EUROnu Beam Window Studies

Stress and Cooling Analysis

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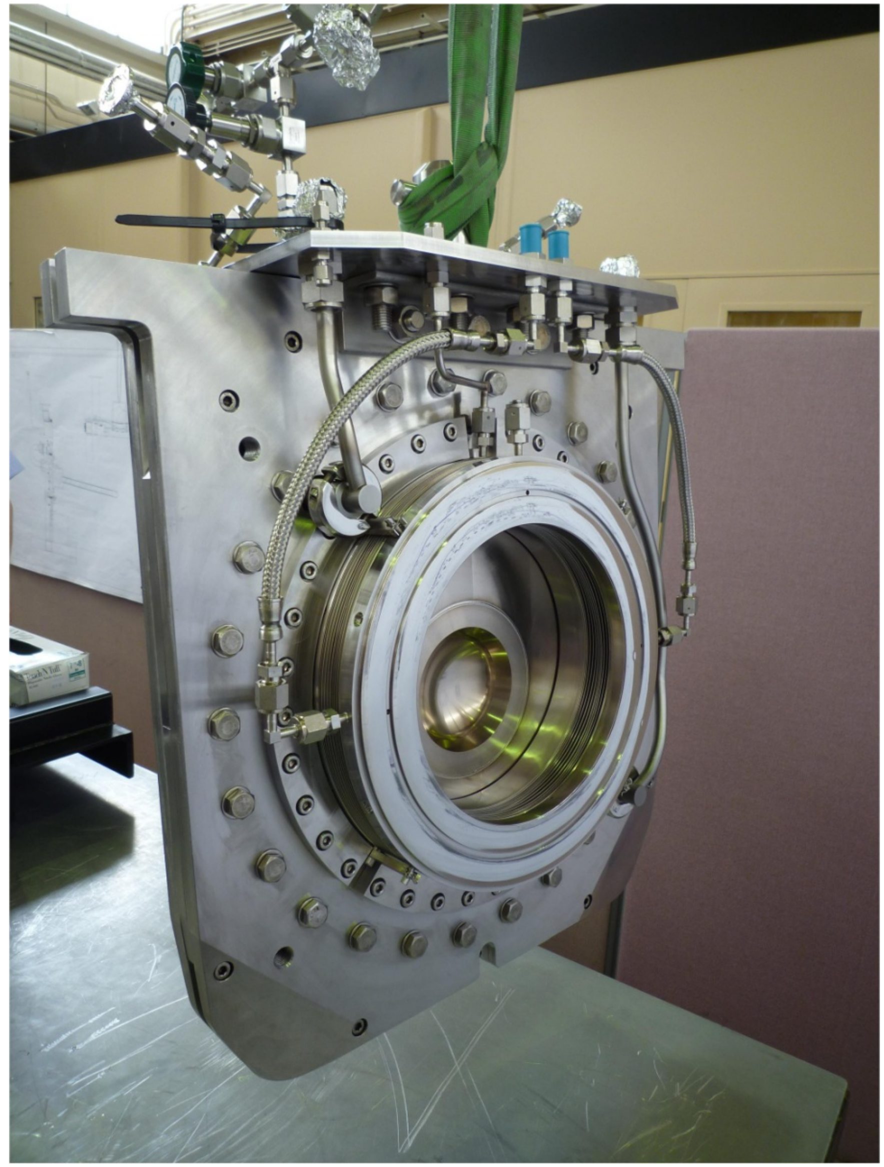
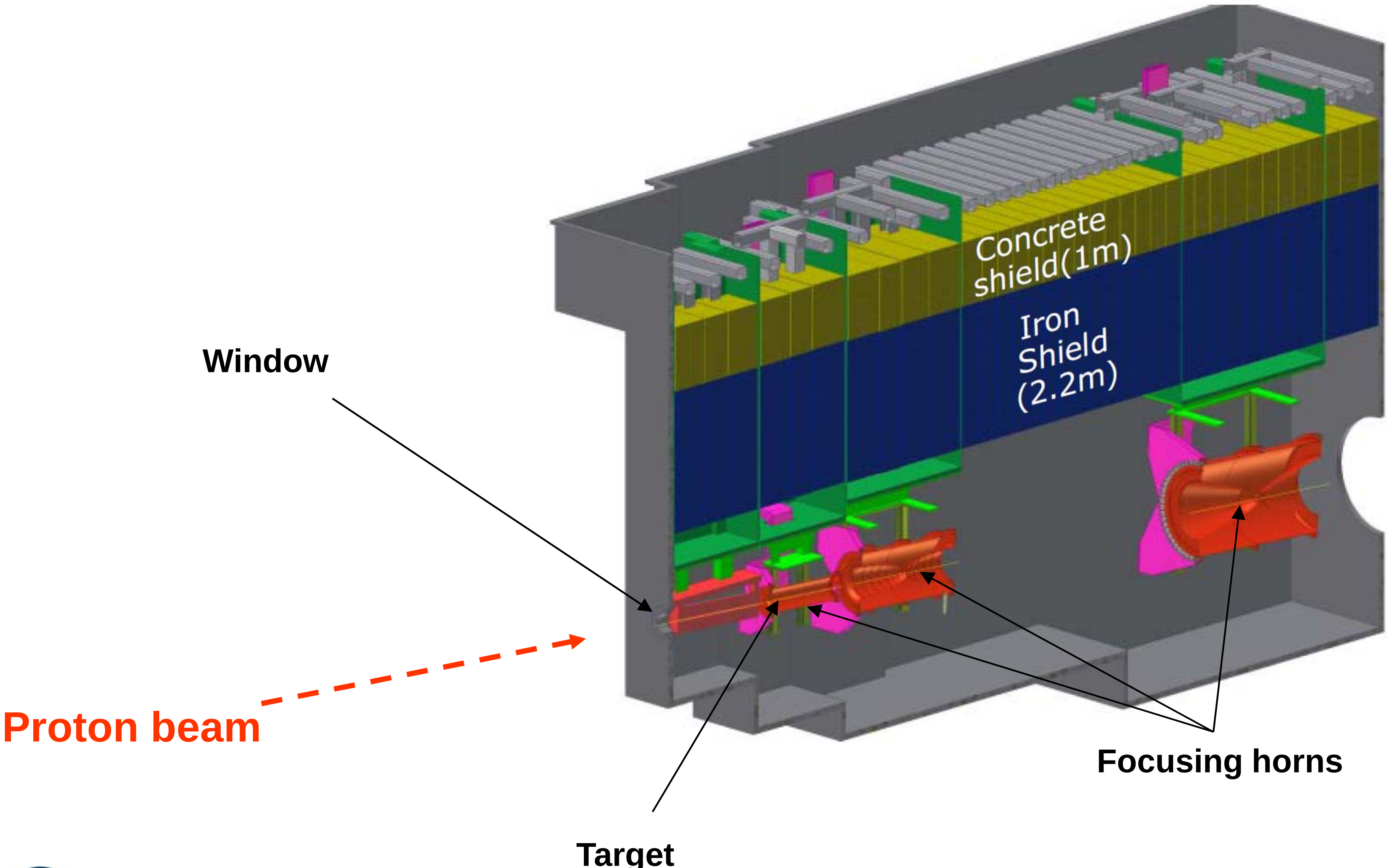
T2K beam window

- Double-skinned titanium alloy window, cooled by helium gas.
- LBNE plan to use a similar design for their beam window. But perhaps beryllium instead of titanium.
- Cost ~ $100k



T2K Target Station



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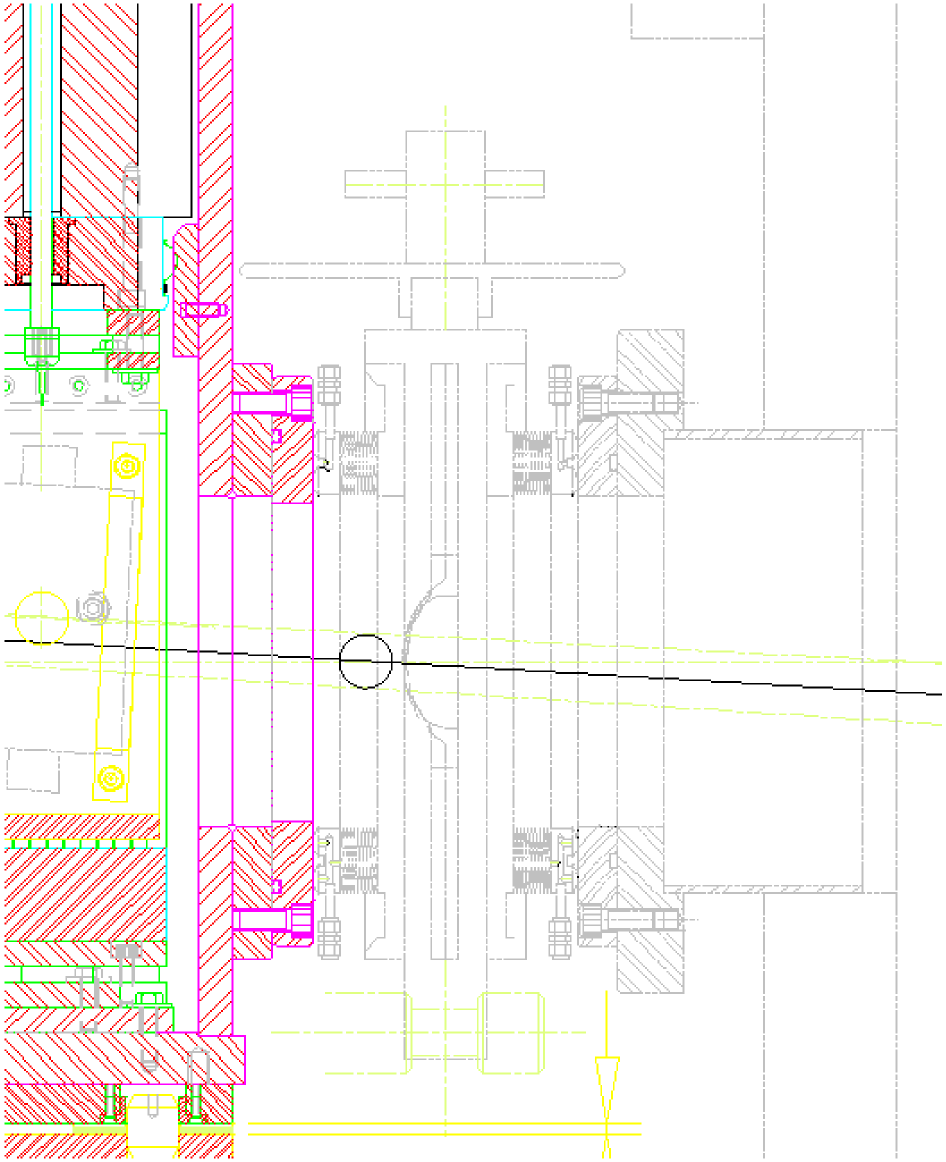
Section view



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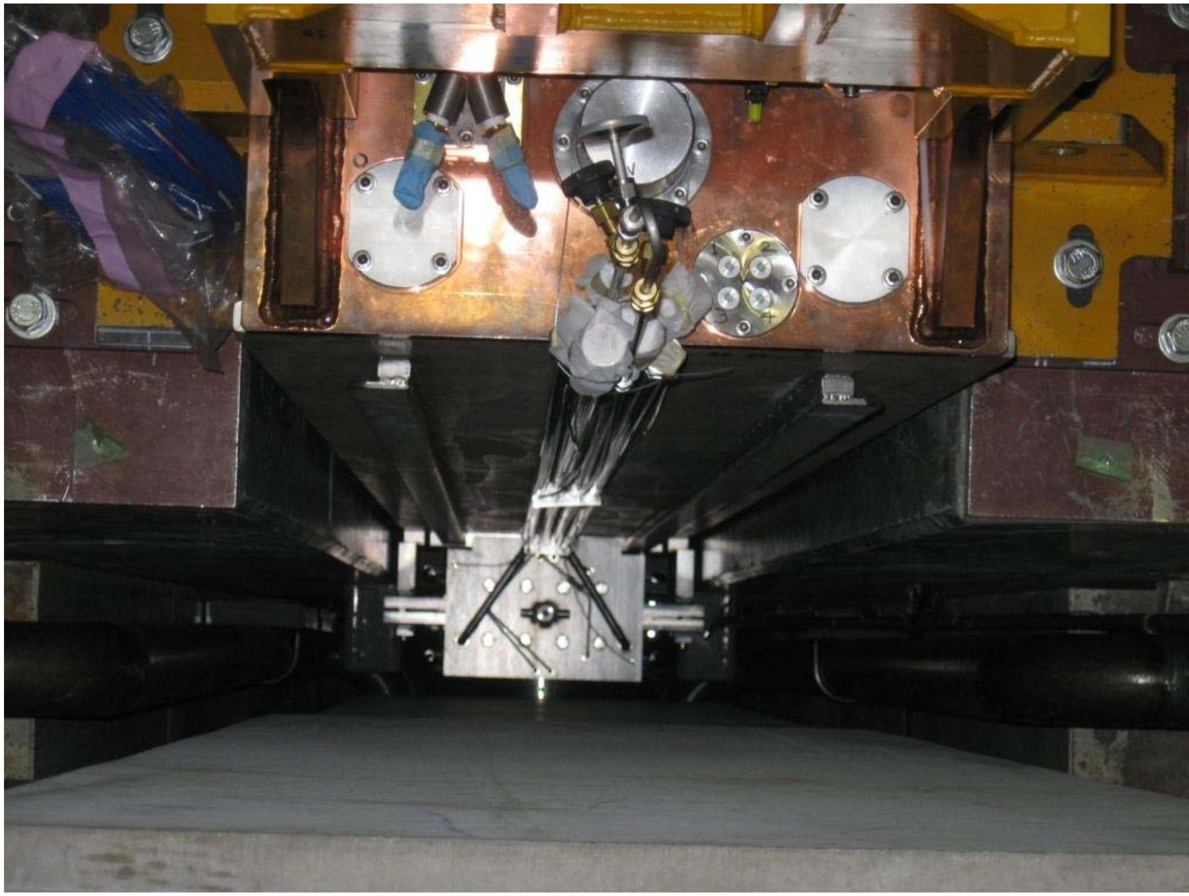
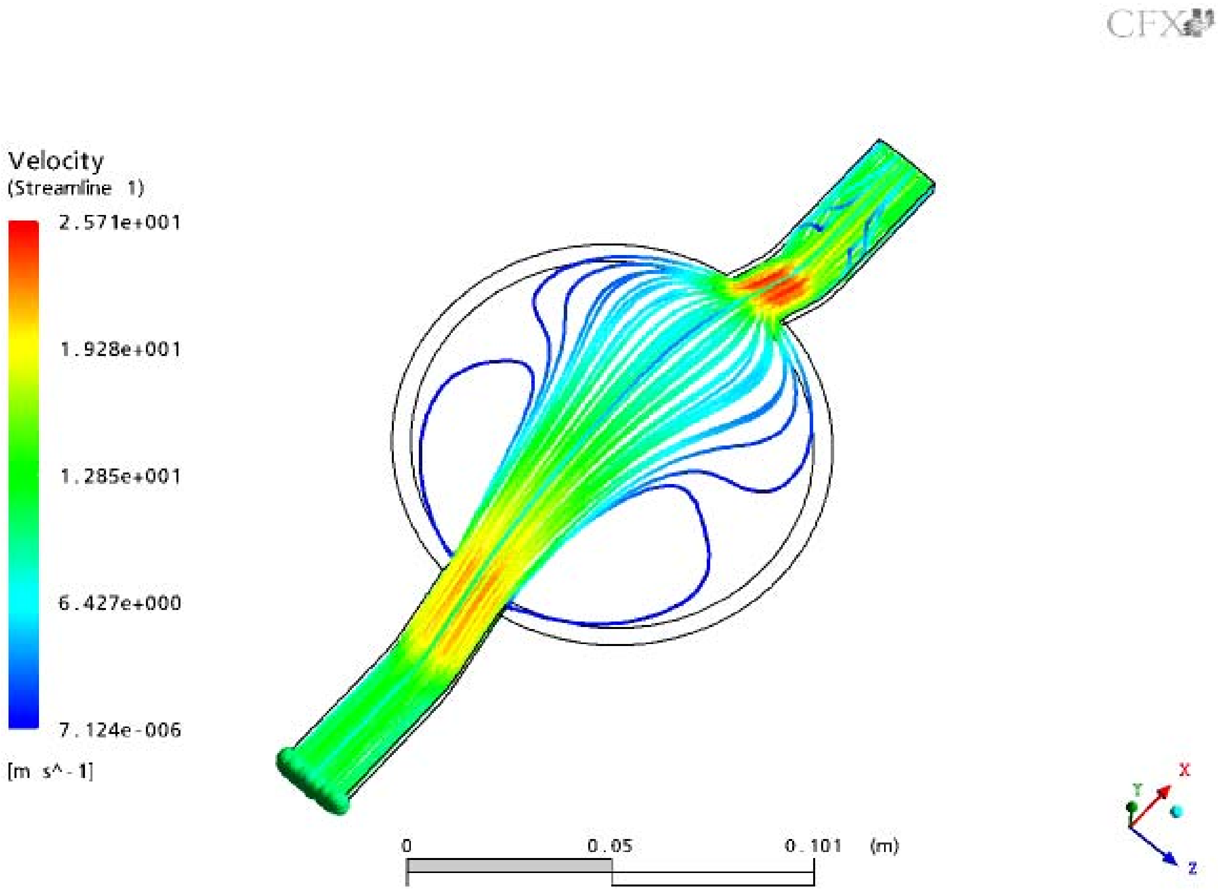


Double skinned window with helium cooling



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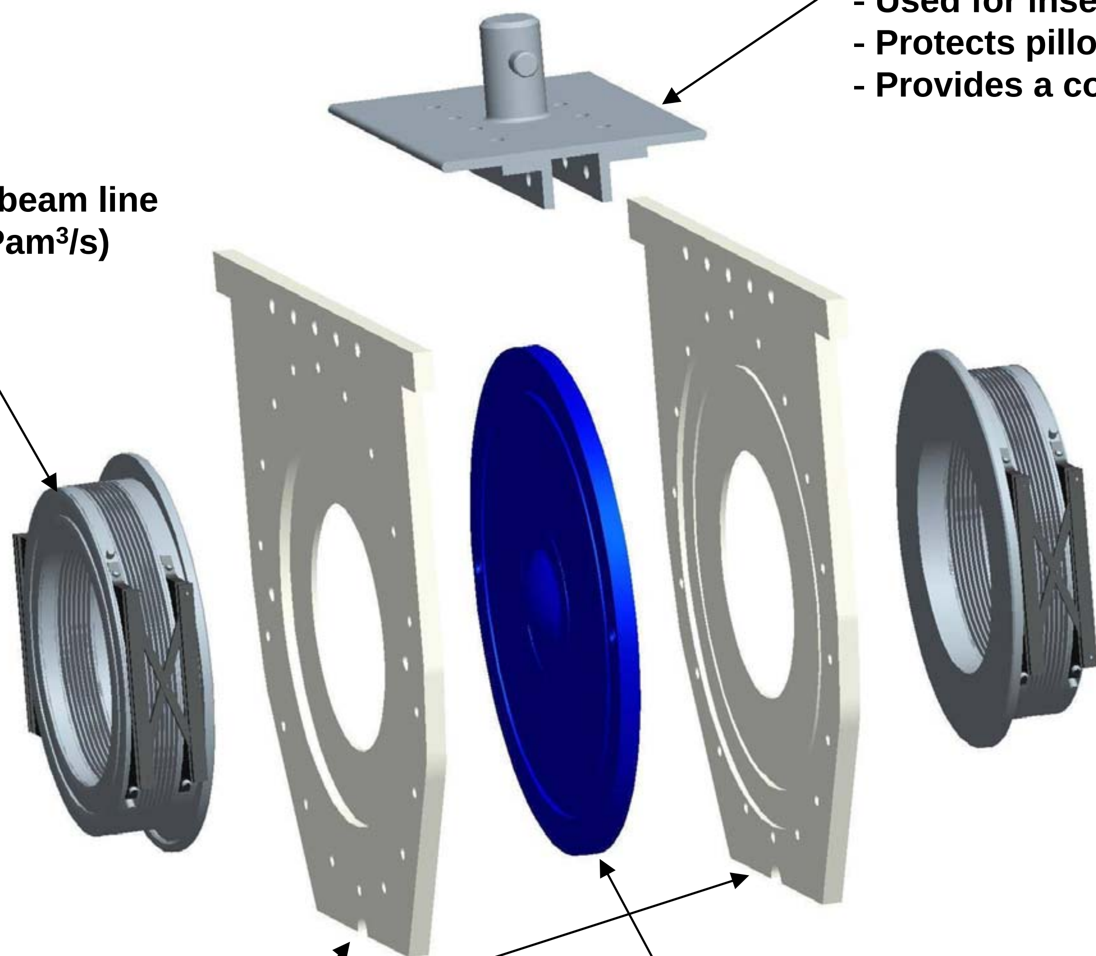
Main components

Top plate
- Used for inserting and removing window
- Protects pillow seals and mating flanges
- Provides a connection point for services

Pillow seals
-Seal helium vessel and beam line
(leak rate spec, 1 x 10^{-7} Pam^3/s)



Side plates
-Provide a firm support for the beam window to hold it in position

Ti-6Al-4V beam window

Inflatable seals

PSI

Picture courtesy of PSI

KEK Muon Group

Picture courtesy of Y. Miyake and S. Makimura (KEK)

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Seal and mating flange

Seal foils (surface roughness, Ra = 0.004 µm, Rt = 0.030 µm)

Polished flange (surface roughness, Ra = 0.020 µm)

Leak performance ~ 1 x 10^{-9} Pa.m^3/s

Cost: ~ $30,000 each

EUROnu window candidate materials

	Beryllium	Titanium alloy	
Density	1844	4540	kg/m3
Specific heat capacity	1925	558	J/kg.K
CTE	11.5	8.7	
Modulus	303	113	GPa
Thermal conductivity	216	7	W/m.K

Others candidates: AlBeMet, GUM, INVAR…

Simple stress comparison

'Thermal stress resistance', $$R = \frac{UTS}{\alpha . E . \Delta T}$$ where $$\Delta T = \frac{EDD}{C_p}$$

UTS – ultimate tensile strength
α – coefficient of thermal expansion
E – Young's modulus
ΔT – temperature jump
EDD – energy deposition density
Cp – specific heat capacity

	ΔT	shock resistance
Graphite	100	10.05
beryllium	37	2.08
titanium	245	4.12
albemet	51	3.26

Superbeam comparison

	EUROnu	LBNE (700 kW)	LBNE (2 MW)	T2K	
Beam power	1	0.7	2	0.75	MW
Beam energy	5	60	60	30	GeV
Protons per pulse	1.50e14	5.60e13	1.6e14	3.30e14	
Beam sigma	4	1.5	3.5	4.24	mm
Peak energy dep.	~ 80	~ 200	~ 128	~ 160	J/cc/spill
Pulse length	5	10	5	5	µs
Frequency	12	1.32	1.32	0.47	Hz

NOTE: Energy deposition is for beryllium.

Euronu stress analysis – variables studied

Beam parameters:

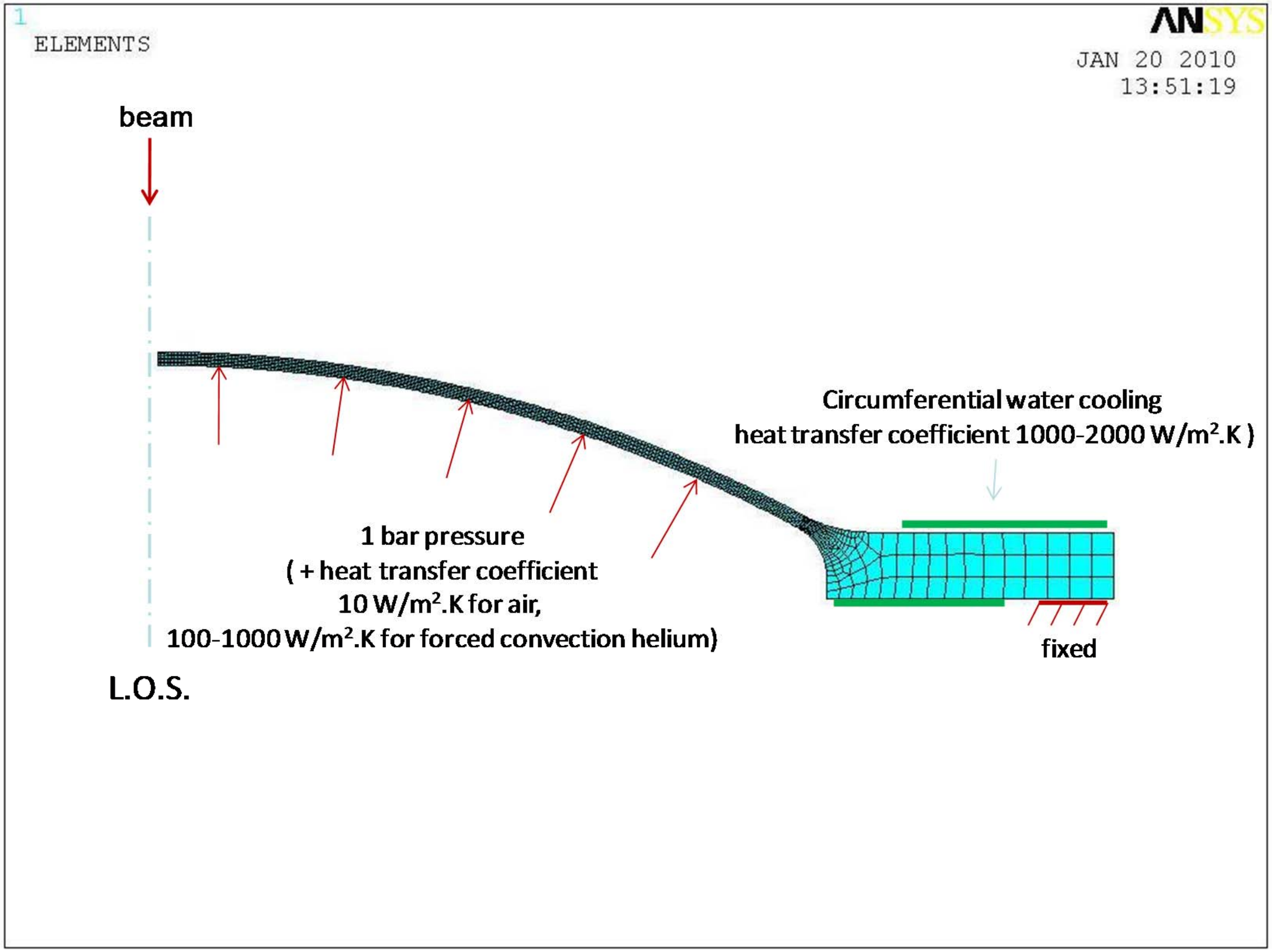
- Power: 1 MW (4 MW divided between four targets/windows)
- Energy: 5 GeV
- 1.5 x 10^{14} protons per pulse
- Frequency: 12.5 Hz
- Pulse length: 5 microseconds
- Beam sigma: 4 mm

Design considerations:

- Materials: Beryllium (S65C), Titanium alloy (Ti-6Al-4V)
- Cooling methods: direct forced convection helium and circumferential water

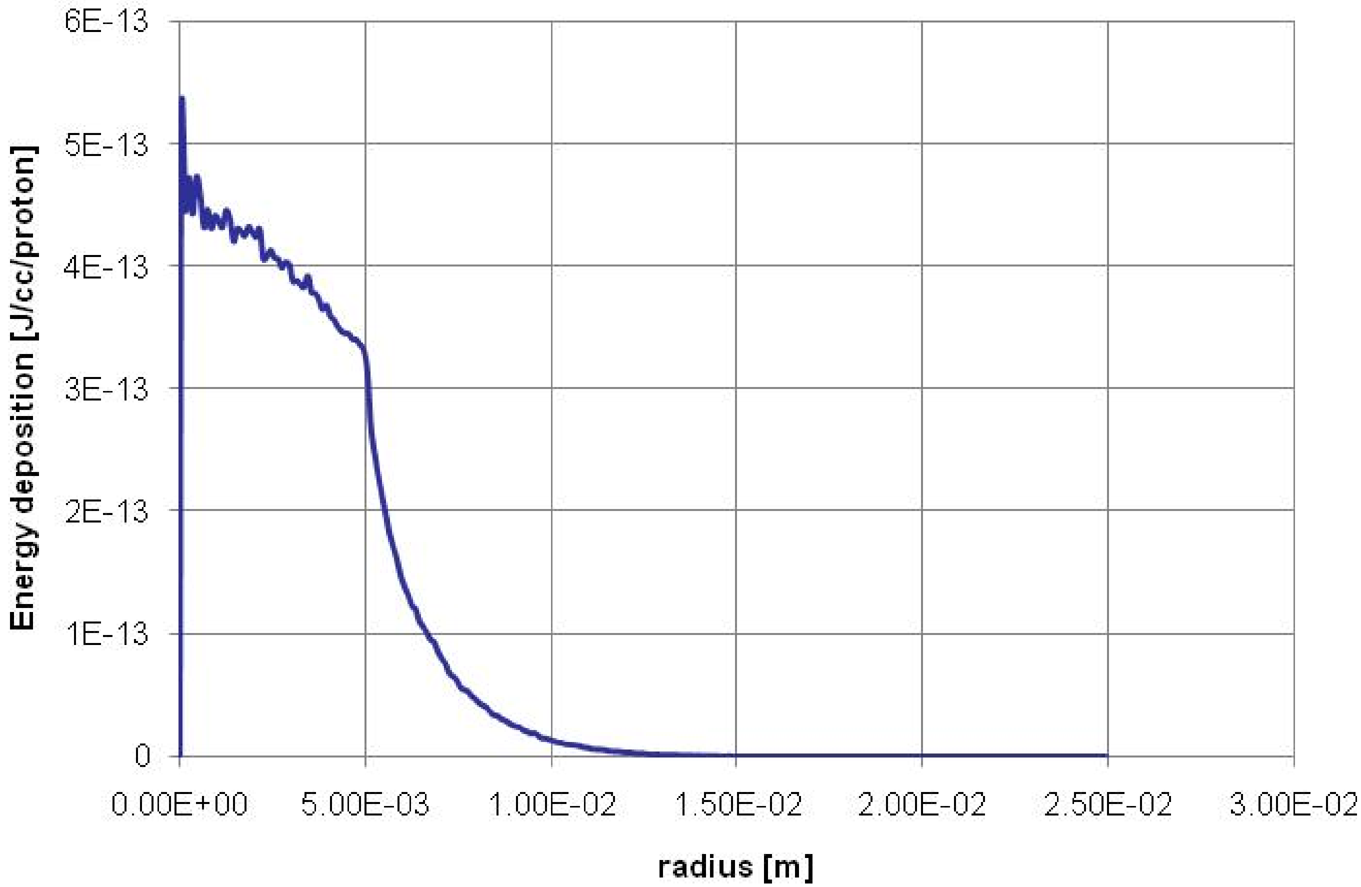
Beam parameters taken from *EUROnu WP2 Note 09-11*

Typical ANSYS model showing cooling options



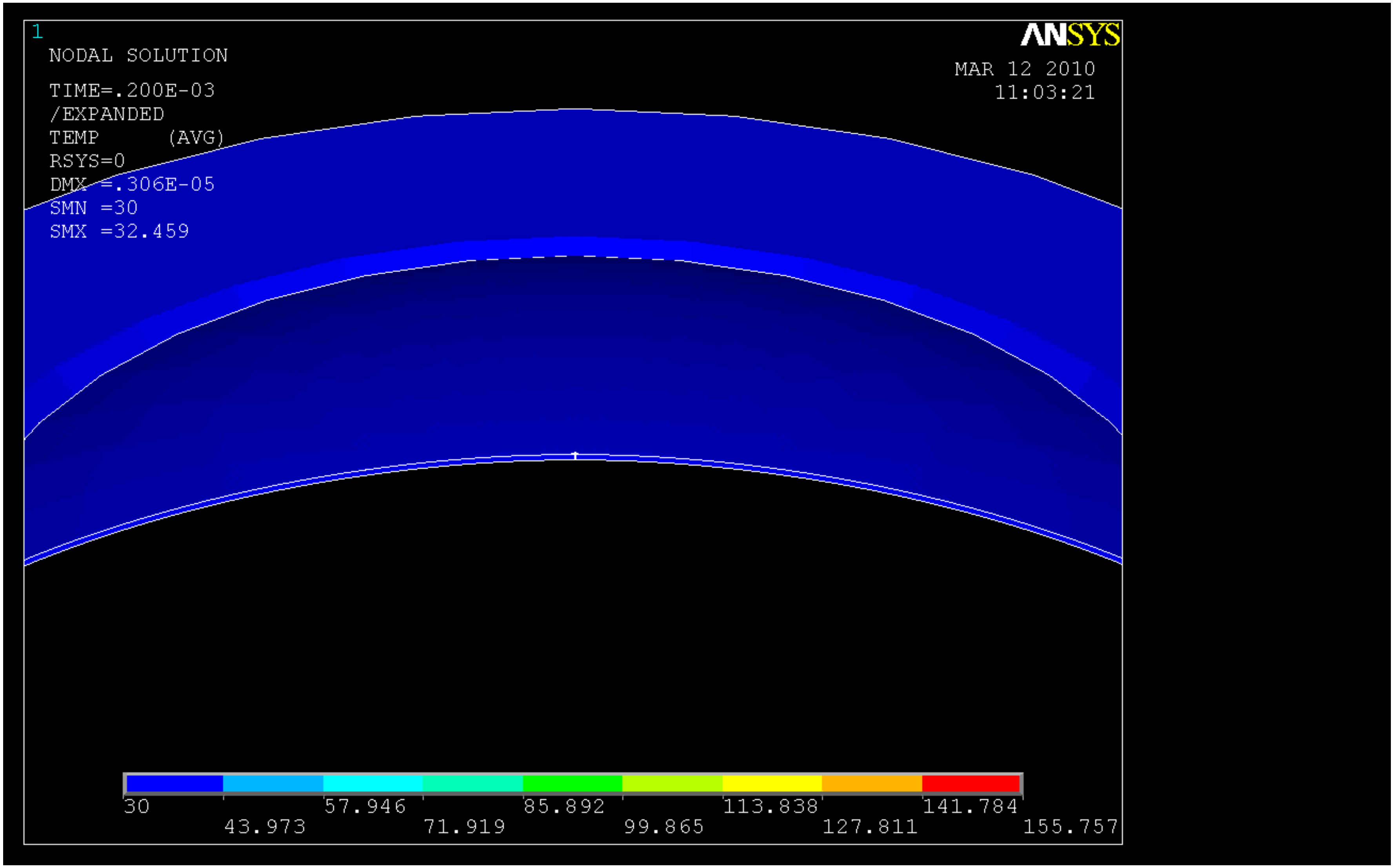
ANSYS Multiphysics v11 used with coupled field elements (axisymmetric model)

Energy deposition profile



NOTE: Data produced by Tristan Davenne (RAL) using Fluka.
A Gaussian approximation of this data has been used in ANSYS for simplicity.
Peak is around 80 J/cc/spill for beryllium window

Transient animation



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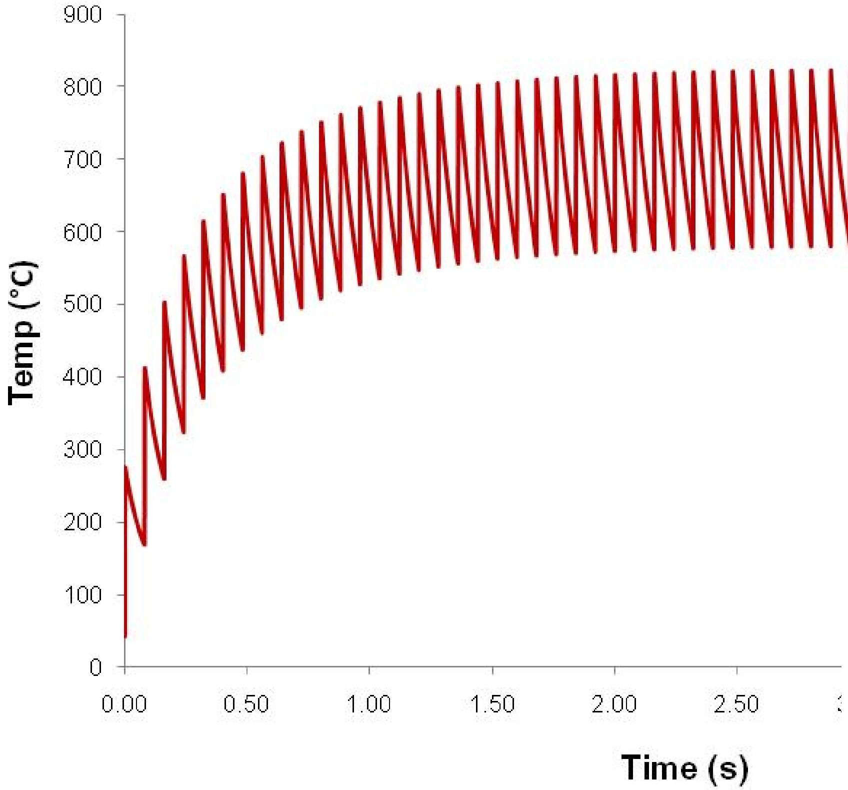
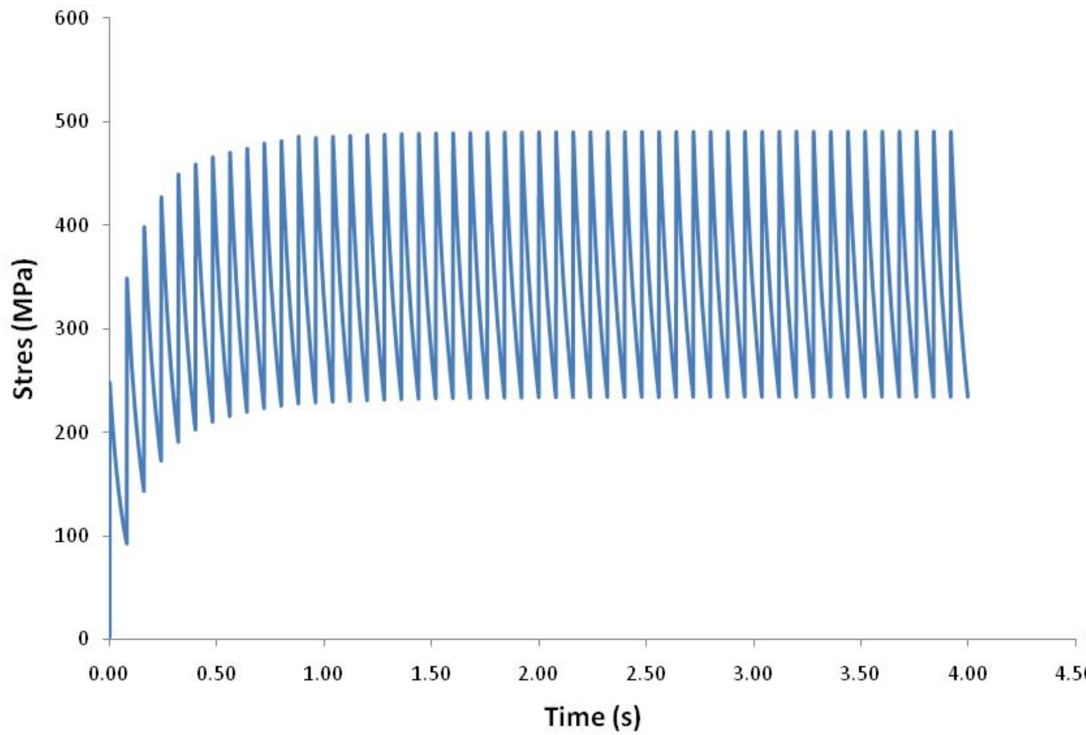
Helium cooled Ti-6Al-4V window (like T2K) is not an option



50 pulses (4 seconds)



0.25 mm thick titanium alloy window
Direct helium cooling
(assumes 1000 W/m^{2}K)

Peak stress of 500 MPa is above yield stress for titanium at 800°C.

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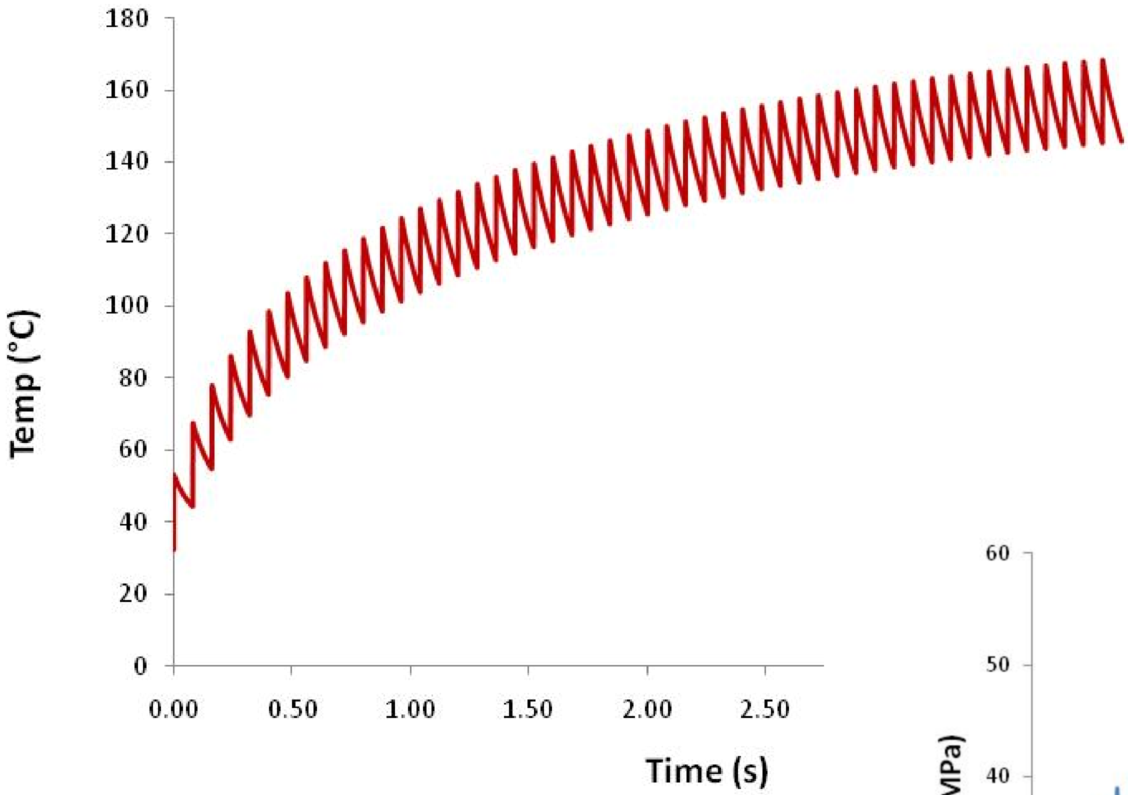
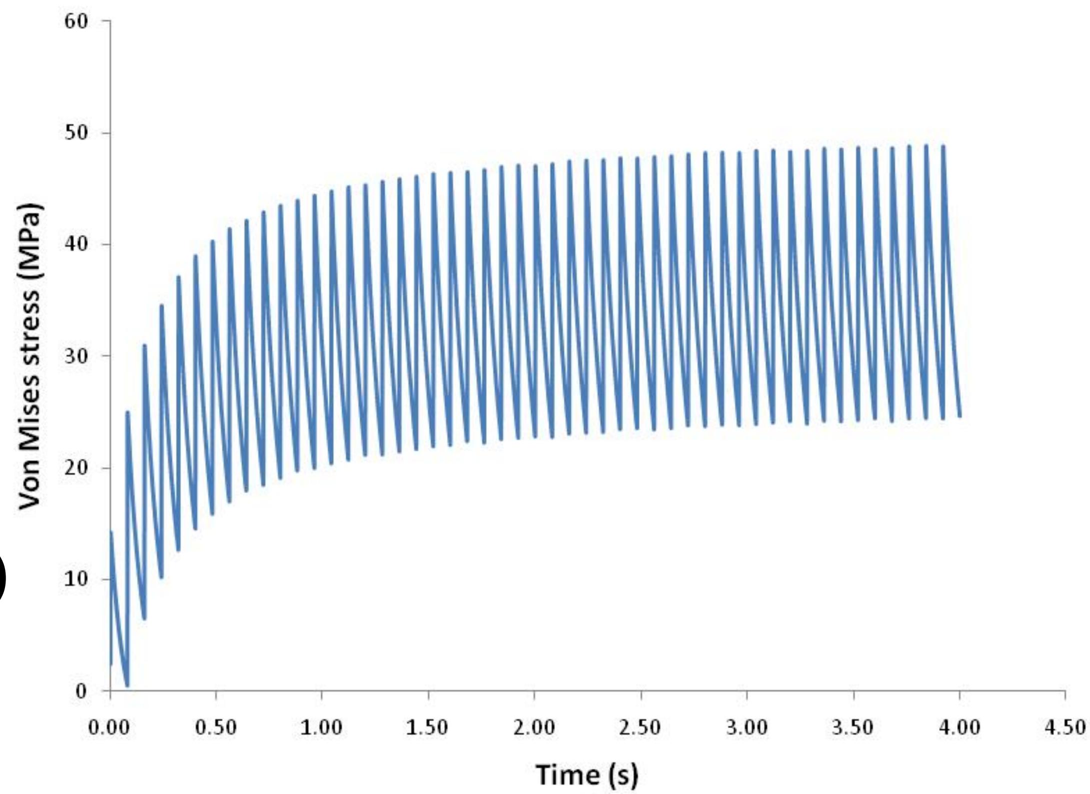
Circumferentially water cooled beryllium window



0.25 mm thick beryllium window
Circumferentially water cooled
(assumes 2000 W/m^2K)
Max temp ~ 180 °C
Max stress ~ 50 MPa (yield ~ 270 MPa)
Acceptable!



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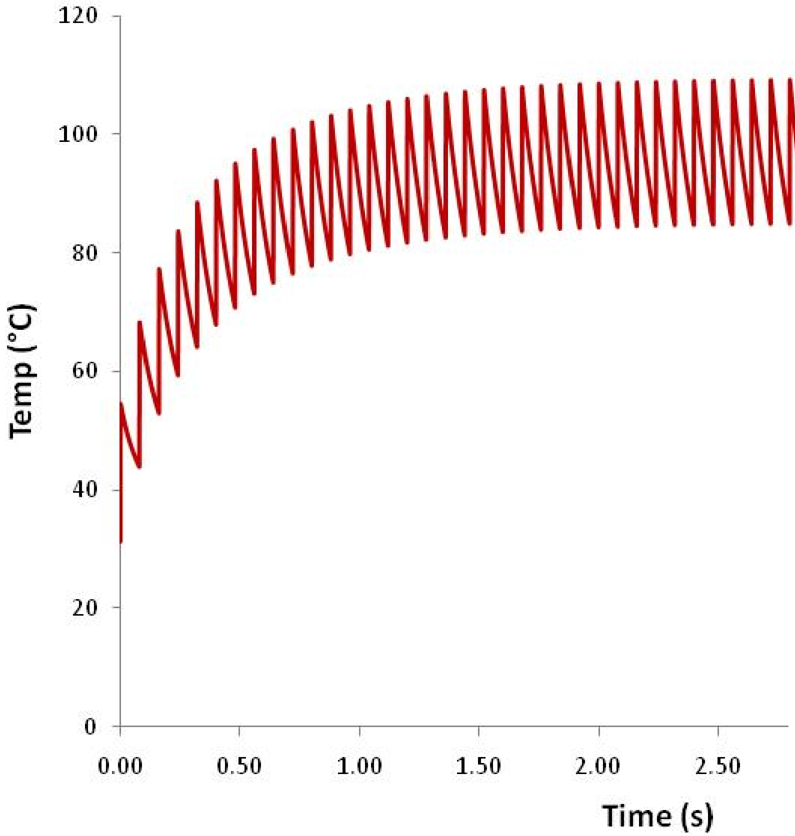
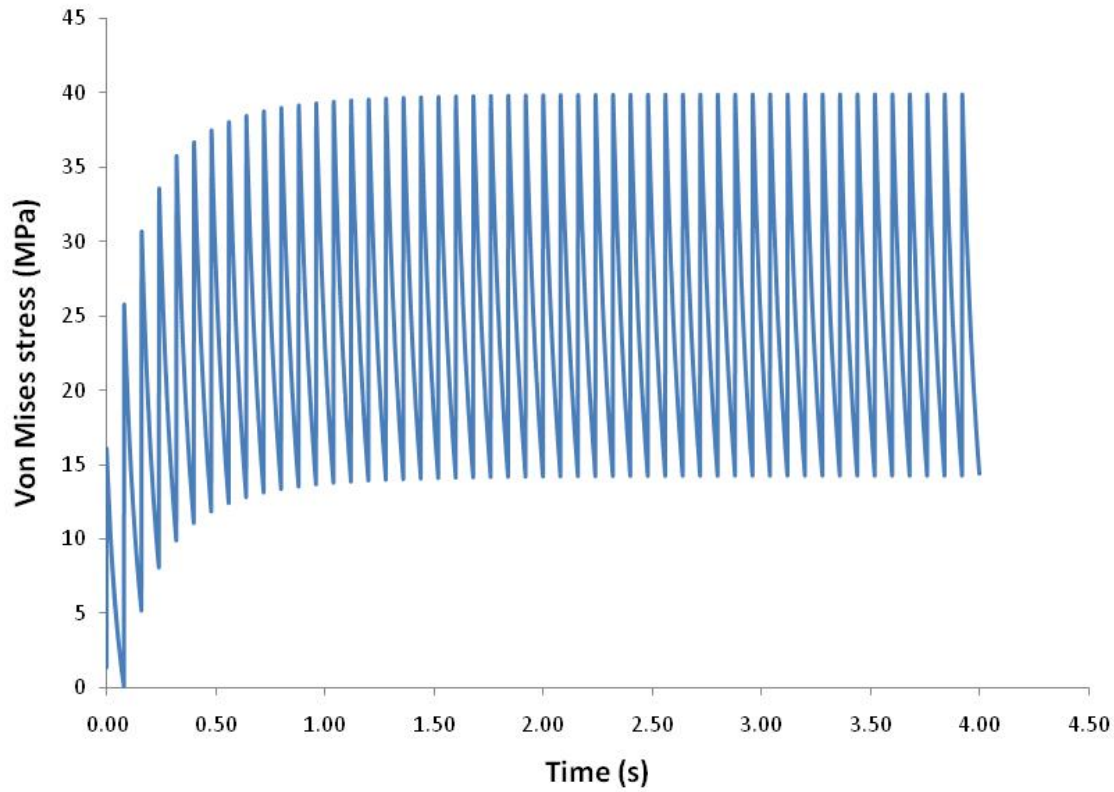
High velocity helium cooled beryllium window





0.25 mm thick beryllium window
Direct helium cooling
(assumes 1000 W/m^2K)
Max temp 109 °C
Max stress 39 Mpa
Better!

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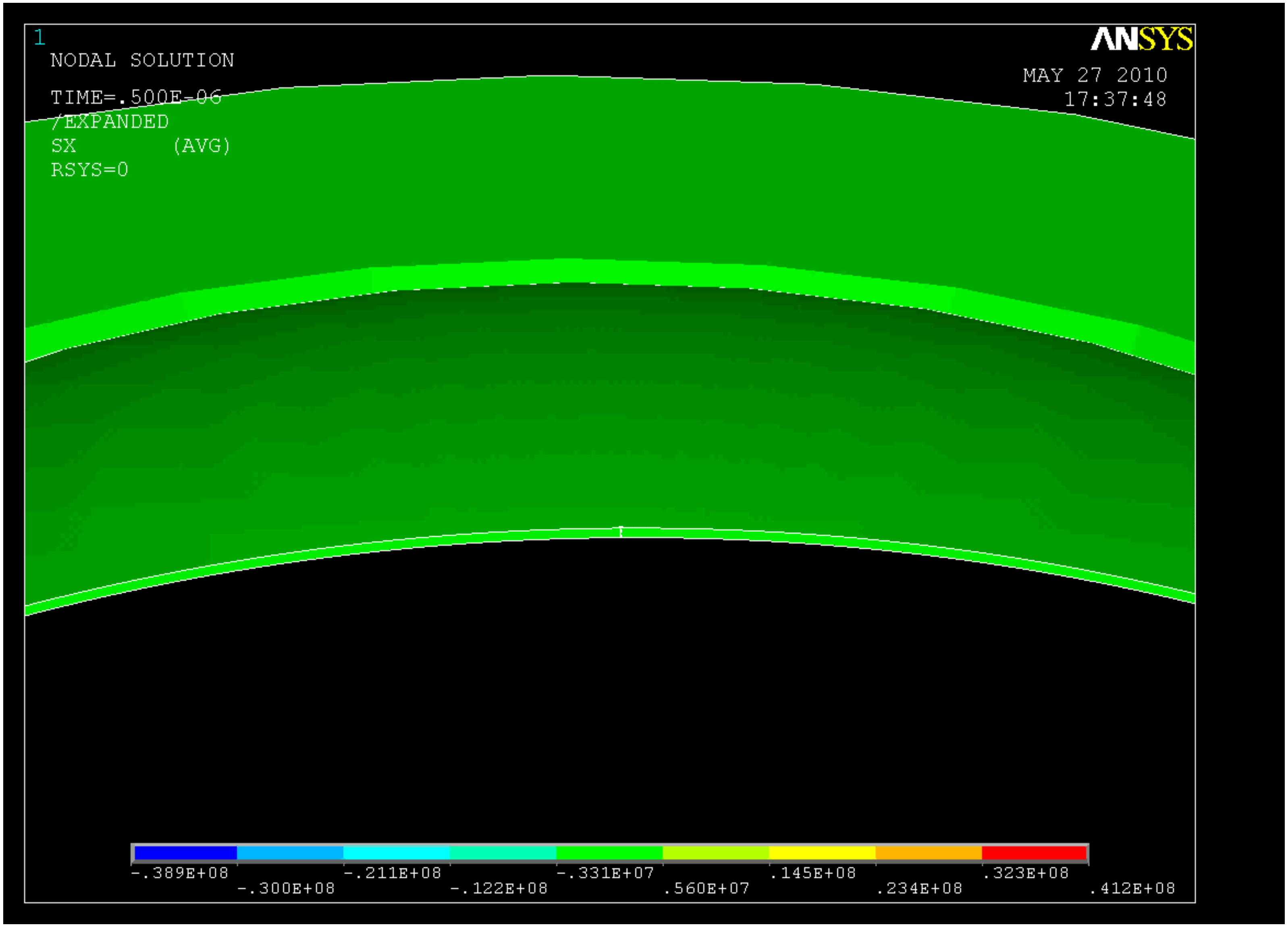
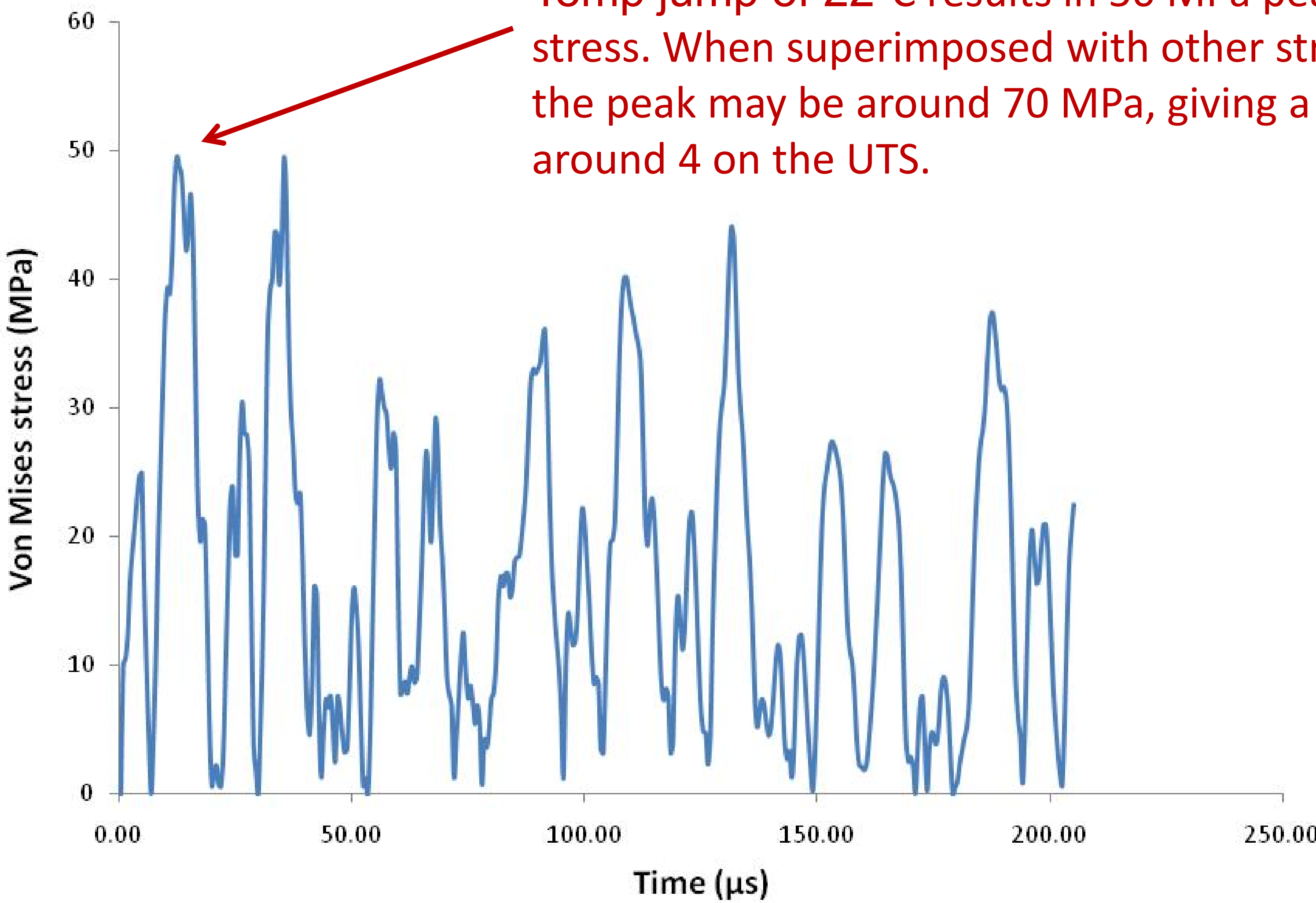
Shock animation

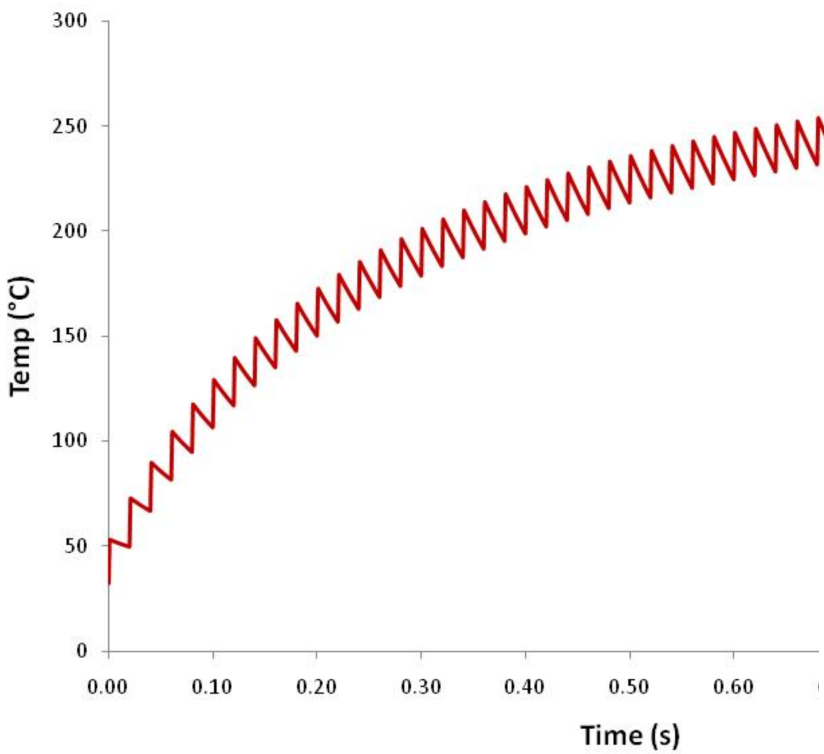


‘Shock’ stress due to single pulse in beryllium window

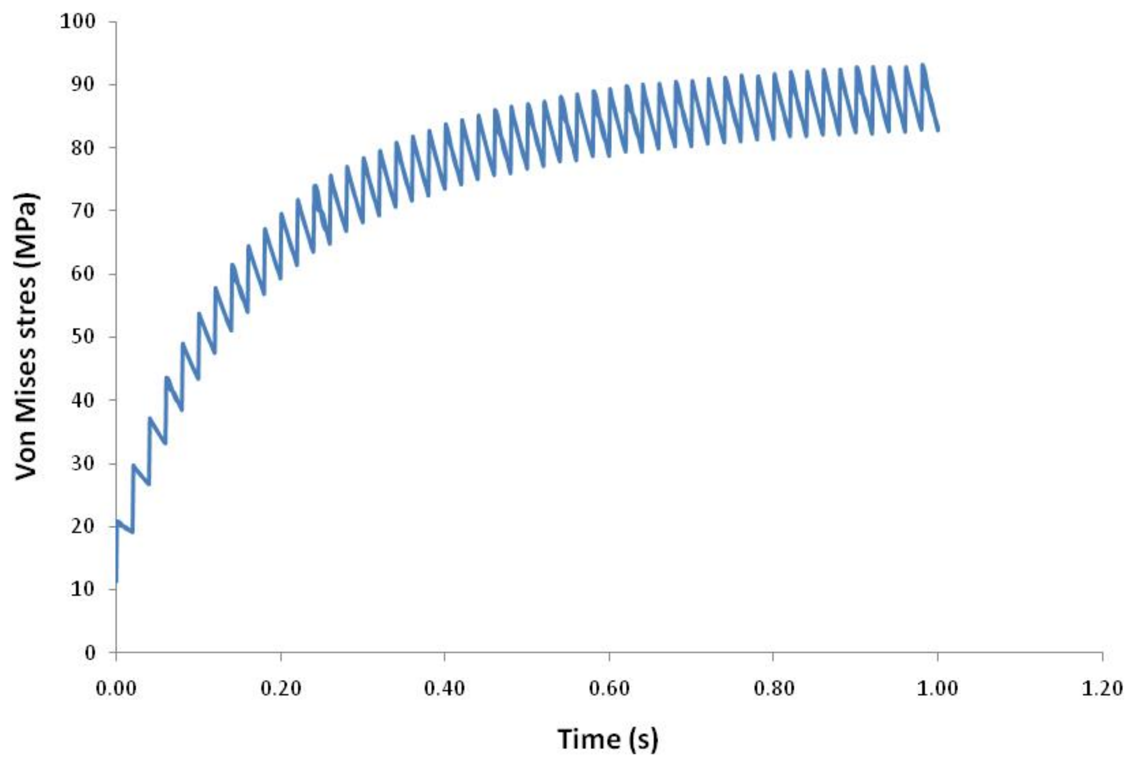


Temp jump of 22°C results in 50 MPa peak stress. When superimposed with other stresses the peak may be around 70 MPa, giving a SF of around 4 on the UTS.

4 MW window for neutrino factory?



50 pulses (1 second)



Yield strength of beryllium @ 260°C is around 200 MPa. This leaves a safety factor of about 2 for a beryllium neutrino factory window with these beam parameters.

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Conclusions

1. High frequency beam makes cooling the main challenge for any window. Actual thermal stress due to each pulse is within acceptable limits.

2. Difficulty in cooling a titanium window makes this a bad choice for EUROnu beam parameters.

3. High frequency beam with low protons per pulse makes beryllium window a possibility due to its high thermal conductivity. Either direct helium cooling on the beam spot or circumferential water cooling may be feasible.

4. Neutrino factory window may be possible with this beam parameters, though safety factor is small and radiation damage would quickly become an issue.