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LLD Front-face temperature rise and the measurement of temperature dependent particle pumping

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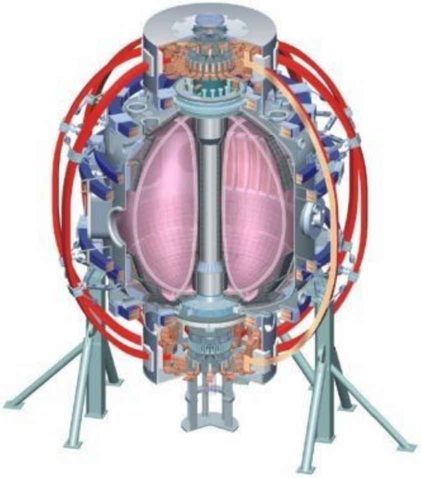
M.A. Jaworski, *et al.*

March 5th, 2010



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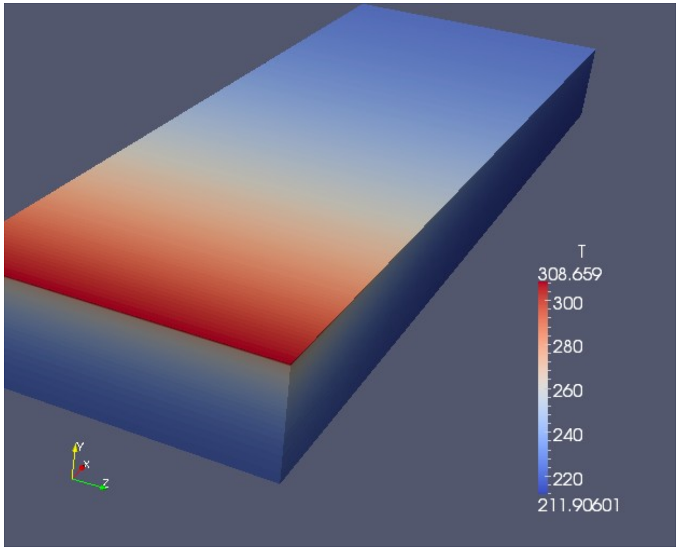
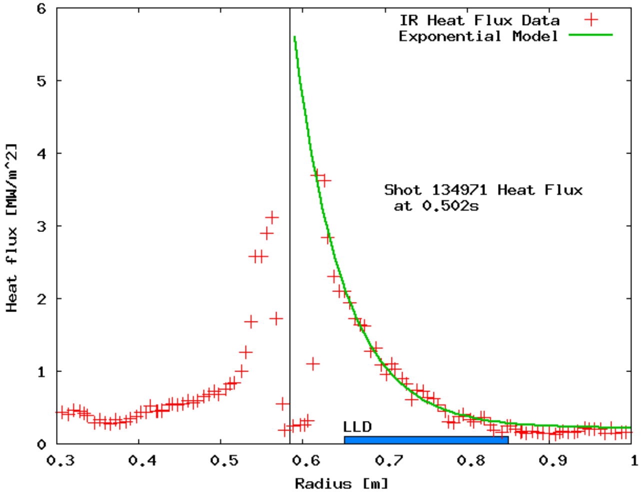
A tool for physics analysis

- Heat transport in solids is the state-of-the-art of the 19^{th} century (Fourier's been dead since 1830)
  - Thermal model of the LLD is not an end unto itself
  - Novelties involved in the present implementation is the inclusion of a porous material model for the Mo-Li system
  - Beyond this, thermal models are pretty "standard-fare" (provided you have someone to run it)
- Purpose of the model is twofold: physics and operations
  - Physics analysis tool for pulling apart temperature dependent processes in the PFC (e.g. sputtering, evaporation, desorption, chemical erosion, impurity gettering, retention, recycling), and building relationships with target plasma conditions (e.g. probe measurements of N_e, T_e, V_f, as well as other diagnostics and plasma models like OSM)
  - Operations support and future planning: provide information to those planning shots and determining maximum allowable machine powers while having a validated tool for future scoping studies (e.g. all metal inboard div.)

Working model for LLD temperature rise

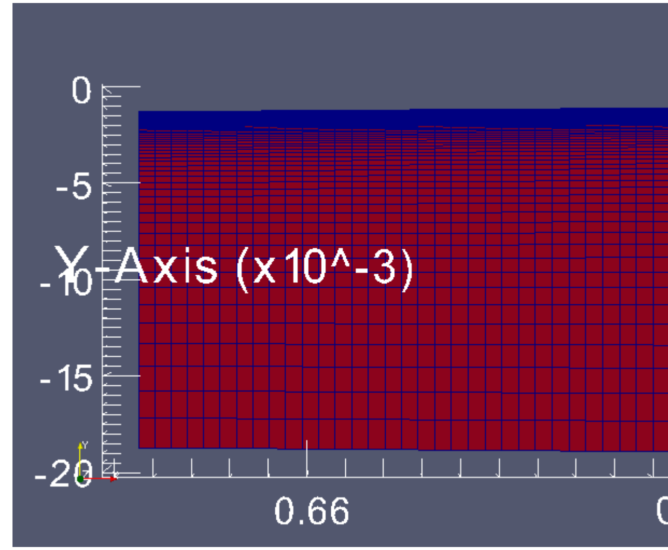
- Implemented model making estimates of temperature rise
  - Using OpenFOAM computational system to perform thermal analysis
  - Toroidal symmetry assumed (wedge modeled)
  - Using IR heat flux measurements for input (J. Kallman and R. Maingi)
  - LLD geometry and materials used (additional porous material model based on Jaworski **JNM** 2008)
- Conservative/Pessimistic boundary conditions
  - Constant heat flux for 1s pulse duration (have added time and shape "waveform" input)
  - No radiation or evaporative cooling (both negligible but have been added recently)
  - Insulated boundaries – how hot can it get?
- End result is upper-bound on temperature during heat pulse and evaporation

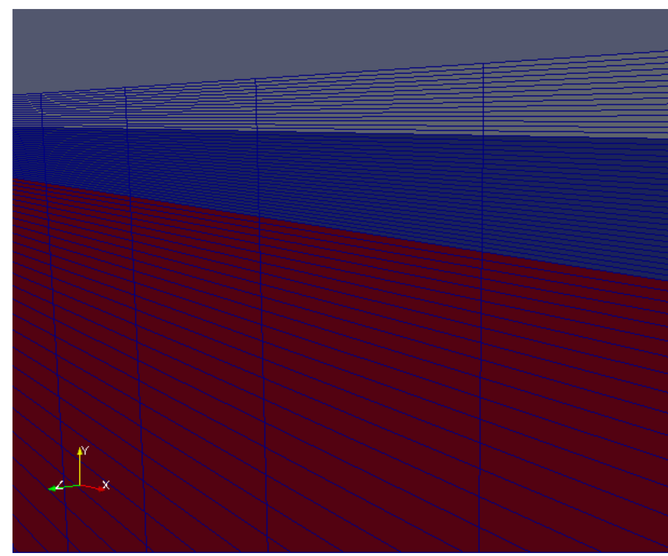




Mesh refinement balance between speed and accuracy

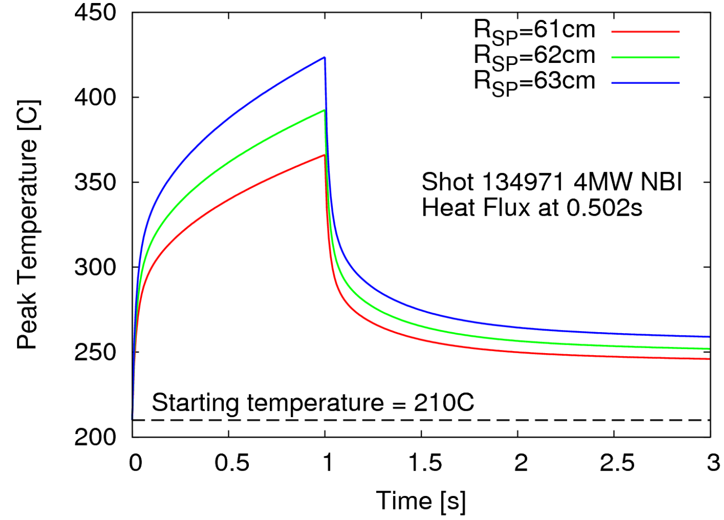
- Three materials modeled
  - Porous Mo/Li layer (0.153mm)
  - SS 316 (0.254mm)
  - Cu (20mm) (initial, have more accurate numbers now)
- LLD segment
  - Inner/Outer Radius = 0.65/0.85m
  - 5° arc segment
- Mesh refinement made for critical areas
  - 10 micron vertical elements in porous and SS layer (1mm elements in radial extent)
  - Graded mesh in Cu
  - Mesh refinement study indicates good accuracy (<2C changes) with this mesh

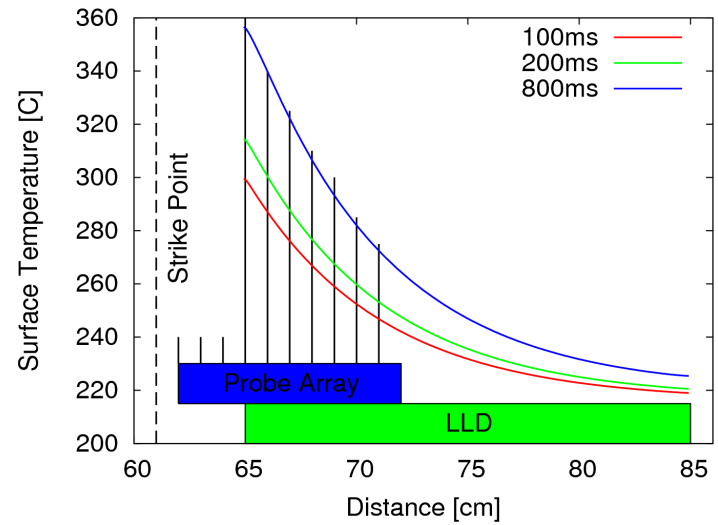




Strike point position significant

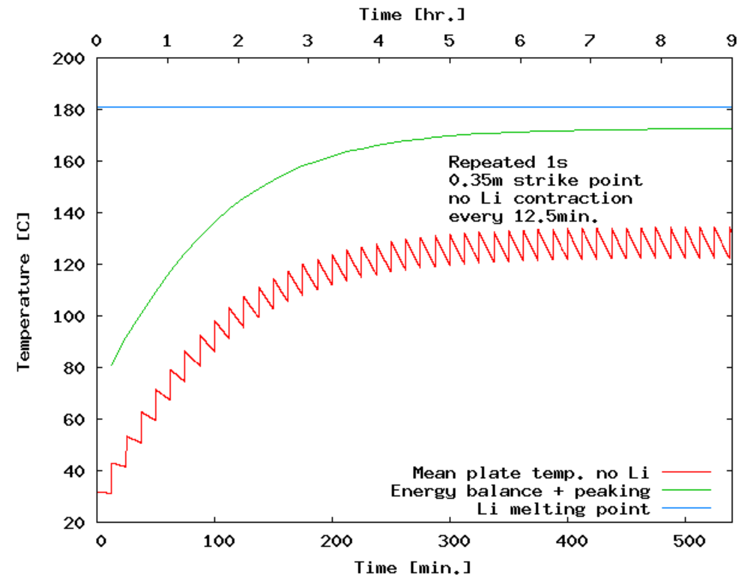
- Same heat flux profile – shifted by 2 cm
  - SOL heat flux gradient significant leading to sensitivity of position control
  - LLD bulk temperature rise could also provide calorimetry data immediately following a shot
- Temporal and spatial profile formed basis of puff-pump XP plan
  - Multiple puffs at different times during the shot
  - Multiple probes at different spatial locations
  - Dense data set of measurements at different temperatures

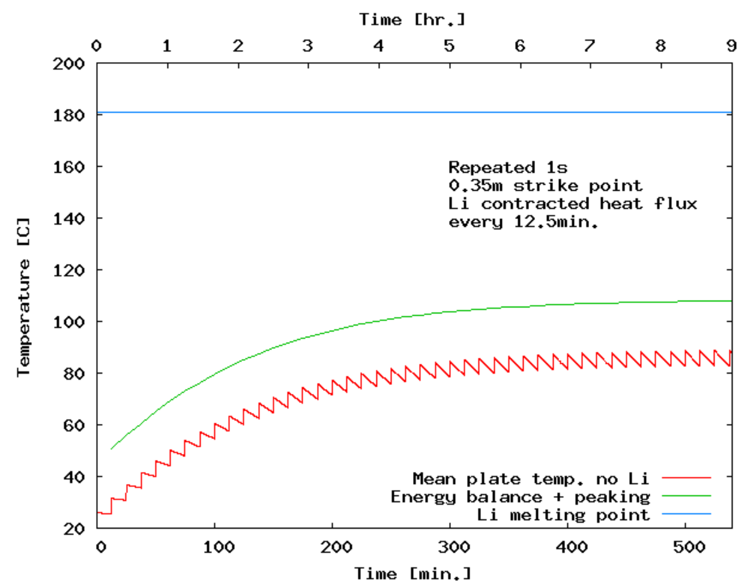




Possible use for *starting* temperature scan

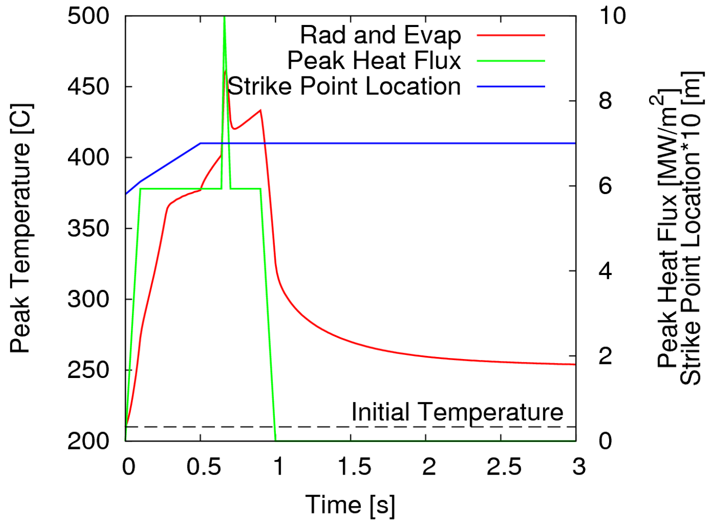
- Temperature of unheated plate will ratchet without cooling
  - Thermal calculations preliminary here
  - Unknown emissivity and effective radiating surface area (geometric and B.B. used here) relevant due to long time-scale
- Fiducial temperature profile used here
  - 1 MW/m2 inboard, 0.6 MW/m2 outboard without Li
  - Contraction to half this due to Li effect (both via. R. Maingi)
  - 12.5 minute shot cycle
  - Potential to transition unheated plate to liquid state within a shot
- More operational data needed and small experiments in C128 to make a better estimate

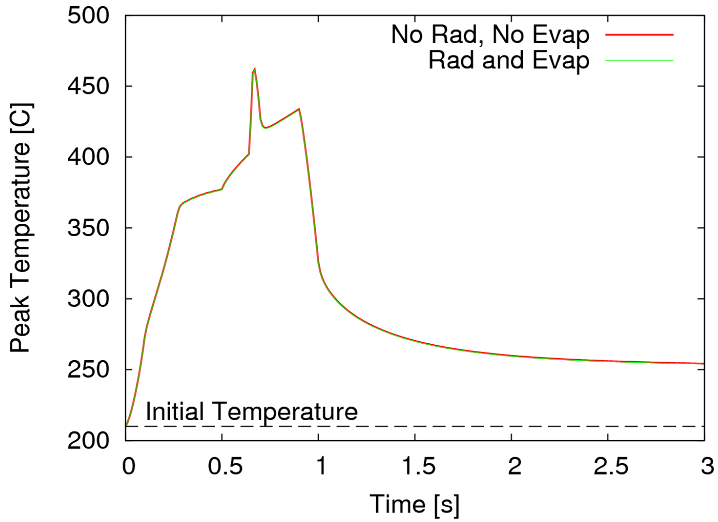




Recent model improvements

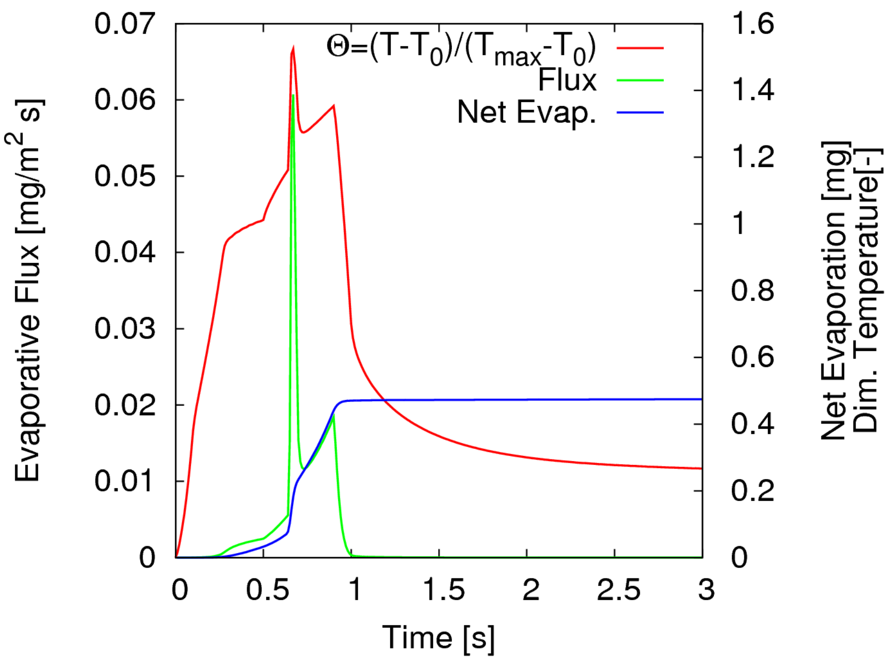
- Temperature dependent material properties
  - Data for Cu, Mo, SS316, Li all utilized
  - Brings peak temperatures downward (Cu thermal capacity rises with temperature)
- Input heat flux “waveforms”
  - “Toy model” result shown at right
  - Ramp-up, strike-point sweep, ELM, ramp-down
- Surface radiation and evaporation
  - Negligible effects from a heat transfer stand point
  - Radiation at 500C is ~0.02MW/m2 from a blackbody source, evaporation is even less
  - No coupling to plasma heat flux





What is the operating temperature limit?

- Thermal capacity of LLD prevents excessive evaporation as compared to LITER
  - Original 375C limit based on dual LITER evaporation rate of 100 mg/min
  - Toy model exceeds this limit by 50%, but the net evaporation is ~0.5mg
  - Total loss from LLD surfaces is complicated...
- What is the operating limit of the LLD?
  - LITER operation can easily cover the evaporative losses
  - Back-O-Envelope estimates of sputtered erosion is a far larger fraction of lost material (~19mg/sec), but still manageable



$$\Gamma^{core}_{ions} \approx 1e22 \text{ [part./s] (Brooks 2005)}$$

$$\Gamma_{sput.} \approx Y\Gamma^{core}_{ions} \approx \mathcal{O}(1) \times 1e22 \text{ [part./s]}$$

Everything lands on LLD assumption!

$$\dot{m} = \frac{\Gamma_{sput.} \times 6.941 \text{ [gm/mol]} \times 1000 \text{ [mg/gm]}}{6.022e23 \text{ [part./mol]}} \times (1/3) \text{ neut.} \times (1/2) \text{ redep.}$$

$$\dot{m} \approx 19 \text{ mg/s}$$

$$\Delta m_{LITER} = \frac{19 \text{ [mg]}}{0.07} \approx 270 \text{ [mg]}$$

$$\dot{m}_{LITER} = \frac{270 \text{ [mg]}}{10 \text{ [min]}} = 27 \text{ [mg/min]}$$

Methodology for pumping characterization

- All shots use intermediate triangularity with same fueling scenario developed in XP1000
- Start with cold LLD and fresh Li
  - Pulse with 3 gas puffs (1 shot + 2 development)
  - Obtains data for all 4 plates at the same temperature
- Pulse after thermal ratcheting with fresh Li
  - Set active plates to expected steady state ratcheting
  - Pulse with 3 gas puffs (1 shot)
  - Obtains pumping metric for expected operating temperature range of malfunctioning LLD plate
- Cold LLD without LITER
  - Pulse with gas puffs and look for Li saturation on cold LLD (~5 shots ?)
- Warm LLD operation with fresh Li
  - Operate other three plates at “warm” setpoint
  - Pulse with 3 gas puffs (1 shot)
  - Obtains pumping metric for higher temperatures and possibly account for 4th plate
- Warm LLD without LITER
  - Repeat shots with gas puffs (~5 shots?)
  - Look for saturation of ATJ surfaces and measure change in pumping metric
  - Compare with Cold LLD shots on previous day
- 15 total shots (uncertainty here)
- Post-calculate temperature for all cases
  - Treat LLD as calorimeter
  - Cross-check heat fluxes

Many unknowns at this point

- Several diagnostics brand new this campaign
  - Langmuir probe array
  - 2-color IR
  - LLD
- A lot of data is already expected to be generated in several XPs
  - XP 1000 – Kugel characterization campaign
  - XP 1001 – Vlad and group pumping XP
  - R. Maingi – Edge and pedestal studies
  - and more...
- Reassess the need for dedicated machine time after gathering more data (e.g. mid-run review)