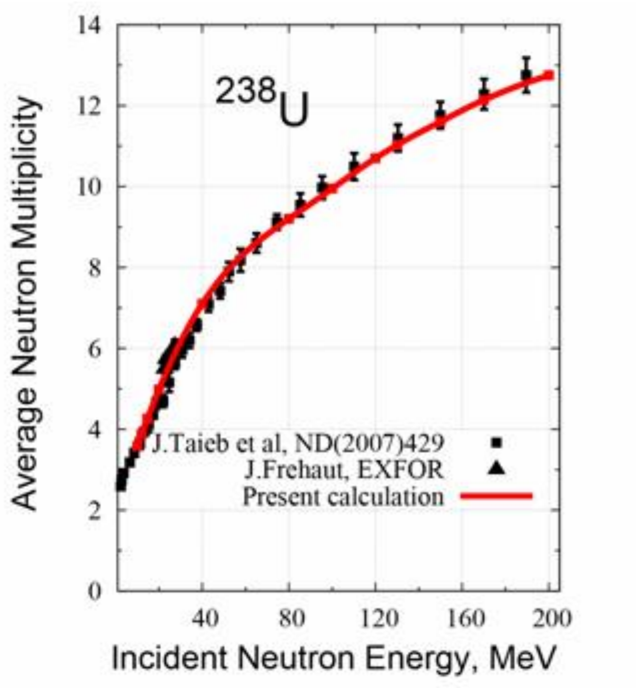
Cross sections (n,f)^{238}U and (p,f)^{238}U for incident neutron/proton energies up to 200 MeV



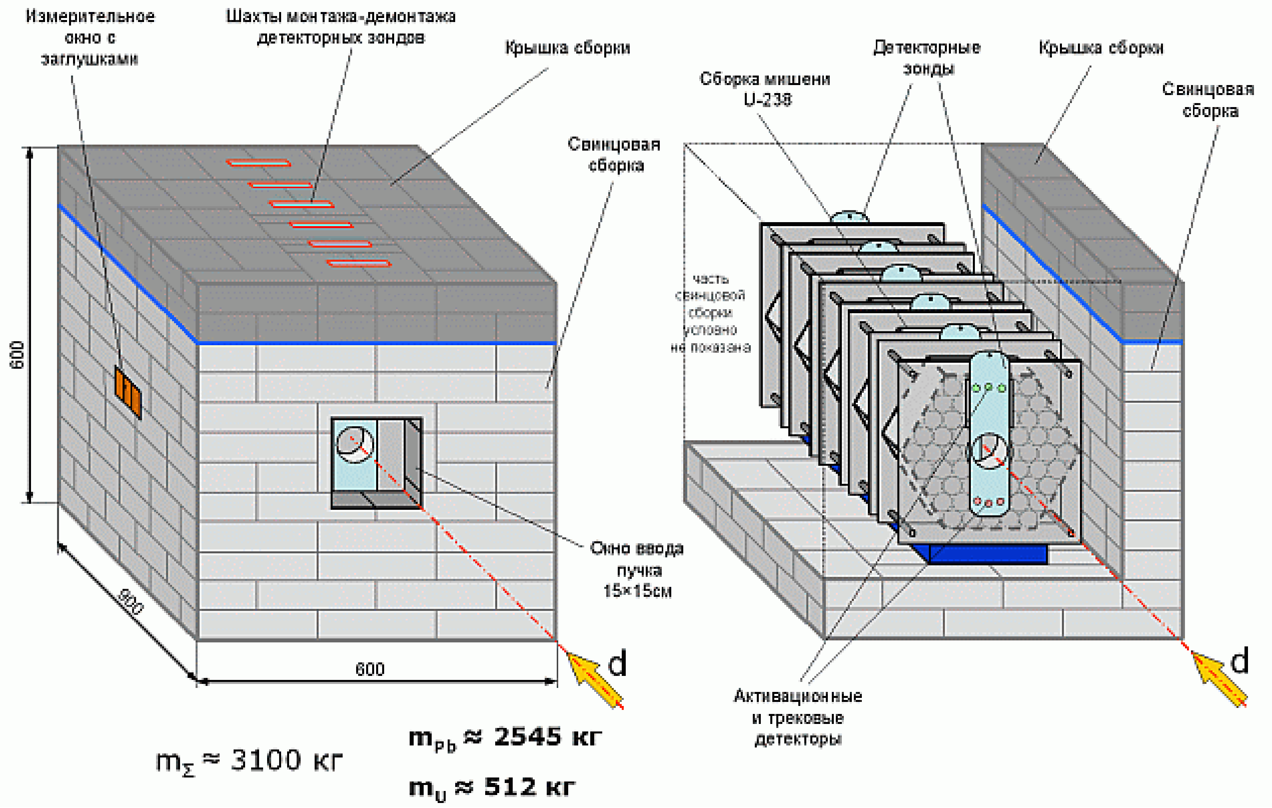


Average neutron multiplicity for $^{235,238}U$ and incident neutrons with energies up to En=200MeV

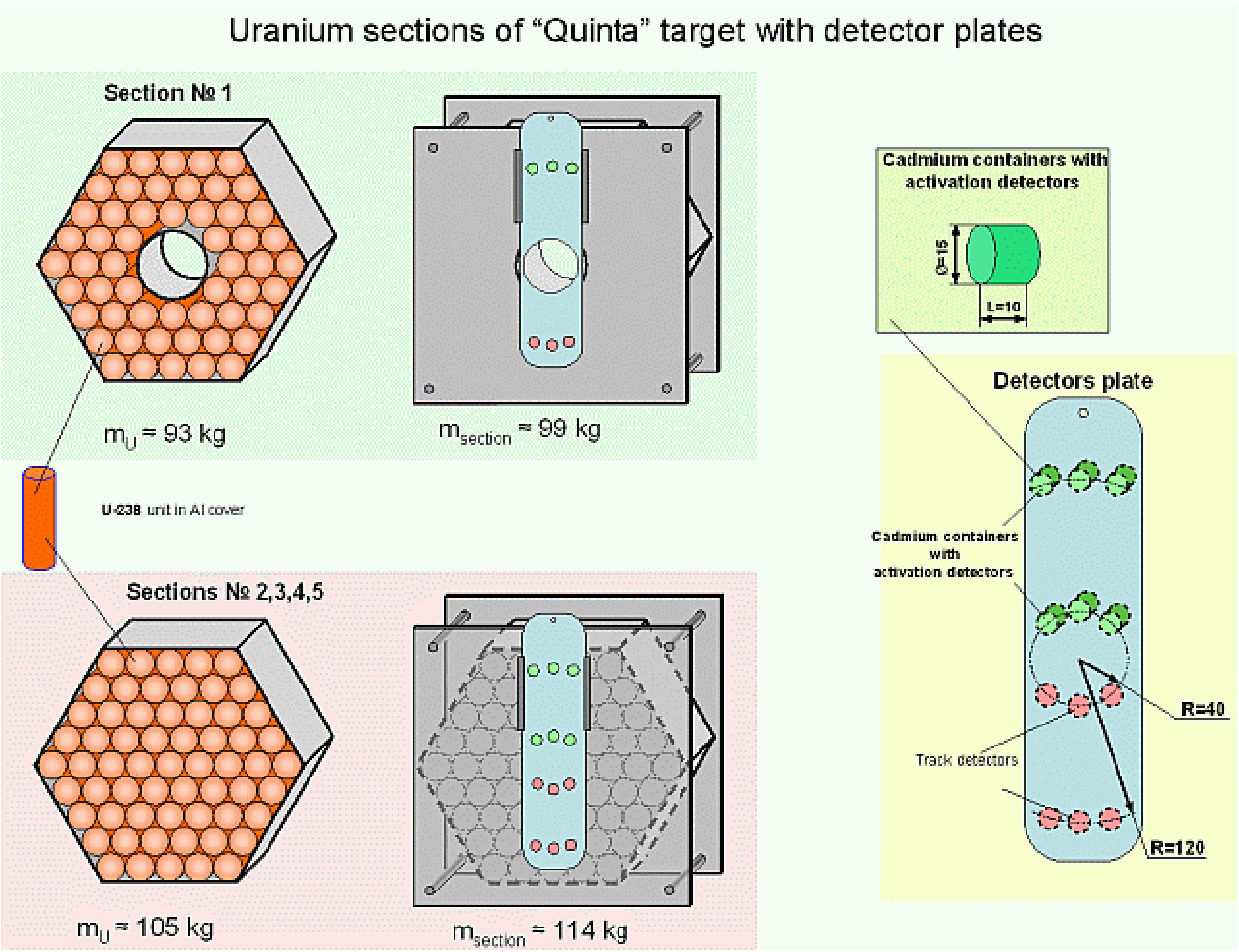




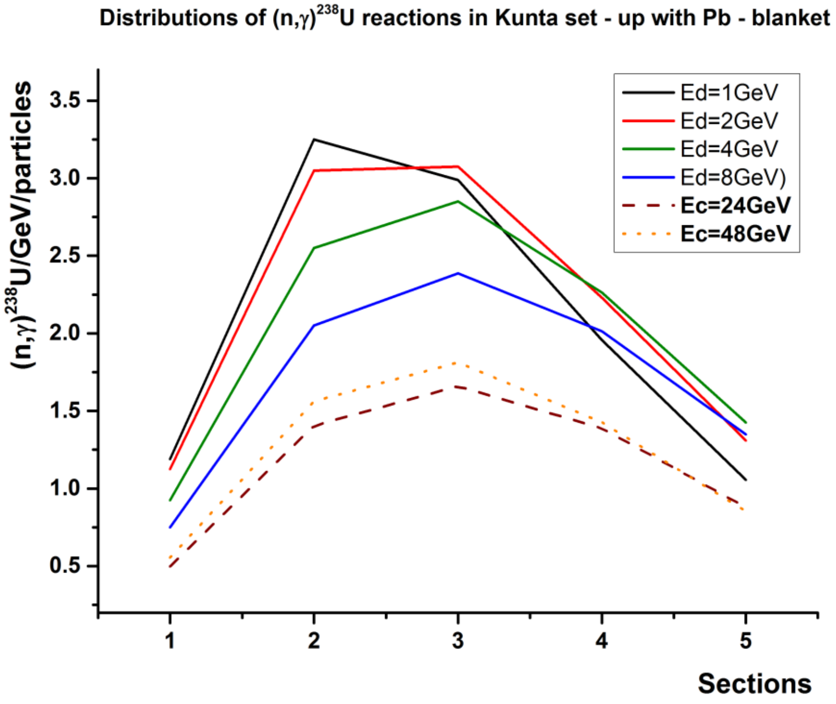
Quinta set-up with Pb-blanket

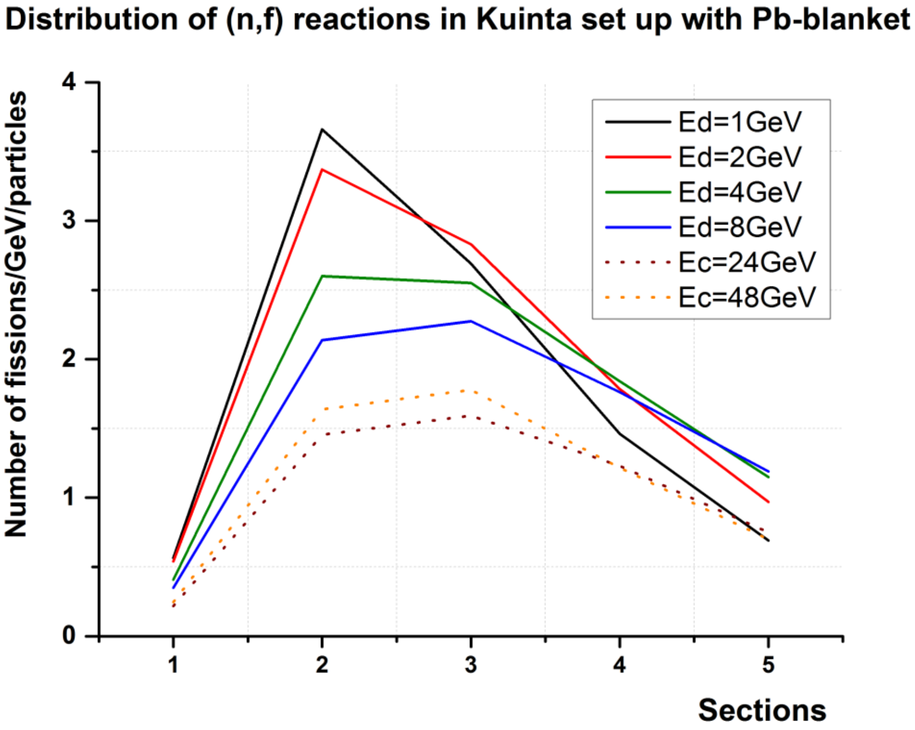


Construction of the sections in Quinta set-up

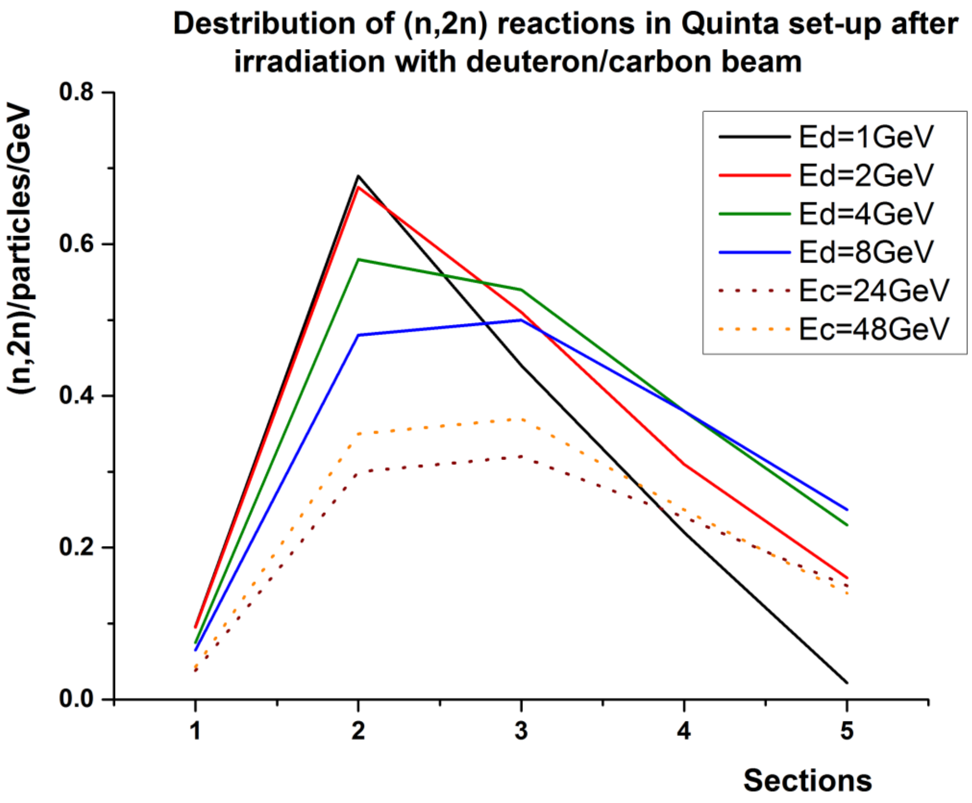


Distribution of (n,fiss)^{nat}U and (n,γ)^{238}U in Quinta set-up for deuteron beams with energies Ed=1,2,4 and 8 GeV and carbon beams with energies Ec=24 and 48 GeV





Distribution of (n,2n)^{238}U in Quinta set-up for deuteron beams with energies Ed=1,2,4 and 8 GeV and carbon beams with energies Ec=24 and 48 GeV



Integral characteristics of Quinta set-up

Ed/Ec (GeV)	N-total	Escaped neutrons	(n,f)total	(n,γ) ^{238}U	(n,2n) ^{238}U	[μ], (En <20 MeV)	[μ], (En>20 MeV)	[μ], (charge, fission)
1	70+17+4	43	6.52+2.17+0.4	10.44	1.55	3.2	8	10
2	146+36+10	91	14.5+4.5+1	22	3.5	3.2	8	10
4	268+56+20	170	27+7+2	40	7.2	3.2	8	10
8	458+112+37	300	48+14+3.7	68	13.5	3.2	8	10
24	981+240+85	614	97+30+8.5	140	25.7	3.2	8	10
48	2079+536+180	1297	207+67+18	300	55.8	3.2	8	10

* - calculation by MCNPX * - add. neutrons and (n,f), En>20MeV, * - add. neutrons and charged particles induced fission

Total number of (n,f)^{nat}U, (n,γ)^{238}U in Quinta set-up

E[GeV]	(n,fiss), En<20MeV	(n,f),total	fiss. total exp	(n,γ) ^{238}U	(n,γ) ^{238}U exp
1	6.5	8.7	10.6	10	11.8
2	14.5	19	21	21.6	25
4	27.7	34.2	41.2	40.1	48
8	48.1	61.7	74.4	68.1	81
24	96.6	126	180	140	208
48	207	267	370	300	374

Charged particles induced fission ~ 4-5% from (n,f) total

Influence of the beam position for capture and fission reactions in Quinta set-up

Carbon beam Ec=48 GeV

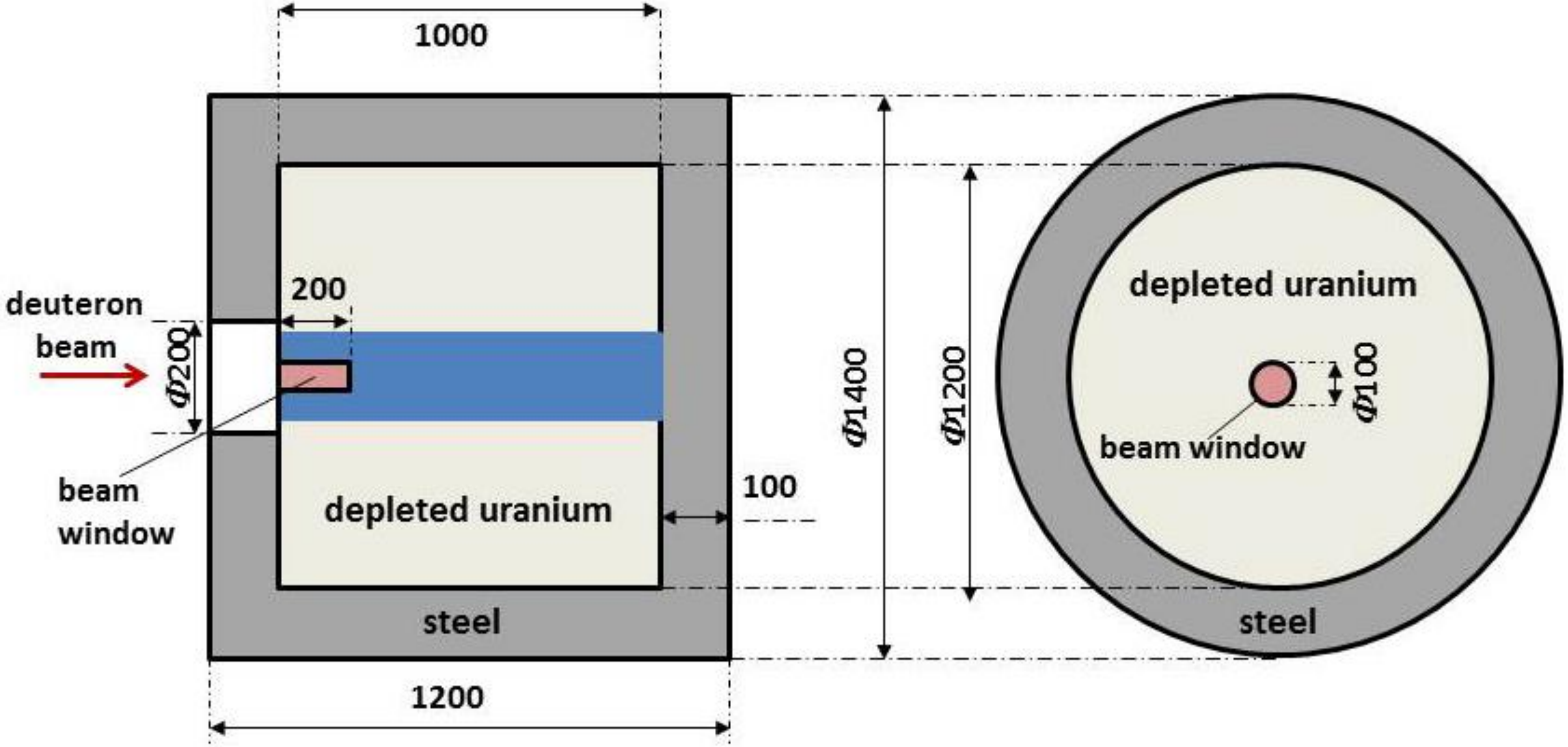
1) X=0, Y=0 and 2) X= -1, Y= -1.4 cm

The beam profile is the same.

Calculation by MCNPX 2.7e

	$(n,\gamma)^{238}U$	$(n,f)^{nat}U$, En<20MeV	$(n,f)^{nat}U$, total	N-total
X=Y=0 cm	330	221	278	2197
X=-1.4, Y=-1cm	300	207	267	2079

Cross sections of the Buran set-up

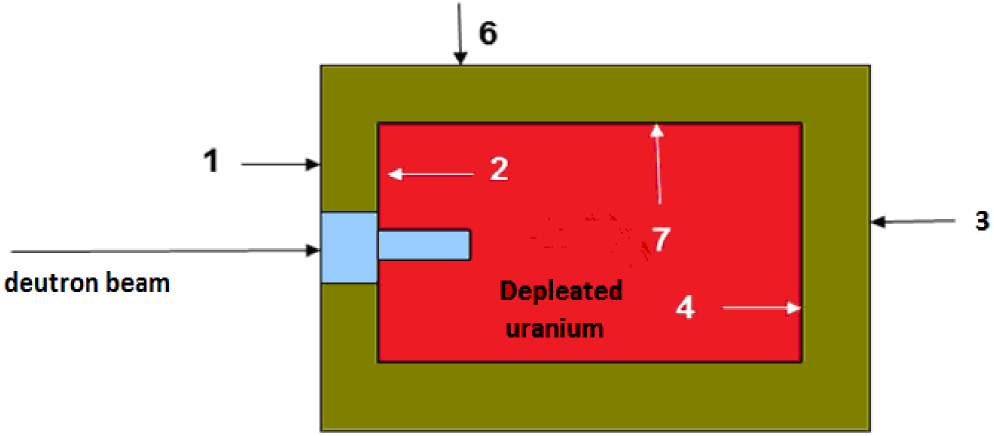


Calculation of ^{nat}U(n,f) and ^{238}U(n,γ) reactions for Buran set-up

E_d [GeV]	1	2	4	6	12
Neutron (total)	129+85	288+170	567+350	823+550	1536+1000
(n,fiss), E_n<20 MeV	15.3	34.5	68	98	184
Escape neutrons	3.5	6	10	13	21
(n,f), with neutron spectra convolution	18.9	42.7	84	122	227
(n,f) total (estimated)	37	81	164	246	460
(p,d,π-fiss)	1.2	2	2.3	5	9.7
(n,γ)	73	164	325	473	883
(n, γ) total (estimated)	132	318	625	904	1663
μ- multipl. (En<20MeV)	3.1	3.1	3.1	3.1	3.1
μ- multipl. (En>20MeV)	8.3	8.4	8.4	8.5	8.5

*Phys. Rev. C. Vol. 24, N 1, 1981. Ch. Chung and J. Hogan. Fission of 232Th at energies up to 90 MeV

Neutron escape balance of Buran set-up



	Deuterons		
Ed, [GeV]	1	6	12
Fe-1	3.2	11	17
U-2	8.1	29	48
Fe-3	0.03	0.95	2.4
U-4	0.2	6	15
Fe-6	0.16	1.8	2.1
U-7	1.2	7.5	14
Total escape	3.3	13	22

Comparison of neutron production/escape in GAMMA-3 set-up with nat-Pb target, free nat-Pb target and Quinta set-up

GAMMA-3 /Pb/Quinta set-up

calculated with MCNPX 2.7e

Ed [GeV]	N-creation	N-escape
2	148/43/156	10/40/98
4	251/73/275	17/67/171
8	445/126/480	28/115/350

CONCLUSIONS

Quinta set-up with Pb blanket

- 72-80% of a total of $(n,f)^{nat}U$ reactions are initiated by neutrons with En<20MeV.

The deuteron beam has energy from Ed=1 to 8GeV.

- The number of fissions ($p+d+\pi$, f) is 4-5% from the total $(n,f)^{nat}U$ reaction

for deuteron beam energy Ed=1-8GeV

- The ratio of reaction $(n,f)^{235}U/(n,f)^{nat}U \sim 0.077$
- Underestimation of total neutron production is more than 30% (40%?)
- The ratio $^{nat}U(\text{fissions})_{exp}$ / $^{nat}U(\text{fissions})_{calc} = 1.3$
- The ratio of reaction $(n,\gamma)exp.^{nat}U$ / $(n, \gamma)_{calc}$ natU= 1.2
- The ratio of reaction $^{235}U(n,f)$ / $^{nat}U(n,f)_{calc} = 0.075$
- The position of the center of the deuteron beam is important for
  (n,f) and (n,γ) reactions.

Buran set – up

- **Escape neutrons form Buran set-up will be 100 times less than in Quinta set-up**

- **Activation of steel protection cylinder have to be expected**

Gamma -3 set - up

1. **Gamma – 3 set-up can be assumed to be quasi-infinite target**
2. **Generation of neutrons in carbon medium is two times more than in the ^{nat}Pb**

The calculations for this presentation were done at the Laboratory of Nuclear Spectroscopy, INRNE, BAS, BG in collaboration with “Energy plus transmutation RW project”, Dubna, Russia with the financial support of the Nuclear Regulation Agency, Bulgaria

Thank you for your attention!