

Thermal Control of the Liquid Lithium Divertor for NSTX

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See also “Physics Design Requirements for the National Spherical Torus Experiment Liquid Lithium Divertor.”

A fundamental issue in operating the LLD (Liquid Li Divertor) with the strike point on or near the LLD is to maximize the shot time while avoiding excessive evaporation of Li.

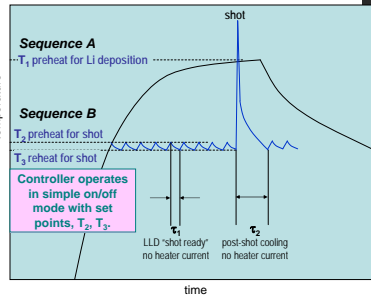
LAYOUT OF THE LLD

- 4 plates (quadrants)
- 22.2-mm Cu plate
- clad with 0.4 mm of SS
- flame-sprayed Mo surface
- inner radius 655 mm
- 215 mm wide
- incline 21.5°, 82.5° toroidal angle
- brazed SS He cooling tube
- center support stalk
- 12 500W heaters with TCs
- 12 control TCs near heaters
- 4 other TCs

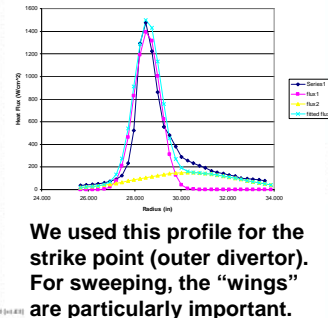
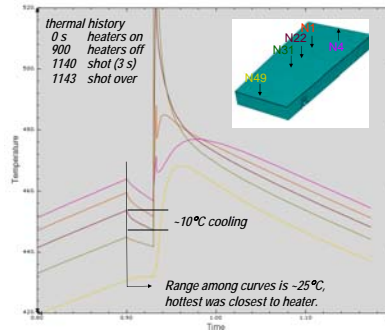
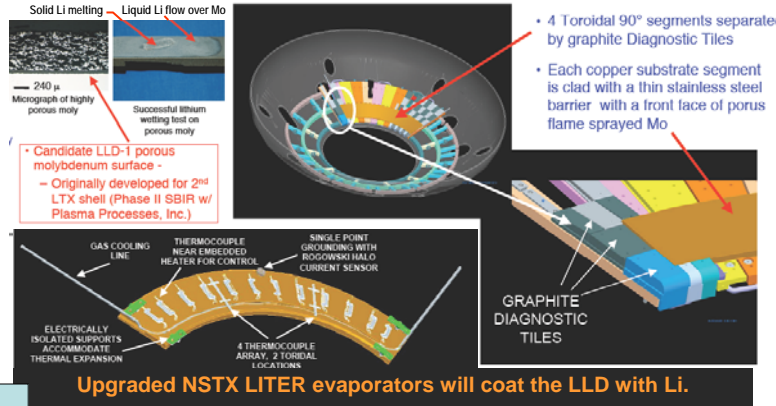
THERMAL CONTROL

Radiation and He flow cools the LLD. During a shot, the plasma heats the LLD. Before a shot, the heater control system puts the LLD into a holding pattern between two trip points, much like a household thermostat. Switching occurs at zero voltage.

SHOT: The sequence begins with a signal that the neutral beams are ready ~2 minutes before the shot. LLD heaters are shut off before magnets energize to avoid JxB forces on the heaters and cables. The upper set point (T_2 , right) is fixed so that the liquid Li remains above its melting temperature (181°C) in the interim after the heaters turn off and before the shot starts.

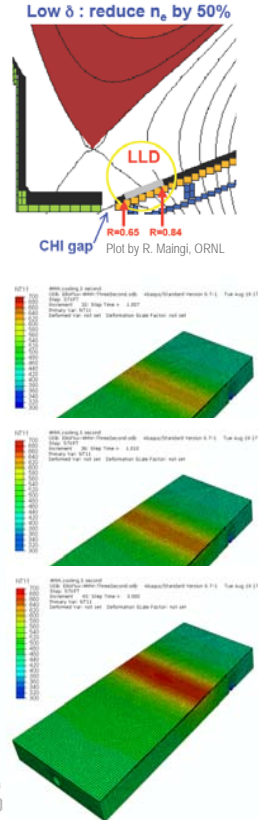
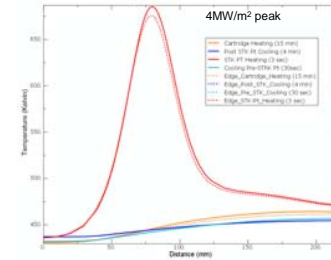


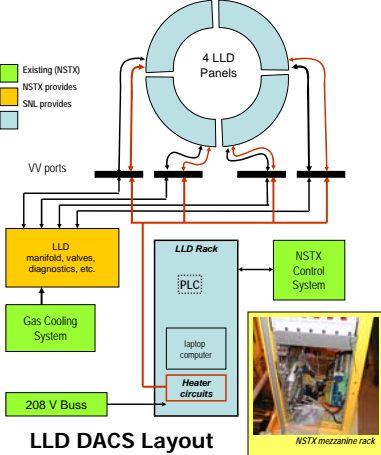
In plot at right, LLD spot cools ~10°C in 4 minute cooling step before shot.



BASIS FOR SHOT LENGTH

- 1) experience with the LLD, and
- 2) thermal analyses for various heat flux profiles.





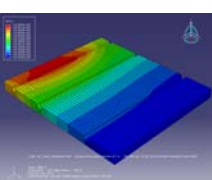
- power conditioning and isolation switches on two hot 208 V lines
- controller and switches for 48 heaters
- data acquisition modules for 112 TCs
- PLC and laptop computer for local control and data management
- flow control switches and pressure monitoring for He cooling lines (4).

FUTURE WORK

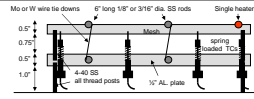
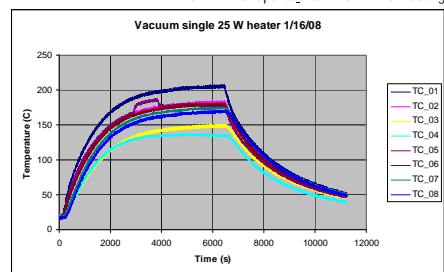
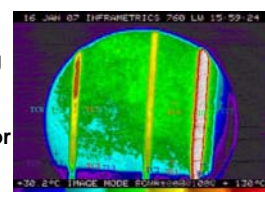
Sandia will procure the LLD plates and prepare the control rack this fall. We will work with the NSTX team to install equipment during the NSTX vent.



INITIAL TESTS ON Mo MESH



Sandia is studying a CVD Mo-coated pyrolyzed C mesh as a Li reservoir for an upgraded LLD.



INITIAL TESTS ON Mo MESH

FUTURE WORK

Sandia will perform some testing of mockups with a He heat transfer system for heating and cooling of a LLD for a future application such as an upgraded LLD for NSTX and for the proposed NHTX.

We tested refractory He-cooled heat sinks built by Ultramet with an integrally bonded internal open porous mesh that very effectively enhances heat transfer.

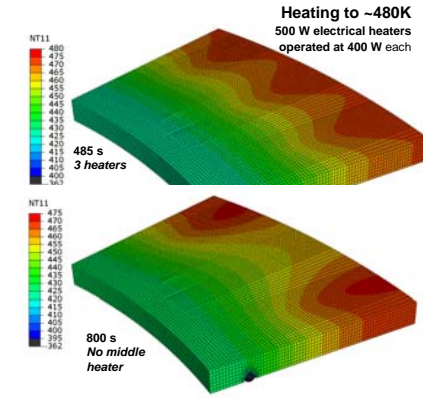
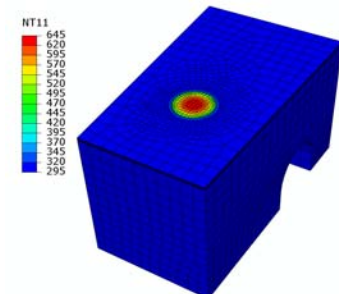
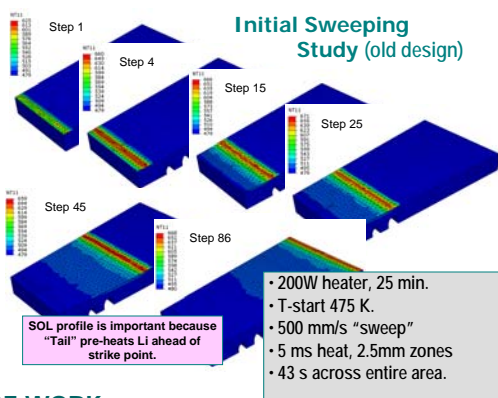
We initially proposed a design for the LLD based on a porous Mo mesh with the added specification that the Mo be deposited over a pyrolyzed carbon skeleton. The objective was to improve the thermal conductance of the mesh material by using high conductivity carbon with a coating of Mo. The mesh also provides a reservoir of Li that would move to the surface by capillary action.

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THERMAL ANALYSES

- stationary on LLD
 - swept across LLD
 - inboard of LLD - pumps the outer SOL*
 - outboard of LLD - pumps private flux region*
- * longer shot times with strike point off the LLD



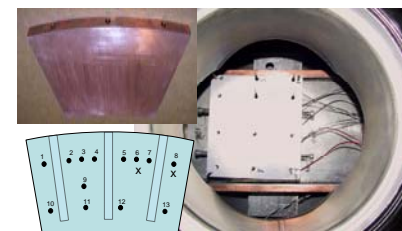
- 0.5 MW/m² top surface
- Spot dia. 6.35 mm (.25")
- Time step 1 s

Other Cases

- startup with a frozen limiter
- failed heater(s)
- braze flaws (SS/Cu)
- alignment hot spots

Cold spots (solid Li) reduce pumping but are not a problem otherwise.

Flaw analysis guide both quality assurance during fabrication and the effects of flaws in operation.



BENCHMARK HEATING TESTS

Benchmark heating tests of a Cu plate mockup with 3 heaters is providing baseline data for our thermal modeling, as well as the load for our shakedown testing of the control rack. The model results shows cases of the mockup with one heater off and with all 3 heaters working.

