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A Target for ESSnuSB

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High Power Targets

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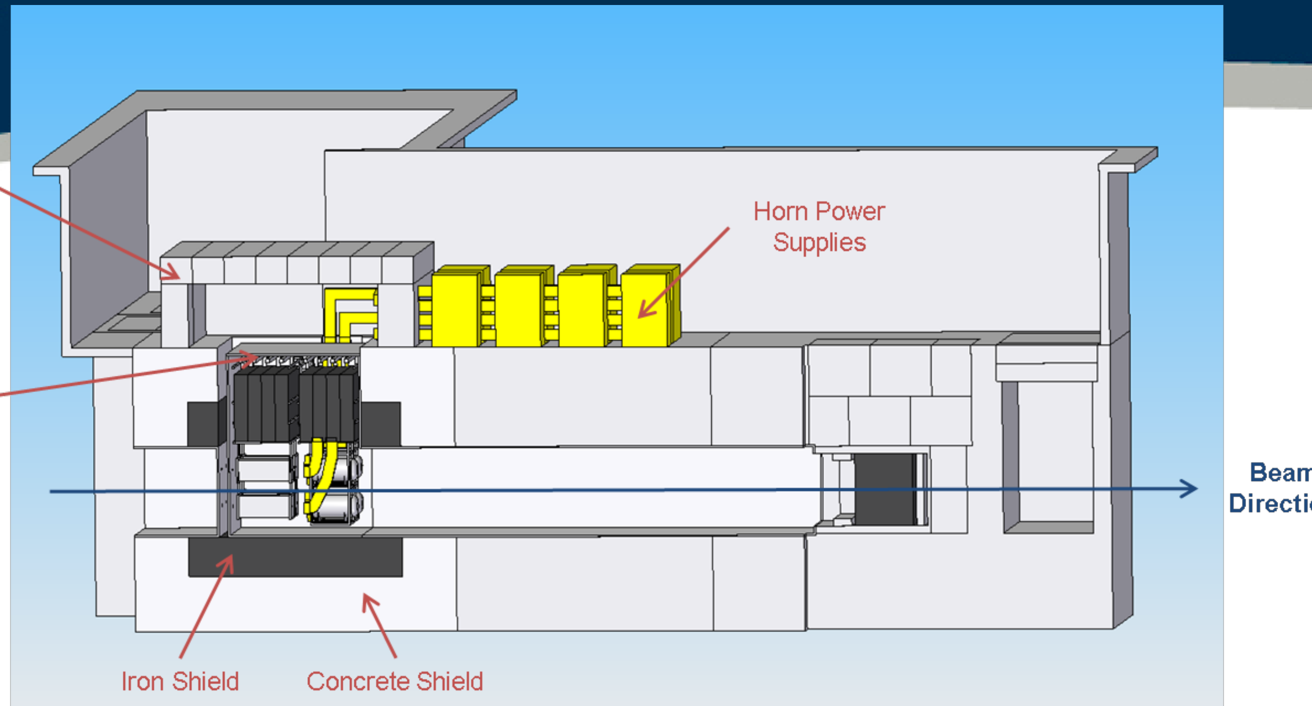
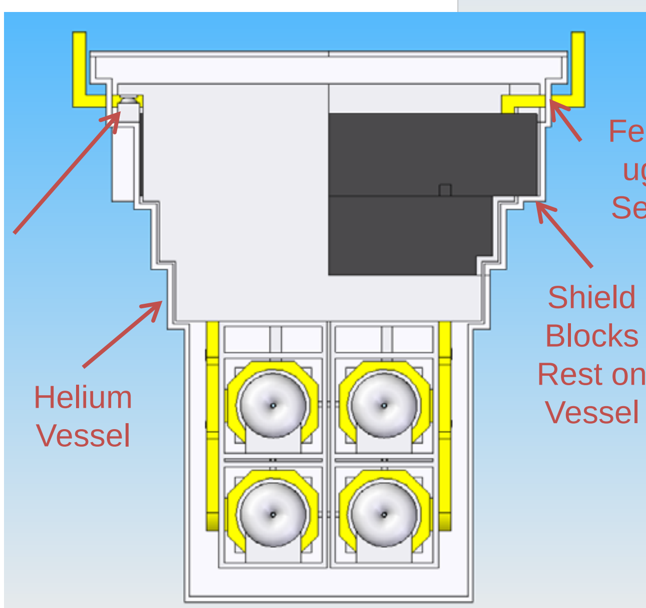


Beam split to
4 targets & horns



Euronu Target Station Layout
Dan Wilcox

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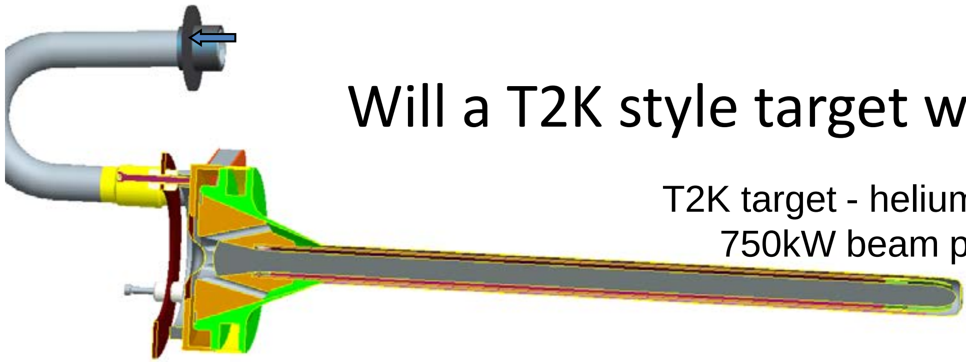
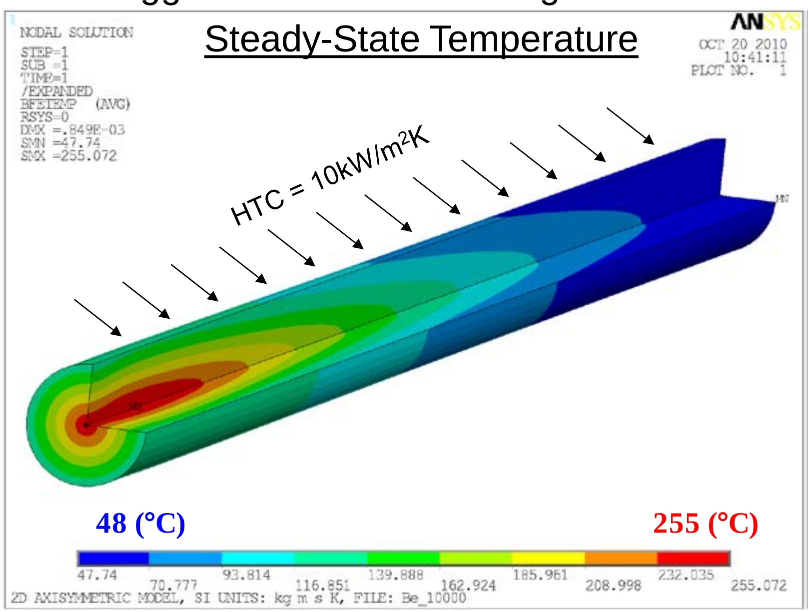


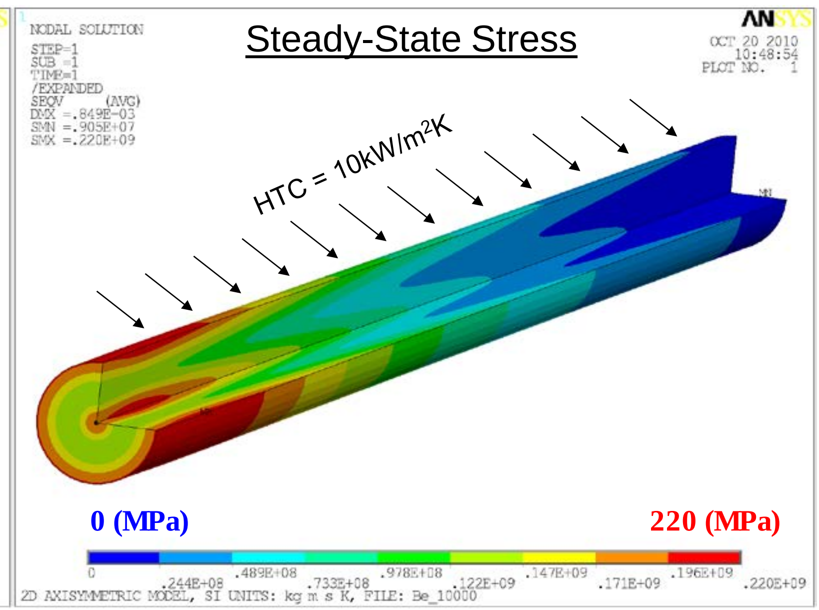
Will a T2K style target work for Euronu?

T2K target - helium cooled graphite cylinder designed for 750kW beam power. Has operated successfully up to 200kW

Consider a 4.5GeV 4MW proton beam incident on 4 beryllium targets (1MW per target so 36kW deposited in target, beryllium preferred over graphite due to better resistance to radiation damage)

- 'low' energy beam results in majority of heating at front of target (this effect increased with 2.5GeV ESS beam)
- The large ΔT between the target surface and core leads to an excessive steady-state thermal stress
- This ΔT depends on the material thermal conductivity and cannot be overcome by more aggressive surface cooling





Why consider a packed bed target?

- Small target segments result in low thermal stress and also low inertial stress (stress waves and excited natural frequencies)
- Not sensitive to off centre beam
- Structural integrity not dependant on target material
- Surface to volume ratio through out target enables significant heat removal while maintaining reasonable target temperature
- Simpler than a flowing target and seems appropriate for the power deposition

Points to note

- Lends itself to gas cooling
- High power designs require pressurised gas
- Bulk density lower than material density (approx factor of 2) may result in a reduction in yield compared to a solid target made of the same material.
- Suitable alternative materials with higher density may be available
- Outstanding question over wear due to relative motion of segments with a pulsed beam

Some relevant papers:

- A helium gas cooled stationary granular target (Pugnat & Sievers) 2002
- Conceptual Designs for a Spallation Neutron Target Constructed of a Helium-Cooled, Packed B of Tungsten Particles (Ammerman et al.)
- The "Sphere Dump" – A new low-cost high-power beam dump concept (Walz & Lucas) 1969

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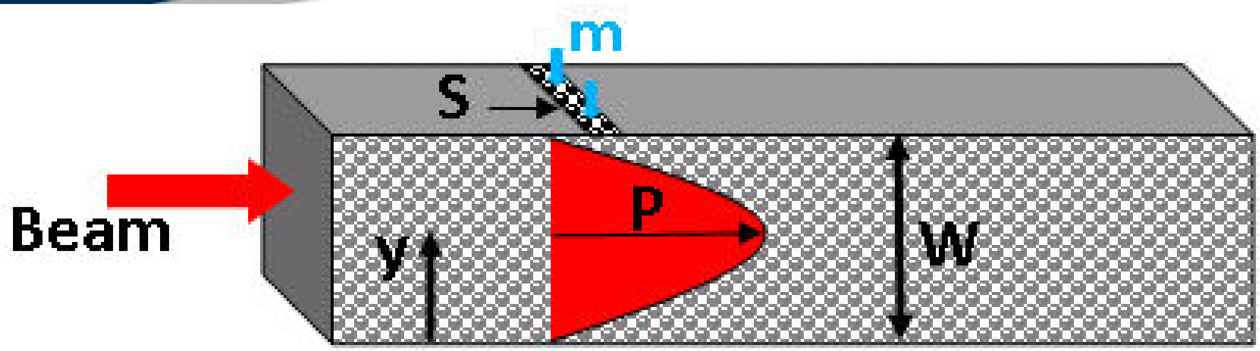
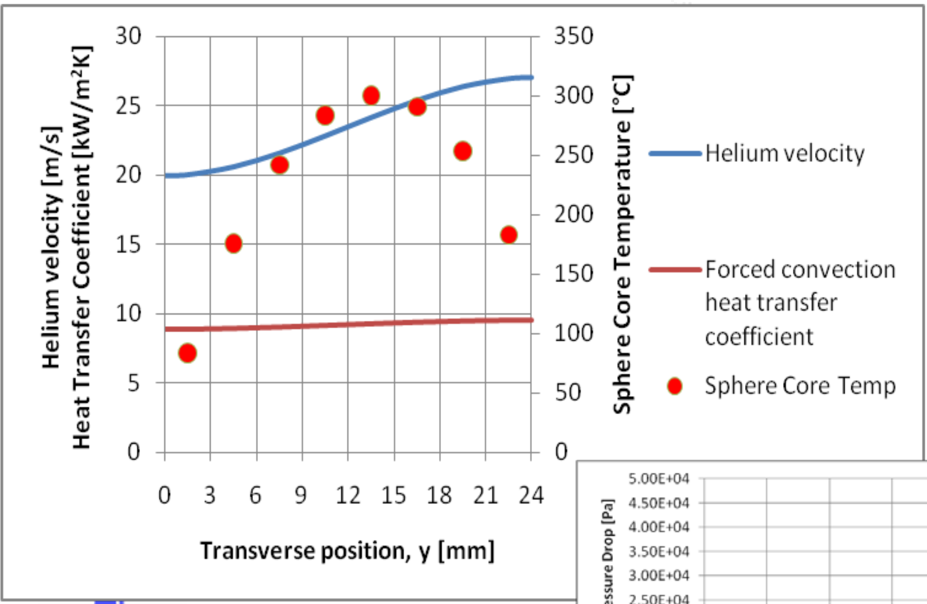
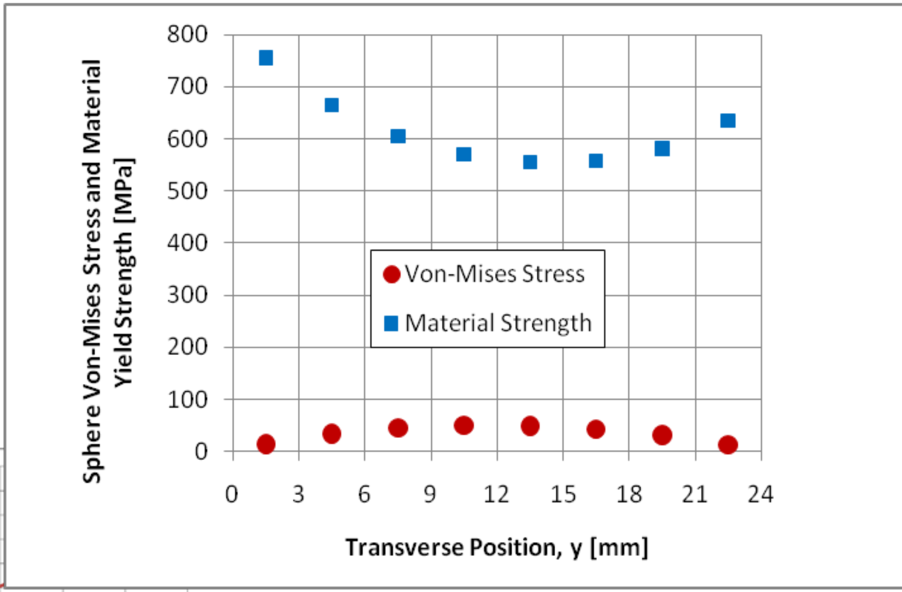
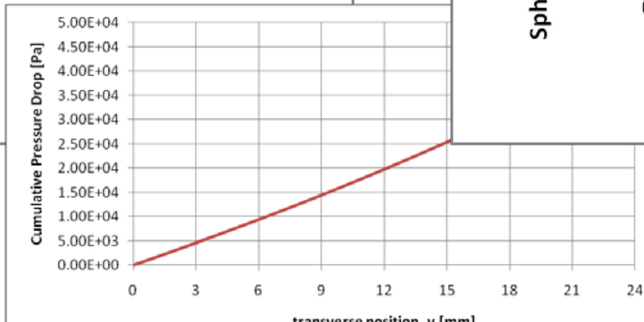
Simple packed bed target model



Target Operating Temperature
Steady state Stress
Pressure Drop





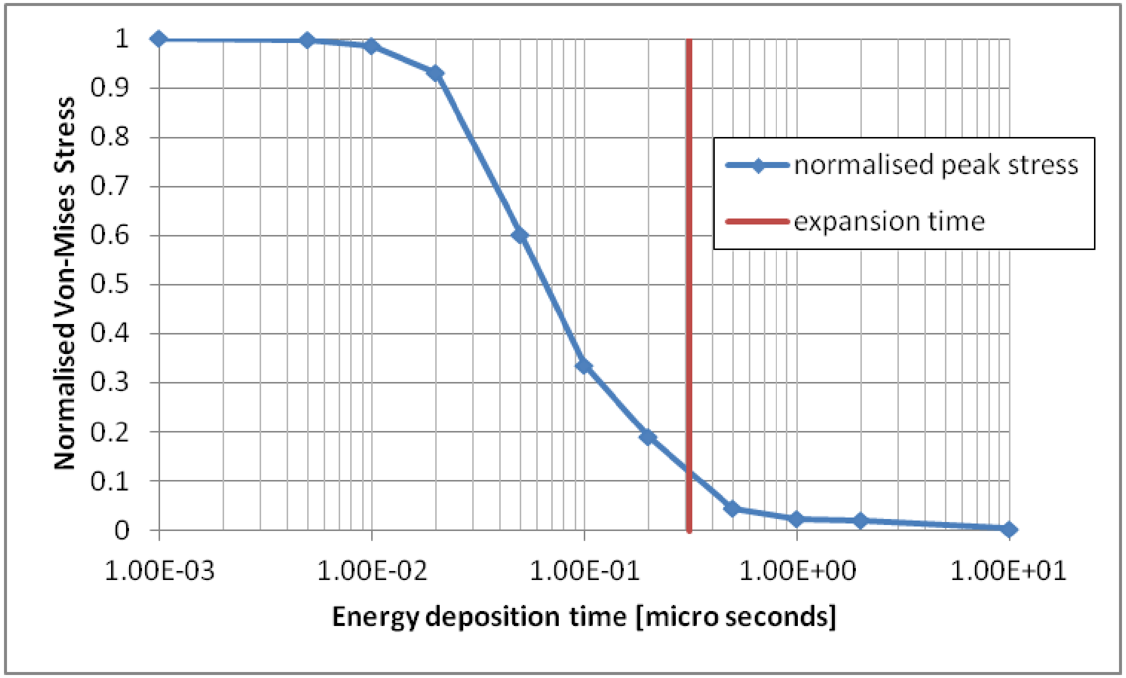


Targets

Inertial stress component

Normalised Peak dynamic stress in a 2mm diameter Titanium sphere as a result of varying spill time (beam pulse length)

ESS long pulse machine but will operate with pulse of a few micro-seconds so some inertial stress expected



Expansion time

$$\tau = \frac{2R}{c_L}$$

Inertial stress is important if spill time << expansion time

Inertial stress is negligible if spill time >> expansion time

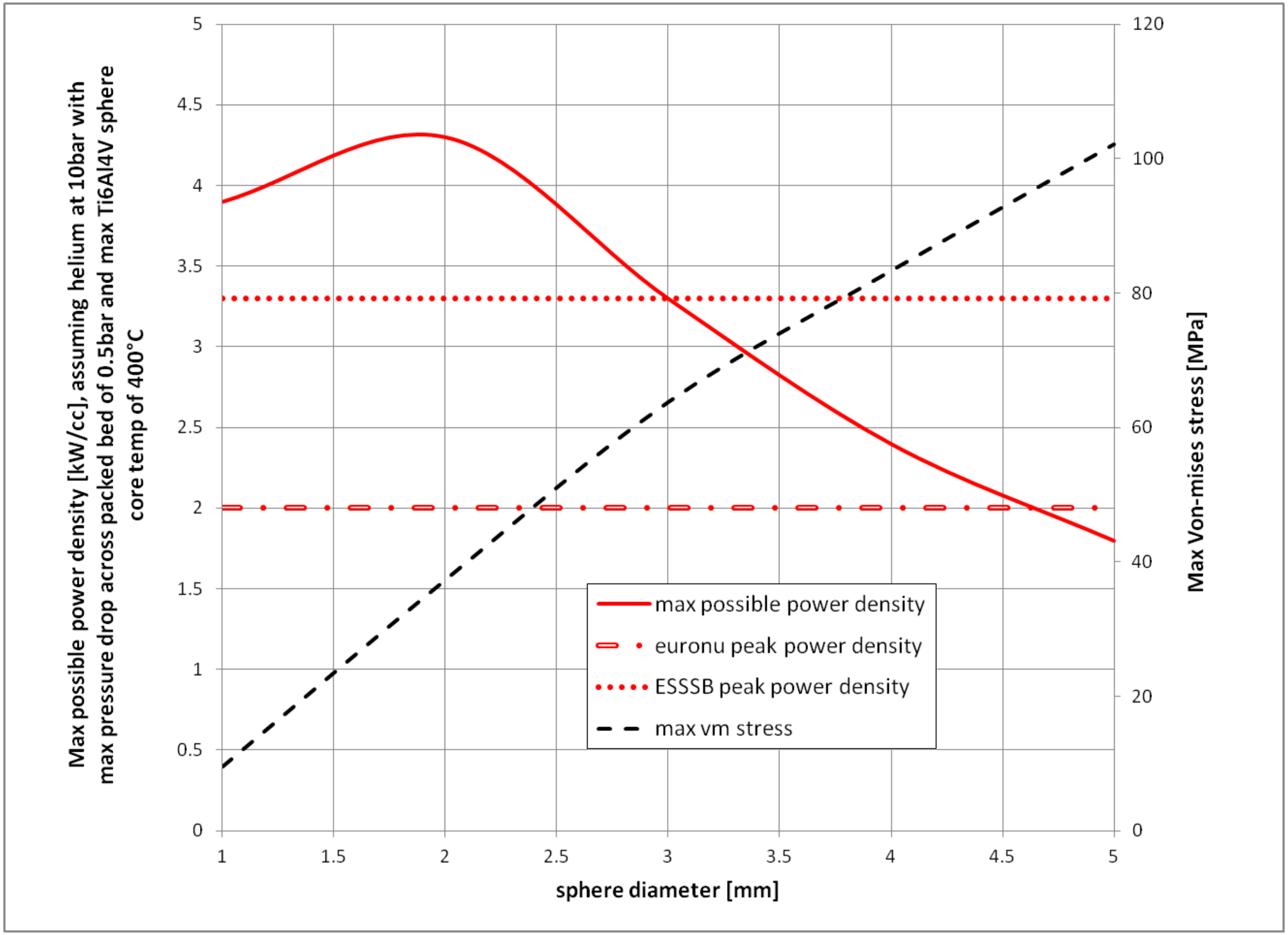
Applicability to ESSnuSB

Max possible power density assuming

max Titanium temp < 400°C

Helium pressure =10bar

max helium pressure drop < 0.5bar



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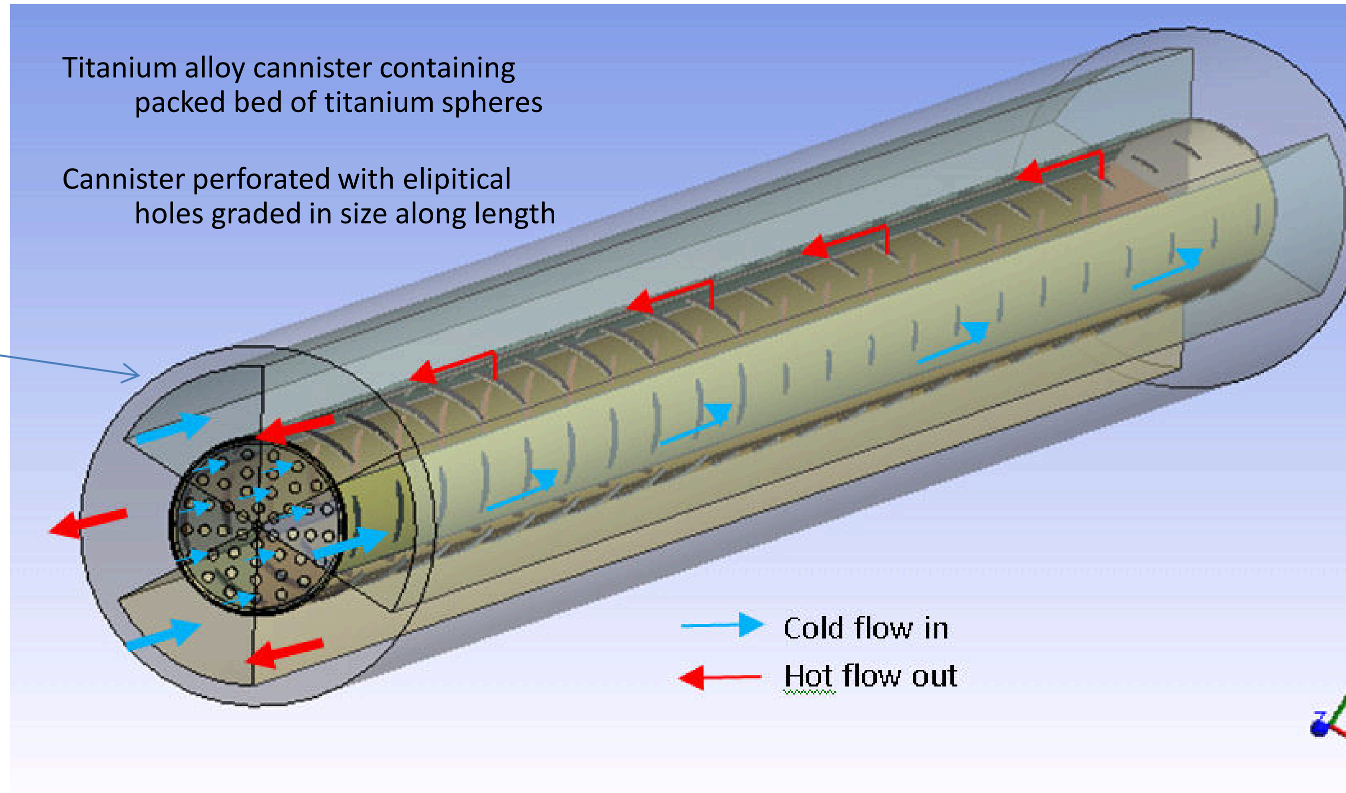
EUROnu Target Concept

Packed Bed Target Concept

Packed bed cannister in transverse flow configuration



Model Parameters

Proton Beam Energy = 4.5GeV

Beam Power = 1MW

Beam sigma = 4mm

Packed Bed radius = 12mm

Packed Bed Length = 780mm

Packed Bed sphere diameter = 3mm

Packed Bed sphere material : Titanium

Coolant = Helium at 10 bar pressure

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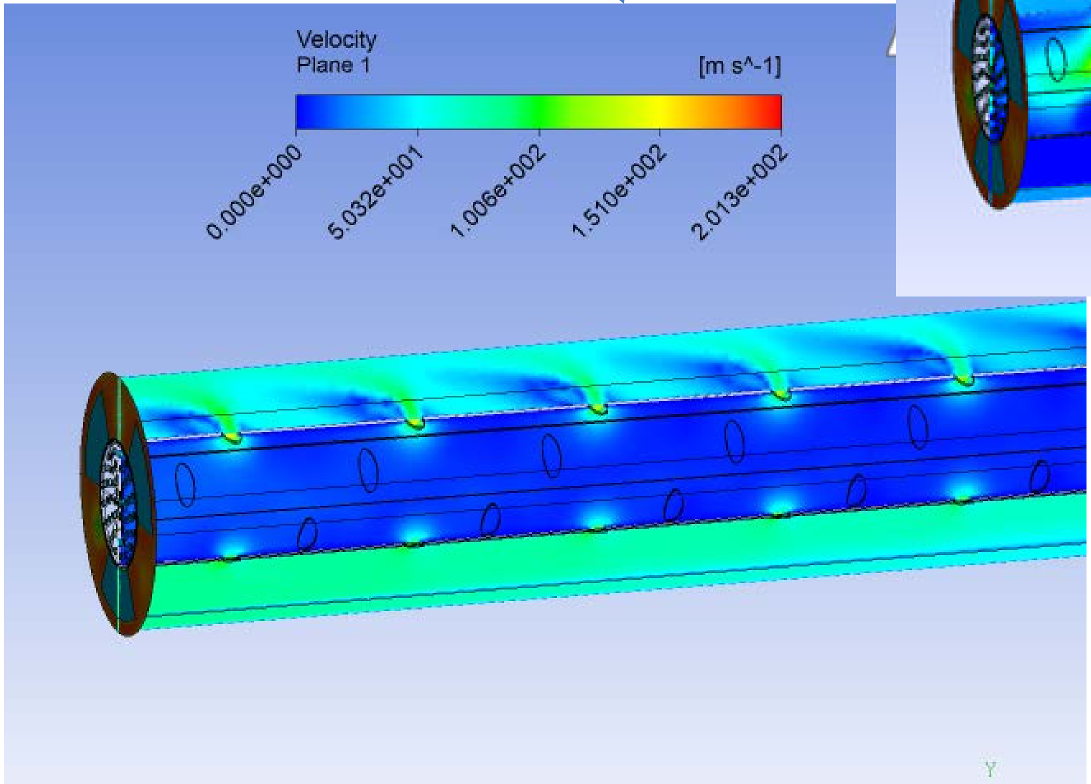
EUROnu CFD model

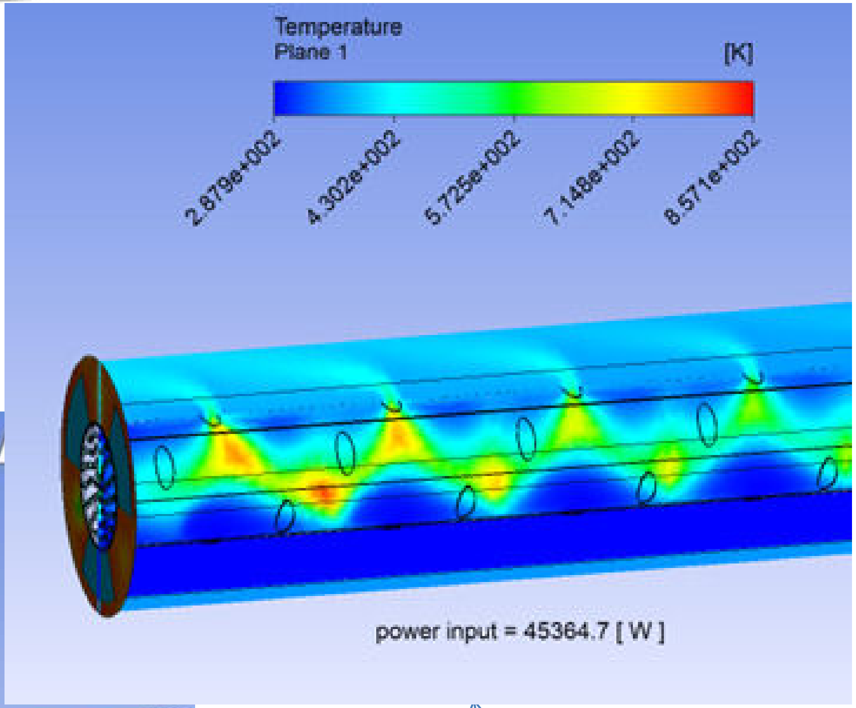
Helium Flow

<u>Helium Velocity</u>

Maximum flow velocity = 202m/s

Maximum Mach Number < 0.2





<u>Helium Gas Temperature</u>

Total helium mass flow = 93 grams/s

Maximum Helium temperature = 857K =584°C

Helium average outlet Temperature = 109°C

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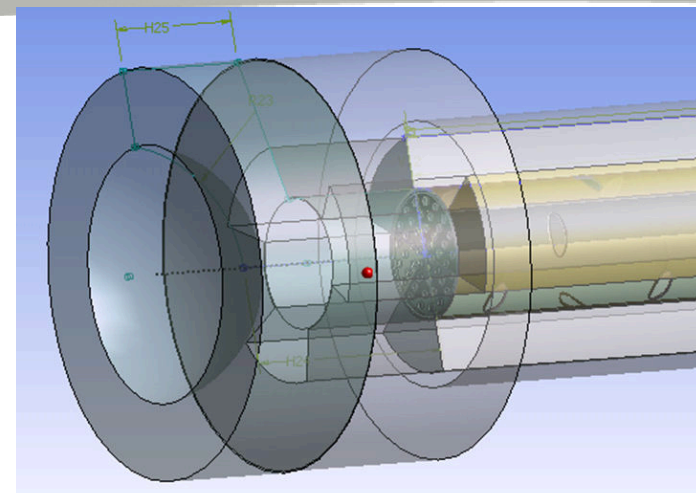
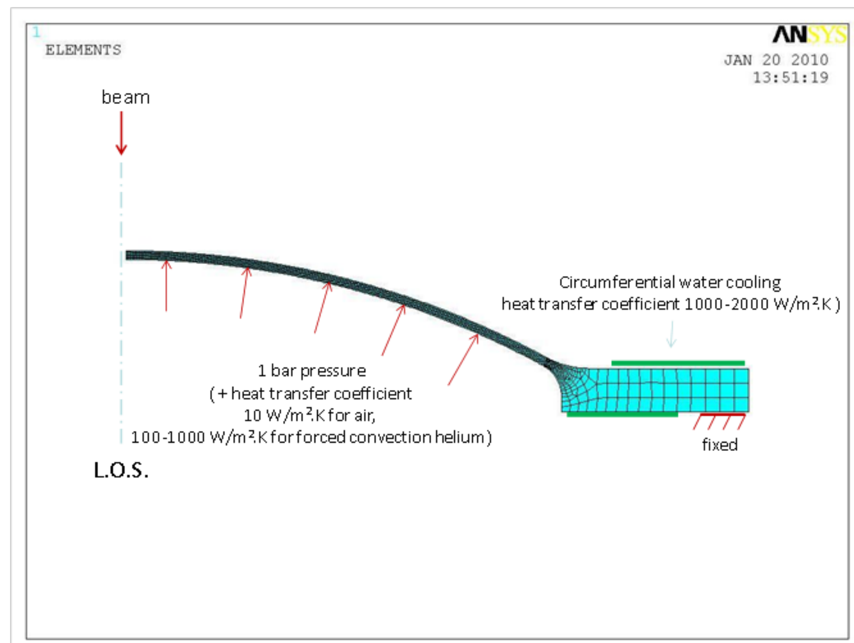
Beam Window study by M.Rooney

- Beam enters the target cannister through a beam window which separates target coolant from target station helium
- Beryllium is a candidate material for the window
- Peripheral or surface cooling look to be feasible options
- Static and inertial stresses result from beam heating are manageable
- Pressure stresses can be dealt with by having a hemispherical window design





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Packed Bed Thermal Testing

Induction heater test
Graydon et al.

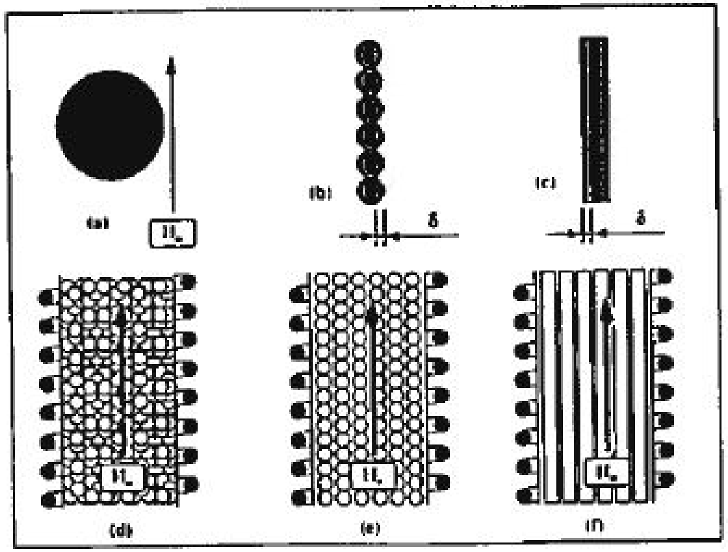


Figure 3 — (a) Path of the eddy currents at the surface of a sphere; (b): sectional view of eddy currents in a well-ordered pile of spheres; (c): sectional view of eddy currents in a cylinder; (d): analogy between a randomly-packed bed; (e): regular piles of particles; (f): a bundle of cylinders.

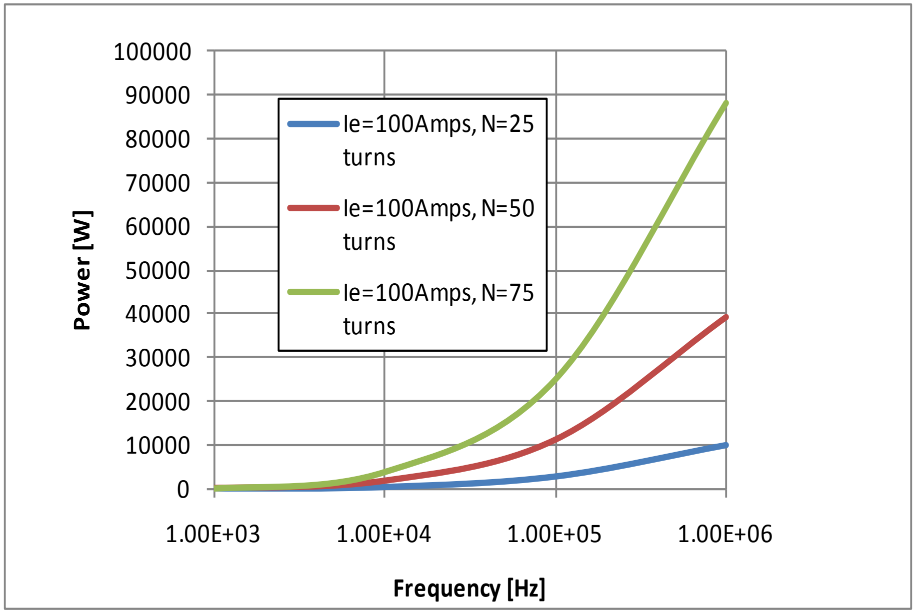
$$R_{eq\,packed\,bed} = 4(1-\epsilon)\left(\pi^2 R^2 N^2 / r_s L\right)\left(\sqrt{10^{-7}\mu_R f/\sigma}\right) F$$

Induction Heating

Packed bed placed in an alternating magnetic field.

Eddy currents induced in conductive spheres.

Resultant Joule heating provides internal heating of spheres.



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Packed bed induction heating theory
Duquenne et al.

Conclusions

- A packed bed target has been adopted as the baseline target design for the EUROnu superbeam project.

  It has inherently low steady state and inertial stress as well as tolerance to off-centre beams.

  Simple analysis and a CFD model of a packed bed target concept showed this to be a feasible concept for dissipating the heat from the EUROnu 1MW super beam.

  The reduced beam energy of ESSnuSB relative to EUROnu results in a higher peak power density although initial calculations suggest a Titanium packed bed would be able to accommodate a quarter or more of the ESSnuSB beam with reasonable operating temp and steady stress.

  Inertial stress levels will depend on beam pulse length and sphere diameter.

  Use of Titanium as a target material has been investigated from a physics output perspective with a positive outcome (Longhin & Zitto)
- Stress in window components, containment vessel, required operating pressure and radiation damage may be the limiting factors for a packed bed target.
- The Euronu target station design would be largely applicable to ESSnuSB

Work required to develop a superbeam target (target work package)

1)Detailed FLUKA and ANSYS simulations of target design and beam window materials. (continuation and development of Euronu effort)

2)Specification of preferred candidate materials for target, target containment and beam windows over range of required operating conditions. Material irradiation tests and off-line shock fatigue tests required to estimate material lifetimes. (Involvement of Radiate collaboration and Oxford Material Scientists is recommended)

3)Prototype preferred target technology.

Carry out off-line heating and cooling tests to verify heat dissipation capability, e.g. inductively heated and helium cooled packed bed target. (RAL HPTG has access to a high frequency induction heater)

Carry out in beam tests to evaluate target response to a pulsed beam. (Possibility to include packed bed test in next Hiradmat experiment)

4)Outline design of target integration with horn

5)Target station layout and design including remote maintenance and handling. (experienced RAL designers working on ESS target handling)

6)Develop detailed design of preferred target technology (HPTG recently delivered nova target to fermilab)