Thermo-Mechanical and Fluka Simulations of TS1

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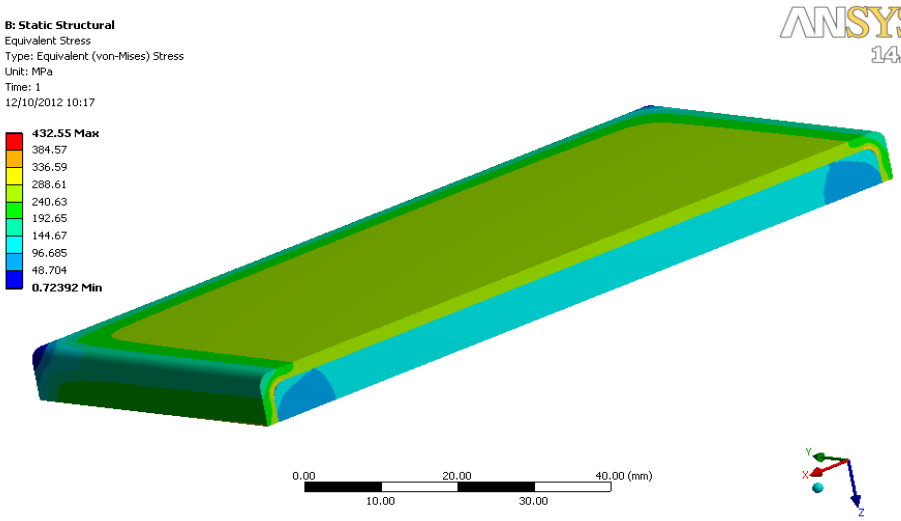
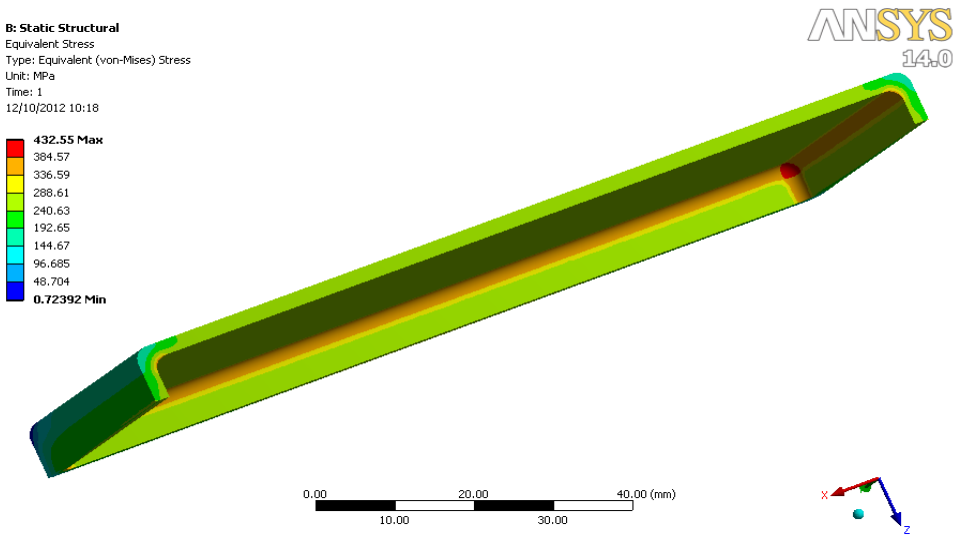
“Standard HIP” cycle used to manufacture target plates

Heat to 1200°C in about 6 hours. (The heating rate varies depending on thermal mass we process but generally is 3-4 degrees per minute)
Hold at 1200°C for 4 hours @ 103 MPa pressure.
Cool to atmospheric conditions at 10°C per minute.

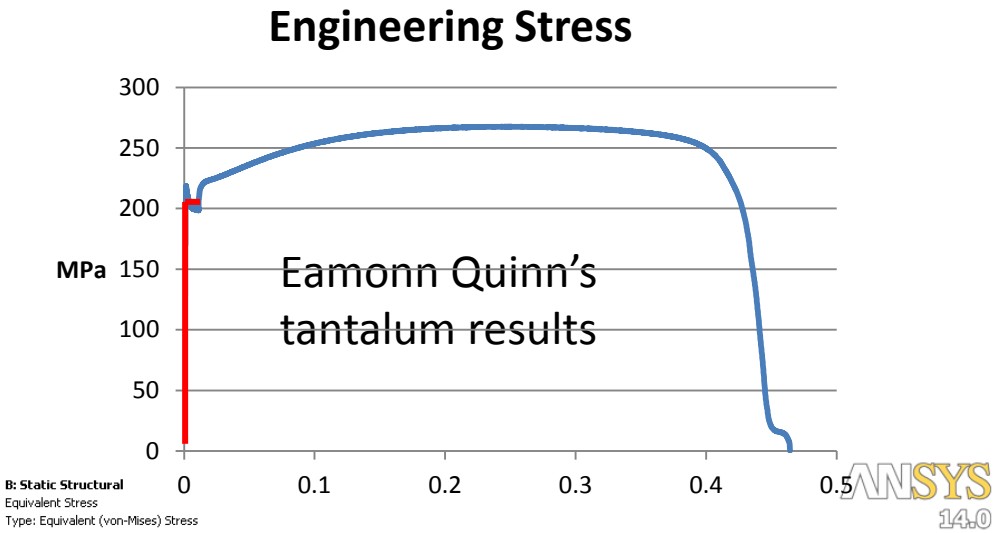
Assuming a ‘lock-in’ temperature of 500°C and linear stress strain relationship

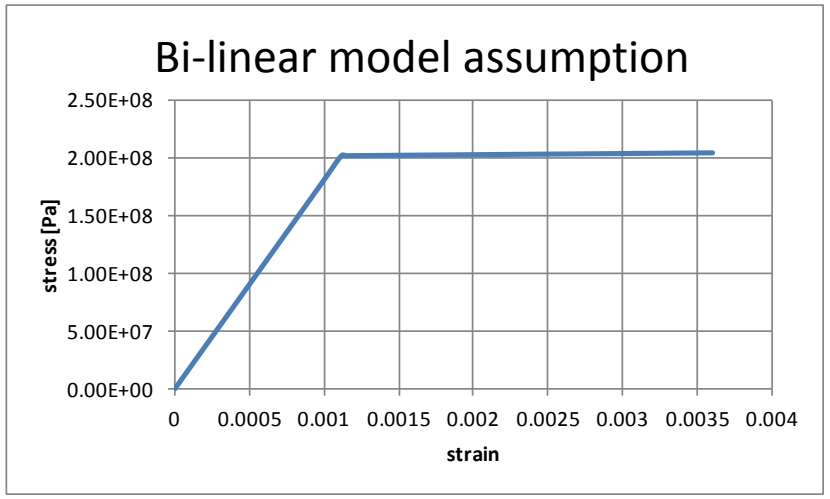




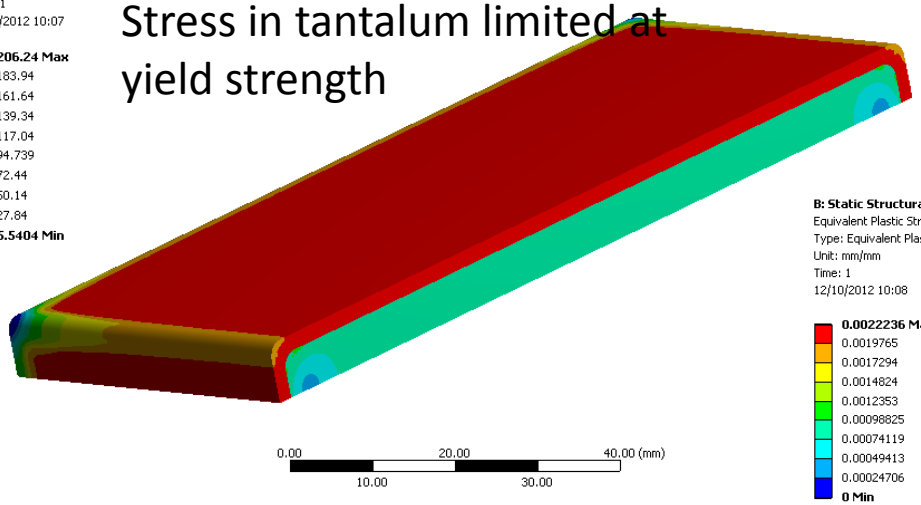
Tantalum is stretched over tungsten due to differential thermal expansion
Peak stress of 432MPa in ‘rounded’ corners, reaching yield stress over large sections too.

Use bi-linear model to predict stress levels

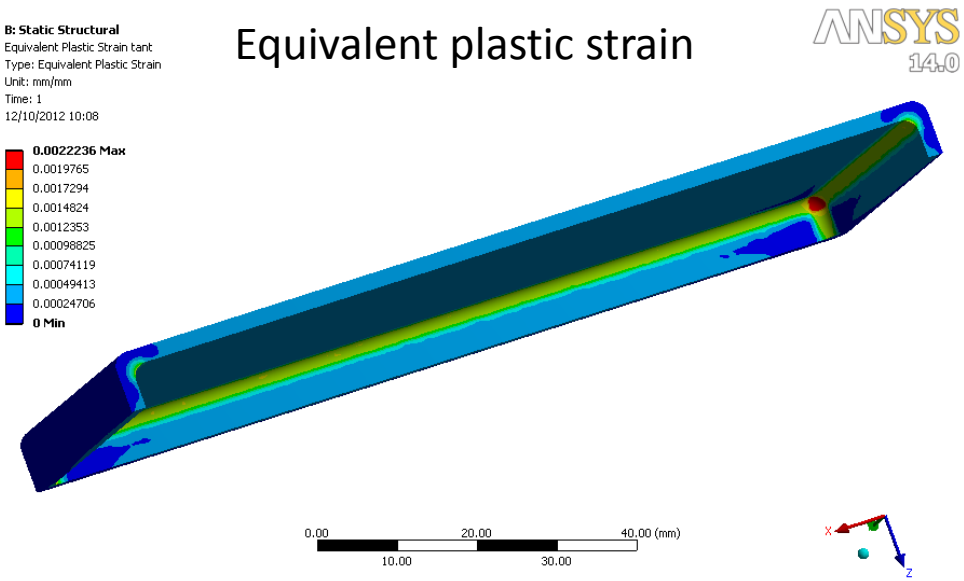




Stress in tantalum limited at yield strength

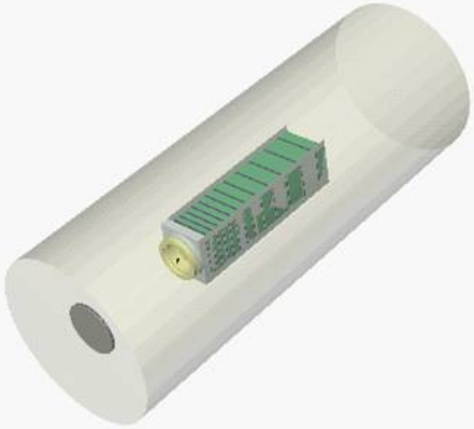


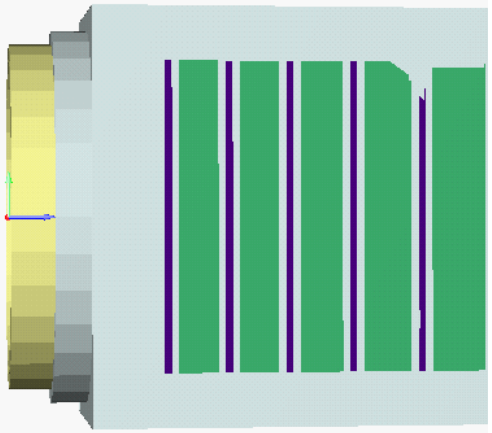
Equivalent plastic strain

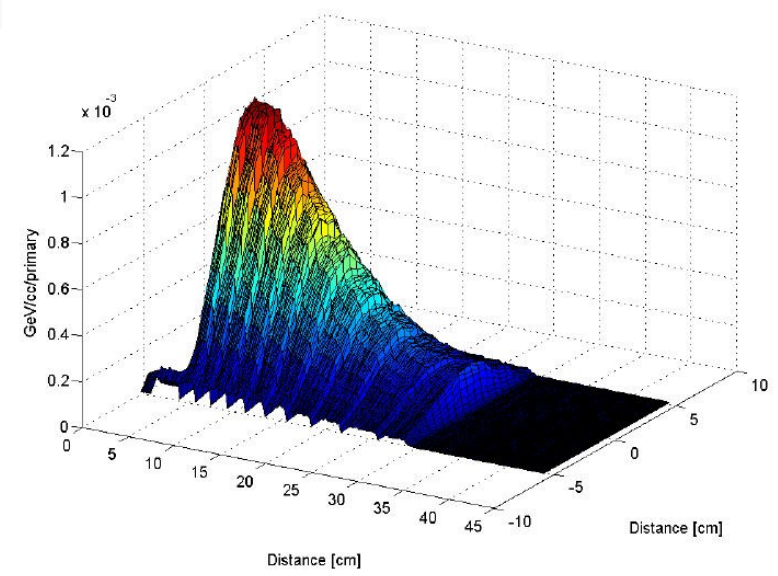


Yielding occurs in path of beam as well as corners

Fluka energy deposition in TS1

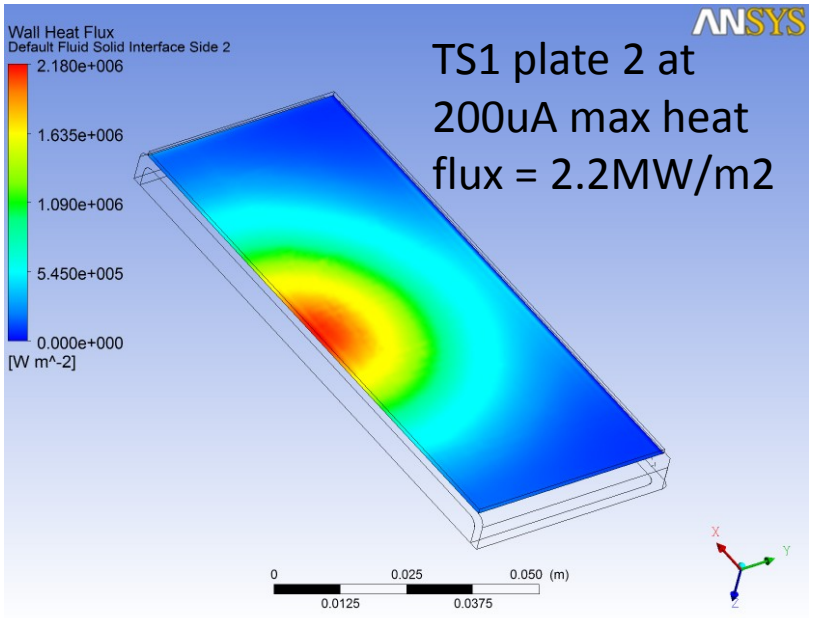


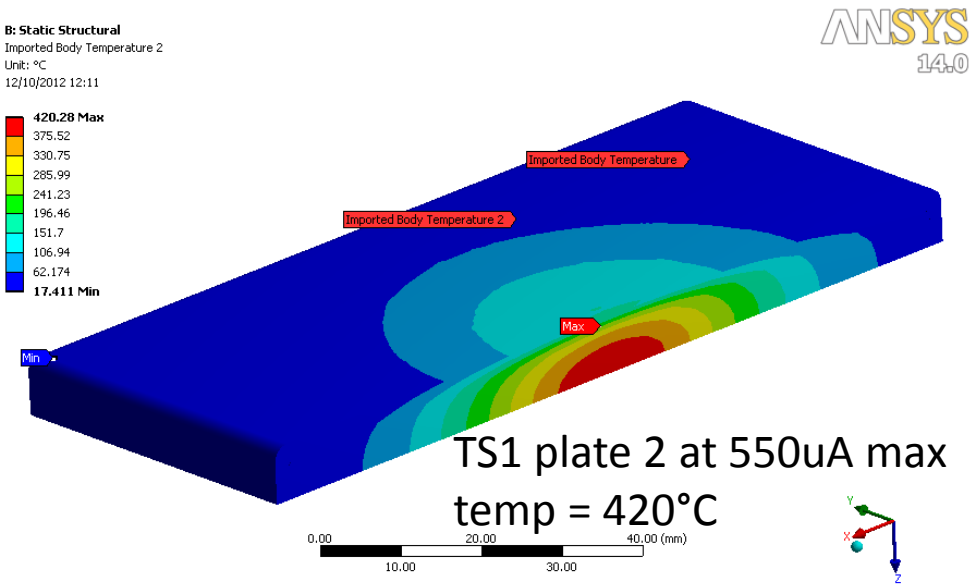




	800MeV 200μA σx=16.26mm σy=16.26mm	
	integrated power [kW]	**Max power density [MW/m^3]**
inconel window	2.17	227.92
inconel cooling water	0.08	34.59
steel window assembly	2.20	199.13
plate 1	11.20	455.84
plate2	11.56	441.84
plate 3	11.60	391.86
plate 4	11.40	349.88
plate 5	10.76	305.89
plate 6	10.44	233.92
plate 7	9.52	176.74
plate 8	8.68	125.36
plate 9	7.92	85.77
plate 10	5.12	60.38
plate 11	0.23	4.90
plate 12	0.10	3.98
TOTAL	**102.95**	

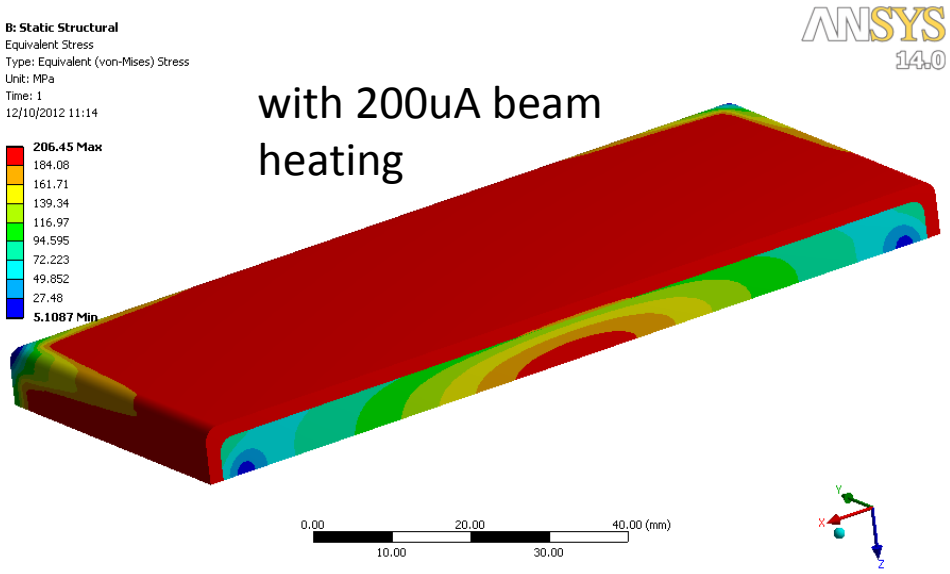
Peak heat flux and temperature



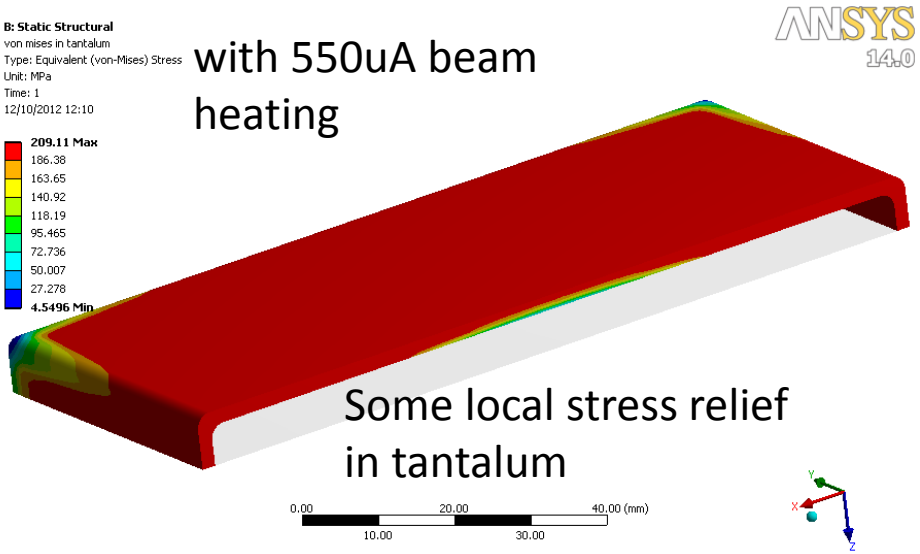


	200uA 6m/s	550uA 9m/s
Peak tantalum surface temp	**90°C**	**161°C**
Peak heat flux	**2.2MW/m2**	**6MW/m2**
Peak temperature in tantalum	**120°C**	**200°C**
Peak temperature in tungsten	**177°C**	**420°C**

Effect of steady state beam heating on tantalum and tungsten stress

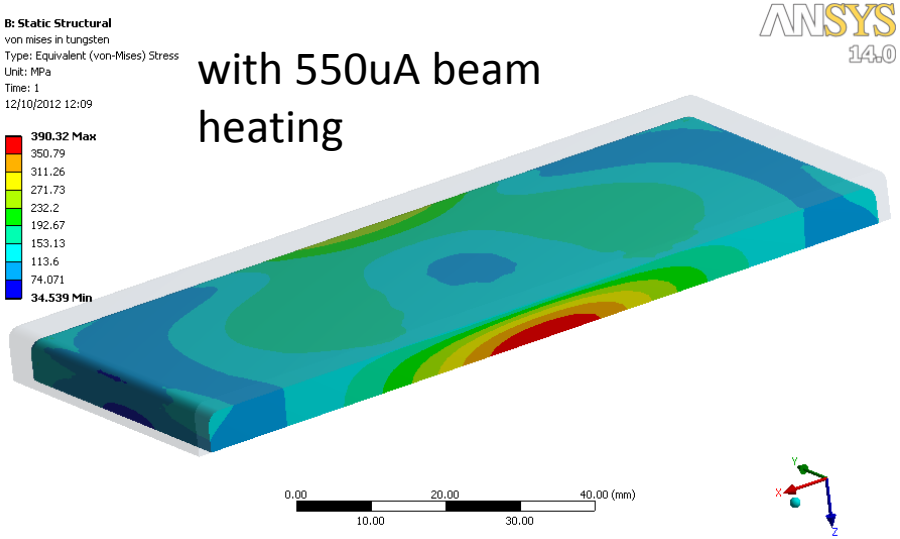


with 200uA beam heating



with 550uA beam heating

Some local stress relief in tantalum



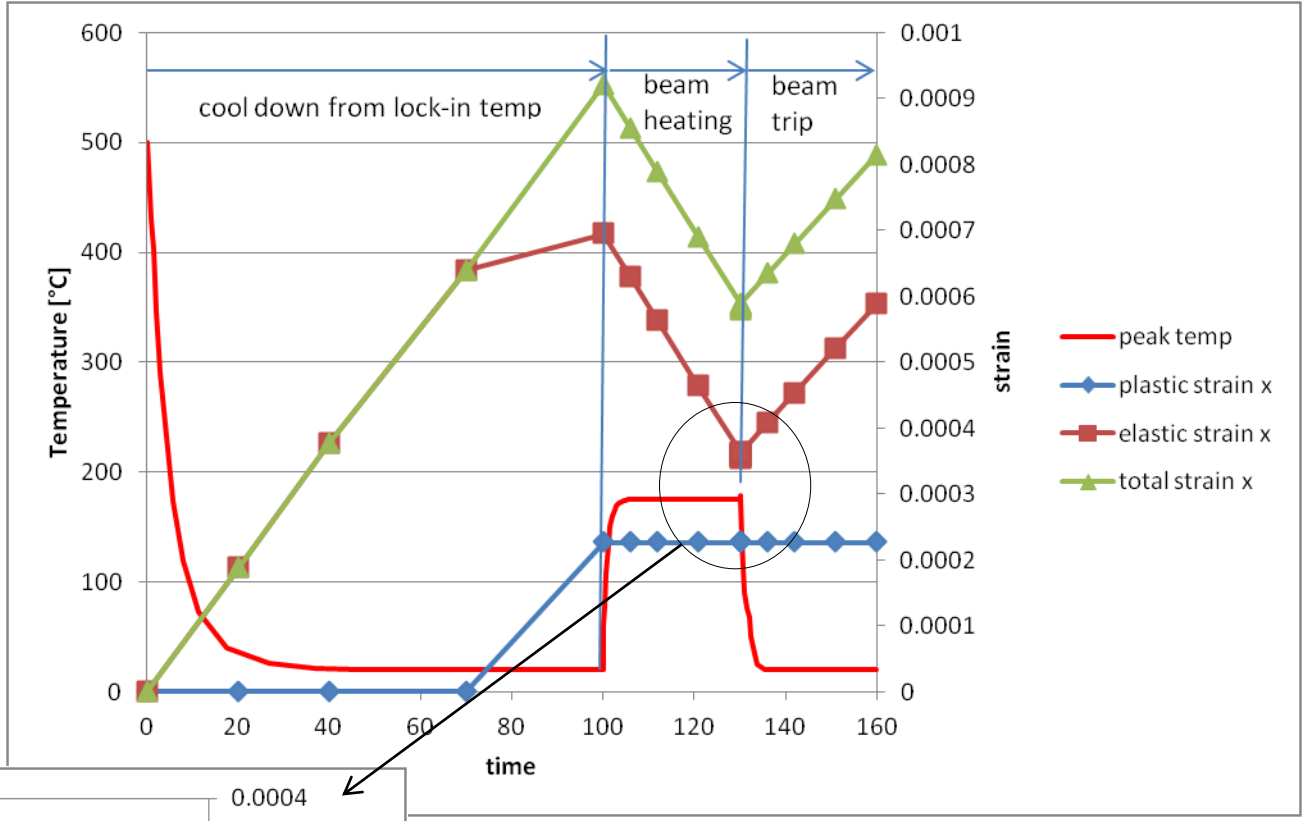
with 550uA beam heating

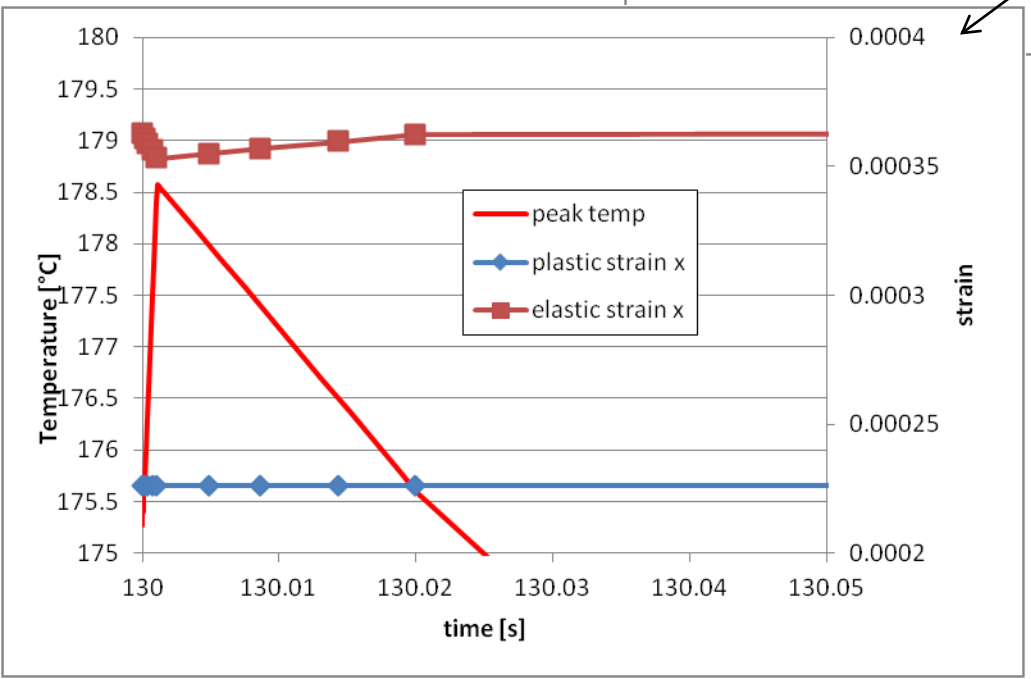
	200uA	550uA
Peak stress in tantalum	**206MPa**	**209MPa**
Peak stress in tungsten	**200MPa**	**390MPa**

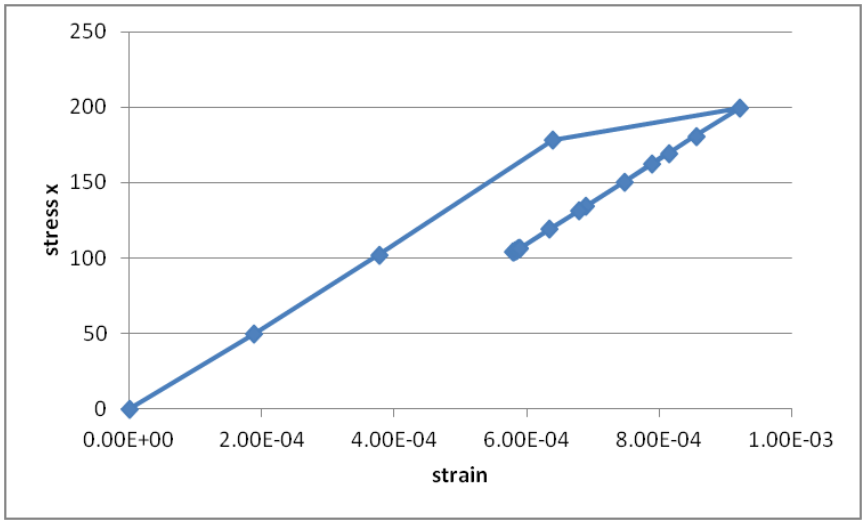
Transient stress strain at central gauge point (on beam axis) in tantalum cladding (200uA)

After first beam heating no further plastic deformation occurs, beam pulses and trips accommodated in the elastic regime, although note peak stress remains close to elastic limit

Life of tantalum depends on fatigue strength

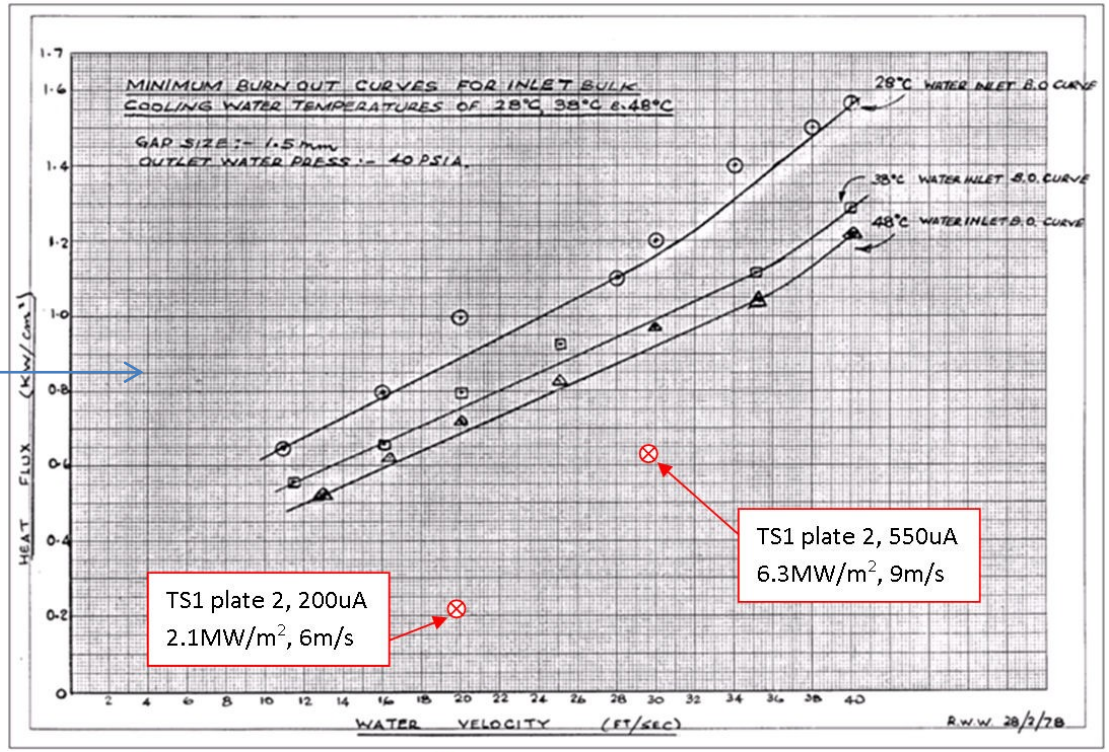




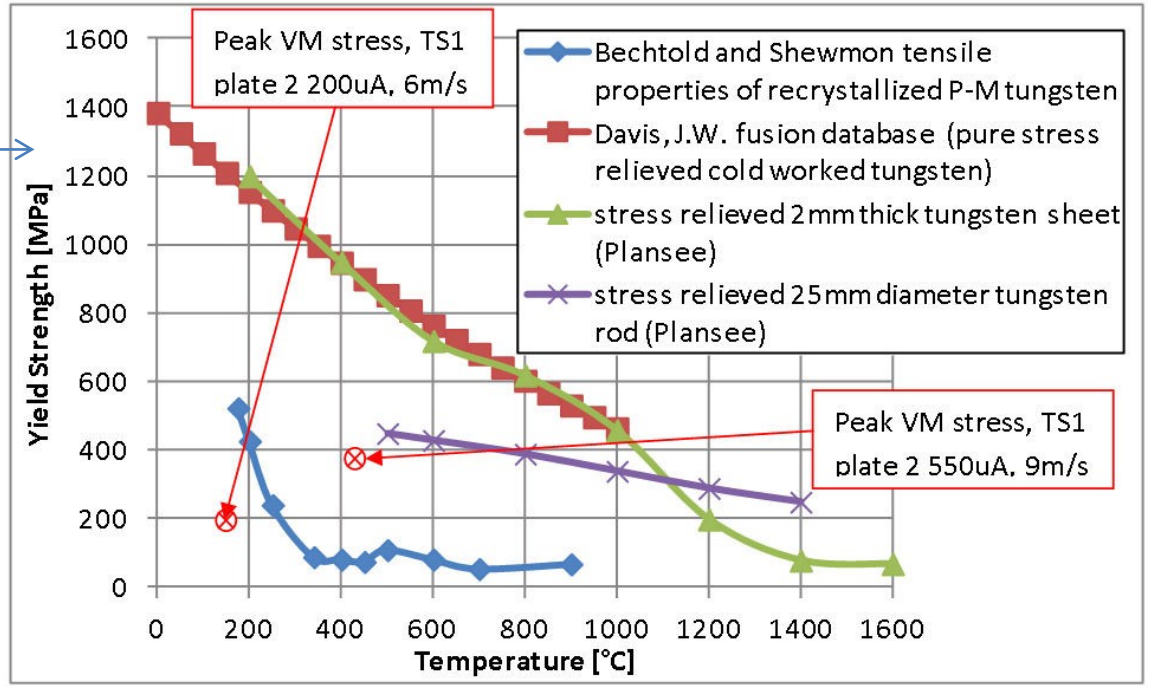


TS1 upgrade limits

heat flux



tungsten stress?



Comparison of pulse intensity

	TS1	TS1 upgrade	TS2
sigma	16.2mm	16.2mm	6mm
Time averaged current	200μA	550μA	40μA
Pulse frequency	50Hz	50Hz	10Hz
Protons/pulse	2.496e13	6.87e13	2.496e13
Peak temp jump in tungsten	3.5K	9.6K	25K

Need to consider fatigue limit of tantalum

Conclusions

- Increasing beam current on existing TS1 design from 200µA to 550µA will result in an increase in peak heat flux from 2.2 to 6MW/m^2 this could be accommodated with an increase in water velocity and operating pressure.
- Peak stress and temperature levels in tungsten will be significantly higher increasing from 200MPa to 390MPa and 178°C to 420°C. Alarming but not necessarily a show stopper.
- Reducing target plate thickness would be a method of reducing peak heat flux, stress and temperature in the tungsten
- Steady state stress in the tantalum will not be significantly different as it is dominated by the HIP process, however a larger cyclic load will be present as a result of a 9.6°C peak temperature jump per pulse compared to the current 3.5°C.
- Tantalum CVD process may offer a lower stress alternative to the current cladding technique.
- A more radical highly segmented design could offer significantly higher heat dissipation capability with reduced stress levels