High energy particles leakage from massive spallation targets

P.Zhivkov, N. Gutev, Ch. Stoyanov

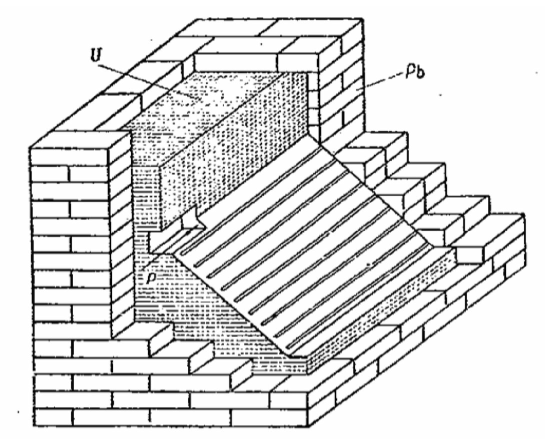
Institute of Nuclear Research and Nuclear Investigations, Bulgarian Academy of Science, Bulgaria

Aim of the work: 1. Simulations of the high energy charged particles and neutron leakage from Dubna Vassilkov-Goldanski, a big U/Pb, natPb, Quinta and Buran experimental set ups.
2. Optimization of experiments with massive spallation targets

Introduction of the topic and the problem.

Irradiation of the heavy targets made by natU, lead, bismuth thorium by high energy beams can generate particles with different energies. The charged particles deposit approximately 1/3 from their energy as ionization losses and the rest by nuclear interactions such as; spallation, (n,xn) or fission reactions. The uranium has spatial properties compared to lead, bismuth and thorium. The fission neutrons have probability to initiate fission (chain reaction) and neutron multiplicity is a function of the incident neutrons. The same is for charged particle induced fission, i.e. multiplicity is a function of the incident particle energy. Those features are key points for neutron generation in the uranium target volume. In case of lead target irradiated by proton beam Ep=660 MeV (lead target d=20, l=60cm or Pb/U set up) the charged particles deliver their energy in the lead. The main reactions in the lead target are spallation, (n,xn) and fission, the neutron multiplicity is one and there is no chain reaction. The leakage of high energy neutrons and energy leakage are negligible.

Vassilkov-Goldanski set up uranium target with dimensions 56x56x64см, paced in ^{nat}Pb cage with 10 cm thickness of the walls, irradiated by E_p=660 MeV и E_p=330 MeV

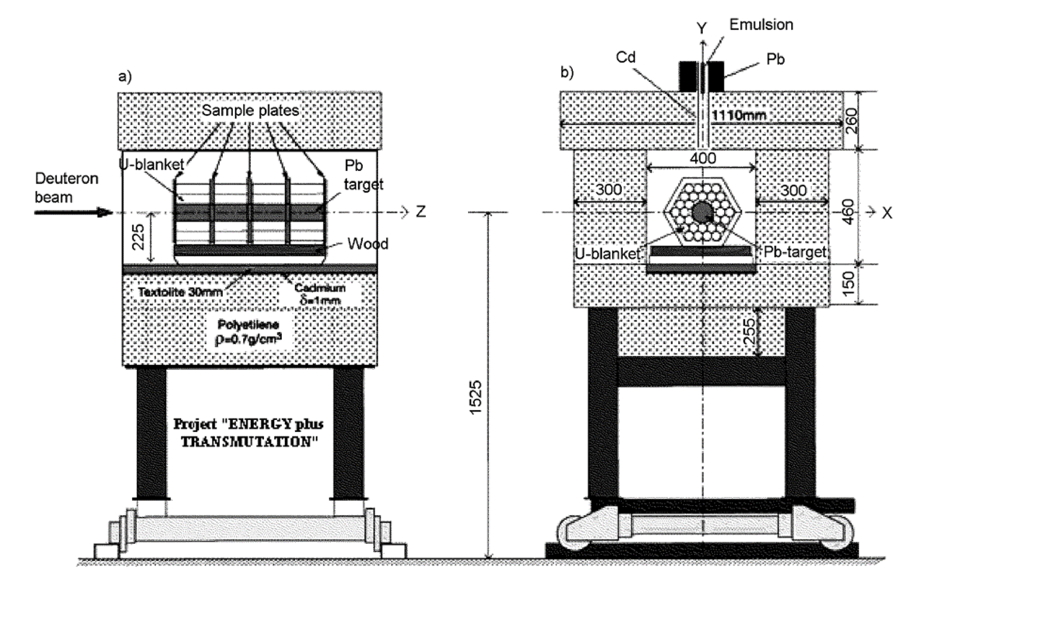


Kexp=E_fiss/E_p=7, Ep=660MeV, natU

Kcalc=E_fiss/Ep =3.3,

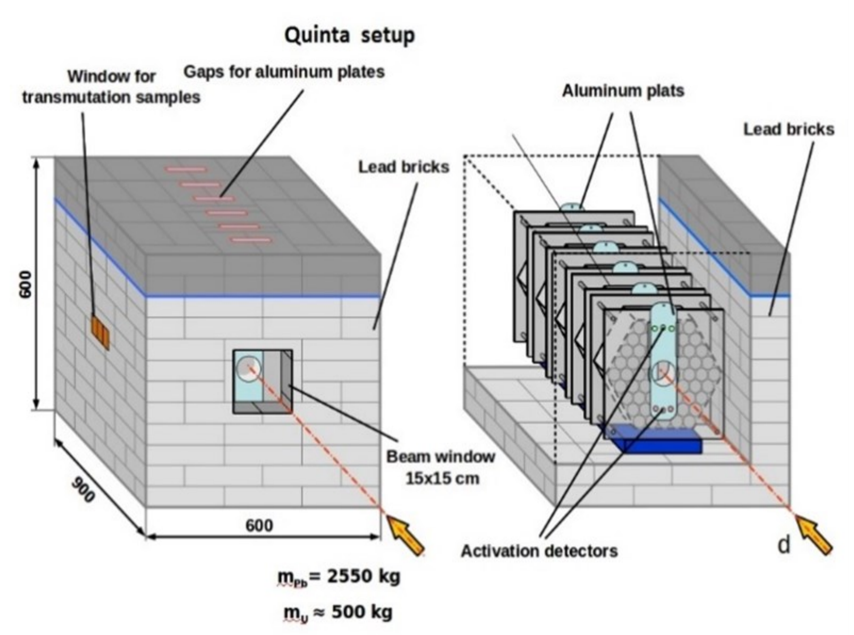
Multiplication of neutrons in uranium irradiated by protons with eneegy 300-660 MeV, Atomic energy, 44, (1978) 329 (in Russian)

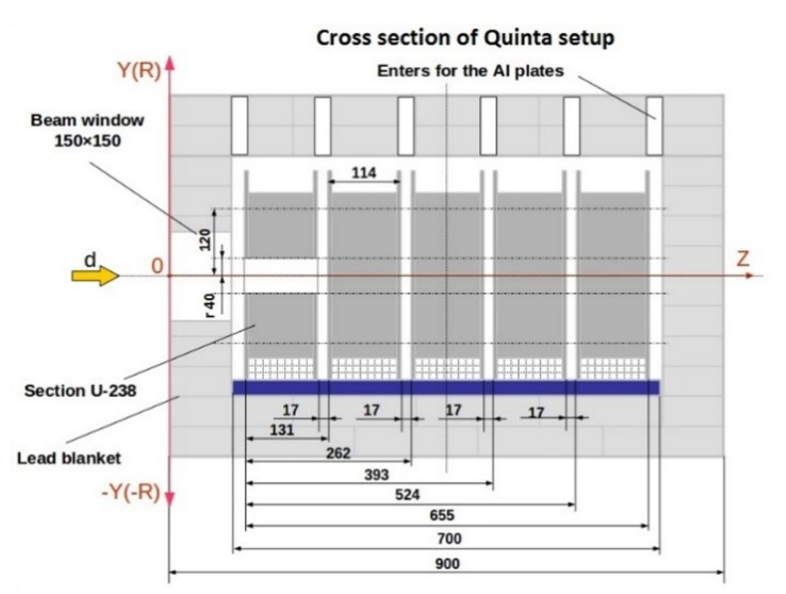
Experimental set up U/Pb set up



First results studying the transmutation of ^{129}I, ^{237}Np, ^{238}Pu, and ^{239}Pu in the irradiation of an extended ^{nat}U/Pb-assembly with 2.52 GeV deuterons. Journal of Radioanalytical and Nuclear Chemistry 279(2):567

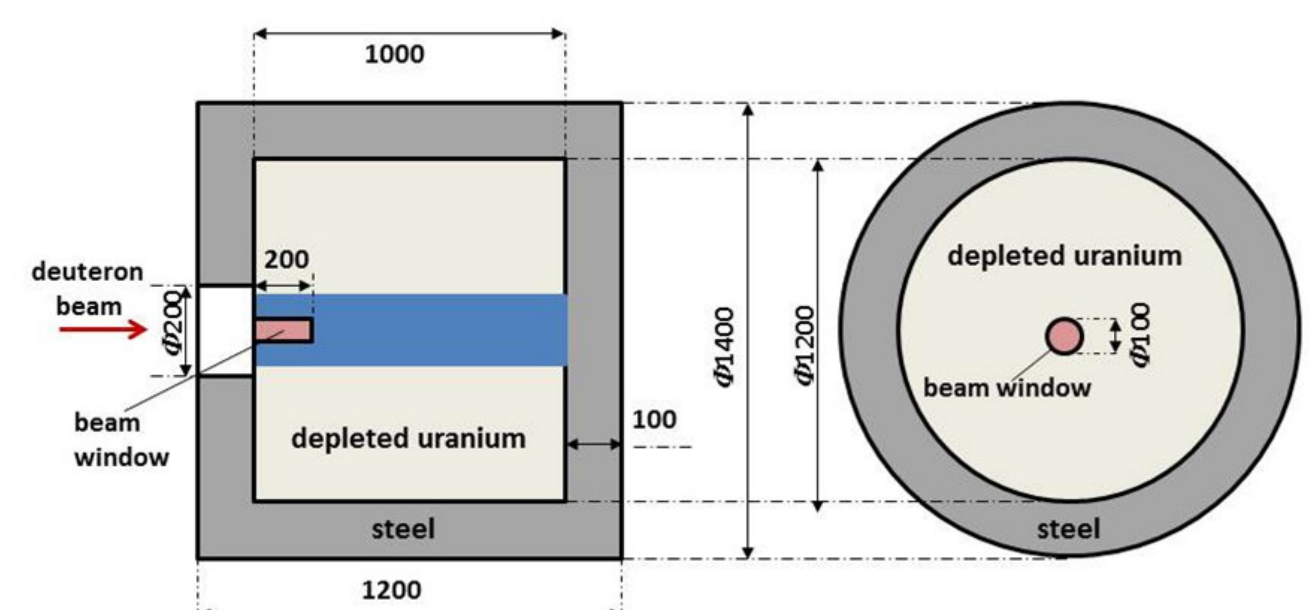
Quinta set up irradiate by deuterons with energies Ed=1-8 GeV



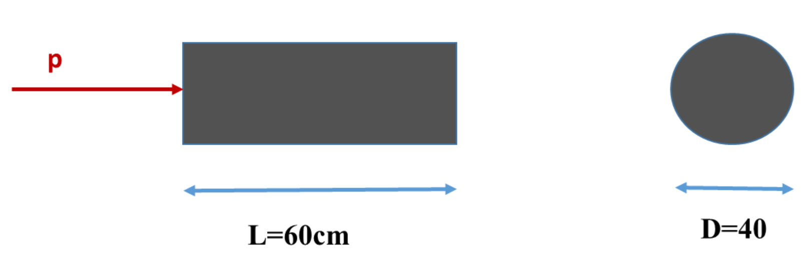


Comptes rendus de l'Acad_emie bulgare des Sciences Tome 70, No 6, 2017

Buran set up 21 tons of depleted uranium packed in steel cage irradiated by proton beam Ep=660MeV. The central (target) part can be use lead, uranium, coper, bismuth or composite materials.

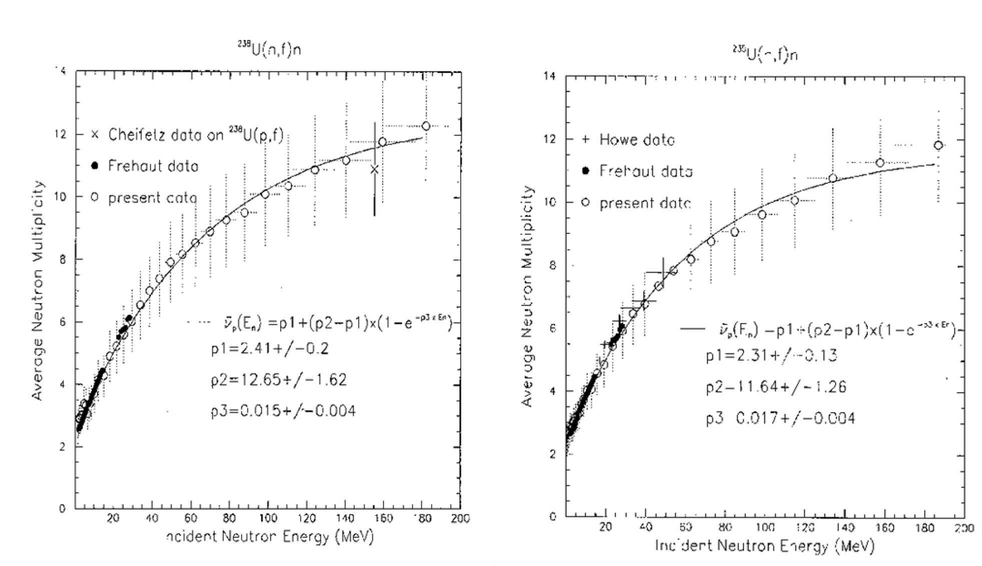


Natural lead target L=60cm, diameter D=40 cm irradiated by relativistic protons up to 3.5 GeV



Образование нейтронов при взаимодействии релятивист- ских протонов и дейтонов со свинцовыми мишенями. Р1-2005-79.

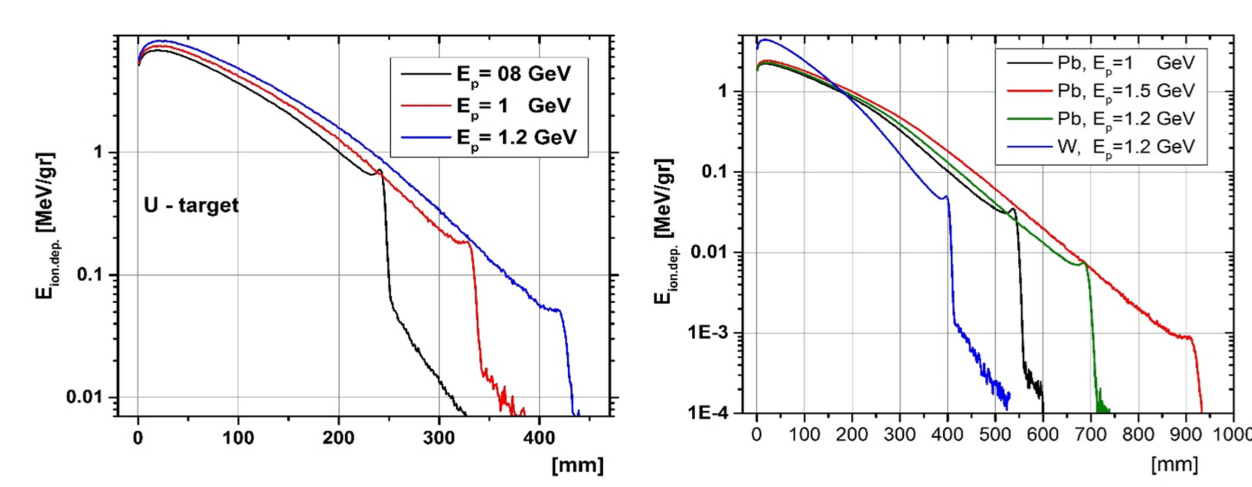
Neutron multiplicity for 235U and 238U. Increasing of the incident neutron the number of fission neutrons increase too.



Measurement of the Average Multiplicity of Prompt-Fission Neutrons from U (n, f) and U (n, f) from 0.7 to 200 MeV, AIP Conference Proceedings 769(1):656 · May 2005

Charged particles leakage from different targets

Ionization energy deposition of ion beam in different targets



Measurement of the Average Multiplicity of Prompt-Fission Neutrons from U (n, f) and U (n, f) from 0.7 to 200 MeV, AIP Conference Proceedings 769(1):656 · May 2005

Neutron leakage and energy losses from Quinta set up for deuteron and carbon beams

Neutron leakage and energy losses from Quinta set up for deuteron and carbon beams

GeV	E_d=1	E_d=2	E_d=4	E_d=8	E_c=24	E_c=48
N_{escape}	51	101	160	315	690	1430
E_{kin} [MeV]	95	230	500	941	1760	4040
$N_{(En>1.4MeV)}$/(MeV)	6.7(76)	14(190)	25(435)	46 (820)	100(1500)	210(3500)
$N_{(En>30MeV)}$ /(MeV)	0.5(53)	1.2(142)	2.3(345)	4 (650)	8(1140)	18(2740)

$N_{(En>30MeV)}/N_{esc.}$ = 0.01 - 0.013
$E_{kin}/E_{kin.esc.}$= 0.55 (E_d=1GeV) and 0.7 E_d=8 GeV

$N_{(En>1.4MeV)}/N_{esc.}$ = 0.13
$E_{kin}/E_{kin.esc.}$= 0.8 - 0.85

1% of neutrons with energy En>30MeV have 0.5 – 0.7 from total neutron leakage energy.
The high energy neutron leakage is negligible but the energy leakage is significant

The influence and importance of the spallation reactions, charged particles induced fission, high energy neutron fission and neutron multiplicity can be observed, if all high energy particles deliver their energy in uranium volume. The lead can be used as a neutron moderator/reflector and radiation protection shield, but not in the target zone.

The big U/Pb and Quinta are completely different experimental set ups, because in the big U/Pb the beam delivers its energy in the lead volume with significant high energy particle leakage. The polyethylene plays a role as a radiation protection shield. In Quint set up the beam delivers its energy in uranium volume and the lead box plays the role of reflector and radiation protection shield.

If the Buran set up with uranium target zone is irradiated by proton beam with energy Ep=660 MeV the experimental results must be very close to those measured in Vassilkov-Goldansy (V-G) set up, where all high energy particles deliver their energy in the uranium volume. The experimental and calculation comparison for V-G set up shows significant disagreement, almost two times, which is unexplainable.

If the Buran target zone is natPb, then the charged particles and spallation neutrons will deliver their energy in lead. In the uranium medium will be irradiated by neutrons with energy less than 20 MeV and neutrons with higher energy will be negligible. Such experiments will be similar, if in the target volume is placed standard neutron source.

Conclusions

1. The preliminary calculations of neutron energy distribution in different set up is necessary for planning of the activation detectors positions.
2. The other important part for experimental planning is to find out the answer of the question: What will improve understanding of the high energy neutron generation in the natU and natPb targets and nuclear reactions induced in them? The V-G experiment is unique and it is never repeated. All experimental set ups have significant neutron and energy leakage.
3. Buran experimental set up with a uranium core has the possibility to investigate neutron and charged particles induced reactions in case of total high energy particle deposition.