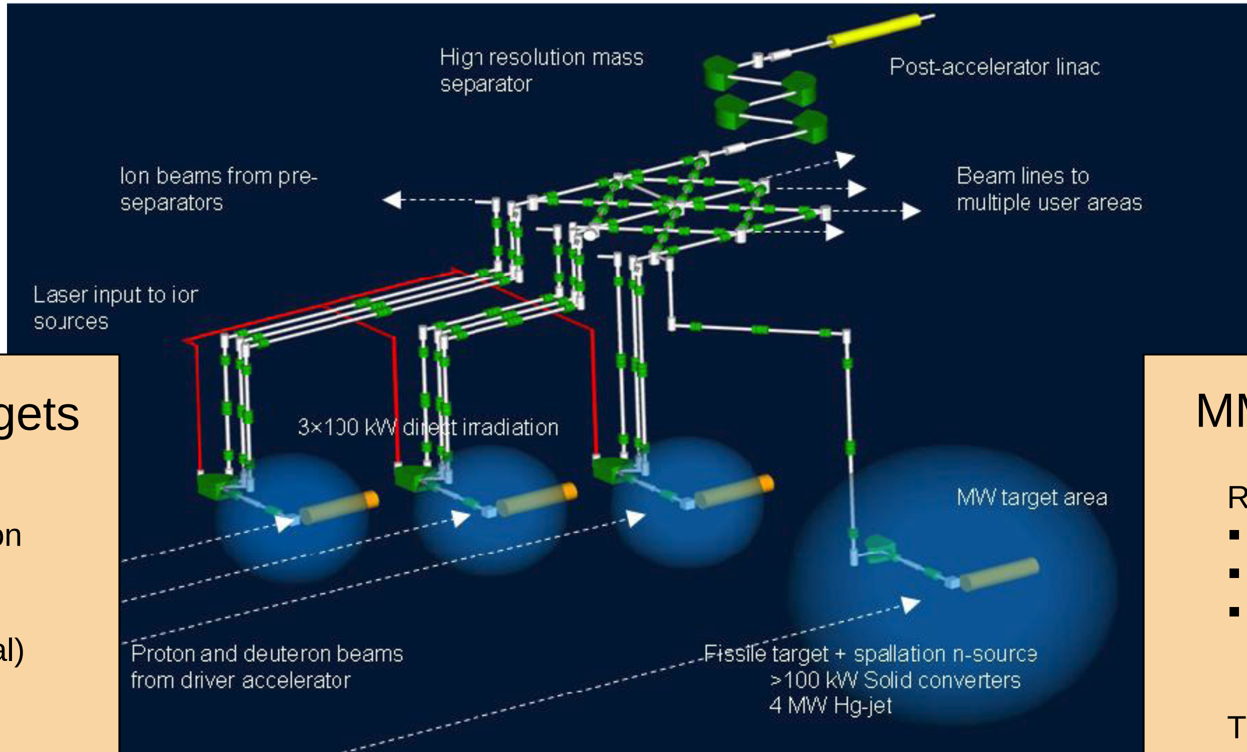
EURISOL-DS Multi-MW Spallation Target Design

Adonai Herrera-Martínez, Yacine Kadi
On behalf of EURISOL DS Task 2

European Organization for Nuclear Research, CERN
CH-1211 Geneva 23, SWITZERLAND
adonai.herrera.martinez@cern.ch

Project supported by the European Commission under the FP6
“Research Infrastructure Action- Structuring the European Research Area”
EURISOL-DS Project Contract no. 515768 RIDS

EURISOL Target Stations



100 kW direct targets

RIB production:

- Spallation-evaporation
- Main: P-rich
  (10 to 15 elements below target material)
- Residues: N-rich
  (A few elements below target material)

Target materials:

- Oxides
- Carbides
- Metal foils
- Liquid metals

MMW fission target

RIB production:

- Fission
- N-rich
- Wide range
  Z = 10 to Z = 65

Target material:

- U (baseline)
- Th

Converter:

- Hg

EURISOL-DS Targetry Challenges

EURISOL shall deliver beams of 3 orders of magnitude higher intensity than 1999 yields.

- Design of “oven + heat-transport system” targets dissipating a direct GeV proton beam power of ~100 kW, to produce spallation generated RIBs.
- Optimisation of the wall material and target geometry of the “*target vessel, transfer line & ion-source*” system to improve the release efficiency.
- Improve ion-source efficiencies and beam purity.
- Design high power density spallation neutron source (~4 MW).
- Design actinide targets efficiently utilising the neutrons generated by high power spallation neutron source.

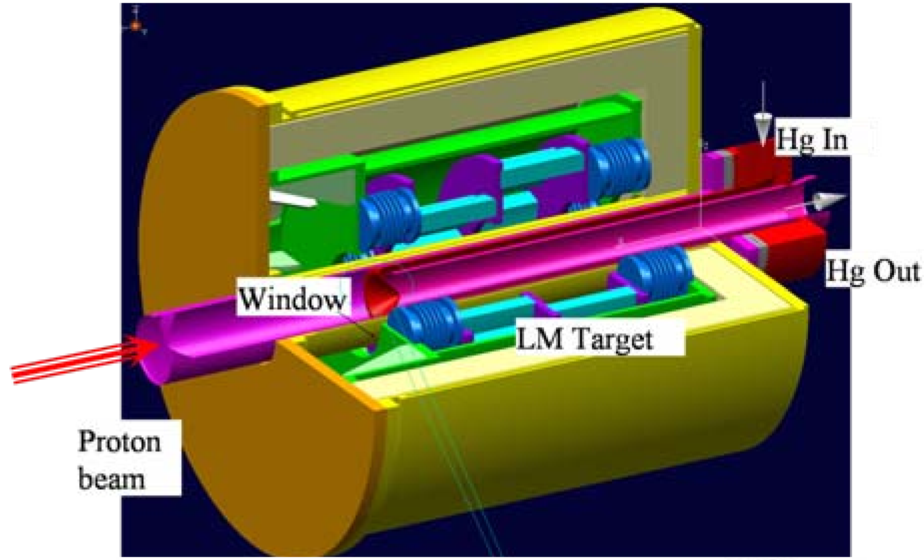
Task#2 – Multi-MW Liquid Hg Target

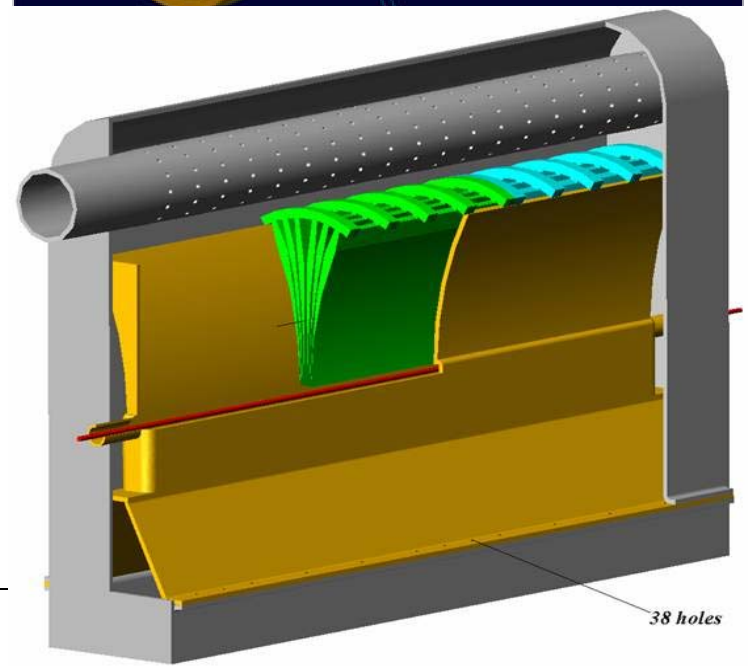
- Compact liquid Hg target with beam widow
- Confined windowless transverse film

Task Goals:

1. Engineering study of the thermo-hydraulics, fluid-dynamics and construction materials of a window or windowless liquid-metal converter.
2. Study of an innovative waste management in the liquid Hg-loop.
3. Engineering design and construction of a functional Hg-loop.
4. Off-line testing and validation of the thermo-hydraulics and fluid-dynamics.
5. Engineering design of the entire target station and its handling method.

Hg converter and secondary fission targets



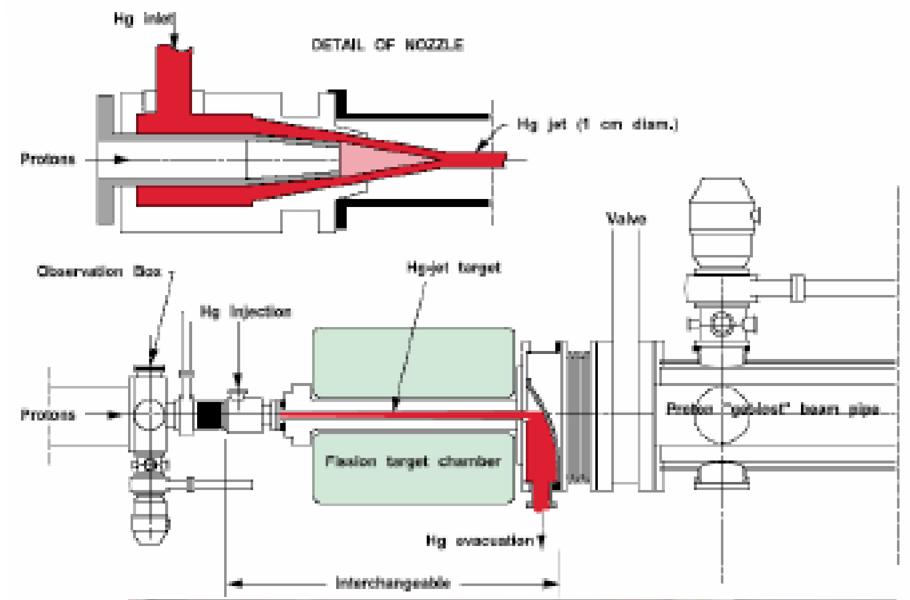


Task#2 – Design Parameters (D1)

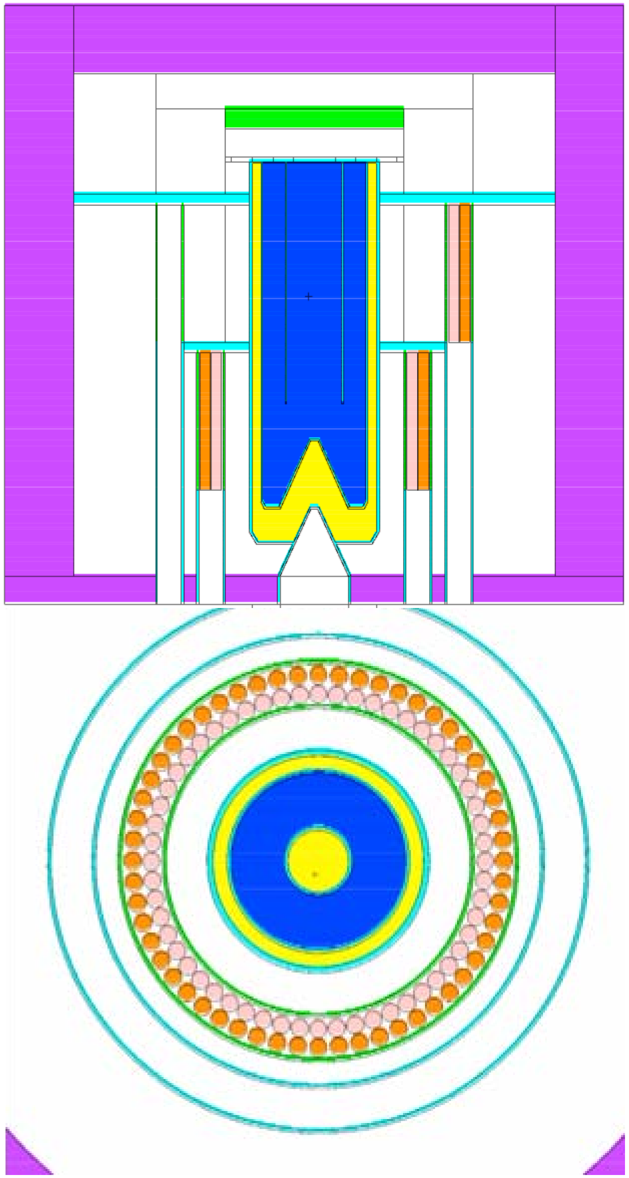
EURISOL Design Study

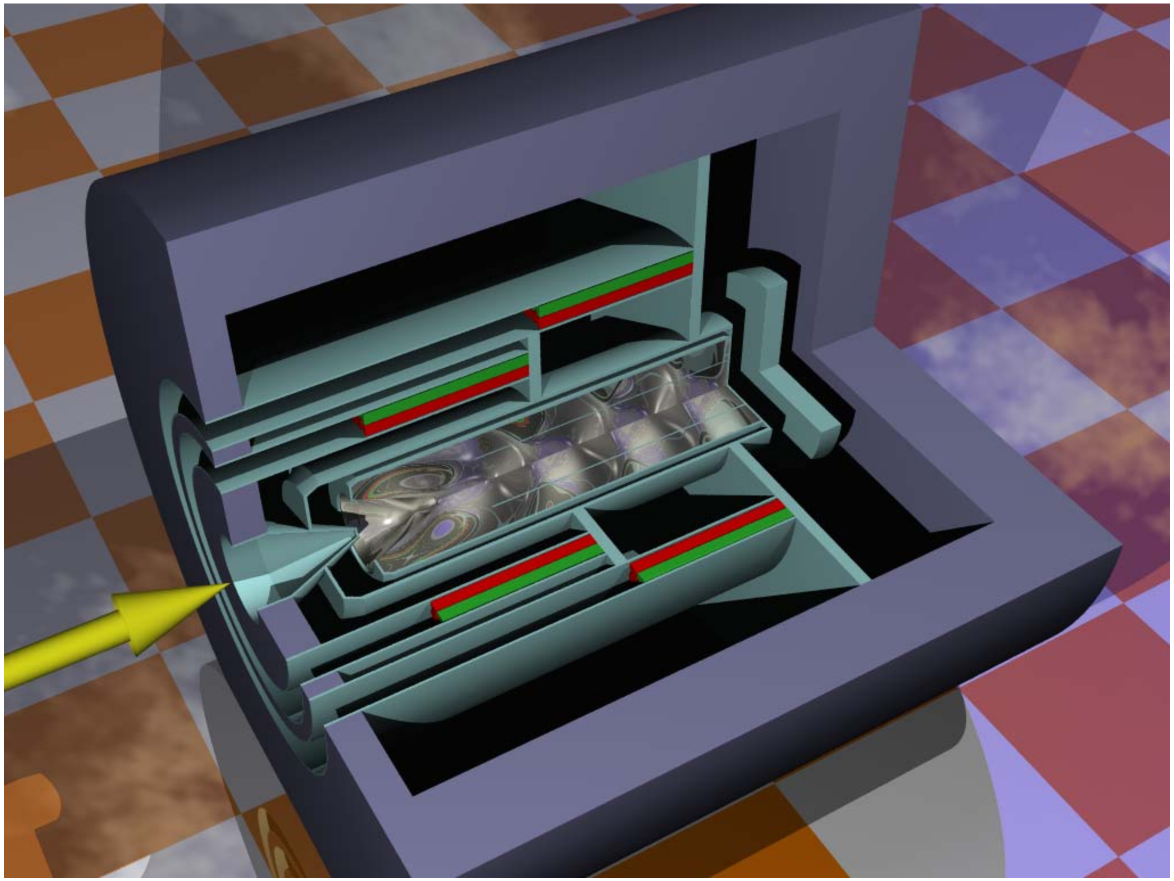
A high pressure **water-jet** based on the windowless **Hg-jet** configuration proposed in the **EURISOL-RTD (2003)** was experimentally tested and results showed a considerable number of obstacles in the implementation of such system

Parameter	Symbol	Units	Nval	Range
Converter Target material	Z_{conv}	-	Hg (liquid)	LBE
Secondary Target material	Z_{targ}	-	UC_x, BeO	
Beam particles	Z_{beam}	-	Proton	
Beam particle energy	E_{beam}	GeV	1	2
Beam current	I_{beam}	mA	4	2 – 5
Beam time structure	-	-	CW	50Hz 1ms pulse
Gaussian beam geometry	σ_{beam}	mm	15	< 25, parabolic
Beam power	P_{beam}	MW	4	< 5
Converter length	l_{conv}	cm	45	85
Converter radius (cylinder)	r_{conv}	cm	8	4 – 15
Hg temperature	T_{conv}	°C	150 – 200	<< 357
Hg flow rate	Q_{conv}	ton/s	0.1 – 0.2	<< 1
Hg speed	V_{conv}	m/s	~5	<< 15
Hg pressure drop	ΔP_1	bar	1 – 2	< 10
Hg overpressure	ΔP_2	bar	5 – 7	< 10
UC_x temperature	T_{targ}	°C	2000	500-2500



Mercury Target Reference Design





- Reasonable charged particle confinement and power densities.
- High neutron fluxes, confined within the assembly.
- Large fission rate densities.
- Proven design (SNS and ESS), technically “simple” concept.

Primary and Neutron Flux Distribution

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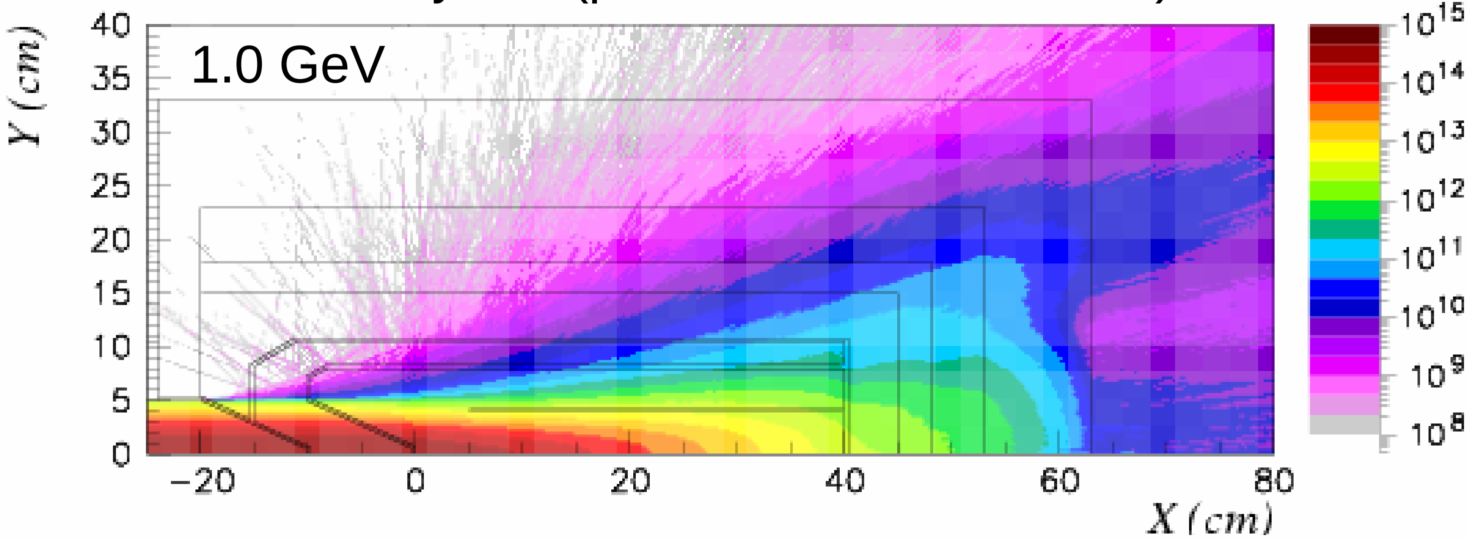
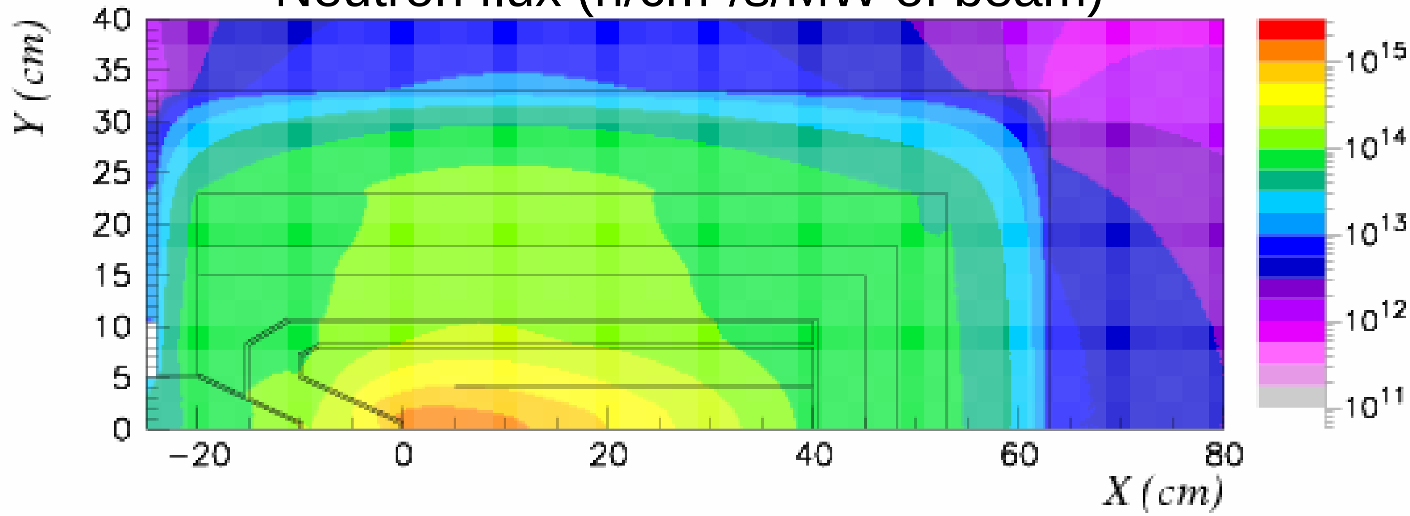
- Proton range ~46 cm: acceptable confinement of primary protons inside the target assembly
- Neutron fluxes in the fission target ~10^{14} n/cm²/s/MW of beam
- Spallation neutrons produced over a larger volume
- Neutron flux dominated by neutrons below 20 MeV

Primary flux (prim/cm²/s/MW of beam)



Neutron flux (n/cm²/s/MW of beam)



Fission Fragment Distributions

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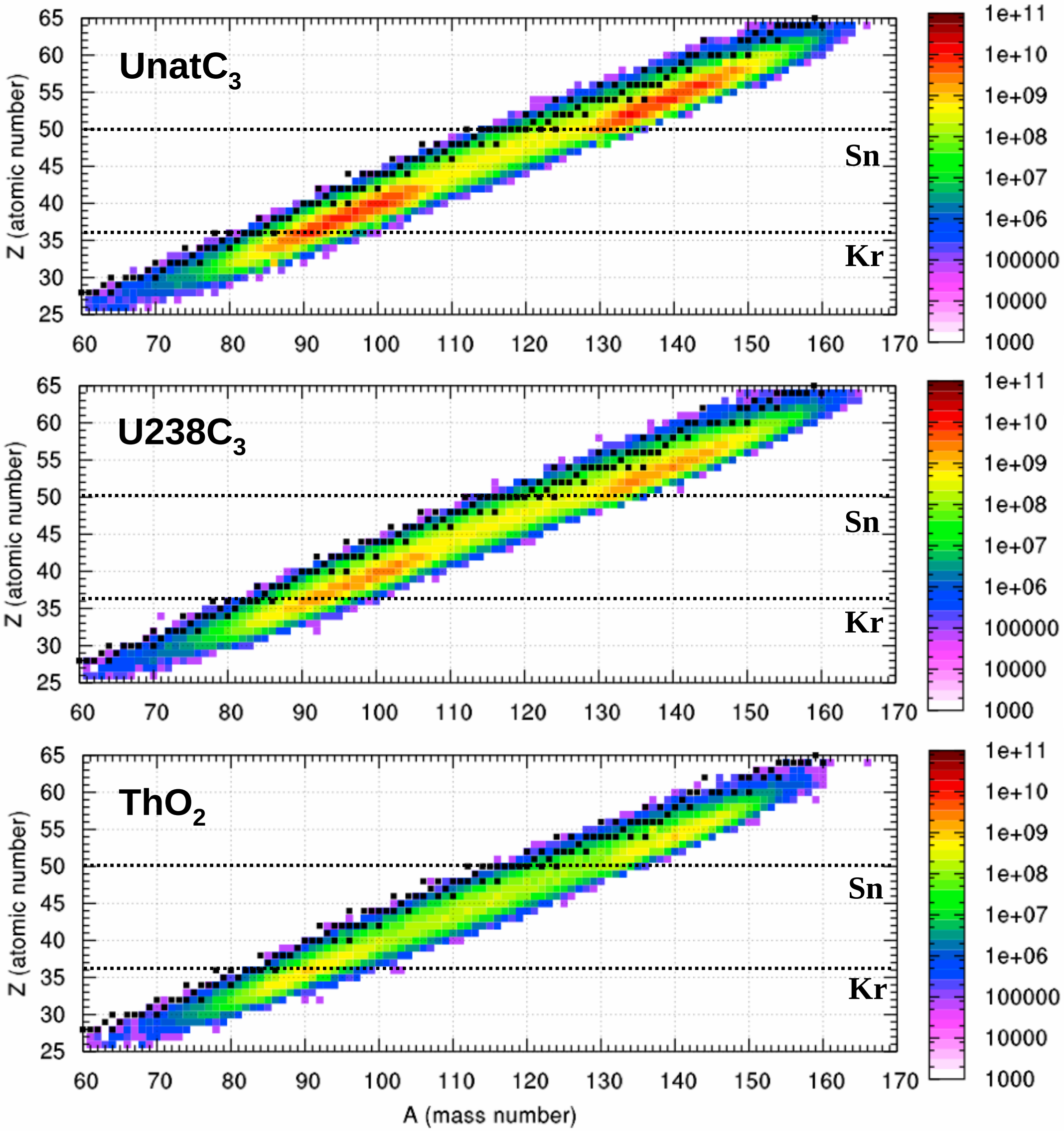
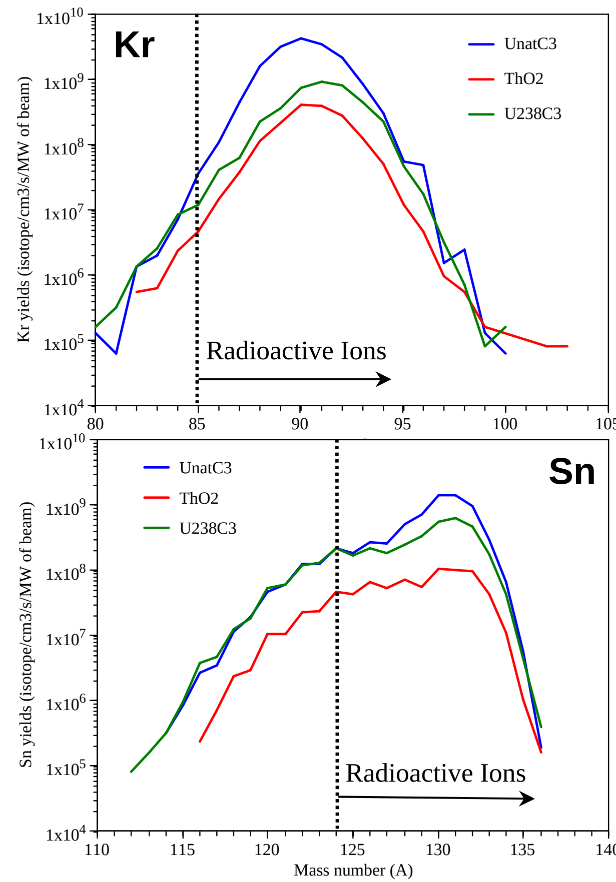
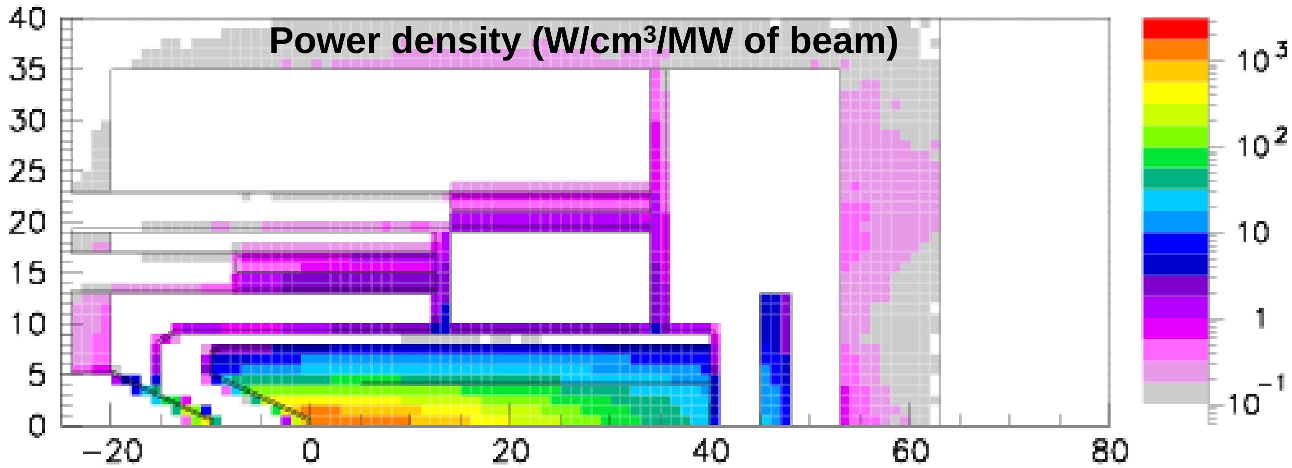
Fission fragment distribution (isotope/cm³/s/MW of beam)

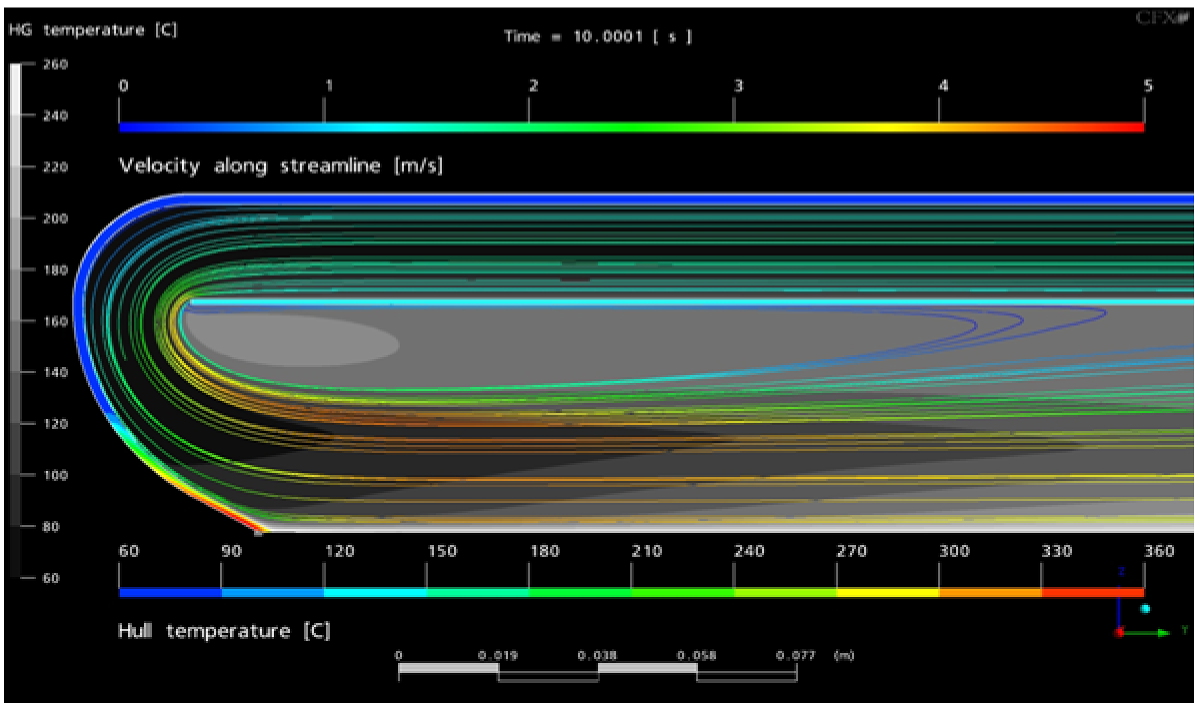




- Intense Radioactive Ion Beams for the selected **neutron-rich** isotopes (up to 10^{14} ions/s of Kr-90 and Sn-132, for the full beam). Clear advantage in using natural uranium.
- Possibility of investigating the lower end of the *terra incognita*, e.g. Nd-157, Tb-167

Engineering Study





- Acceptable power densities in the Hg. Flow pattern not optimised; maximum temperature ~260 ºC.
- Acceptable maximum temperature in the beam window (~350 ºC).
- Large temperature gradient in the window, inducing mechanical stresses above the acceptance limits.

Energy Deposition in the Window

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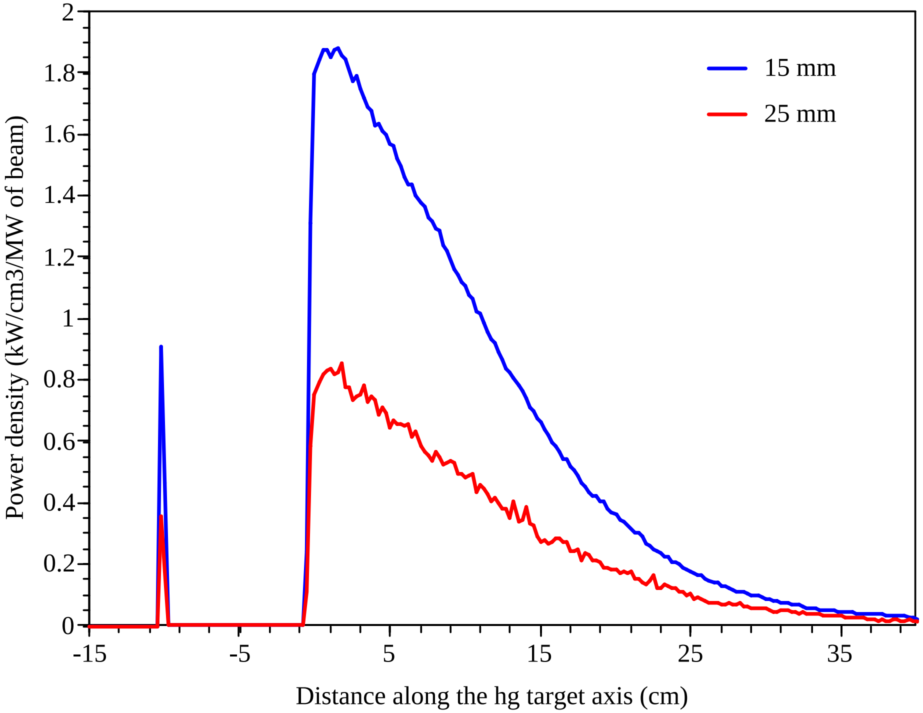

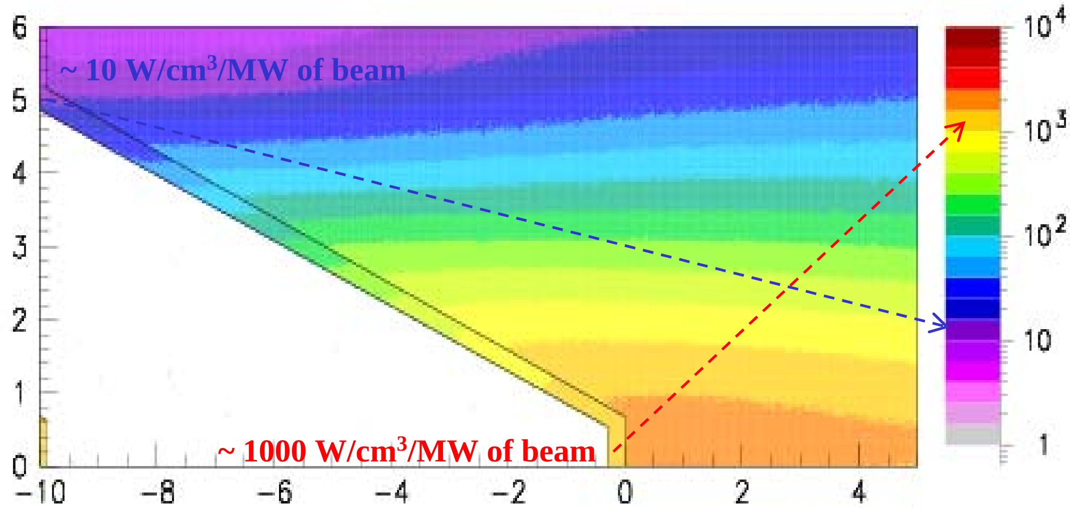

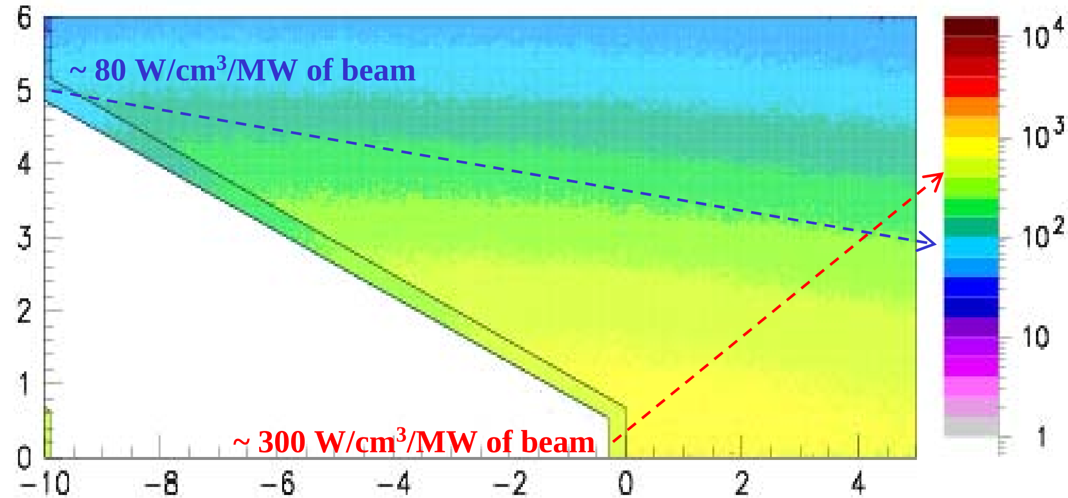

- Max. power density: 1.8 vs 0.8 (kW/cm^3/MW of beam).
- Beam window: 0.9 vs 0.3 (kW/cm^3/MW of beam).
- Significant differences in power density gradients in the beam window.

3D CFD & Structural Analysis

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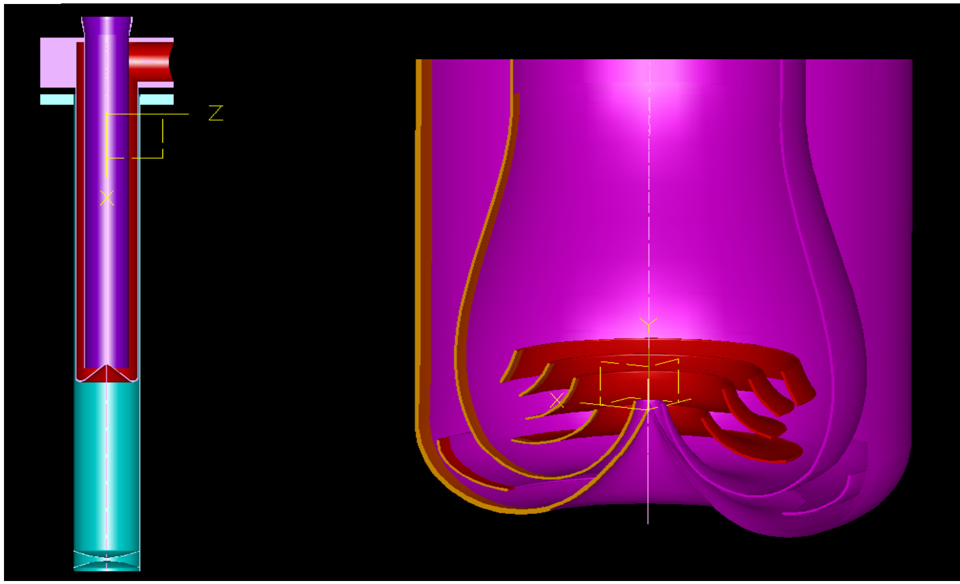
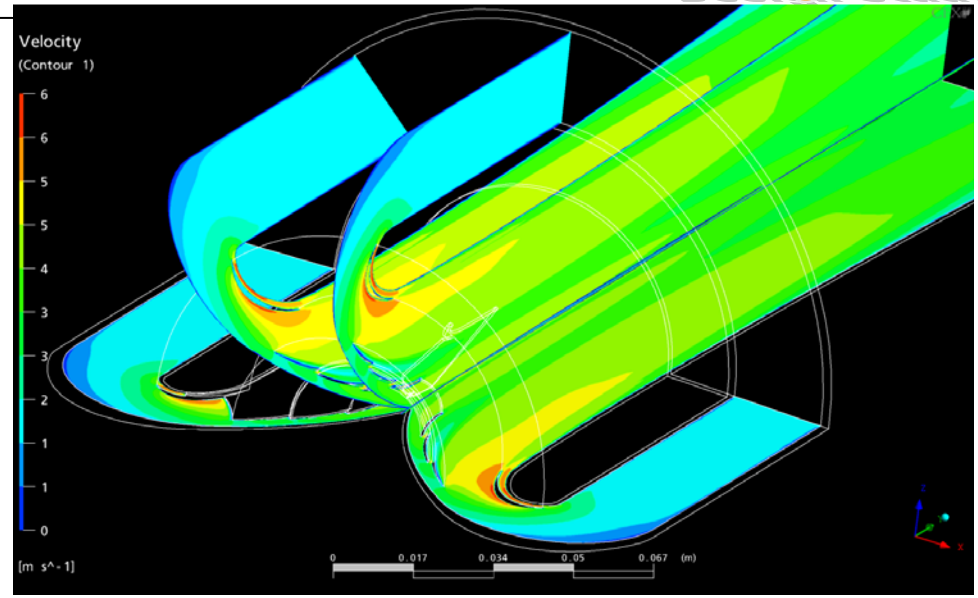
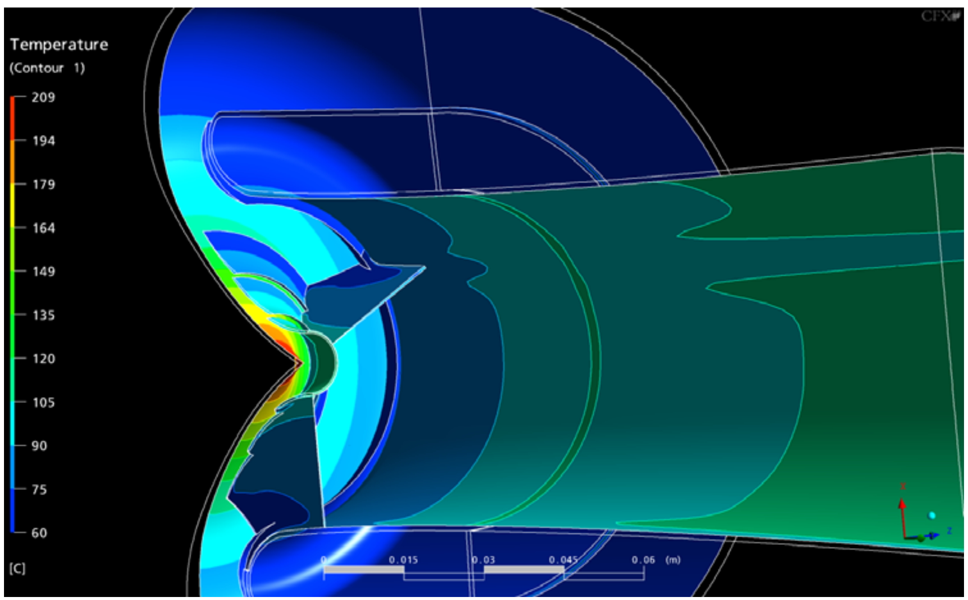
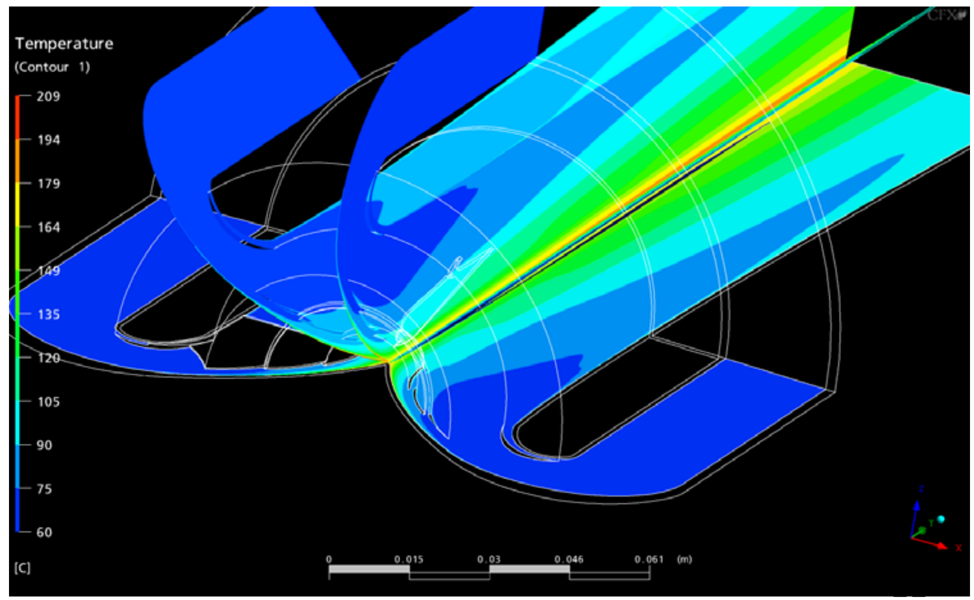
Design Study









Transverse Hg Film Target

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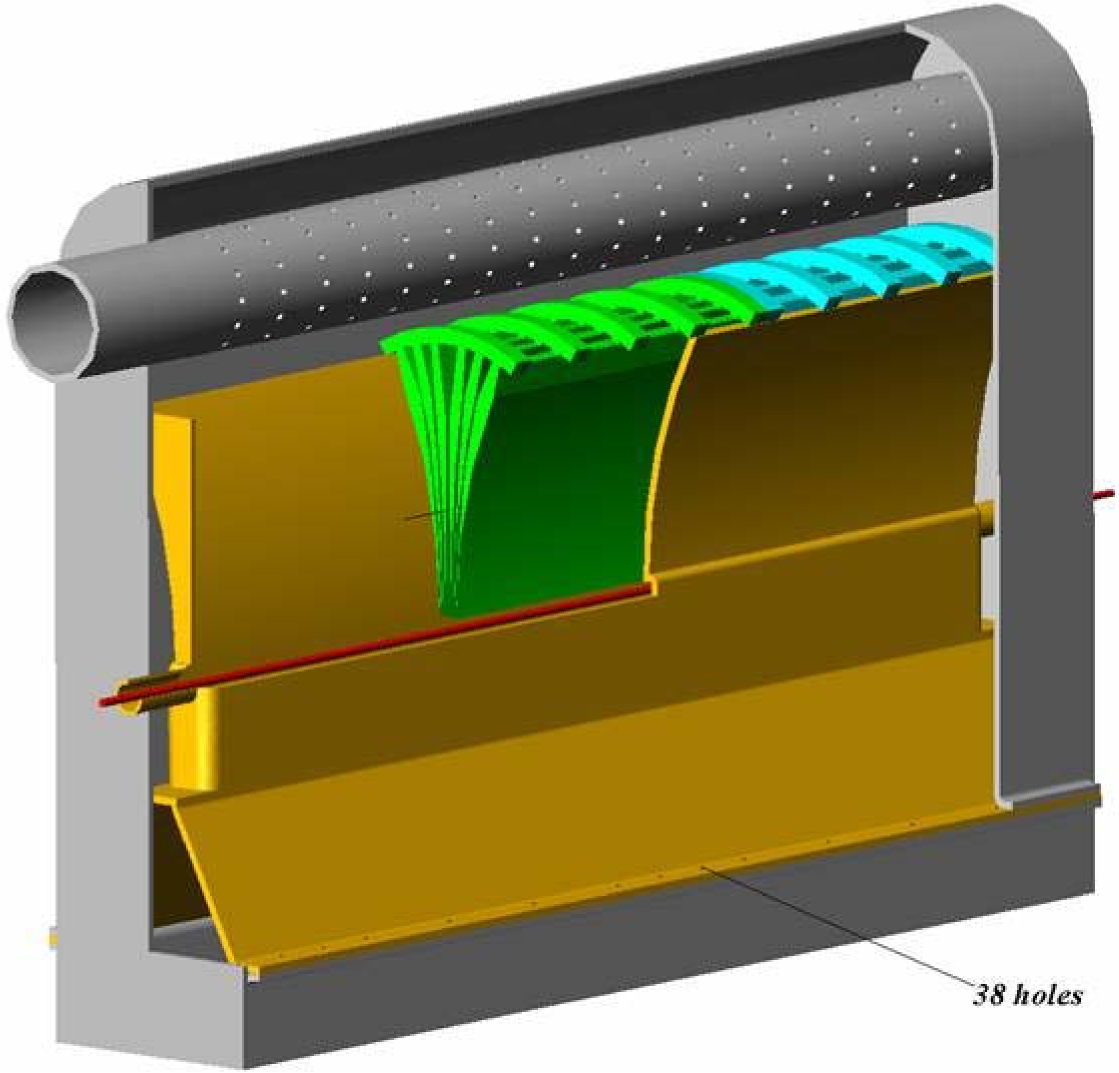
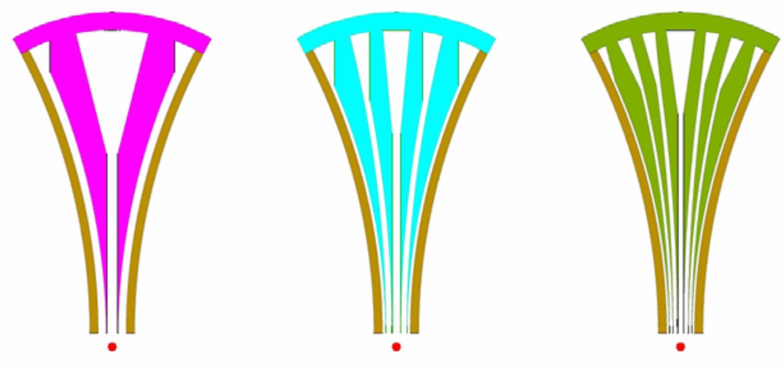


- Allows for different velocities in the Hg flow by changing the distance between of the flow-guides, according to the local heat deposition.
- Total Hg flow rate ~12 l/s. Local velocity for a 3 mm gap ~4.4 m/s -> 118 K temperature increase for a beam σ ~2 mm.



Simplified Transverse Target Model

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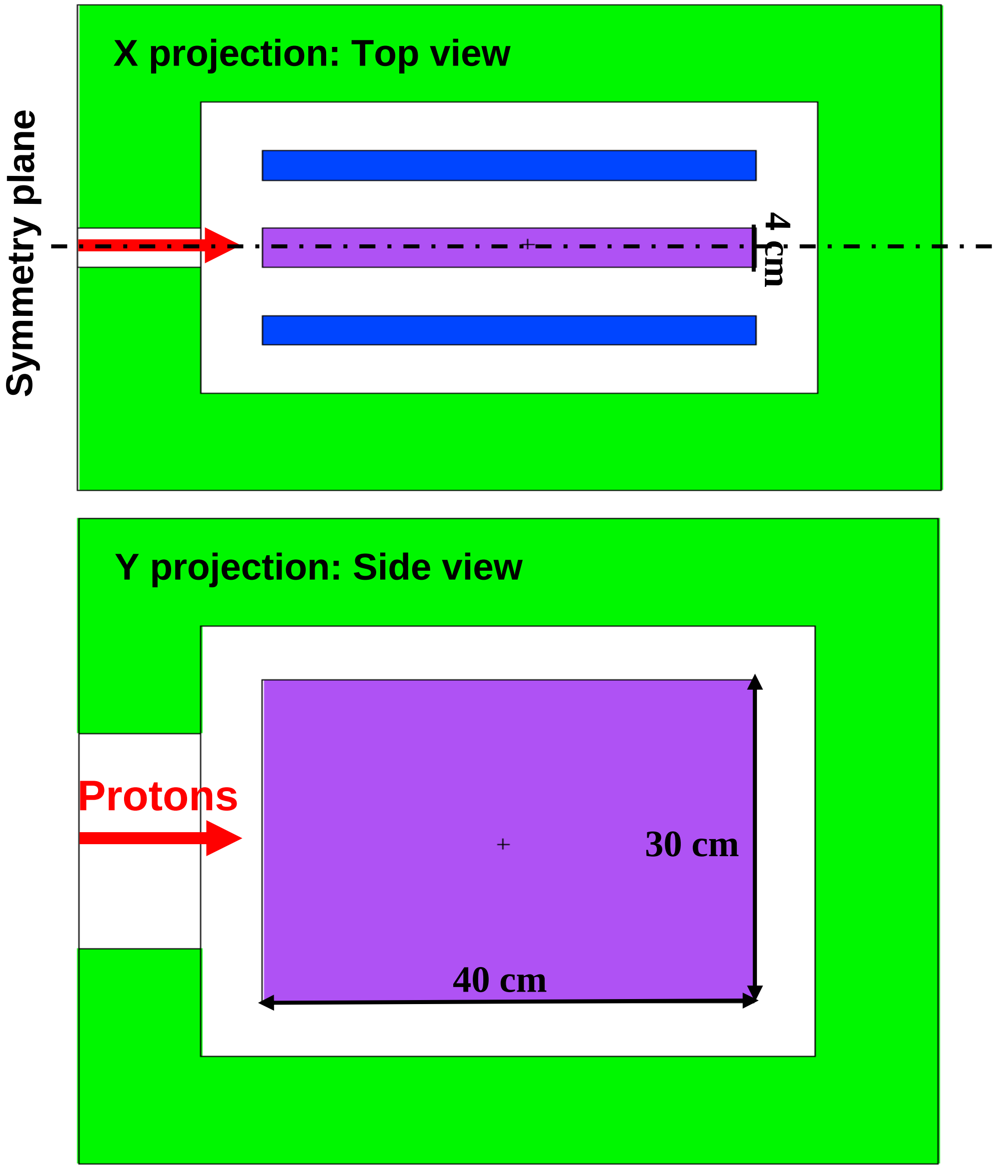

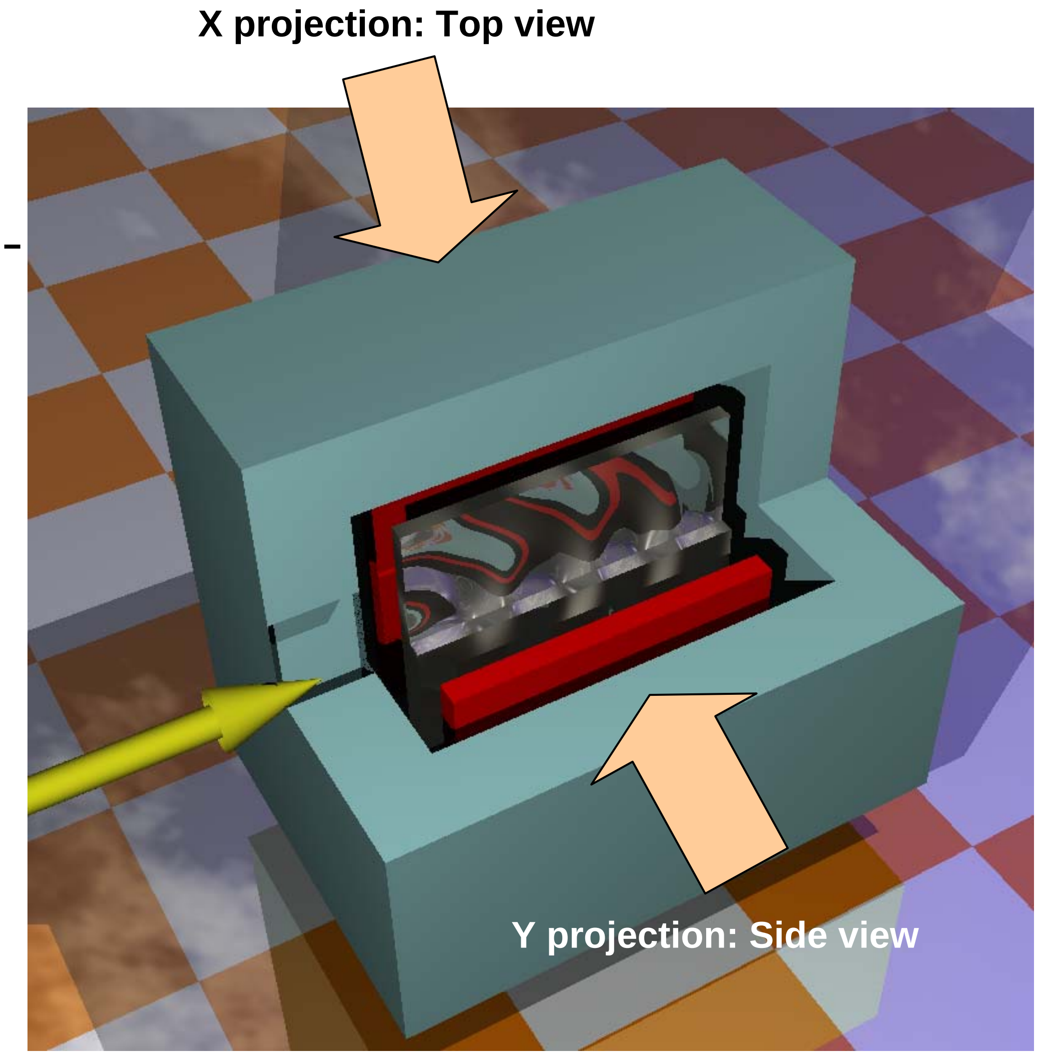

- **Beam distribution: σ_x~4 mm, σ_y~30 mm**

Neutron Balance, Fission and Power Densities

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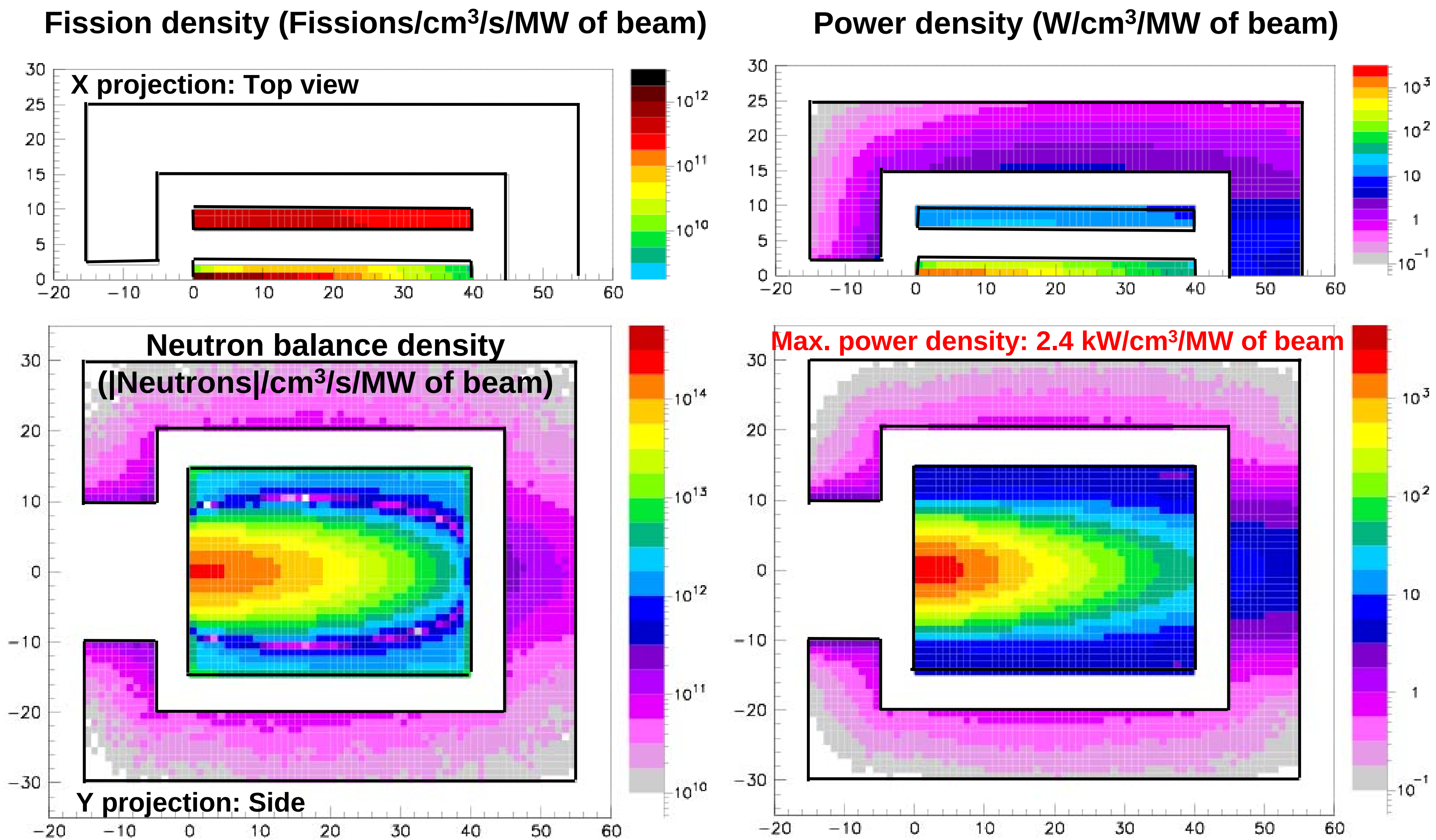

Fission Density Comparison

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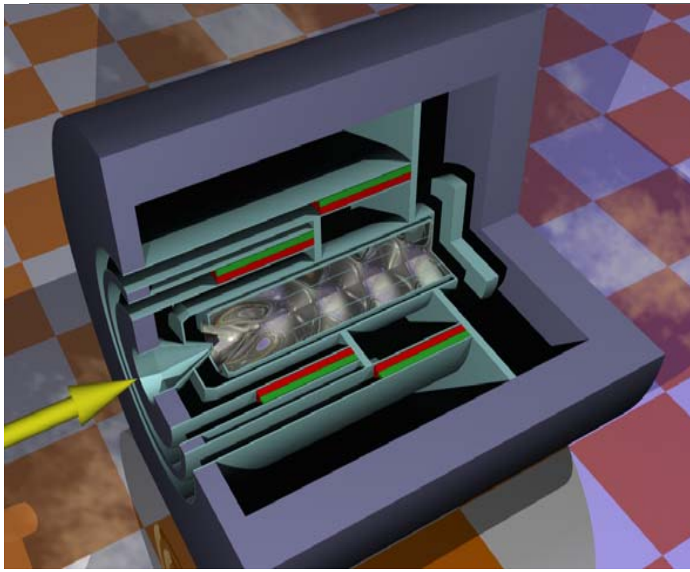
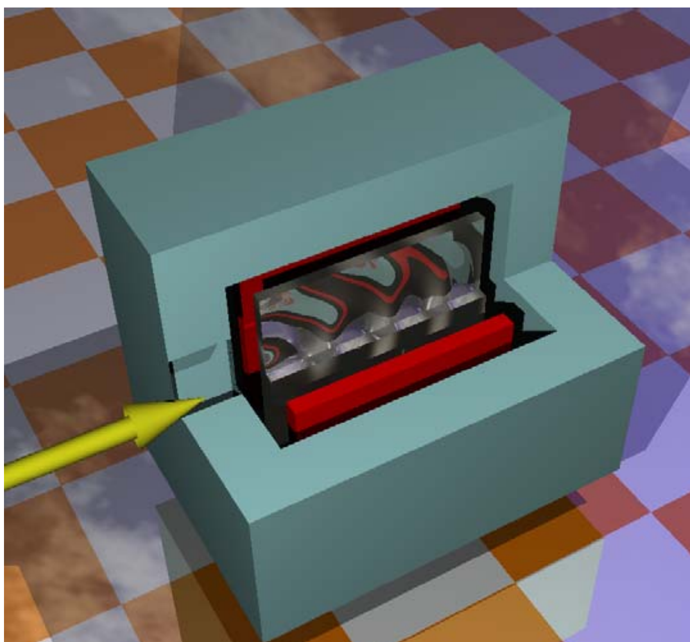
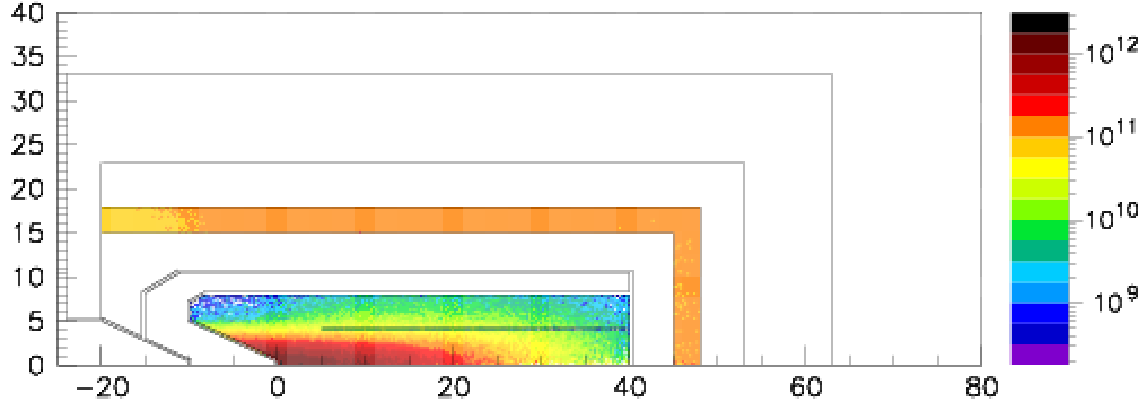
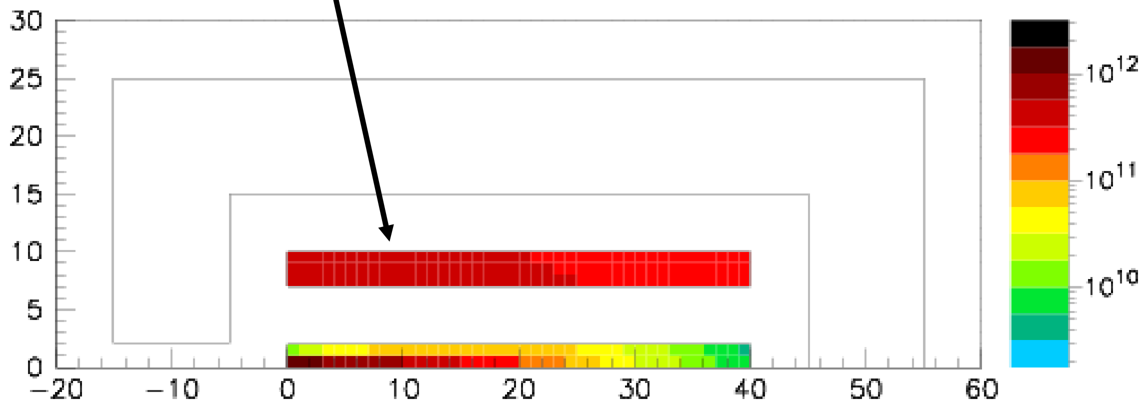




Fission density (fissions/cm^3/s/MW of beam)



Large number of fissions may be achieved with reasonable target volumes and beam power. For example, the aimed ~10^{15} fissions/s may be homogeneously produced within a 1 litre Unat target and 4 MW of proton beam power



Radioactive Ions Production: Kr and Sn

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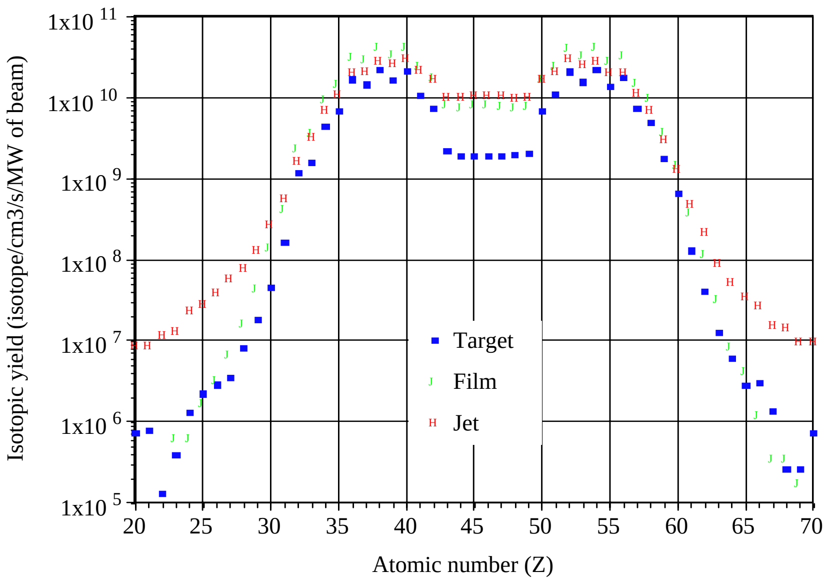
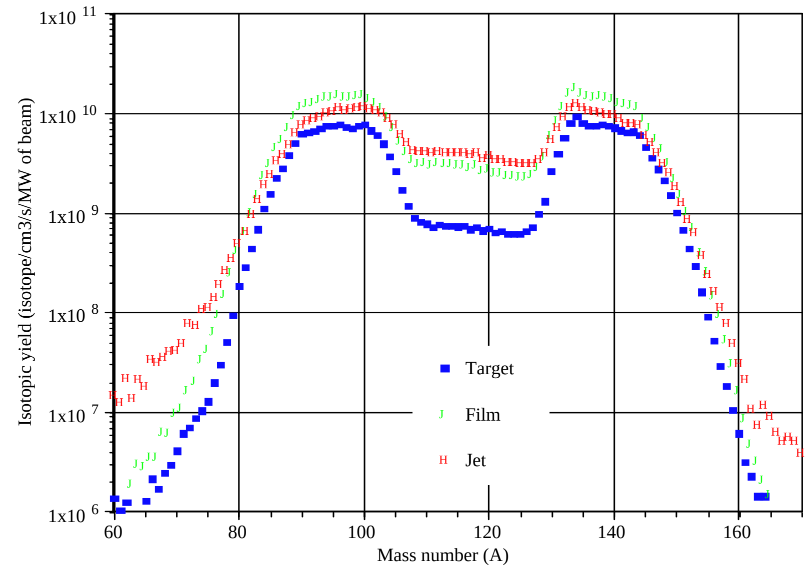
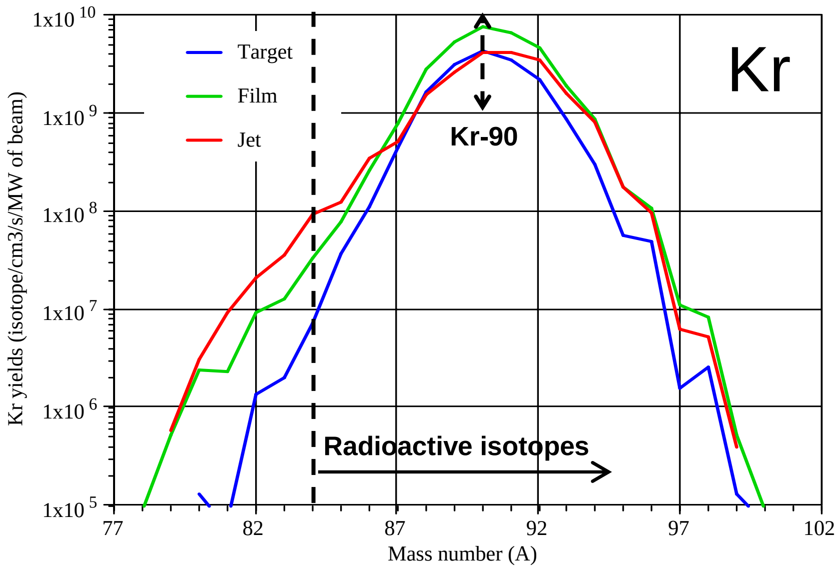
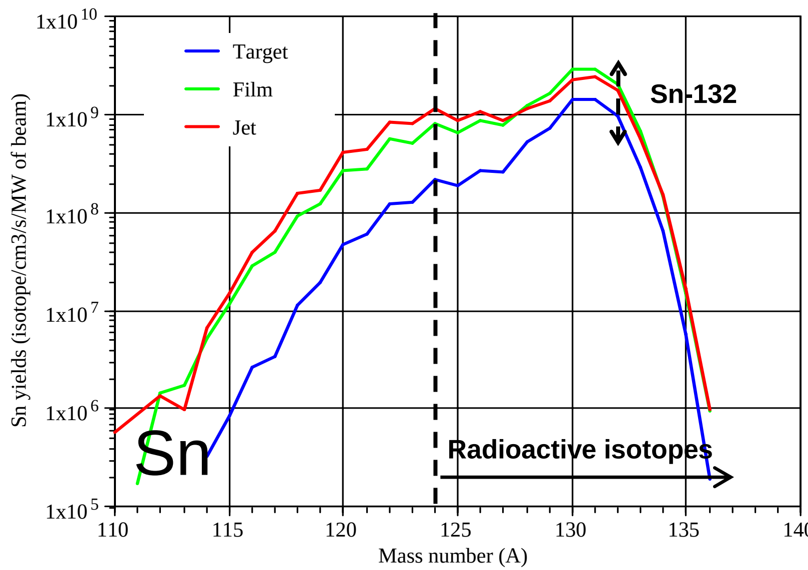
Design Study



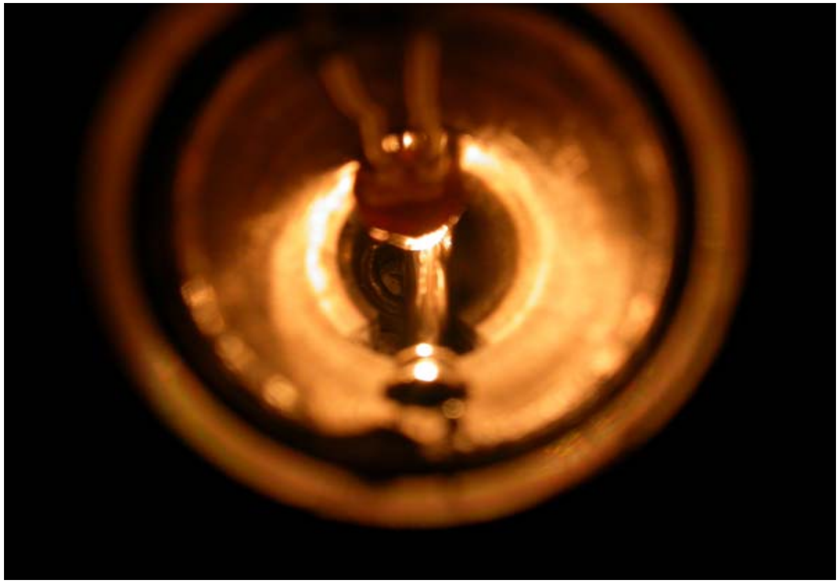


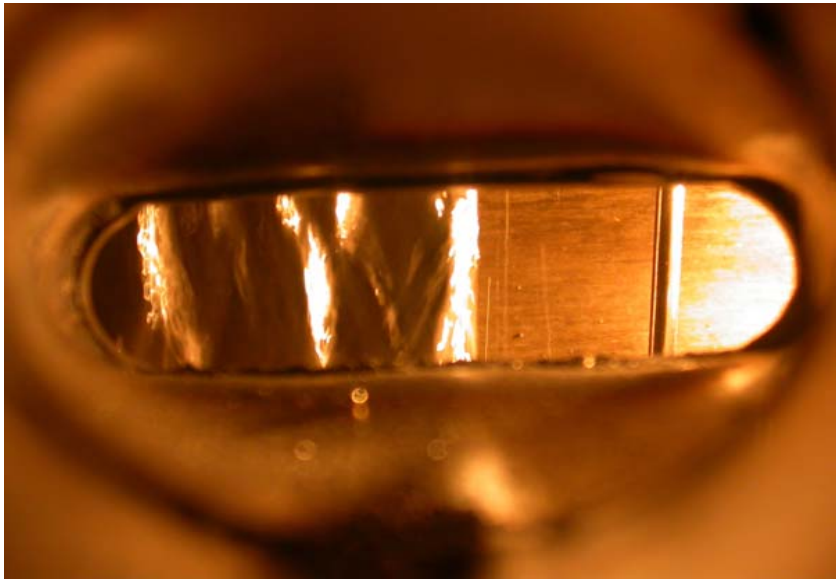
Isotope production (Isotope/cm^3/s/MW of beam)



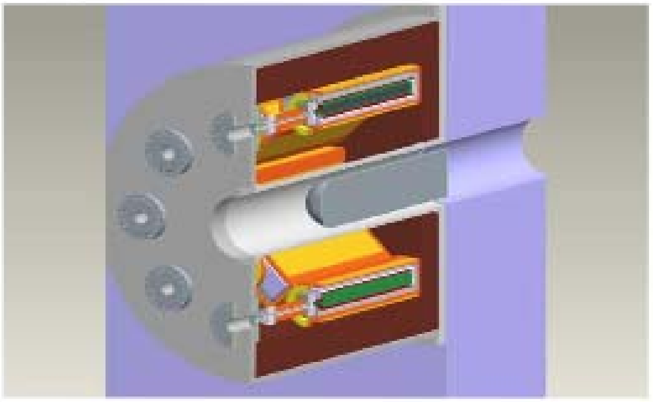


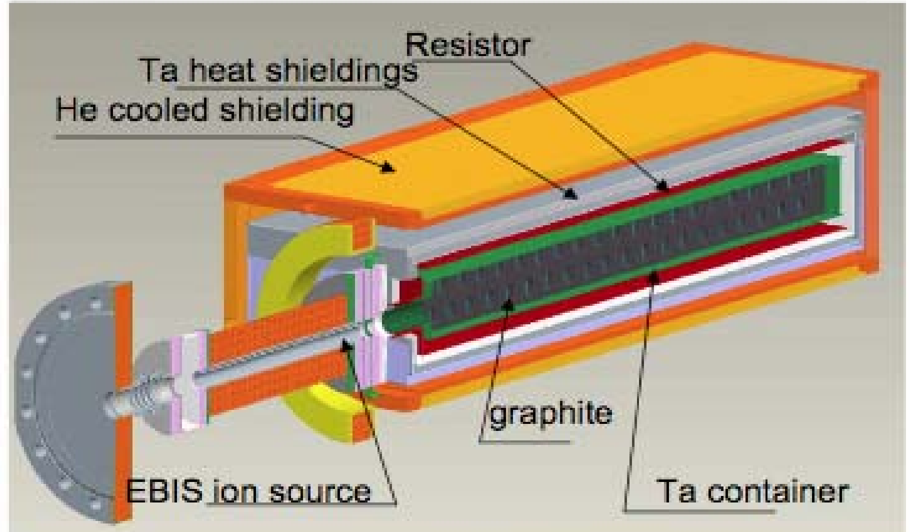
Engineering design and construction of a functional Hg loop (D3)

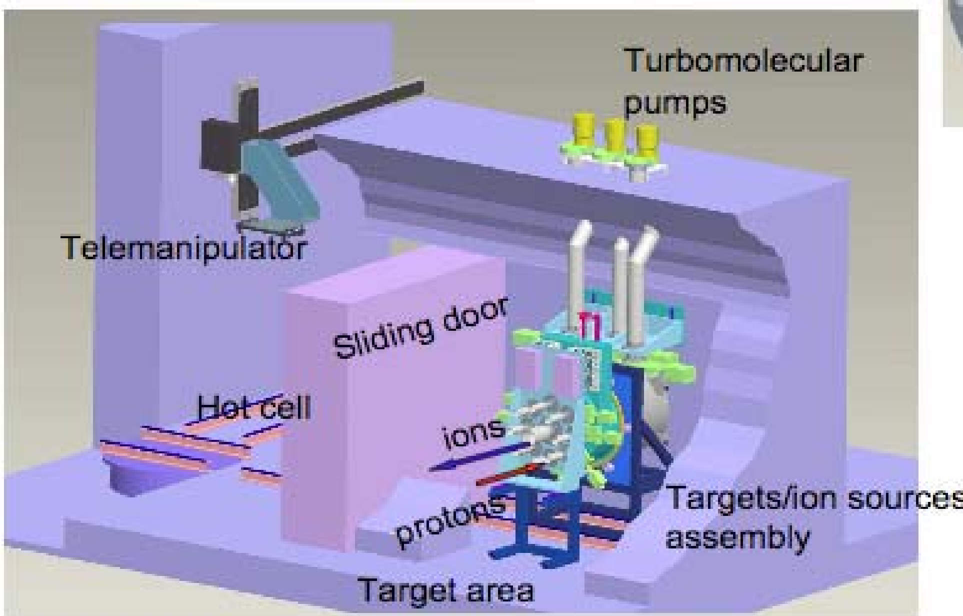




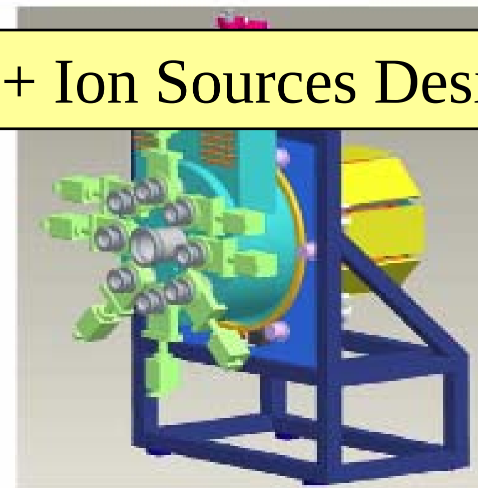
Fission Target Design & Integration







D3: 1+ Ion Sources Design



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.

• 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 (4 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.

• The detailed study of the Transverse Hg Film Target is strongly advised due to its intrinsic technical simplicity and improved neutronic performance.

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