Rotating Tungsten Helium cooled Target RoTHeTa

EUROPEAN SPALLATION SOURCE

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4th High Power Targetry Workshop

Malmö 2011-05-02

Outline

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>Practical motivation for Rotating Target
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Some history

>Granular Tungsten target helium cooled was first proposed by Peter Sievers for a MW neutrino factory

>First we have considered spheres in a stationary target
⇒Optimum configuration for cooling, thermal shock and thermal stress
⇒Heavy cooling requirements (High Pressure!)

Under the ESS condition a rotating wheel, fitted with tungsten rods and cooled with helium is a viable solution…

Practical Motivation for Helium Cooling

> Objectives:

Avoid Liquid metal technology
Avoid Water cooling / corrosion issue related to tungsten target and therefore avoid cladding

> Advantages:

Known technology
Low activity in the cooling fluid
Leak tightness

> Drawbacks:

Pressurized gas equipment (3-10bar)
Leak tightness

Practical Motivation for Granular Target

> Objectives:

Allows cooling fluid to remove heat within the target (directly where it is deposited)

> Advantages:

High density target (75% to **90%** of pure tungsten)
No thermal shock and low stress level
Flexible target material (choice, arrangement, geometry…)

Practical Motivation for a Rotating Target

> Objectives:

Increase lifetime (window, tungsten…)
Alleviate the heat removal

> Advantages:

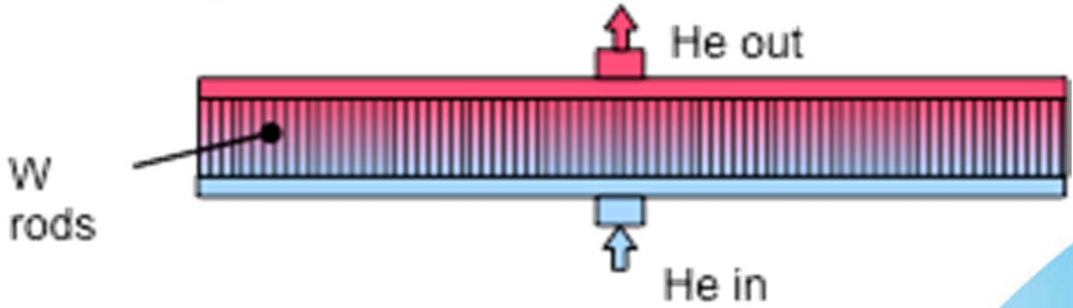
Dilution of specific activity and after heat
Less frequent maintenance and handling of radioactive material
Solid waste
Upgradeable for higher beam power

> Drawbacks:

Not yet proven concept (but we do not need to re-invent the wheel!)
Rotating seals to be adapted from existing solutions
Heavy assembly

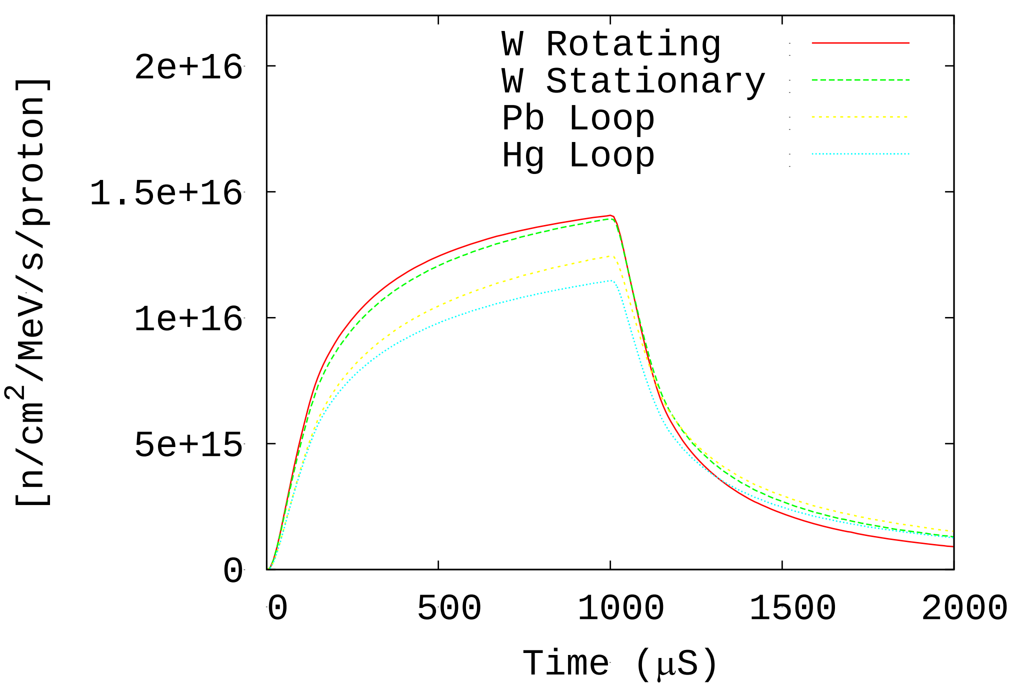
Main Parameters of the Helium Cooled Rotating Granular Target

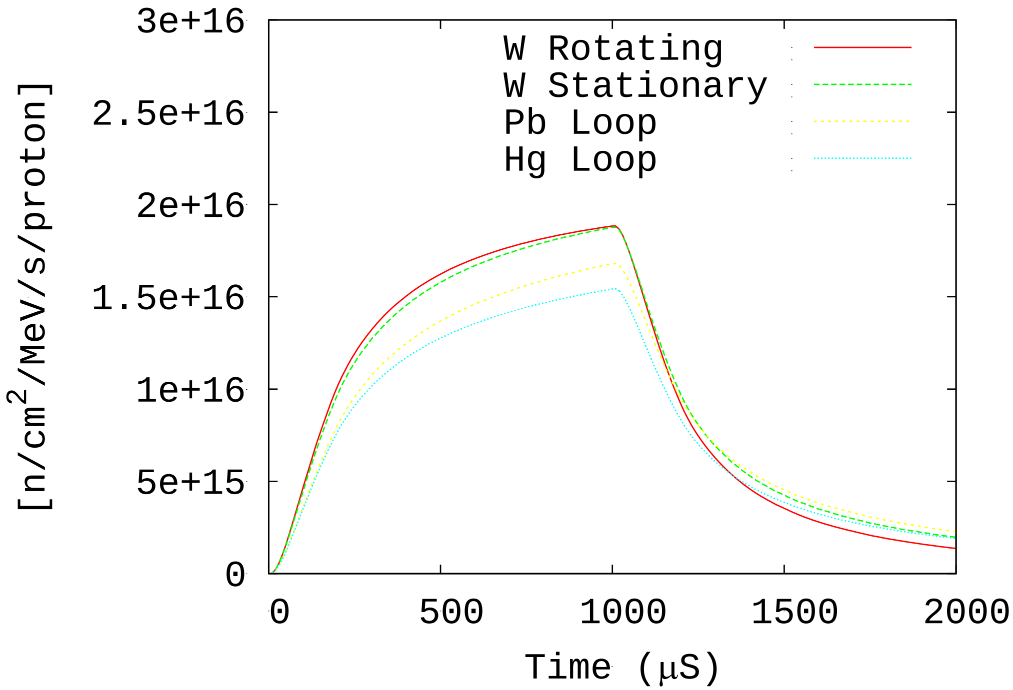
- A 2.5GeV elliptic Gaussian beam with an RMS of σ_x= 5 cm and σ_y= 1.5 cm (beam footprint at 4σ of 20cm x 6cm), an average power of 5 MW, pulsed at 20 Hz
- The wheel is rotating at 30RPM (0.5Hz)
- The energy deposition calculated with FLUKA gave a maximum Power density (time average for 1/40 of the wheel) of 75W/cm^3 (40 times less than in the static target case).
- External wheel diameter is150 cm and internal diameter of 50 cm. The helium is blown over the total surface continuously.
- Initially rods of 2cm diameter, now 1cm diameter



Neutronic performance

Brightness at 5 MeV (left) and at 10 MeV (right) on the moderator surface for a 1ms pulse length.





→ The rotating target made of rod cooled by helium will allow a density of 90% of the raw material, which shall give a performance close to the pure tungsten configuration.

courtesy F. Sordo et al.

Neutronic performance

> Franz Gallmeier investigation (previous TSCS meeting) extended
  Rotating target configuration (run though optimization loop)
  Extrapolation with density (not so accurate)

Element	Effective density (1/cm^3)	Φcold@10m (n/cm^2/prot.)	Φcold@10m Perf in % vs. Best	Φcold@10m Loss in % vs. Best	Comment
W	19.4	6.28E-08	100.00%	0.00%	Calculated
Sphere pure W	14	5.66E-08	90.07%	9.93%	Calculated
Sphere Densimet (*)	13.875	5.61E-08	89.26%	10.74%	Educated guess
Rods Densimet (*)	16.65	6.06E-08	96.47%	3.53%	Educated guess

➡ Tungsten is the most favourable target material, and its dilution is not affecting significantly the neutron production

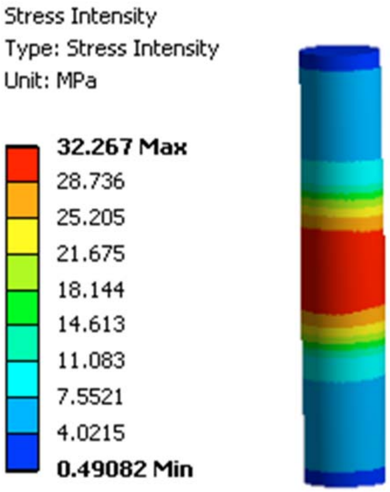
*DENSIMET is a tungsten alloy with appropriate properties

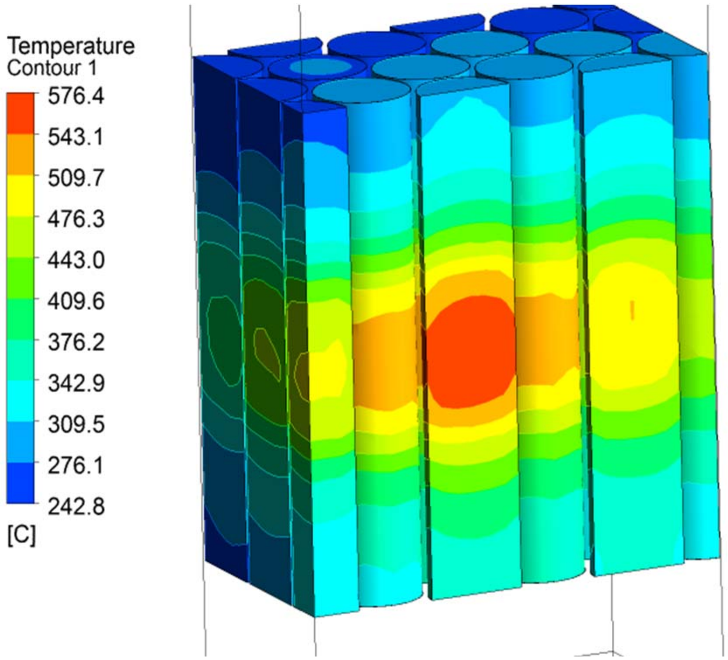
courtesy F. Gallmeier

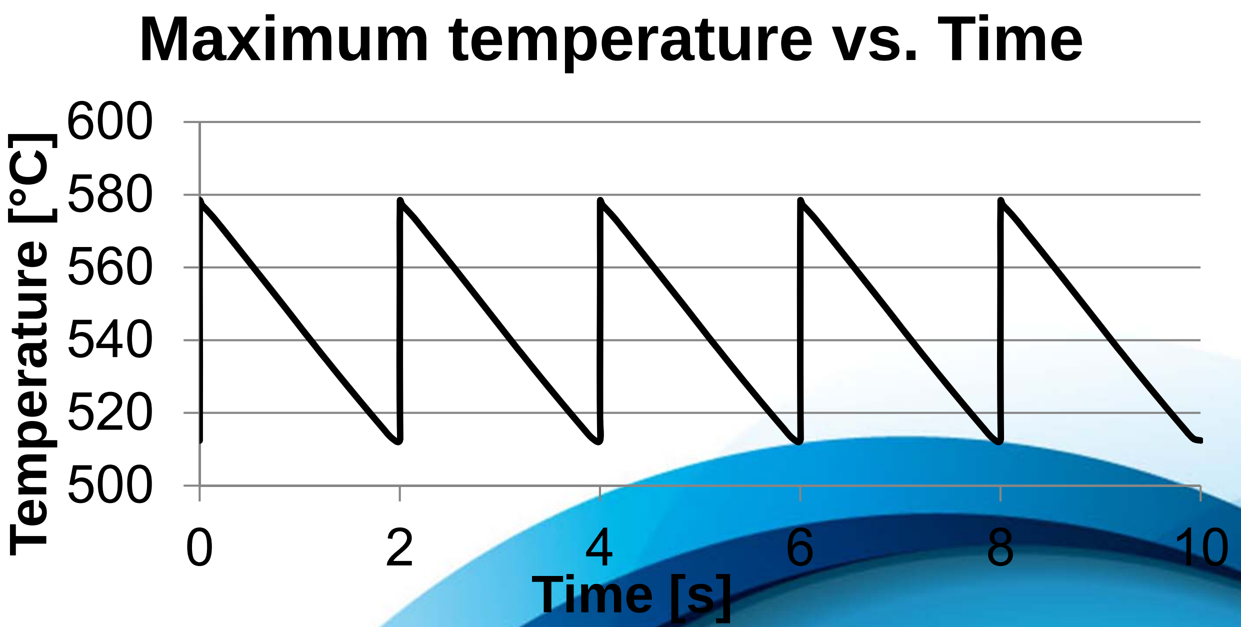
Thermo-mechanical study 2cm Rods

With a He-cooling circuit set at: Po = 10 Bar, v(He) 8 m.s^{-1}(mass flow of about 20kg/s!!! Which could reduced by tuning it for different zones)

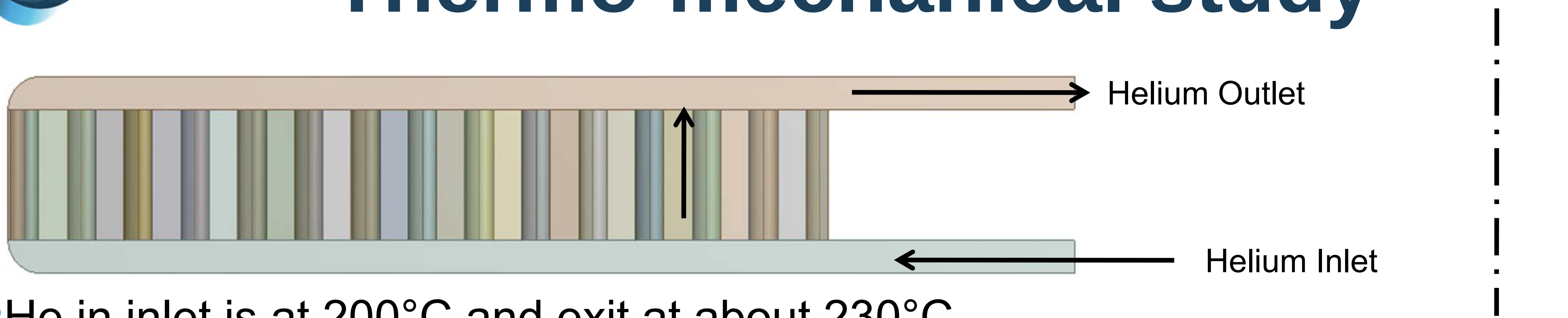
- The peak temperature in the hottest rods is about 577°C (Inlet Temperature was 200°C)
- Helium ΔT_{bulk}=30K
- Stress in the rods is low even in a fatigue regime (endurance), about 30 to 50 MPa



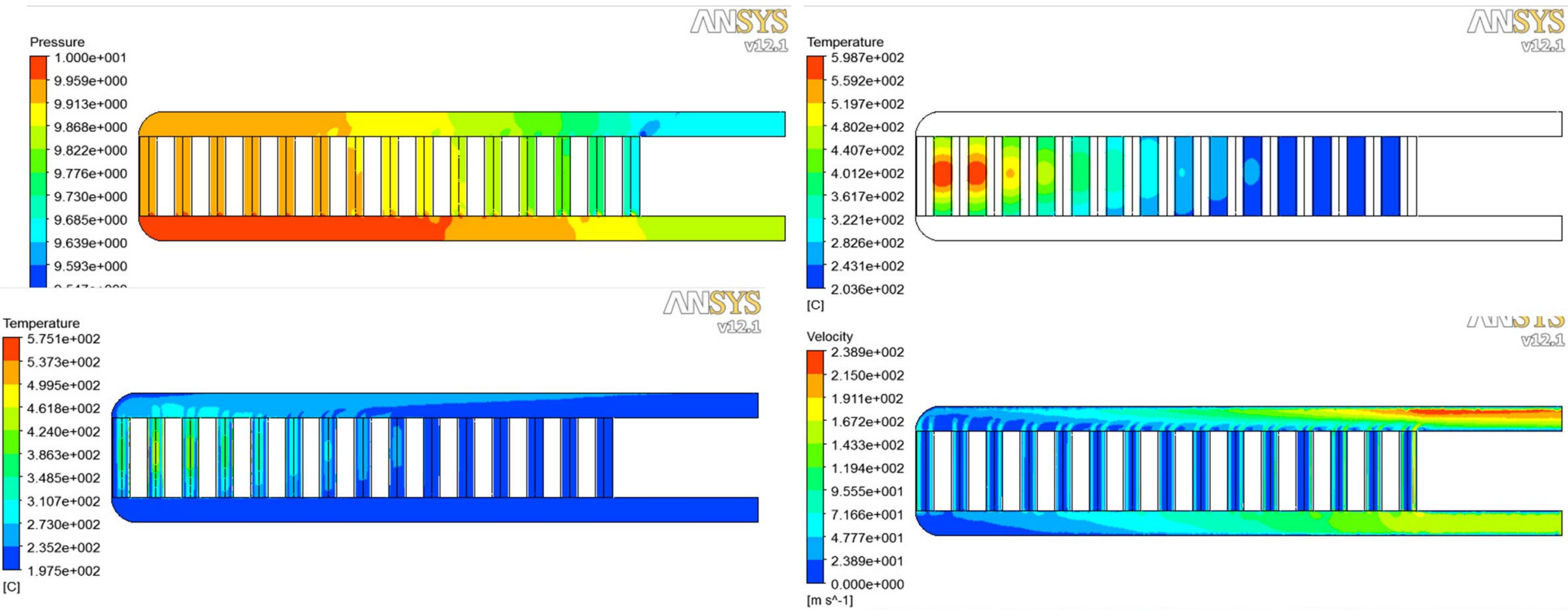




Thermo-mechanical study



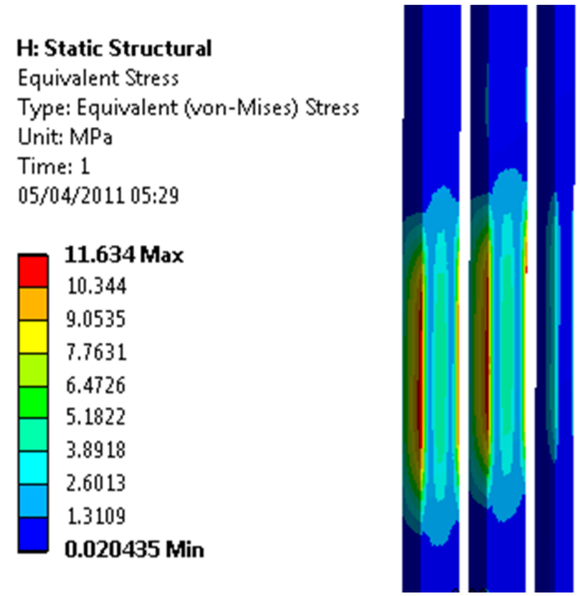
- He in inlet is at 200°C and exit at about 230°C
- Pressure drop is about 0.2bar and Pumping power about 250kW

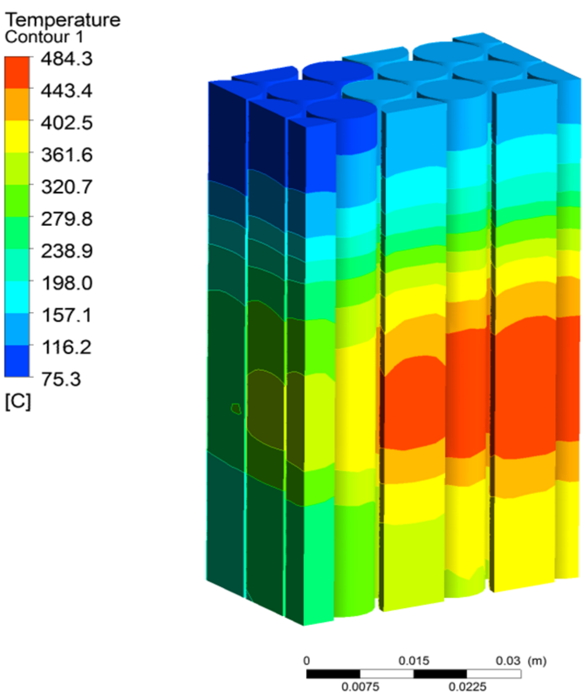


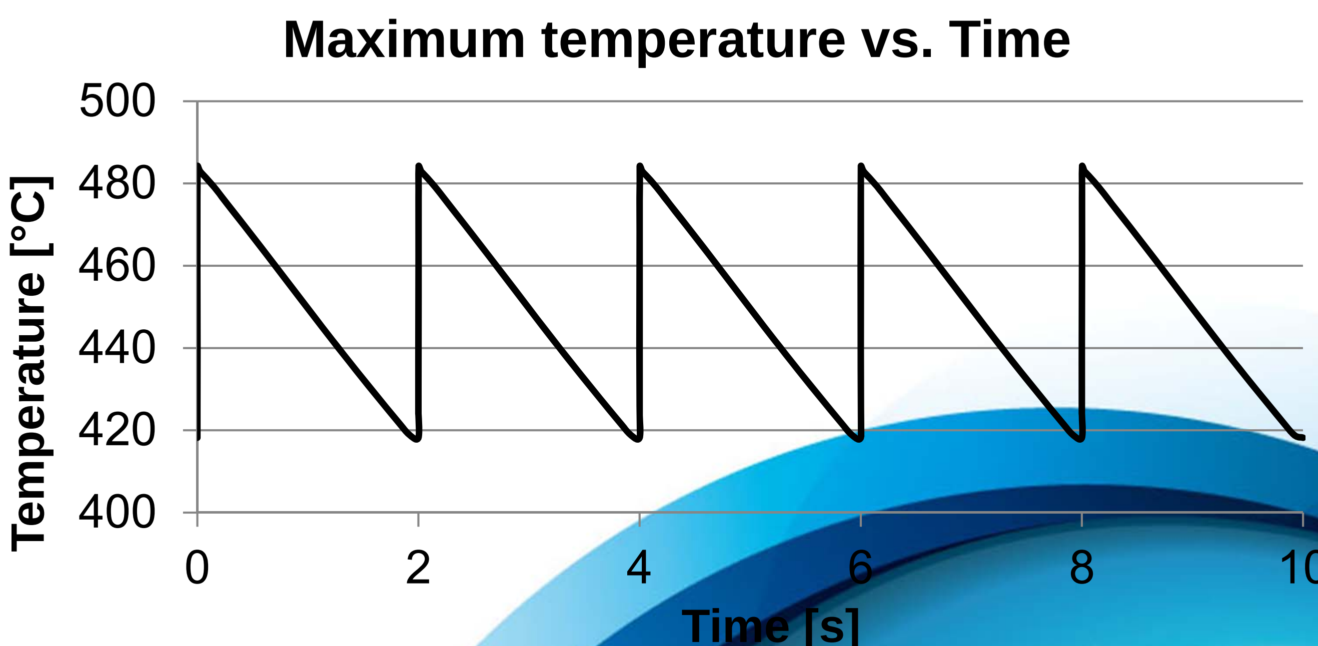
Thermo-mechanical study 1cm Rods

With a more moderate He-cooling circuit (Po = 3 Bar, inlet v(He) of 4 m.s-1, mass flow of 3kg/s)

- The peak temperature in the hottest rods is about 485°C
- Helium ΔT_{bulk}= 200K
- Stress in the rods is very low even in a fatigue regime (endurance), about 10 to 20 Mpa



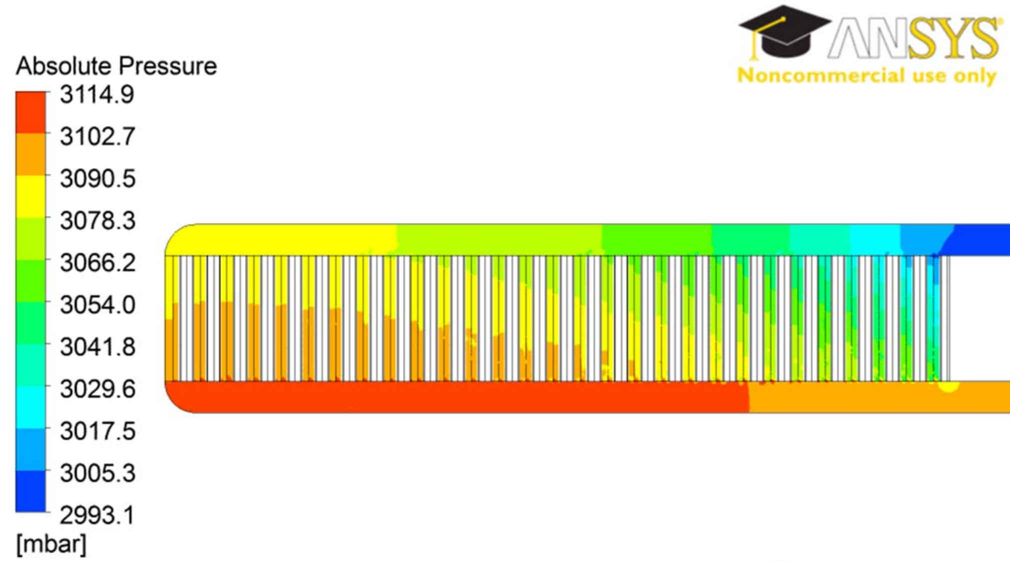


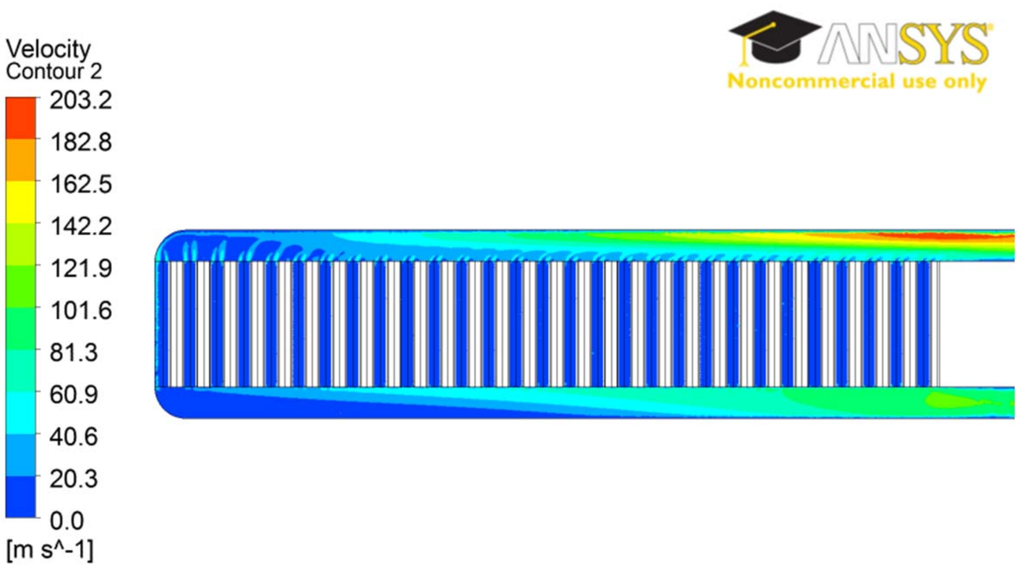


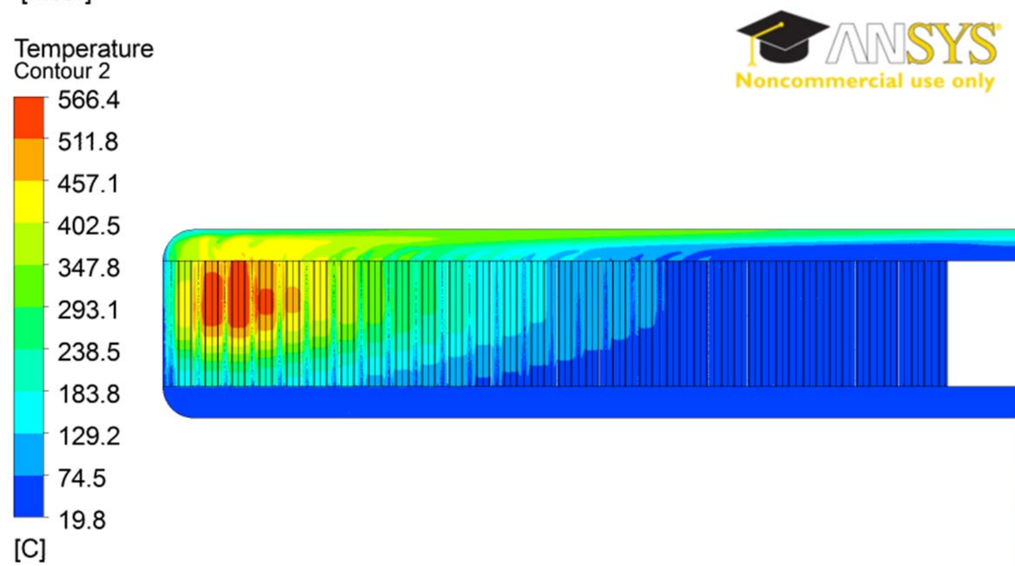
Thermo-mechanical study 1cm Rods

For 3kg/s mass flow rate for 3 bar He

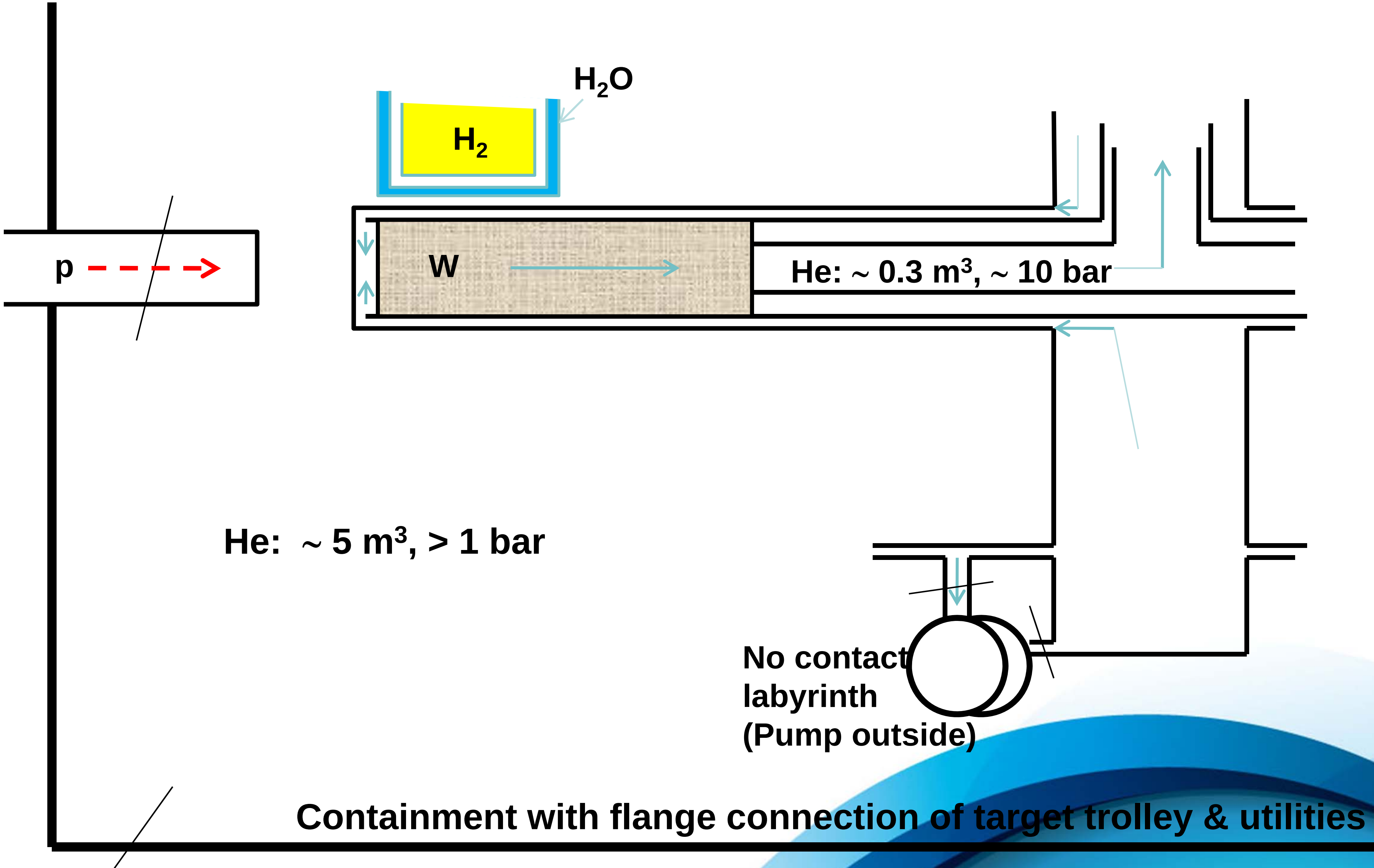
Here the pressure drop is 0.1bar equivalent to 62kW of pumping power.







Cross flow configuration

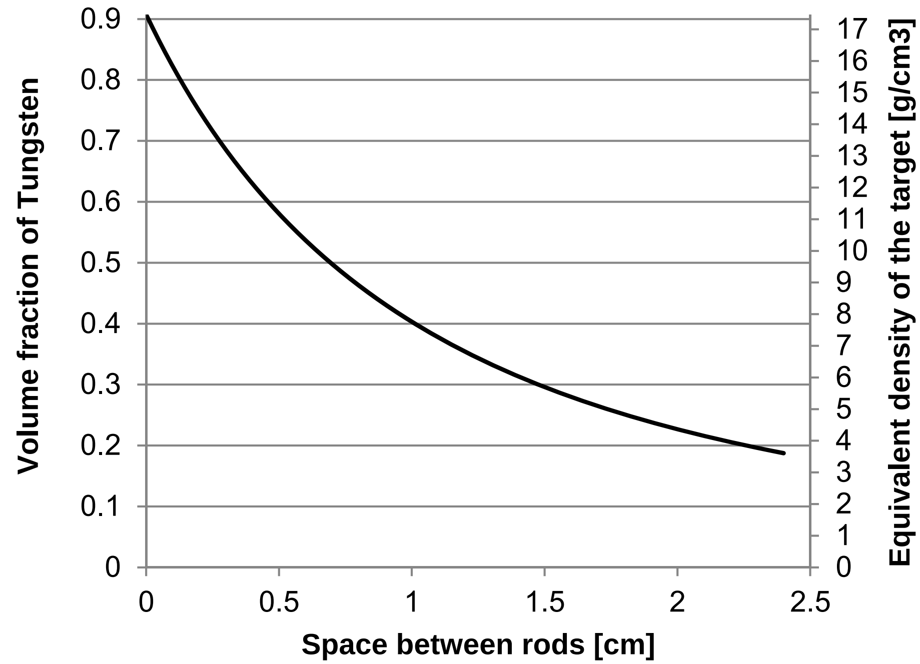


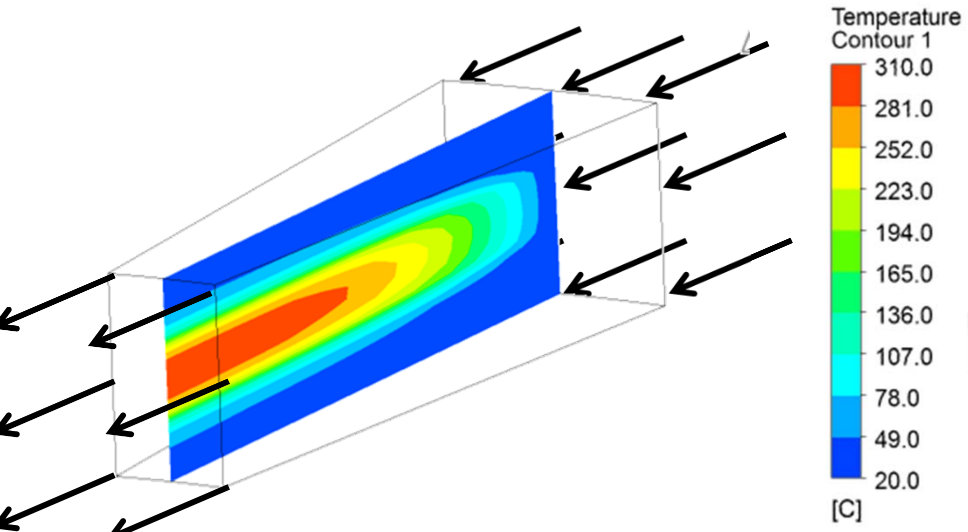
Thermo-mechanical study
Cross flow configuration

- Transverse cross flow is under estimation
- The objective is to use a lower mass flow rates and increase the bulk ΔT in Helium
- First estimation show the possibility to consider 2cm rods with 1mm gap (82%of the full W density).

    Mass flow rates is about 3kg/s
    ΔT_{bulk}=200K
    $T_{max\ in\ He}$=310°C
    ΔP≈1bar (VDI WärmeAtlas)

Volume Fraction of Tungsten vs. Space between rods for 2cm diameter rods





Helium loop Pressure drop estimation

>The main component of the loop to be considered for the overall pressure head required at the pump are:

- The target material (see previous slides)
- The target shaft and other straight pipe (Half of the target)
- The Inlet rotating seals and outlet rotating seals
- The filters (Half of the target)
- The heat exchanger (Half of the target)

>The Inlet and Outlet rotating seals could be assumed to have the same pressure drop

>The Heat exchanger could be assumed to have half of the pressure drop seen in the target material

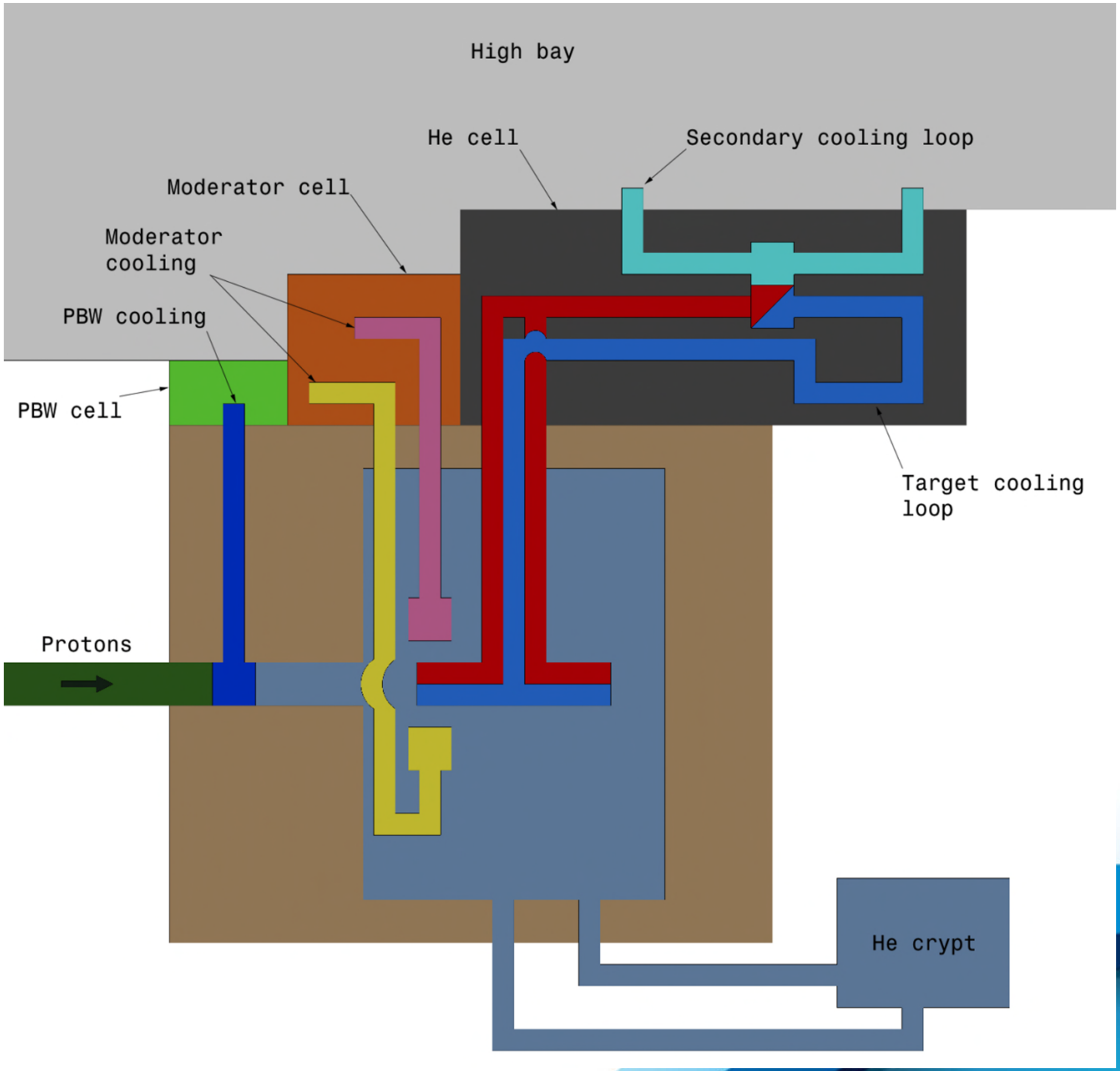
Helium loop Pressure drop estimation

A preliminary assessment could give indication of the pressure drop in the main component of the loop, for Helium flowing at 3kg/s and 3bar for a global volume of $2m^3$

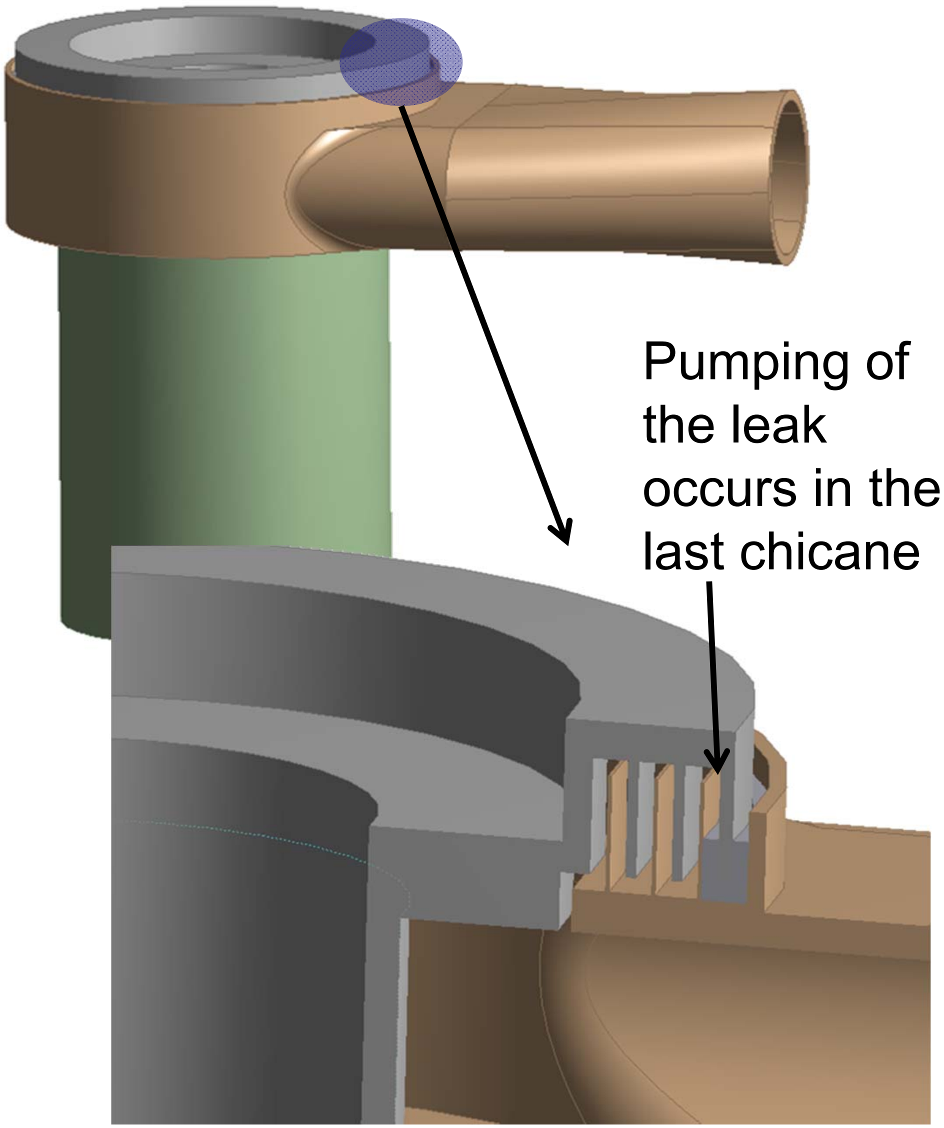
	Pressure drop [bar]	
The target material	0.1	
The target shaft and other straight pipe	0.05	
The Inlet rotating seals	0.1	
The outlet rotating seals	0.1	
The filters	0.05	
The heat exchanger	0.05	
	0.45	Total
Pumping Power	282.7 kW	

Preliminary estimation

Helium Loop and ancillaries loop



Leak in Rotating Seals



>Differential pumping seal with chicanes between 3 bar and atmospheric pressure.

>For 0.1mm wide and 50cm long path => at most 2g/s

Structural analysis

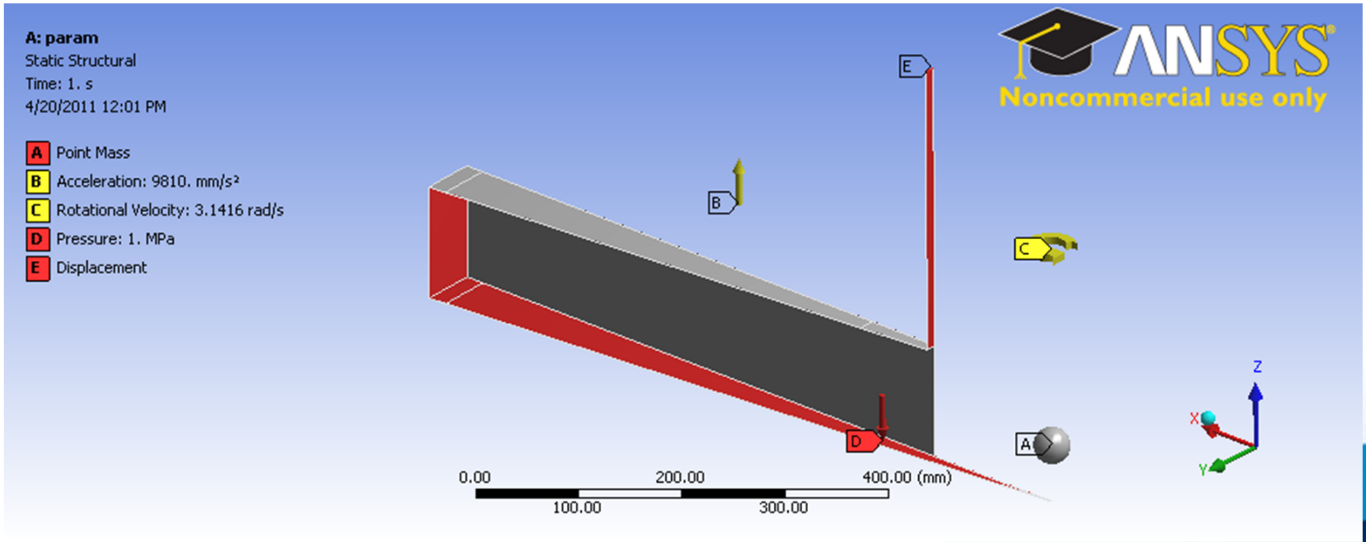
> Structural analysis

Simplified shell model (sector)

Parameterized model (number of ribs, thickness)

No thermal loads defined, but gravity, pressure (3bar), rotational velocity

Simplified post-processing using RCC-MRx criteria

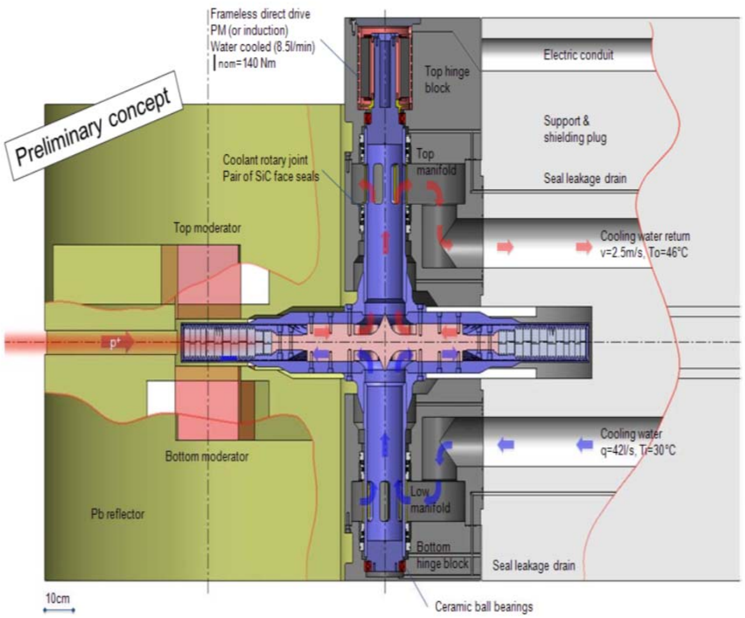


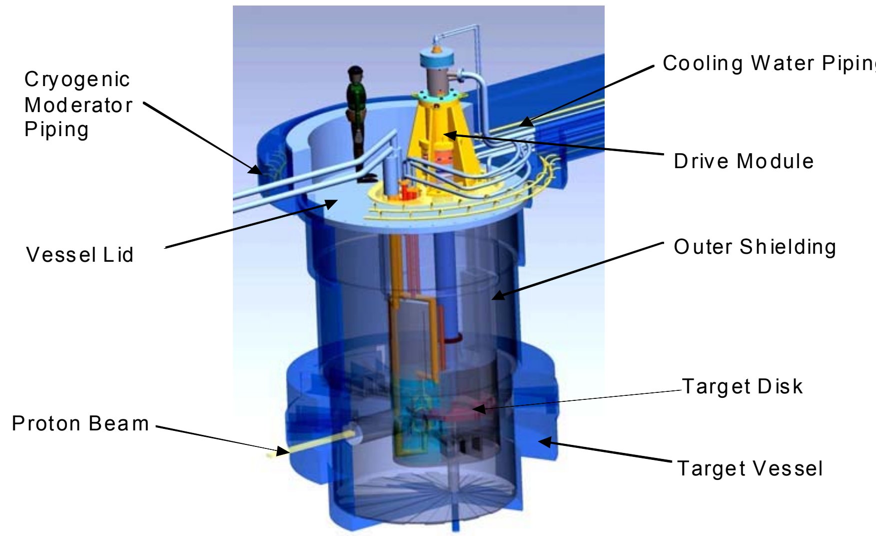
Structural analysis

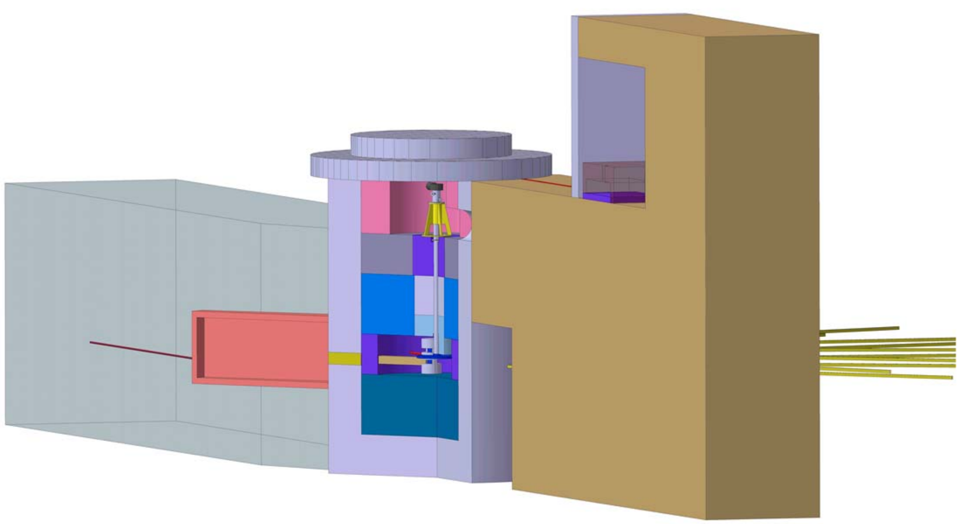
>The table here summarize the ratio between the acceptable limit (according to RCC-MRx criteria) and the calculated stress.
>At 3bar with ribs every 12degree, the minimum thickness of material could be 3mm.
>If the pressure can be further reduced, the number of needed ribs (or shell thickness) will be reduced

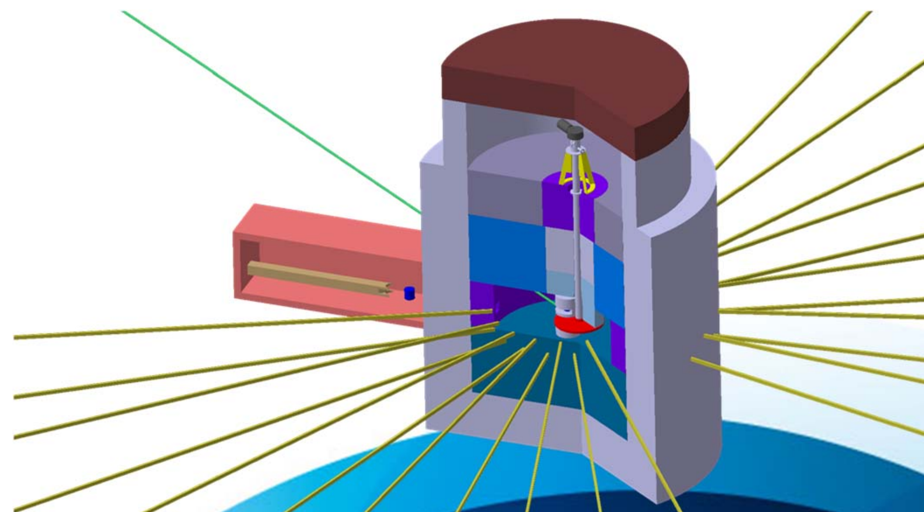
		Angle between 2 ribs				
		9	12	30	45	60
Thickness (mm)	3	0.57	0.94	3.35	4.70	5.69
	4	0.32	0.53	2.24	3.57	4.51
	5	0.21	0.34	1.48	2.62	3.53
	6	0.14	0.24	1.03	1.91	2.72
	7	0.11	0.17	0.76	1.42	2.08
	8	0.08	0.13	0.58	1.09	1.61

Maintenance / Layout

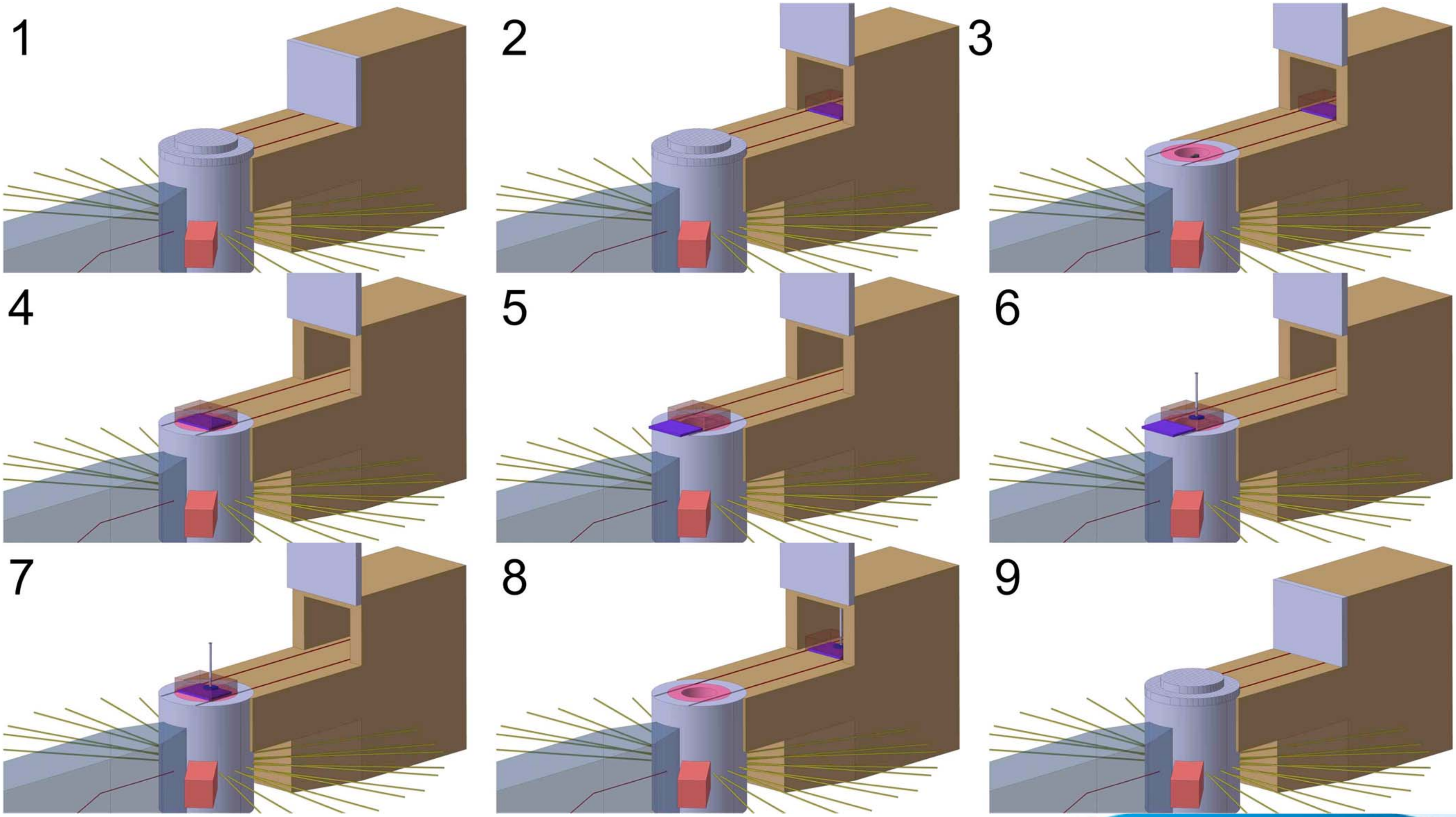








Maintenance / Layout



Maintenance / Layout

- Exchange procedure: a proposal
  - Hot cell could be separated from the target station / monolith allowing an operation of it more disconnected from the target operation
  - In order to reduce the weight carried by the overhead crane the flask is moved on rails

- Basic maintenance is performed on helium circuit (rotating seal, filters, pumps, heat exchanger) by hands on it. The exposure to radiation shall be low.

Lifetime

> The lifetime of such target is supposed to be about 40 times longer than the static target

- As radiation damage will be spread over a large surface/volume
- Fatigue is negligible in the first estimation (non irradiated)

Facility	Target	Damage	Int. Beam	Max. Power	Max. current density	Max. charge density	Time Online
		[dpa]	[MW.hr]	[MW]	[μA.cm^{-2}]	[C.cm^{-2}]	[weeks]
SINQ	Cannelloni Online	25	6840	0.86	31.4	900	104
	MEGAPIE predicted	6	1368	0.72	31.4	214	20
	MEGAPIE online	6.8	1678	0.78	31.4	243	18
SNS	Hg Predicted	10	5000	1.0	12.5?	225	52
	Hg Target 1 online	7.5	3055	0.85	12.5?	162	144
	Hg Target 2 online	7.2	3215	1.0	12.5?	145	52
	Rotating predicted	10	75000	1.5	27.2	4900	520
JSNS	Predicted (no cavitation)	5	6400	1.0	15.5	357	67
	Predicted (cavitation)	2	2500	1.0	15.5	140	26
ESS2003	Predicted [bauer, vlad]	10	7320	5.0	79.6	420	15
ESS2010	Predicted Hg [Ene]	10	10000	5.0	42.5	306	21
ESS2010	Predicted [He-cooled rot.]	10	400000	5.0	42.5	306	840

Conclusion

- 3bar of pressure seems a viable option with 1cm rods, but further study shall be carried on to confirm and determine the minimum pressure acceptable
- Neutron yield is optimum
- Some of the main challenges lie in the replacement of the target and its associated downtime
- Attention has to be paid to local leak and radioactive release
- Special attention has to be paid to the rotating seal

Thank you for your attention