Science & Technology
Facilities Council

TS2 Target Analysis

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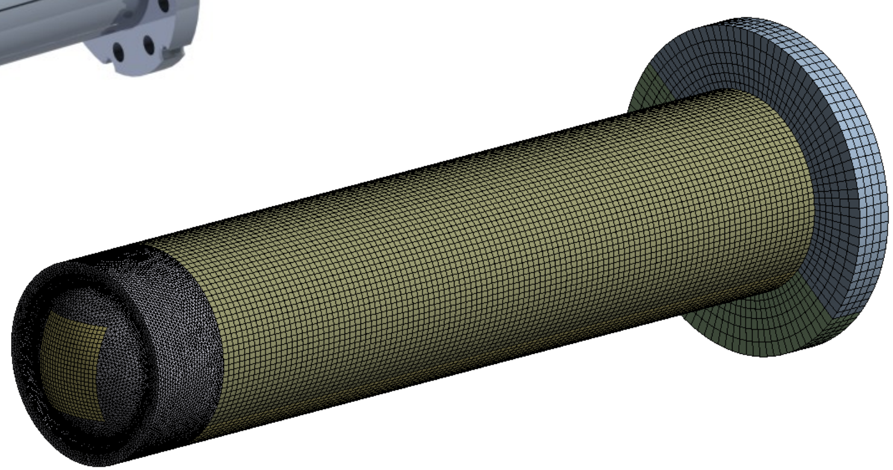
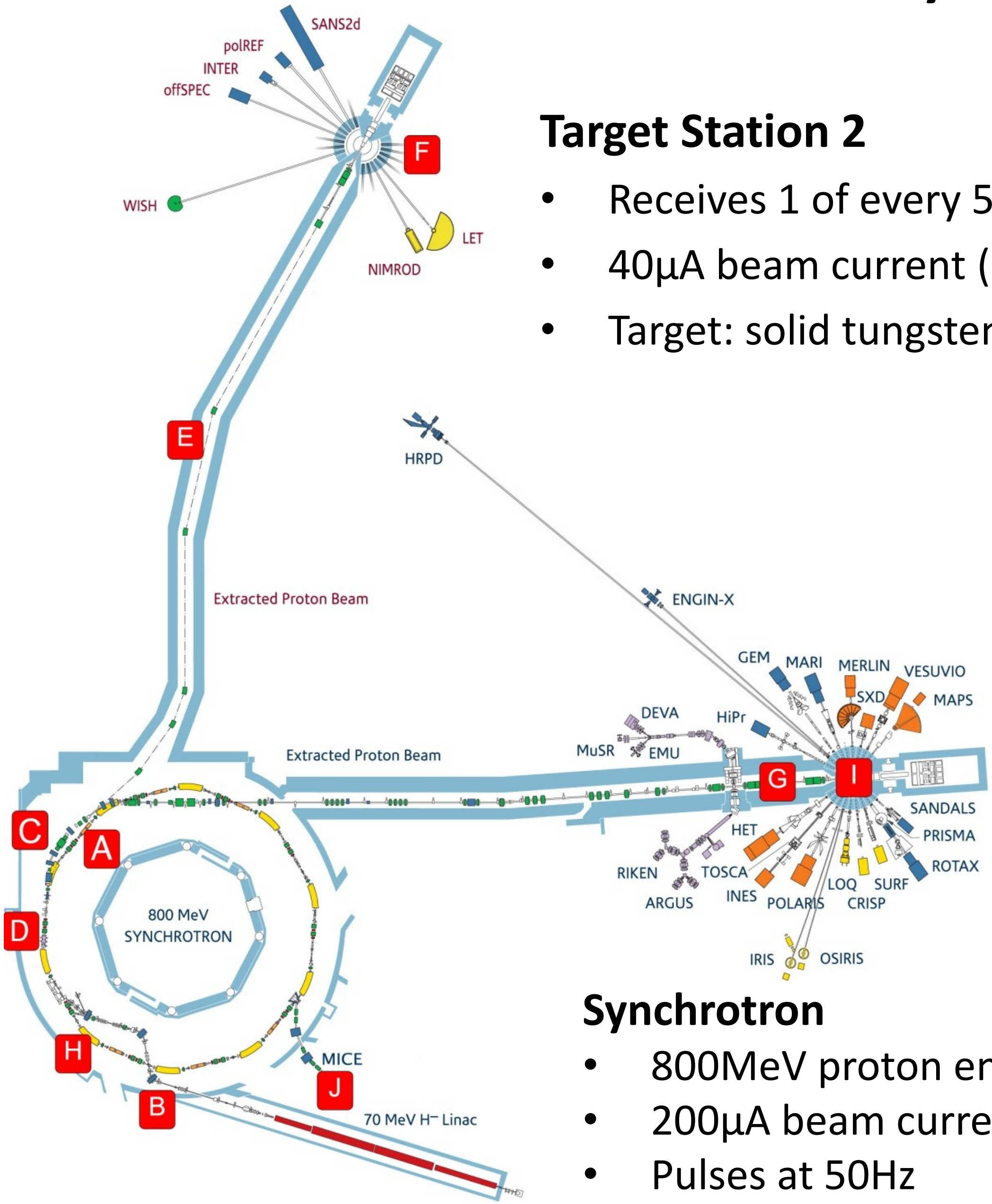
Background

- Aims:
  - To better understand operating parameters of the ISIS TS2 target
    - Create thermal and structural models
    - Consistent approach for TS1 and TS2
  - Estimate target lifetime
  - Inform design of future ISIS targets



ISIS Layout



Target Station 2

- Receives 1 of every 5 beam pulses (10Hz)
- 40µA beam current (32kW power)
- Target: solid tungsten rod

Target Station 1

- Receives 4 of every 5 beam pulses (40Hz)
- 160µA beam current (128kW power)
- Target: tungsten plates

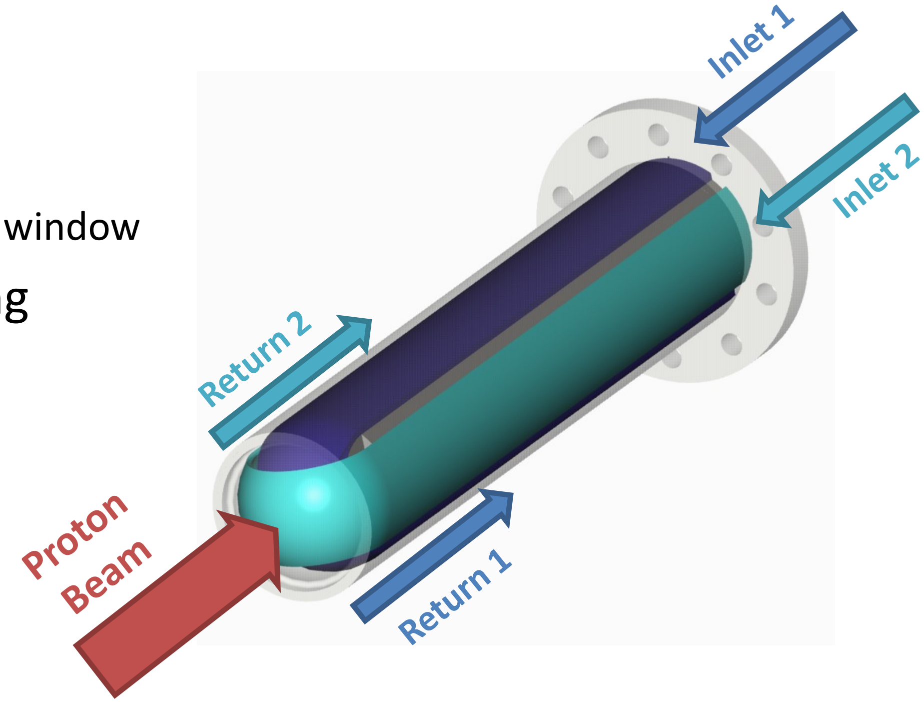
Synchrotron

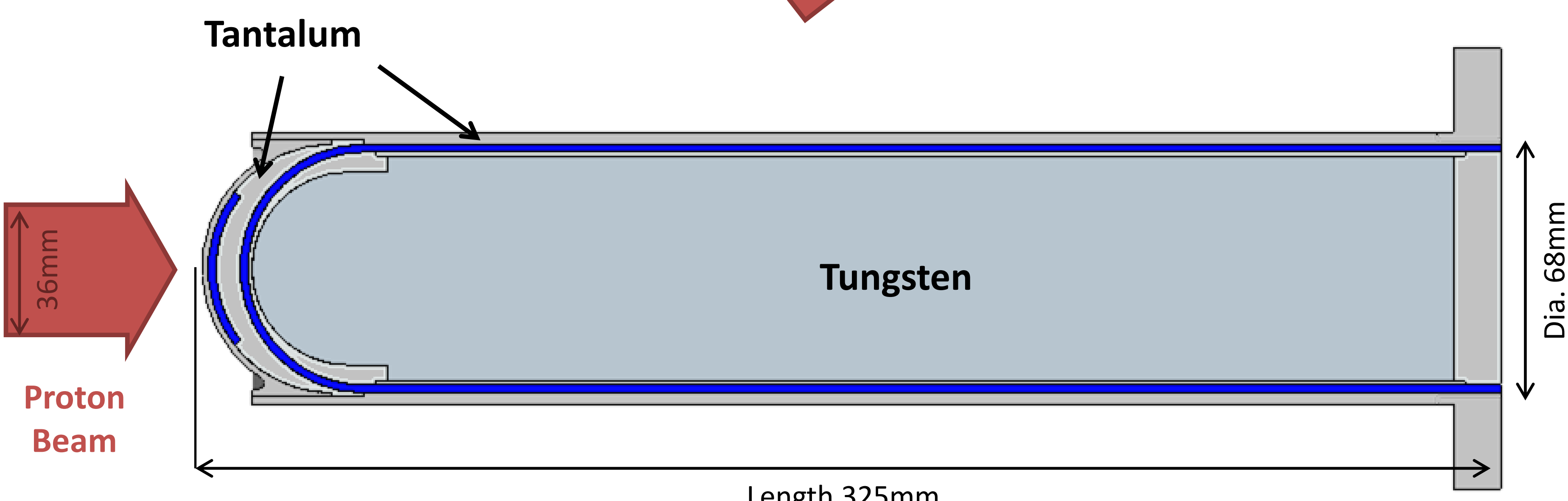
- 800MeV proton energy
- 200µA beam current (160kW power)
- Pulses at 50Hz

Image: http://www.isis.stfc.ac.uk/about-isis/annual-review/2007/accelerator-and-target-developments-7641.html

TS2 Target Geometry

- Solid tungsten rod
- Water cooled via two channels
  - Channels cool both core and beam window
- Tungsten core, tantalum cladding
  - Tungsten gives high neutron yield
  - Tantalum prevents corrosion

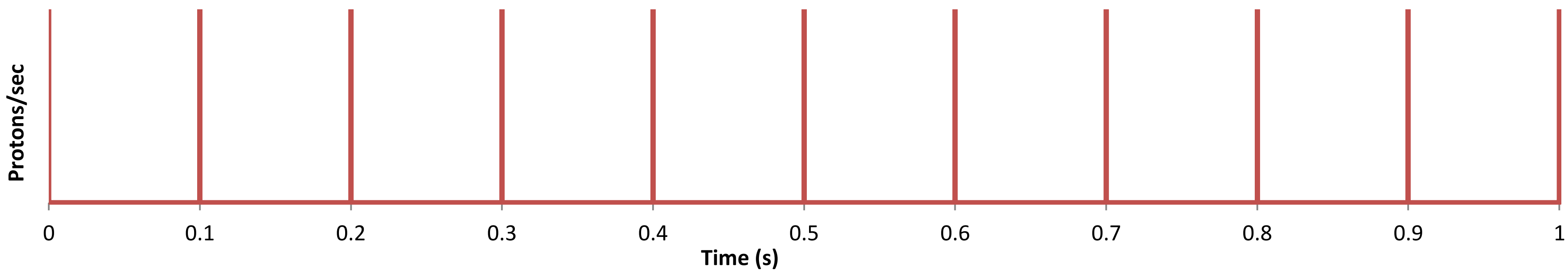




TS2 Beam Structure

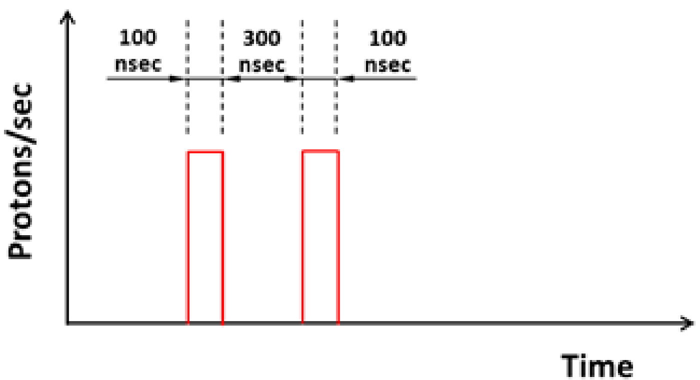
- The beam consists of many pulses:

Time structure of beam



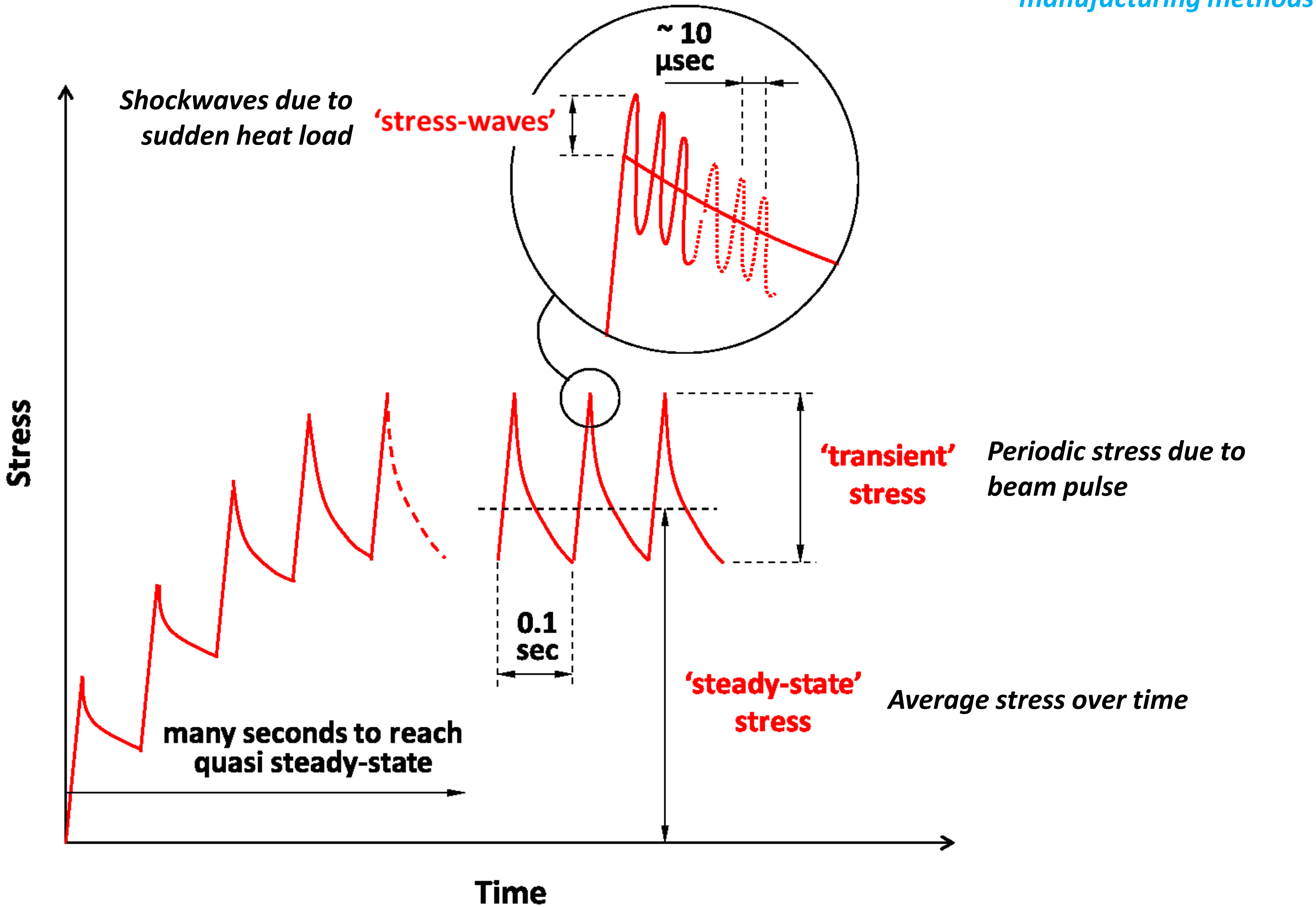
- 10 pulses per second
- 500ns pulse length
- Each pulse consists of two bunches:

Time structure of a single pulse



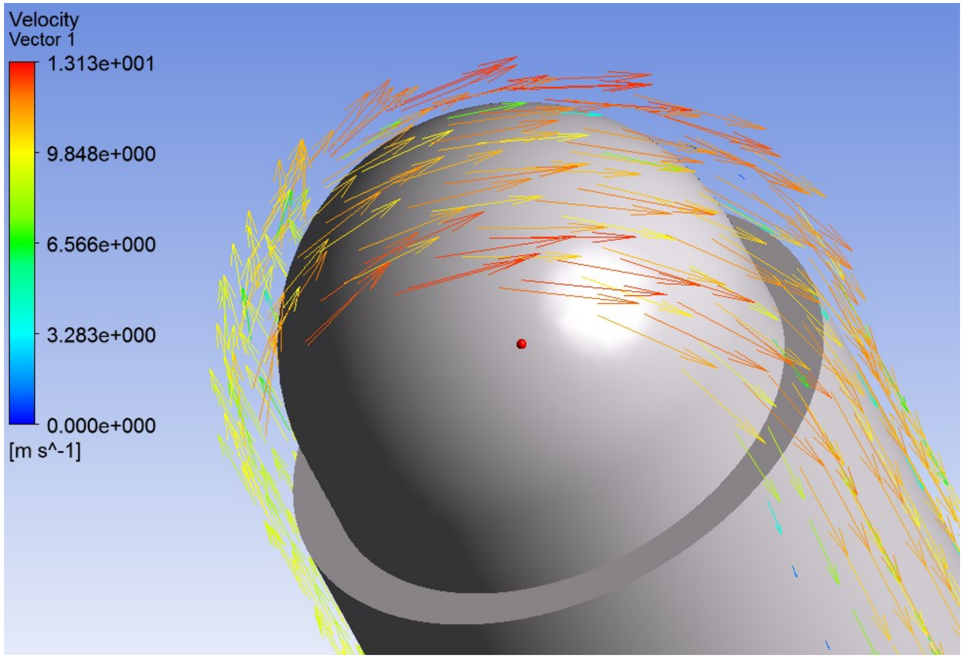
Overview of Beam-Induced Stresses

- Must also consider pre-stress from manufacturing methods

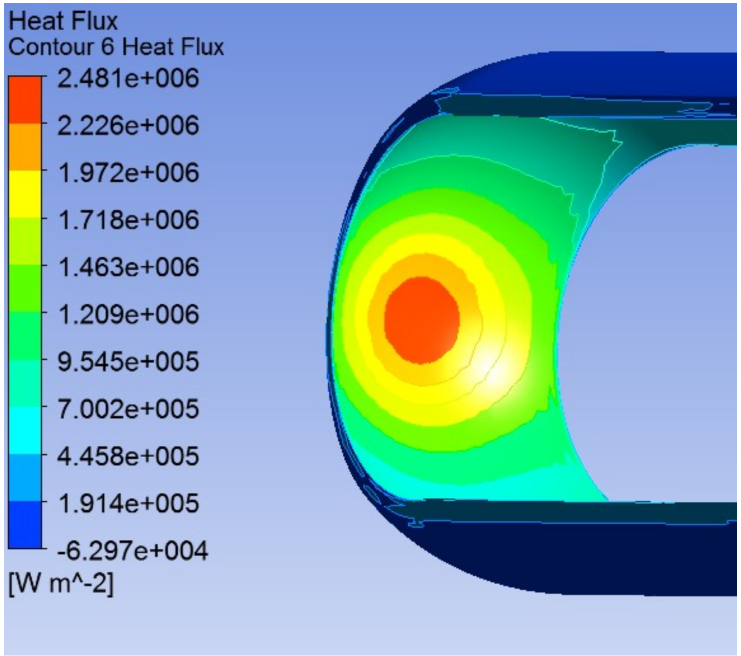


Steady State Analysis

- Time averaged beam heating
- Temperature varying material properties from ITER handbook
- Combined fluid/solid model



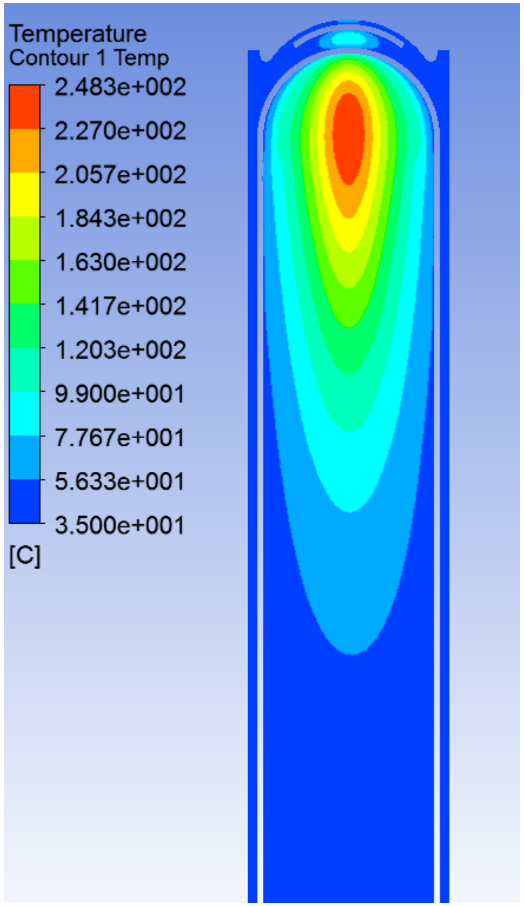
Velocity vectors at inner channel turnaround



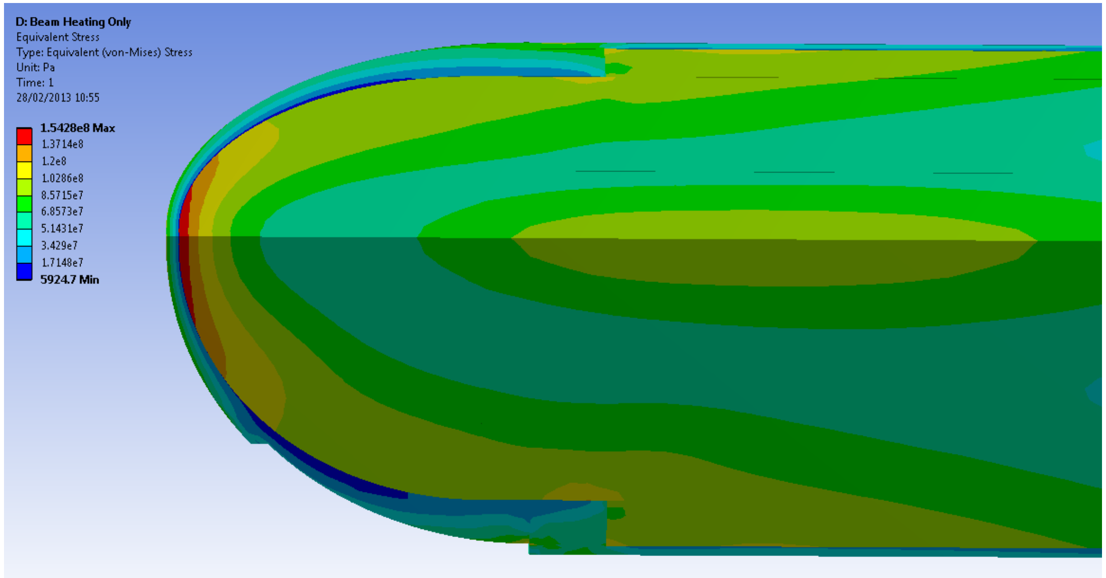
Location of maximum heat flux

Steady State Results

- Fluid results (velocity, ΔP, ΔT, etc.) agree with data from ISIS
- Maximum stresses occur at target 'nose'
- Tantalum in tension, tungsten in compression



Temperature contour plot

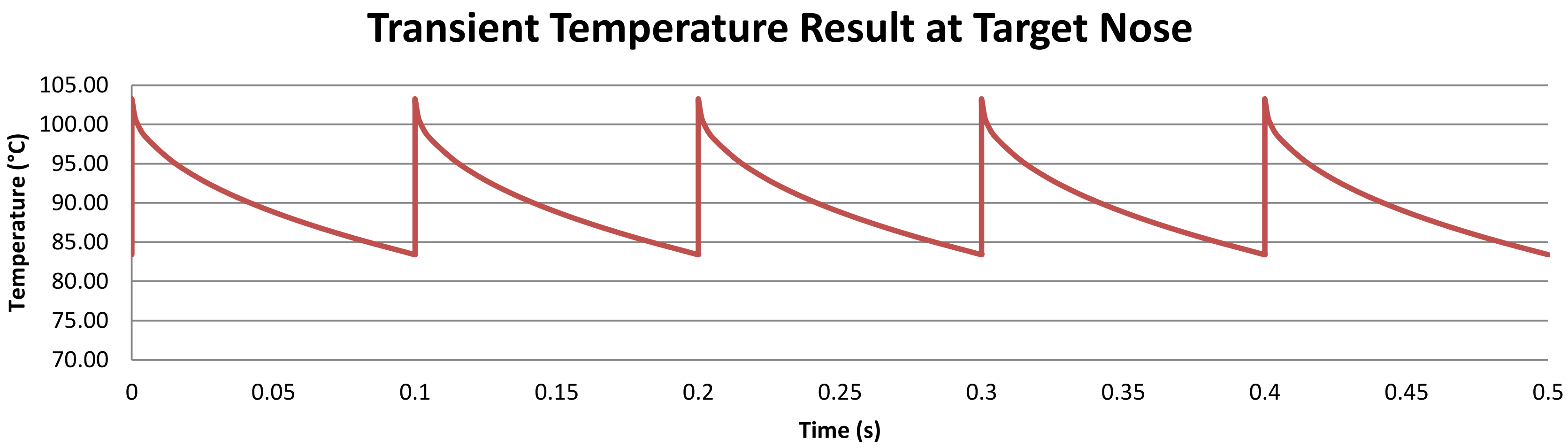


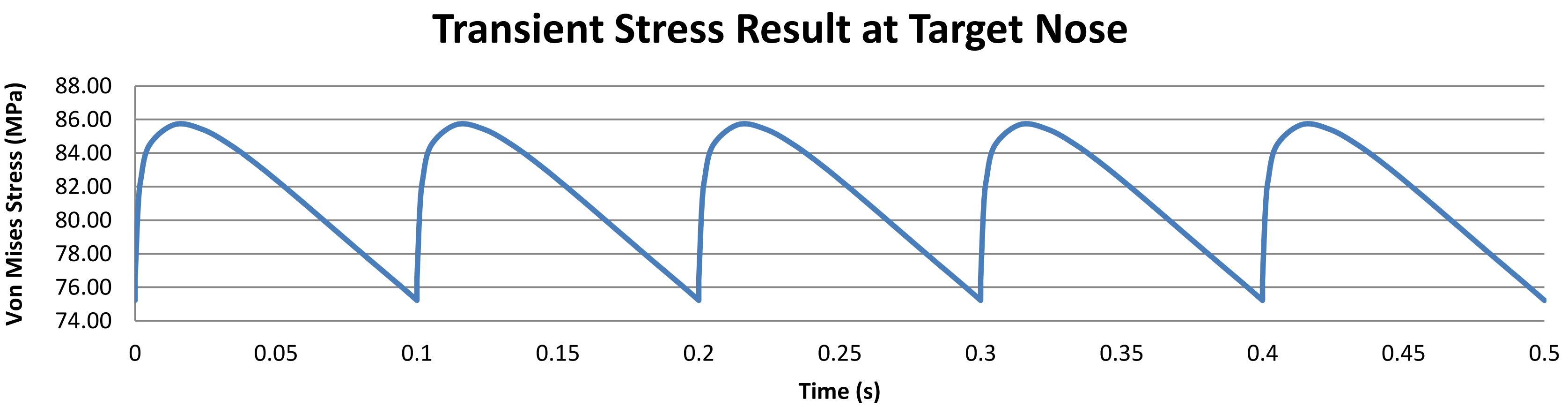
Contour plot of Von Mises stress

- Maximum temperature = 248°C
- Maximum stresses = 154MPa (tungsten)
  90MPa (tantalum)

Multi-Pulse Transient

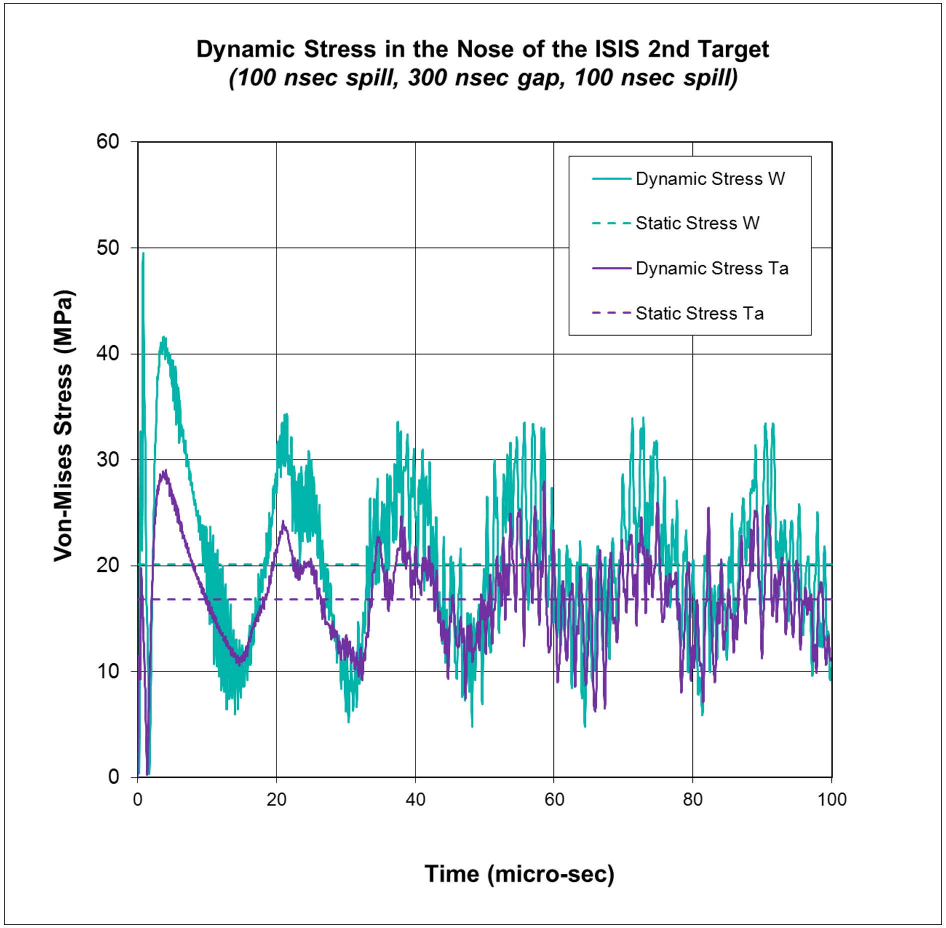
- Pulsed beam heating
- Steady state heat transfer coefficient assumed (fluid flow not modelled)

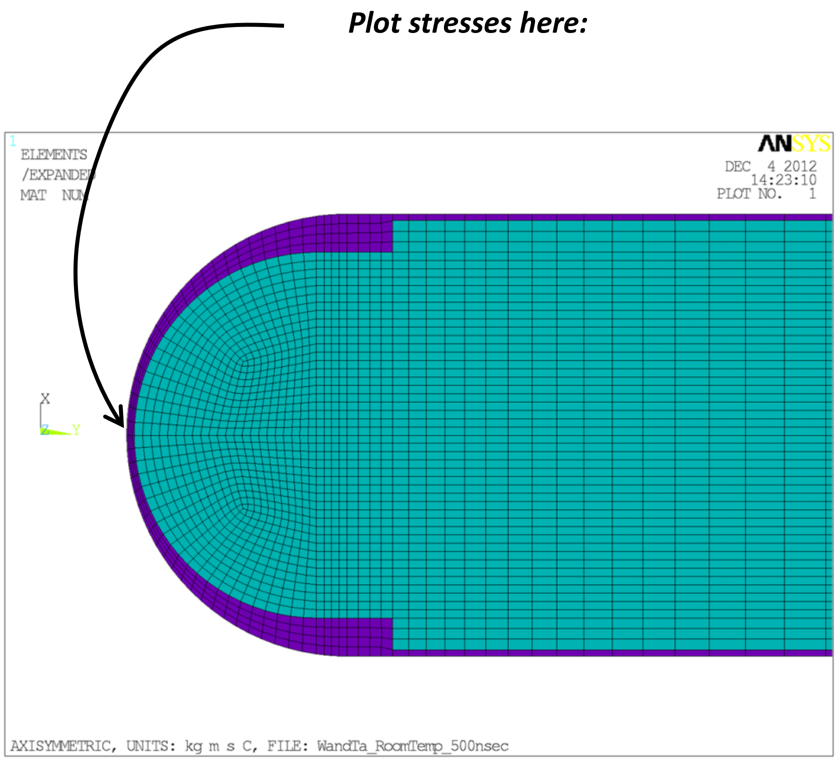




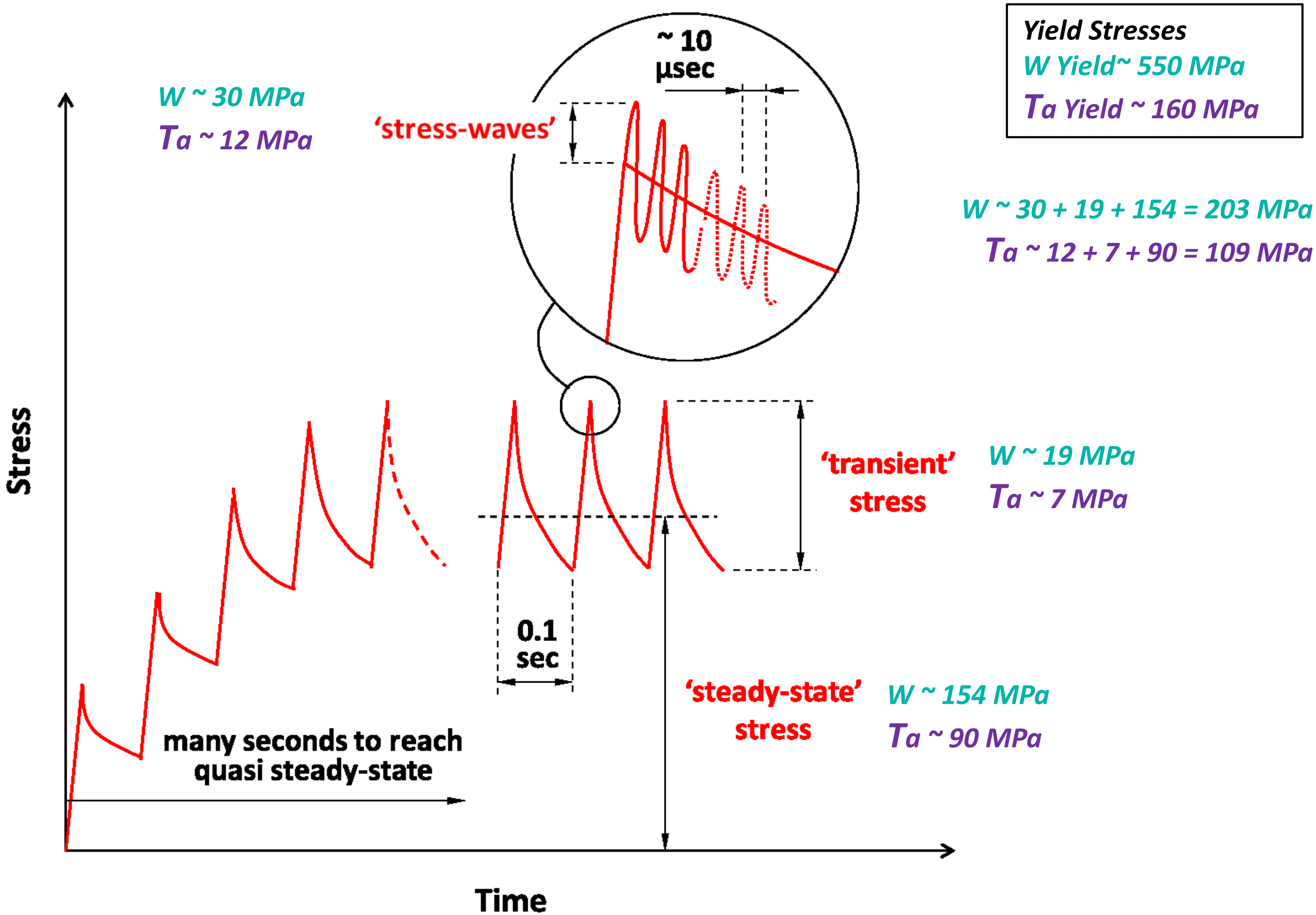
Stress-Wave Transient

- Dynamic stress response (includes inertia)
- Simplified 2D geometry – many time steps required





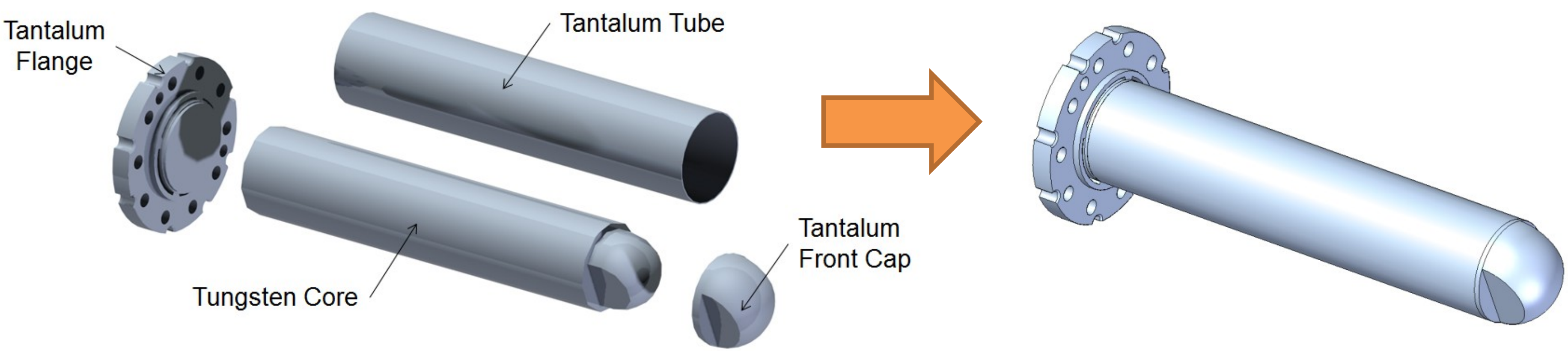
Stress Results at the Target Nose



HIP Process

- Good thermal contact between tungsten and tantalum is essential

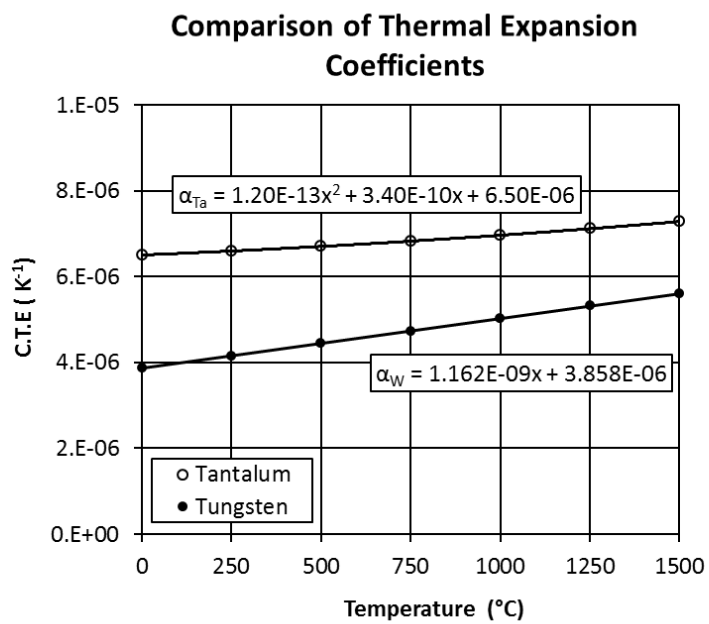
- Hot Isostatic Press (HIP) used to create a diffusion bond
  - Tungsten core sealed inside tantalum ‘can’ by electron beam welding under vacuum
  - Assembly heated to ≈1500°C
  - Pressure of ≈200MPa applied to force parts together until they bond
  - Gradually returned to room temperature and pressure
  - Tantalum machined down to final size



Components of HIP assembly

HIP Effects

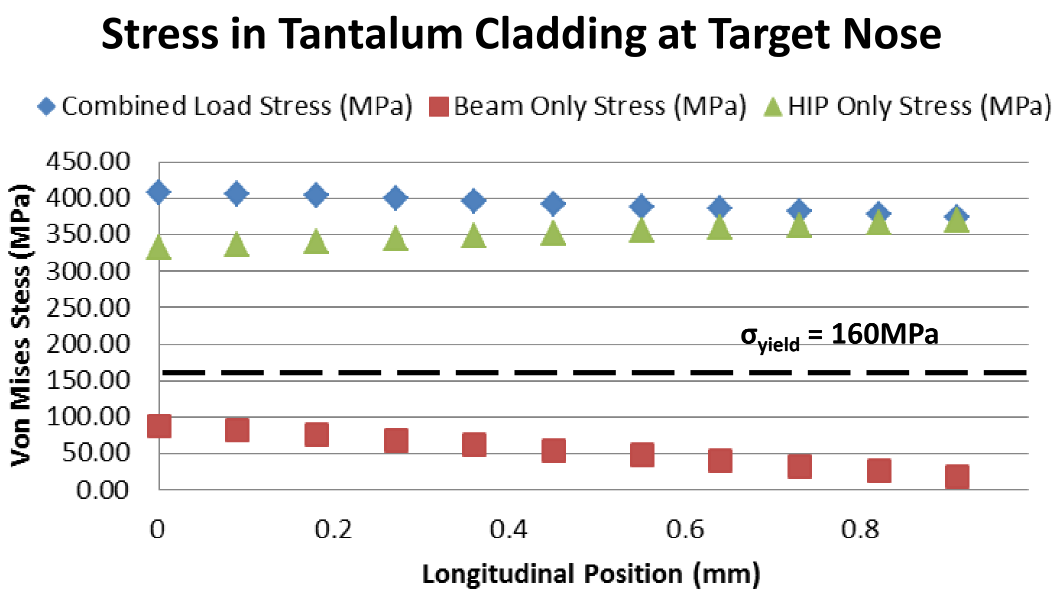
- Results in significant pre-stress
  - High pressure deforms tantalum can
  - However, this occurs above annealing temperature
  - Cooling causes shrink-fit residual stress (tantalum contracts more than tungsten)
  - Stresses thought to ‘lock in’ at around 500°C



- May also effect material properties
  - This is being investigated in detail by ISIS

Modelling HIP Pre-Stress

- Two load steps:
  1. Target is cooled from 500 to 20°C
  2. Steady-state beam-induced stress is applied



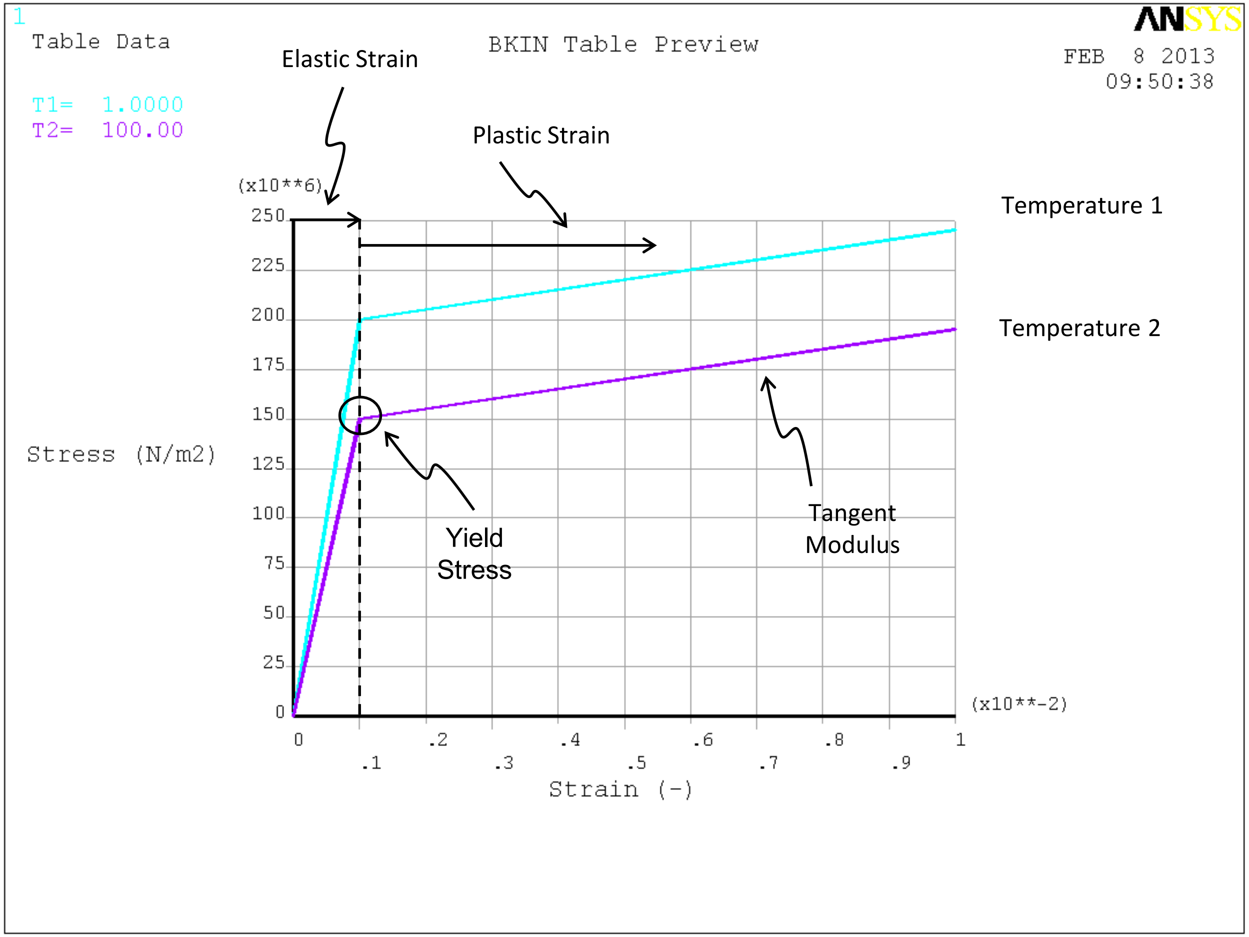
Tantalum yield stress:
160MPa (as received)
200MPa (after HIP)

- from experiments carried out by ISIS

- Conclusion: Tantalum has yielded before the beam is applied

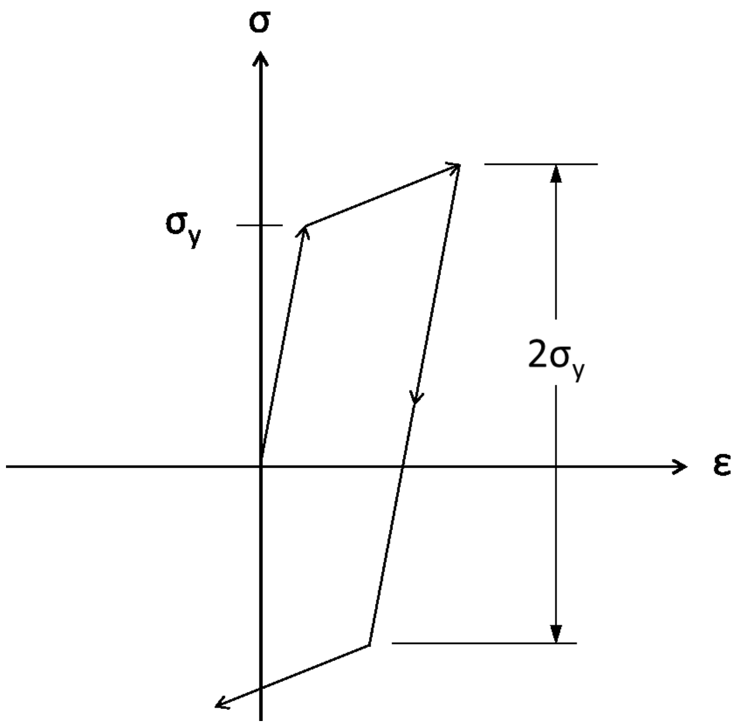
Yielding of Tantalum

- Bilinear model for stress/strain:
  - Define yield stress and tangent modulus
  - Data input at various temperatures
  - Total Strain = Elastic Strain + Plastic Strain

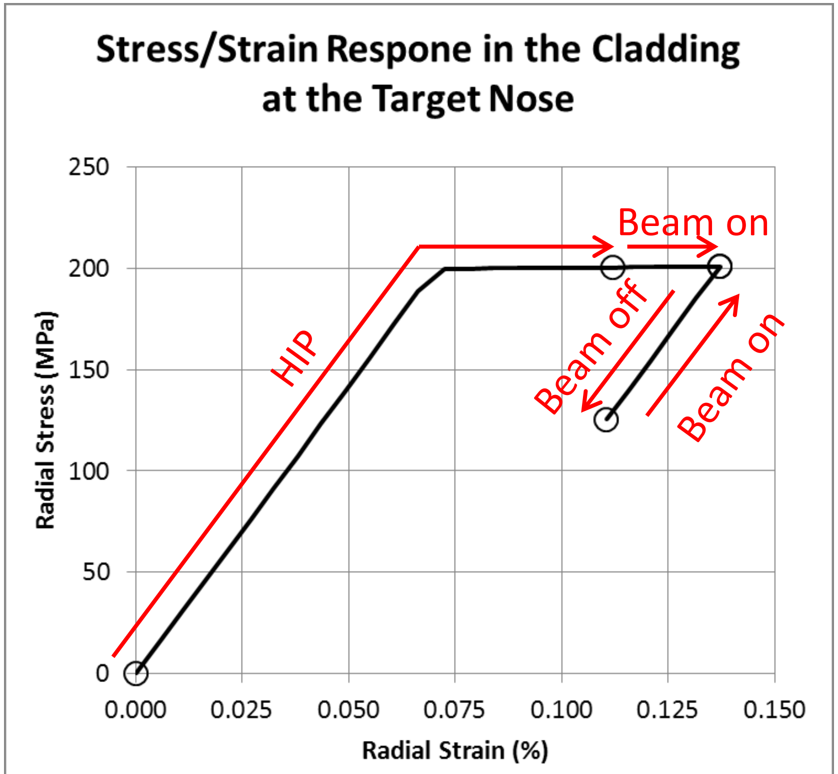


Elastic-Plastic Analysis

- Periodic loading applied to yielded material
- 'Kinematic Hardening' model selected in ANSYS
  - an increase in yield stress in one direction is compensated for by a decrease in yield strength in the opposite sense (Bauschinger effect)
  - the total linear stress range is equal to twice the yield stress



Kinematic Hardening Model



Results from elastic/plastic analysis

Conclusion

- All beam-induced stress components have been modelled
- Effects of HIP process are partly understood
  - Need to determine ‘lock in’ temperature
  - How are material properties affected?
- Stress levels in tungsten are acceptable
  - Safety factor of at least 2 even in worst case
- Significant yielding in tantalum cladding
  - How does this affect fatigue life?

Next Steps

- Experiments to understand HIP pre-stress
  - Bimetallic strip
  - ISIS Engin-X* (strain measurement by neutron scattering)
- Experiments to understand material properties
  - Tensile testing HIPed tantalum
  - Fatigue testing tantalum samples
- Fatigue life calculations
- Compare TS1 and TS2
- Explore alternative methods of coating tungsten
- Inform design of future ISIS targets

* http://www.isis.stfc.ac.uk/instruments/engin-x/engin-x2900.html