Quasi-infinite uranium and thorium targets irradiated by deuterons /protons with relativistic energies

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♦ **This presentation analyzes the reactions rates (n,γ), (n,n'), (n,2n), (n,f)**

and the fission neutron multiplicity in a "Big" uranium

or thorium targets.

♦ **Defines a quasi-infinite target (medium) as a function**

of beam energy

♦ **Simulations and experiments**

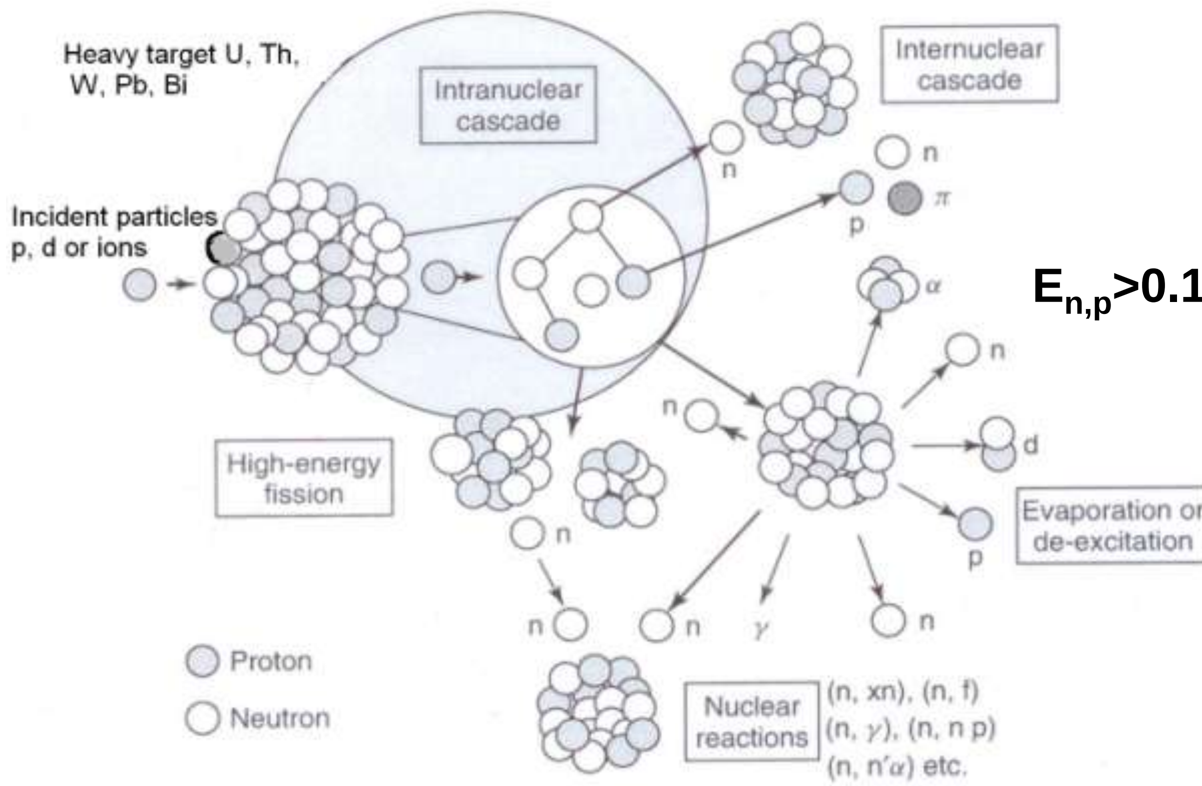
Wasil'kov-Goldanski set-up and experiment

simulation of future experiments with Buran set-up

Neutron production in targets (238U, depU and 232Th) by irradiation with high energy protons and deuterons

1. Spallation reactions

$E_{p,d}$=0.2-20GeV



$E_{n,p}$>0.1-1GeV

2. Fragmentation of the uranium/thorium core.

- neutron multiplicity and neutron spectra

3. Neutrons induced fission (n,f).

- neutron multiplicity, neutron spectra and fragments

4. Charged particles and gammas induced fission (p,f), (d,f), (π,f) and (γ,f).

- neutron multiplicity, neutron spectra and fragments

5. Reactions (n,2n), (n,3n) and (n,4n).

6. Radiative capture and inelastic interactions (n,γ) and (n,n').

The aim of ADS

1. Energy production.

Neutron induced fission of ^{238}U and ^{232}Th.

♦ production of ^{239}Pu by radiative capture:

$$^{238}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \longrightarrow {}^{239}_{92}\mathrm{U} \xrightarrow[23.5\ \mathrm{min}]{\beta^-} {}^{239}_{93}\mathrm{Np} \xrightarrow[2.3565\ \mathrm{d}]{\beta^-} {}^{239}_{94}\mathrm{Pu}$$

♦ production of ^{233}U by radiative capture:

$$\mathrm{n} + {}^{232}_{90}\mathrm{Th} \rightarrow {}^{233}_{90}\mathrm{Th} \xrightarrow{\beta^-} {}^{233}_{91}\mathrm{Pa} \xrightarrow{\beta^-} {}^{233}_{92}\mathrm{U}$$

2. Transmutation of nuclear waste and possibility to use it as fuel for ADS.

MCNPX calculation of "BIG" ^{238}U, $^{depl.}U$ and ^{232}Th targets

1. MCNPX limitations for $^{238,235}U$ and ^{232}Th.

- Incident neutrons energy for the reactions (n,f), (n,xn) $^{235,238,233}U$ and neutron multiplicity are defined up to E_n=20MeV. Charged particles and photons induced fission are not included.

- Incident neutrons energy for the reactions (n,f), (n,xn) ^{232}Th and neutron multiplicity are defined up to E_n=60MeV. Charged particles and photons induced fission are not included.

Simulations and nuclear data

Target: Cylinder from ^{238}U or ^{232}Th. Size L=1 – 4m, R=0.4 – 1.2 m

and Buran set-up

MCNPX 2.7e transport code.

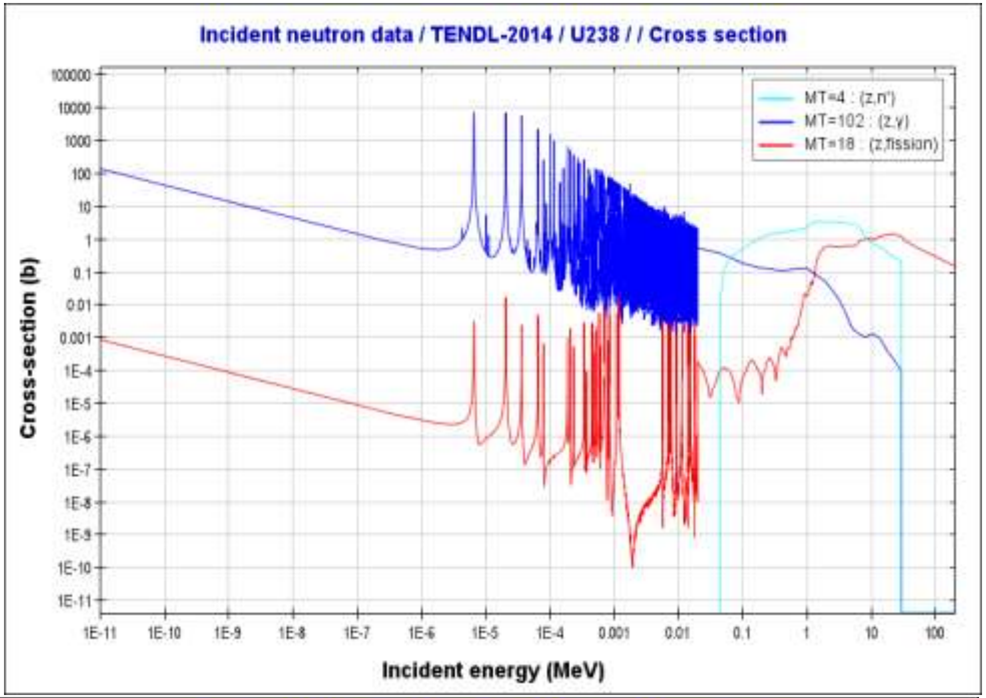
Nuclear models: CEM03, INCL4+ABLA, QGSM

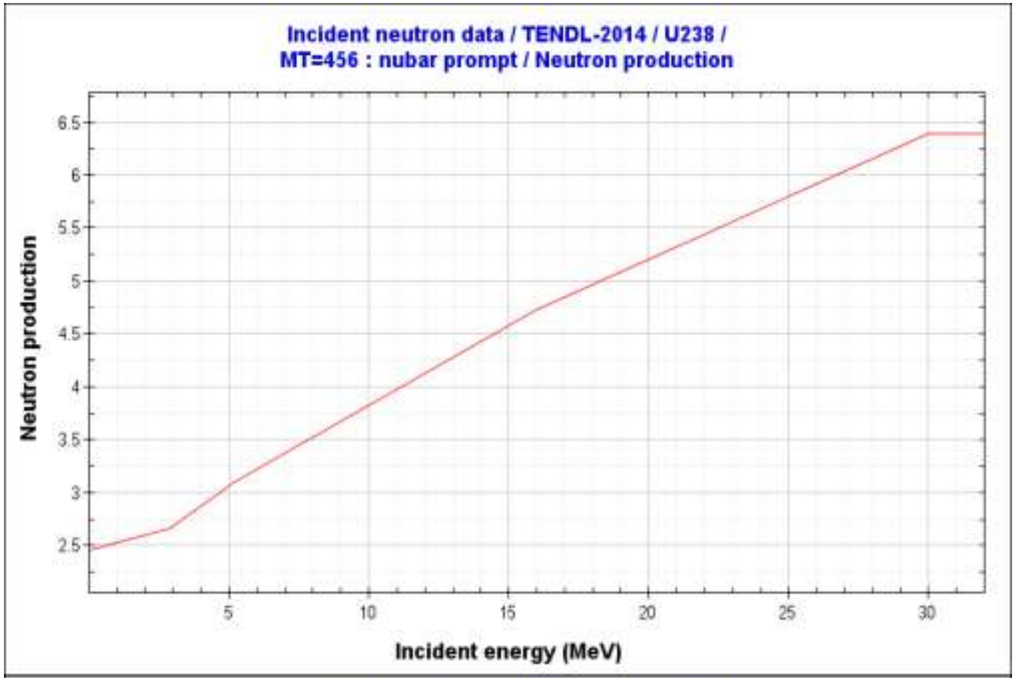
ENDF and TENDL data tables.

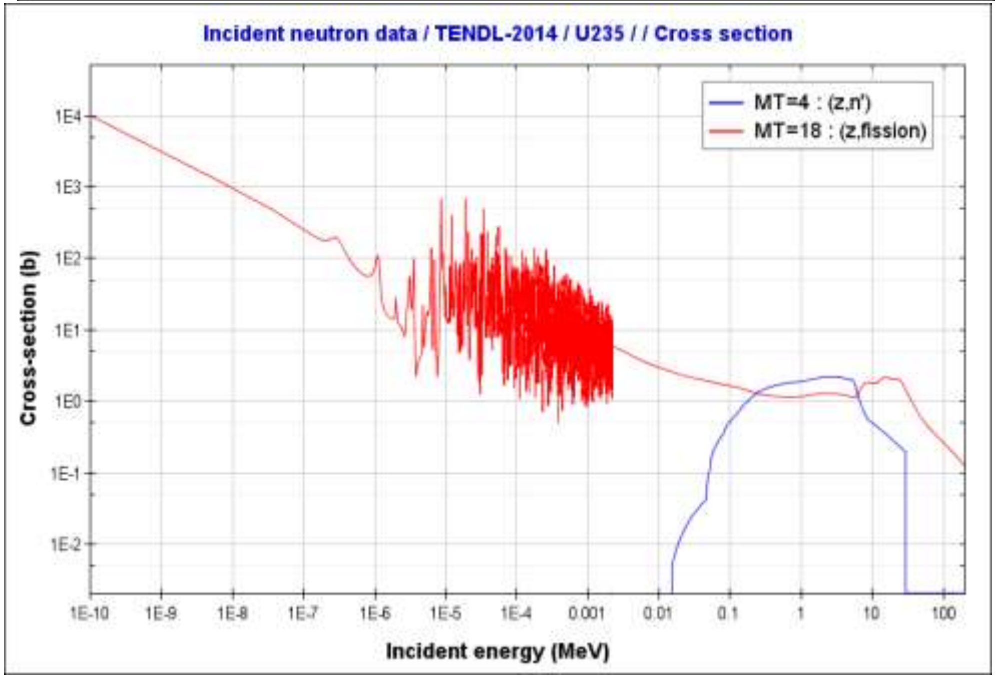
For the reaction rate calculations were used:

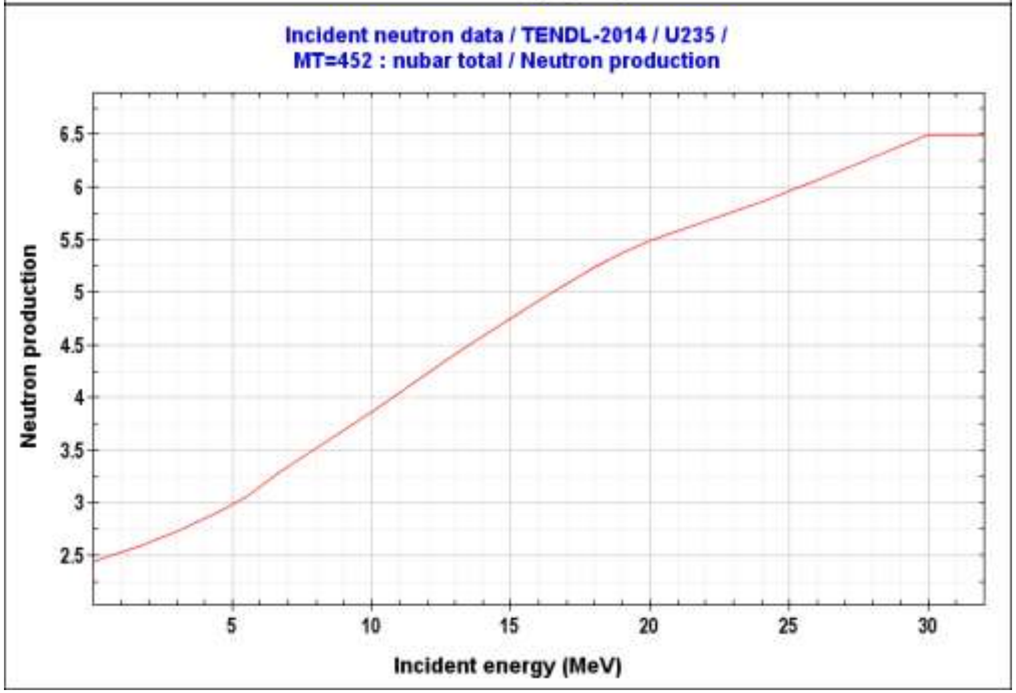
1. FM card $C\int_{E1}^{E2} \Phi(E)\sigma(E)dE$
2. Output file
3. Convolution method $N=\sum \Phi(E)\sigma(E)dE$
4. Fission energy deposition

Cross sections (n,f), (n,γ) and (n,n') and multiplicity for ^{235}U and ^{238}U



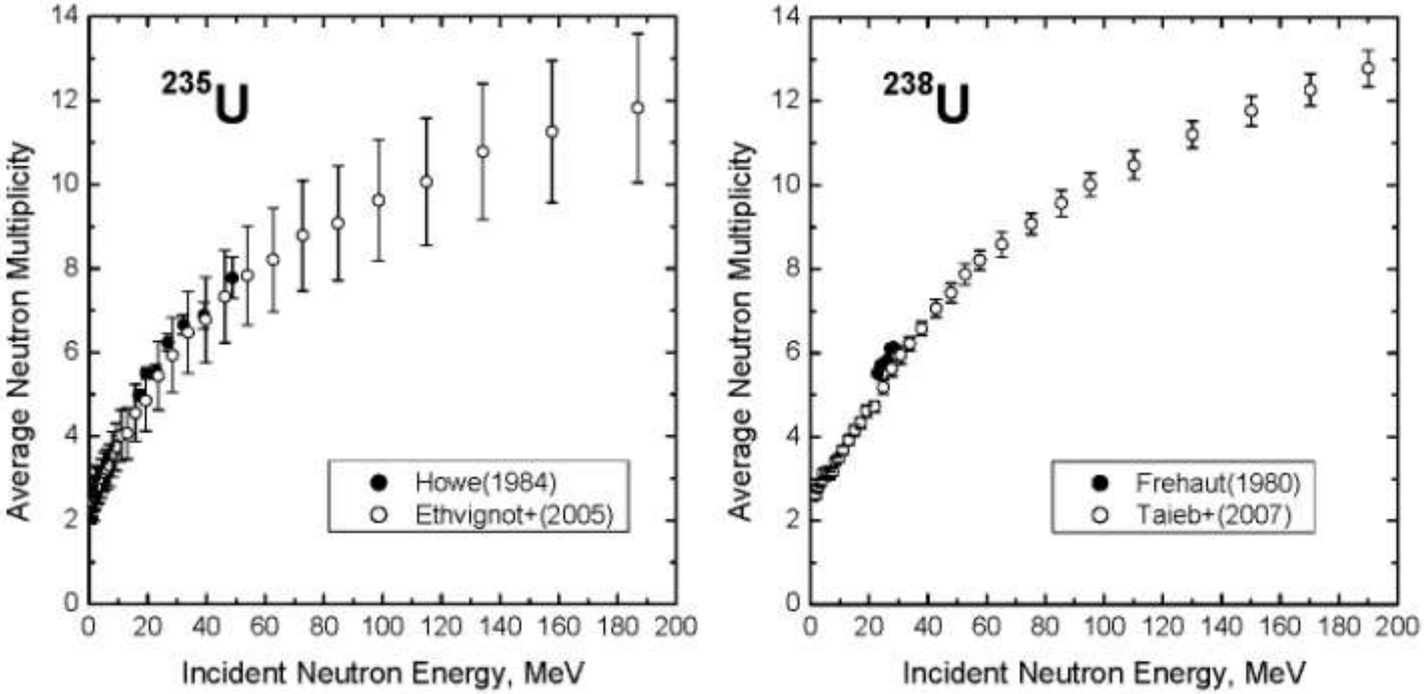






Multiplicity for of U isotopes

- Average fission neutron multiplicity as a function of incident neutron energy is known quite well for nuclei ^{235}U, ^{238}U up to 200 MeV

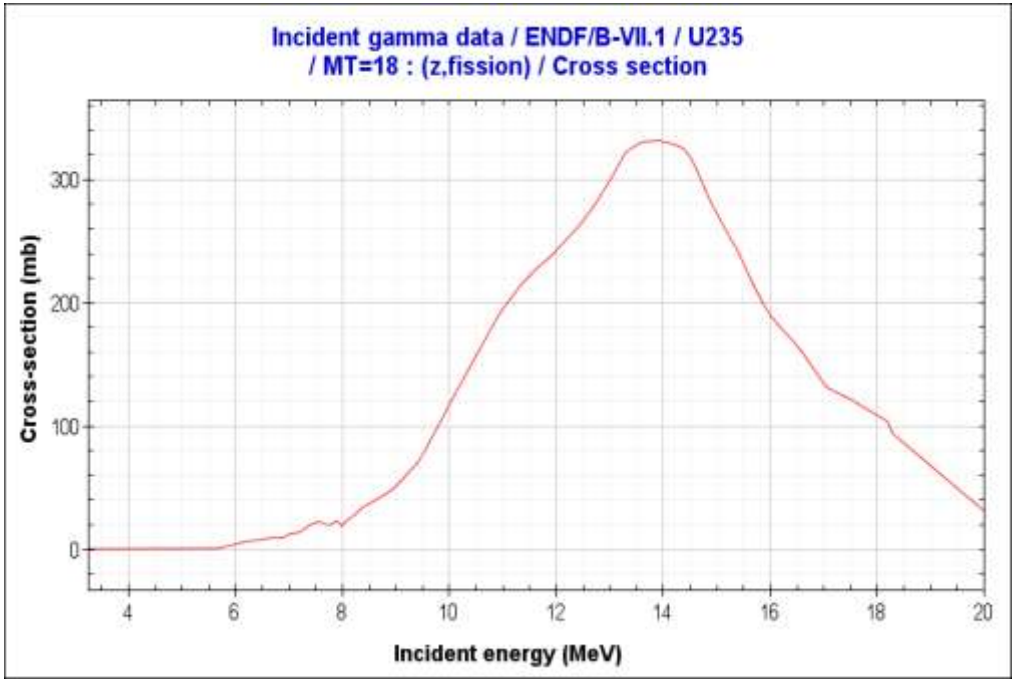


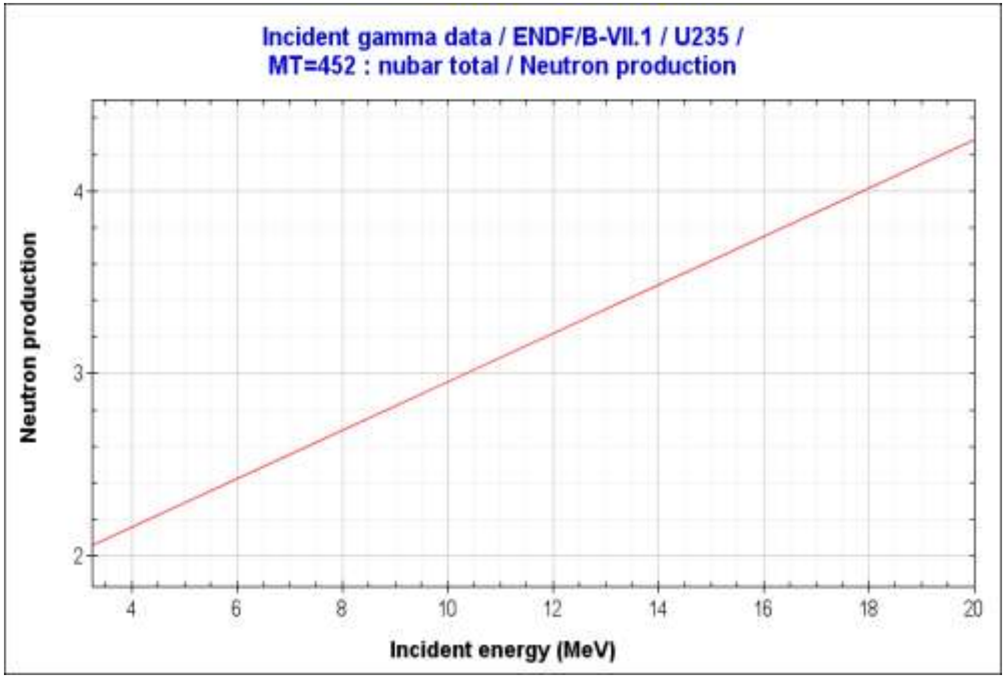
Ref. (^{235}U):
R.Howe,
Nucl.Sci.Eng. 86(1984)157
T.Ethvignot et al.,
PRL 94(2005)052701

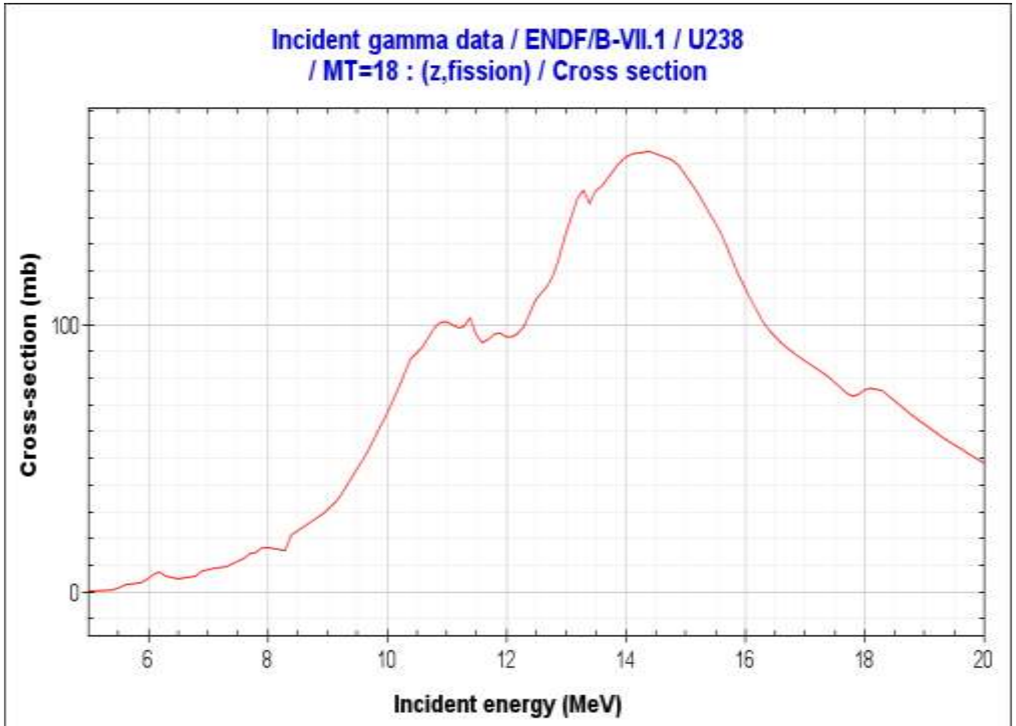
Ref. (^{238}U):
J.Frehaut ,
EXFOR data 21685.003
J.Taieb et al.,
ND-2007 (2007)429

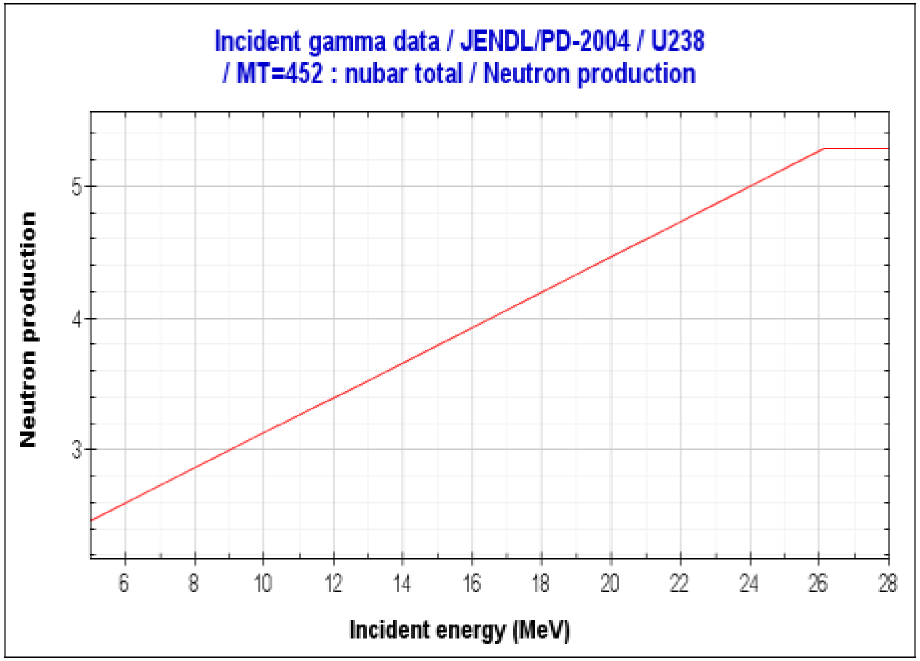
Alexander laptev, LANL

Gamma induced fission in $^{235,238}U$

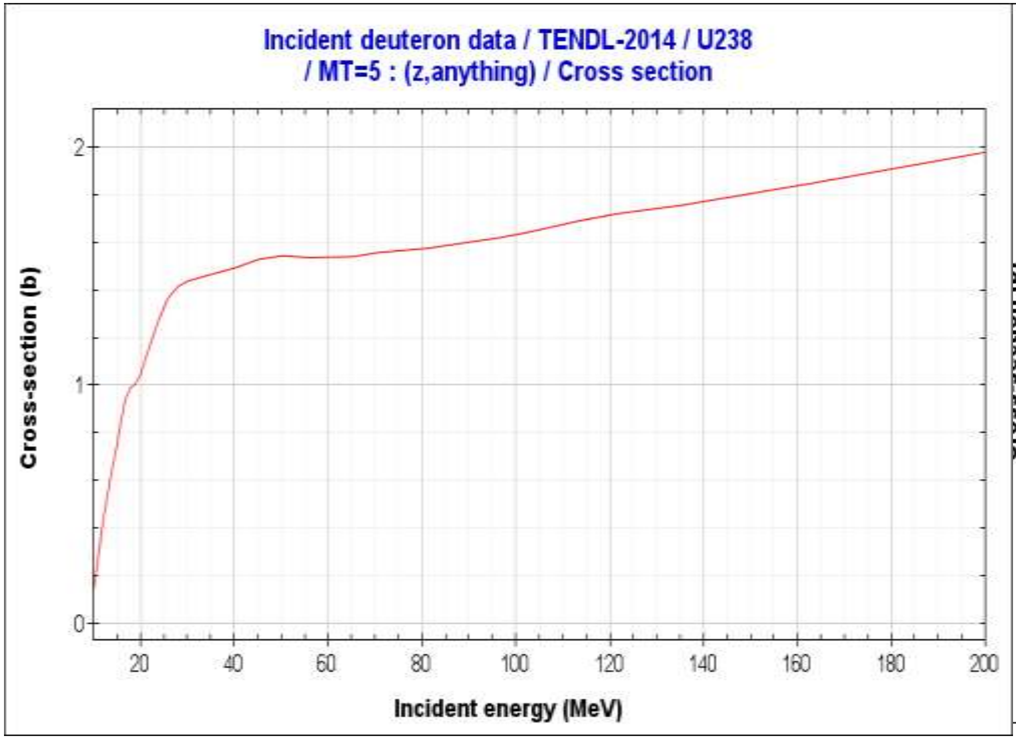


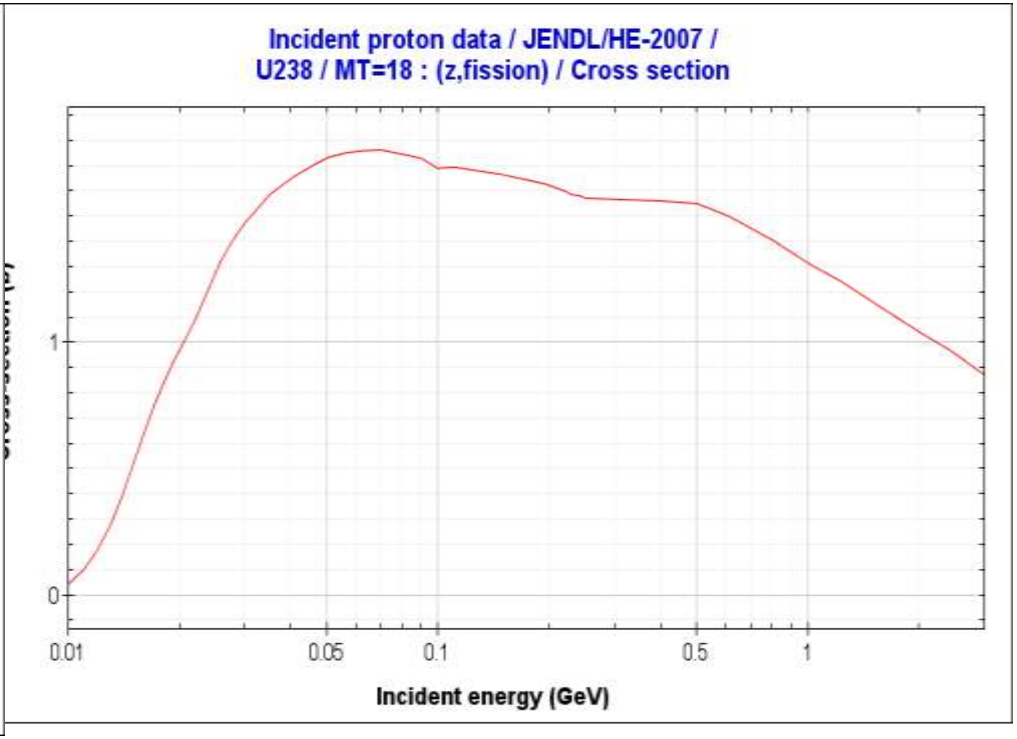




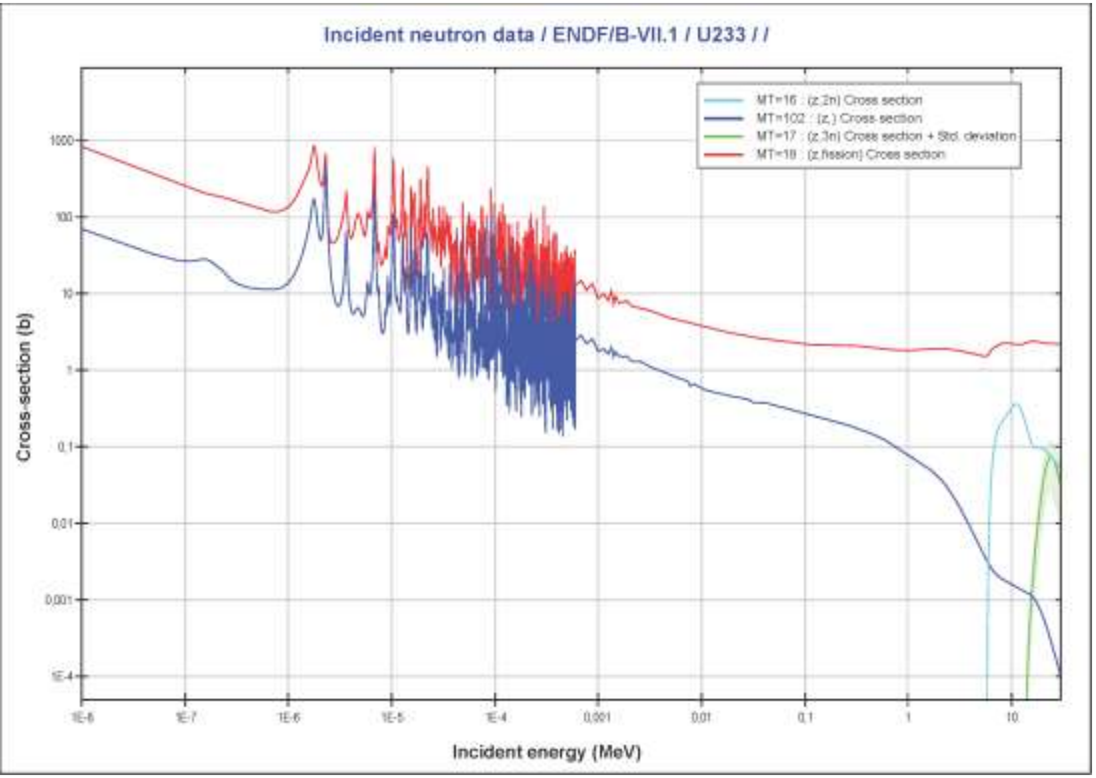


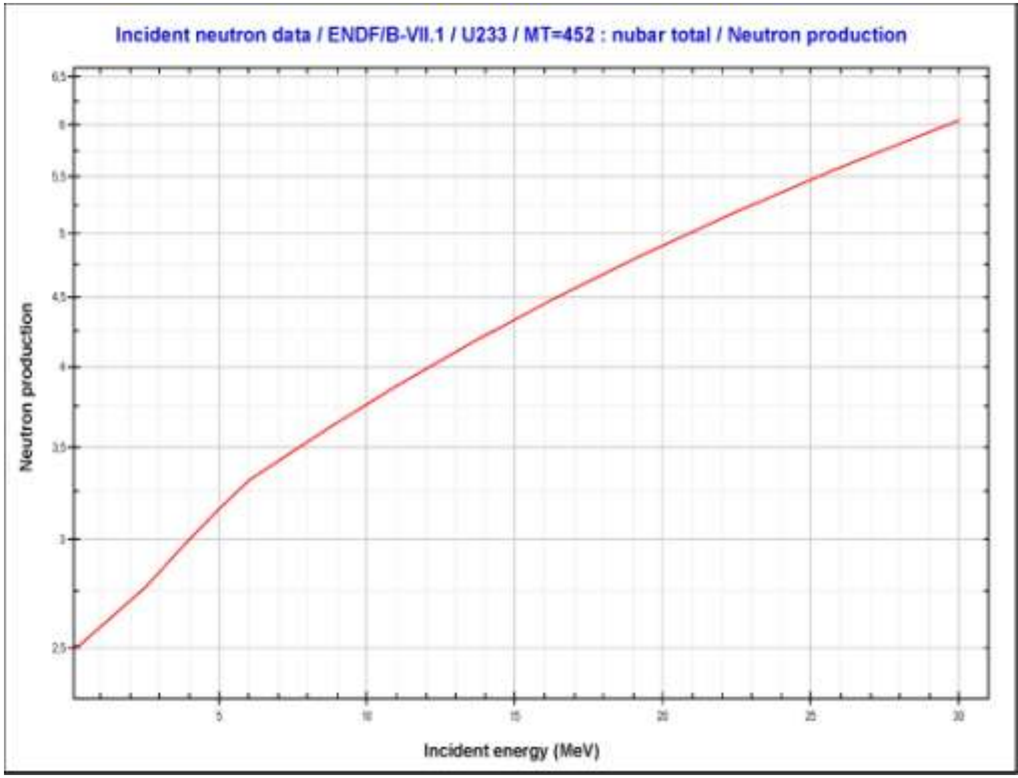
Deuteron and protons induced fission.
Cross sections for ^{235}U and ^{238}U



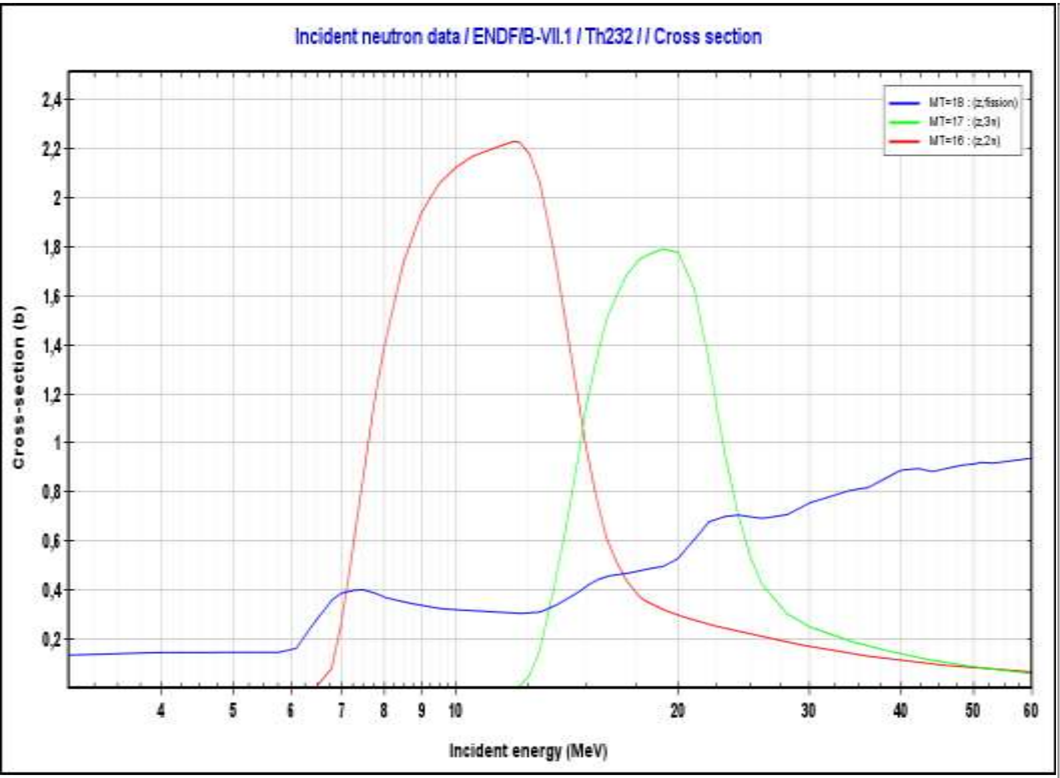


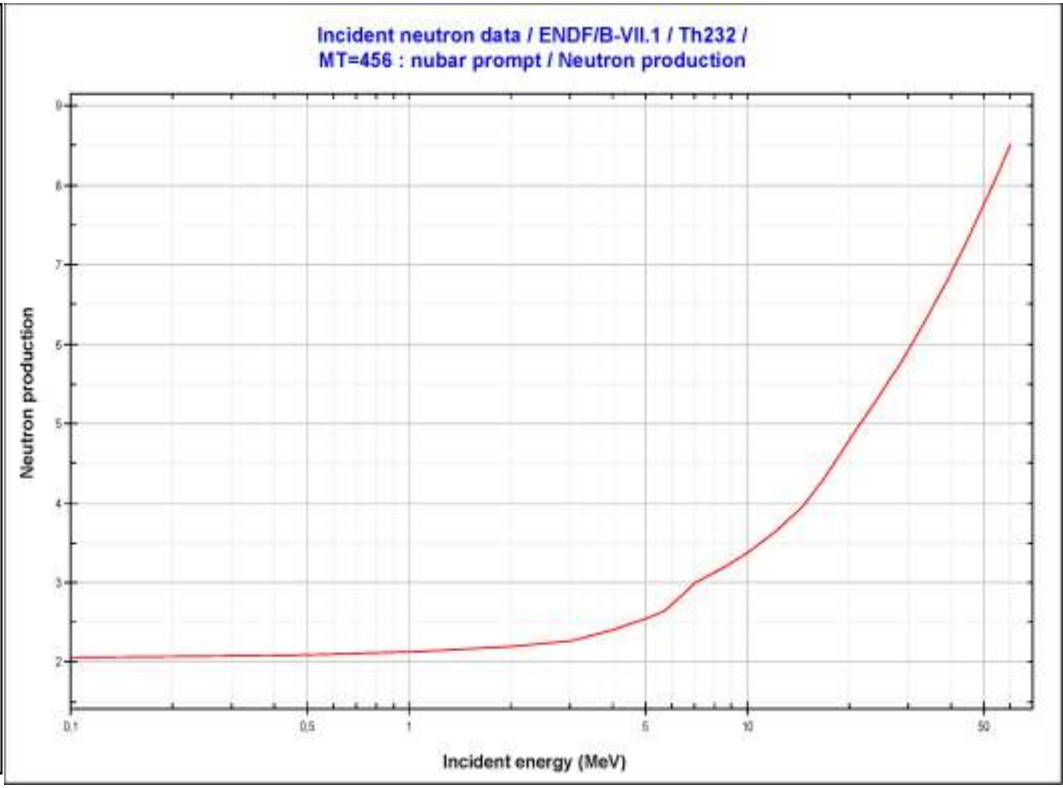
Cross sections (n,f)^{233}U and multiplicity constant



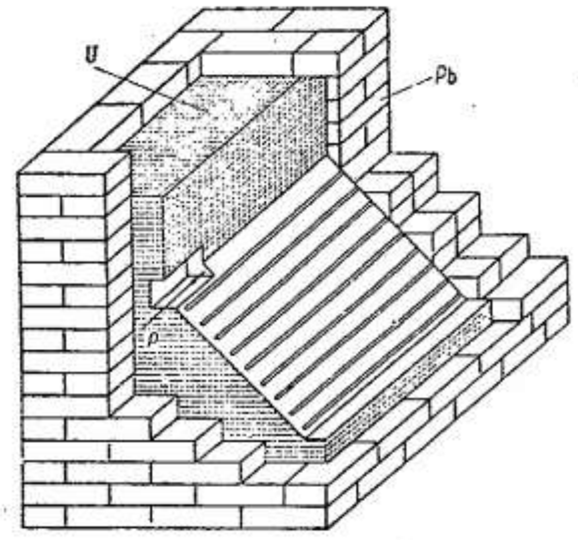


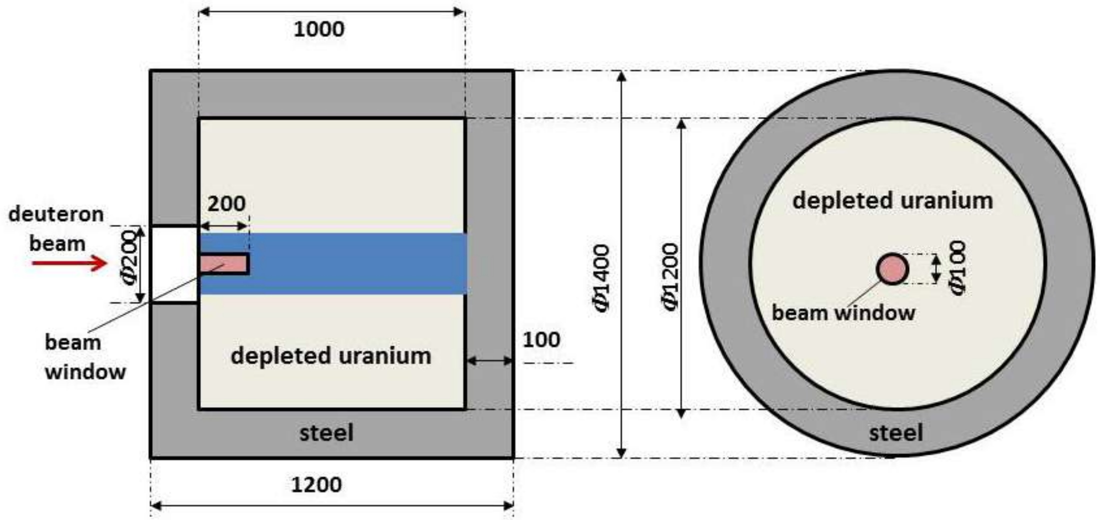
Cross sections (n,f)^{232}Th and multiplicity constant





Vassil'kov- Goldanski experiment. Buran experimental se





Target assembly of the experiment. Dimensions of uranium target 56x56x64cm, 3.5 tons. The thickness of the lead shield is 10cm.

Buran set up cross sections. It is composed of two materials: depleted uranium, 21 tons (central part D=18x80cm and the rest part) and steel container.

MCNPX calculations + est. impact of high energy neutrons, a=0.25 (5) Vasil'kov-Goldanski set-up with Buran set-up

E_d [GeV]	Vasil'kov-Goldanski set-up, ^{nat}U	Buran set-up, ^{nat}U
$N_{totmcnpx}$	69	80
$N_{tot\ est}$	114	127
Nescape	15	2
$(n,f)_{MCNPX}$	10	11
$(n,\gamma)_{MCNPX}$	32	42
$N\gamma_{tot\ est}$	66	80
$Nf_{tot\ est}$	22.3/(22exp.+-10%)	24
BPG_{est}	8	8.9

Quasi infinite-targets

all high energy particles (charged particles and neutrons) deliver their energy in the volume. The reactions rate of (n,f), capture, (n,xn) and neutron leakage are approximately constant with the increase of the target volume

Quasi targets

The high energy neutrons induced reactions turn approximately constant, but the radiation capture and neutron leakage are still increasing and decreasing respectively with the increase of the target volume

Calculation of (n,f), $(n,\gamma)^{depl}U$ reactions for Buran set up. The average multiplicity for incident neutrons with energies up to E_n<20 MeV is $<\mu>=3.2$ neutrons, for E_n>20MeV is <m>=8.5 neutrons and for charged particles induced fission is $<\mu>=10$ neutrons. The leakage of the neutrons is about 5-10 %

1	E_d [GeV]	1	2	4	6	12
2	MCNPX calculations					
3	N_{tot}	129	288	567	823	1536
4	$N_{\gamma\, tot}$	73	164	325	473	883
5	$N_{f\, tot}$, E_n<20MeV	15.3	34.5	68	98	184
6	$N_{f\, tot}$, total E_n spectrum	18.9	42.7	84	122	227
7	$N_f(p+d+\pi+\gamma,f)^{235,238}U$	1.2	2	2.3	5	9.7
8	BPG_{MCNPX}	6.15	6.26	5.7	5.54	5.14
9	MCNPX calculations + estimated impact of high energy neutrons					
10	$N_{tot\, est}$	200	450	884	1297	2386
11	$N_{\gamma\, tot\, est}$	123	276	545	803	1472
12	$N_{f\, tot\, est}$	37	83	163	216	439
13	BPG	9.4	10.3	9.8	8.9	8.8

CONCLUSIONS

1. Quasi-infinite target for targets of ^{238}U and ^{232}Th for E_d=8GeV are:
   uranium cylinder D=120cm, L=80cm
   thorium cylinder D=200 cm, L=160.cm

2. Vasil'kov-Goldanski set up is a not quasi-infinite targets for Ep=660MeV

3. Buran set-up can by assumed to be a quasi-infinite target for deuteron beam with energy up to Ed=8GeV (MCNPX calculations)

4. Up to now there have been no experiments with quasi-infinite spallation targets made of (Pb, W, Bi) or fission nuclides, irradiated by relativistic particles.