Update on ELMS and Thermal Creep in the ARIES Divertor

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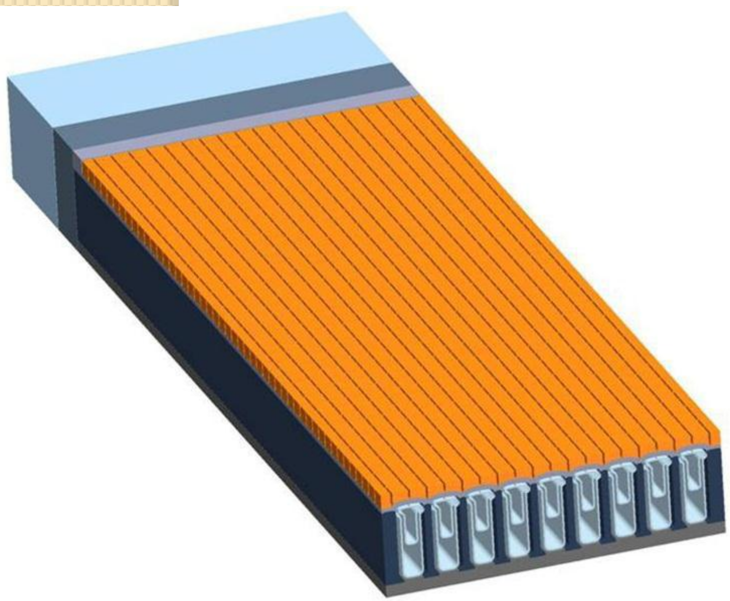
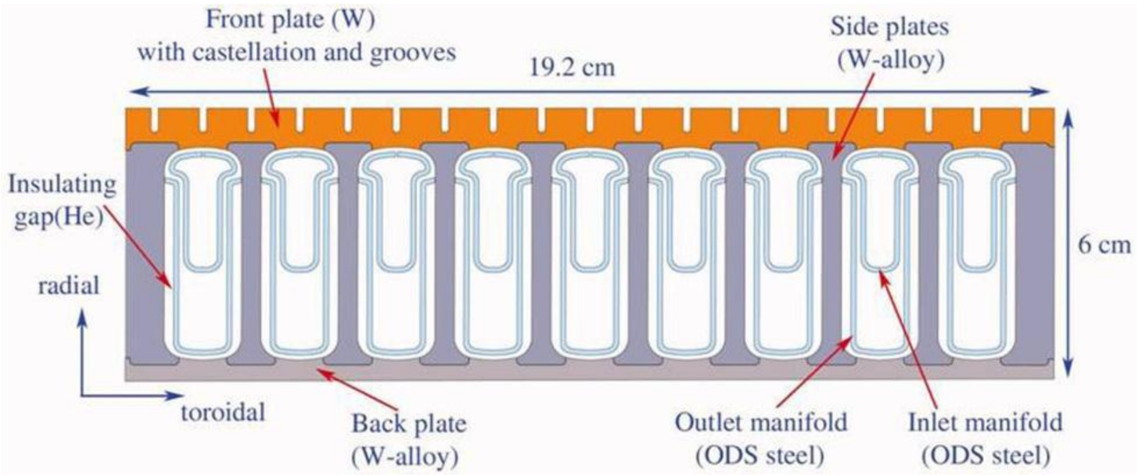
Tungsten HCFP(Helium-cooled Flat Plate) divertor

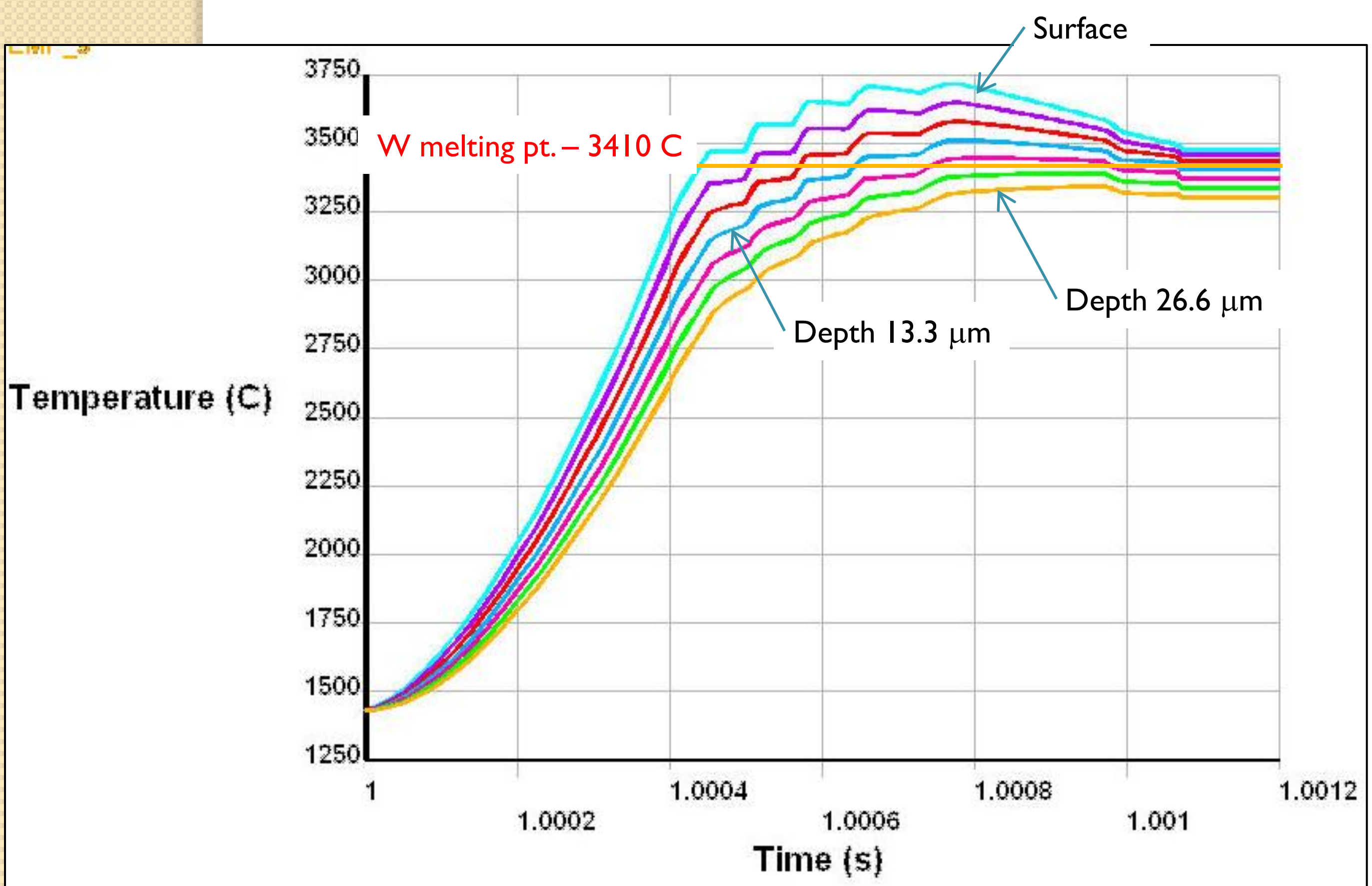




Parameters Used in ELMS Analyses

	Large ELM	Small ELM	Old Small ELM
ΔW_{ELM} (MW)	24	5.9	6.0
A_{ELM} (m^2)	1.38	1.38	1.44
Energy to Divertor	50%	80%	50%
Divertor Split	65%	65%	65%
Applied ΔW_{ELM} (MW)	7.8	3.1	2.0
$\Delta t_{ELM,rise}$ (ms)	0.44	0.44	0.4
$\Delta t_{ELM,fall}$ (ms)	0.88	0.88	0.8
Avg ELM Flux (MW/m^2)	**4280**	**1720**	**1130**
Inter ELM Flux (MW/m^2)	**9.5**	**9.5**	**6.7**

Old Small ELM Heating of Divertor Analysis indicates ~20μm Melt Depth



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Small ELM – No Melting

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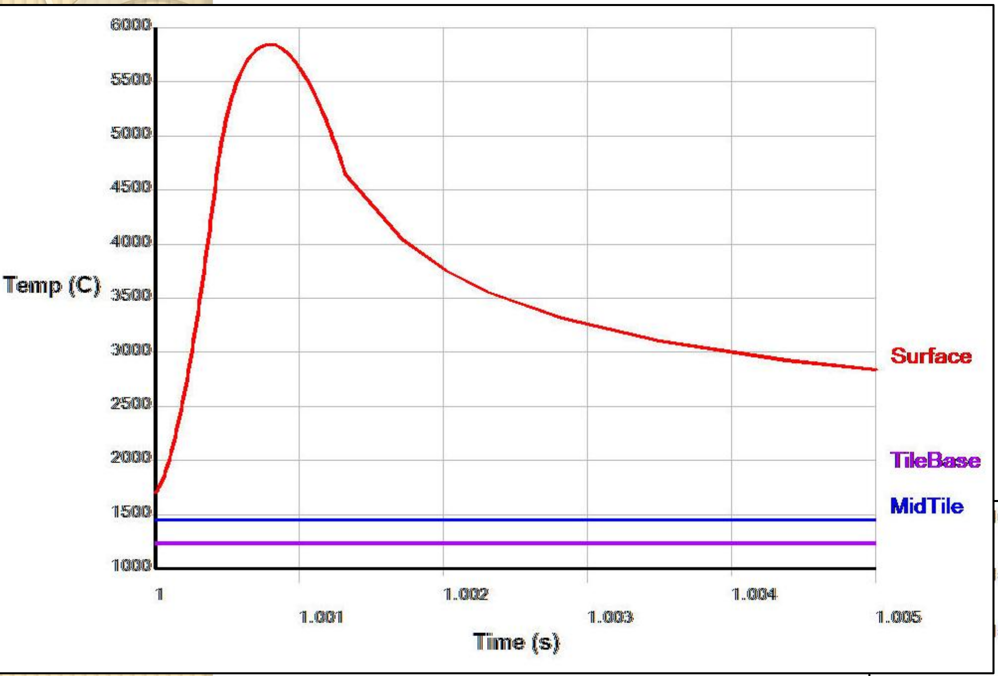

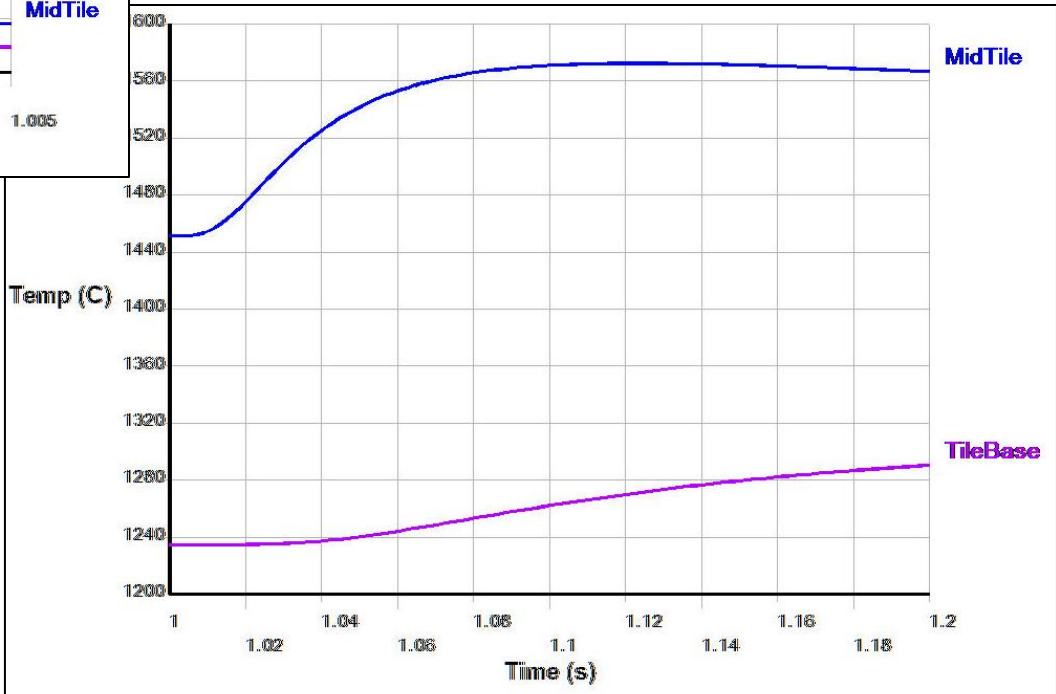

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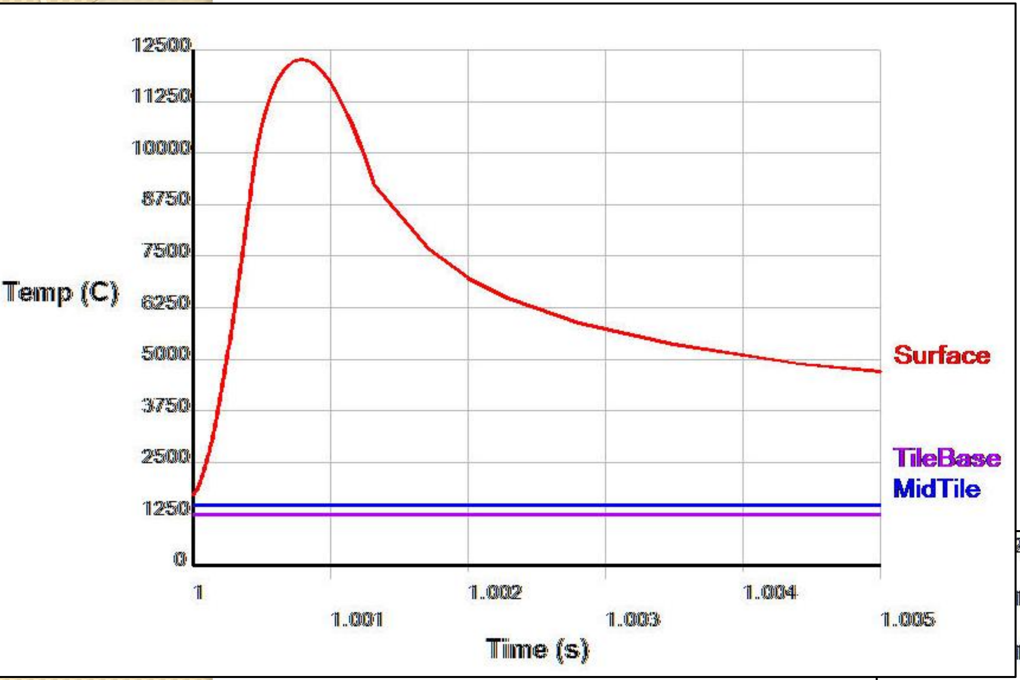
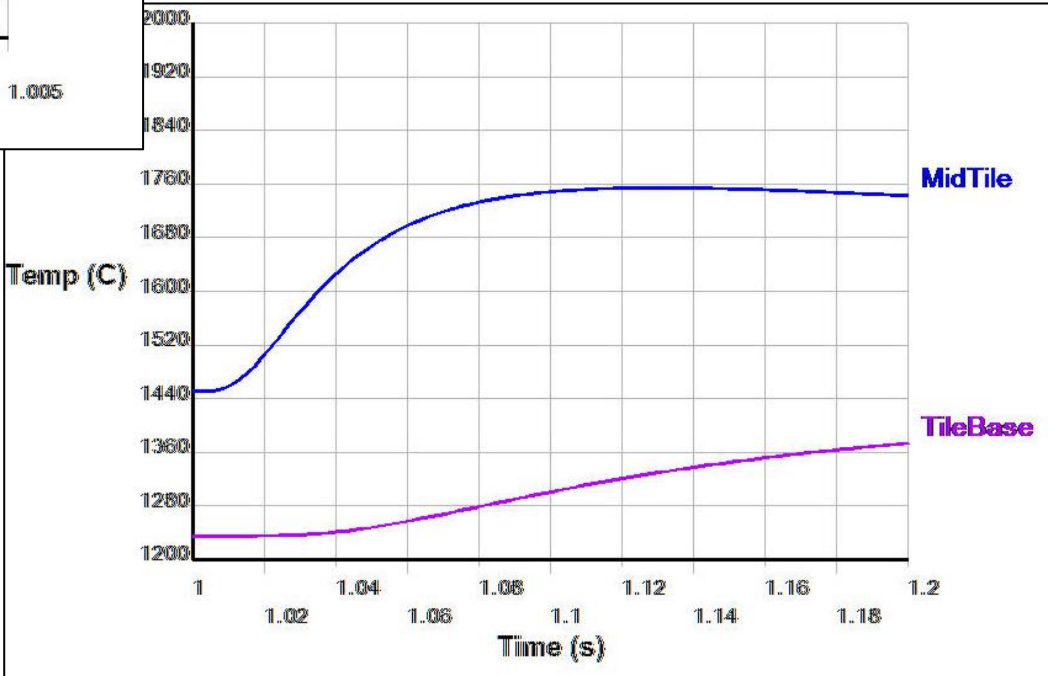
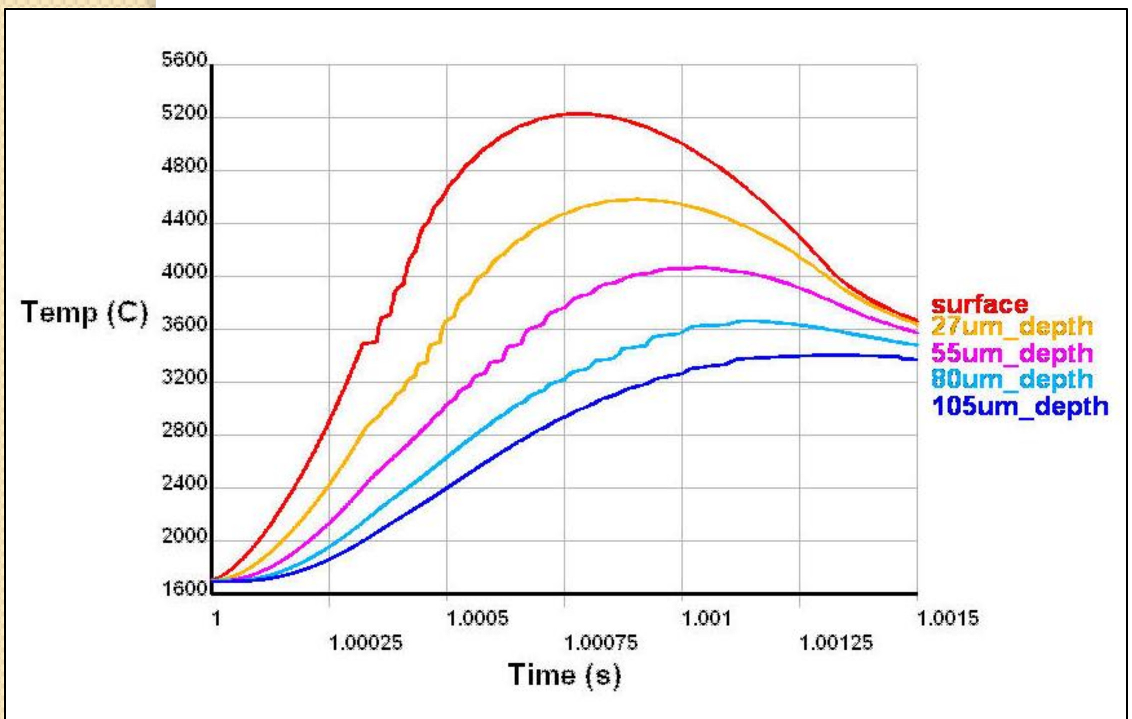




Small ELM Thermal Analysis with Melting

Analysis indicates approximately 100 μm of Tungsten (T_{melt}=3410 C) will melt during a single small ELM event.



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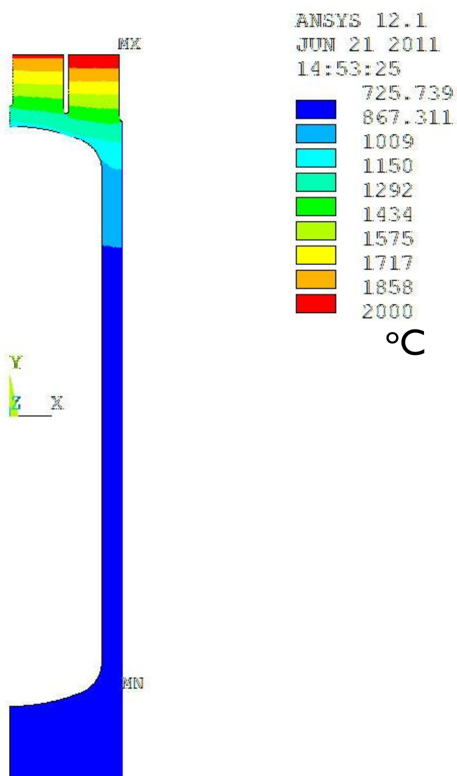
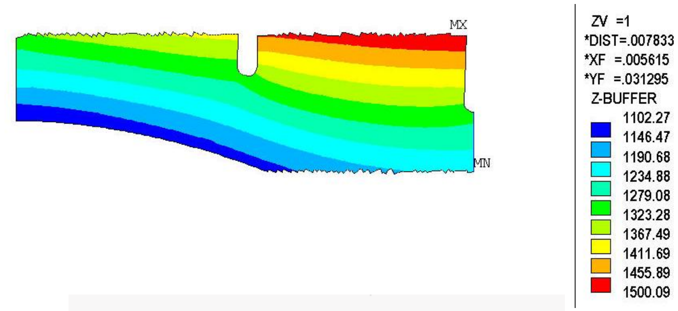
Thermal Creep

Thermal Analysis Shows Temperatures in the 1100 – 1300 °C Range in the W Structure

- While structural temperatures are only ~0.4 T/T_m data indicates that Tungsten does creep at these temperatures.
- Power law creep model added to ANSYS analysis to evaluate creep behavior

$q'' = 11\ MW/m^2$
$q''' = 17.5\ MW/m^3$
$P = 10\ MPa$
$T_{coolant} = 600\ ^oC$
$Max.\ T_{armor} = 2000\ ^oC$
$Max.\ T_{structure} = 1310\ ^oC$
$Min.\ T_{structure} = 725\ ^oC$





$$\dot{\epsilon} = 1.3 \times 10^{3} \left[e^{\frac{-53370}{T}} \right] \times \sigma^{3.53} \qquad (1)$$

where

$\dot{\epsilon}$ = steady state creep rate, h^{-1}

σ = creep stress, MPa, $\sigma \leq 20.0$ MPa

$1500 \leq T \leq 2900$, K

A. Purohit N. A. Hanan S. K. Bhattacharyya E. E. Gruber "Development of a steady state creep behavior model of polycrystalline tungsten for bimodal space reactor application." Argonne National Lab., IL 1995

Assumed Creep Strain Rate May not be Applicable to this Application

- Most W creep data is for higher temperatures and lower stress
- Limited available data for temperatures/stresses of interest indicate creep behavior is different in this range

ITER is investigating W creep in this range:
http://www.extremat.org/ib/site/publication/downloads/Paper%20Rieth%20No.%201951.pdf

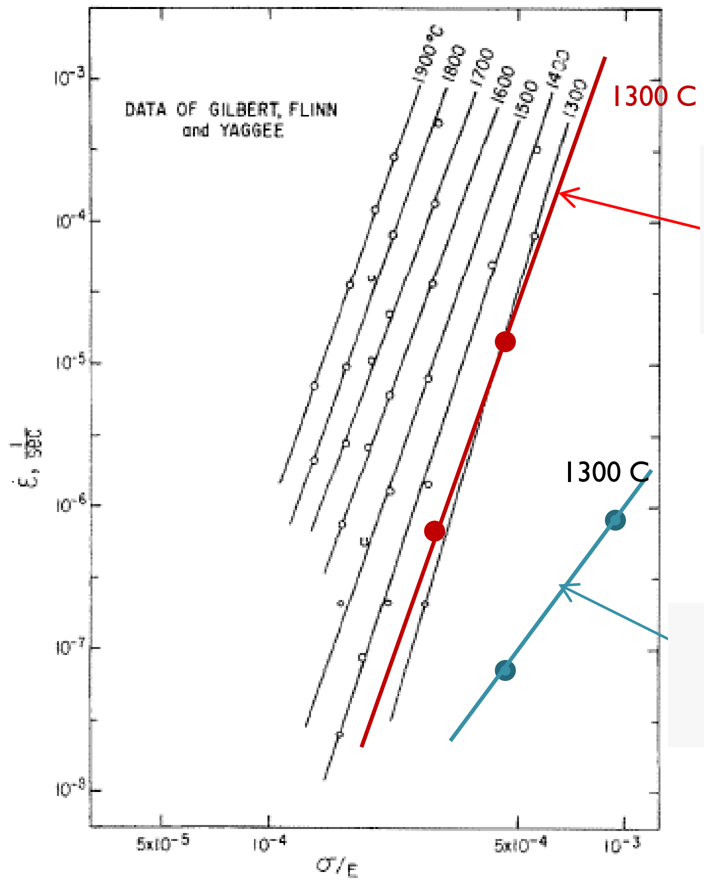


FIG. 4. Steady state creep rate of tungsten as a function of modulus corrected stress.

$$\dot{\epsilon} = 156 \left[e^{\frac{-53370}{T}} \right] \times \sigma^{5}$$

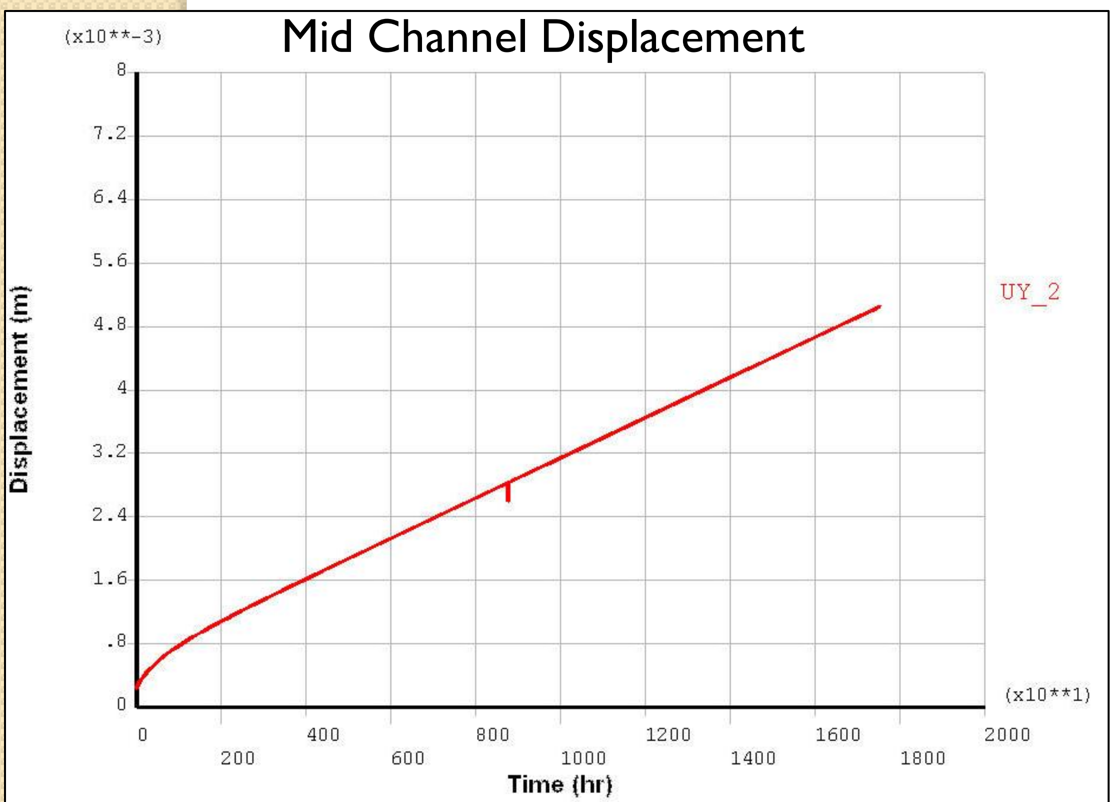
$$\dot{\epsilon} = 1.3 \times 10^{3} \left[e^{\frac{-53370}{T}} \right] \times \sigma^{3.53}$$

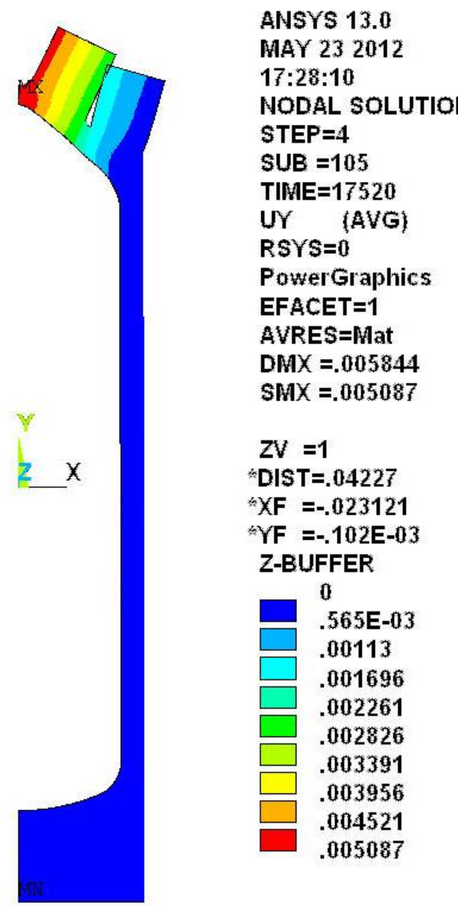
$\dot{\epsilon}$ = steady state creep rate, h^{-1}

σ = creep stress, MPa, $\sigma \le 20.0$ MPa

$1500 \le T \le 2900$, K

Using Data Fit from Previous Page Produces Excessive Creep Deformation

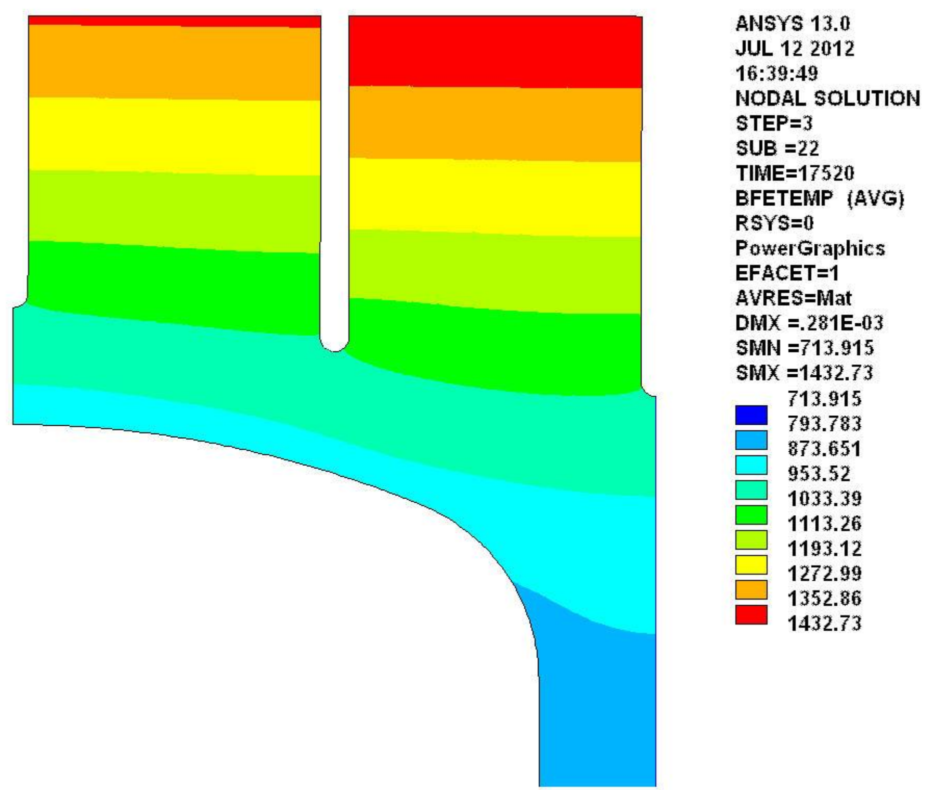




Results for Reduced Heat Flux

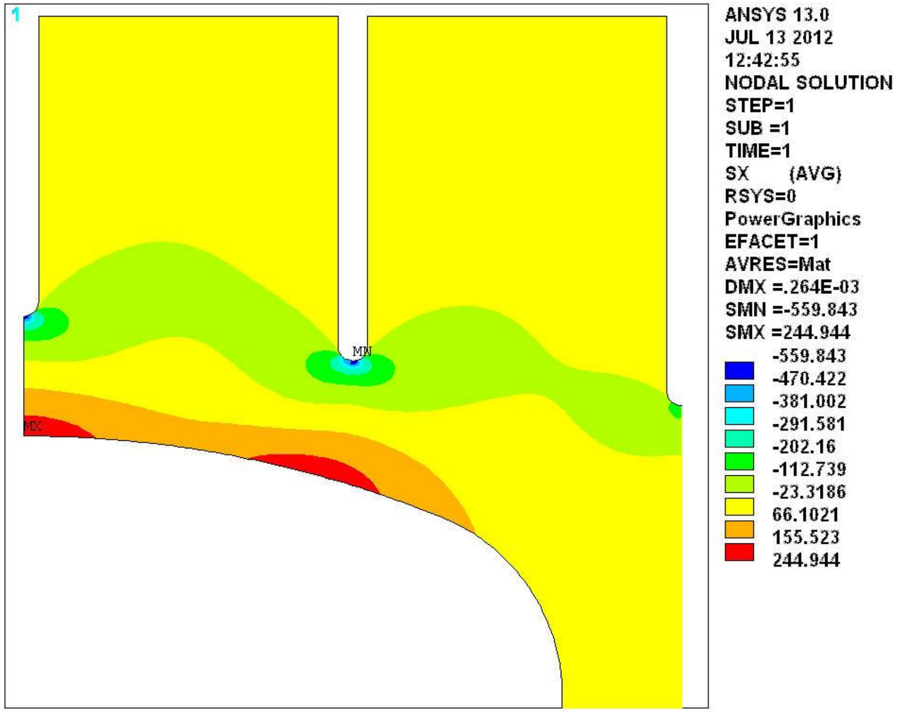
- Reducing surface flux to current design value of 6.7 MW/m^2 reduces maximum divertor temperature to 1433 ^{o}C
- Structural temperatures where creep occurs in the 900-1000 ^{o}C range

q''=6.7 MW/m^2
q'''=17.5 MW/m^3
P=10 MPa
$T_{coolant}$=600 ^{o}C
Max.T_{armor}=1433 ^{o}C
Max.$T_{structure}$=1310 ^{o}C
Min.$T_{structure}$=714 ^{o}C

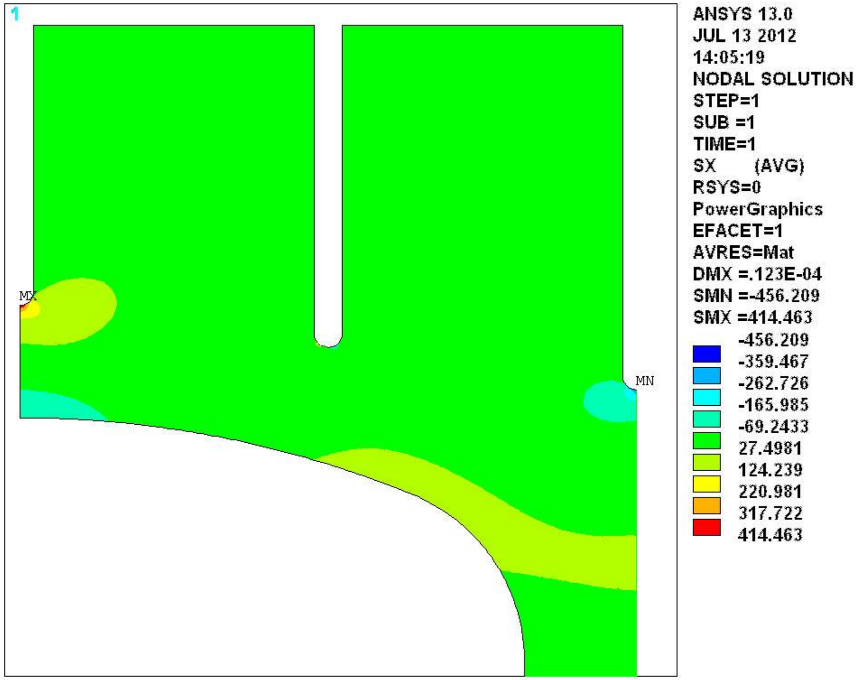


Stresses in Armor from Thermal and Pressure Loads

Thermal Load Stresses (MPa)



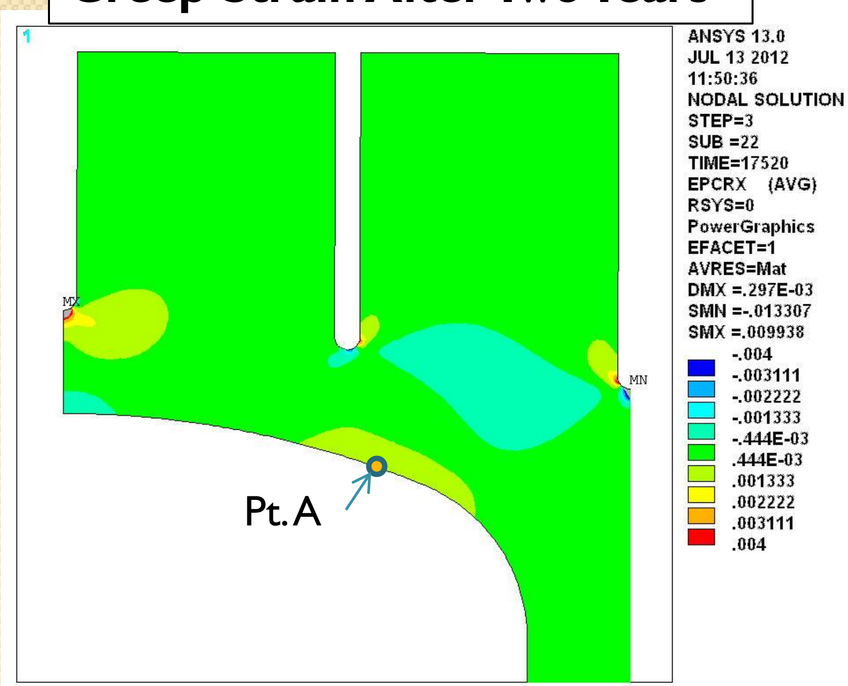
Pressure Load Stresses (MPa)



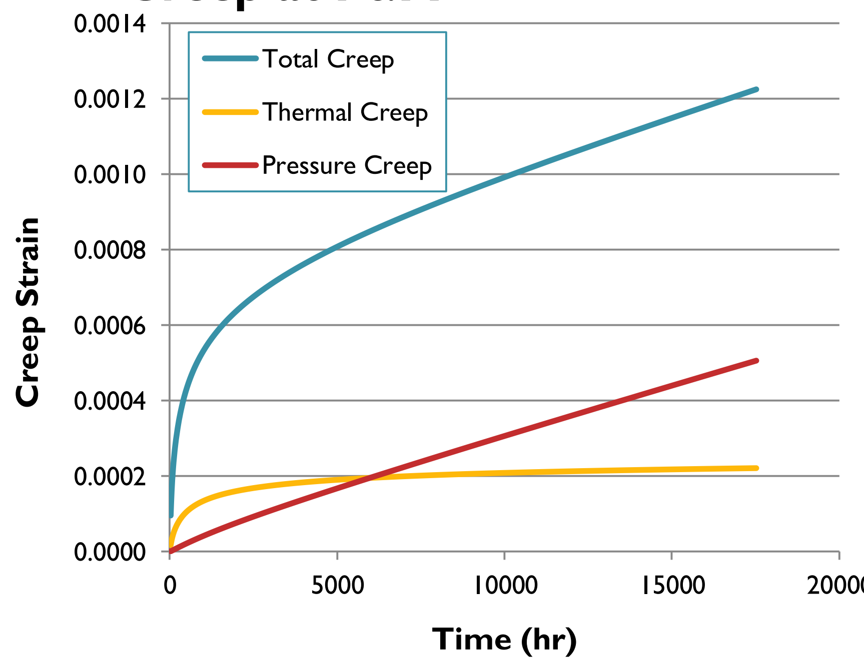
Creep Behavior of Tungsten Armor Over Two Year Exposure

- Creep from combined thermal and pressure loads considerably greater than sum of the individual components
- Thermal creep rate is initially high, but slows as stress is relieved. Pressure creep rates are constant.

Creep Strain After Two Years

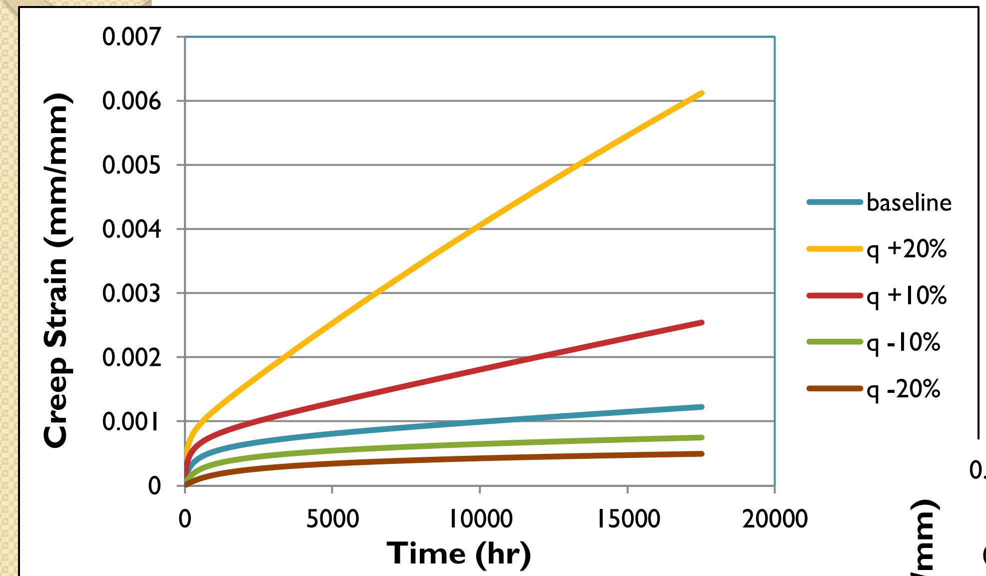


Total Creep Strain along with Pressure Only and Thermal Only Creep at Pt. A

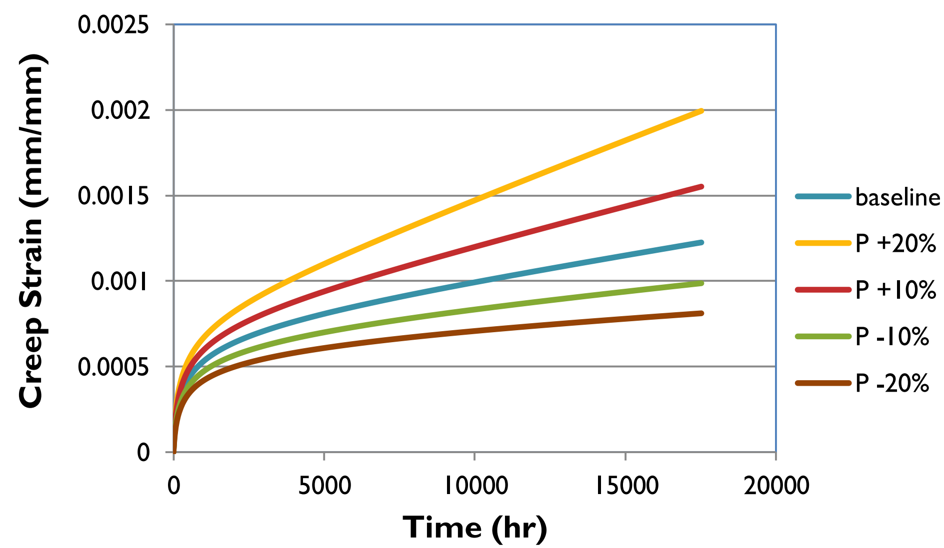


Sensitivity of Creep Rates to Changes in the Thermal and Pressure Loads

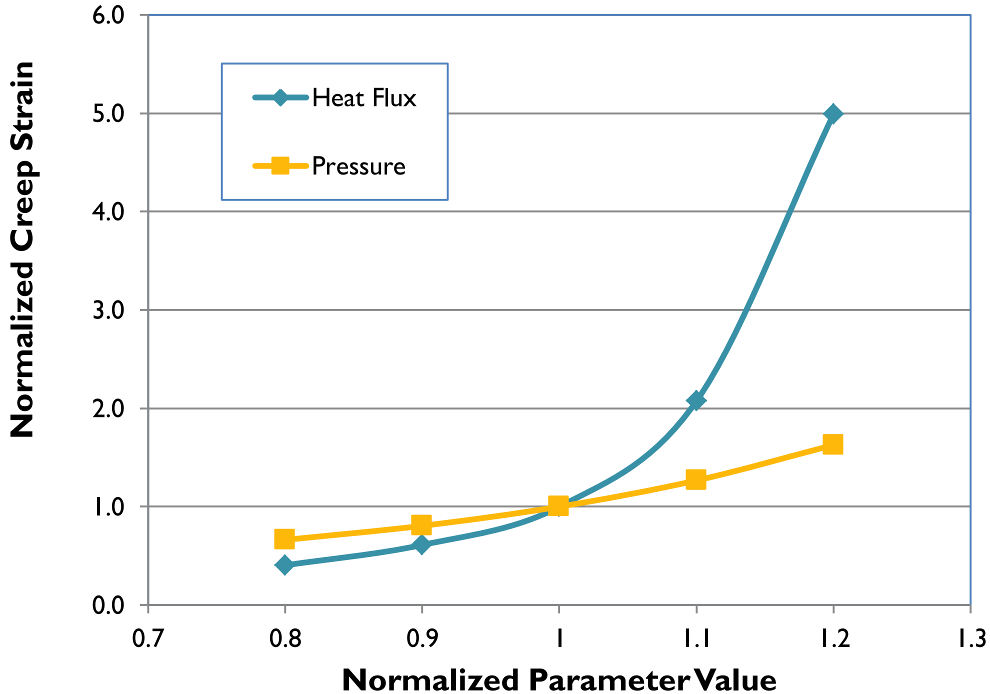
Creep Sensitivity to Surface Heat Flux



Creep Sensitivity to Coolant Pressure

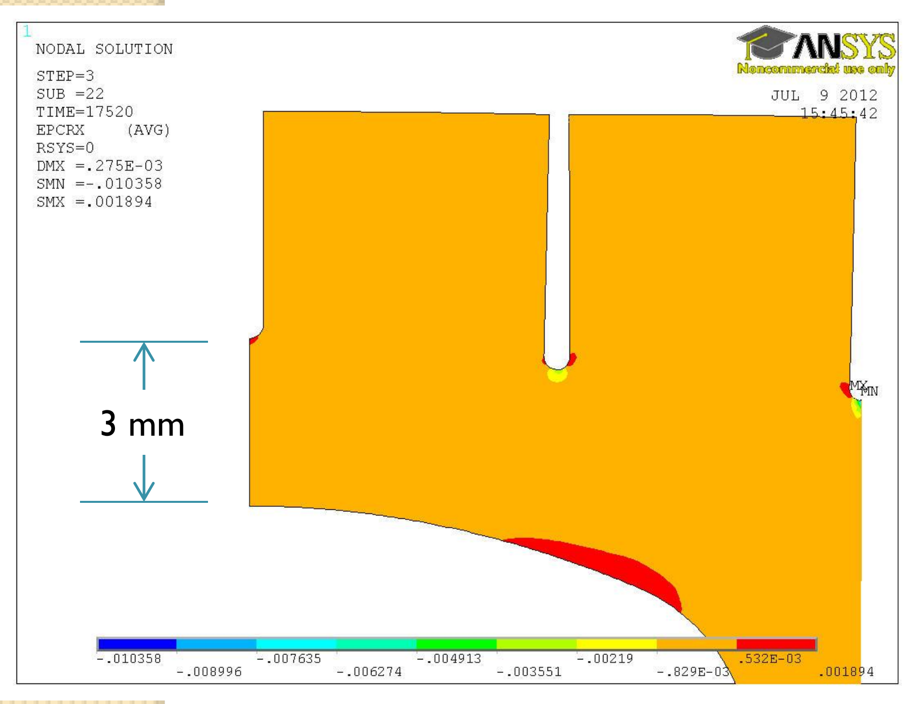


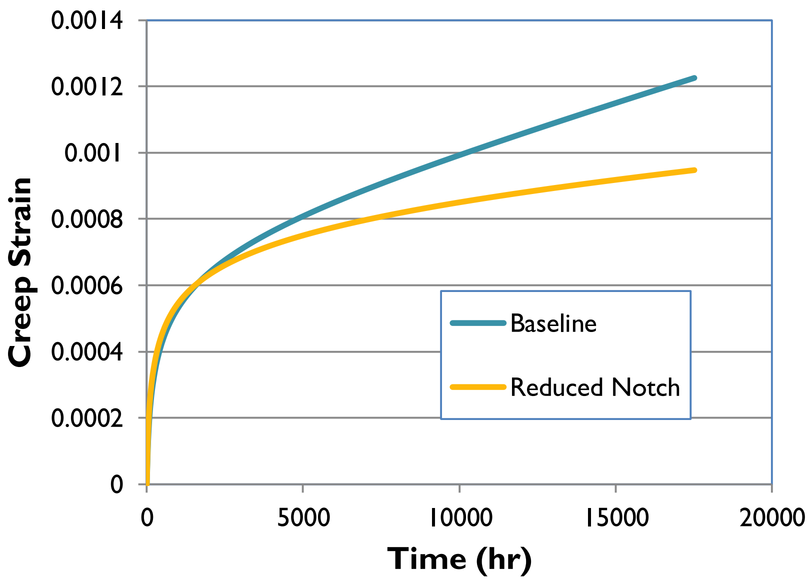
Results Show Creep Rates are Very Sensitive to Changes in Temp. and Stress



Reduce Tile Notch Depth by 1 mm

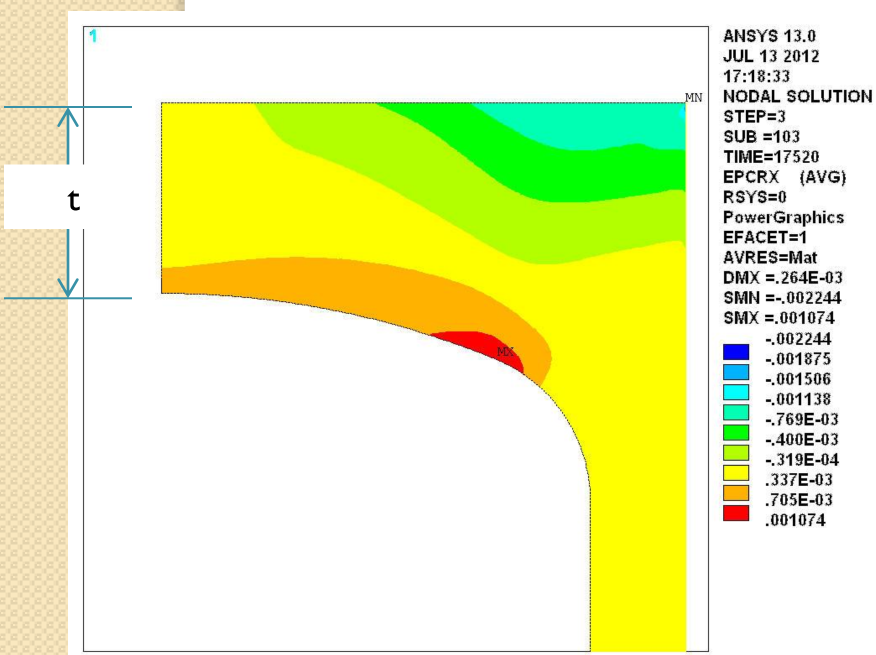
- Reducing notch depth increases minimum wall thickness to 3 mm (from 2 mm) reducing pressure stress in wall with some increase in thermal stress.
- Two year creep strain is reduced by 23% and rate is also significantly reduced.

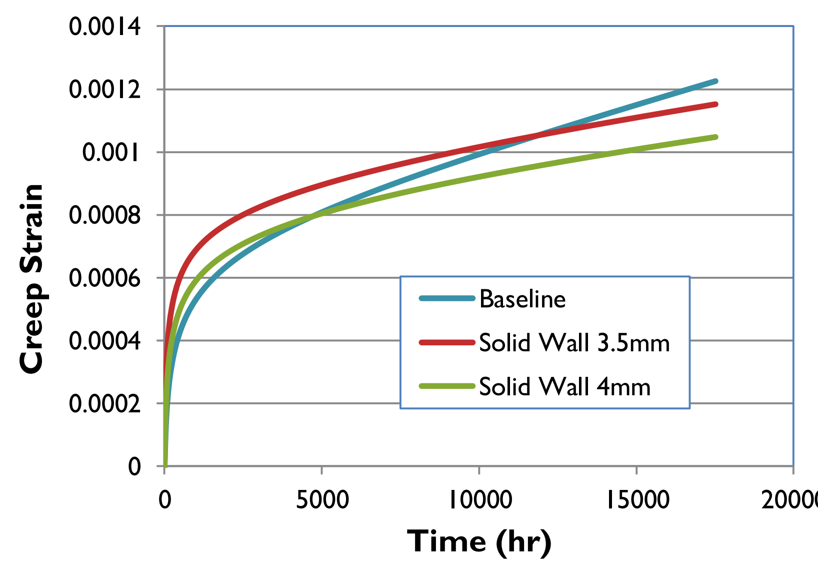




Remove Notch Completely

- Removing alleviates stress concentrations and lowers surface temperature. Thermal stresses increase however.
- Two year creep strain is reduced by 7% for 3.5 mm wall and 15% for a 4 mm wall.
- 4 mm wall reduces maximum surface temperature by 162 °C vs baseline.





Conclusions

- All ELM cases are causing melting
- Thermal creep looks manageable
- We still require a consistent analysis accounting for ELMS, inter-ELM heating, and thermal creep
- We have yet to address disruptions

Future Plans

- Spread ELM heating over larger areas (parametrically)
- Address disruption heat loads
- Address runaway electrons
- Do a consistent analysis with proper steady state heat load and a set of ELMS