EURISOL-DS PROJECT
MULTI-MW TARGET DESIGN

Radioactive Ion Beam Production by Fast-Neutron-Induced Fission in Actinide Targets at EURISOL

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Overview

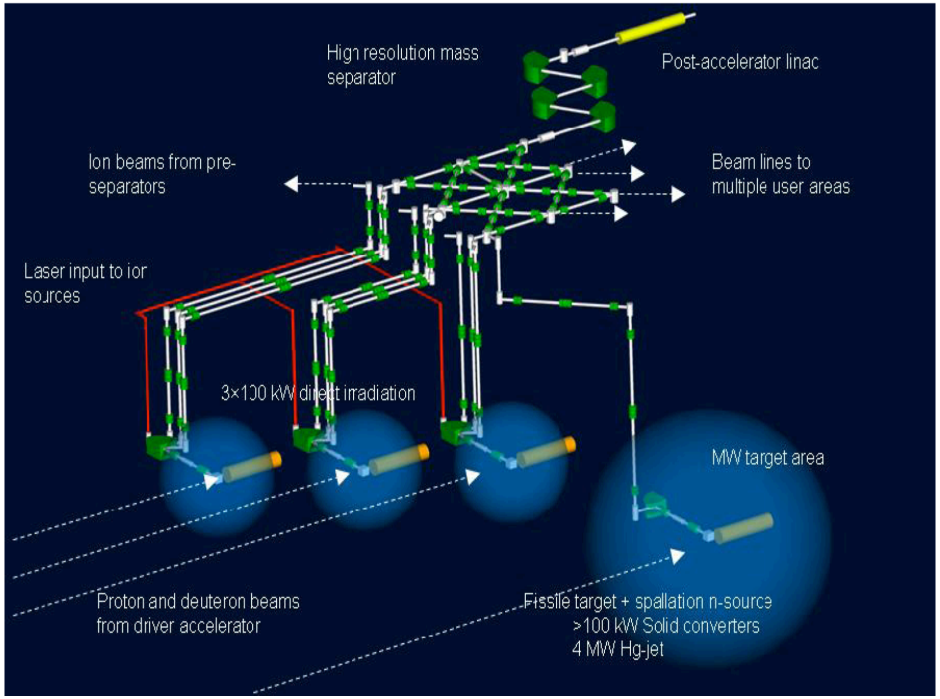
1. EURISOL-DS: Multi-MW Target Station
2. Baseline Design Characterisation
3. Design Options for the Spallation Source
4. Actinide Fission Target Comparison
5. Conclusions

EURISOL Design Study

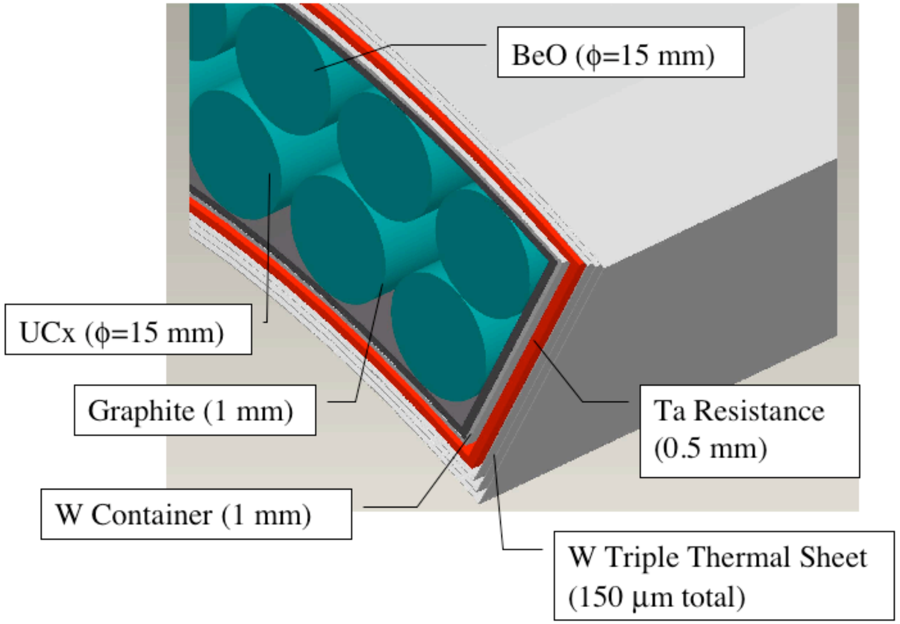
- A next generation European ISOL-type RIB facility, with a RIB intensity 10^2 - 10^4 higher than presently available, has been recommended by the nuclear physics community.
- The roadmap to EURISOL has been established; the present stage is the Design Study, funded by the EC, aiming to start the construction of the facility in the next decade.
- The present design includes a 1 GeV, 5 mA p,d HPSL driver accelerator and a 100 MeV/u post-accelerator.
- Intermediate steps towards EURISOL will be:
    - – the planned SPIRAL II project at GANIL
    - – the proposal SPES at Legnaro
    - – the upgrade of REX-ISOLDE at CERN
    - – the MAFF project at the Garching reactor

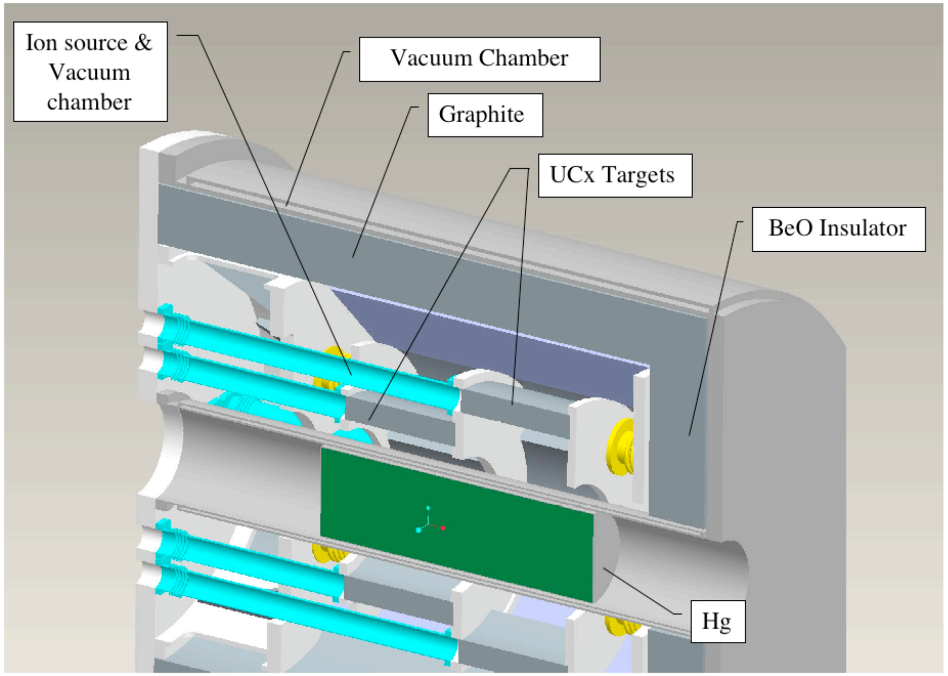
ensuring leading edge research with RIBs

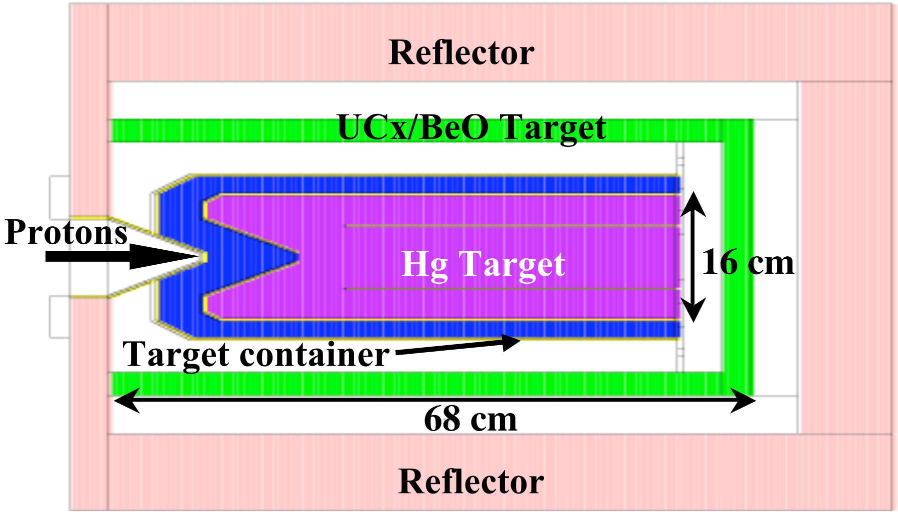
in Europe for the near future.



Multi-MW Target Station







- Shape of compact Hg proton-to-neutron converter optimised for neutron production.
- 15 mm sigma proton beam, contained in the Hg target.
- $U_{nat}C_3$ (3 g/cm^3) fission target, to also induce fission with neutrons below 1 MeV. Higher yields if high-density carbide is used.
- Use of a BeO reflector to improve neutron economy, to shield HE particles and, possibly, to produce ^{6}He for the beta-beam, through (n,α) reactions in ^{9}Be.

Proton Flux Distribution and Power Densities

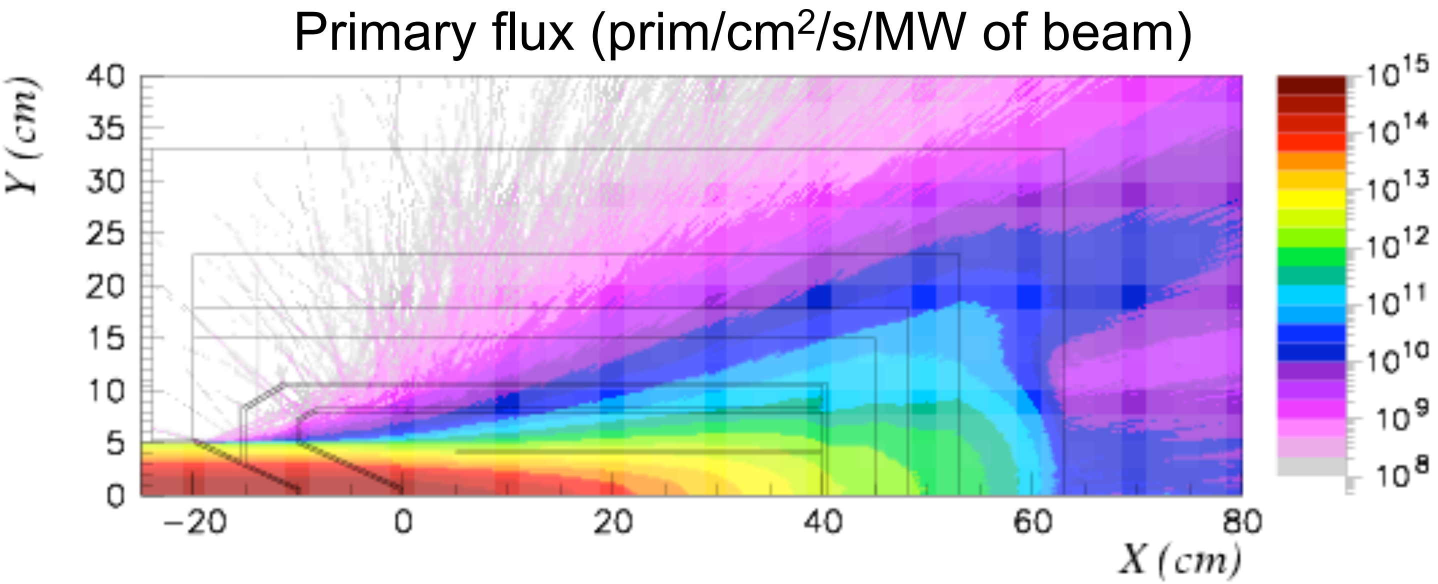
EURISOL Design Study

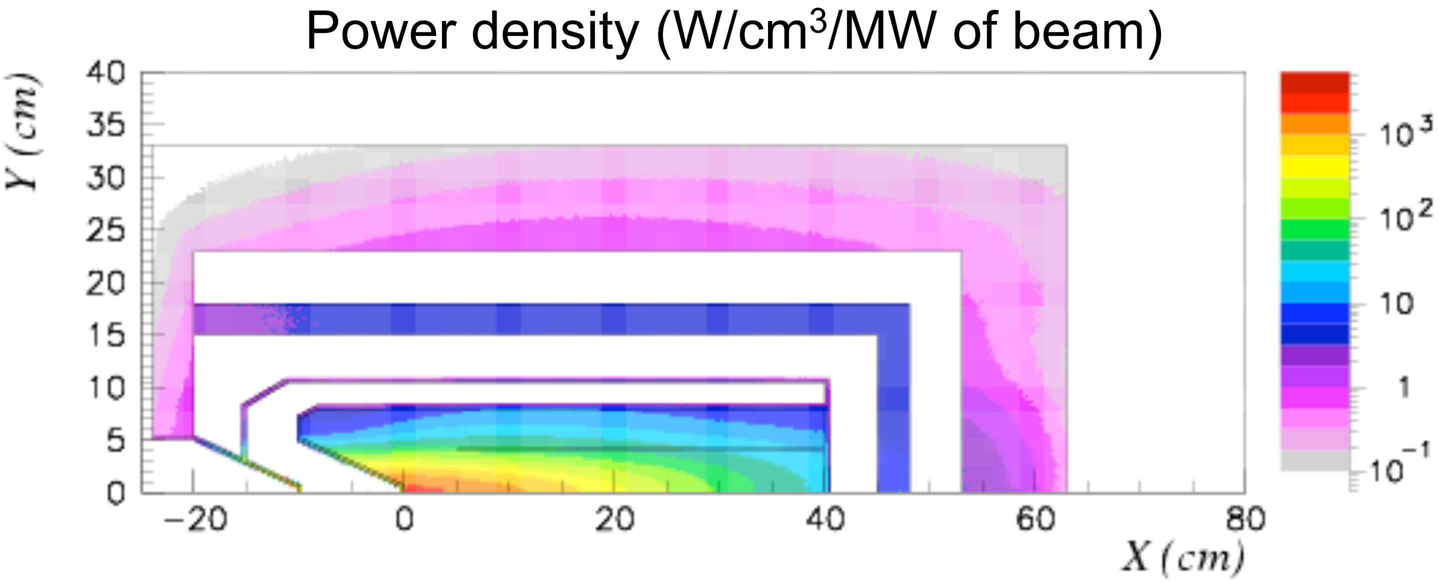
- 1GeV proton range ~46 cm. Beam mostly contained by the reflector.

- Beam window suffering ~100 μA/cm^2/MW of beam (radiation damage limit).

- Maximum power density in Hg: ~2 kW/cm^3/MW of beam.

- Power density in the $U_{nat}C_3$ target: ~5 W/cm^3/MW, homogenously distributed in the fission target.

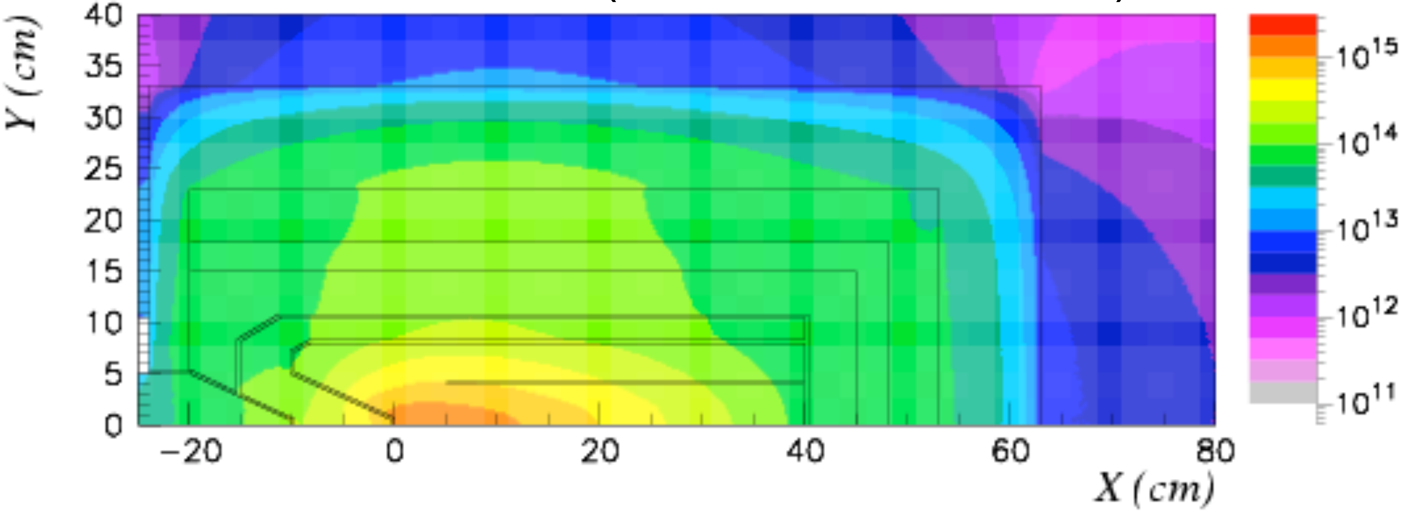




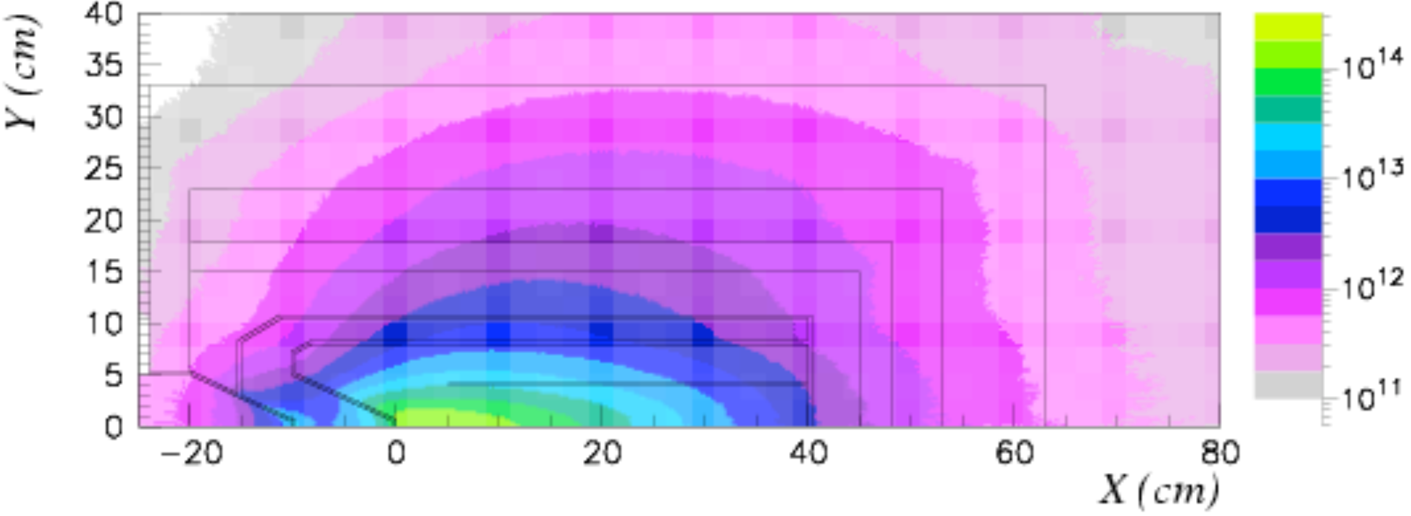
Neutron Flux Distribution

- Neutron fluxes in the fission target ~10^{14} n/cm^2/s/MW of beam ⇒ Similar to nuclear reactor fluxes.
- ~3×10^{12} High Energy n/cm^2/s/MW of beam reaching the fission target and ~3×10^{11} HE n/cm^2/s/MW of beam escaping the reflector ⇒ Relevant for shielding and structural damage.

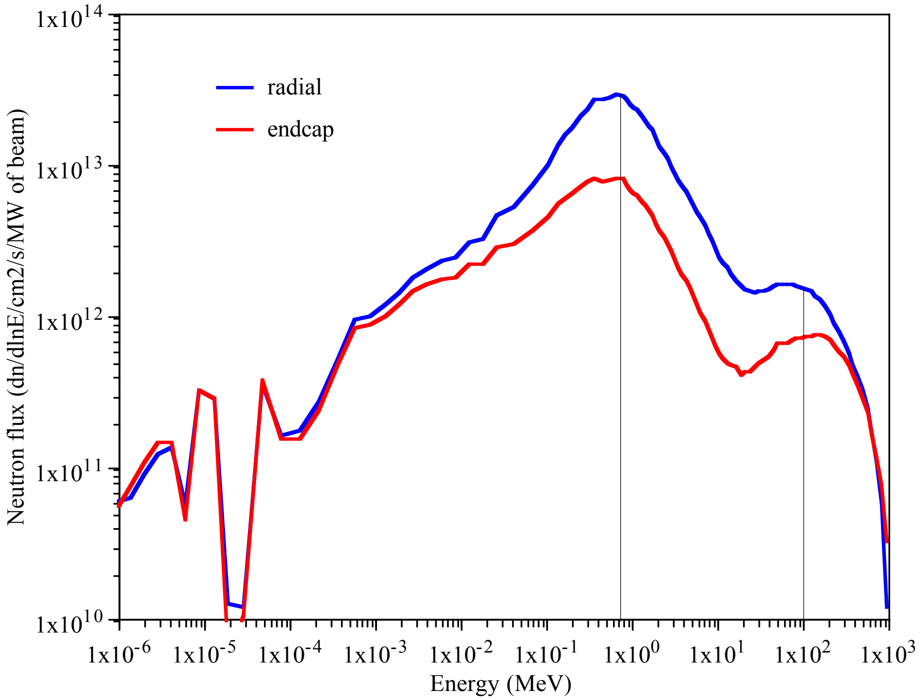
Neutron flux (n/cm^2/s/MW of beam)

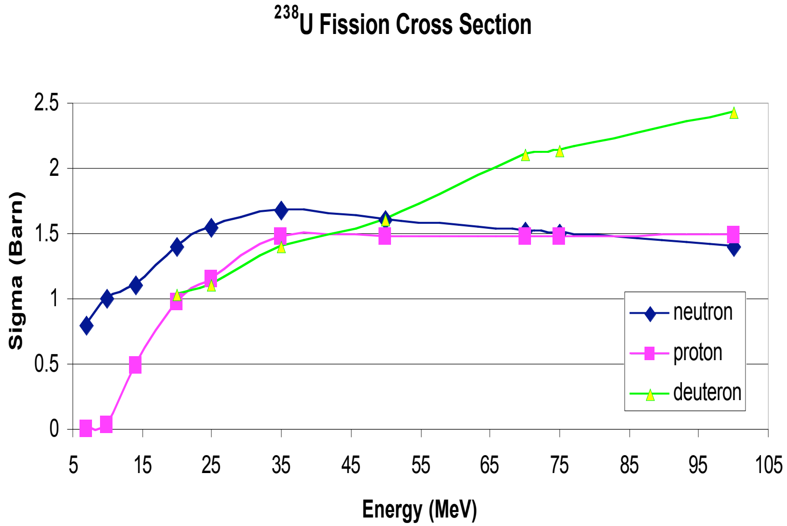


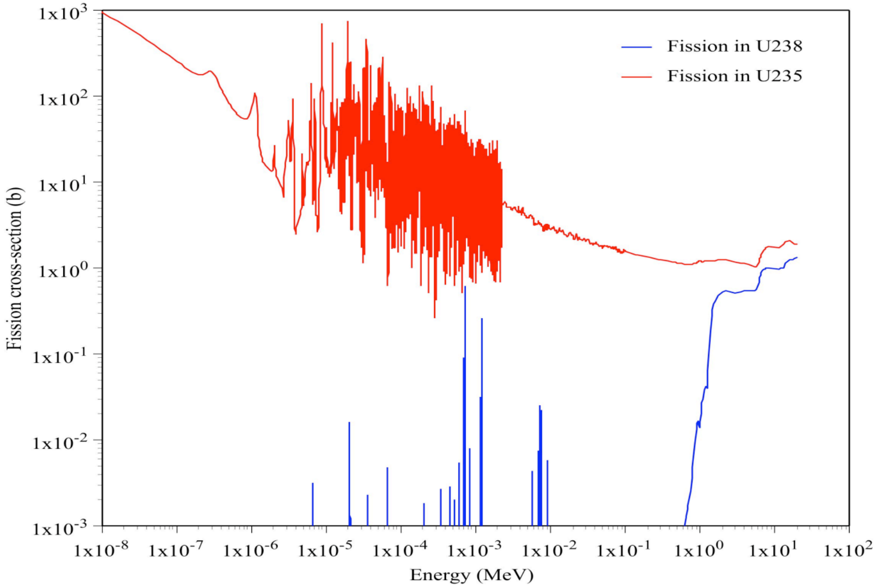
HE neutron [>20 MeV] flux (n/cm^2/s/MW of beam)



Neutron Energy Spectrum vs. Fission Cross-Section in Uranium

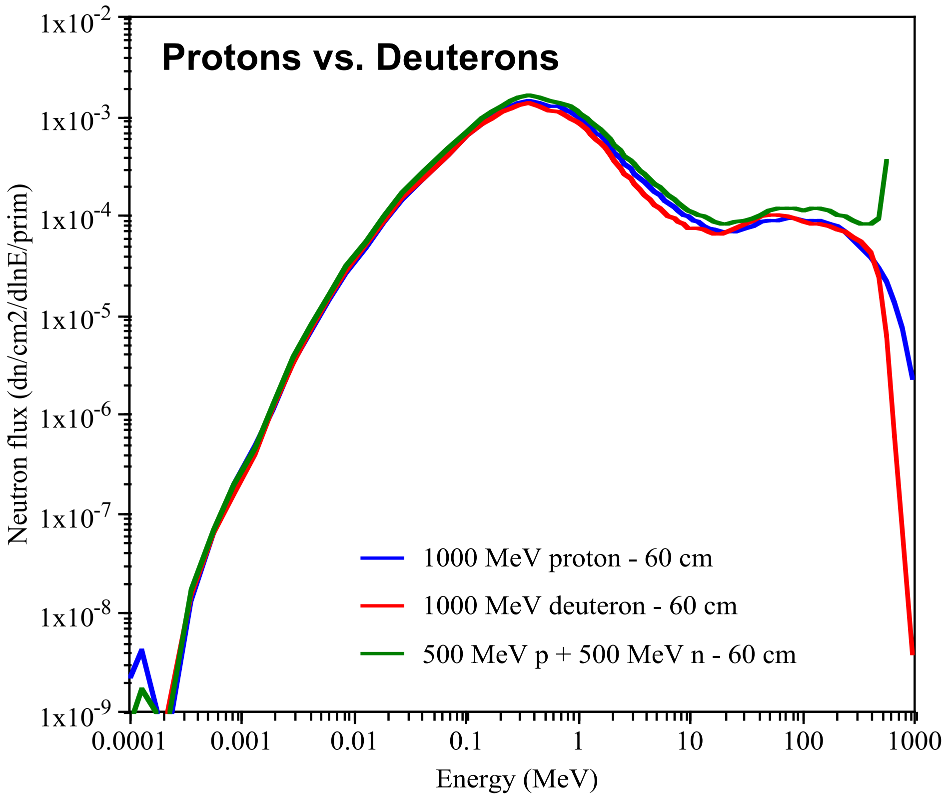


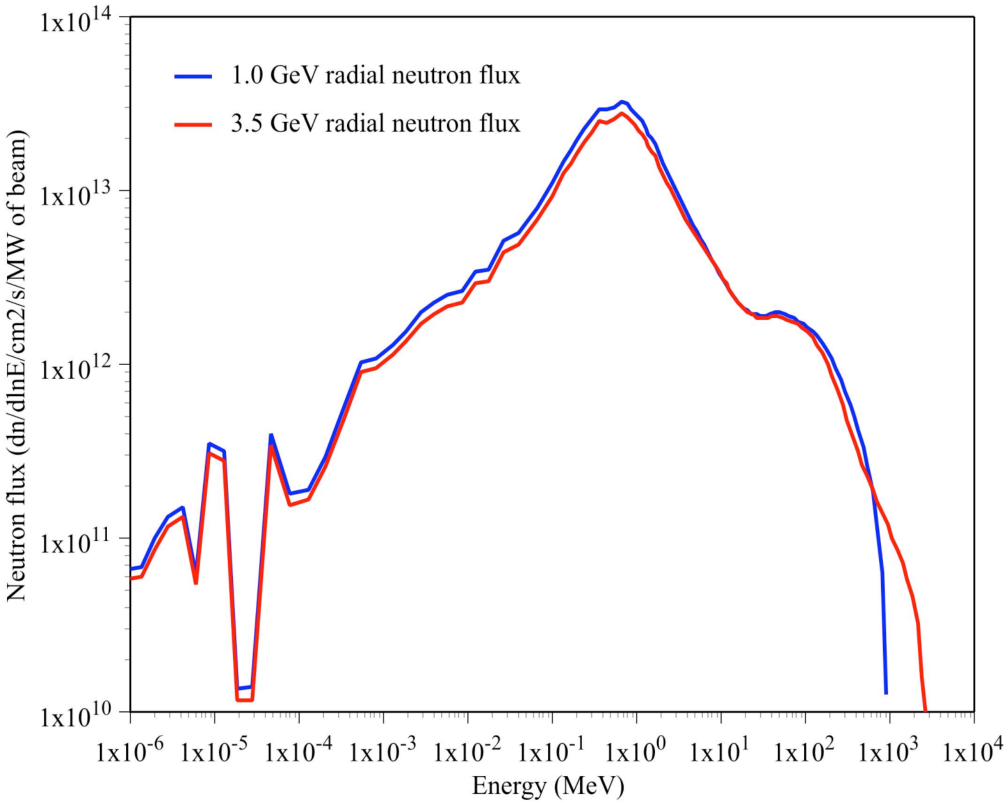




- Escaping neutron flux peaking at ~700 keV (evaporation neutrons), with a 100 MeV component in the forward direction (direct knock-out neutrons).
- Very low fission cross-section in ^{238}U below 2 MeV (~10^{-4} barns). Optimum energy: 35 MeV.
- Use of natural uranium (^{235}U 0.7% wt.) and neutron reflector ⇒ 3 times more fissions.

Projectile: Protons vs. Deuterons. Different Primary Energy





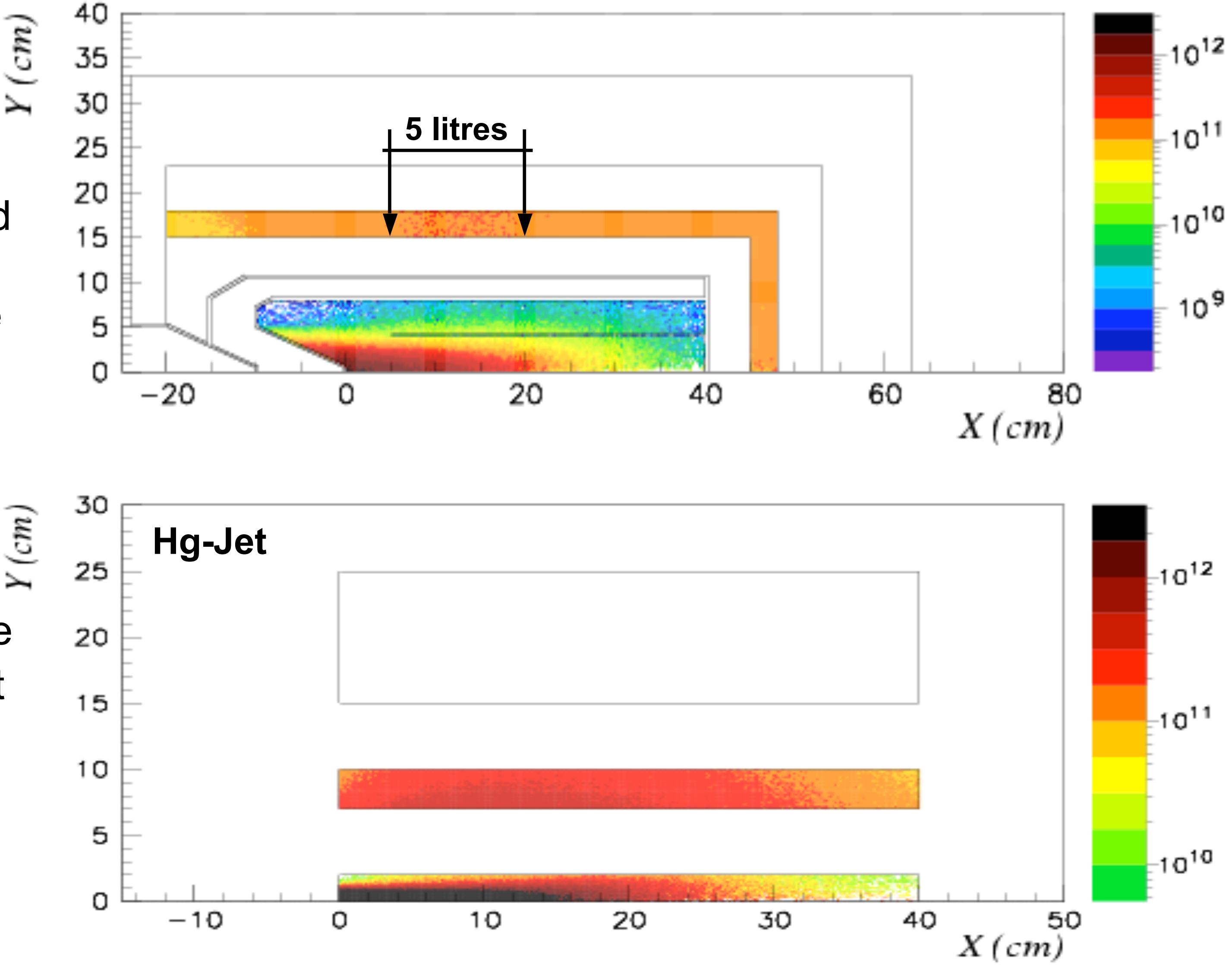
- No significant difference between the radial neutron flux produced by protons and deuterons as primary particles. 15% higher neutron yield by using deuterons, but 30% higher maximum power density.

- Minor differences in the radial neutron flux for 1 and 3.5 GeV protons, except for the very high-energy (GeV range) flux ⇒ Structural damage and radiological issue.

Fission Density Distribution in $U_{nat}C_3$

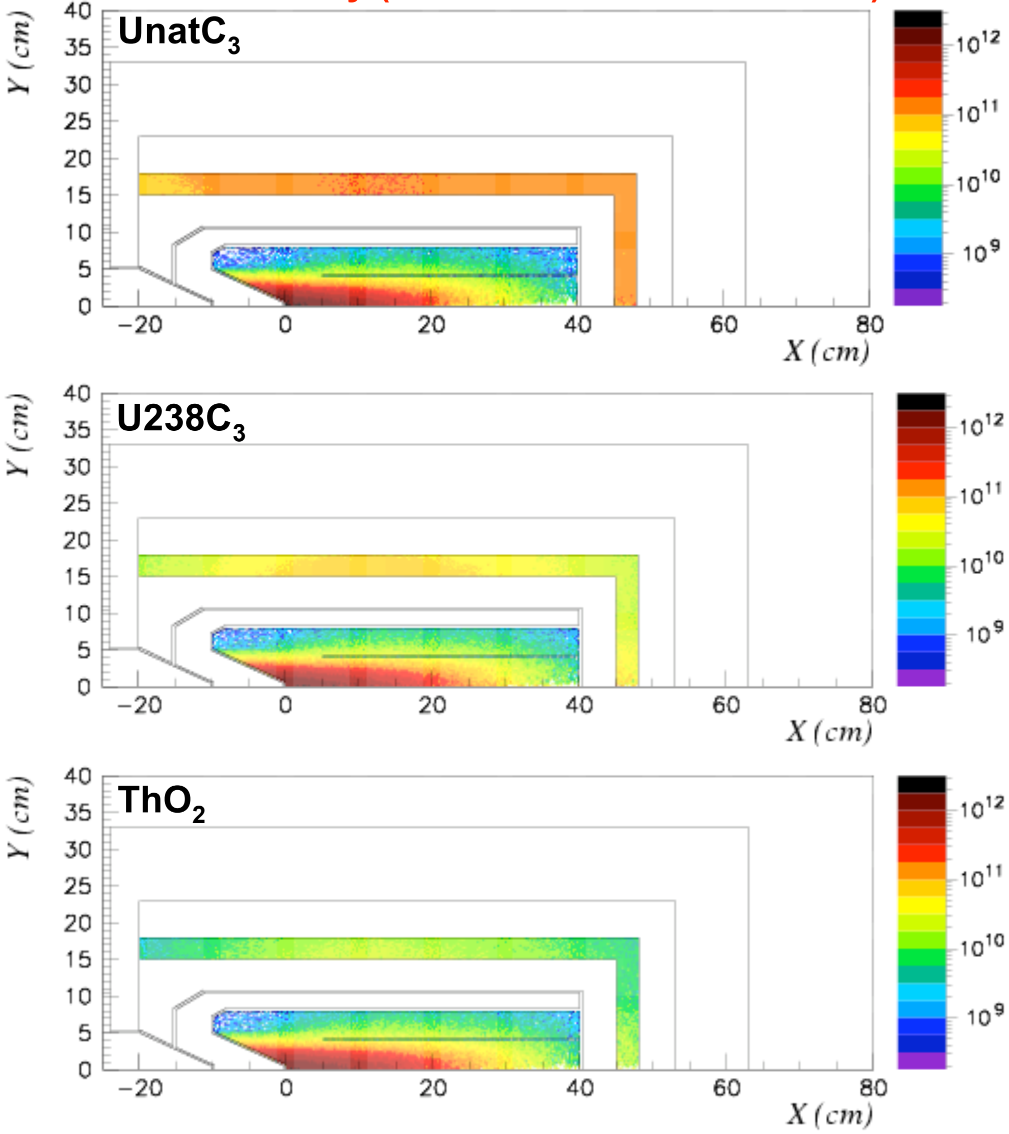
- High-energy fissions in Hg ⇒ Radioactive isotopes in Hg.
- 2×10^{11} fiss/cm^3/s/MW, homogenously distributed ⇒ ~10^{15} fissions/s for 1 MW of beam and a 5 litre $U_{nat}C_3$ (3 g/cm^3) fission target.
- To achieve higher fission densities a larger and **harder flux** would be required, as in the Hg-Jet option (2 times more fissions) ⇒ Important technical difficulties.

Fission density (fissions/cm^3/s/MW of beam)



Fission Densities: Different Actinide Targets

Fission density (fissions/cm^3/s/MW of beam)

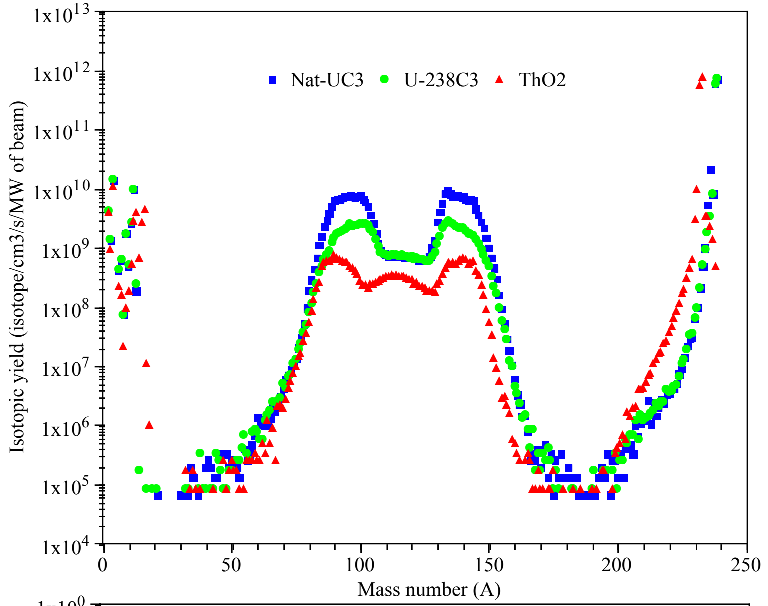


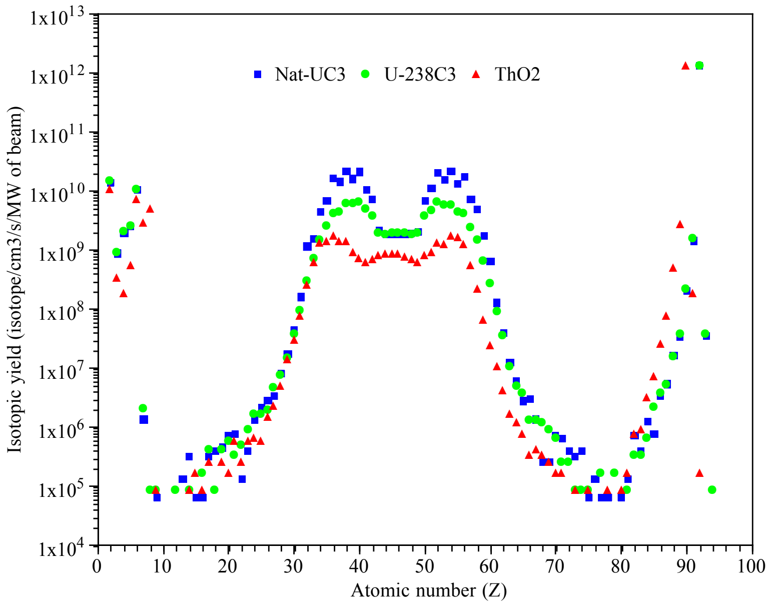
- UnatC$_3$: 2×10^{11} fiss/cm^3/s/MW, homogenously distributed.

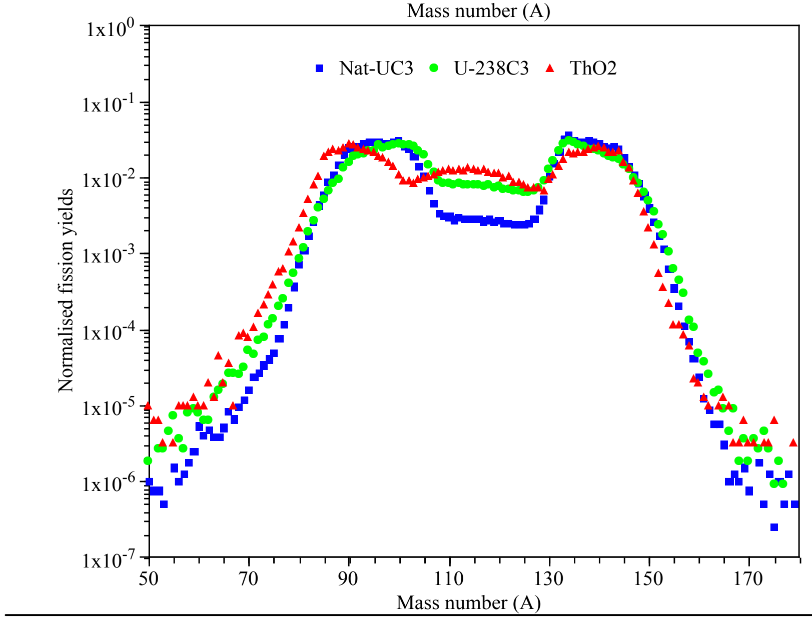
- U238C$_3$: 6.5×10^{10} fiss/cm^3/s/MW, heterogeneously distributed. Maximum around ~16 cm and in the forward direction (HE fissions).

- ThO$_2$: 2×10^{10} fiss/cm^3/s/MW, heterogeneously distributed. Main advantage: No plutonium production. Lower yields and ^{231}Pa, ^{232}U and ^{233}U generation.

Isotopic Yield Distributions





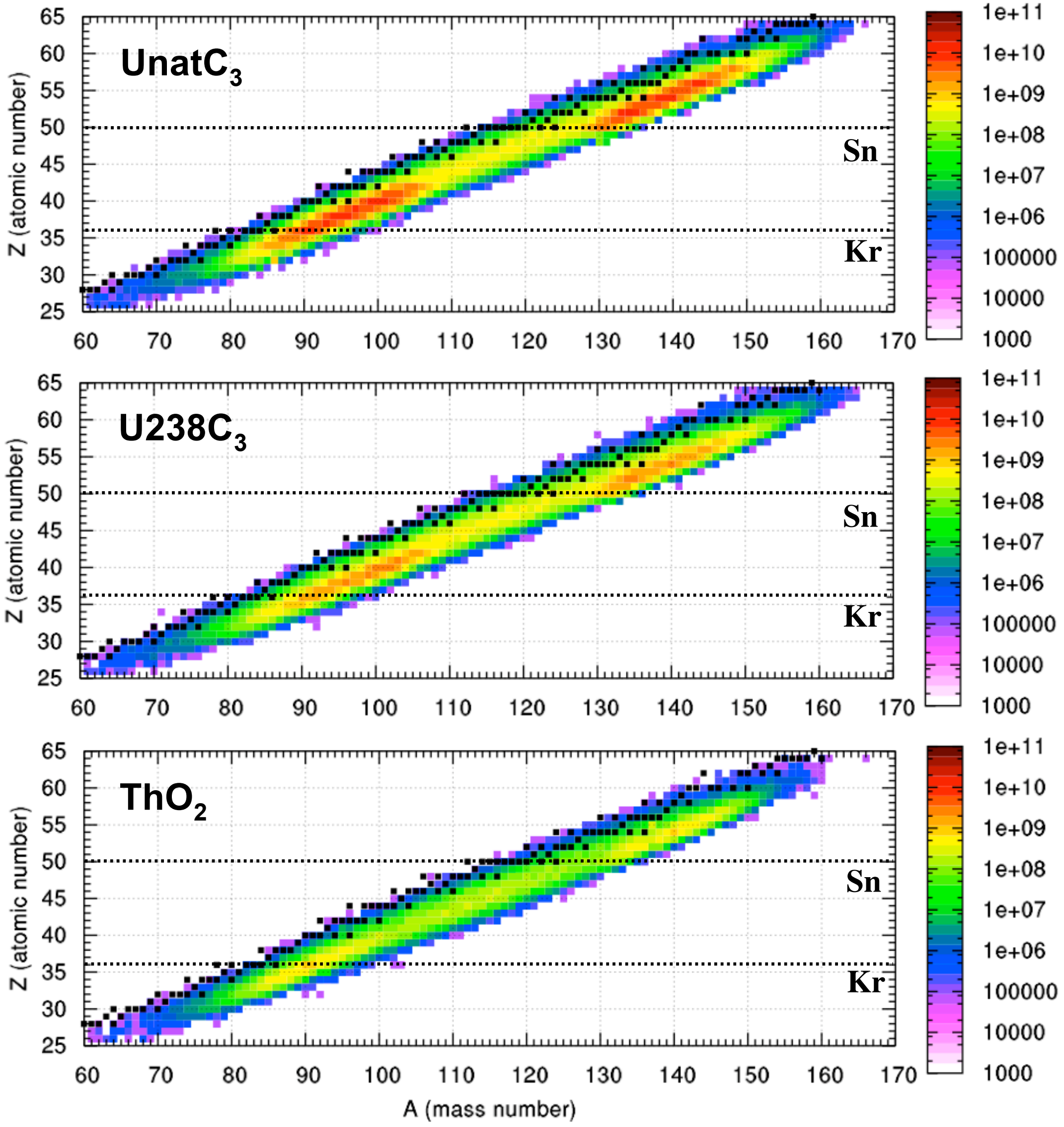


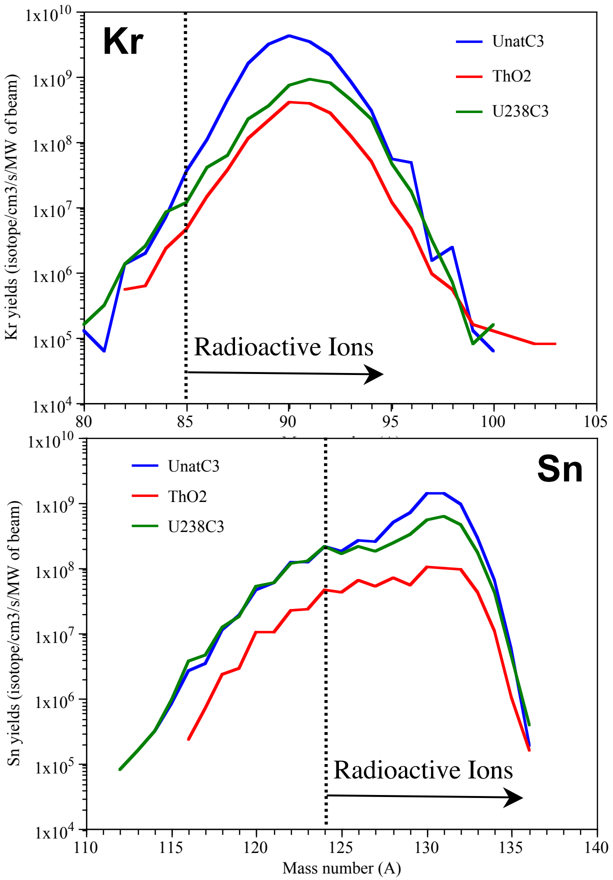
- Natural Uranium presents ~3 times more asymmetric fissions and the same level of symmetric (high-energy) ones.

- As previously shown, ThO_2 presents a lower level of fission yields, with lighter fission products and higher importance of symmetric fission.

Fission Fragment Distributions

Fission fragment distribution (isotope/cm³/s/MW of beam)





- Intense Radioactive Ion Beams for the selected **neutron-rich** isotopes (up to 10^{14} ions/s of Kr-90 and Sn-132, for the full beam).

Conclusions

- The technical feasibility of such an innovative facility has been demonstrated. The fission densities aimed for can be obtained with the proposed Multi-MW target design using moderate beam intensities and fission target volumes, independently of the actinide composition.

- Potential synergies, with other EURISOL and nuclear physics activities (e.g. design of an escape line for time-of-flight measurements and material science).

- A 1 GeV proton beam on a compact proton-to-neutron converter seems favourable to obtain ~10^{14} n/cm^2/s/MW of beam in the fission target, producing intense RIBs, up to 10^{14} ions/s of Kr-90 and Sn-132 for the full beam (5 MW).

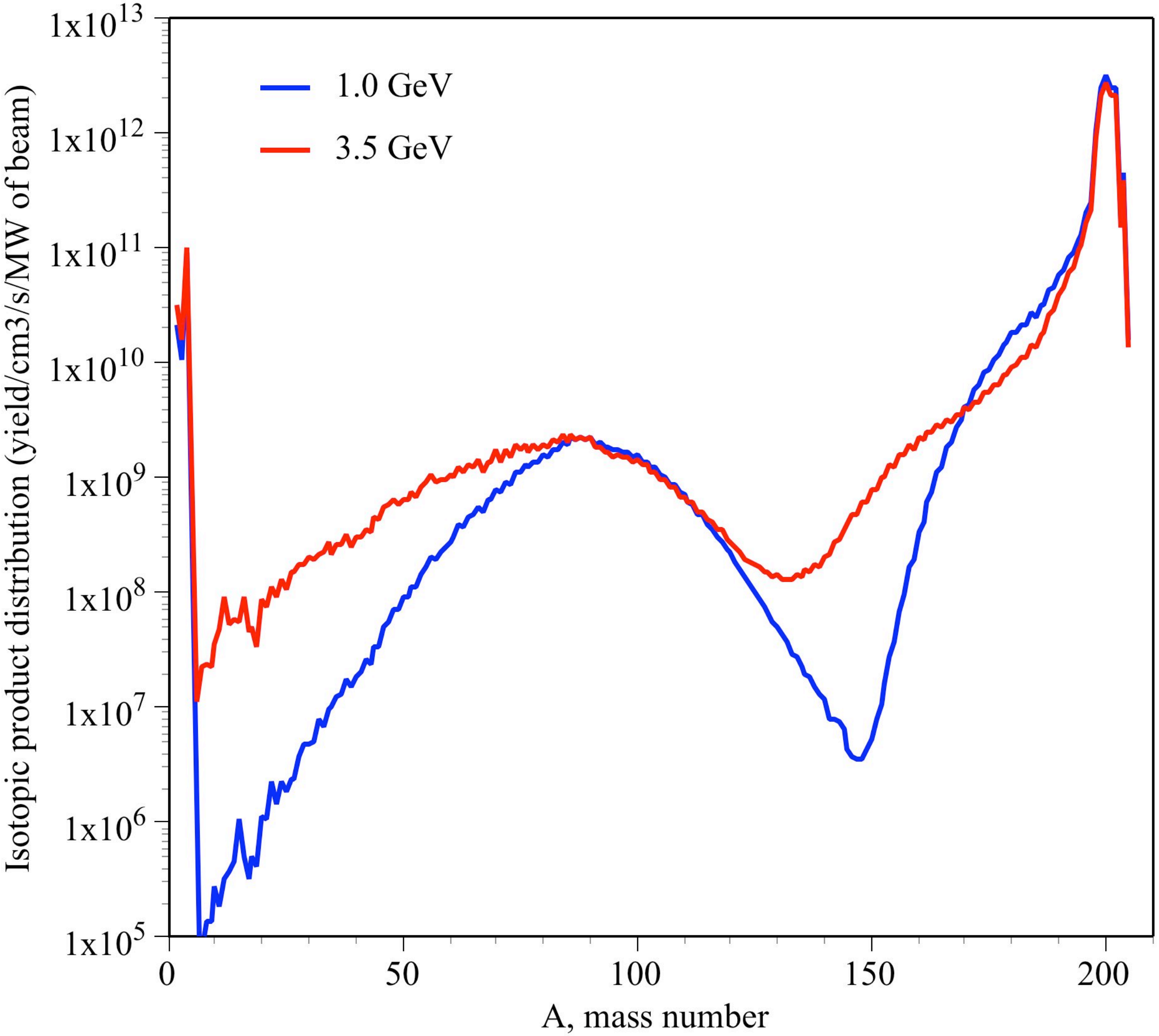
- The use of ThO_2 as fission target material would suppose a trade between higher actinide production and fission yields (one order of magnitude less fissions in ThO_2), for the same target densities.

- In terms of radiotoxicity, ThO_2 targets would generate negligible amounts of Plutonium. Nevertheless other hazardous isotopes, such as Pa-231, U-232 and U-233, would be produced instead.

Thank you for your attention!

Residual Nuclei Distribution in Hg

- At high masses it is characterized by the presence of three peaks corresponding to (i) the initial target nuclei, (ii) those obtained after evaporation below and (iii) those obtained after activation above (A+1).
- Three very narrow peaks corresponding to the evaporation of light nuclei such as (deuterons, tritons, ^{3}He and α).
- An intermediate zone corresponding to nuclei produced by high-energy fissions (symmetric distr.)
- At higher proton energy nuclei from evaporation and multi-fragmentation (light nuclei) are more abundant.



Next Steps

- Accurate evaluation of the fission yields by modifying the residual nuclei scoring routine in FLUKA, to generate all fission products (weighted by the total) for every fission reaction (drastically improve statistics).

- Burn-up evolution of the fission target in order to assess:

  - Concentration of relevant actinides (namely, Plutonium in the case of Uranium-fission targets and U-233 in the case of Thorium ones), until equilibrium is reached.

  - Impact of these isotopic evolution in the neutron multiplication of the system as well as in the fission yield rates.

  - The precise radiotoxicity of the fission target after burn-up to accurately compare the advantages and disadvantages of different target materials.

- Model and analyse the new geometry with a transverse Hg flow. Preliminary evaluation.