Target Engineering Design: Studies and Options

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MOTIVATIONS

- A mandatory condition prior to the execution of the second phase n TOF-Ph2 is the upgrade of the present spallation target.
- This target, consisting of lead, has been in direct contact with water serving at the same time as a coolant and a moderator during phase I.
- The lead target, which is uncladded, needs to be replaced by a new cladded spallation target.

n_TOF Target Design Specification OPTION #1

The design parameters taken in account in this proposal are:

- Target material: lead
- Target cladding: aluminum alloy
- Target cooling: water (existing system)
- Target dimension: ~40x40x55 cm, ~ 100 liters, ~1.1 tons
- Moderation: water/heavy water, exchangeable during the run
- Useful n-beam diameter at the exit of the target: 40 cm
- n-beam losses (versus old configuration): 20% at low energy,

5% at high energy

- Orthogonal flight-path: foreseen
- Minimization of the 2.2 MeV γ flash: optimized
- Installation of the new target and moderator exchange: via the shaft
- Hoist system: same functionality of the existing one

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

The decision to privilege the aluminum is motivated by the following reasons:

- No limitation of the cladding thickness due to the transparency to neutrons
- Lower activation for decommissioning and final disposal (no production of ^{60}Co)
- Metallurgical compatibility between lead and aluminum
- Uniformity of the material in the cooling basin to avoid corrosion (aluminum walls).

OPTION #1
Bibliography

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Cladding Options

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Cladding Options Ct'd

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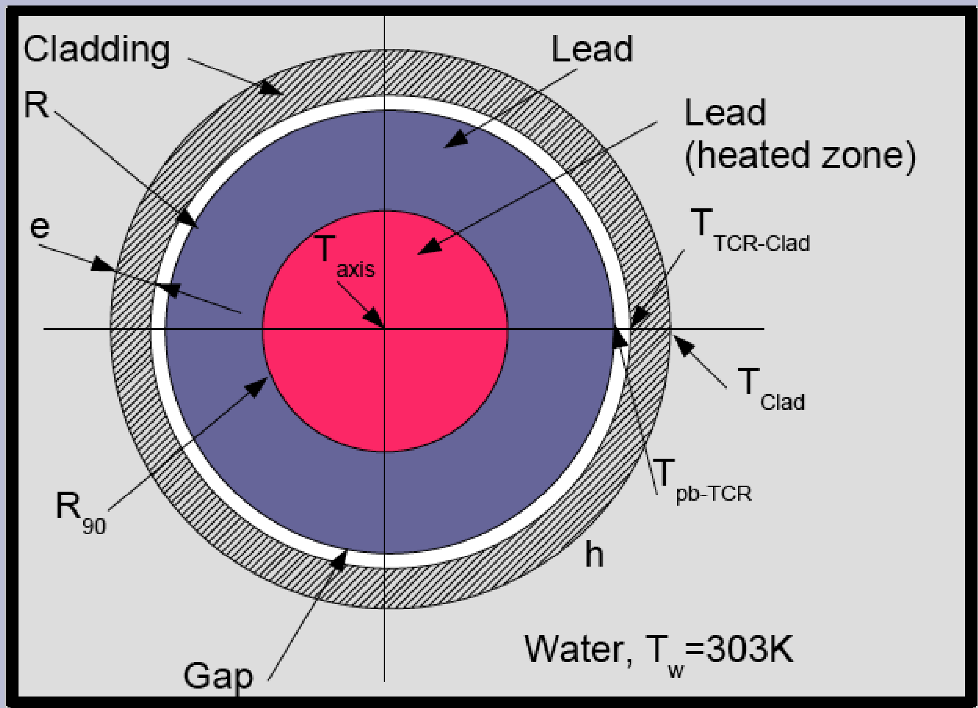
OPTION #1
Thermal Analysis

Protons at 20 GeV: 7×10^{12} p/pulse
Pulses per Supercycle (16.8 s): 5
Protons per year: 3.2×10^{19} (typical value for the previous runs1.3×10^{19})
Corresponding to an average power of 3.4 kW deposited in the lead.

30-11-2006 SBM-Ingénierie CERN nTOF Lead Target

LEAD TARGET: Ct'd
EQUIVALENT THERMAL MODEL



Thermal conductivities (W/m/K):
K_{clad} (Al~200 / SS,Ti~20)
K_{pb}=33
K_{w}=0,6

Thermal contact Resistance (m^2.K/W):
TCR~168.10^{-4} (Ref.2)

Convection (W/m^2/K):
h~10^3

Radii (m):
R=0,265
R_{90}=0,130
e~5.10^{-3}

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Thermal Analysis Ct'd

- The heat is evacuated in the radial direction.
- The thermal behavior is dominated by the conduction in lead (Δ_{Pb}=~49°C) and by the thermal contact resistance at the interface lead-cladding (Δ_{TCR}=~86°C).
- The temperature difference between the lead core and the cooling water is Δ_T= 138°C
- Due to the lead expansion, the cladding structure is subject to severe structural constrains.
- A controlled radial gap between the lead and the cladding at ambient temperature could be the solution.

==> Further thermo-mechanical calculations are needed to get an optimal initial gap

OPTION #1
Cooling Efficiency

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OPTION #1
Cooling Efficiency Ct'd

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OPTION #1
Cooling Efficiency Ct'd

Remarks:

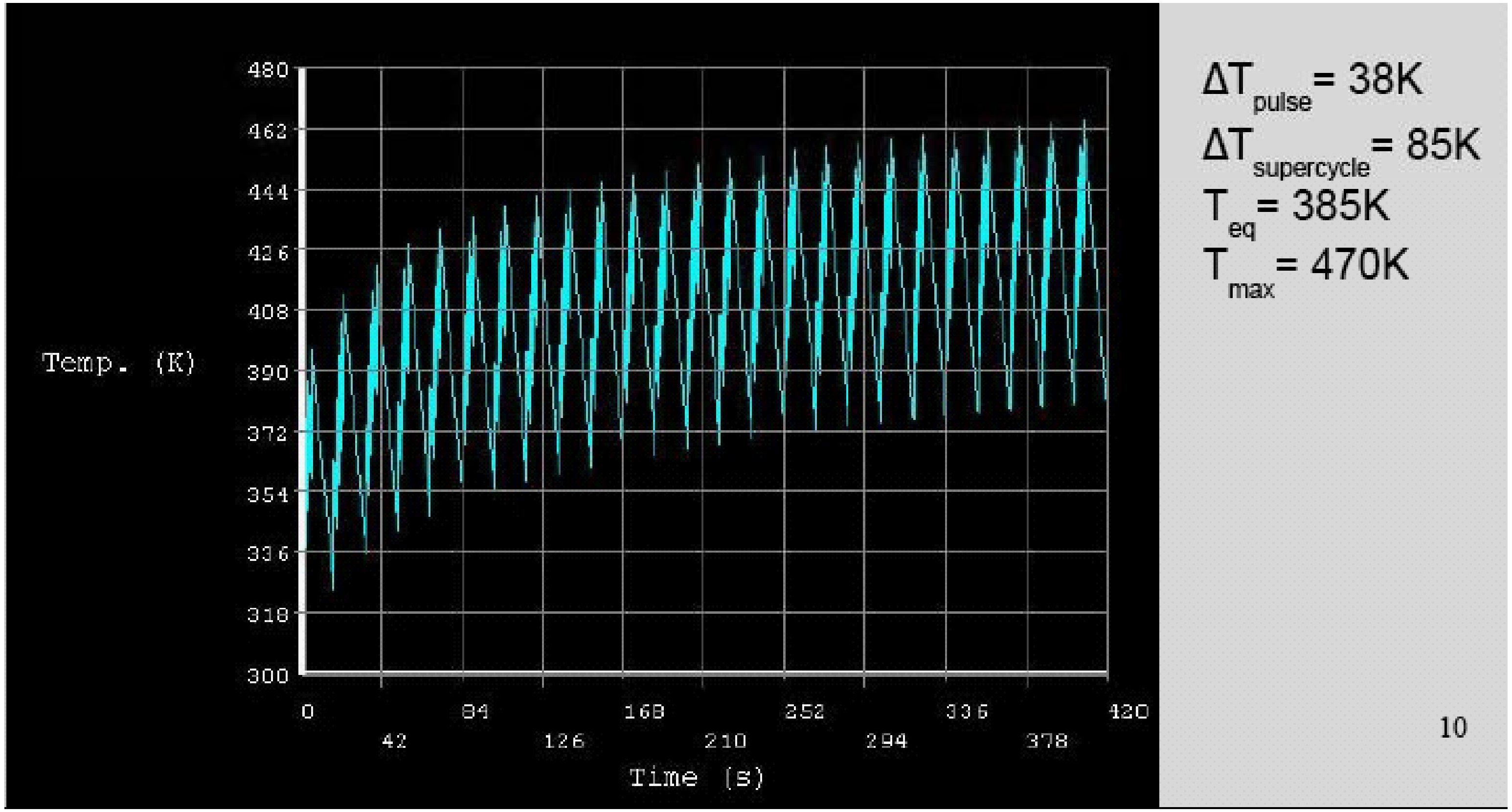
1. Lead target is cooled to expectations (DT ~ 138K)
2. Average cooling water temperature rise is < 2K
3. Peak cooling water temperature rise is ~ 30K

General conclusions:

1. Filling part proved to be efficient
2. Impact on target integration and target support to be evaluated
3. Complex geometry

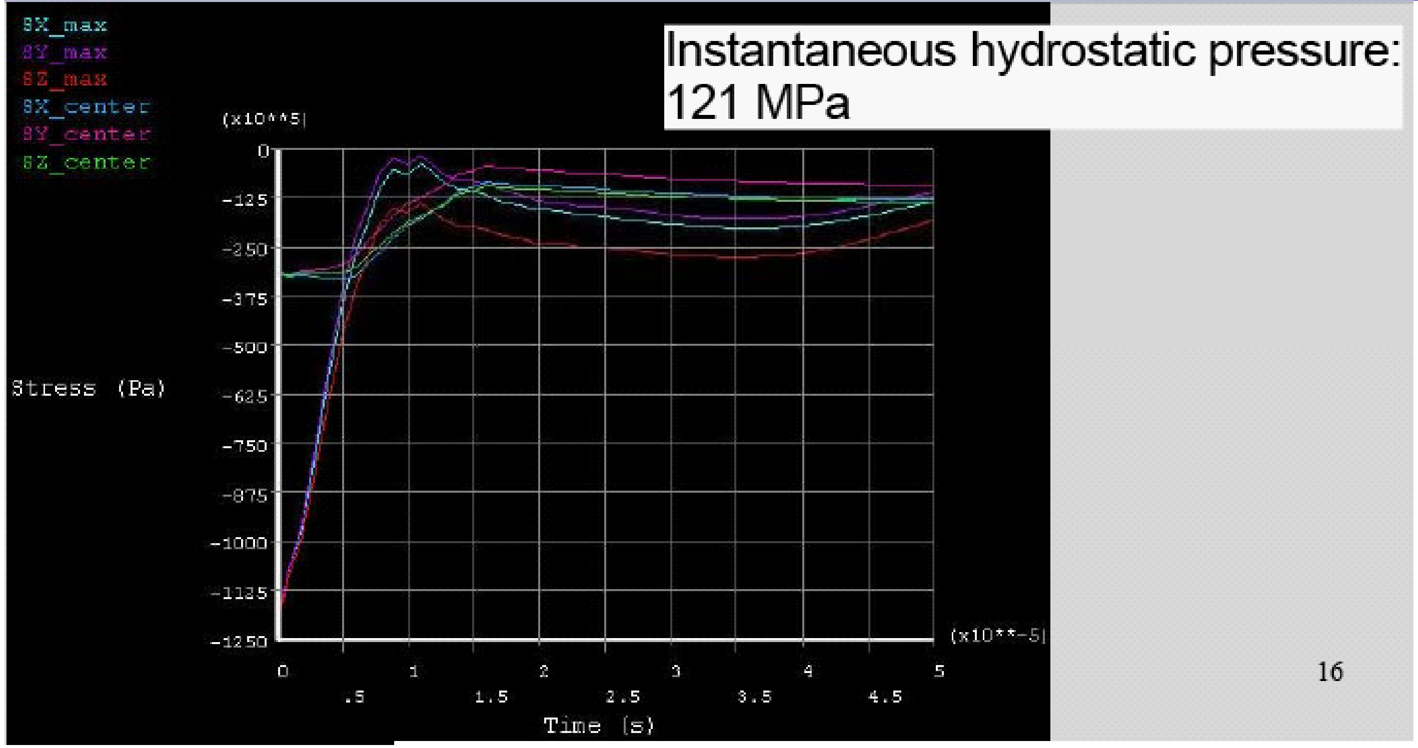
OPTION #1
Thermo-mechanical Transient Analysis:

Temperature evolution in the hottest point for the nominal proton intensity at a repetition rate of $7x10^{12}$ p/pulse, 5 pulses per 18.6 s Super-Cycle



The results obtained with ANSYS are confirming the analytical simulations and are predicting a maximum lead temperature inside the target body of 200°C. These results are obtained assuming the thermal contact resistance at zero pressure between lead and cladding (giving a Δ_{TCR}=~86°C in the analytical study).

Transient Elasto-Plastic Study:
Target behavior in response to one proton pulse:



QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Transient Elasto-Plastic Study

Conclusions:

1. Strain hardening of a portion of the central region occurs in response to a single nominal p pulse
2. Max Von Mises equivalent plastic strain is 0.07%
3. => Failure of the target in this region will occur (number of cycles depend on detailed material properties)

Next steps:

1. Get detailed material properties (literature/experiments)
2. Implement failure criteria in the model
3. Take into account the contact gap and the cladding material
4. Fatigue analysis of both lead and cladding

The inspection of the old target after five years of running (6.5×10^{19} p on target) could give an answer to this question in case of evident damage of the lead entrance surface

OPTION #2
The Mini-Pool Concept

- The lead core is immersed in a sealed aluminum container.
- A water layer, between the lead and the container walls, provide the laminar flow for the heat removal ==> substitution of the thermal contact layer by a water convective layer
- The aluminum container is cooled with the existing system

=> it would avoid the problems arising with the interface with lead and cladding, namely the large thermal resistance and the structural constraints due to the lead expansion.

Thermal model used for the Mini-Pool Concept

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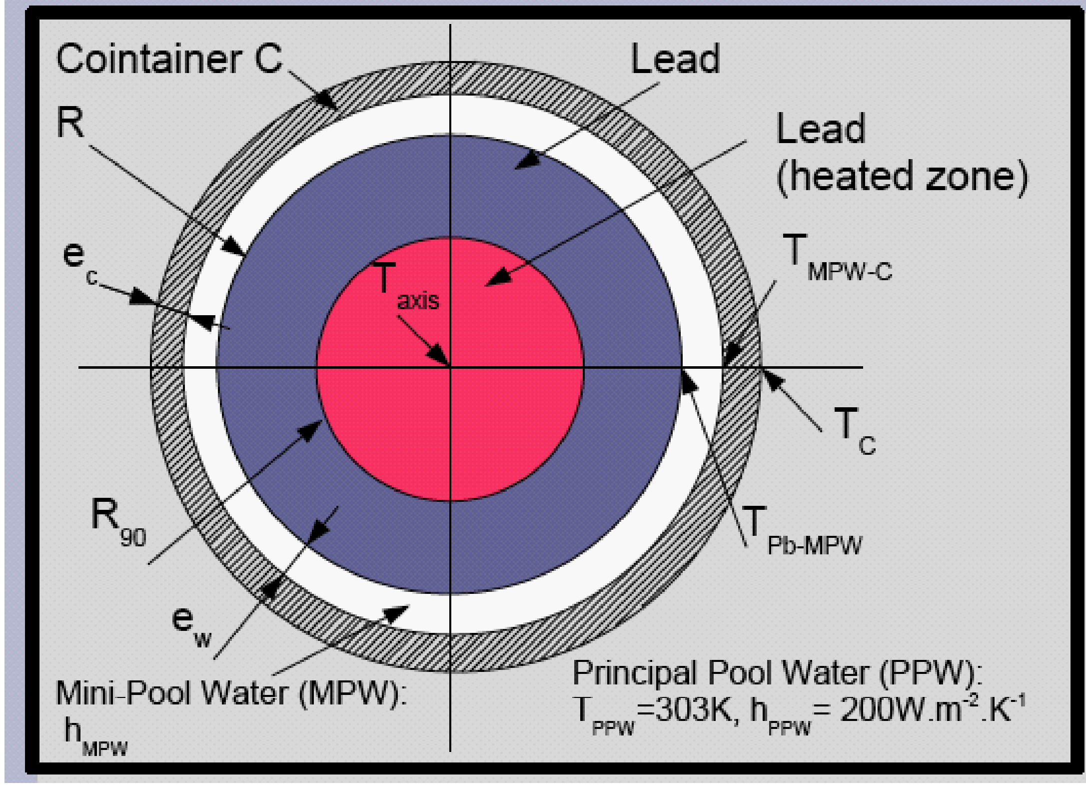
I. ANALYTICAL STUDY Ct'd



Thermal conductivities (W/m/K):
K_c (Al~200)
K_{pb}=33
K_w=0,6

Radii (m):
R=0,265 $e_c=2.10^{-3}$
R_{90}=0,130 $e_w=10^{-2}$

h_{PPW} from [2]

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OPTION #2
The Mini-Pool Concept

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The Mini-Pool Concept

1. Lowering the temperature in the cooling system just above the dew point (~15°C drop)
2. Providing fins on the Mini-Pool external walls to increase the heat exchange surface (estimated ~9°C drop)
3. Increasing the pressure allowable inside the Mini-Pool to raise the water ebullition temperature level (~20°C at 2 bars).

==>

Providing a double shell container to optimize the water laminar flow.

OPTION #2
The Mini-Pool Concept

* With recirculation guide:

MAX T_C = 326 K (53°C)

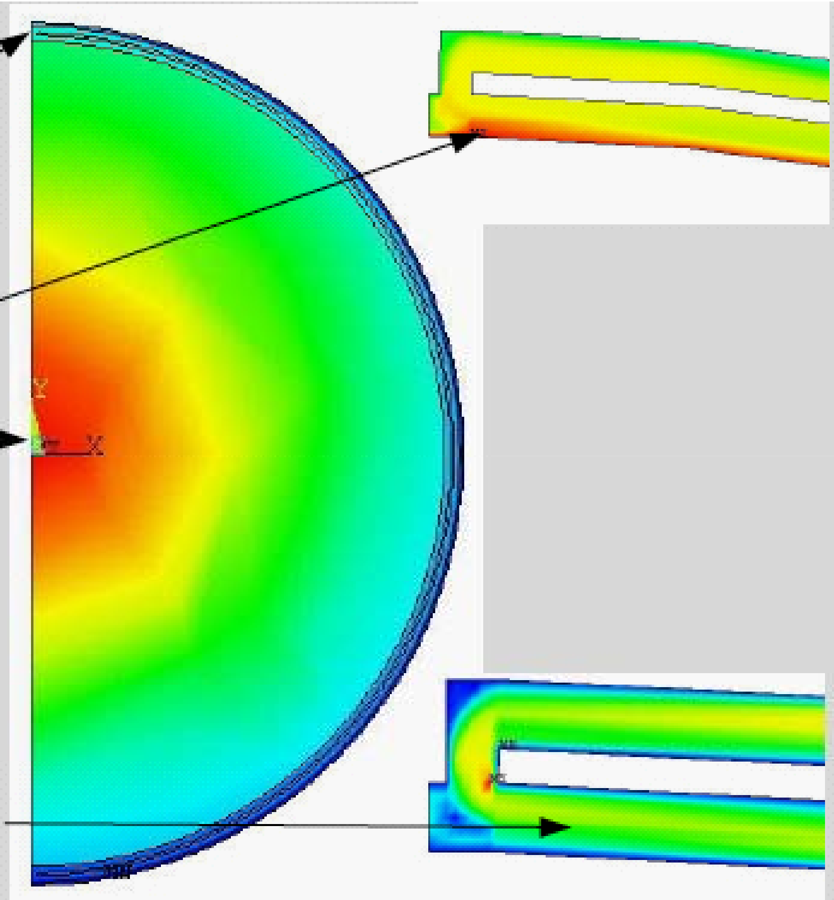
MAX $T_{pb\text{-}MPW}$ = 343 K (70°C)

MAX T_{pb} = 383 K (110°C)

ΔT_{MPW} = from 12K to 25K

h_{MPW} = from 180 to 920 W/(m^2.K)

velocity = from 1,3 to 1,9 10^{-2} m/s



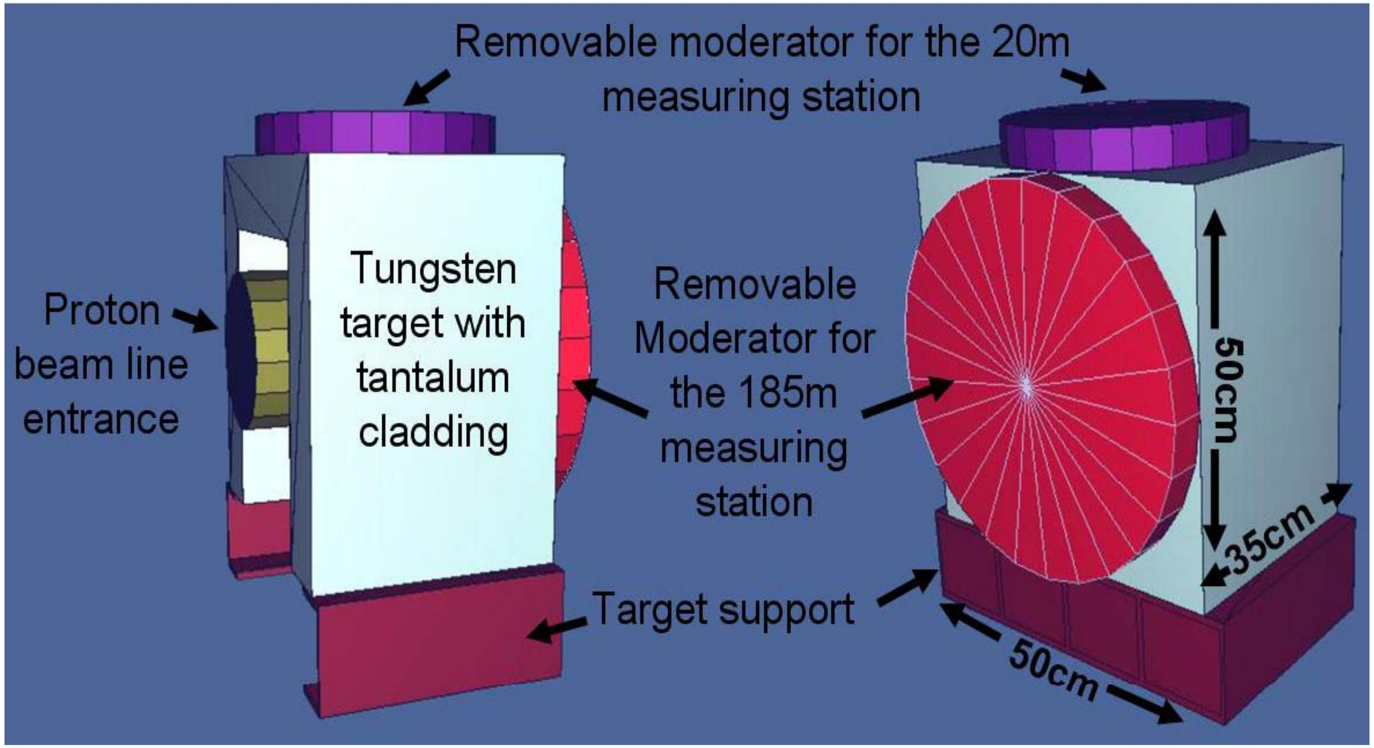
General conclusions:

1. The Mini-Pool solution needs the production of a new lead core
2. The design and construction of a double shell aluminum container
3. The design of this part must follow the rules applying for the pressurized vessels (CODAP)

==> Strong design & financial effort

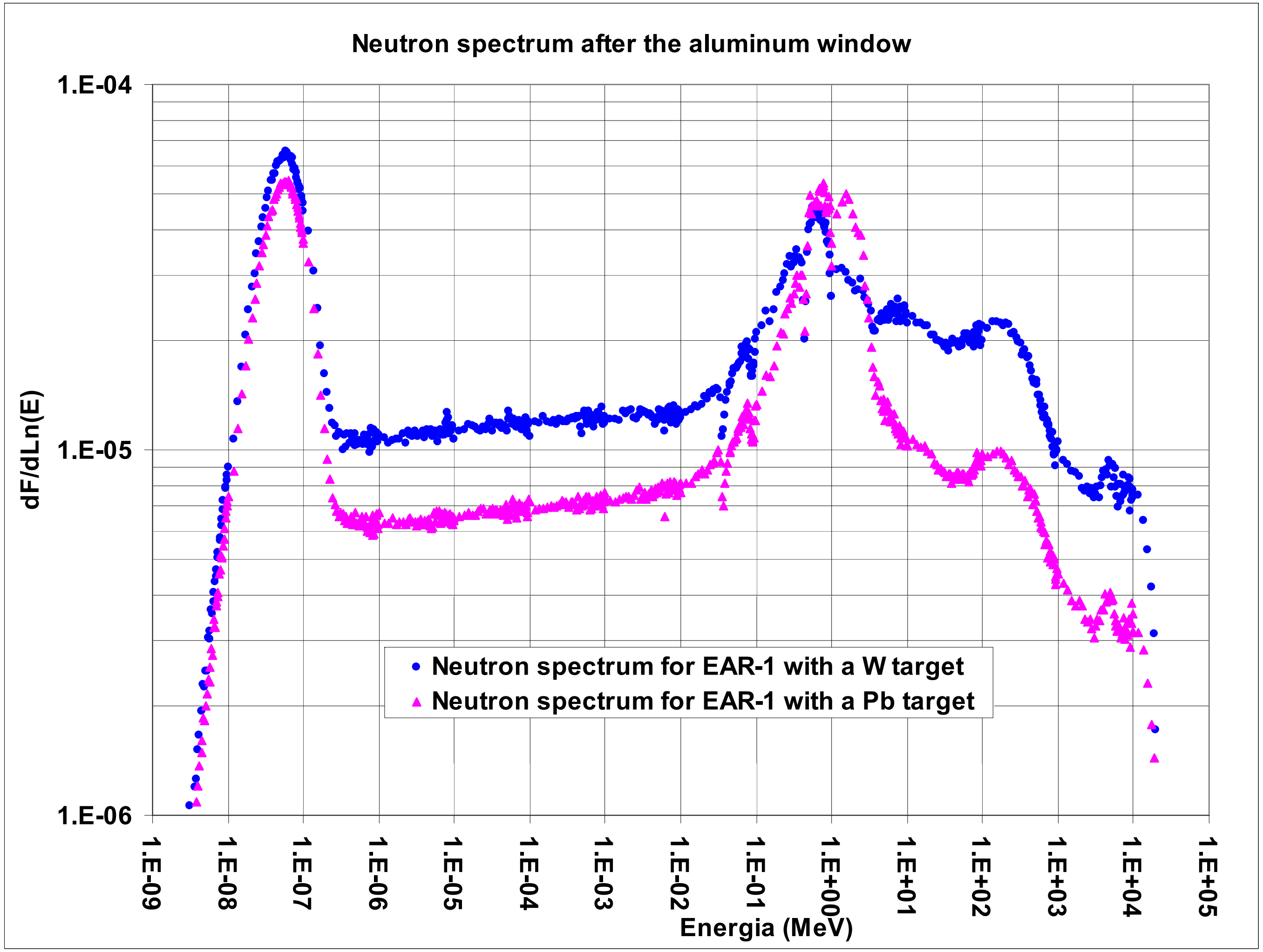
==> handling/Decommissioning of activated water

The Air-Cooled W Target Concept



1. The new target setup consists of a Tungsten target (50 x 50 x 35 cm^3) with a cladding layer of Tantalum (0.1mm).
2. The moderators are two cylindrical blocks consisting of Aluminium canning encapsulating the moderation material (water).
3. Water is replaced by air as coolant medium

OPTION #3
The Air-Cooled W Target Concept



General conclusion:

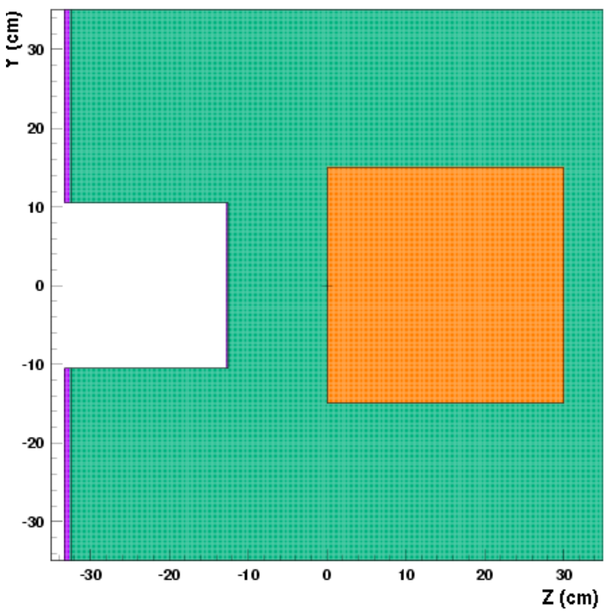
1. The neutron fluence is almost a factor 2 higher for the tungsten target in the energy range of relevance for the n_TOF experiments

==> Design & Engineering Study

==> handling/Decommissioning of radio-active parts

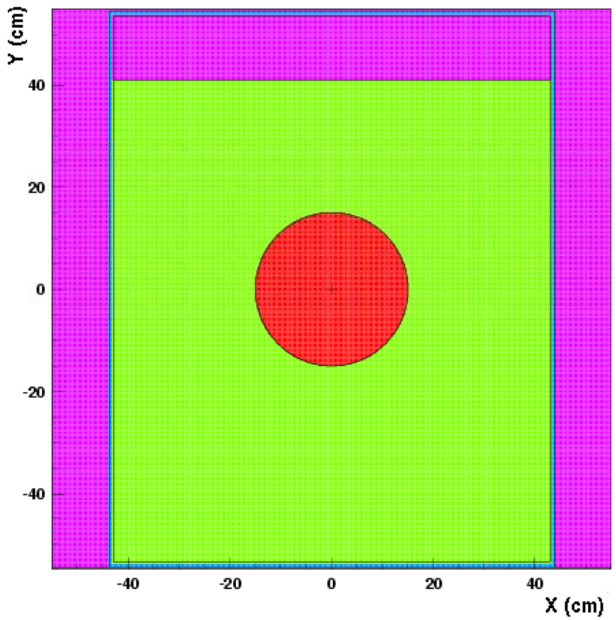
OPTION #4
The Water-Cooled Ta Target

Side view



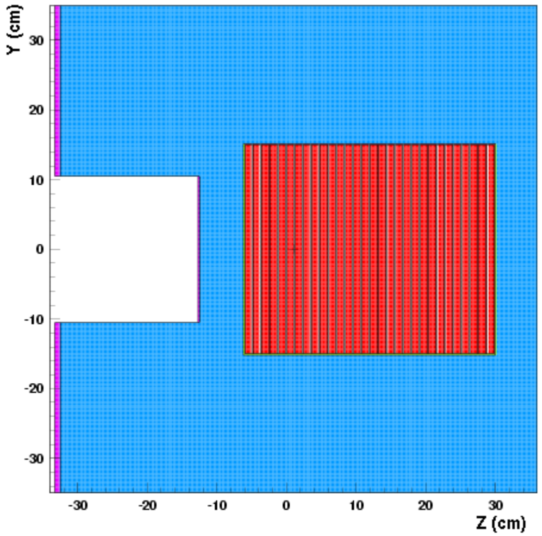
- Length: 30 cm
- Diameter: 30 cm

Front view

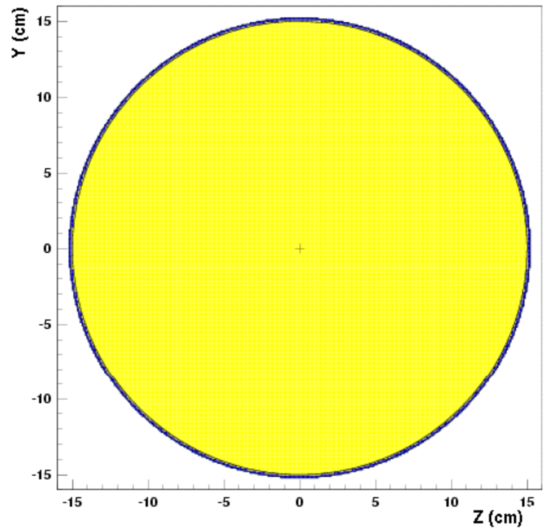


The Air-Cooled Al-Cladded Ta Target

Side view

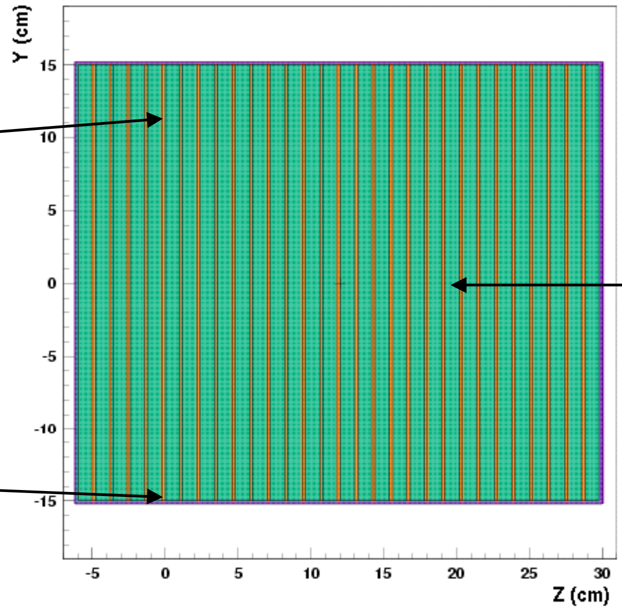


Front view



- Length: 30 cm
- Diameter: 30 cm

0.2 cm air thickness

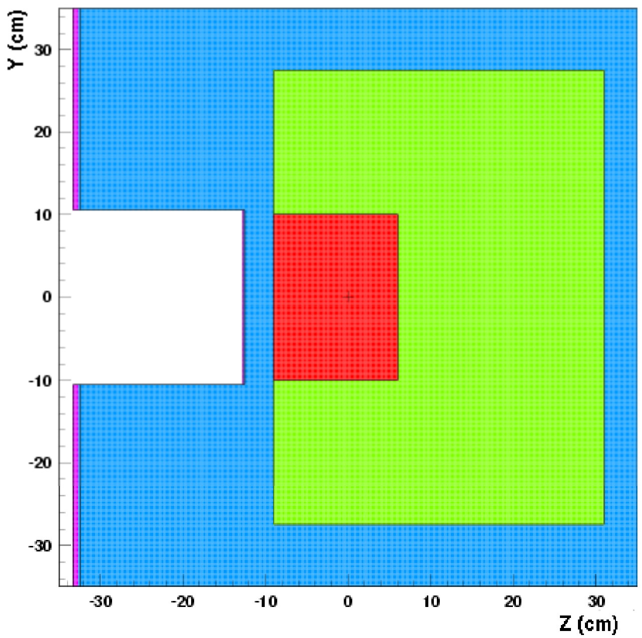


1 cm tantalum thickness

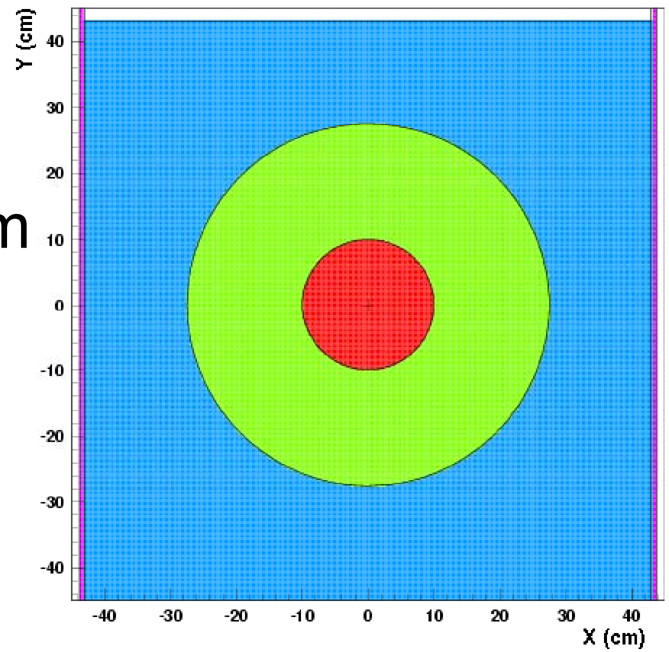
0.2 cm Al cladding thickness

OPTION #6
The Water-Cooled Ta-Filled Pb Target

Side view



Front view



→ Tantalum:

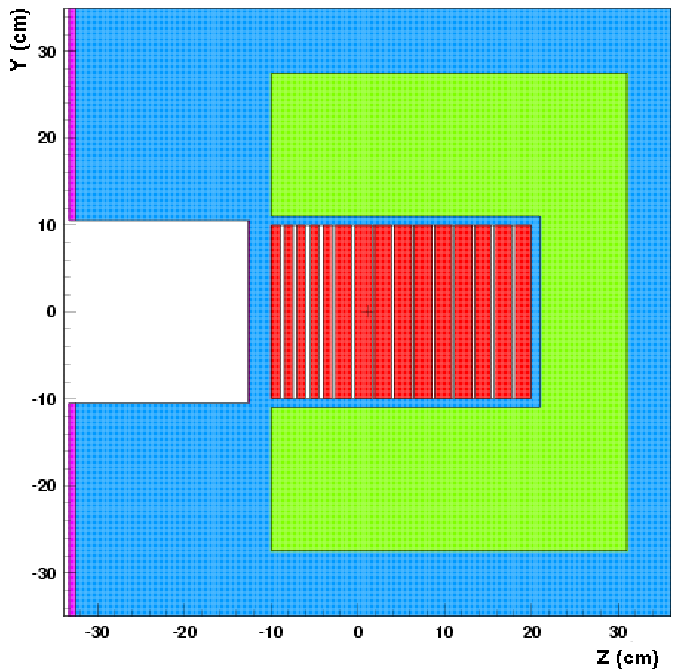
- Length: 15 cm
- Diameter: 20 cm

→ Lead:

- Length: 40 cm
- Diameter: 55 cm

The Water-Cooled Ta-Filled Pb Target

Side view



→ Tantalum:

- Length: 25 cm
- Diameter: 20 cm

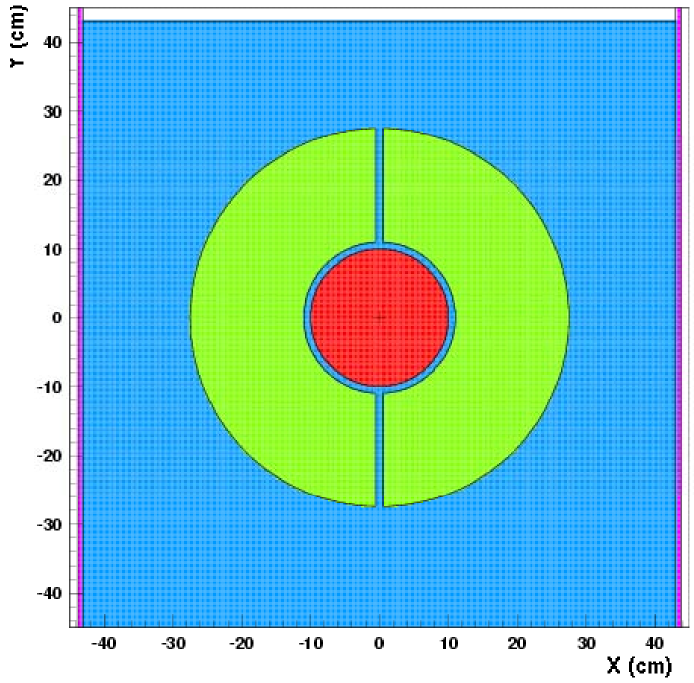
→ Lead:

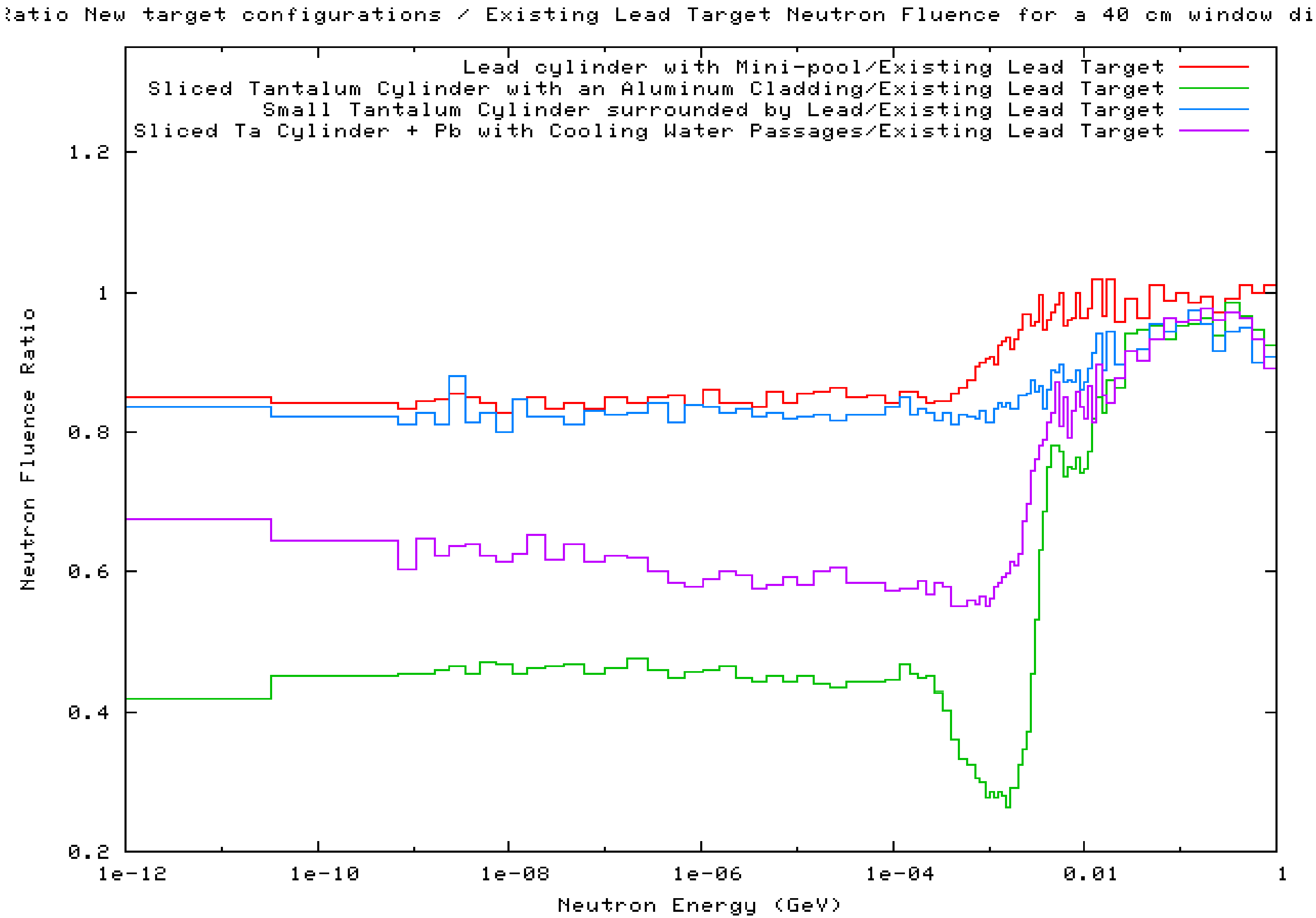
- Length: 40 cm
- Diameter: 55 cm

→ Water:

- Thickness: 1 cm

Front view




Ratio New target configurations / Existing Lead Target Neutron Fluence for a 40 cm window di
Lead cylinder with Mini-pool/Existing Lead Target
Sliced Tantalum Cylinder with an Aluminum Cladding/Existing Lead Target
Small Tantalum Cylinder surrounded by Lead/Existing Lead Target
Sliced Ta Cylinder + Pb with Cooling Water Passages/Existing Lead Target
Neutron Fluence Ratio
Neutron Energy (GeV)
1.2
1
0.8
0.6
0.4
0.2
1e-12
1e-10
1e-08
1e-06
1e-04
0.01
1

Conclusions

- Detailed Engineering Design
- Target Handling
- Fatigue Analysis
- Cooling Efficiency
- Radiation Impact

==> Fabricability & Cost Estimate