R&D Studies on **Solid Targets** in the UK

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Jim Morgan and Pat Hurh, FNAL

Jacques Lettry, Helge Ravn, Peter Sievers, CERN

A reminder of the work in Europe:

Neutrino Factory Target Studies in Europe

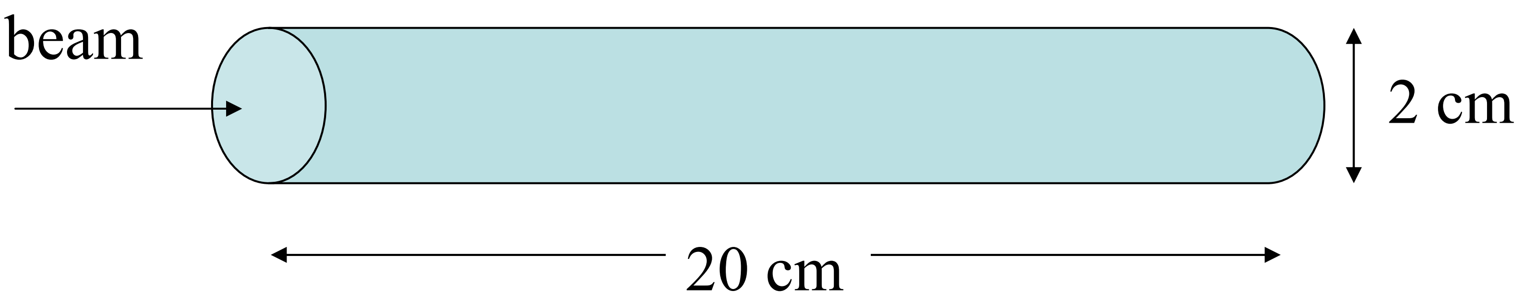
1. Mercury Jets, Adrian Fabich, Jacques Lettry, Helge Ravn, CERN
   with Harold Kirk, BNL and Kirk MacDonald, Princeton, et al
2. Solid Tantalum Toroid, RAL
3. Granular Target – Peter Sievers, CERN

Parameters of the NF Target

Proton Beam

pulsed	10-50 Hz
pulse length	1-2 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)
energy density	0.3 $kJcm^{-3}$ (50 Hz)

The RAL scheme

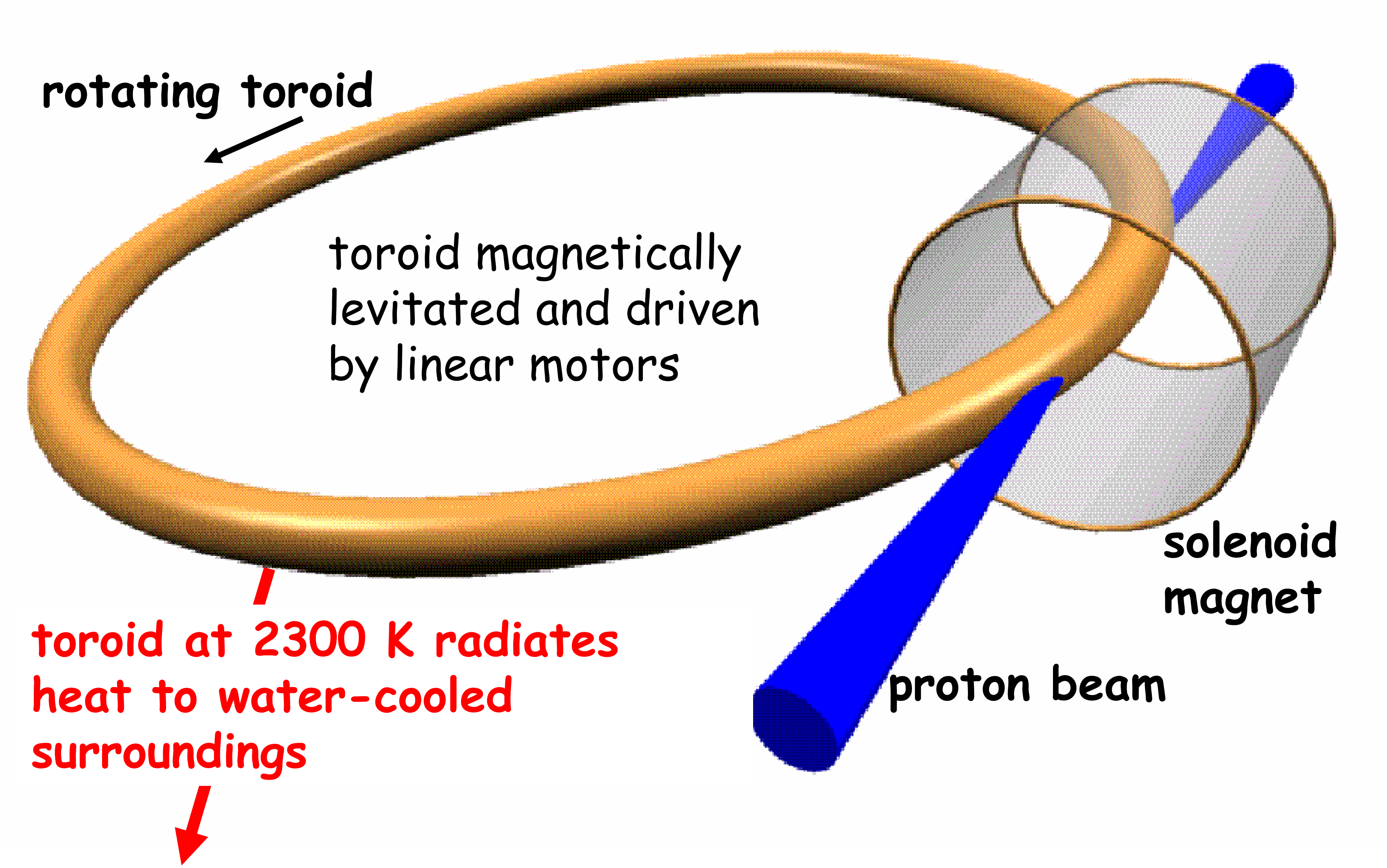
Large rotating toroid cooled by

Thermal Radiation

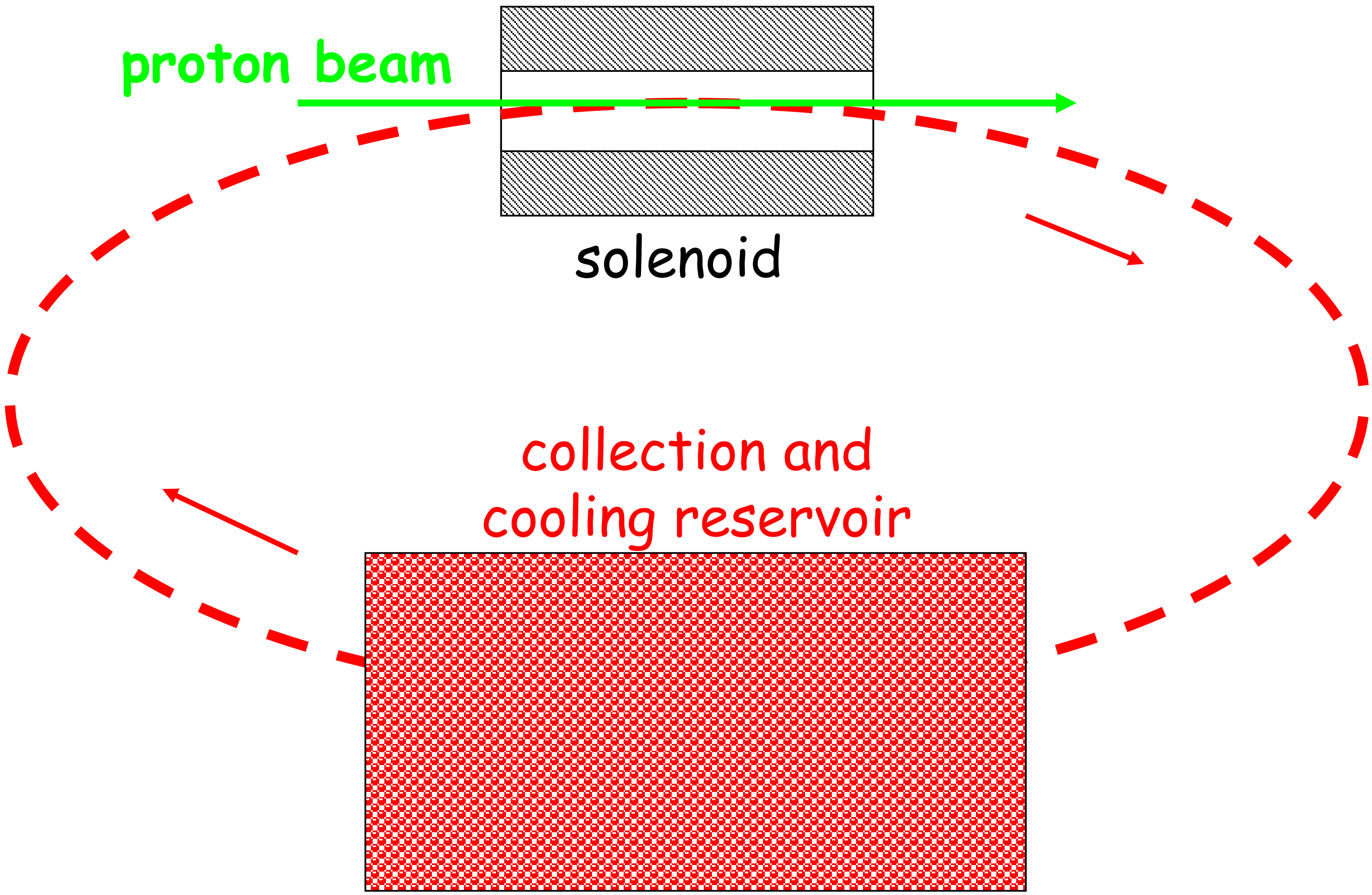
This is very effective at high temperatures due to the T^4 relationship (Stefans law).

$$W = \varepsilon \sigma A \left(T_1^{\,4} - T_0^{\,4} \right)$$

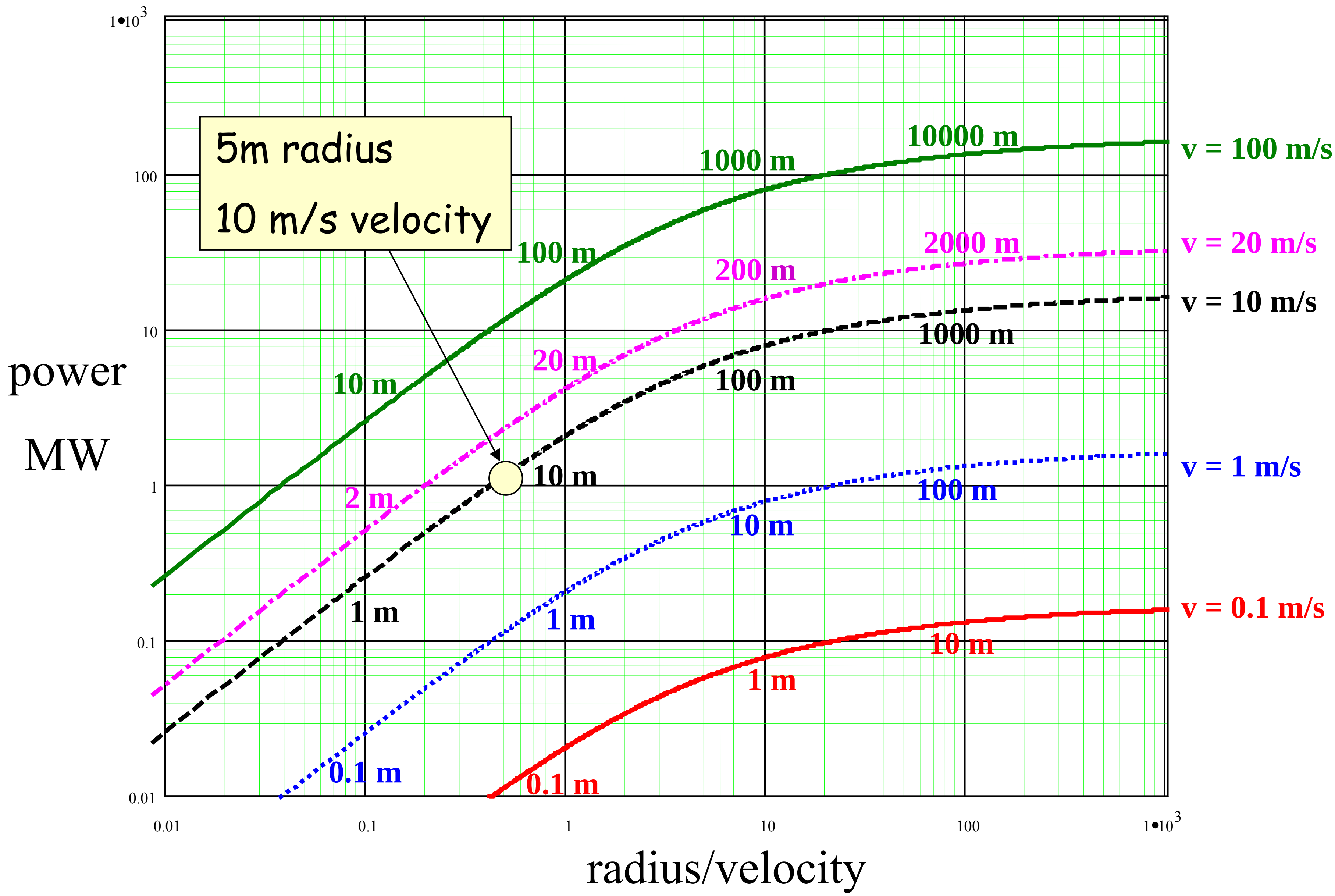
Schematic diagram of the radiation cooled rotating toroidal target



Levitated target bars are projected through the solenoid and guided to and from the holding reservoir where they are allowed to cool.



POWER DISSIPATION



The problem is:

Thermal Shock

Table comparing some high power density pulsed targets

Facility	Particle	Target material	Energy density per pulse J cm^{-3}	Life, no. of pulses
NuFact	**p**	**Ta**	**318**	**10^9 ($7x10^6$ for the toroid)**
ISOLDE (CERN)	p	Ta	279	$2x10^6$
Pbar (FNAL)	p	Ni	7112	$5x10^6$ Damage
NuMI	p	C	600	Shock not a problem
SLC (SLAC)	e	W26Re	591	$6x10^5$
RAL/TWI	e	Ta thin foil	500	10^6

On the assumption that

several much high power density pulsed targets

were already surviving for considerable periods of time,

it seemed reasonable to assume that

the solid target has a good chance of success.

BUT

R&D is needed to prove this.

Proposed R&D

1. Calculate the energy deposition, radio-activity for the target, solenoid magnet and beam dump.
   Calculate the pion production (using results from HARP experiment) and calculate trajectories through the solenoid magnet.

2. Model the shock
   a) Measure shock properties of tantalum at 2300 K
   b) Model using hydrocodes developed for explosive applications at LANL, LLNL, AWE etc using constitutive equations.
   c) Model using dynamic codes developed by ANSYS

Proposed R&D, continued

3. Radiation cooled rotating toroid
   a) Calculate levitation drive and stabilisation system
   b) Build a model of the levitation system

4. Individual bars
   a) Calculate mechanics of the system
   b) Model system

5. Continue electron beam tests on thin foils, improving the vacuum

6. In-beam test at ISOLDE - 10^5 pulses

7. In-beam tests at ISIS – 10^7 pulses

8. Design target station

PPARC Award - £550k

Selected only – Shock Studies (considered priority)

1. Measure (in the lab.) mechanical strength characteristics of tantalum under shock conditions at 2000°C
2. Model the shock for different geometries
3. In-beam test (proton)

Measuring the parameters of the material strength under the particular conditions is proving difficult.

Will have to measure in-beam.

Recently Jacques Lettry measured a Tantalum bar in-beam at ISOLDE at room temperature using VISAR equipment.

The data has yet to be analysed.

The bar was 1 cm diameter, 10 cm long.

The proton pulse was composed of 4 pulses 230 ns long, separated by 370 ns, $3x10^{13}$ p/macropulse, 0.25 cm half-width at half-max at 1.4 GeV from the PS Booster.

This dissipates over **700 J/cm3** in the target, **twice** the energy density of the NF target. **No obvious visible signs of damage.**

Jacques has done part of the experiment that we want to do!

Fatigue

- Repeated stress/creep build up with successive pulses - may lead to mechanical failure.

- Would like a minimum life of 1 year– 10^7 pulses.

- Not easy to model this. Many competing processes – crystal growth, small crystal formation, compression and tension, annealing, plastic deformation and reduced shock, etc. etc.

- Test at 2300 K with up to 10^5 pulses will give some indication of lifetime.

The Plan

1. Make preliminary calculations, using material models and data that is outside their normal valid range. This is the best that can be done before measurements are taken.

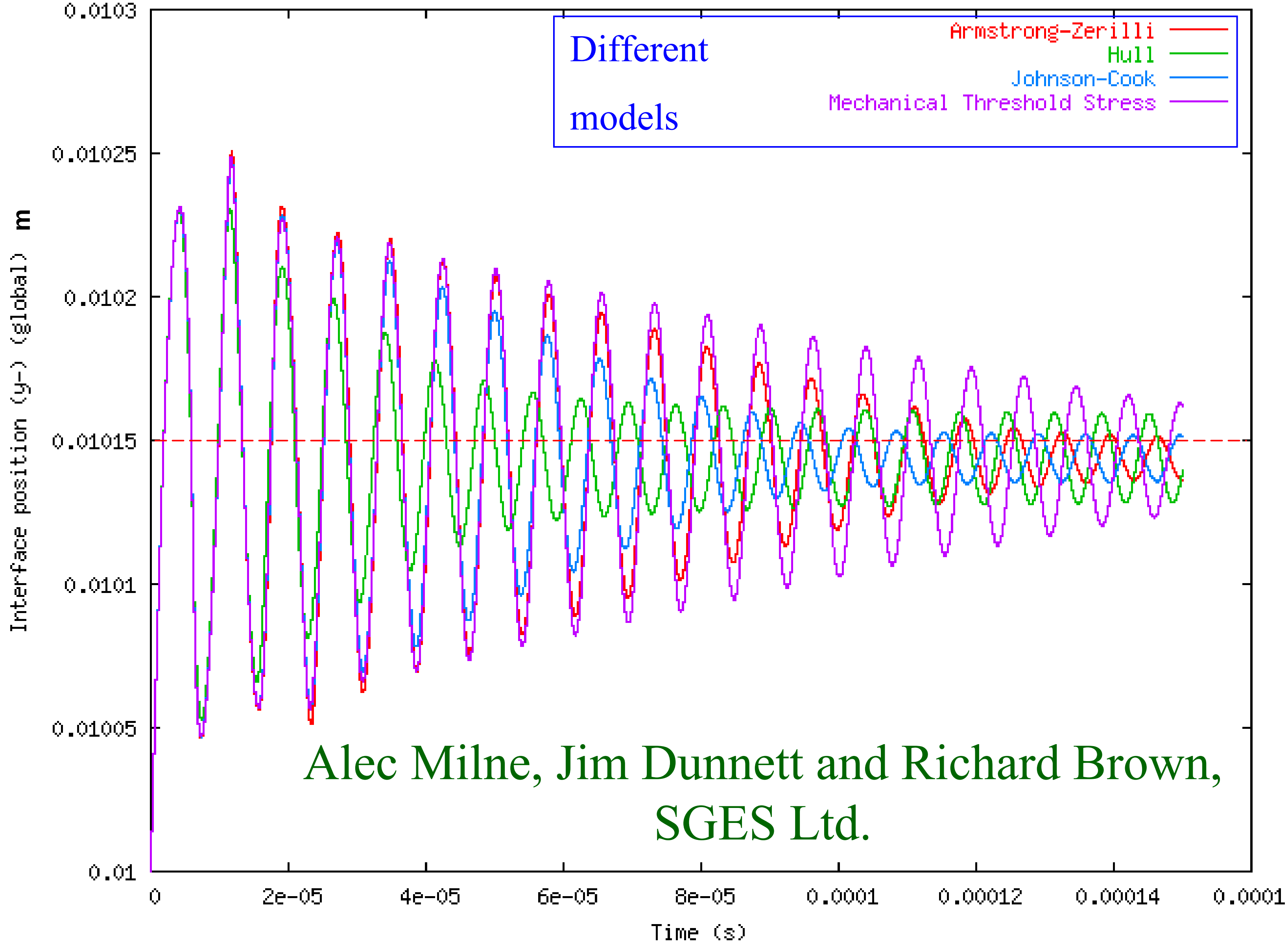
2. Investigate, with *RMCS*, the possibilities of making off-line tests to determine the strength characteristics of tantalum at 2000°C.

3. Obtain beam time at *ISOLDE* (or *ISIS*) and make measurements. This will give:
   a) strength characteristics of tantalum and tungsten at 2000°C.
   b) show if the target is damaged after a few pulses ($\sim 10^4$).

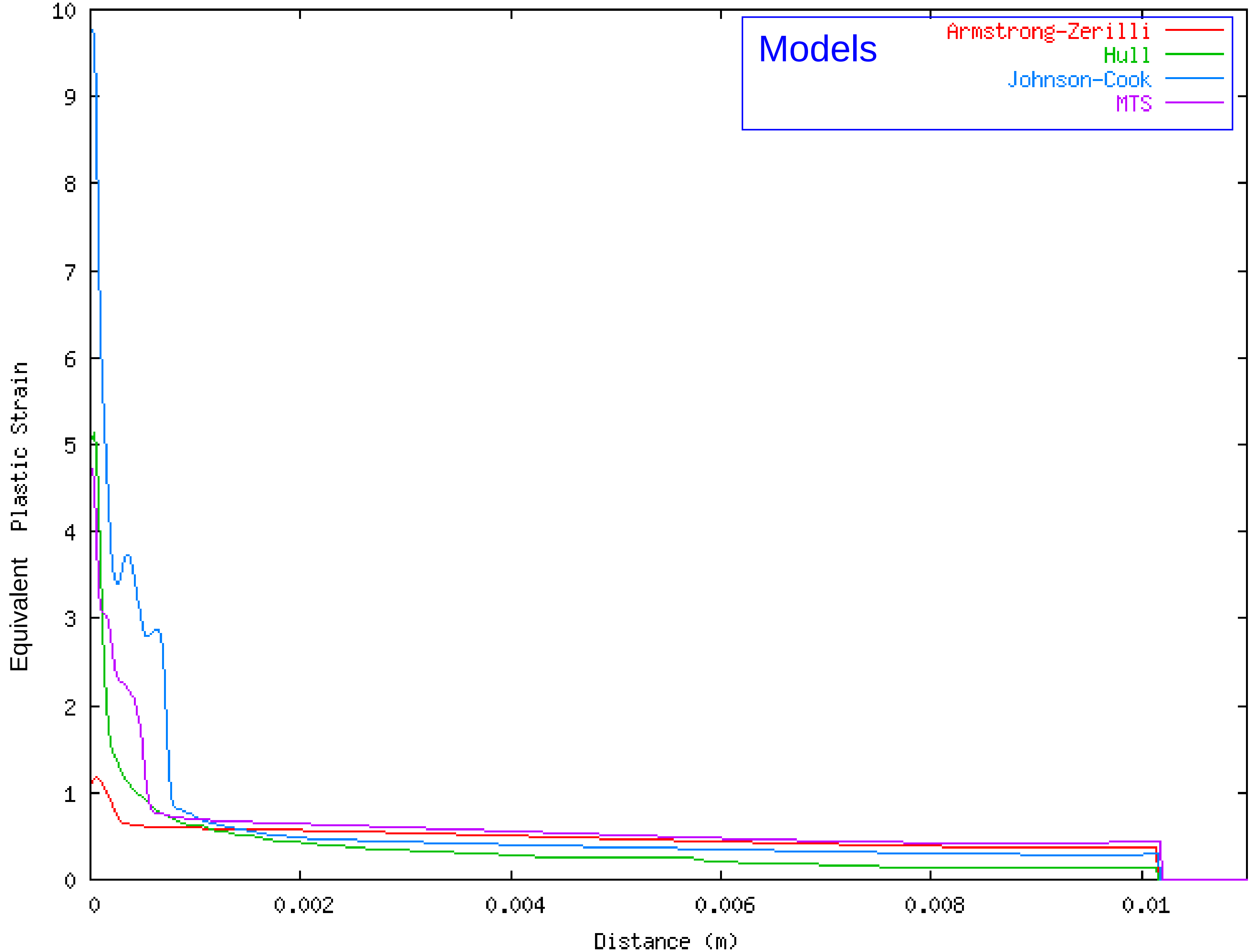
4. Computer model the target and determine the optimum geometry for pion production of the beam and toroid section diameters.

Preliminary Calculations by Alec Milne et al, FGES

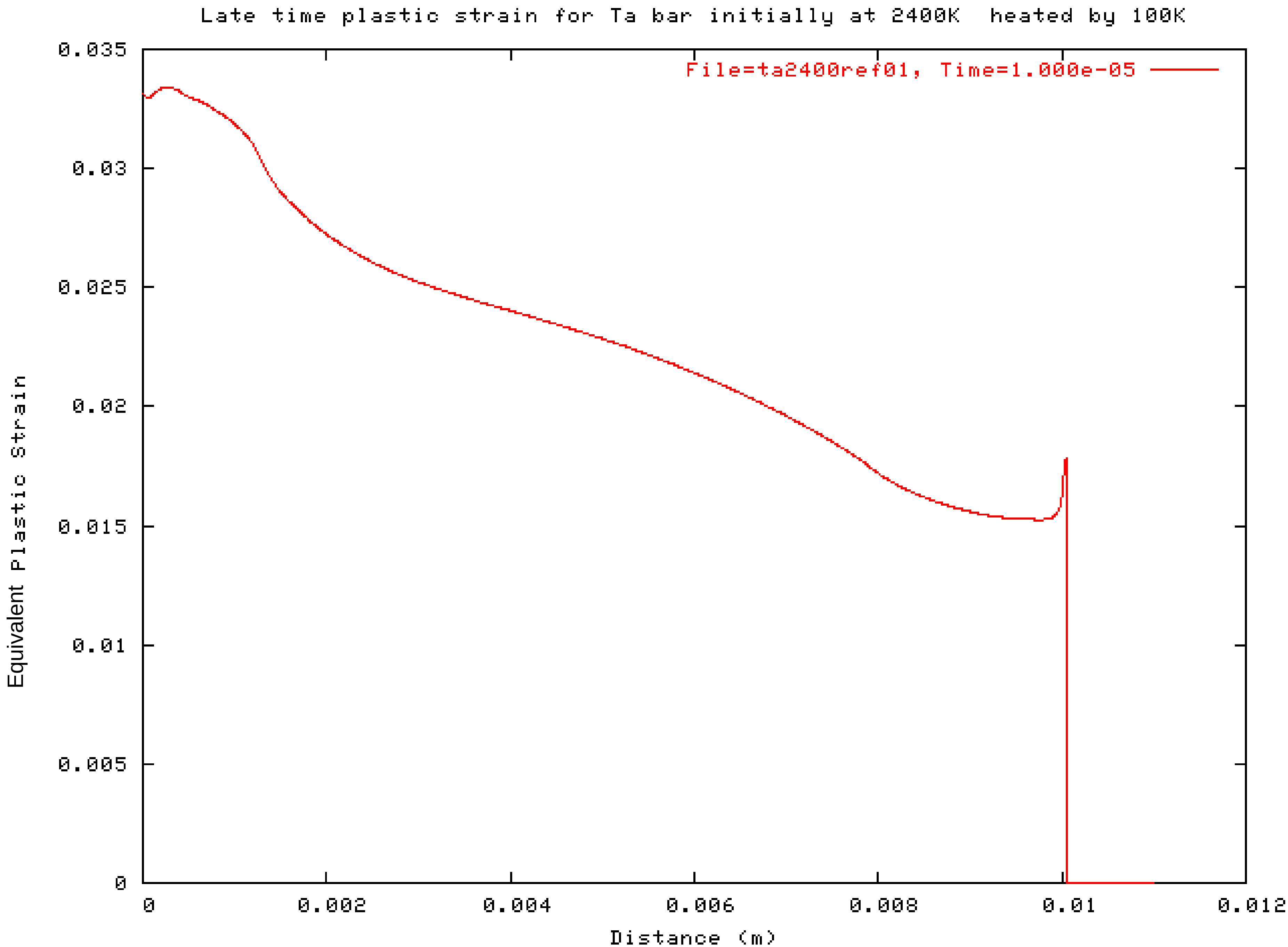
1. The calculations use existing material models outside their normal range of validity.
2. A tantalum bar, 2 cm diameter, 20 cm long, is subjected to an instantaneous temperature rise.
3. Calculations for a single pulse. Many pulses are likely to give more damage.



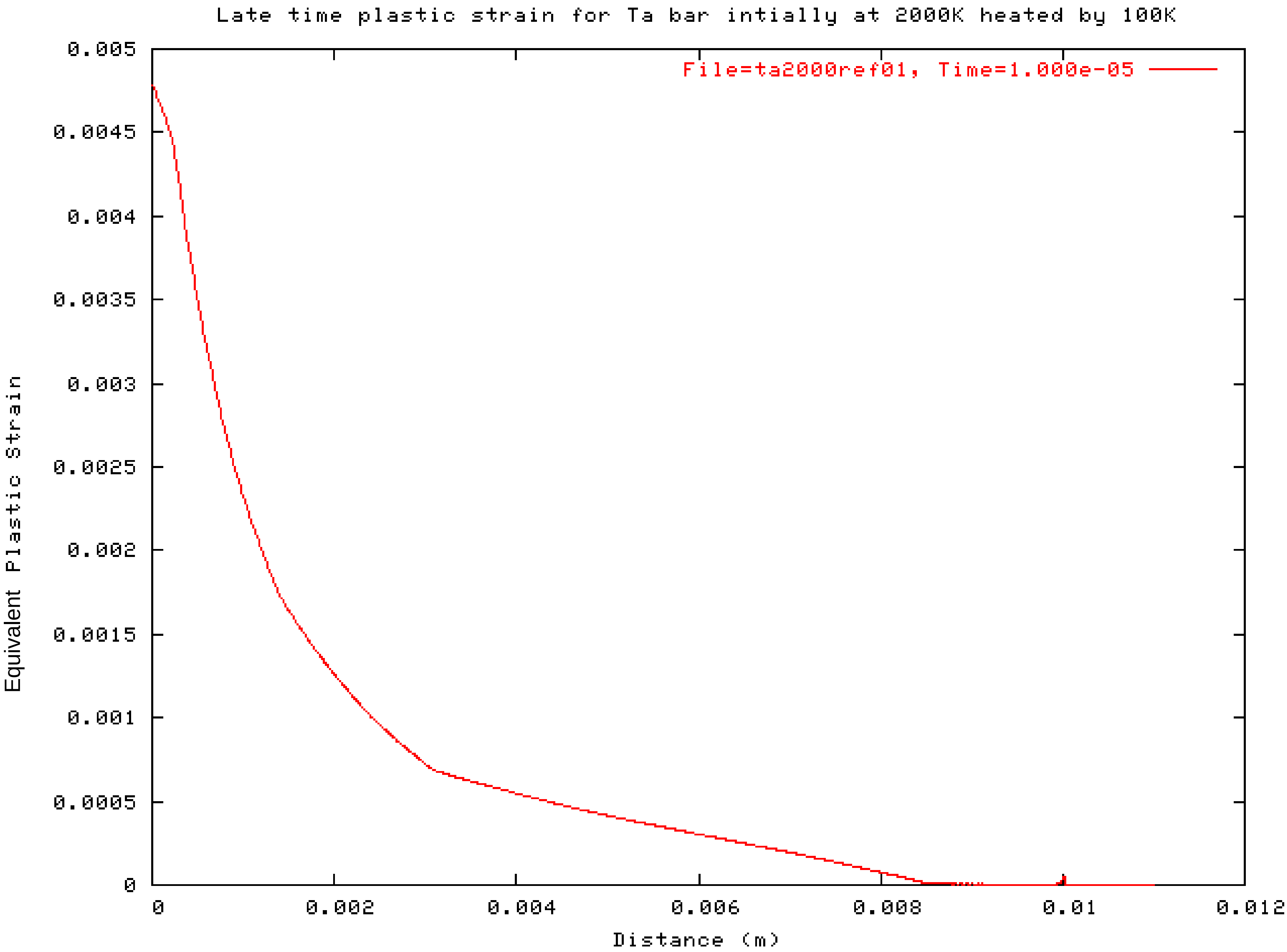
The radius of the bar versus time for a single pulse. Temperature jump from 300 to 2300 K.



“Accumulated” Plastic Strain versus Radius.



Late time plastic strain for Ta bar initially at 2400K heated by 100K
File=ta2400ref01, Time=1.000e-05
Equivalent Plastic Strain
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
0.002
0.004
0.006
0.008
0.01
0.012
Distance (m)


Late time plastic strain for Ta bar intially at 2000K heated by 100K
File=ta2000ref01, Time=1.000e-05
Equivalent Plastic Strain
Distance (m)
0.005
0.0045
0.004
0.0035
0.003
0.0025
0.002
0.0015
0.001
0.0005
0
0
0.002
0.004
0.006
0.008
0.01
0.012

Test of a Tantalum Disc in the FNAL PBAR Target

Jim Morgan, Pat Hurh and Tony Leveling.

120 Gev proton beam with $\sigma = 0.15$ mm, 5.5×10^{12} ppp

Energy density ~10000 Jcm^{-3}

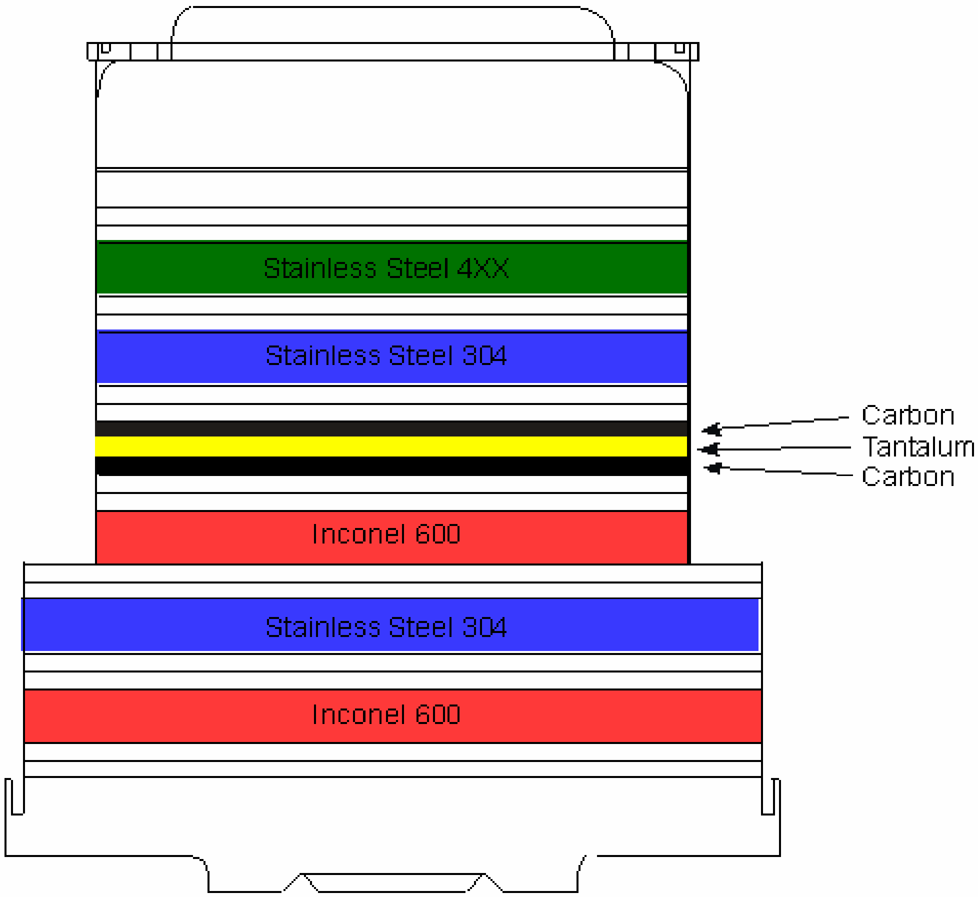
(Neutrino Factory: target energy density of 300-600 Jcm^{-3})

Can melt the target in a single pulse along the beam path.

Can see spallation of material - probably by shock damage

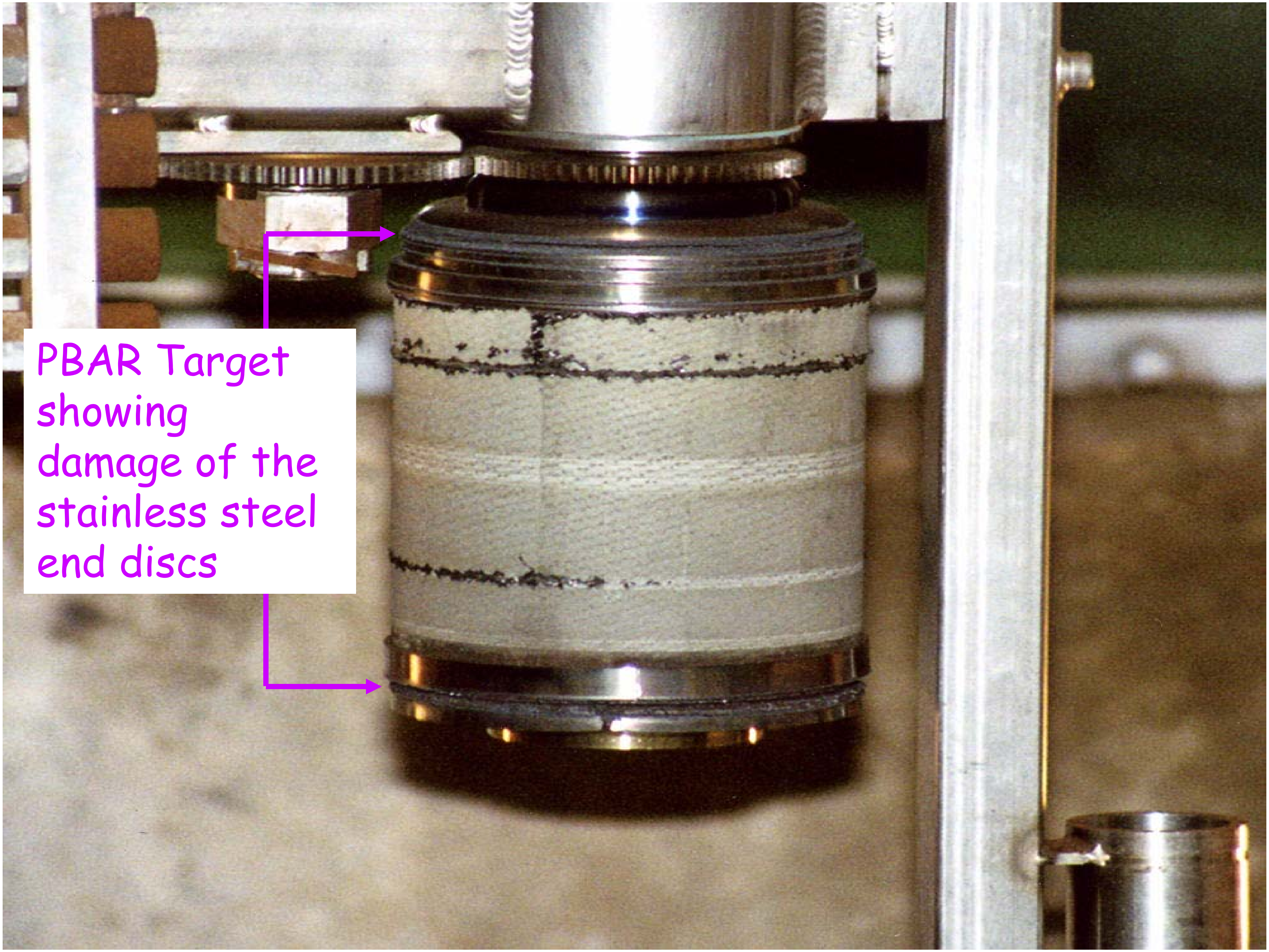
Will test a beam of $\sigma = 0.5$ mm diameter into the 1 mm thick tantalum disc at a range of energy densities.

Run II Target III



Use nickel cooling disks if available

Antiproton Source Department
February 6, 2004


PBAR Target showing damage of the stainless steel end discs

Conclusions

1. Calculations using models and material data *that are possibly invalid in the required regime* indicate that **Shock would appear to cause damage to the target at the energy density of 300 Jcm^{-3} in a single pulse .**

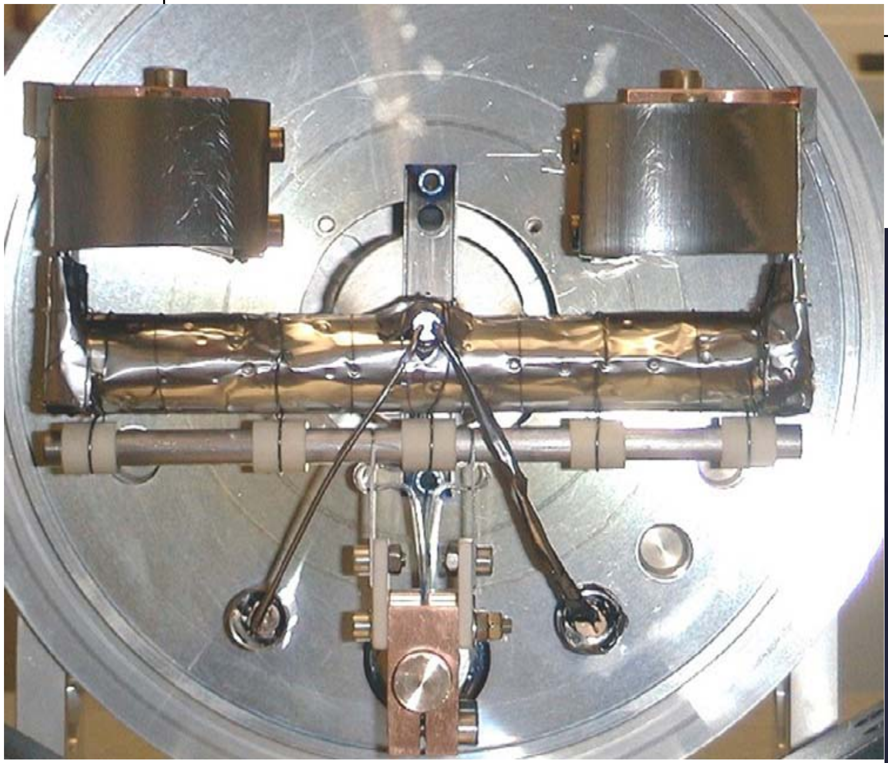
2. Tests with beam are needed to confirm the calculations.

3. Tests at FNAL with the pbar target will take place soon.

4. We will apply for beam time on ISOLDE to do tests on a tantalum or tungsten bar at high temperature (~2000 K) and measure the surface with a VISAR.

5. A reminder: Tests at ISOLDE (Jacques Lettry) at high temperature (~1000 K) show extreme distortion of a bar, 1 cm diameter 20 cm long.

ISOLDE converter targets



Ta-converter mounted below the UC target before irradiation

Ta-rod after irradiation with 6E18 protons in 2.4 μs pulses of 3E13

The prospects for solid targets may not look too good right now.

Wait for the results from the in-beam tests.

Of course, there is always the granular target.

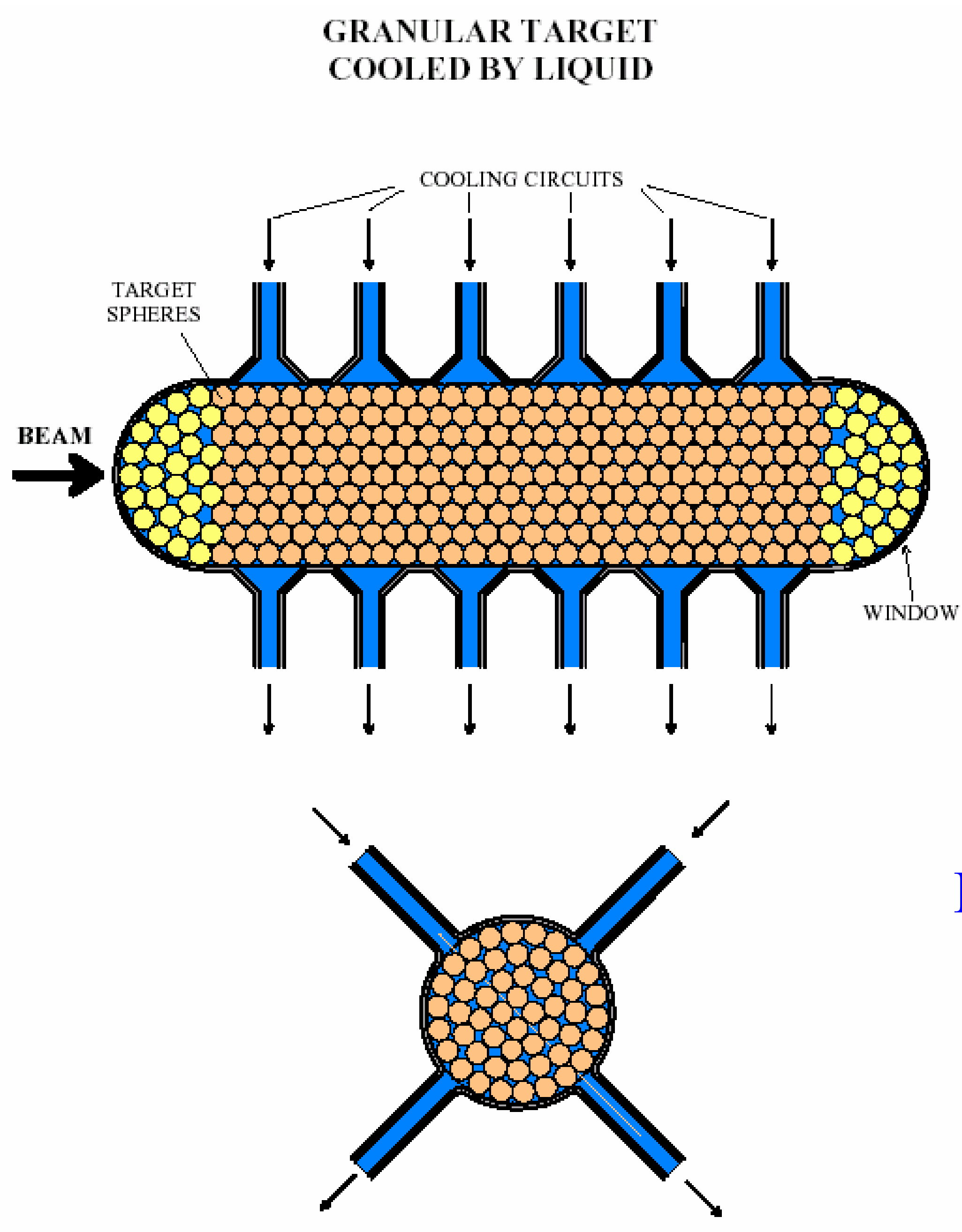


Fig. 1 : Principle lay-out of a liquid cooled, granular target. Tantalum spheres with a diameter of about 2mm are confined in a Titanium container and cooled by water (or possibly liquid metal) traversing the voids between the spheres.

Peter Sievers, CERN