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

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Energy Production Demonstrator
MARS15 Model

- Solid targets
- $R = 60 \text{ cm}; \ L = 110 \text{ cm}$
- $R_{\text{beam}} = 5 \text{ cm}$
- Optimal dimensions for neutron leakage minimization
- $W, \ Th, \ U$-nat targets
- Energy Production/Materials Testing
- $U$-nat, 3 GeV, Energy deposition, GeV/p/cm$^3$

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 gain (amplification) = \( \frac{E_{\text{released}}}{E_p} \)

Only U has a maximum

The maximum is at 1(2) – 4 GeV

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

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

$\chi_s$ - number of neutrons per GeV (here – produced), $k_{\text{eff}} = 0.98$; $\varphi^*$ - neutron importance $= 1$; $v = 2.5$ (neutrons per fission), $E_f$ – fission energy, 0.2 GeV;

$P_{\text{th}} = I \cdot E \cdot G$ (thermal output power)
Thermal output power at \( I_p = 1 \text{mA} \) and output power fraction to operate accelerator

\[ P_\text{0th at } I_p = 1 \text{mA}, \text{ MW} \]

\[ f = \frac{1}{(G \varepsilon \eta)}, \quad \varepsilon - \text{electric to beam power conversion efficiency, 0.4; } \eta - \text{thermal to electric power conversion efficiency, 0.45;} \]
Simplest cooling scheme (yellow – water lines with T=20C. 
$E_p = 3$ GeV; $I_p = 0.5$ mA ($3.1E15$ p/s); bunch duration=$4E-11$ s; 
between bunches=$6.08E-8$
Temperature rise is $\sim 30000$ 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

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.