Converter targets for high power spallation neutron sources

Etam Noah

ESS Target division

>Outline

MW-class spallation neutron sources

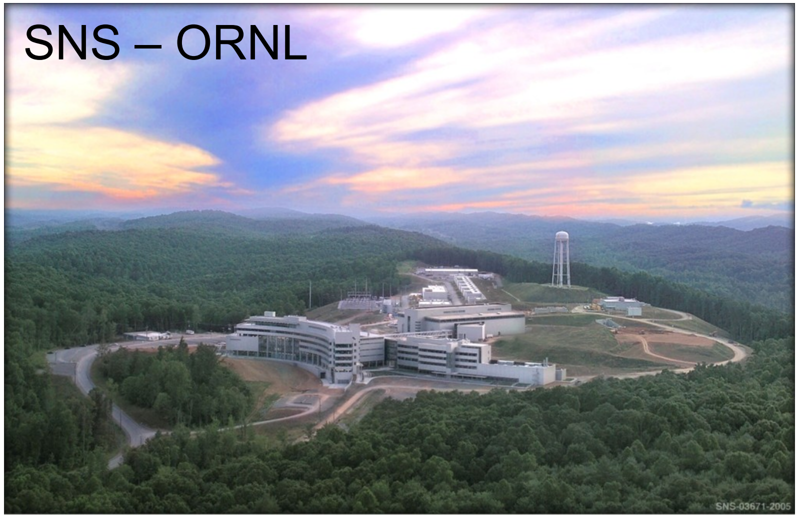
The ESS project

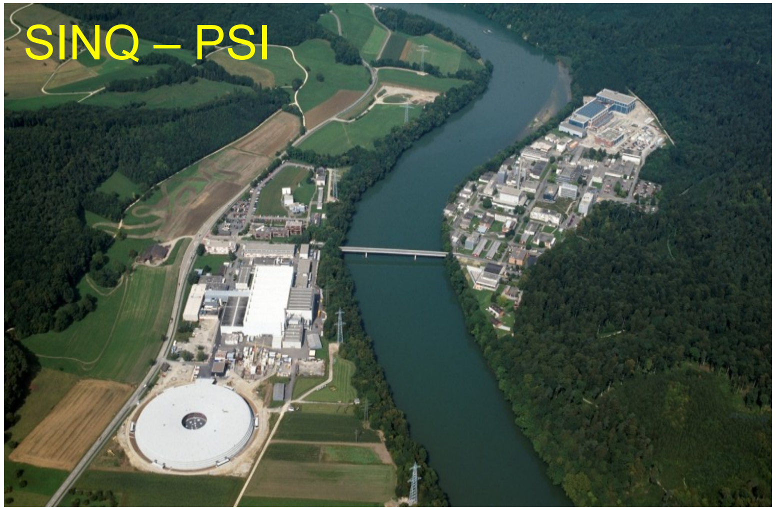
ESS baseline parameters

The ESS target selection process

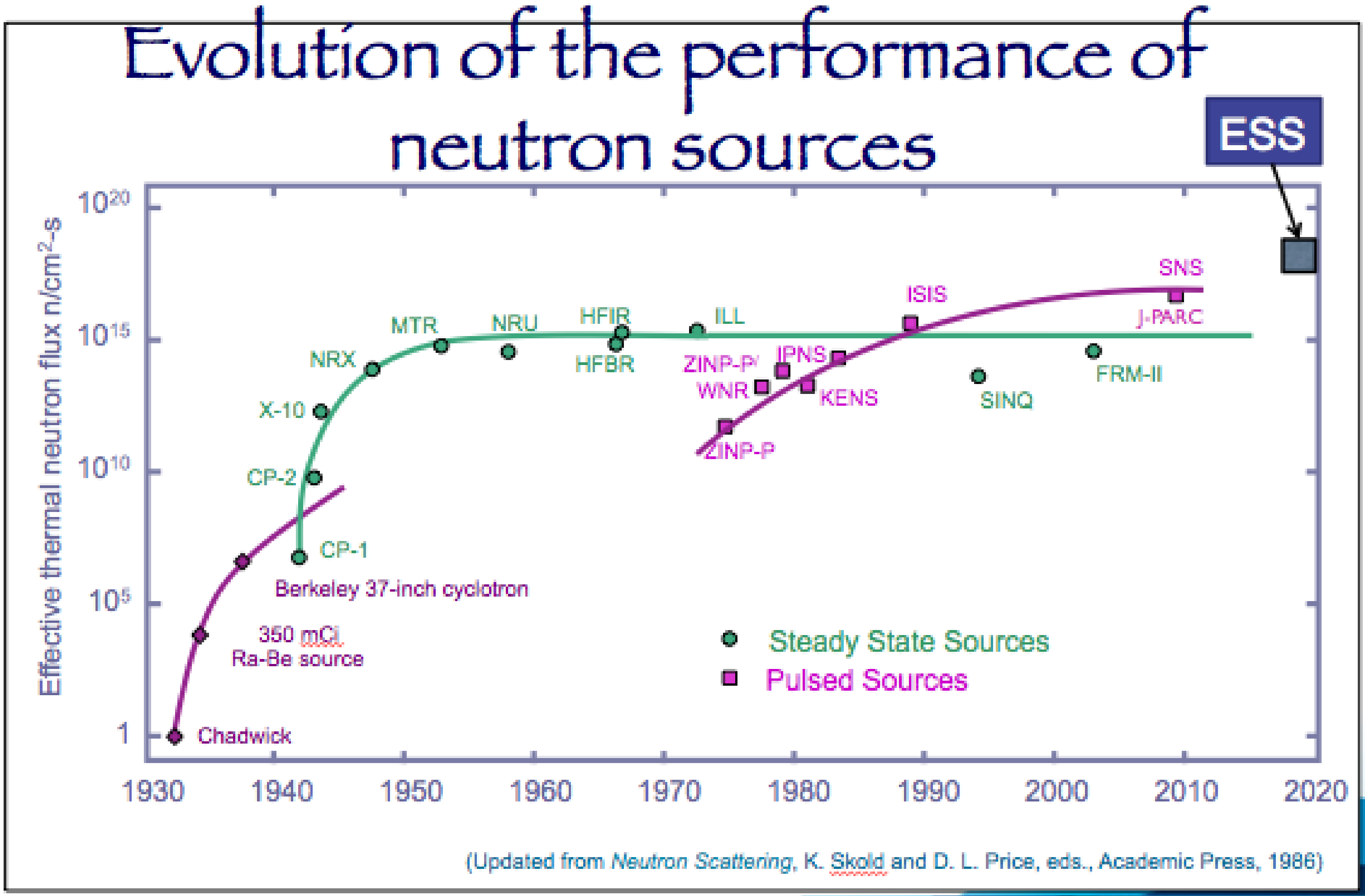
EUROPEAN SPALLATION SOURCE

MW-class Spallation Neutron Sources



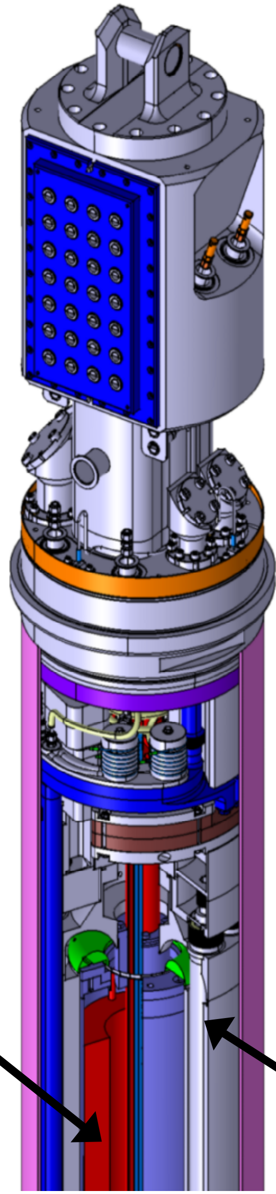


Flux at Spallation Sources



MEGAPIE @ SINQ (2006)

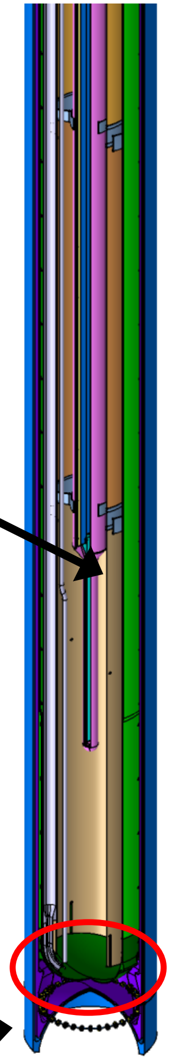
target head



electro-magnetic pumps

heat exchanger

central flow guide tube



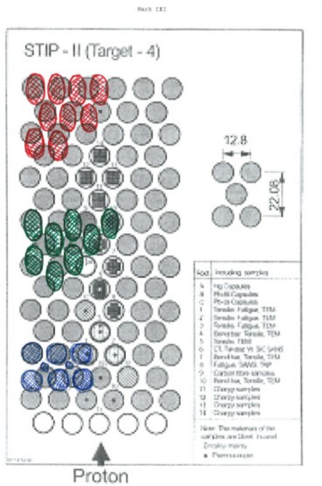
lower target assembly

safety hull

beam window

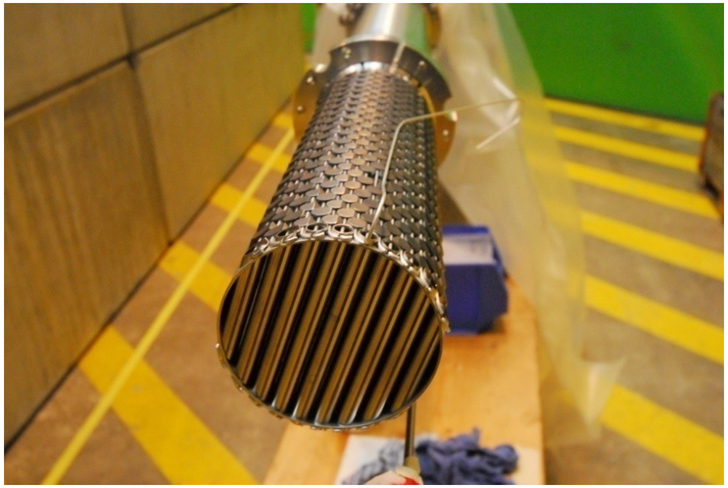
EUROPEAN SPALLATION SOURCE

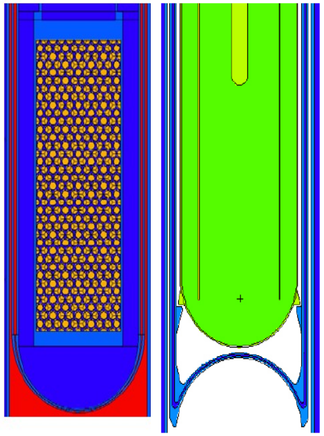
Improving Cannelloni



Scetch from Knud Thomsen

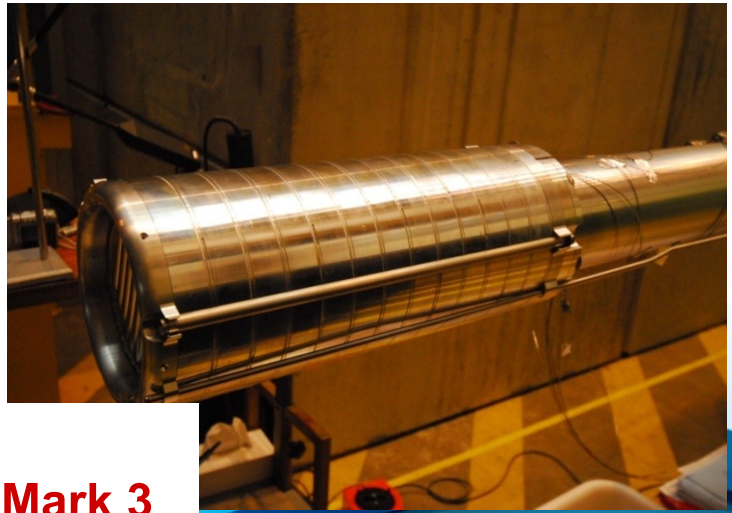
Zr-clad Pb:
predicted gain ~ 50%





Status:
Operated @ 0.9 MW
April 2009 – Dec. 2010

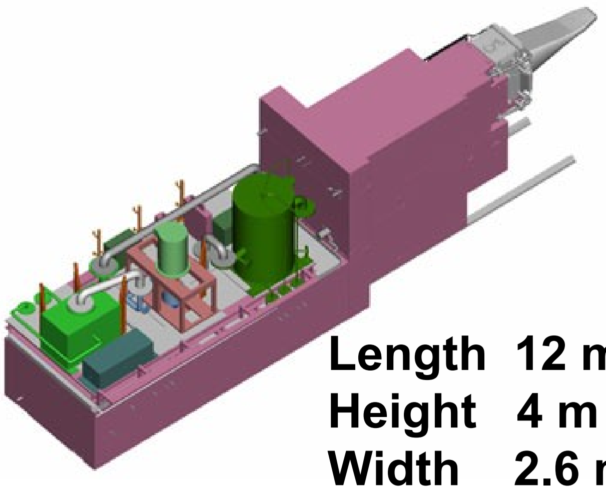
Neutron flux gain:
54% compared to Target Mark 3 (2004 / 2005)



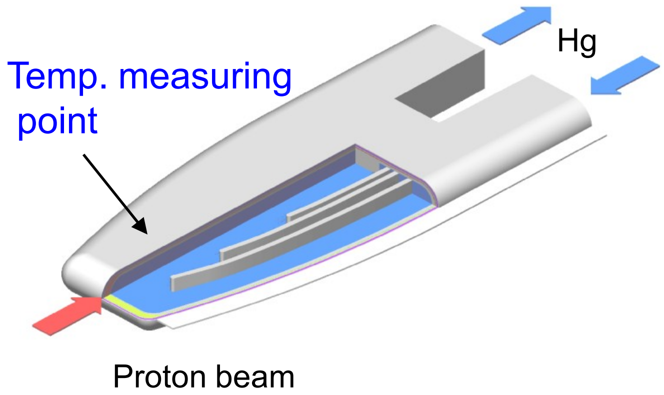
Ref: W. Wagner

JSNS – Hg Target

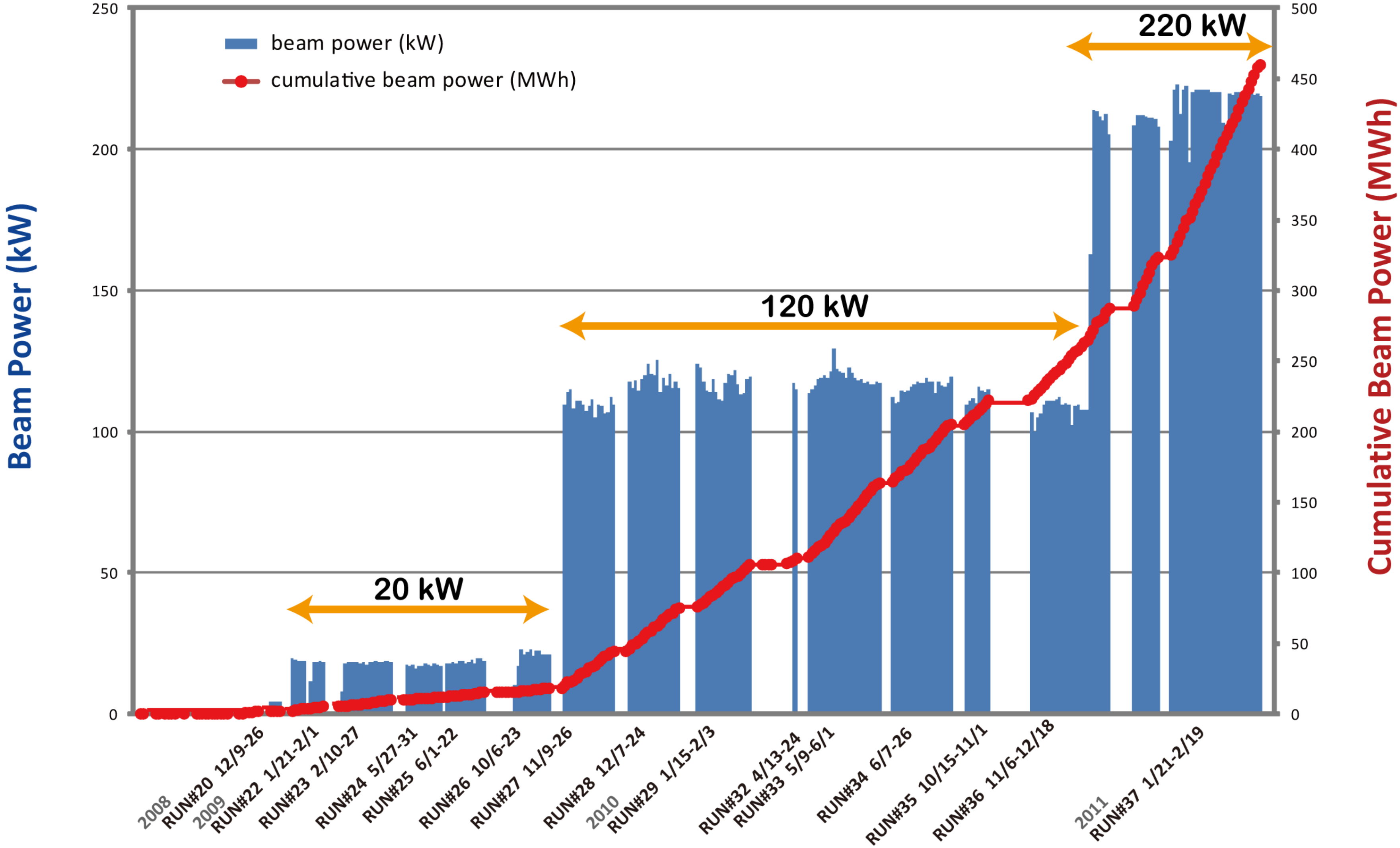
- **Proton Beam (design parameters):**
  - **3 GeV, 25 Hz rep rate, 0.33 mA ⇒ 1 MW**
- **Hg Target:**
  - **Cross-flow type, with multi wall vessel**
  - **Hg leak detectors between walls**
  - **All components of circulation system on trolley**
  - **Hot cell : Hands-on maintenance**
  - **Vibration measuring system to diagnose pressure wave effects**



Length	**12 m**
Height	**4 m**
Width	**2.6 m**
Weight	**315 ton**

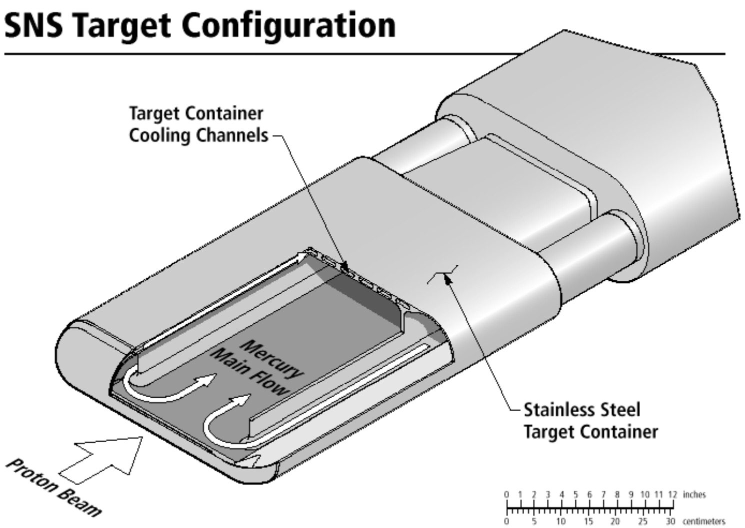


JSNS – Beam History



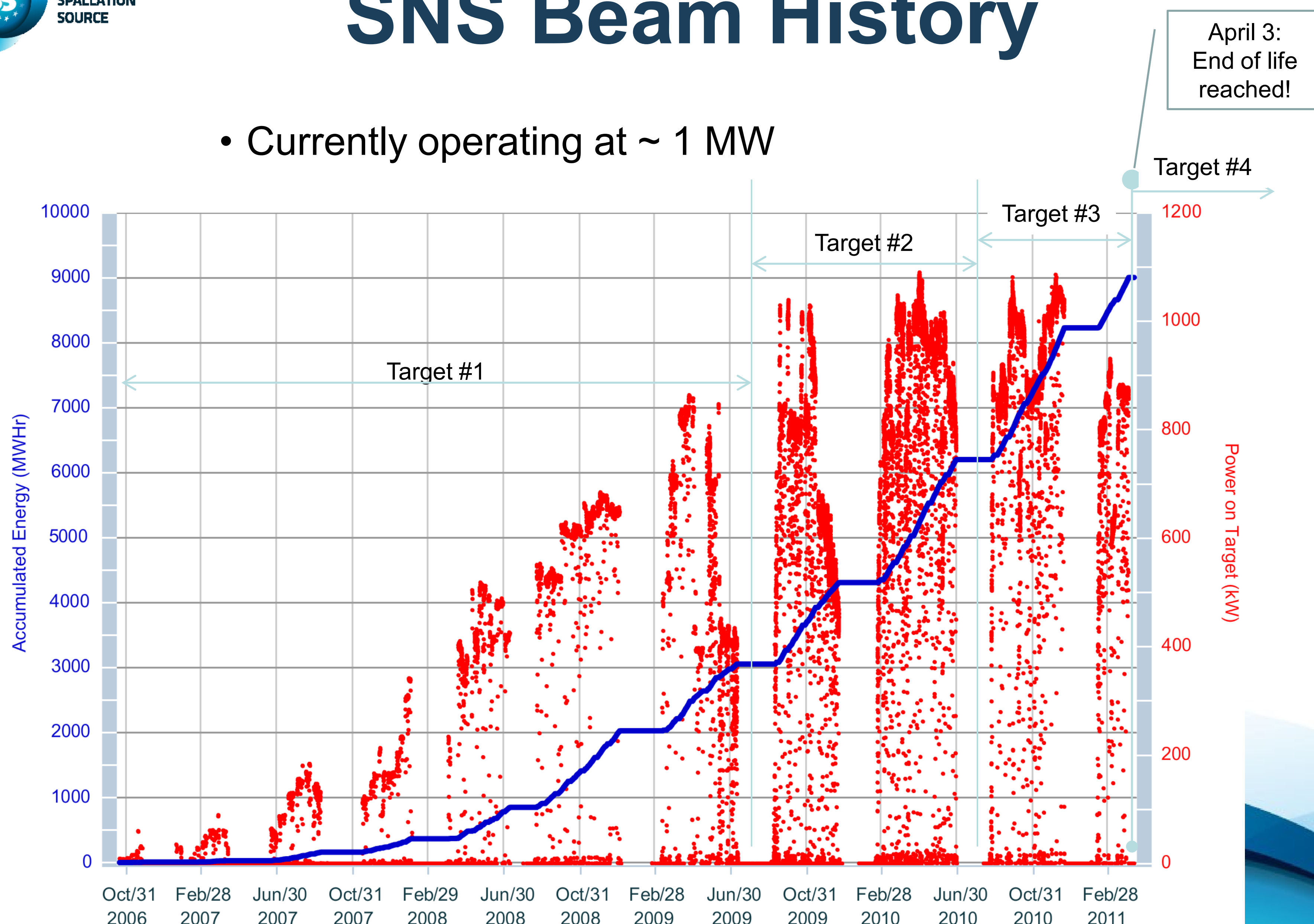
SNS – Hg Target

- Beam parameters (studied/nominal)
  - Average power: 2 MW
  - Energy: 1 GeV
  - Pulse length: 0.7 μs
  - Rep. rate: 60 Hz
- Power absorbed in Hg 1.2 MW
- Nom Op Pressure 0.3 MPa
- Flow Rate 340 kg/s
- V_{max} (In Window) 3.5 m/s
- Temperature
  - Inlet to target 60ºC
  - Exit from target 90ºC
- Total Hg Inventory 1.4 m^3
- Centrifugal Pump Power 30 kW

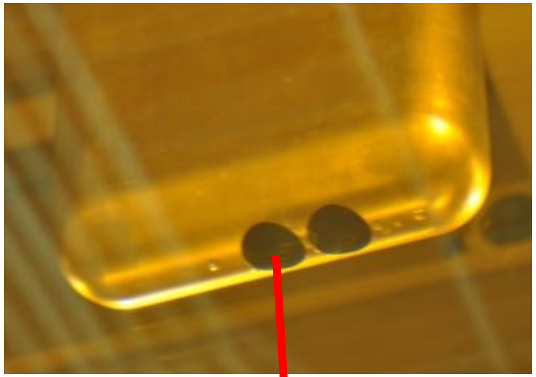


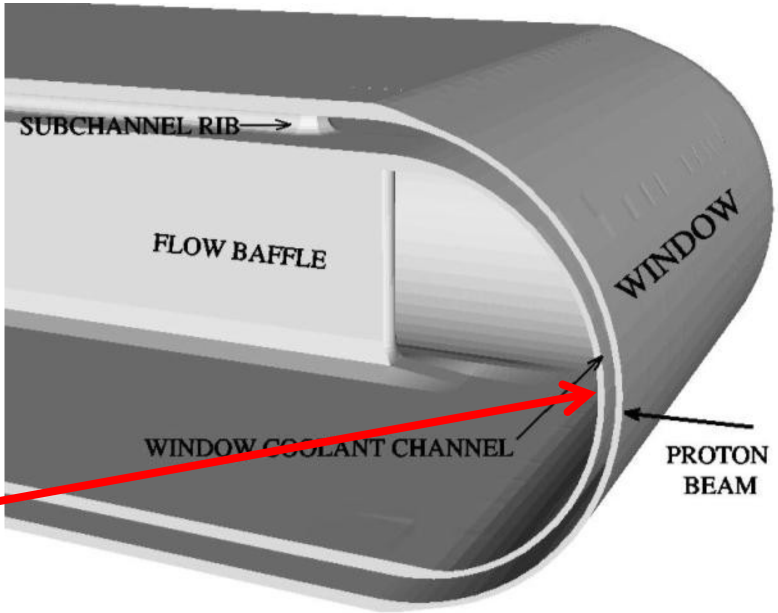
SNS Beam History

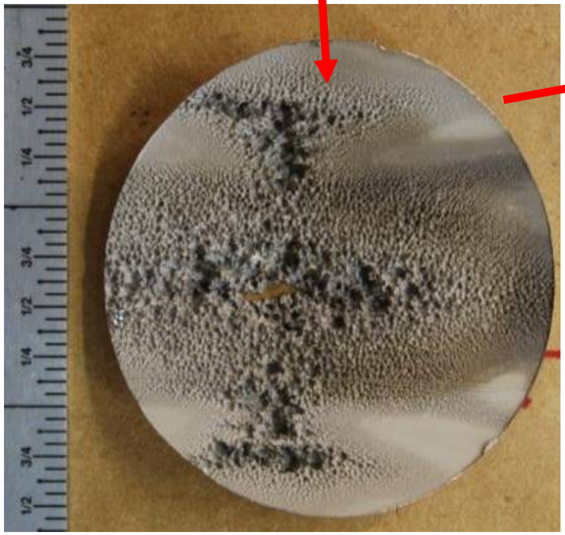
- Currently operating at ~ 1 MW



SNS Target PIA



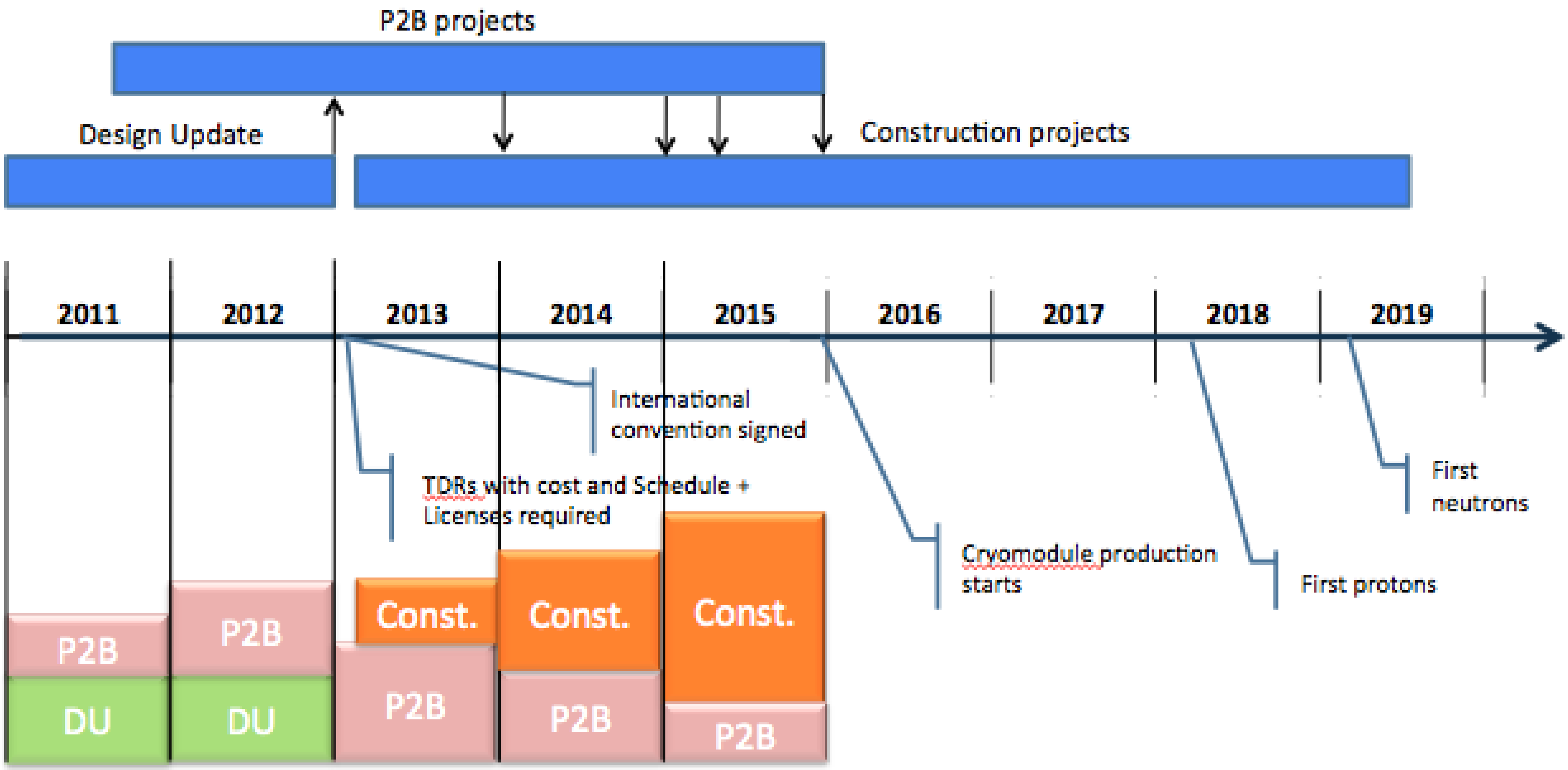




60 mm
Inner surface of wall between bulk Hg and small channel

- Target #1:
  - Cavitation damage phenomenon confirmed on inner wall at center of target
  - Outer wall fully intact; inner wall at off-center location shows little or no damage
  - Damage region appears to correlate with regions of low Hg velocity, but not such a clear distinction on Target #2

The ESS Project



ESS Parameters

Proton beam
- 2.5 GeV proton linac
- 2 mA average beam current
- 1-2 ms pulse length
- 16.67 – 20 Hz rep. frequency

Target options:
- Molten LBE
- Solid Tungsten (or W alloy)

ESS Safety

- General Safety Objectives being finalised
- PSAR – work is ongoing, focusing on Target Design Concepts
- EIA – work is ongoing
- Safety Advisory Committee is being set up

Required by authorities

Foreign and domestic experts. Some cross membership with TAC.

First meeting in late summer. Review GSO and PSAR work.

- The required licenses are foreseen to be available by early 2013, with a slight reservation for the time needed by the Environmental Court. Risks are mitigated by Swedish government permissibility right.

The ESS TSCS process and its outcome

Rotating		$Stationary
#Gas-cooled Granular	Water-cooled Concept	Lead Bismuth Eutectic

$Stationary structural containment: flowing LBE.
#Helium is baseline cooling gas.

Focused Cross Flow LBE Target FCT

Practical Motivation for LBE

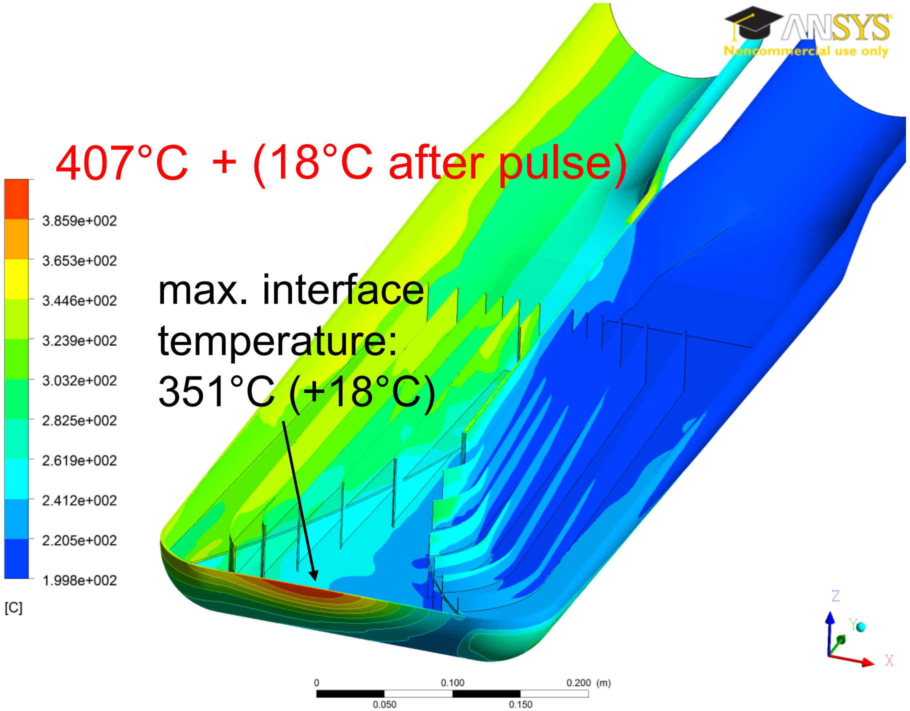
> **History of use of Pb/LBE in previous systems:**
- 80 operational years of experience (ALFA class Russian submarines LBE-cooled 155 MW fast breeder reactors)
- MEGAPIE at SINQ-PSI (first MW-class liquid metal (LBE) spallation target)

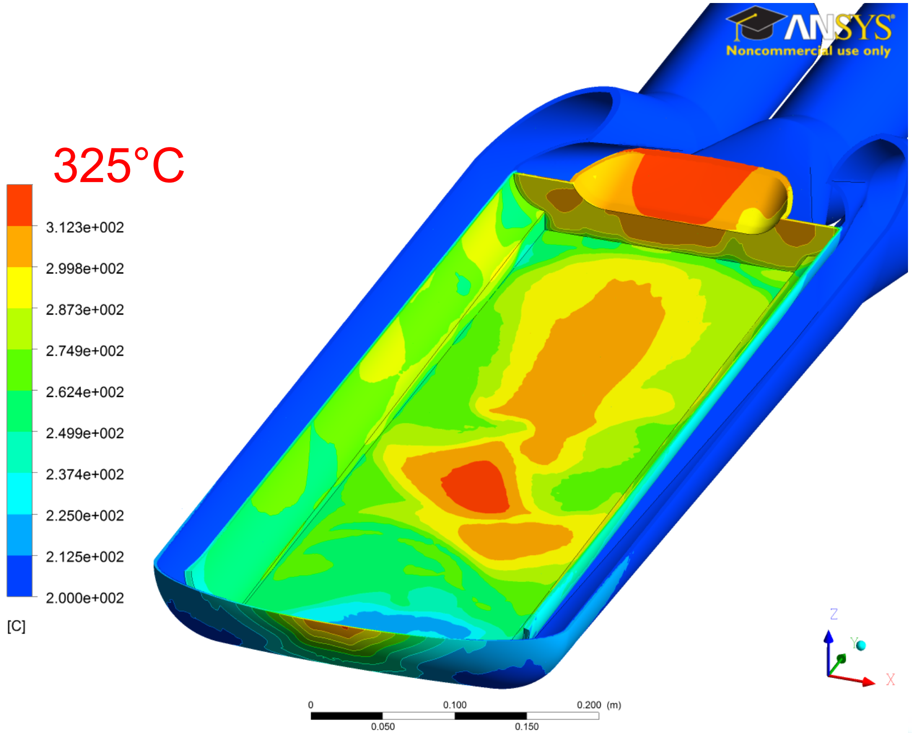
> **Pb-based target is licensable in Lund:**
- MEGAPIE at SINQ-PSI licensing case could benefit to ESS Lund
- Hg target with its high volatility and disposal issues

> **Pb/LBE is planned in future projects:**
- reactor core coolants for fast reactors
- fusion energy blanket applications (PbLi)
- Target material for accelerator-driven systems (ADS) (e.g. recently approved Belgian MYRRHA project)
- The Material Test Station under consideration at LANL also plans to use LBE to cool tungsten plates in its MW spallation target.

Focused Cross Flow Target concept vs. ESS 2003

- window cooling inferior to 2003 reference design





left: structural temperatures for focused cross flow target

right: structural temperatures for the 2003 target design

Courtesy of J. Wolters (FZJ)

Summary: LBE

>**LBE targetry** is **proven at MW** level.

>With anticipated **licensing** and **disposal difficulties** for a Hg target at ESS, the LBE target option is the most viable liquid metal target alternative.

>**Neutronics** performance studies shows about 10%difference with the best configuration with W

>**Focused Cross-flow** is a more viable flow pattern

>LBE **target design** can proceed by **reviewing** and **updating existing procedures** (licensing) and technologies.

Rotating **T**ungsten

Helium co

RoT

Some history

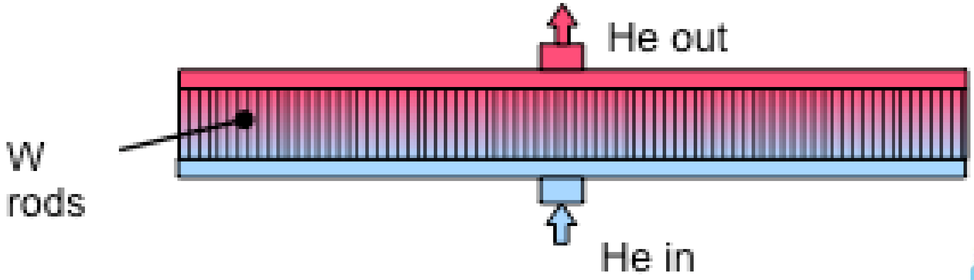
>Granular Tungsten target helium cooled was first proposed by Peter Sievers for a MW neutrino factory

>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…

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 (90% packing)



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 a Rotating Target

> Objectives:

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

> Advantages:

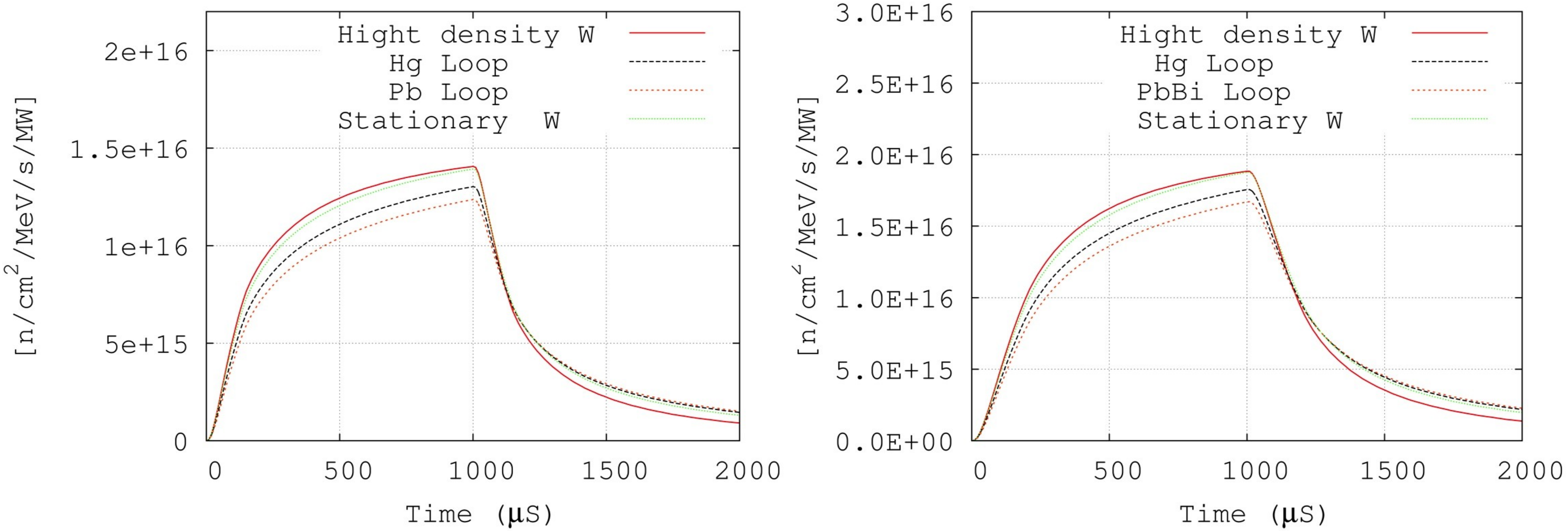
Dilution of specific activity and after heat
Less frequent maintenance and handling of radioactive material
Solid waste
Upgradeable for higher beam power

> 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

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	density		Φcold@10m	Φcold@10m	Φcold@10m	Comment
	Density fraction relative to raw material	(g/cm^3)	$(n/cm^2/prot.)$	Perf in % vs. Best	Loss in % vs. Best	
W	100.0%	19.4	6.59E-08	100.00%	0.00%	**Calculated**
W sphere	72.2%	14	5.66E-08	85.89%	14.11%	**Calculated**
W Rods	90.7%	17.6	6.28E-08	95.28%	4.72%	**Extrapolated**

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

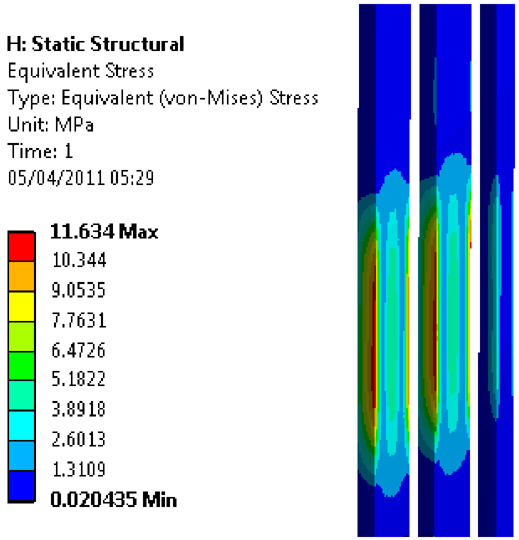
*DENSIMET is a tungsten alloy with appropriate properties

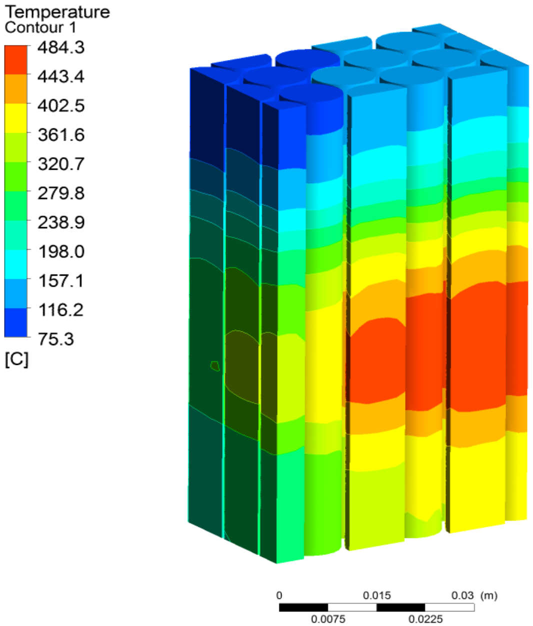
courtesy F. Gallmeier

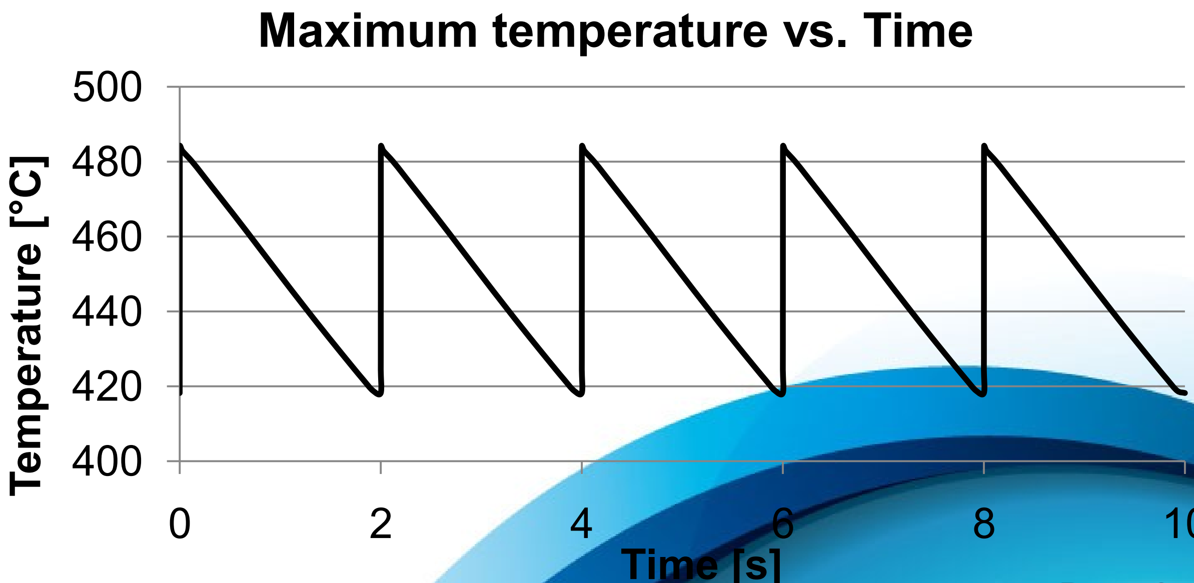
Thermo-mechanical study 1cm Rods

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



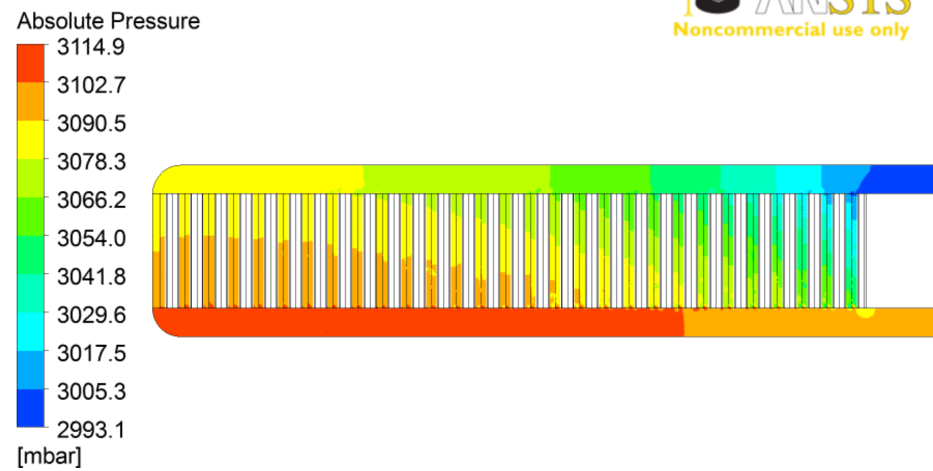


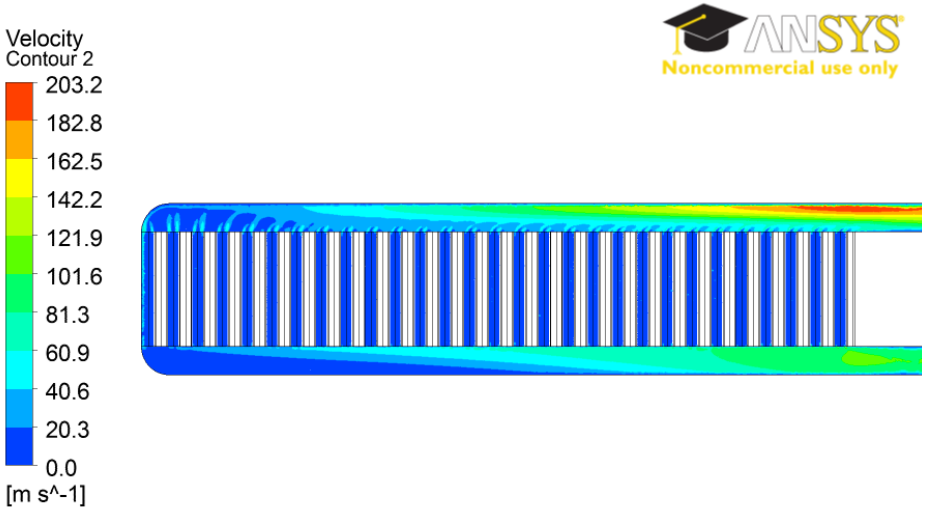


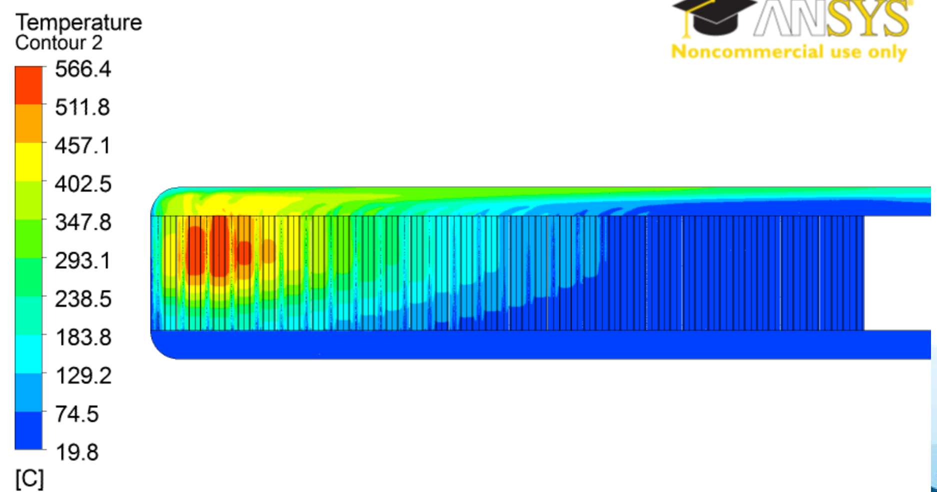
Thermo-mechanical study 1cm Rods

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

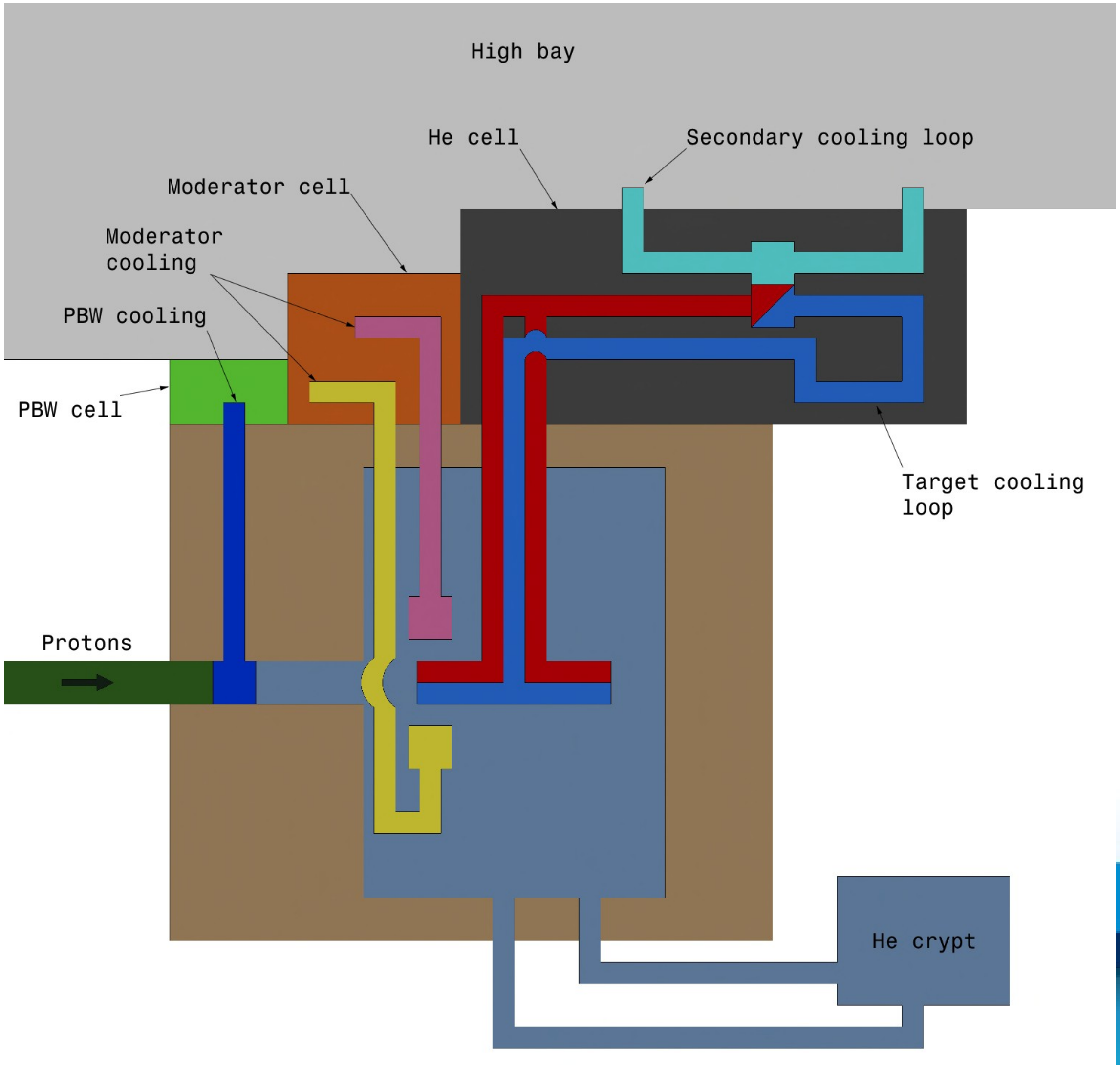
Here the pressure drop is 0.1bar equivalent to 62kW of pumping power.







Helium Loop and ancillaries loop / Enclosure



Summary: RoTHeTa

- 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

Summary

> Main factors driving target choice/design:
  - Safety
  - Cost
  - Neutronics (minimal)

> CW vs pulsed beams:
  - When possible, move away from short beam pulse lengths.
  - Cavitation lifetime limiting for liquid metal targets > 1 MW.

> Outlook for future projects:
  - Several ongoing: ESS, MYRRHA, SNS-STS, CSNS, MTS.
  - Solid and liquid targets considered.