Energy Production Demonstrator Model for the GeV-range Megawatt proton beams

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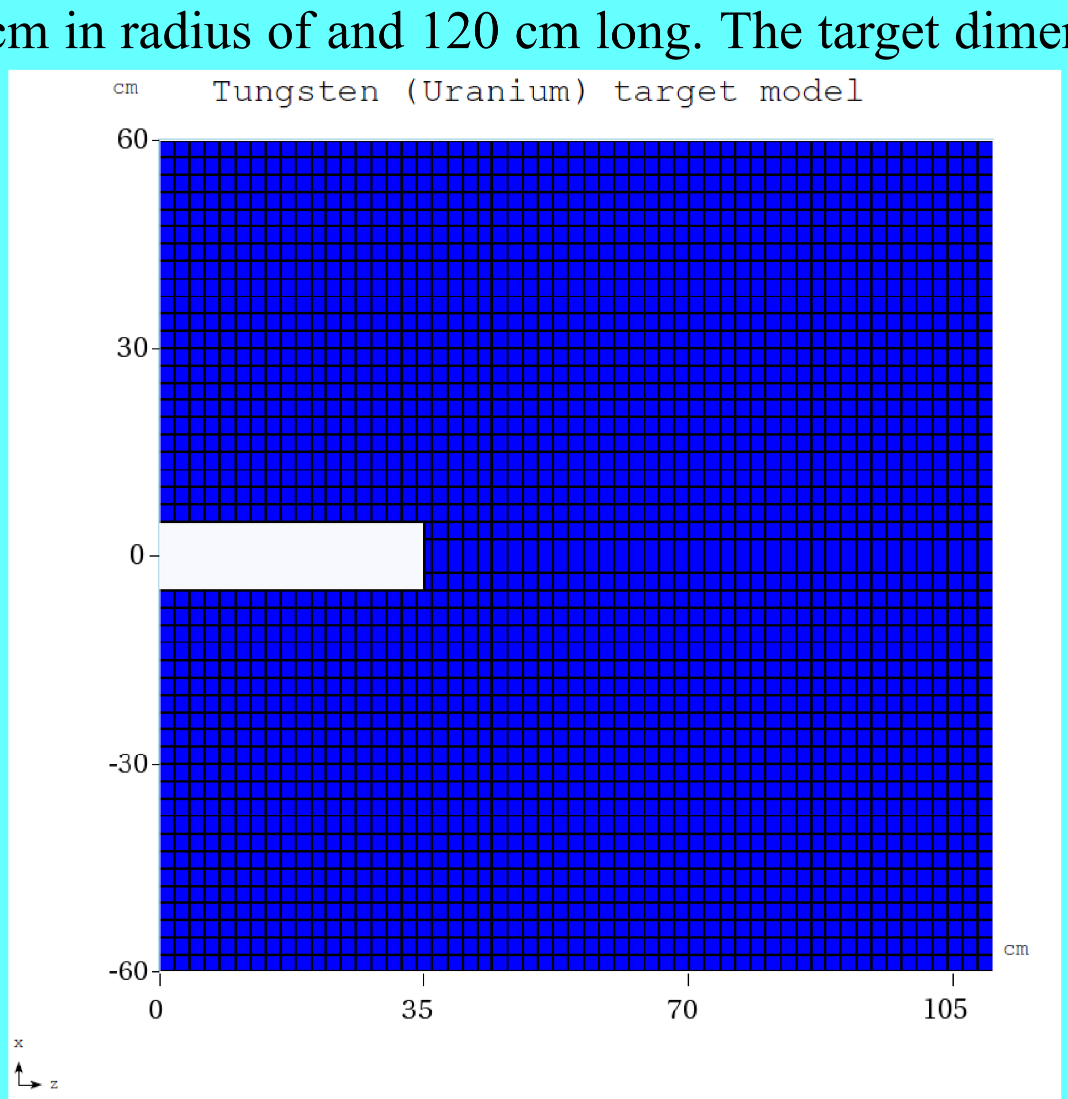
Abstract

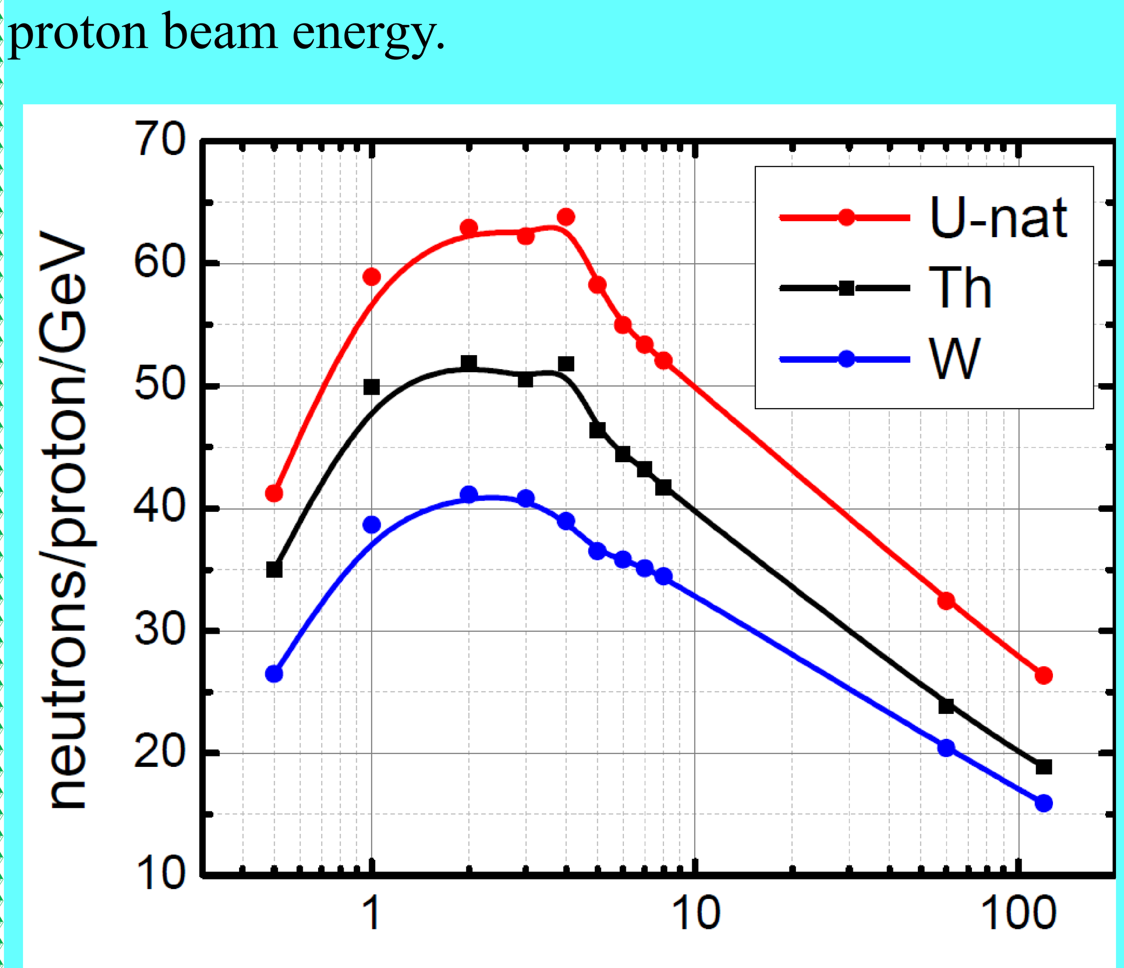
A preliminary study of the Energy Production Demonstrator (EPD) concept, a heavy metal target irradiated by GeV-range intense proton beams and producing more energy than consuming, is carried out. Neutron production and fission are simulated using the MARS15 code for tungsten, natural uranium, and thorium target options, along with energy deposition and gain, peak DPA rate, materials testing volume and helium production in the proton energy range of 0.5 to 120 GeV.

The study indicates that the proton energy range of 2 to 4 GeV is the most practical for both the natural uranium EPD and the tungsten testing station that would be the most suitable for proton accelerator facilities. Based on the simulations, conservative estimates not including breeding and fission of plutonium suggest that the proton beam power of 6 MW is appropriate in the first case which can produce more energy than use for accelerator needs. Simulation results reveal that the thorium target is not efficient for the energy production purpose. The ANSYS thermal analysis of the target is also ongoing. An existing prototype of the depleted uranium-based EPD target residing at JINR, Dubna is discussed as a possible candidate for benchmark experiments.

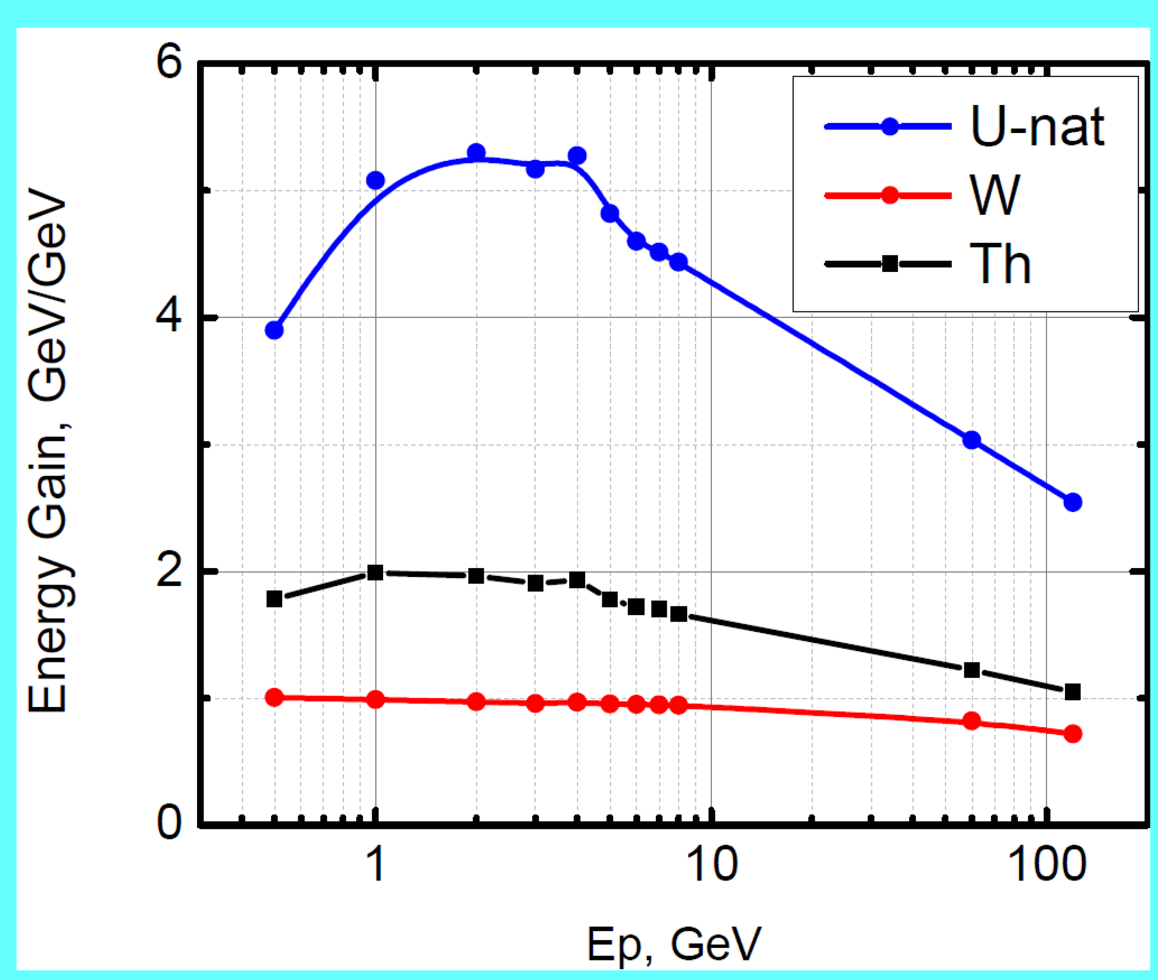
The MARS15 model used in this work is shown in Figure below. It is a natural uranium cylinder 60 cm in radius of and 120 cm long. The target dimen-



sion were chosen to minimize the neutron leakage from the surface down to the level of <2%. There is a 10 cm in diameter 35 cm beam entrance hole at the target center. The Figure below shows the neutron production in the target as a function of the proton beam energy.

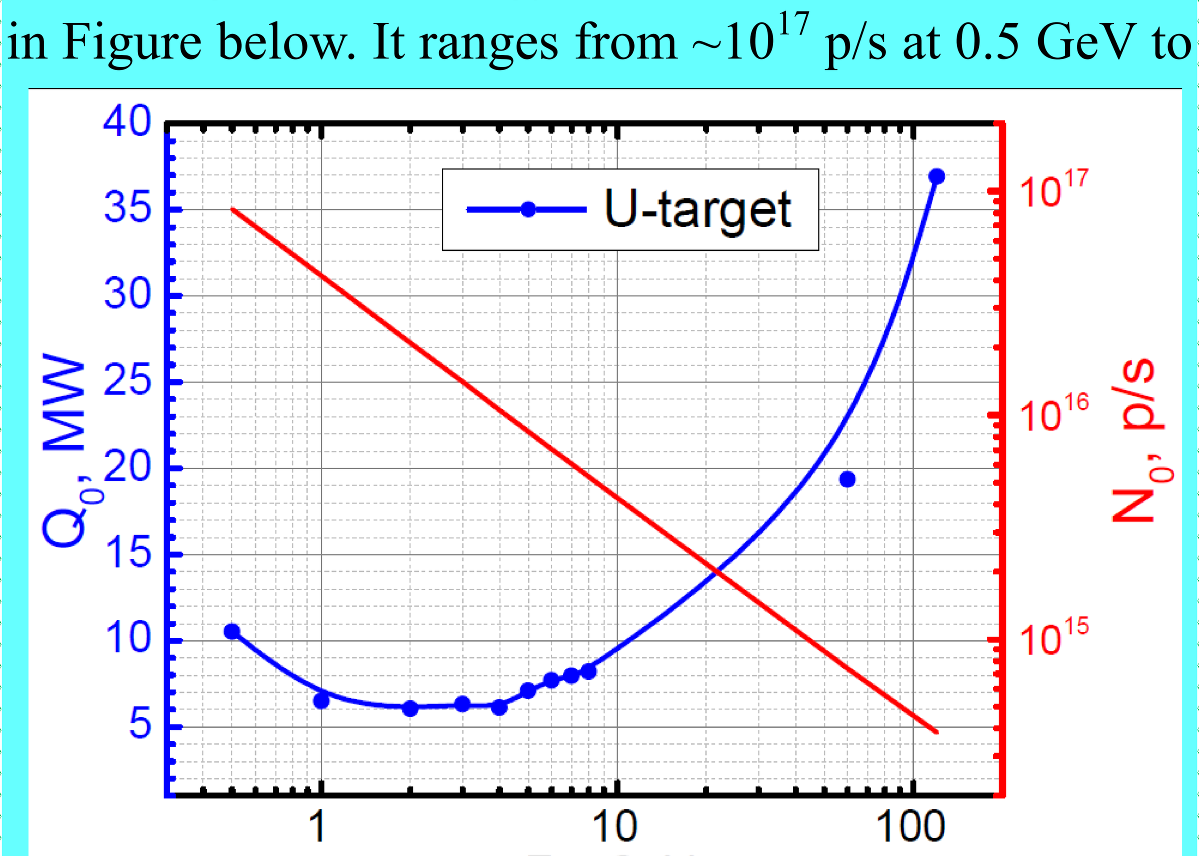


The peak neutron production is between 1 and 4 GeV, it is 50% higher in ^{nat}U than in W and 20% than in Th targets. The energy gain (or the ratio between the energy released in the target to the proton kinetic energy is given in the Figure below. As in the previous plot, the maximum is between 2 and 4 GeV,

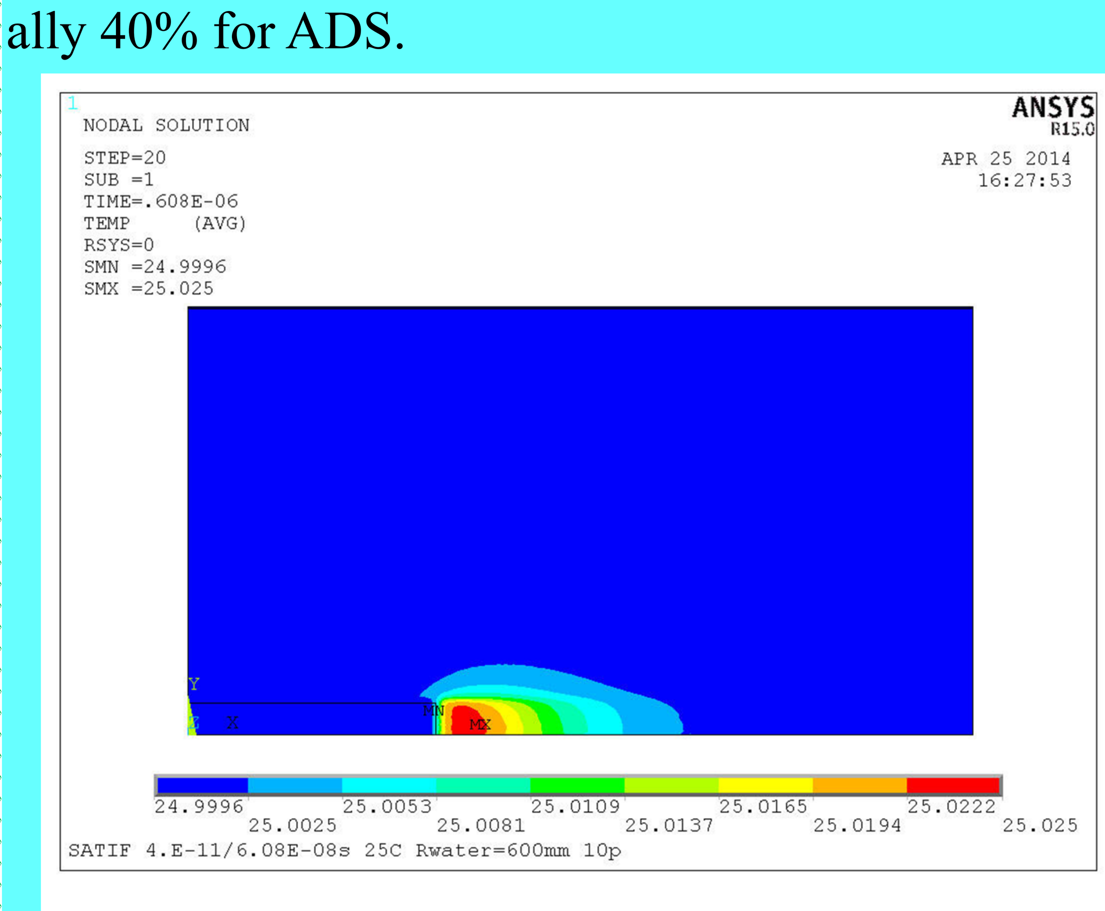


and the peak energy gain in the ^{nat}U is ~5. The Th target reveals the peak gain ~2, while there is no gain in the W target (as the fission cross section of W is negligible).

The calculated proton intensity necessary to produce in the target more energy than consume (N_0) is shown in Figure below. It ranges from ~10^{17} p/s at 0.5 GeV to



$3\cdot10^{15}$ p/s at 120 GeV. The same plot gives the proton beam power necessary to equate the consumed and released energies (Q_0), it has a minimum of ~6 MW in the range 2-4 GeV. In these calculations the power to run the accelerator in the idle mode was assumed to be P_0 = 20 MW, and the power fed to RF $P_{acc}=2\cdot N\cdot E_p$. The calculated required beam power does not take into account neither ^{239}Pu production nor thermal to electrical energy conversion efficiency, which is usually 40% for ADS.



An ANSYS thermal analysis is being carried out to identify requirements to the cooling of the target. In the calculations the bunch duration was taken to be $4\cdot10^{-11}$ s, $6.08\cdot10^{-8}$ s between bunches, and $1.9\cdot10^{8}$ protons per bunch that corresponds to $3.125\cdot10^{15}$ p/s. First results shown above indicate that the target center is heated very rapidly due to a low thermal conductivity of uranium, and a dedicated cooling scheme needs to be developed, without which the core would melt down in milliseconds.

A similar to the EPS MARS model discussed, independently developed 20-tonne depleted uranium prototype target with exchangeable cores residing at JINR (Dubna) can be used for the EPD neutron production studies and code validation.