Update on Sandia Effort on W Rod Tiles for C-MOD

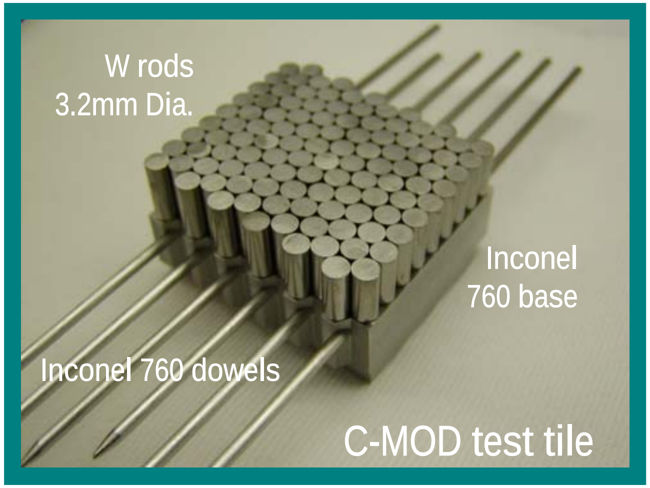
Richard Nygren	Sandia, thermal analysis
Dennis Youchison	Sandia, testing
Tom Lutz	Sandia, testing
Ken Troncosa	Sandia, testing
Fred Bauer	Sandia, testing
Chuck Walker	Sandia, braze
Carter Hodges	Sandia, braze
Walter Olson	Sandia, braze
C-MOD Team	MIT, tile design/fab

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company,
for the United States Department of Energy under contract DE-AC04-94AL85000.

C-MOD W-rod tiles
MIT/Sandia Collaboration

- Sandia tested mockups with “tethered” rods in tests in EBTS and found that a plasma formed at the surface of the rods due to charging of the rods and ionization of residual gas.

- Sandia suggested brazing the W rods. With MIT’s concurrence and more rod samples, we developed a braze procedure with a hydrogen furnace and successfully brazed six shaped tiles now in C-Mod.



- Nicrobraz® 130 (BFNi3) was selected as the best choice for this application. The amount of braze and time at temperature were minimized to reduce flow.

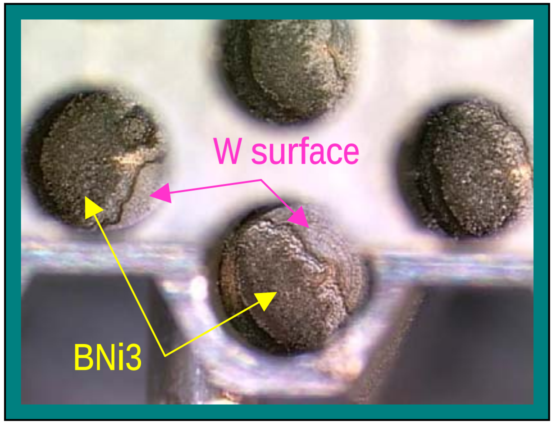
Braze Filler Metal	Nominal compositions (wt. %)	Solidus	Liquidous
Incusil® ABA:	Ag-59.0, Cu-27.25, In-12.50, Ti-1.25	605°C	715°C
Nioro®:	Au-82.0, Ni-18.0	955°C	955°C
Nicrobraz® 130:	B-3.1, Si-4.5, C-.06 max, Ni-Bal.	980°C	1040°C

Success! Success! Success!

Bruce, [Lipschultz]

… the brazed tiles are back
….They look beautiful. …

Thank you Sandia....
Jim [Irby]



View down holes in Inconel shows braze on bottom of W rods after final braze run on shaped C-Mod tiles.

We drew upon expertise in brazing in our Thin Film, Vacuum and Packaging Dept.

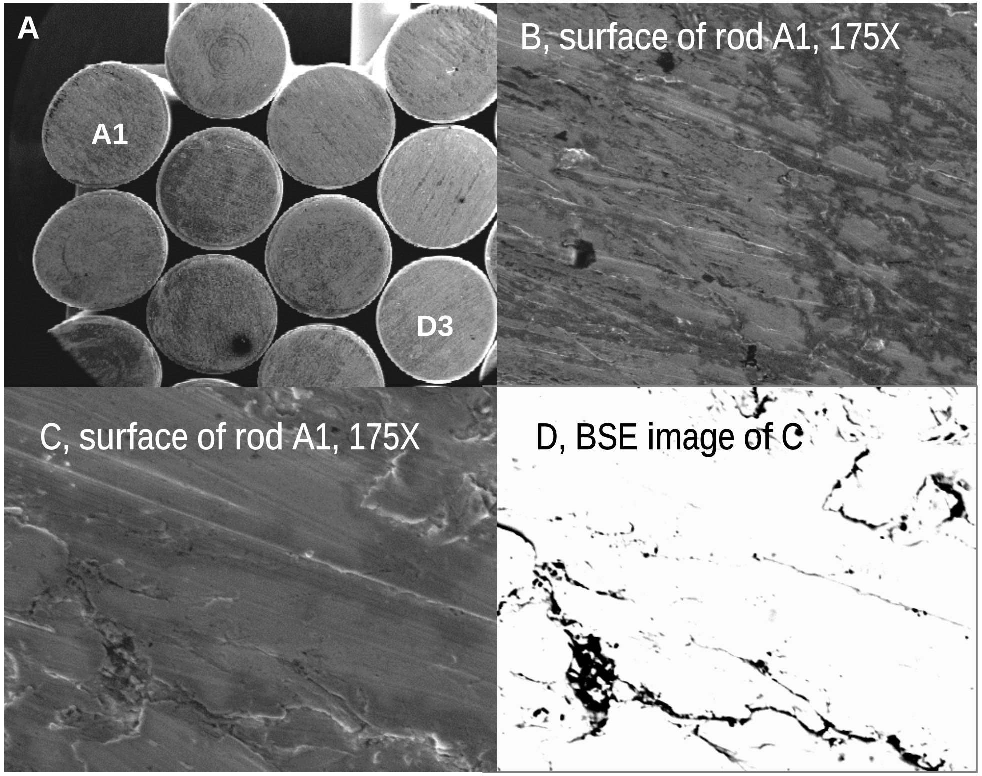
Key factors in reducing the braze flow from the base up the rods were:

(1) minimizing the amount of braze, and

(2) the time at temperature.

Post Test SEM Views of (brazed) Tile #2

- SEM views indicated only machining marks.
- No indications of deleterious effects from testing were seen, but heat flux was fairly low.
- Broken rods were found in an untested tile. The breaks were at the base of the rods or the "waist." We believe these rods broke during handling.



MIT: How much power can the tiles take?

- **HEAT:** We tested one brazed tile but limited heat flux due to braze on the rods.

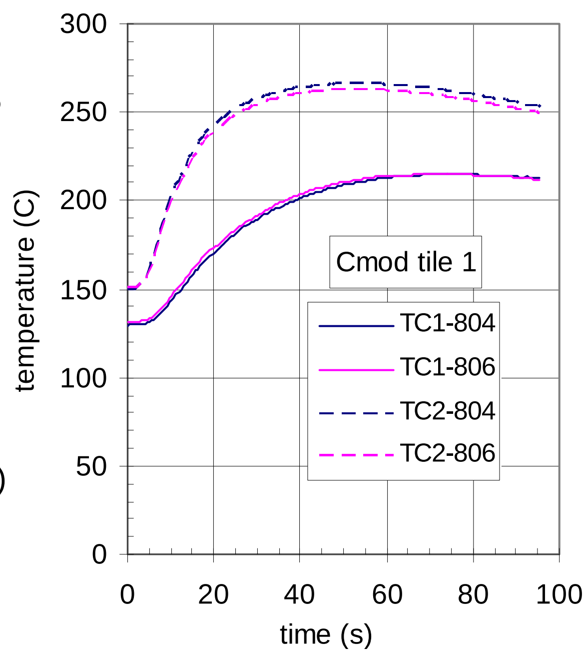
  ***q"**$_{abs}$ ~2MW/m^2 (based on 30% of beam power absorbed)*

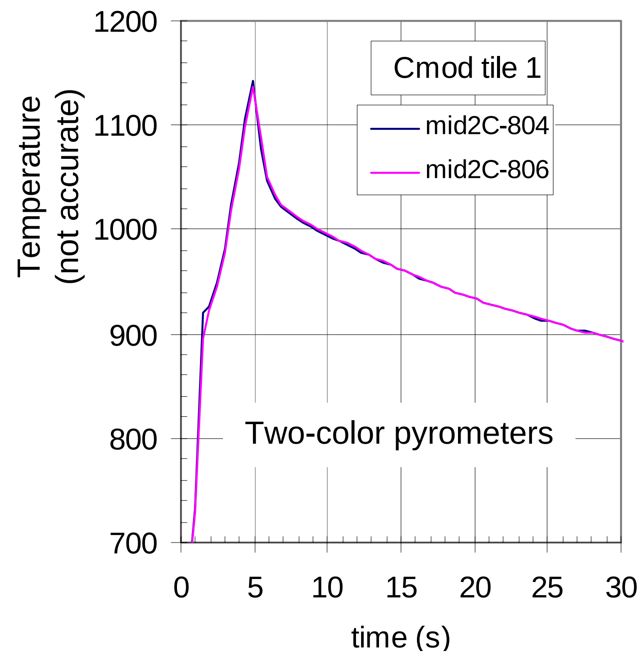
- **TEMPERATURE:** Measurements were severely limited by diagnostics.

  (1) contact resistance of spring loaded TCs, (2) pyrometer spot > rod dia.

E-beam shots
187804 & 187806
C-Mod tile #1

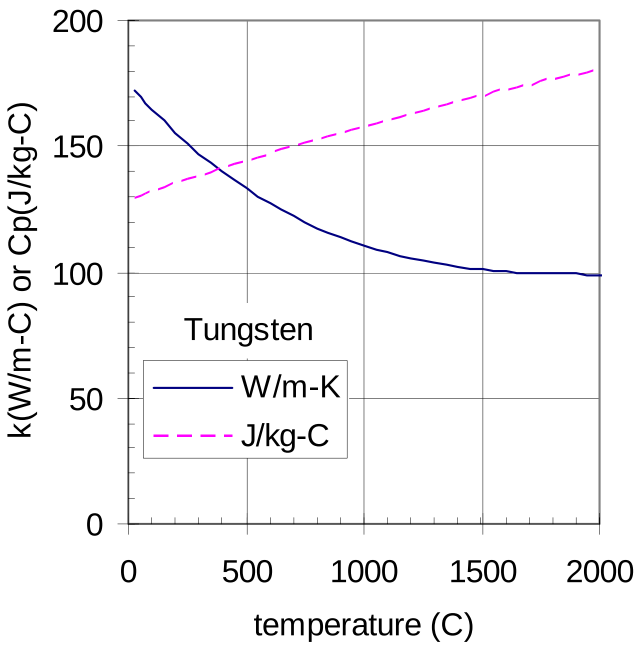
TC2 (bottom of rod)
TC1 (Inconel base)





Thermal Modeling

- Temperature dependent material properties are important in modeling fusion heat sinks.
- The thermal diffusivity of W changes by almost a factor of two from 25˚C to 2000˚C.

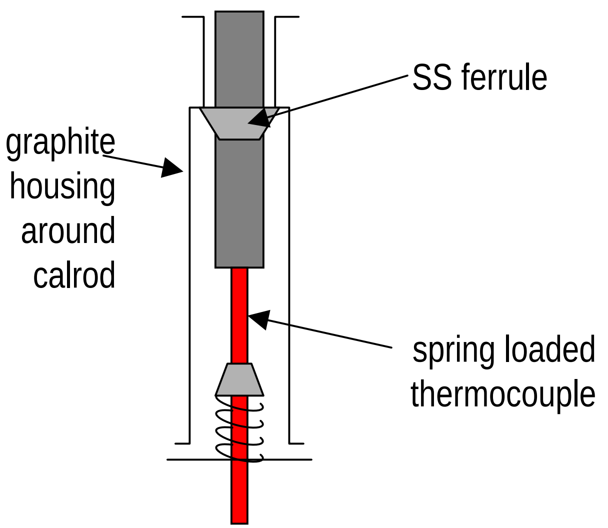


thermal conductivity (W/m-K) and heat capacity (J/kg-C) for tungsten

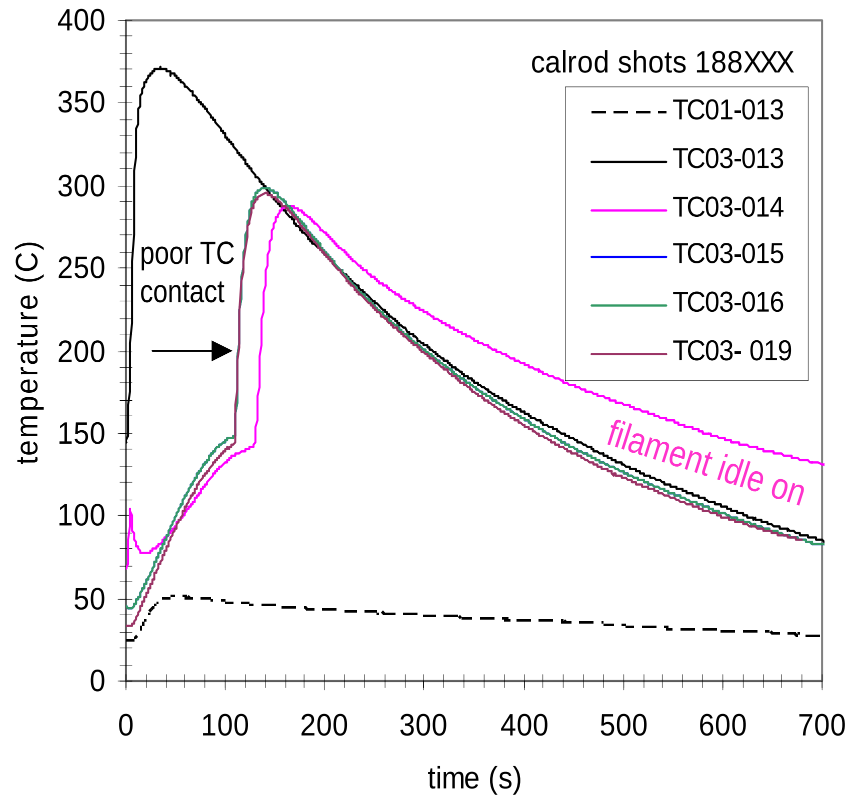
- We want to **correlate heat flux** with **surface temperature**.
- We want to find the fraction of beam power absorbed. $f_{abs} = \frac{q_{abs}}{q_{beam}}$
- For a given heat pulse, each value of assigned emissivity produces its respective cooling curve.
- We can match the thermal model to the cooling curve of a rod by setting the power and emissivity.

Calorimetry Rod Approach

- We tested a thermally isolated rod (CalRod) to compare with thermal models.
- The cooling curves in testing were consistent (with idle current off).



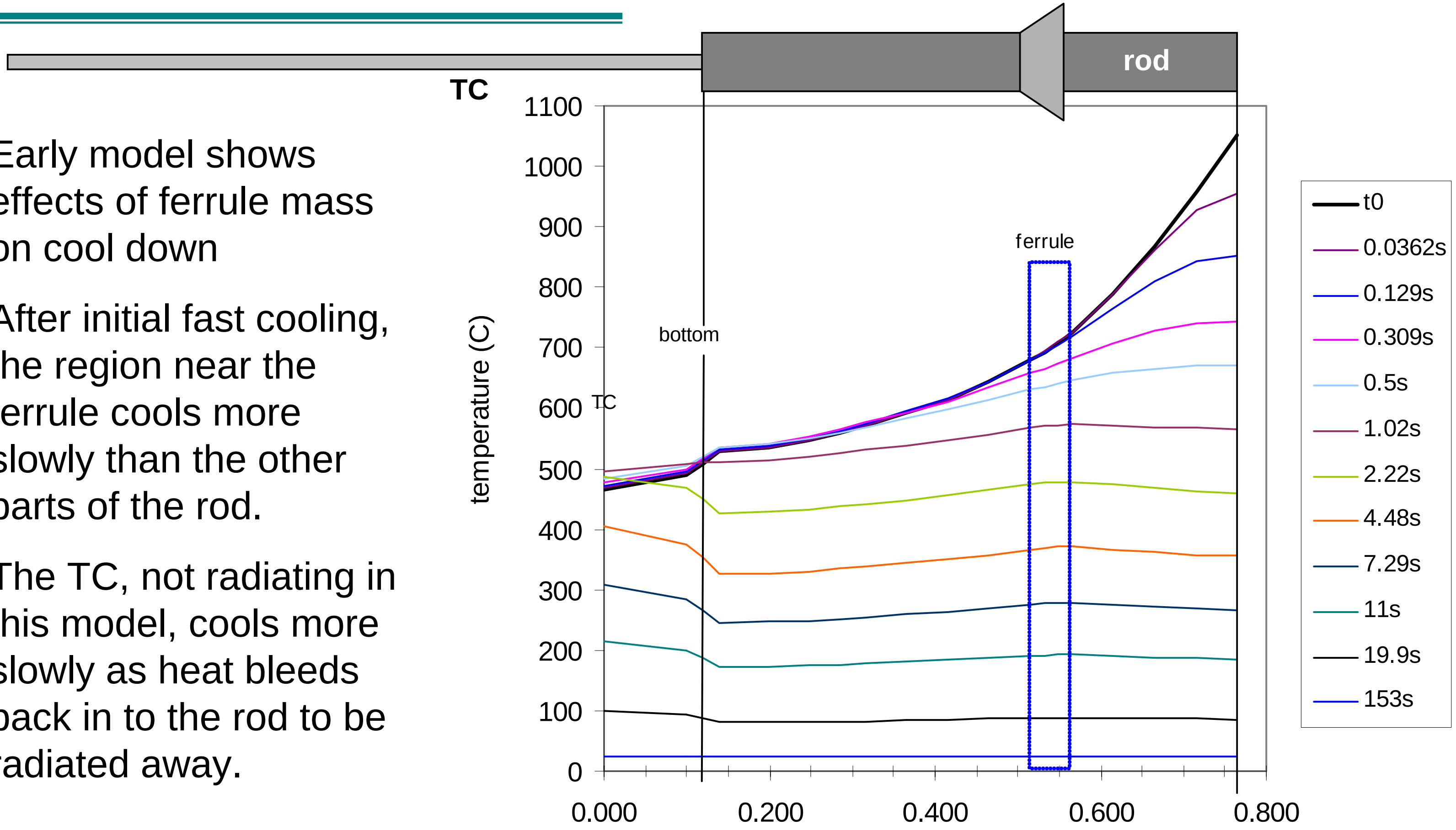
calorimetry rod arrangement



TC readings for 5s CalRod shots 188013-106 & 019
Leaving filament idle current on affected cool down.

Calorimetry Rod Modeling

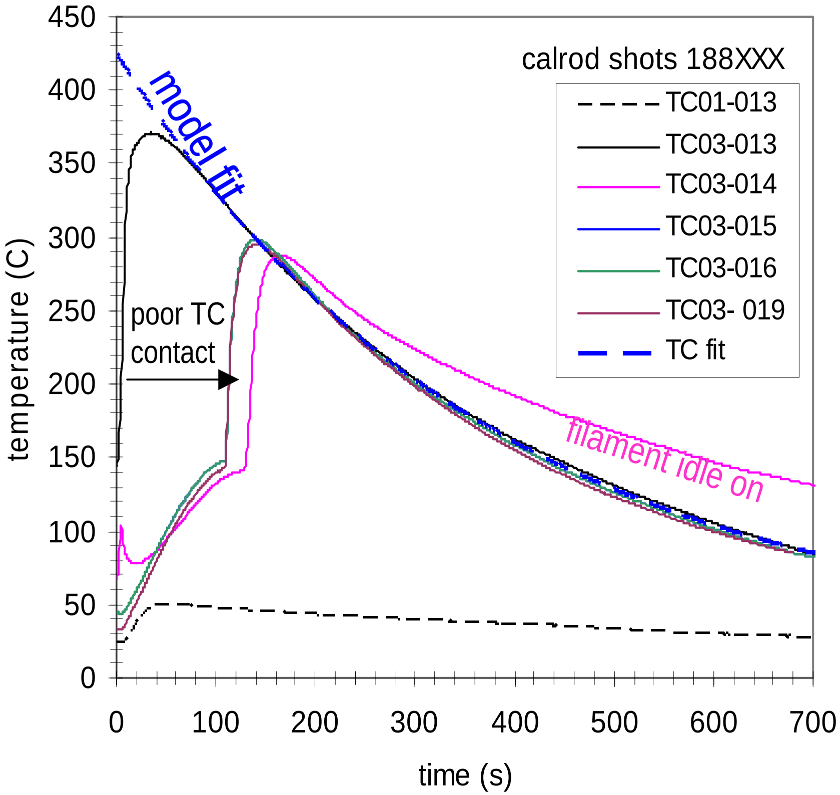
- Early model shows effects of ferrule mass on cool down
- After initial fast cooling, the region near the ferrule cools more slowly than the other parts of the rod.
- The TC, not radiating in this model, cools more slowly as heat bleeds back in to the rod to be radiated away.



CalRodA model, Cool down after 9s at $10 MW/m^2$

Calorimetry Rod Modeling

- Modeling to fit the cooling curves is relatively straightforward. However, it may not be sufficiently sensitive.
- Modeling and interpretation of the data continues at a slow pace.
- Using the slopes of the pyrometer curves at ~1, 20 and 100 s after the heat pulse may provide additional insight.



CalRod cooling curves

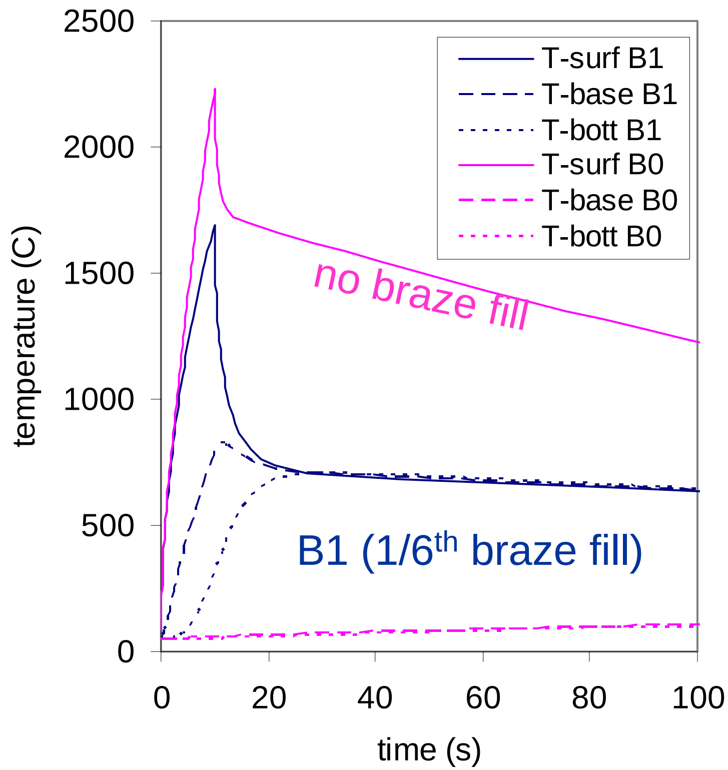
C-mod W Rod Tile Modeling

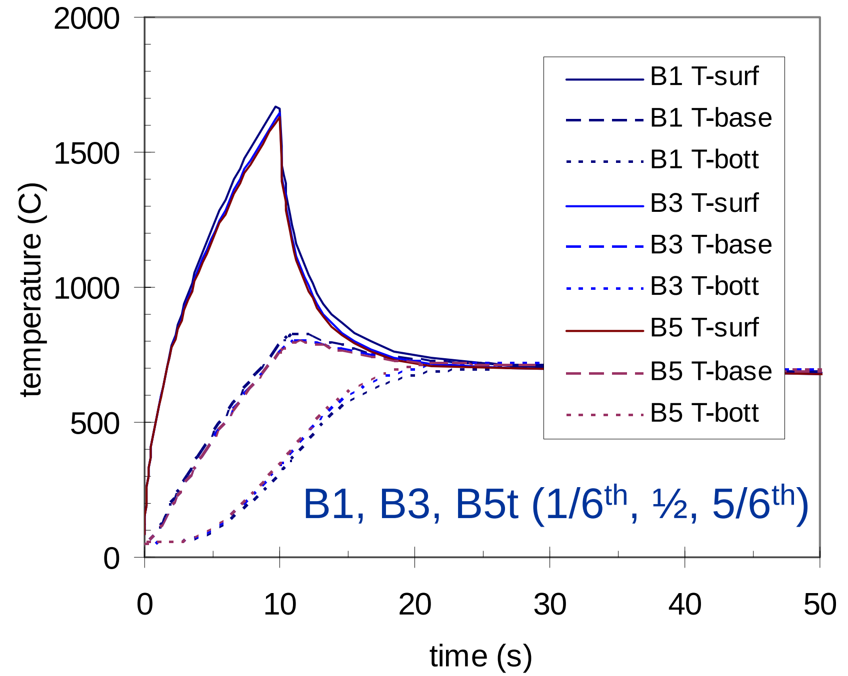
- We modeled the effect of the thermal resistance of the braze joint.

  A modest thermal contact is sufficient and there is little change after this.

- For this single rod model, with even a modest amount of braze fill,

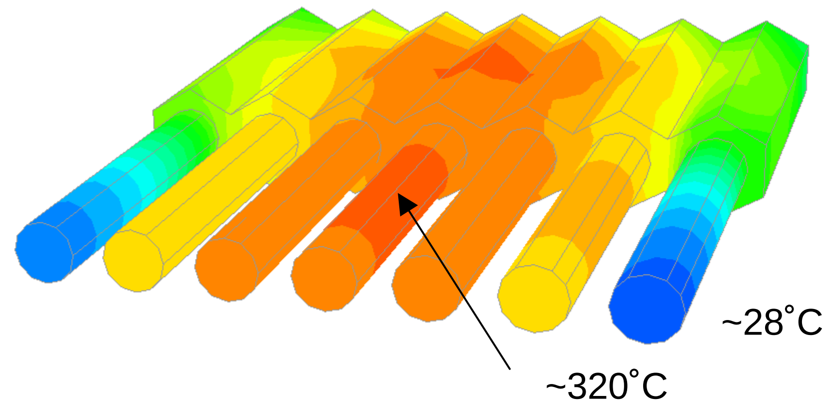
  at **10MW/m^2 for 10s, Tmax is >1700°C.**

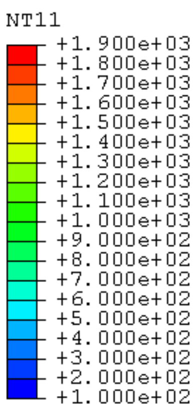




C-mod W Rod Tile Modeling

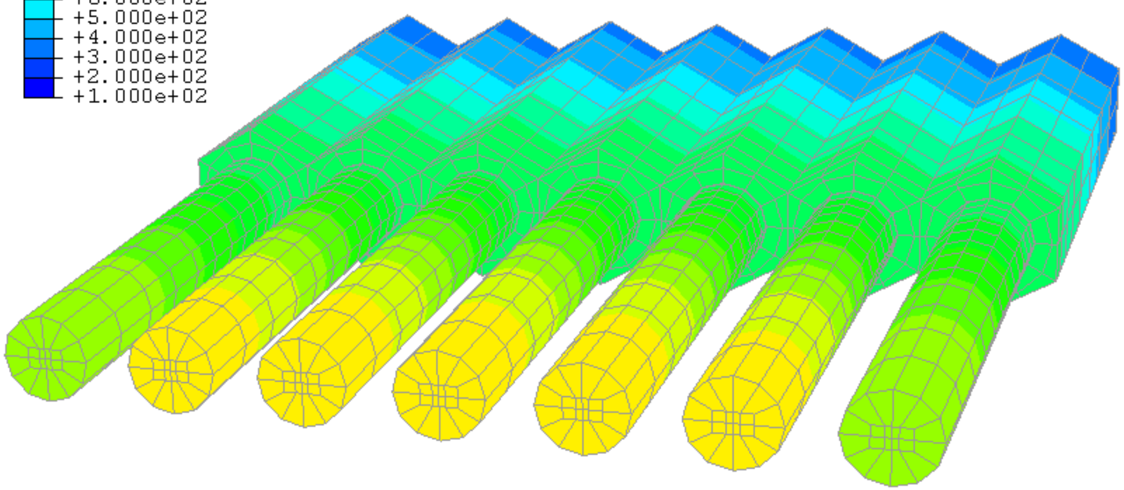
- In a 7 rod model with 10MW/m^2 for 10s and radiation from outside surfaces only, the outside rods cool faster.





After 0.5s of cooling, Tmax is ~1460 ˚C.

After 100s of cooling, Tmax is ~320 ˚C and outside rods are cold



Concluding Remarks

- The C-MOD tiles should withstand heat loads of **$10 MW/m^2$ for 10s** without melting, based on our thermal modeling.
- Long cooling times between shots may be needed for rods to cool to low temperatures (>100˚C); more thermal modeling is needed here.
- Sandia intends to continue its collaboration with MIT by
  1) conferring on the new tile design and testing of new tiles,
  2) participating in the experiments when C-MOD W rod tiles are exposed to high heat fluxes this fall, and
  3) assisting with interpretation of data from these experiments.

• *The JET Program is deploying W tiles as part of its support for ITER.*

• *Nygren will get more information in Garching during a visit in June.*