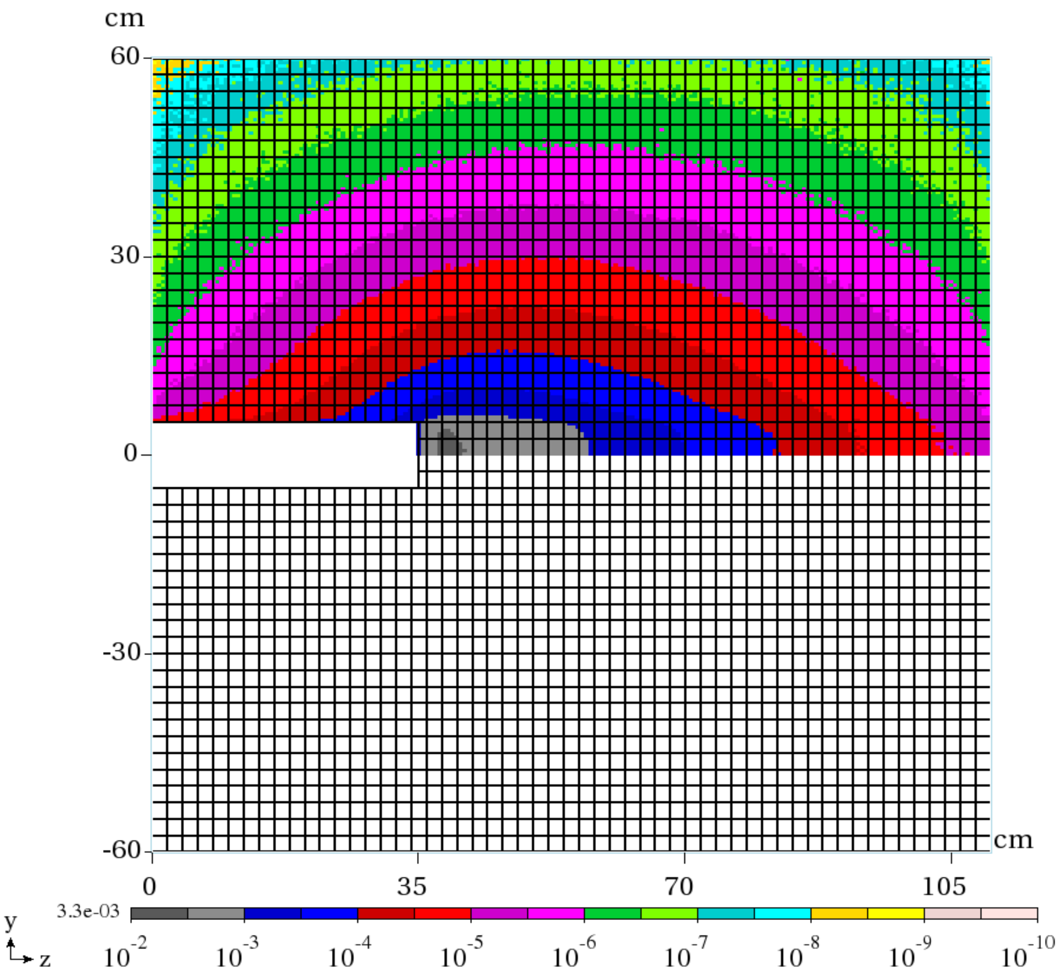
MARS15 study of the Energy Production Demonstrator Model for Megawatt proton beams in the 0.5 – 120 GeV energy range

V. S. Pronskikh, N.V. Mokhov, I. Novitski, S.I. Tyutyunnikov

21 May 2014

High Power Targetry Workshop HPT5, Fermilab

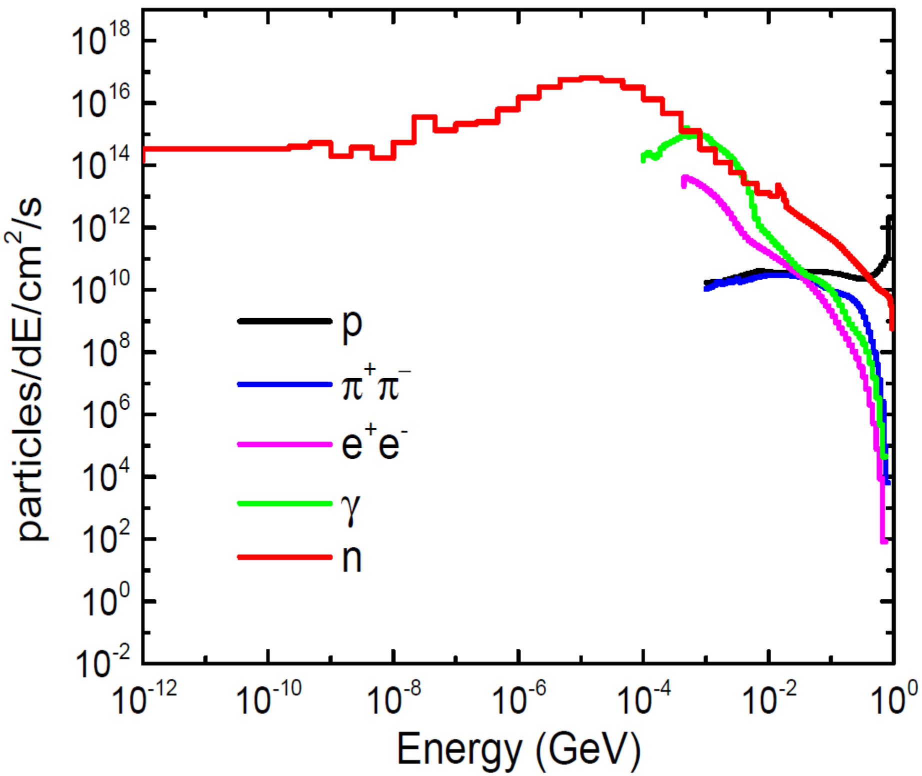
Energy Production Demonstrator MARS15 Model

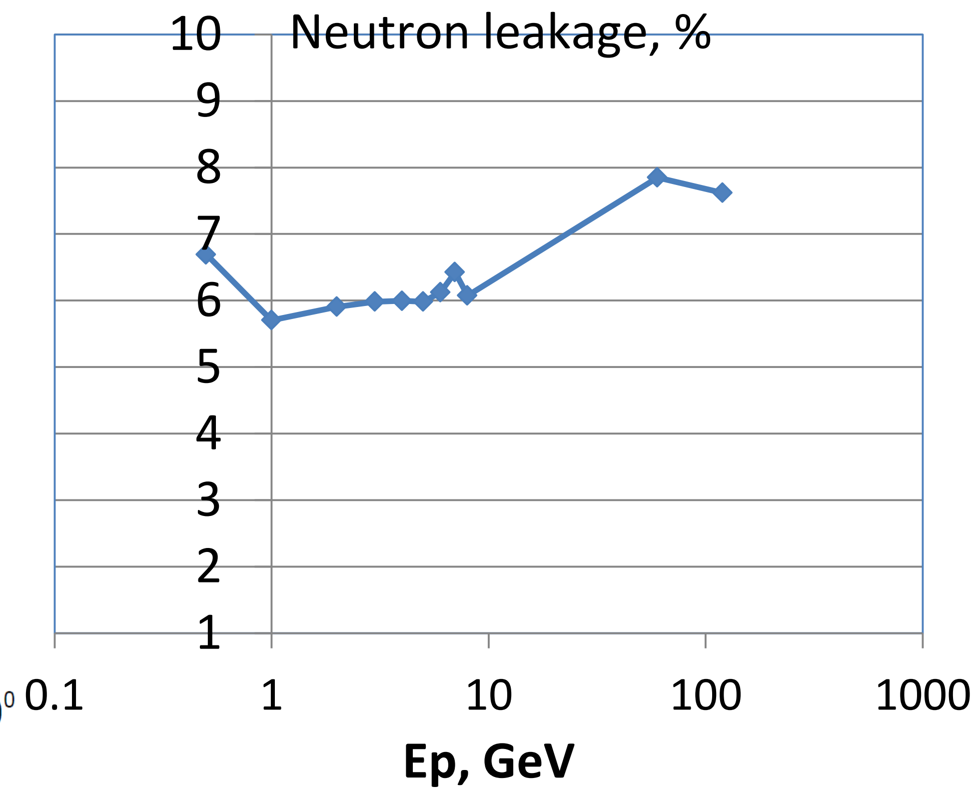


U-nat, 3 GeV, Energy deposition, GeV/p/cm^3

- Solid targets
- R= 60 cm; L= 110 cm
- R_{beam}=5 cm
- Optimal dimensions for neutron leakage minimization
- W, Th, U-nat targets
- Energy Production/Materials Testing
- LAQGSM/CEM generators were used

Secondary particle spectra in the target



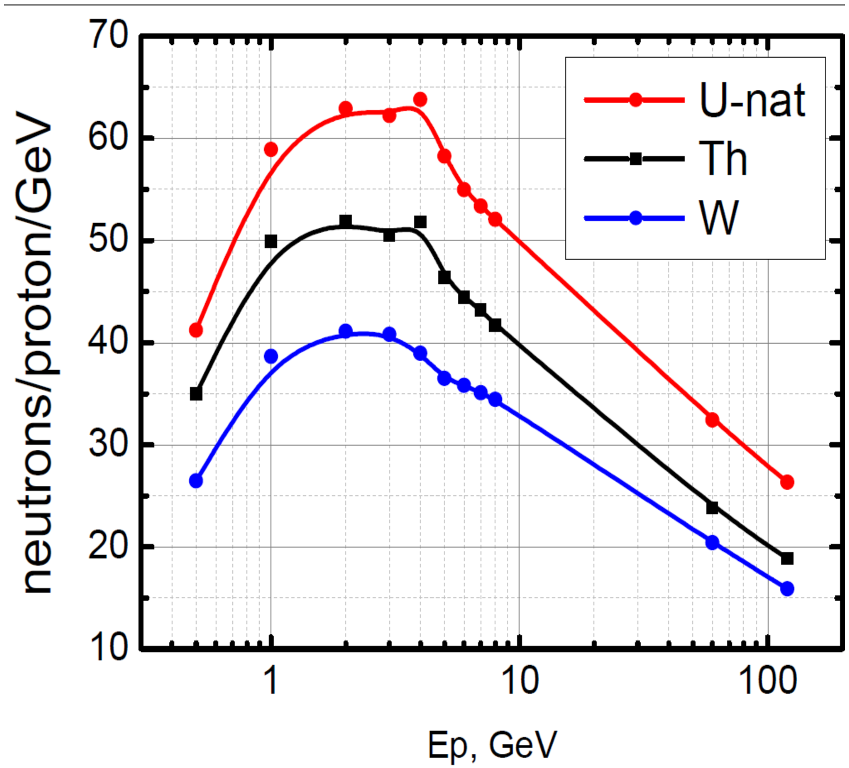


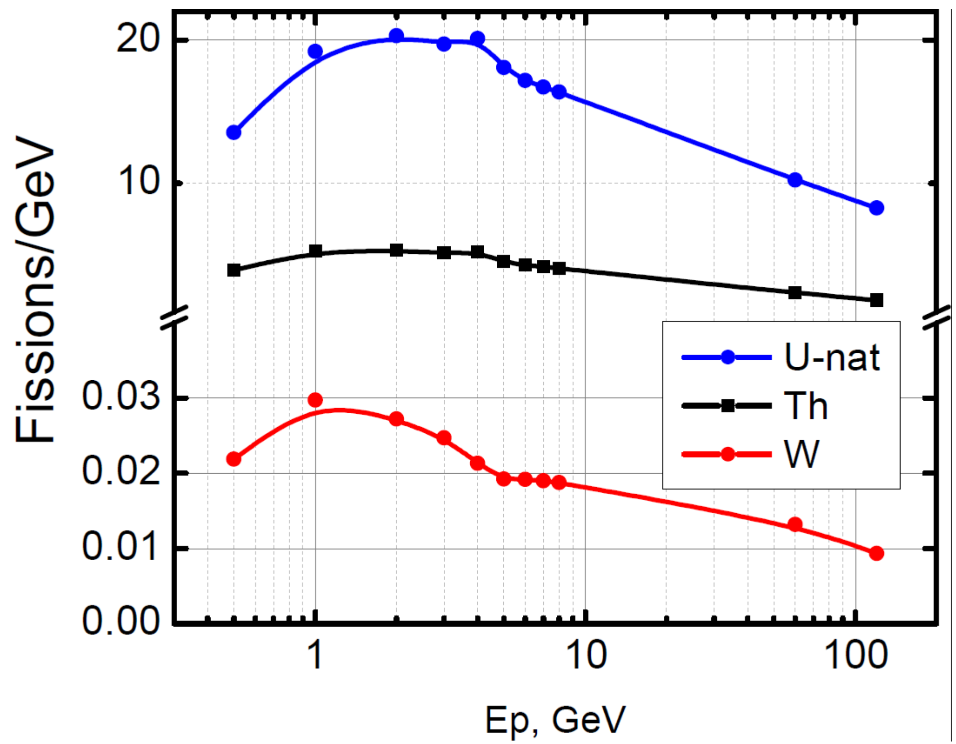
- Spectra for W target
- En> 0.001 eV
- Thresholds: 100 keV (photons, e+e-), 1 MeV (pions)

Neutron leakage per neutrons produced (U target)

No significant growth

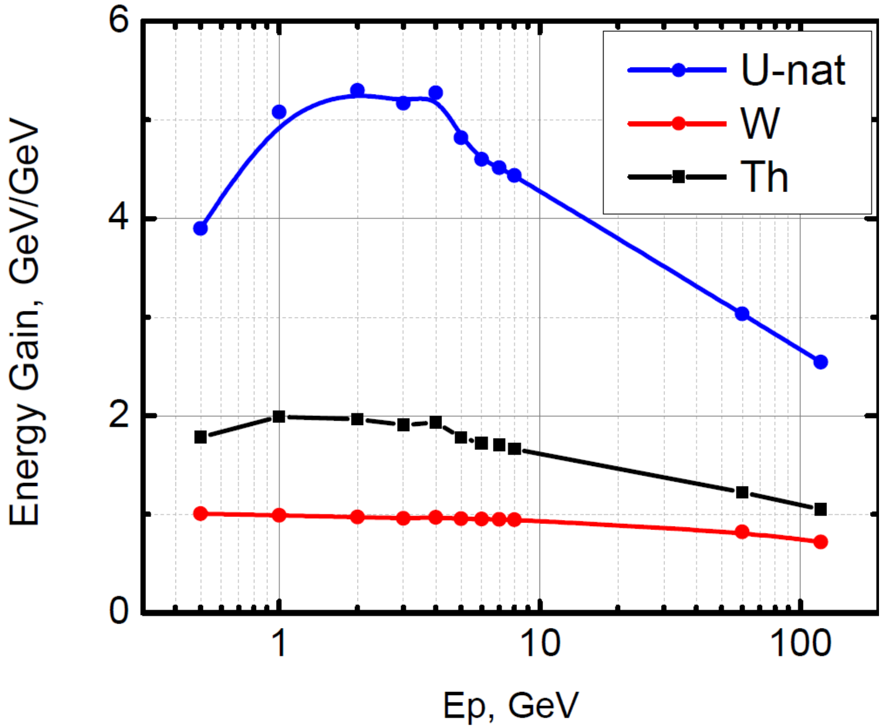
Neutron production in EPD

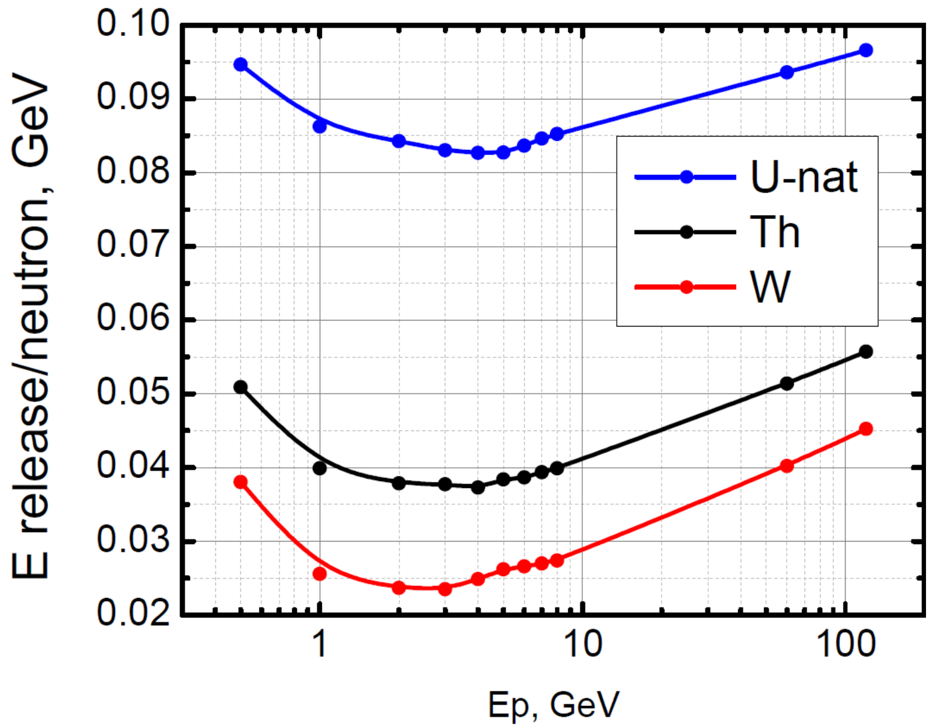




Fission in all target materials is taken into account
2-4 GeV is optimal for neutron production
Large fission contribution in Th and, especially, U.

Energy deposition in EPD

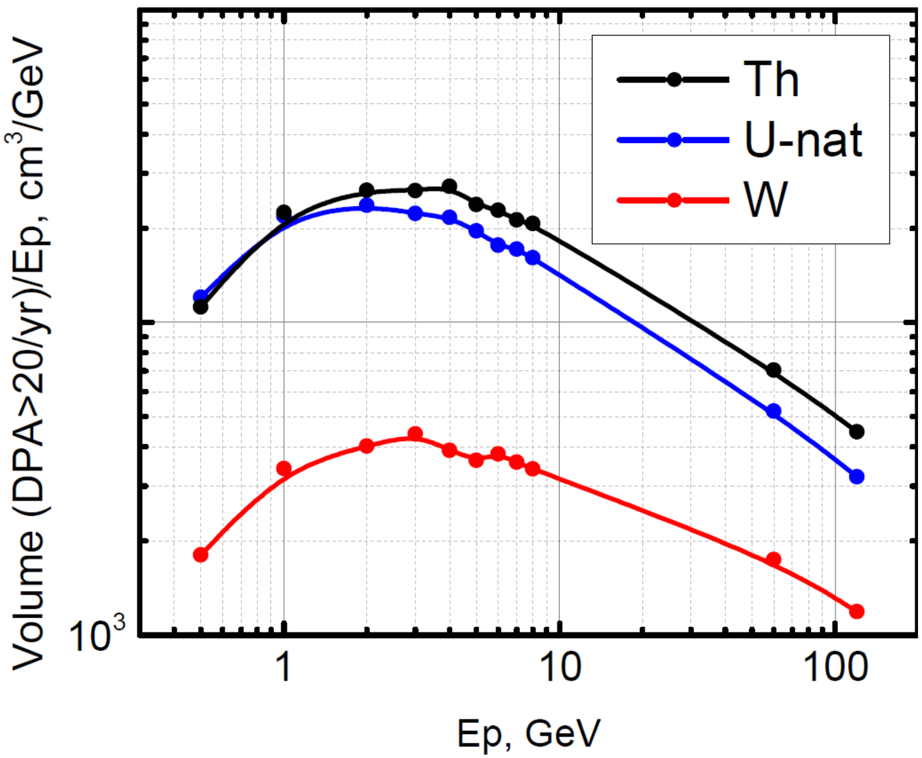


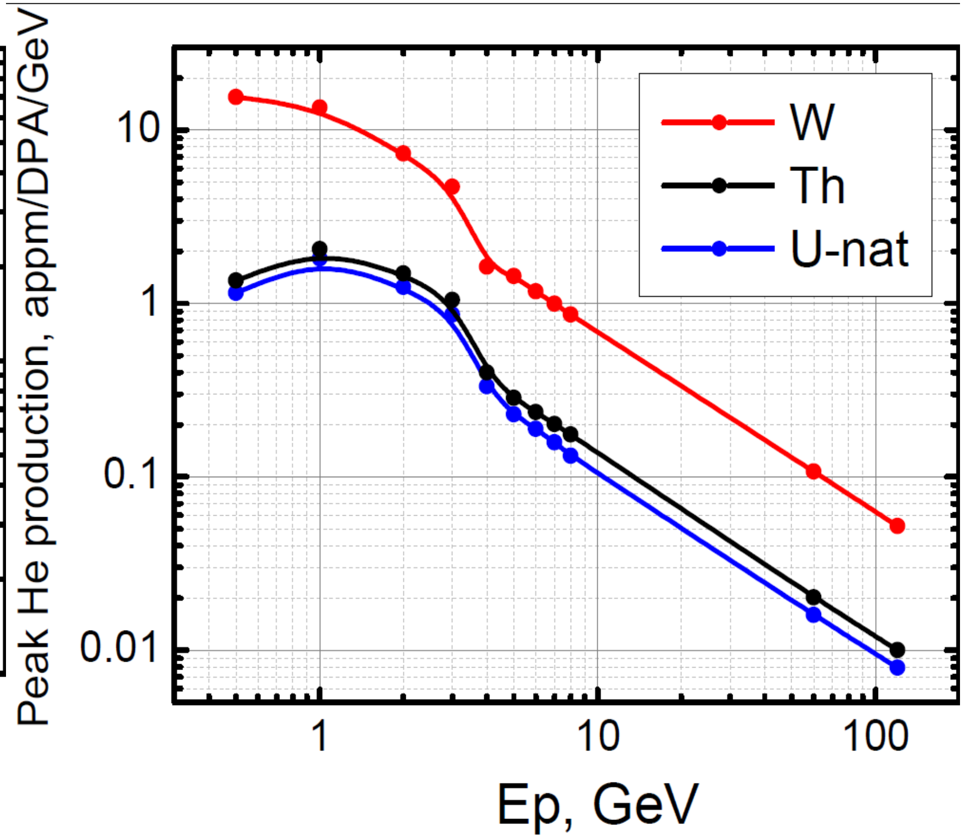


Energy gain (amplification)=Ereleased/Ep
Only U has a maximum
The maximum is at 1(2) – 4 GeV

Energy released per neutron has a minimum at 2-4 GeV

DPA and He production in EPD

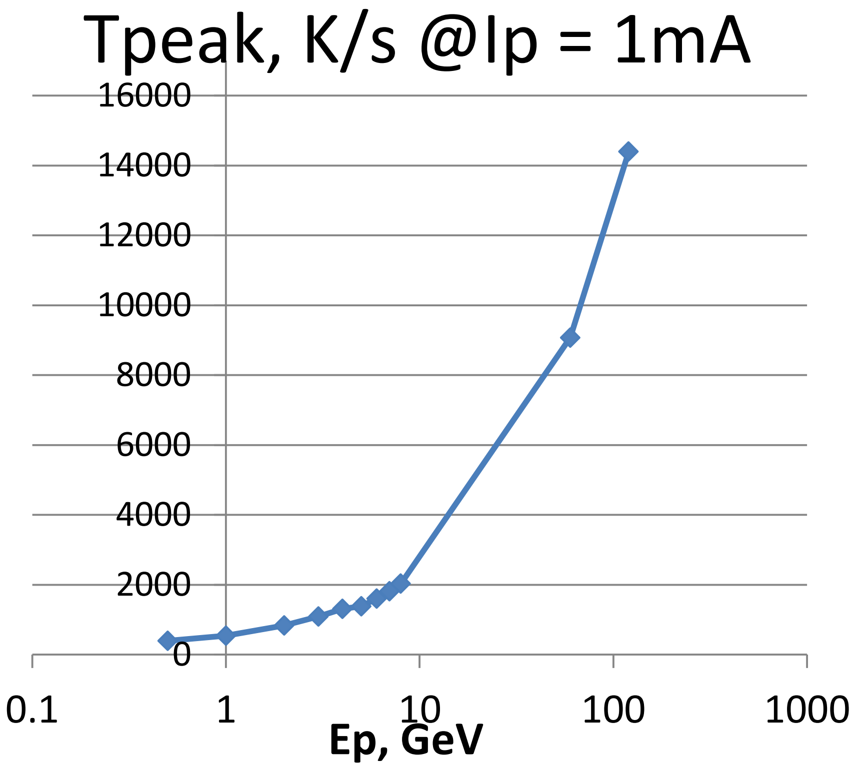


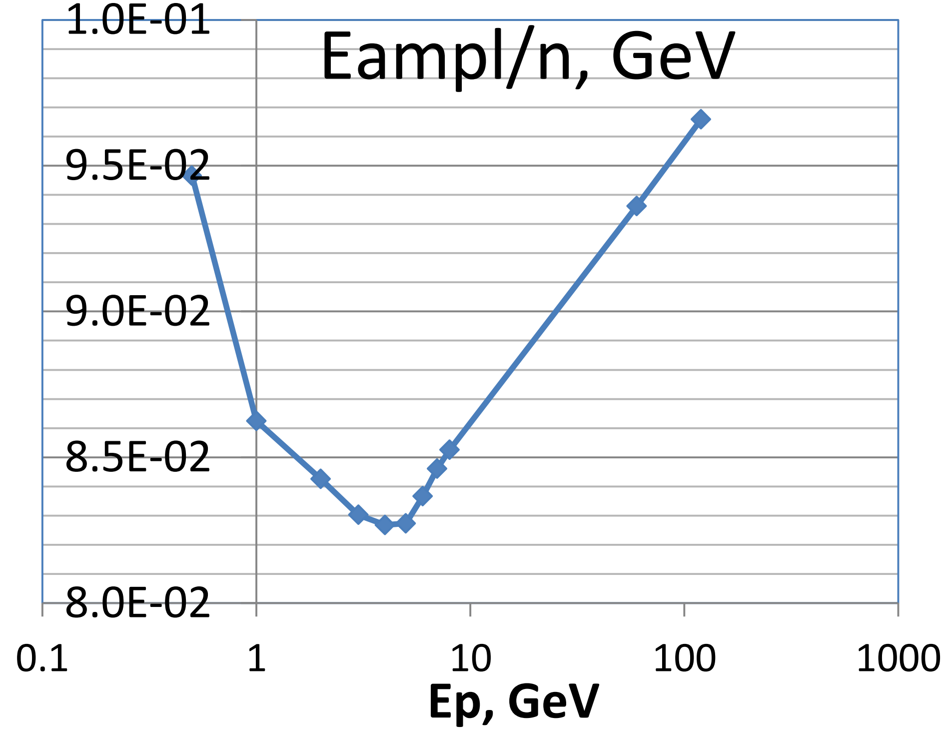


U-nat and Th have highest DPA testing volumes (DPA>20 yr) per GeV (28 liters for Th and 4 liters for W) (peak is again at 2-4 GeV)

He (and other gases) production drops per GeV with energy (for U-nat and Th above 4 GeV)

Peak temperature and energy multiplication per neutron (U-nat)

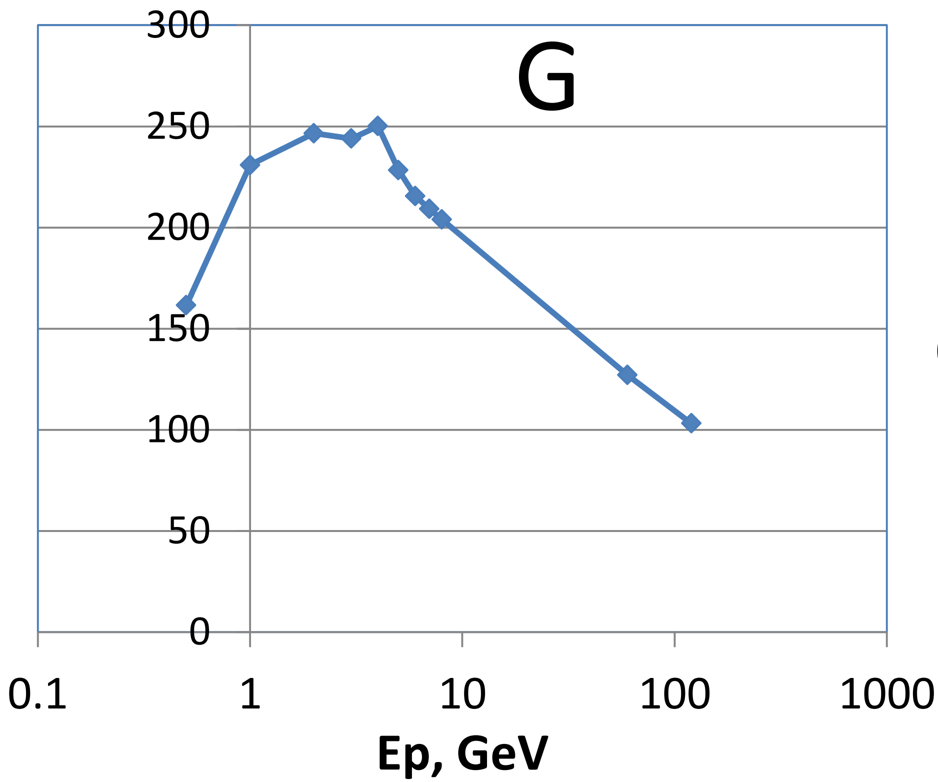


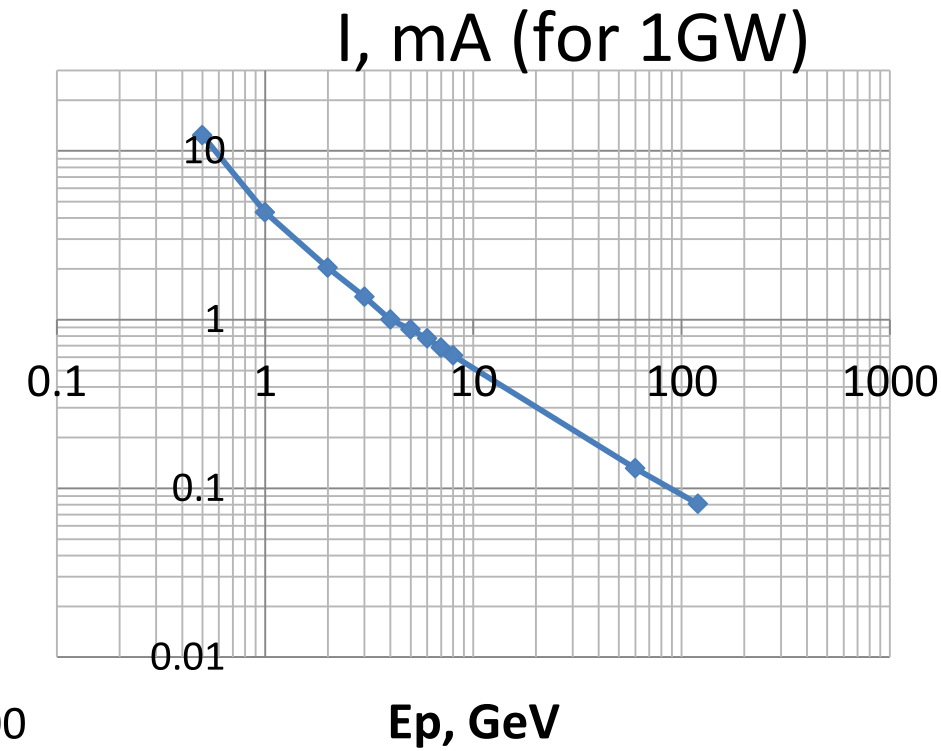


Local temperature peak grows rapidly > 10 GeV (flat per MW)

Energy amplification is minimal per neutron at 2-4 GeV (10% difference)

Energy gain G and beam current for 1 GW thermal output power



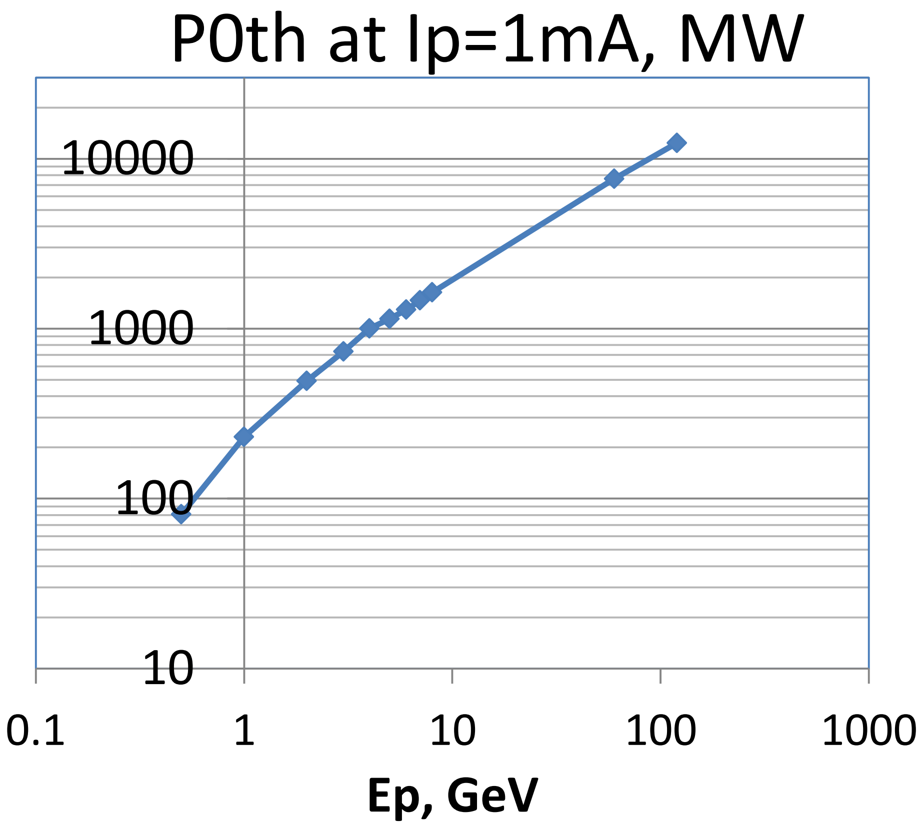


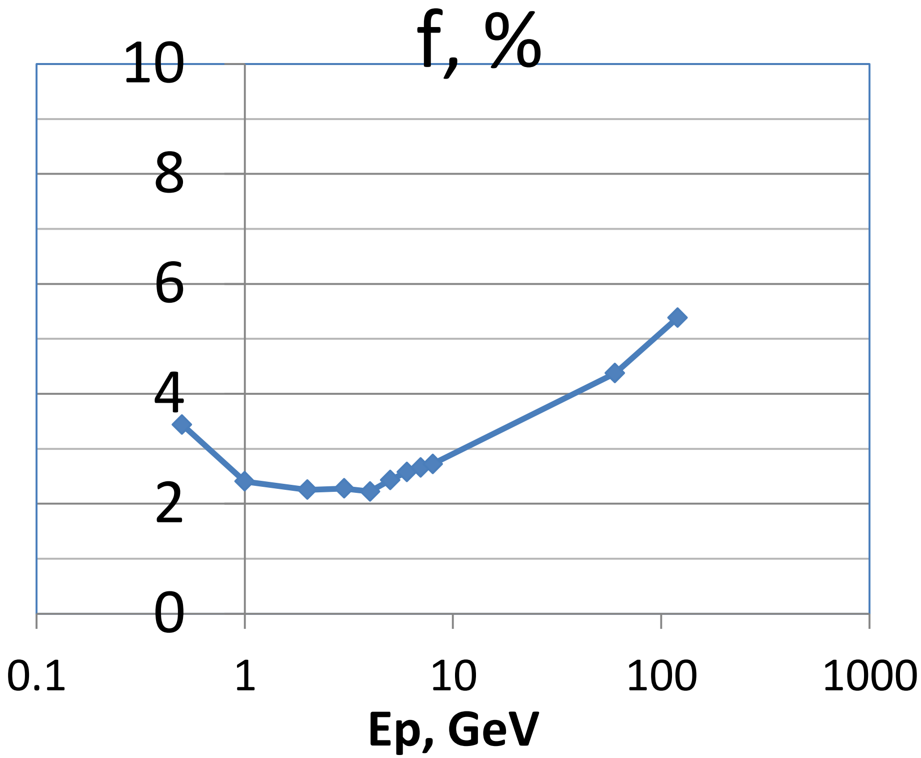
$$G = \chi_s \cdot \frac{\varphi^* k_{eff}}{\nu(1 - k_{eff})} \cdot E_f$$

χ_s - number of neutrons per GeV (here – produced), k_{eff} = 0.98; φ* - neutron importance =1; ν=2.5 (neutrons per fission), E_f – fission energy, 0.2 GeV;

P0th = I*E*G (thermal output power)

Thermal output power at Ip= 1mA and output power fraction to operate accelerator

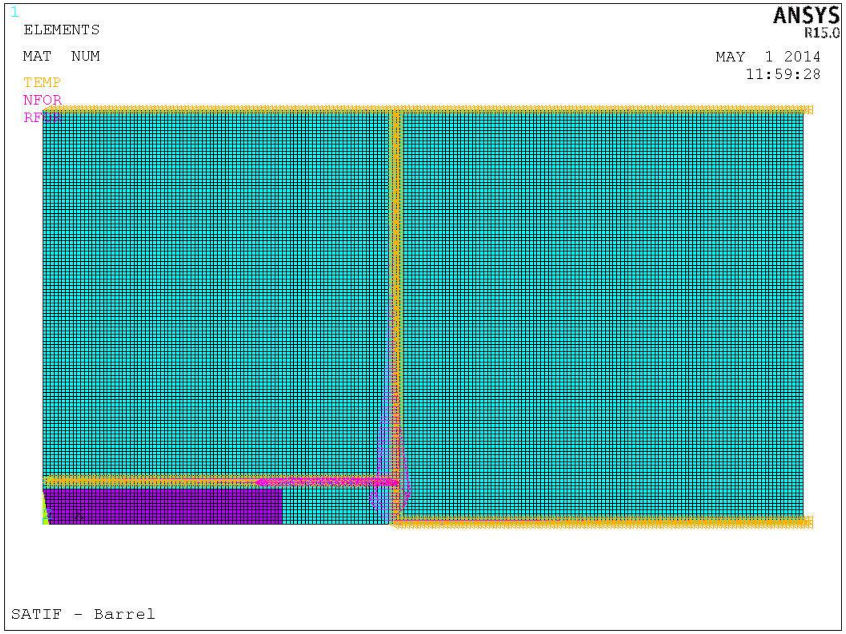


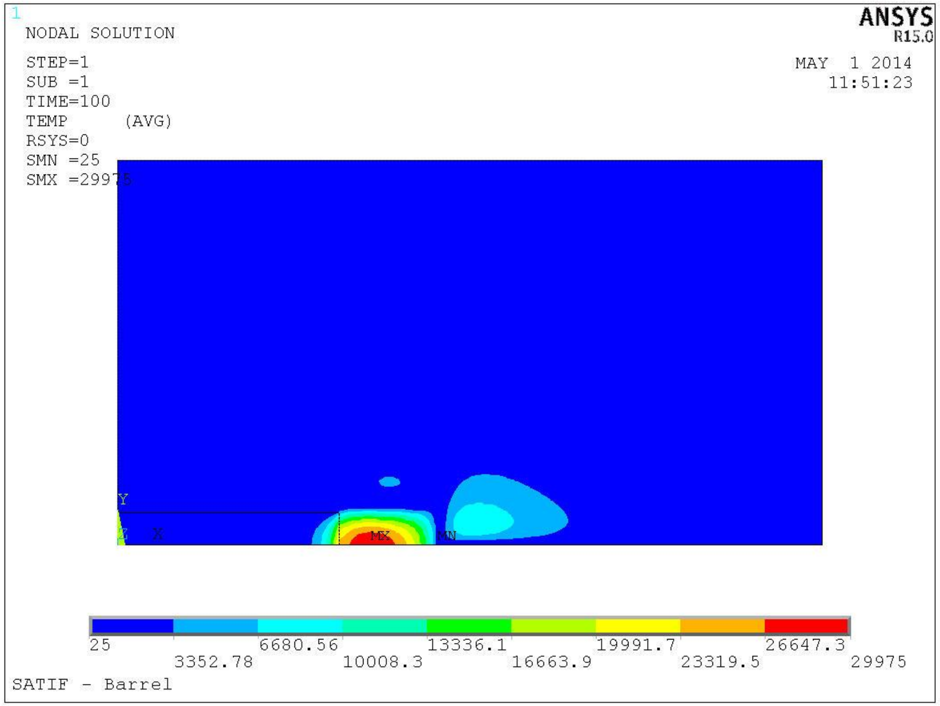


f=1/(G*ε*η), ε – electric to beam power conversion efficiency, 0.4;

η – thermal to electric power conversion efficiency, 0.45;

Thermal analysis. R=5 cm beam



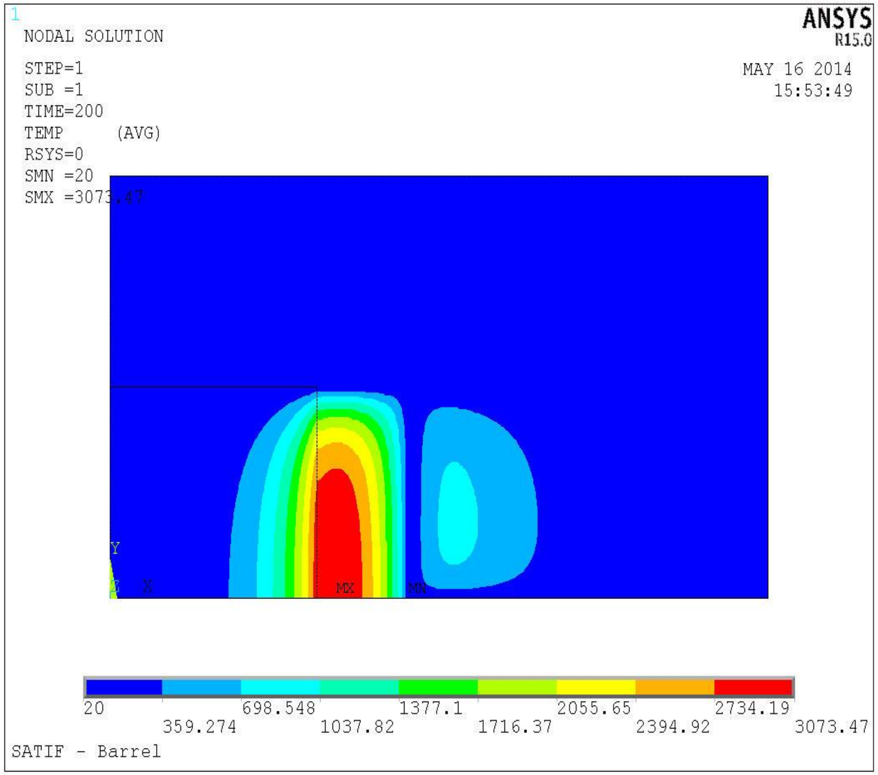


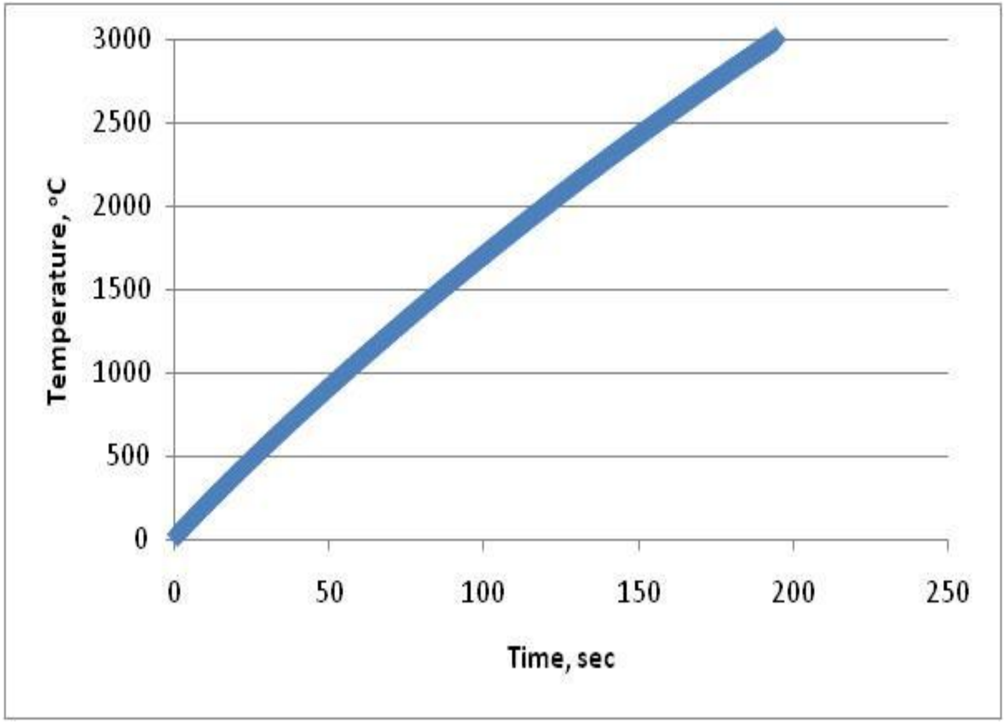
Simplest cooling scheme (yellow – water lines with T=20C.

Ep= 3 GeV; Ip= 0.5 mA (3.1E15 p/s); bunch duration=4E-11 s; between bunches=6.08E-8

Temperature rise is ~ 30000 C for 100 s.

Thermal analysis. R=30 cm beam





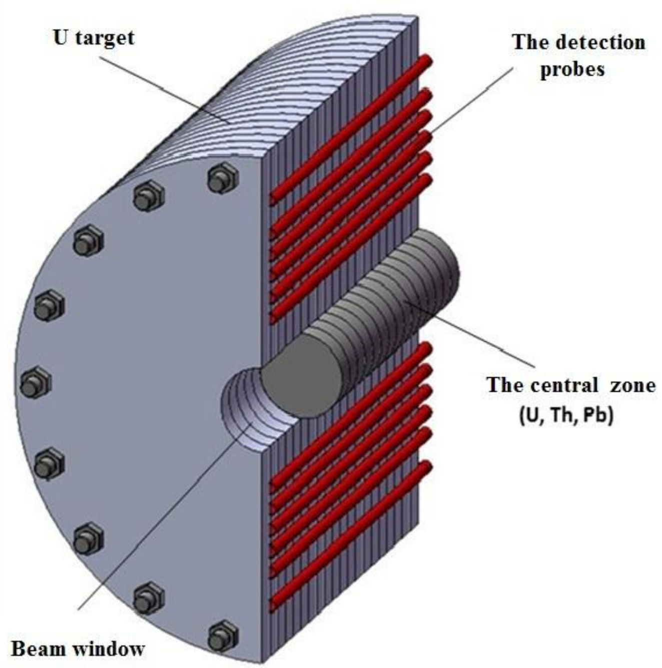
Rastered beam. During 200 s T peak reaches 3000 C

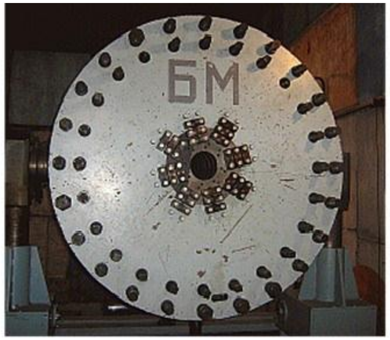
Dropped by a factor of ~ due to rastering.

Still unacceptable.

Possibilities: more rastering, scanning, more cooling lines.

Benchmark possibilities





Back view

A prototype U-nat target was build at JINR (Dubna) (~20 years ago).

21 tonnes in weight.

D=120 cm, L = 100 cm

Exchangeable cores.

Only low-intensity (nA) beams exist. Neutron flux distribution and isotope production are possible to measure.

Summary

- U, Th, and W targets have been studied as Energy Production and material testing options (neutron leakage ~ 6-8%).
- The 2-4 GeV energy range was found to be optimal for both material testing and energy production
- In that range the target undergoes the highest radiation damage and gas production (largest testing volume)
- The U-nat target can produce 1 GW thermal output power at a 1-2 mA 2-4 GeV proton beam
- The peak temperature is too high but there are ways to mitigate it (rastered beam, beam scan, more cooling lines, longer bunches)
- A prototype target can be used for model benchmarks.