Solid Targets for the Neutrino Factory

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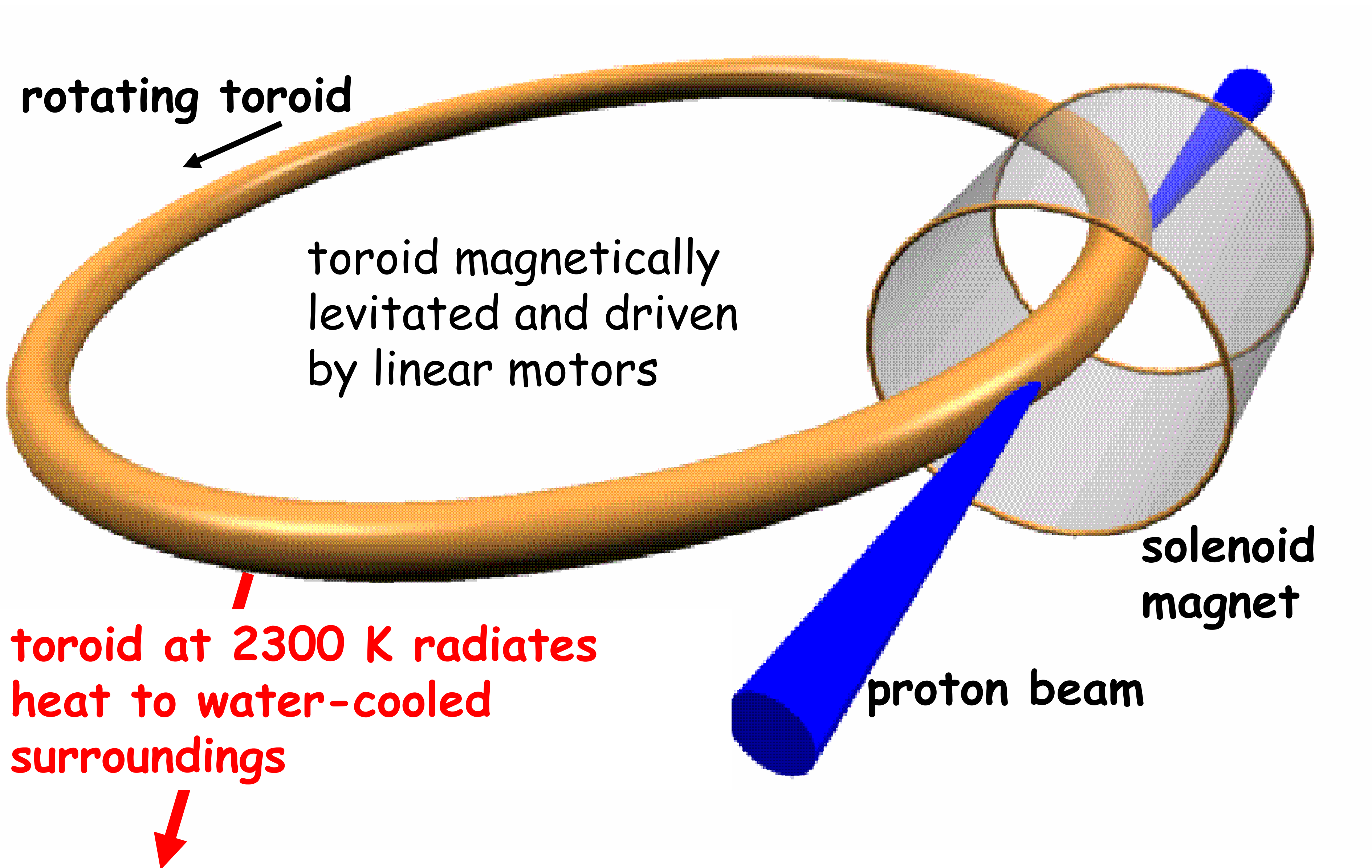
Schematic diagram of the RAL radiation cooled rotating toroidal tantalum target

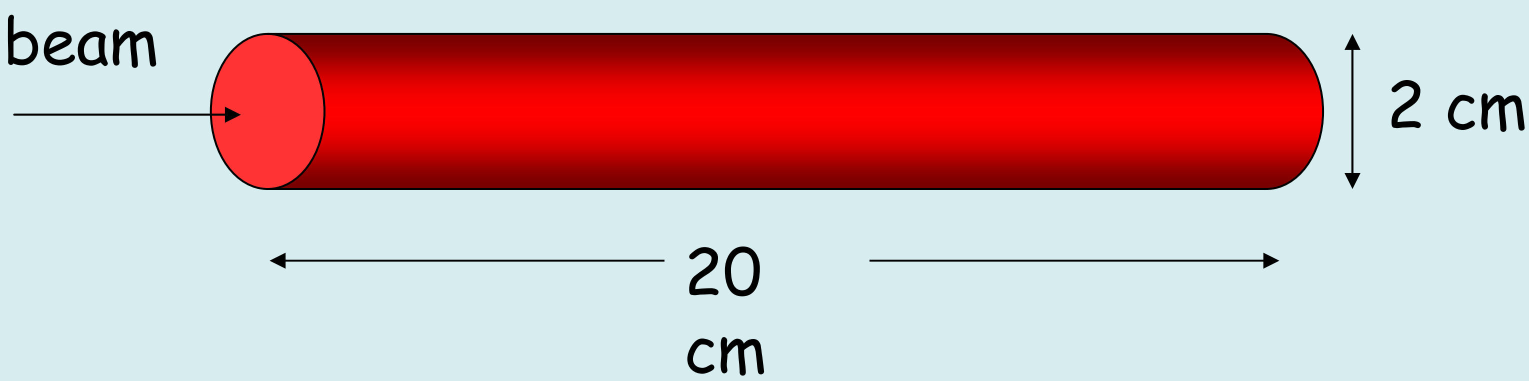


Parameters of the RAL NF-Target

Proton Beam

pulsed	10-50 Hz
pulse length	1 ns -1 μs
energy	2-30 GeV
average power	~4 MW

Target (not a stopping target)



mean power dissipation	1 MW
energy dissipated/pulse	20 kJ (50 Hz)
average energy density/pulse	0.3 kJ/cm^3 (50 Hz)

Thermal Shock

• Solid targets suffer from thermal shock when subjected to pulse beams.

• In some cases the stress exceeds the strength of the material or it suffers fatigue.

• For a 2 cm diameter target, 20 cm long, dissipating 1 MW of beam power at 50 Hz, the average energy density is 300 Wcm^{-3} and the temperature rise in tantalum is 100 K.

• At high temperatures, ~2000 K, the tantalum is too weak to sustain the stress.

• Tungsten may be satisfactory at high temperatures. (Tests proceeding.)

The Shock Test Programme

1. Simulate shock by passing a pulsed current through a wire.

2. Measure the radial (and longitudinal) motion of the wire to evaluate the constitutive equations (with 3.).

3. Use a commercial package, LS-DYNA to model the behaviour.

4. Life time/fatigue test.

5. Investigate the possibility of widely spaced micro-bunches of proton beam to reduce the shock impact.

Shock, Pulse Length and Target Size

When a solid experiences a temperature rise the material expands. Because of mass inertia there will always be a slight lag in the expansion. This causes pressure waves to ripple through the material. When the temperature rise is relatively large and fast, the material can become so highly stressed that there is permanent distortion or failure - shock.

Short high intensity beam pulses will give rise to shock in a target.

The shock wave travels through matter at the speed of sound,

$$s = \sqrt{\frac{E}{\rho}}$$

where E is Young's modulus of elasticity and ρ is the density.

The time taken for the wave to travel from the outer surface to the centre is given by

$$\tau_s = \frac{d}{s}$$

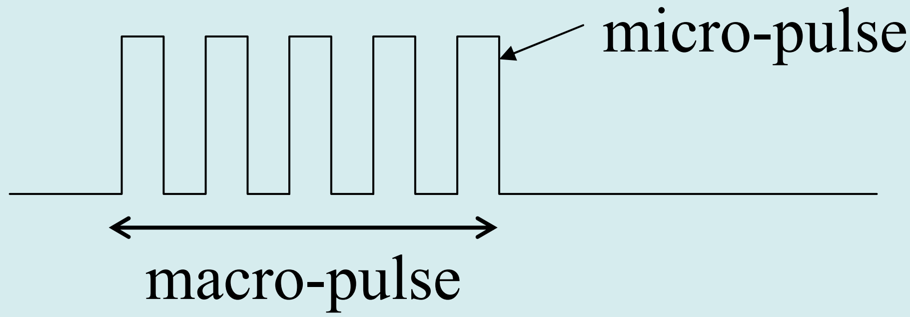
If the beam pulse (τ_p) is long compared to the characteristic time τ_s, then little energy goes into the target in this time and the shock wave in the target is reduced.

If the target is *small* compared to the beam pulse length the shock is reduced.

If $$\tau_s = \frac{d}{v} < \tau_p$$ No problem!

Must have sufficient pulsed energy input!

The Proton Pulse



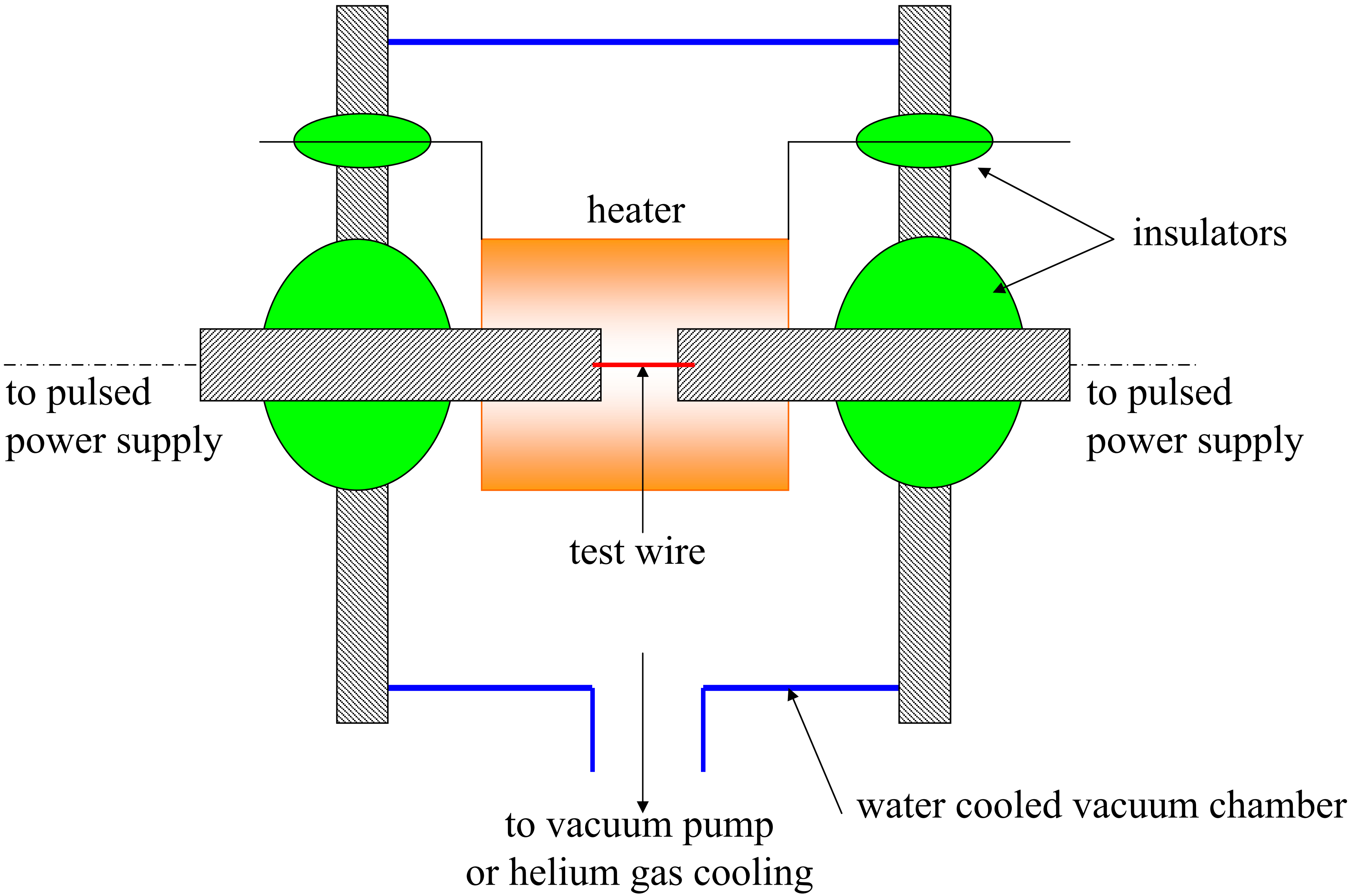
Proton beam "macro-pulses" and "micro-pulses".

Traditionally we have considered the micro-pulses as ~1 ns wide and **the macro-pulses as ~1 μs wide**. The temperature rise per macro-pulse is Δ*T* ~ 100 K.

For the tantalum bar target, radius 1 cm and length 20 cm, then:

- The time for the shock wave to travel a radius is 3 μs
- The time for the shock wave to travel a half the length is 30 μs

However, in the RAL proton driver scheme with ~10 micro-pulses, it is likely that they could be spaced apart by **~50 μs**, thus reducing the effective thermal shock to only **Δ*T* ~ 20 K**.



Schematic diagram of the wire test chamber and heater oven.

VERY Preliminary Results

Tantalum

$\Delta T = 150$ K (equivalent to 450 Jcm^{-3})

$T = 1600$ K

Damage after 32,000 pulses

Tungsten

$\Delta T = 100$ K (equivalent to 375 J cm^{-3})

$T = 2300 - 2400$ K

500,000 pulses and no sign of damage

In 1 year (300 days, 24 hours) a bar receives 9×10^6 pulses.

Search for Low Thermal Expansion Metals

- BNL are looking into superalloys which have low thermal expansion thereby overcoming the thermal stress problem.

- Some problems with radiation damage causing loss of properties – but recovered by moderate heating.

- R& D ongoing.

Conclusions (PRELIMINARY)

- Metals will probably be satisfactory at low temperatures where they retain their strength.

- At high temperatures, ~2000 K, tungsten is probably satisfactory.

- More R&D needs to be done. Currently underway at RAL, BNL and CERN.