Sandia EB1200 Experiments:
ELM Simulations on W Rod Mockups & Thermal Modeling

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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.

Outline

I. Heat loads for ITER ELMs and capability of EB1200

II. Initial results from EB1200 experiments on a new W rod mockup made by Plasma Processes, Inc. (PPI)

III. Thermal modeling of ITER ELMs on W rod armor

Youchison presentation on W rod mockups

Mockup V2-02-15Q

Rods: lanthanated W 3.2mm dia.

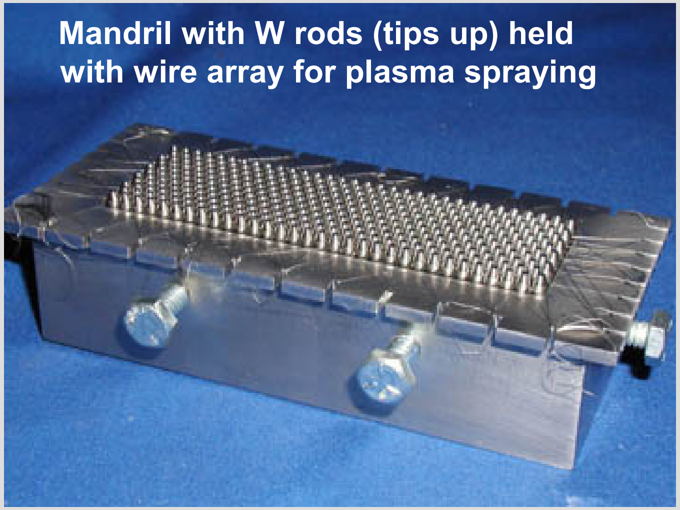
Rod Tip: ~2mm, 45° truncated, Ni coating

Bed: plasma sprayed CuCrNb (1mm)

Armor: 5 mm high, 32 x 95 mm

Heat Sink: CuCrZr, E-beam welding

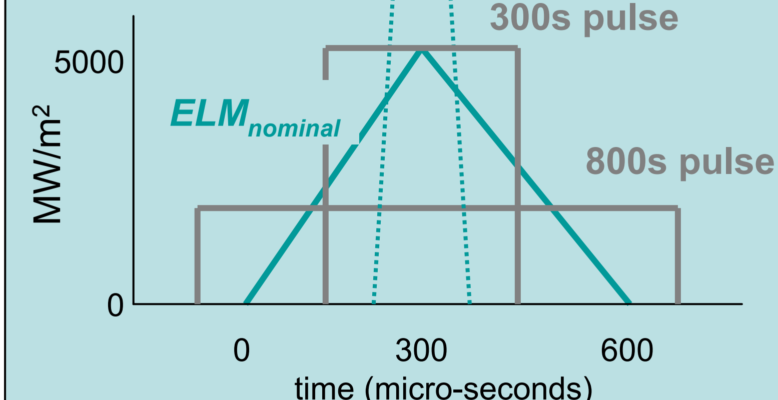
Cooling: 10 mm dia. channels (2), water cooling, twisted tape insert (tt=2)



ITER ELMs will loose 12 MJ of energy (12% $E_{pedestal}$) from the plasma in ~200 μs.

A. Loarte et al., "Predicted ELM Energy Loss and Power Loading in ITER-FEAT," IAEA Meeting

- The nominal "ITER ELM" has 300 μs rise time and 300 μs fall with a 5000 MW/m^2 peak for 8m^2.
- For q" = 5000 MW/m^2, tungsten initially at 1200°C reaches its melting temperature of 3377°C in **~50μs**.
- The integrated power density can be represented by square pulses:
  5000 MW/m^2 for 300 μs or
  1900 MW/m^2 for 800 μs.



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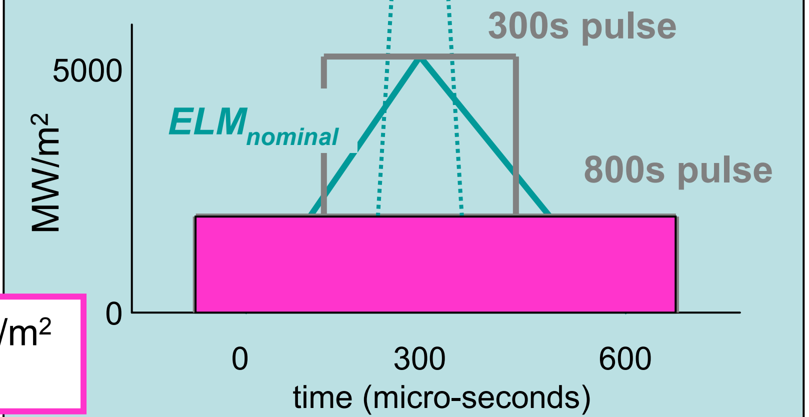
- Cases with deposition areas of 8 or 16m² and times of 100-300 μs were analyzed.
- Mitigation of ELM heat loads is an area of active study.

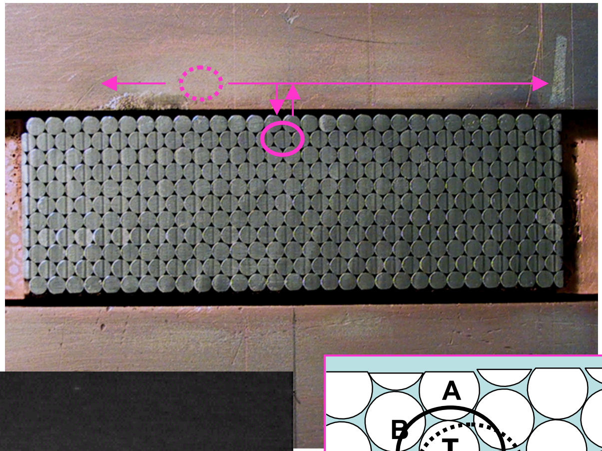


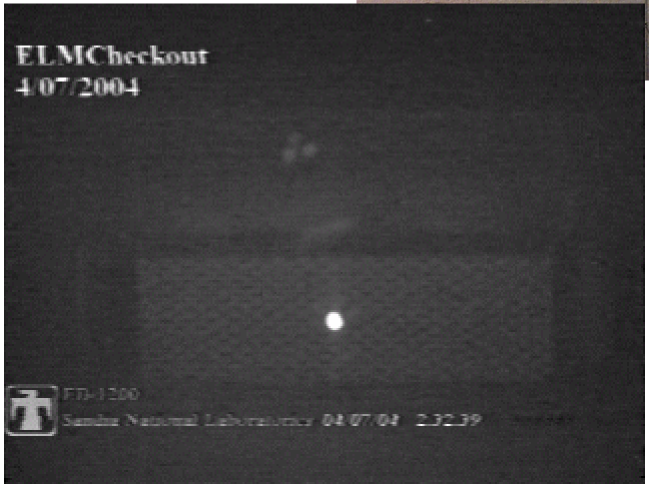
- Our tests investigate heat loads of 1000-2000 MW/m² and times of 300 and 800 μs.

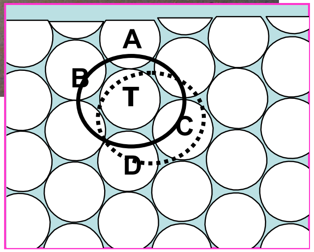
EB1200 can pause the beam spot for pulses of ~200μs.

EB1200:

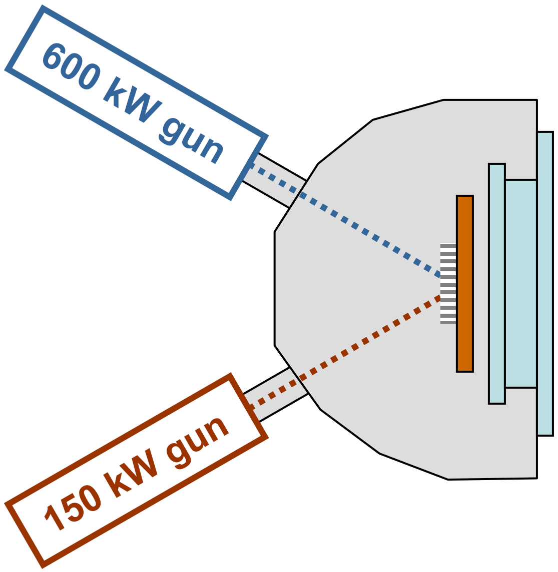
- Youchison's digital rastoring system maps the beam pattern in a series of discrete spots.
- Restoring frequency (coils) is 10kHz max. Minimum "spot" time is ~100 μs.
- A reasonable minimum is 200-300 μs when we move onto and off a target.
- We can tell if a spot is aligned on the target rod (**T**) by looking at the temperatures of the surrounding rods.







We will use a "two gun" approach.



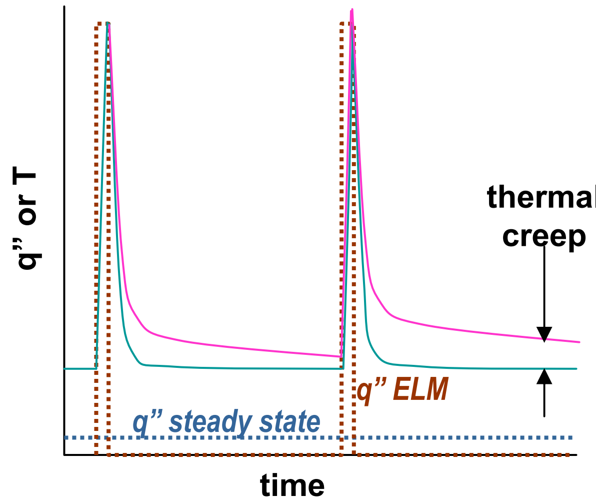
Procedure:

- Maintain a **steady surface temperature** on the mockup with the 600 kW gun.
- Move the defocused beam from the 150 kW gun* from a sweep pattern on the shield to a target W rod for a **300 or 800 μs "ELM"** and then back to the shield.
- Measure the temperature of a target W rod with a **fast IR pyrometer at 10μs frame**.
- Monitor the mockup with **pyrometers, TCs, IR camera, and water calorimetry**.
  (30 Hz IR frames can give some data on "tail.")
- Compare results with **thermal modeling**.

**With its smaller beam spot of ~2 mm diameter, the 150 kW gun can give a higher heat load on an individual rod than the 600 kW gun. With the spot is defocused to a 4 mm diameter, we expect a maximum $q''_{absorbed}$ of ~4.1 GW/m^2 with 60% reflected power and an incident angle of 60°.*

"Thermal creep" from repeated ELMs is a key factor.

- ITER's estimated ELM frequency is 2-5 Hz.
- Initially, thermal penetration is very shallow.
- An assumption that ELMs produce only a surface perturbation is dangerously wrong!
- We see a significant tail in the cooling curve in the modeling and experimental results.



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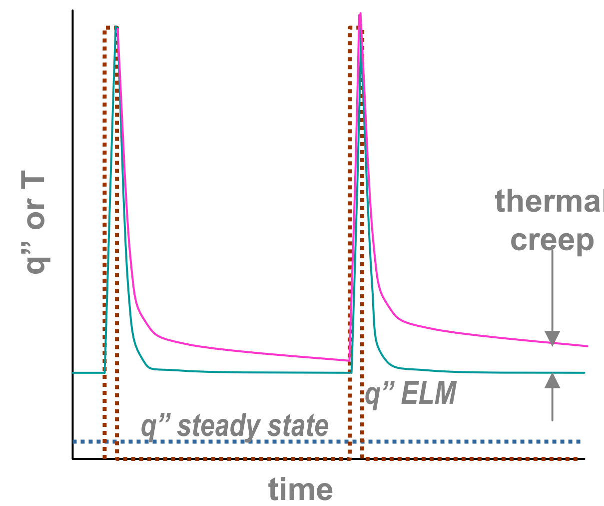
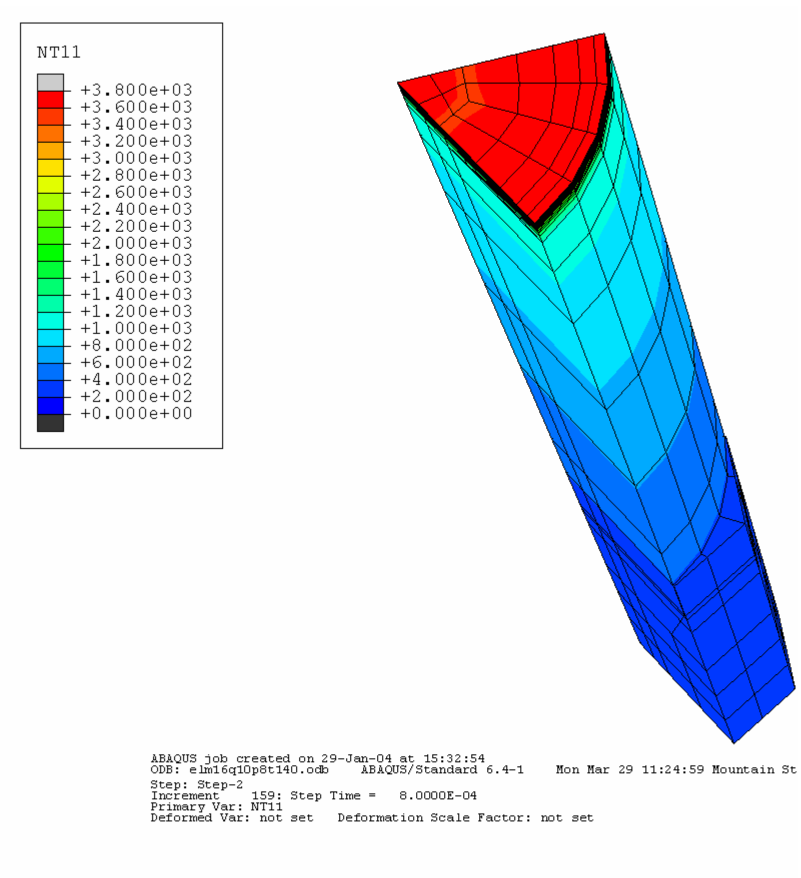


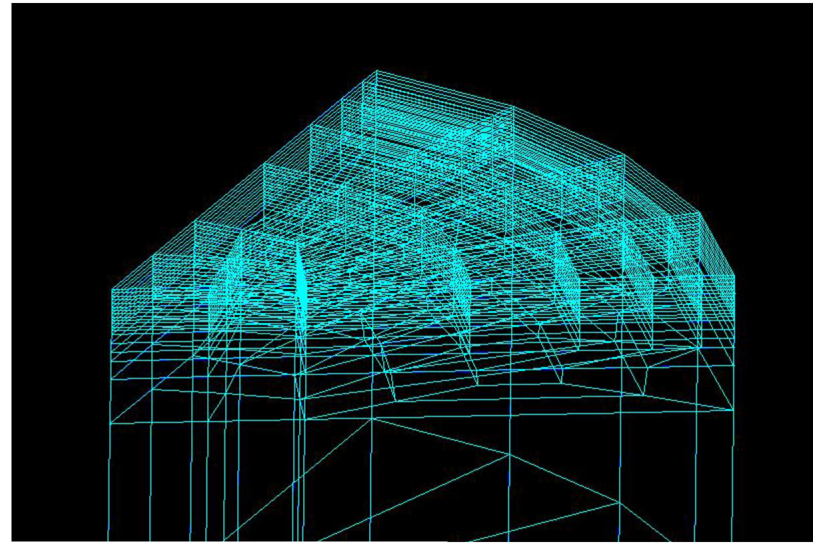
Major objectives include measuring the following:

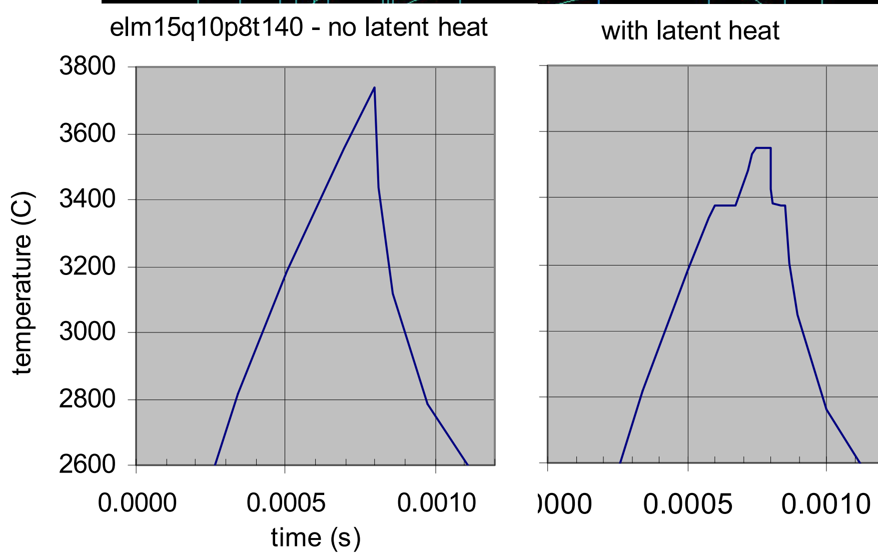
- **ELM power to initiate melting** (varies with the starting temperature)
- **$T_{surface}$ vs. time** (including "**thermal tail**") for various ELM heat loads.
- **Response to repeated ELMs** (thermal creep, i.e., increasing $T_{surface}$ with cycles.
- We just began testing (shakedown) with heat fluxes up to ~**14MW/m^2**.
- We have **no "ELM" data yet**.

Initial 3-D model too coarse.

This model is was modified from one used for steady state thermal analysis.

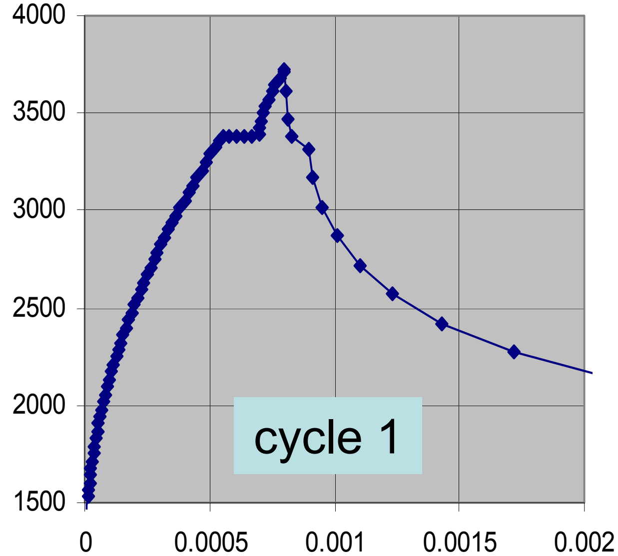


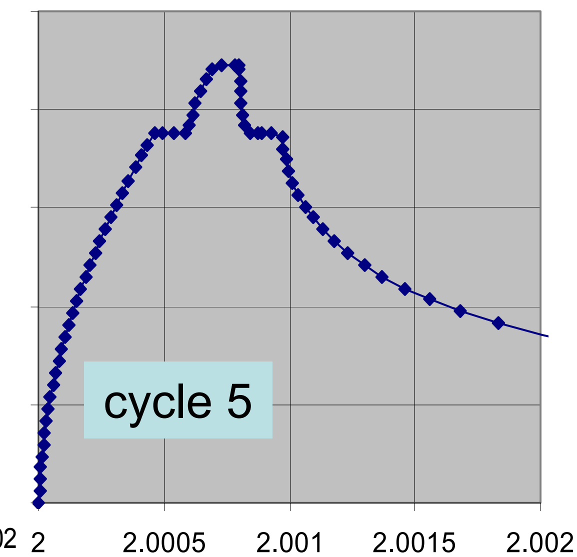




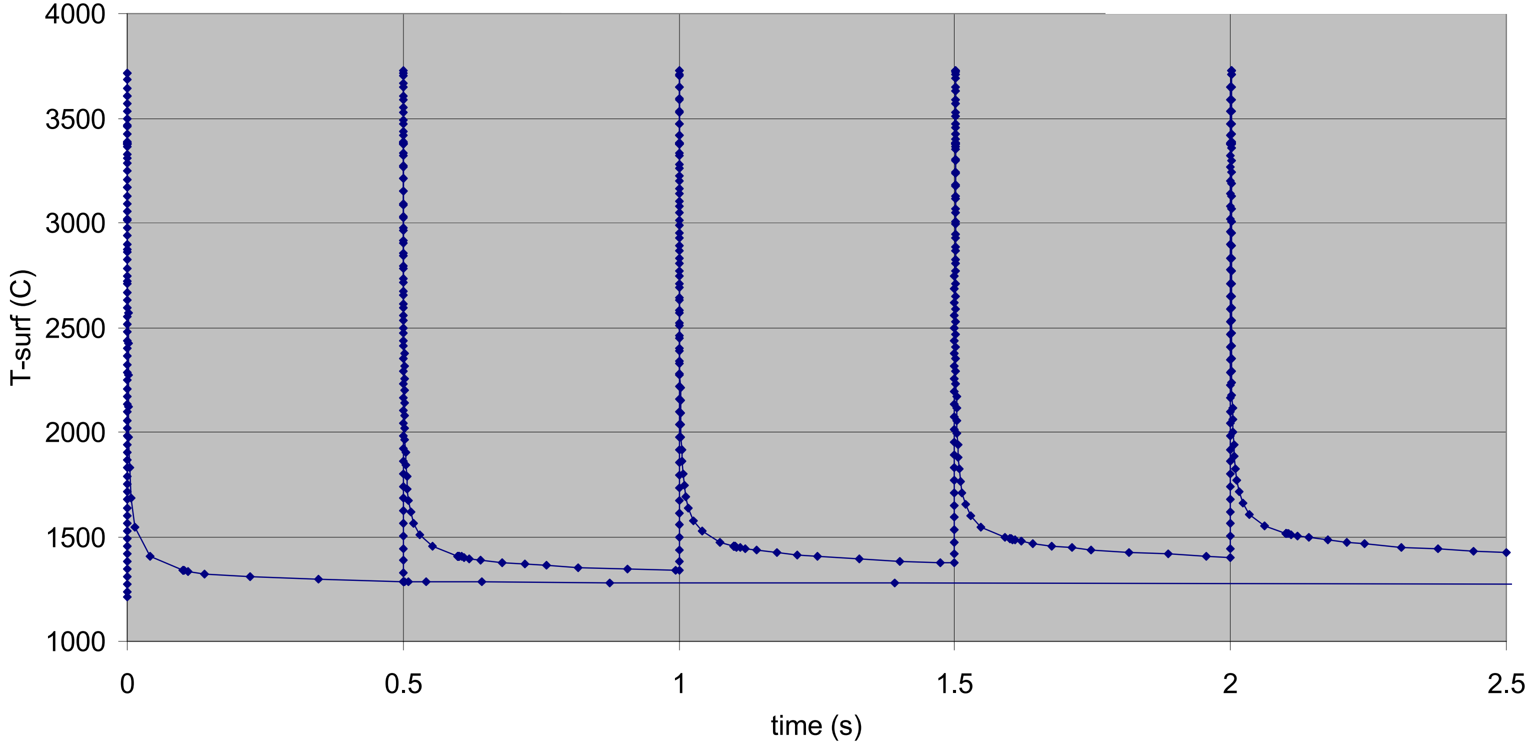
First 2-D model

- Still too coarse.
- But thermal creep is evident.





elm2D1500p8t100cool2Hz



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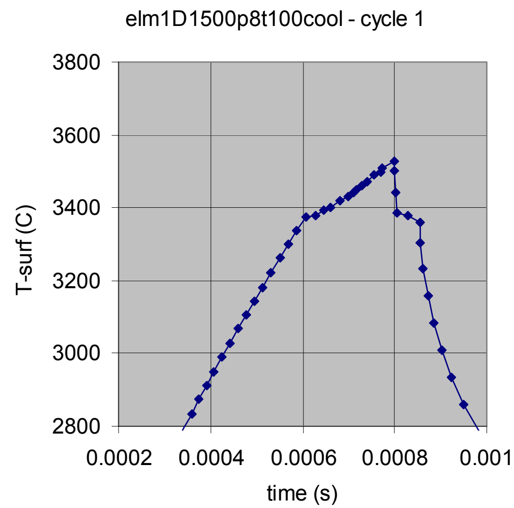
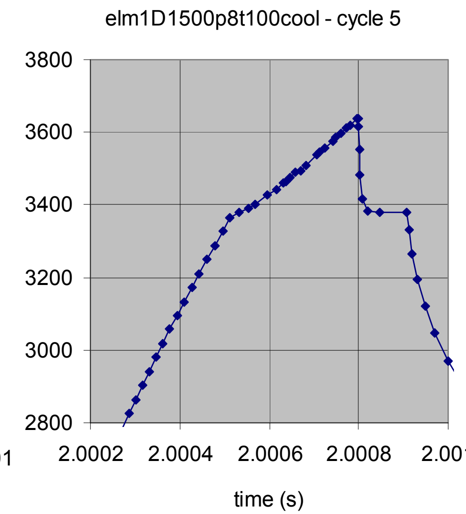
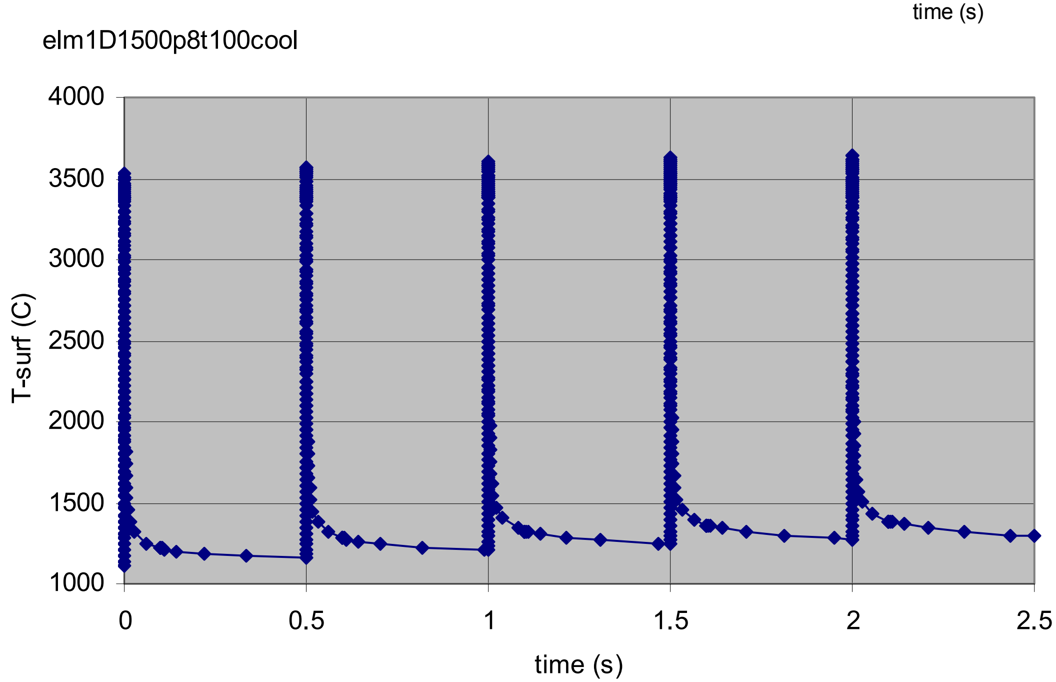
1+D model works.

- No apparent problem with discrete layers.
- Thermal creep is significant.
- Case: 1500MW/m^2 800μs 2Hz *(~1 of 10 points plotted)*







cycle	*Tpeak (C)*	*Tstart (C)*
1	**1161**	**1112**
2	**1210**	**1182**
3	**1246**	**1230**
4	**1274**	**1267**
5	**1295**	**1294**

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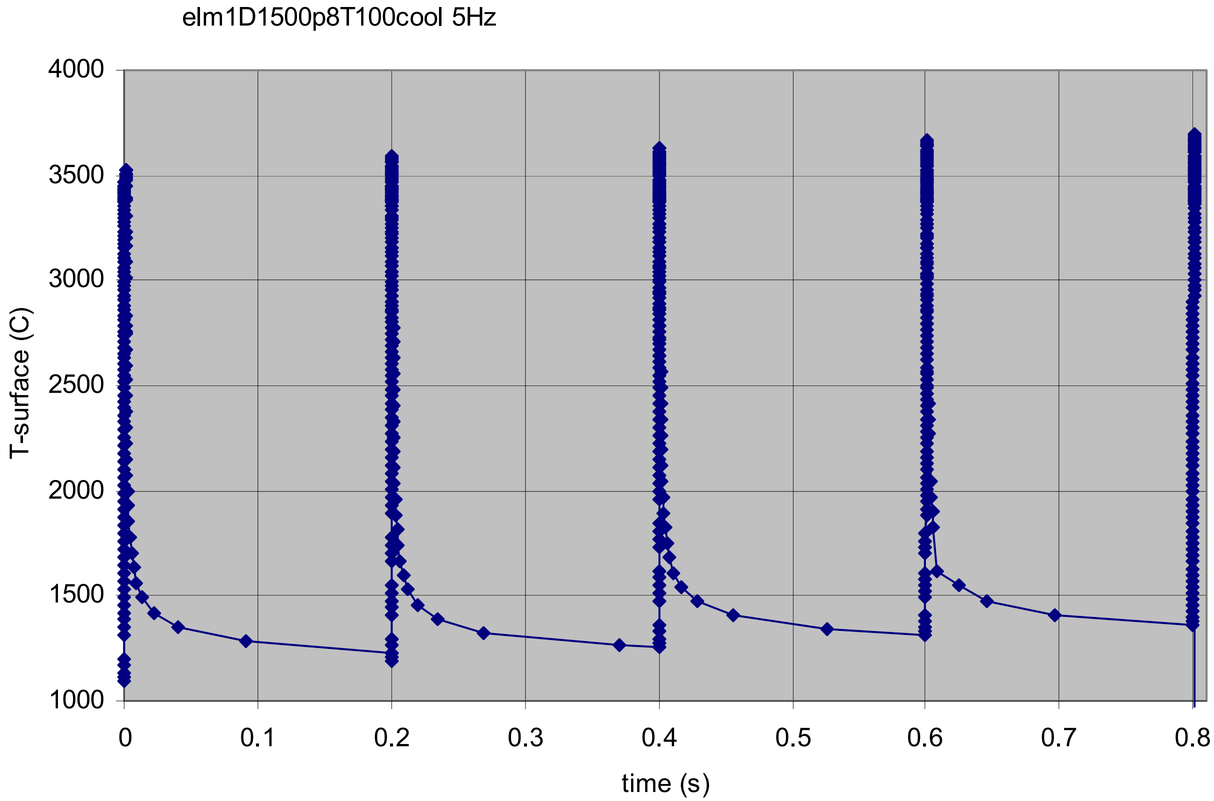
1^{+}D model case: 1500MW/m2 800μs 5Hz

- Thermal creep is greater (as expected) than for 2 Hz case.
- First pulse to pulse increase is ~95°C.
- This decreases to ~48 °C on 5th pulse.



cycle	*T-peak (C)*	*T-start (C)*
1	3528	1091
2	3588	1186
3	3632	1254
4	3664	1310
5	3695	1358

Summary

- Initial thermal analyses suggest that repeated ELMS will increase the surface temperature of PFC armor in ITER.
- We have demonstrated the capability of EB1200 to produce ELM-like heat loads on a target W rod in a W rod mockup.
- We anticipate having initial experimental data to include in our PSI paper on ELM testing.

"Simulation of ELMS in HHF Tests of W Rod Armor"
R.E. Nygren, D.L. Youchison, M.A. Ulrickson,
J.M. McDonald, and T.J. Lutz