SAND2007-4052P

Presentations by RE Nygren at PFC Meeting 4-6 June 2007

A. Notes on Heat Transfer in (1) ITER Divertor, (2) NSTX LLD
B. Status of EB60 and EB1200
C. Participant in WG8 - Comments ITER Design Review
D. NSTX Liquid Lithium Divertor - Sandia & UCSD Effort

Notes on Heat Transfer in
(1) ITER Divertor, (2) NSTX LLD

presentation at the

PFC Meeting

June 4-6, 2007 at Argonne National Laboratory

Richard E. Nygren

Manager Fusion Technology, Sandia Dept. 01658

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

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Outline

just "notes" - not comprehensive

ITER div.

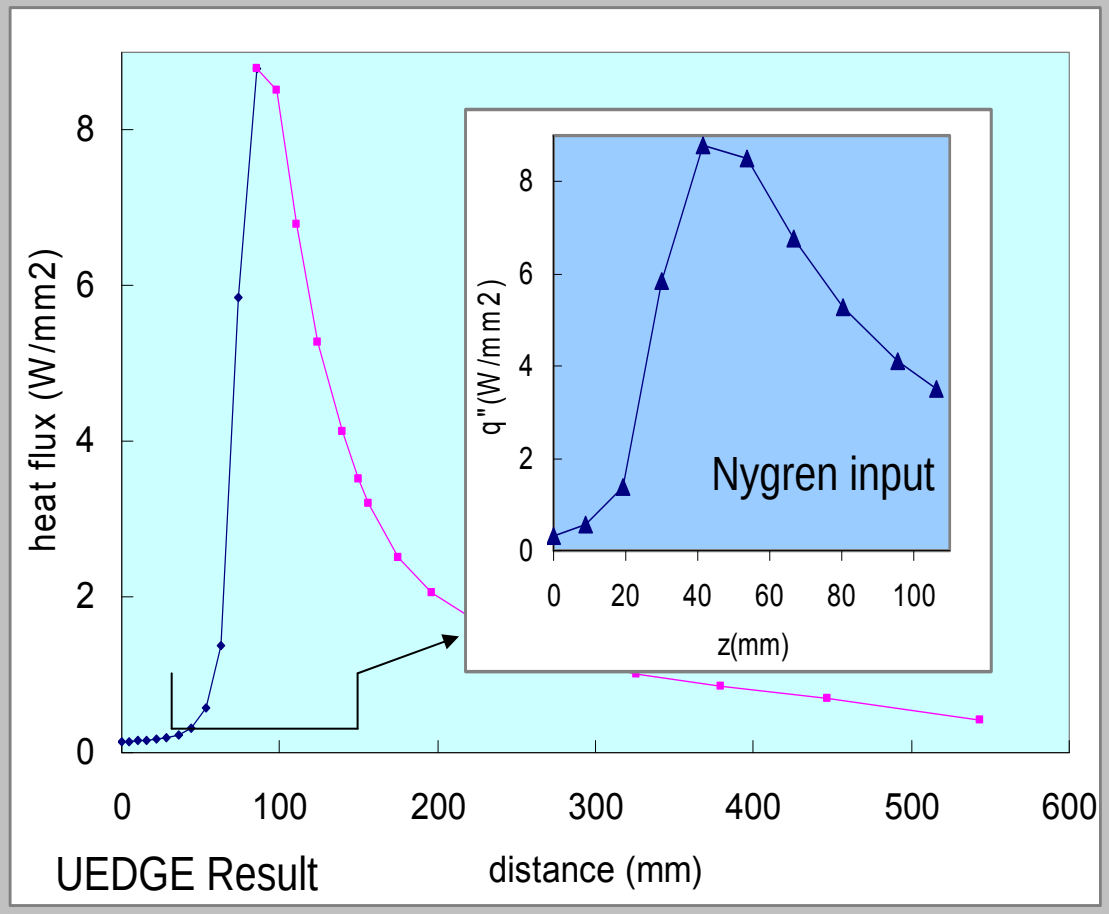
- Heat load profile from Roglien
- Input for edge/PMI models by Brooks and by Allain
- Brief remarks here on basis of model

  [and my thanks for their patience]

NSTX

- Presentation in NSTX session
- Notes here on some heat transfer details and ideas

ITER divertor – UEDGE Heat Load Profile



- **Heat to surface is piece-wise curve from UEDGE for ITER divertor.**
- **Distance is along surface parallel to length direction of div. “fingers”**
- **0 is redefined to be at end of model.**
- **Lateral (toroidal) distribution is uniform.**

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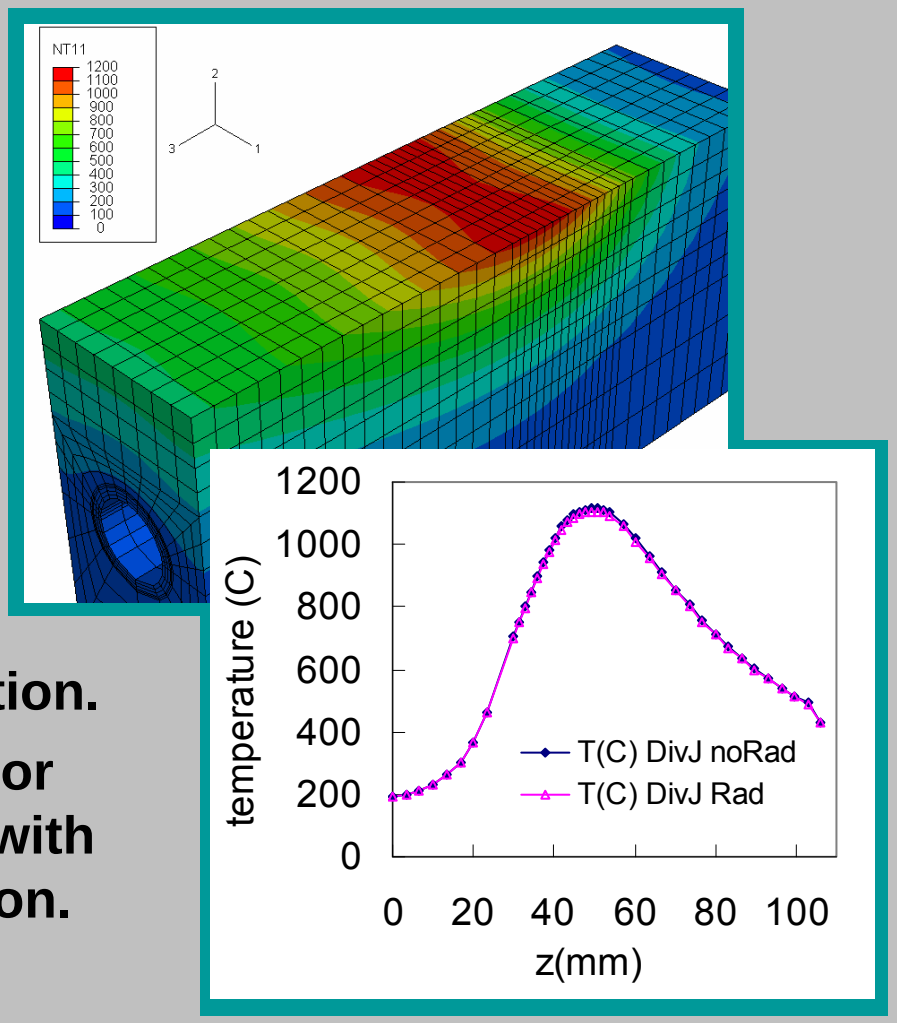
ITER divertor – CUBIT/ABAQUS model

- **Materials' properties are temperature-dependent.**
- **HTC from FILM** (T. Marshall)**, 3.8**MPa**, 112**^{o}C**, 10**m/s**, 2** Y_{twist}



- **Little effect of loss from radiation.**
- **Direct comparison to W divertor would require another model with differing heat sink configuration.**

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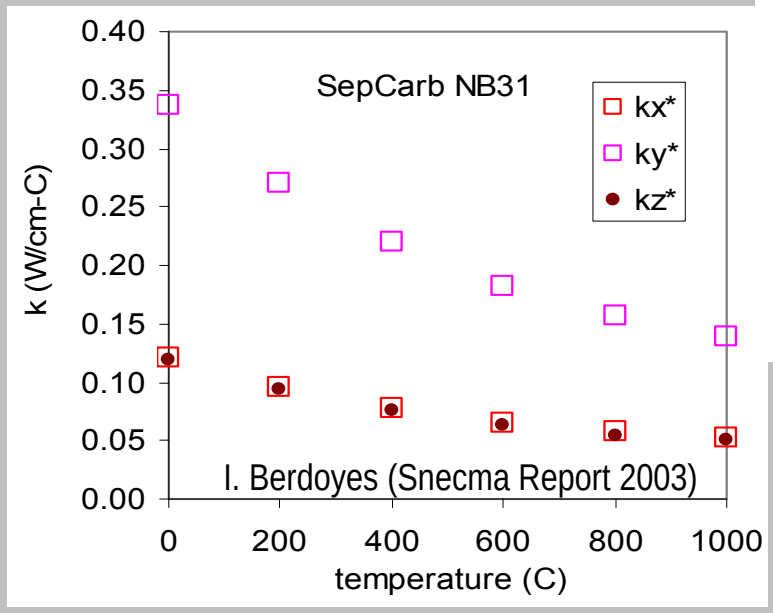
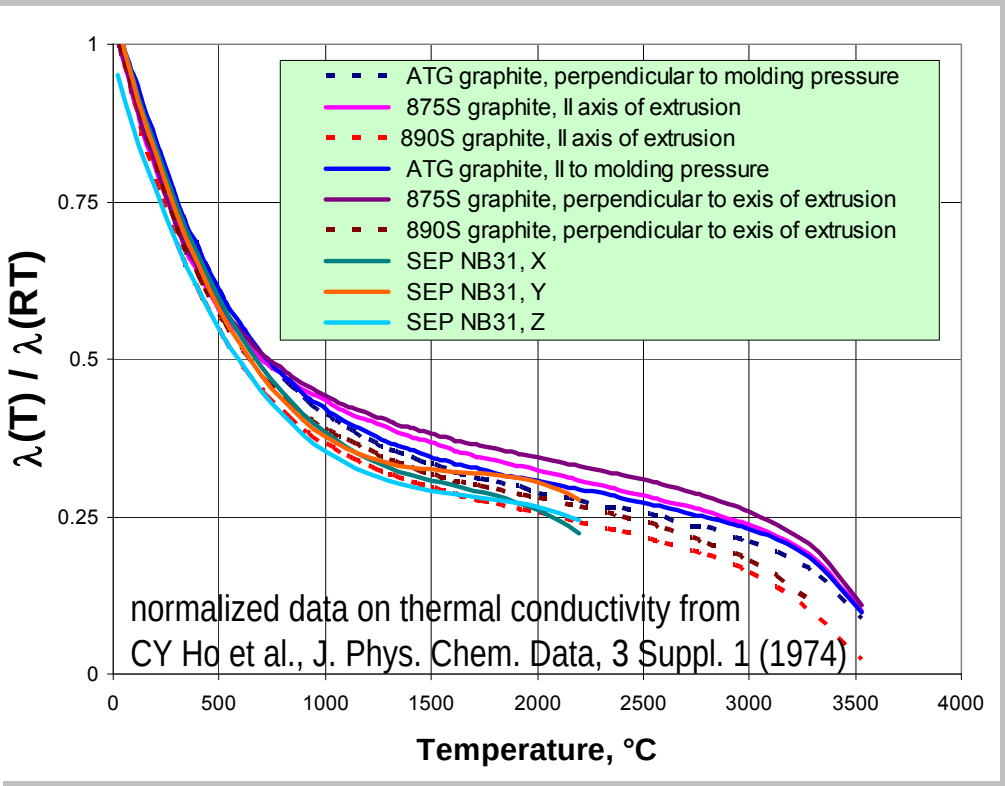
ITER divertor – Thermal conductivity of CFCs

K_2 of SepCarb NB31 is ~2.8x higher than K_1 or K_3.

**In ABAQUS, *ORIENTATION defines local orientation for orthotropic mat'l; *DSFLUX calls user-defined subroutine that specifies position-dependent (or time-dependent) heat load.*





Data cited in *High temperature properties of CFC and impact on thermal erosion,* V. Barabash, G. Federici, S. Pestchanyi, Cheng-du PSI Meeting

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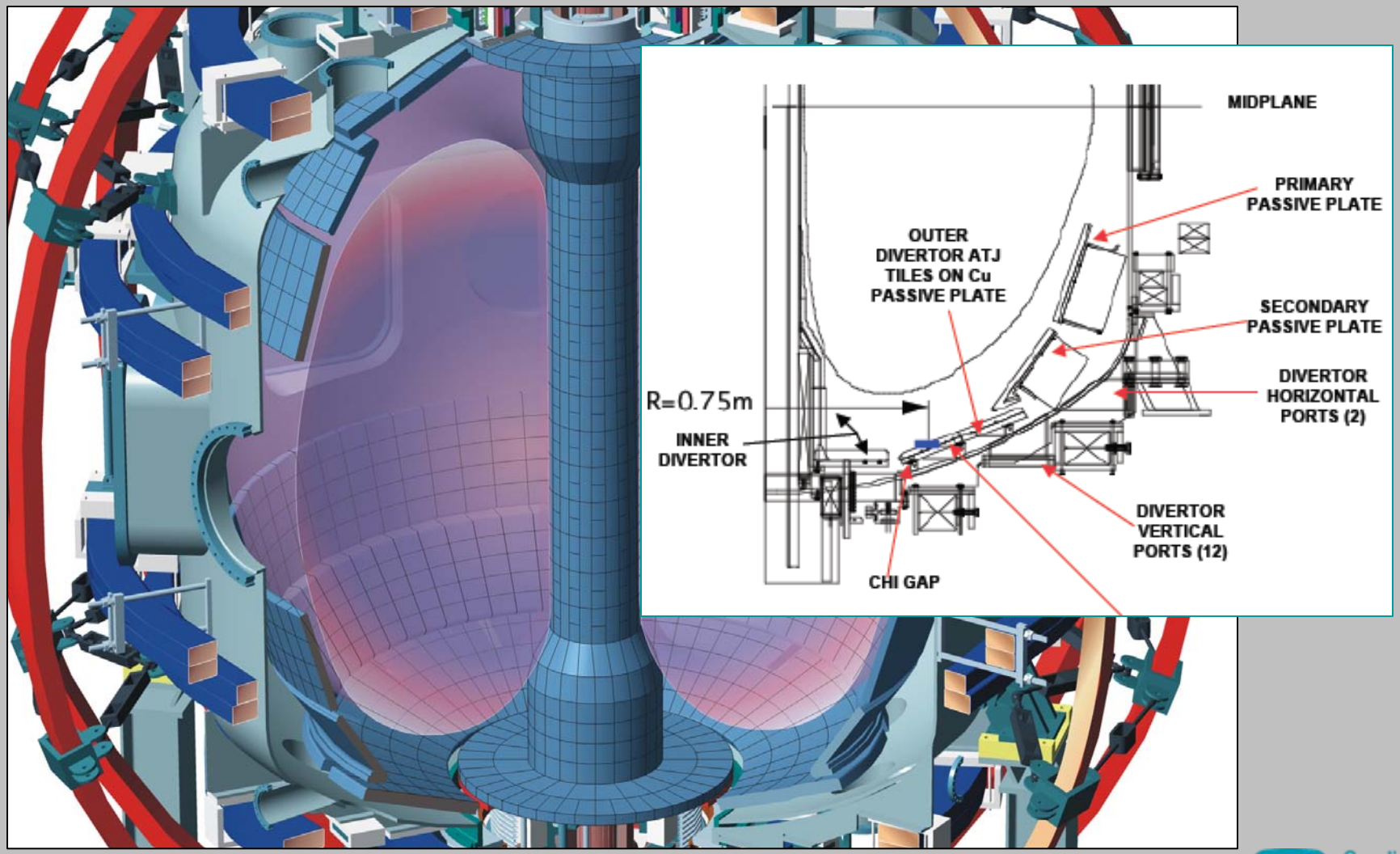
NSTX LLD (Liquid Li Divertor)



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NSTX LLD (Liquid Li Divertor) – Heat Transfer

Leonid Zahkarov is proposing a Li-covered plate in NSTX preceding and supporting the LLD.

Google:[Leonid Zakharov] → http://w3.pppl.gov/~zakharov

Operational and design space of LLD, Li/Mo Capillary Porous System (CPS) and Li/SS/Cu plate

Leonid E. Zakharov PPPL

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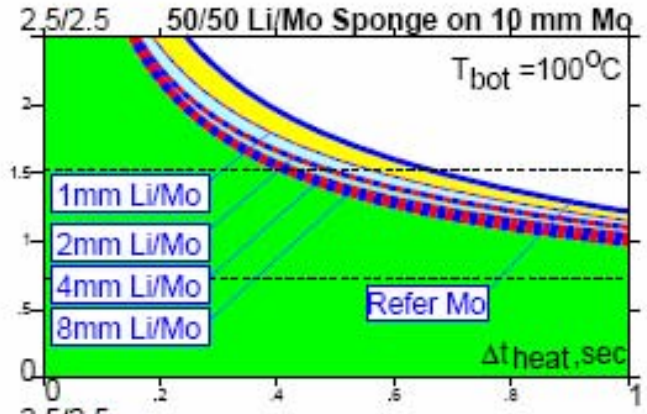
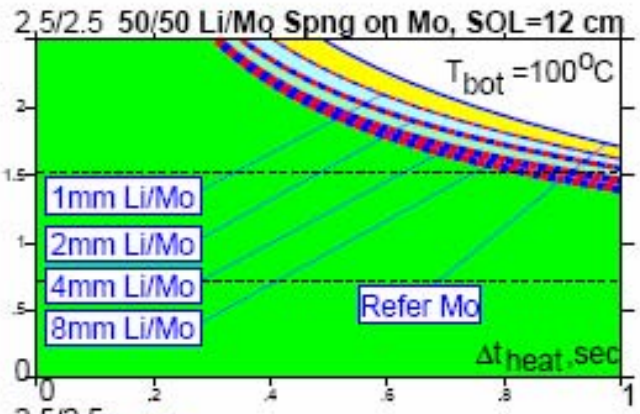
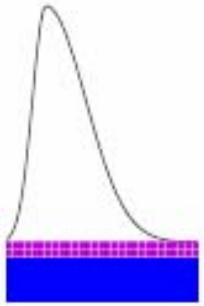
50/50 Li/Mo CPS may have the best characteristics

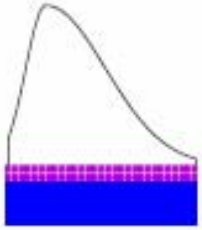


$d_i = 2, d_e = 6$ cm



$d_i = 3, d_e = 9$ cm

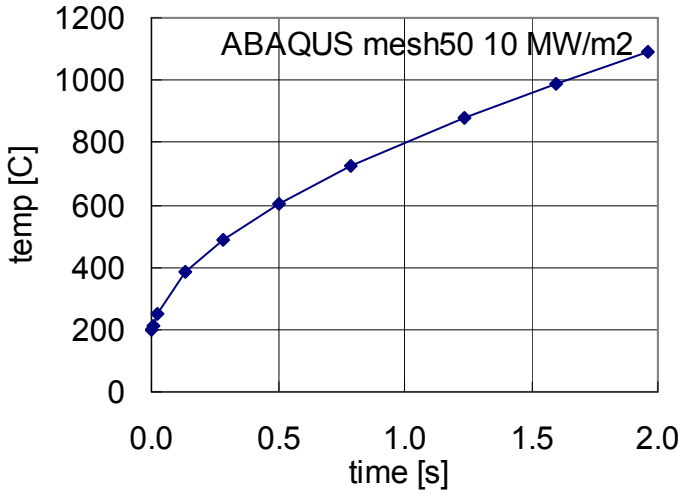


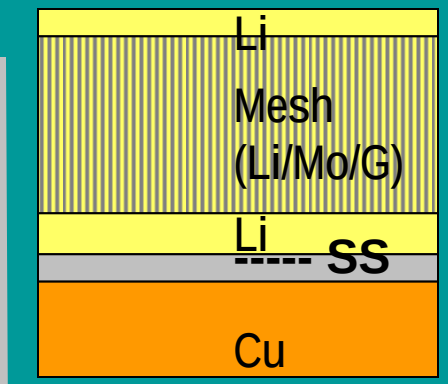


Potential clogging by LiOH, LiD, etc requires technology studies

NSTX LLD (Liquid Li Divertor) – Heat Transfer

- **Li thermal conductivity is low.** (W/m-K 400 Cu, 146 Mo, 46 Li, 14 SS)
- **Thin Li layer limits heat load.**
- **Directions that might increase the allowable heat load:**
  - **a) Increase thermal diffusion**
  - **b) Increase convection**
  - **c) Permit more evaporation**
  - **d) Actively cool the Li**
- **We are exploring ideas to increase the thermal diffusion with a Mo mesh.**
- **We hope modeling** (UCLA) **and tests may also show beneficial convection.**





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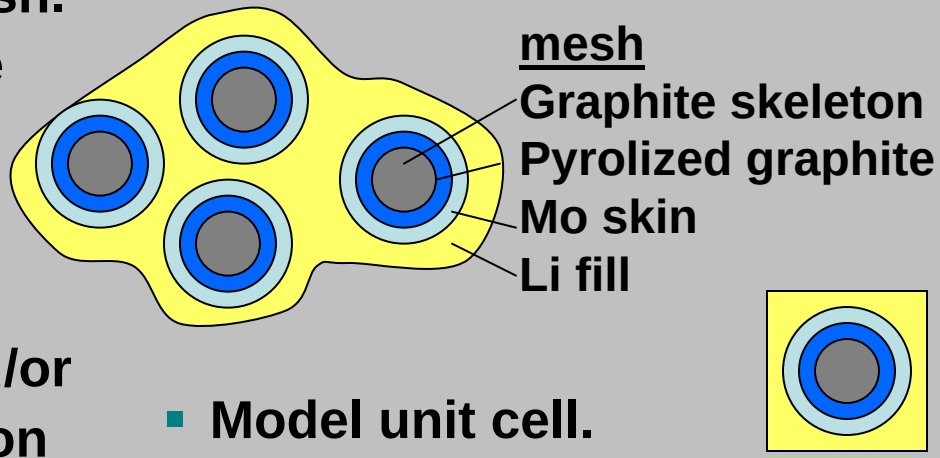
NSTX LLD – Mesh and Heat Transfer

- Ultramet, Inc. (Pacoima, CA) makes refractory metal mesh. They pyrolize polyurethane foam to obtain a carbon skeleton on which they deposit (CVD) metals.
- The can mold the foam and/or machine the carbon skeleton to produce desired shapes.
- To add mass, they can add pyrolized carbon or metal.



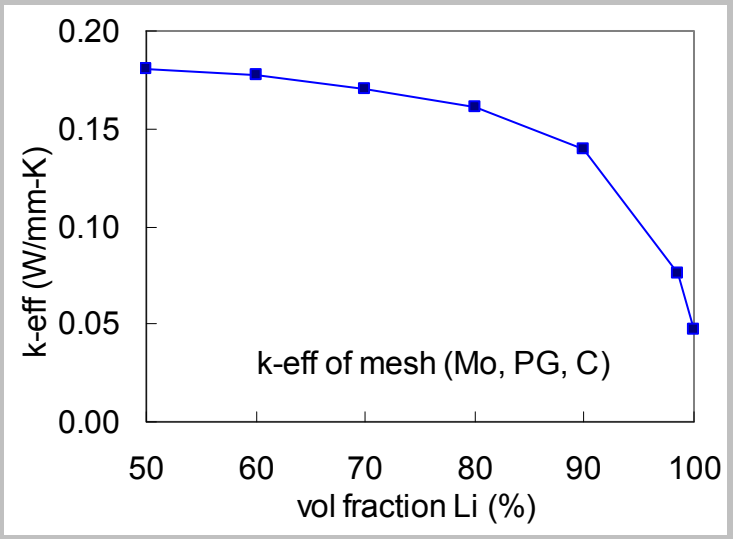
- Model unit cell.

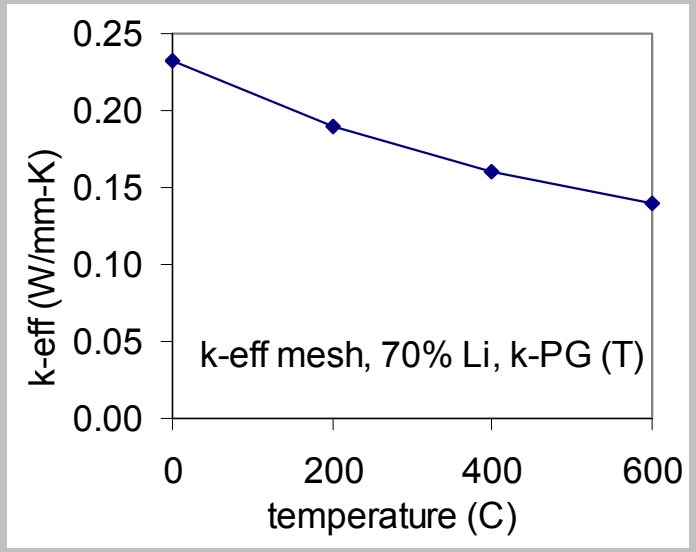
  See effects of increasing the PG and Mo while keeping an open mesh.

- Pyrolized carbon has higher thermal conductivity than Mo at temperatures below 1000C.

NSTX LLD – Mesh and Heat Transfer

- **Mesh is mostly open with Li and has ligaments of Mo and graphite that conduct heat.**
- **Simple parallel conduction $1/R = K_{eff}A = K_1A_1+K_2A_2 + ..$**





- **$K_{mesh}(T)$ depends mostly on $K_{PG}(T)$**

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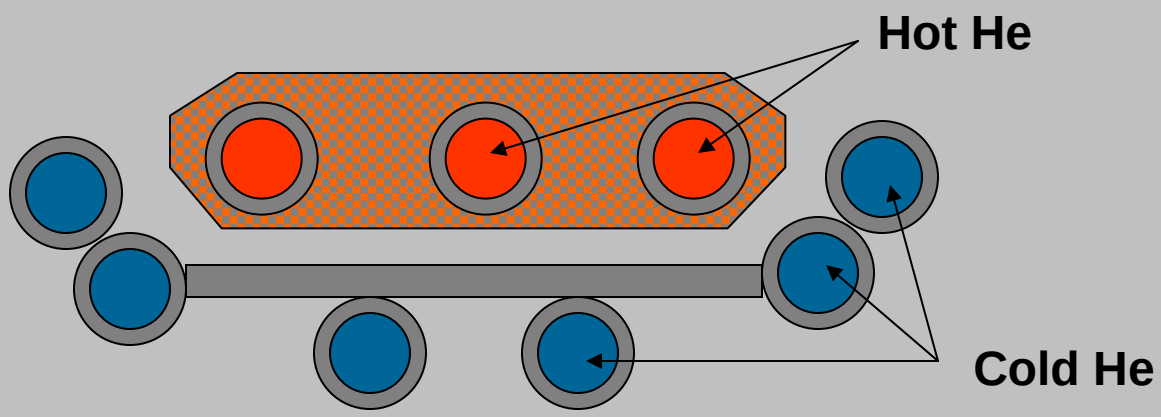
NHTX LLD – Mesh and Heat Transfer

- **Sandia proposes to study gas heating and cooling with He of a LLD as a forward-looking application for steady state heat removal and thermal control for NHTX.**
- **This will utilize an upgrade to out He loop anticipated in 2008.**



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Sandia Plasma Materials Test Facility

Status of EB60 and EB1200

presentation at the

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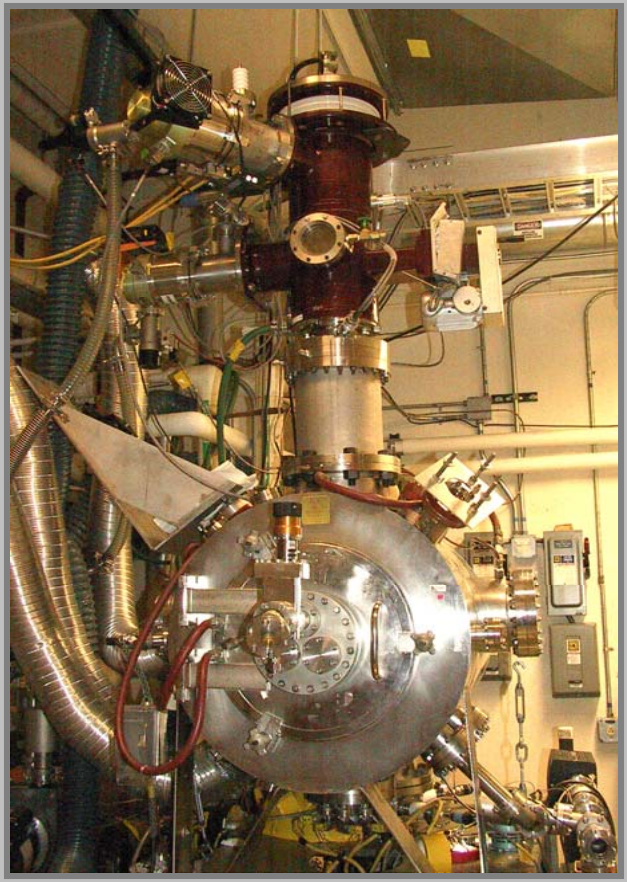
EB60 replaces EBTS at Sandia's Plasma Materials Test Facility



- E-gun and PS were reapplied from elsewhere at Sandia.
- Adaptations of a new grid control and power hook-up were funded by base program for labor & parts.

- Hookup is done. We are checking vacuum and powering circuits to check wiring, interlocks, etc.

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EB60 replaces EBTS at Sandia's Plasma Materials Test Facility

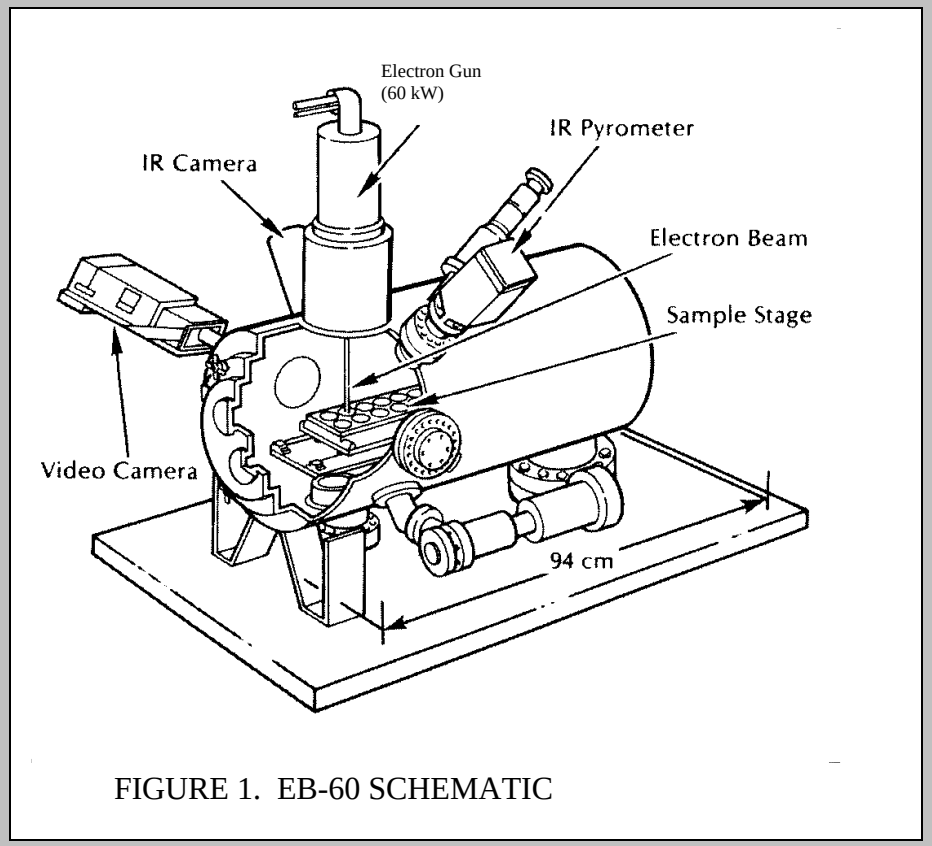

FIGURE 1. EB-60 SCHEMATIC

- **Increase in capability**
  - 60kW vs. 30kW (EBTS)
  - more reliable power supply
- **Use for ITER testing**
  - joining R&D
  - small US Be/Cu mockups
  - Korean Be/Cu mockups

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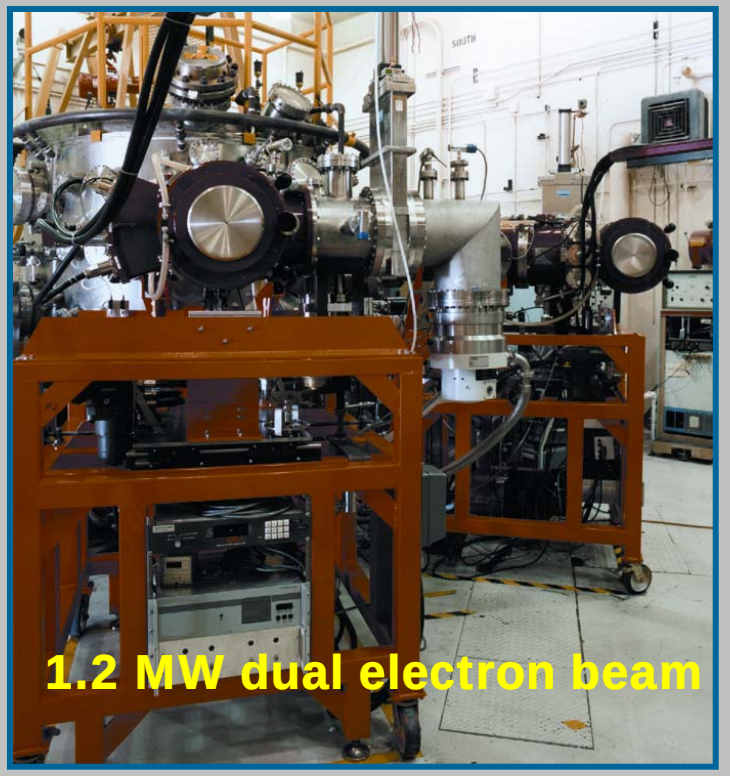
EB1200 suffered a burnout of a secondary winding in one of two stacked 600kW power supplies.

- The problem occurred last year before our lab shutdown last summer (HVAC replacement), and we replaced a coil.
- In restarting PMTF this year, a problem with the PS remained.
- Rebuilt and new coils for this ancient PS are being shipped.
- We are also setting aside funds from ITER testing for foreign parties for future purchase of a new power supply.



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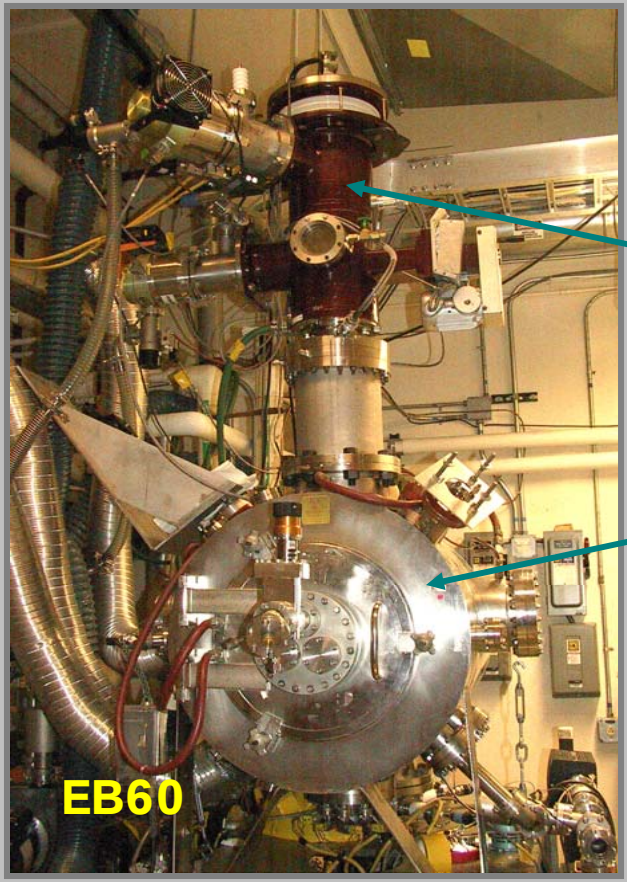
EB60 is nearly operational.
EB1200 will operate in late summer.



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Participant in WG8

Comments ITER Design Review

presentation at the

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Personal Observations

Not "official" Reviewer Comments

- **Teams requested. Working Groups formed.**
- **Review Meeting (#3, first for WGs) at CEA, April 16-20**
- **Working Groups have been preparing drafts.**

- **WG1 *Design Requirements and Physics Objectives* included Hawryluk & Stambaugh** (primary US contacts)
- **WG8 *In-vessel Components* led by Michael Pick with Chris Lowry** (recorder/facilitator) **and Igor Mazul** (ITER).
  - **Raffray/Nygren – High Heat Flux Components**
  - **Skinner –Operational Req'rm'nts** (Tritium & PFC Mat'ls)
  - **Stangeby – First Wall Layout (**conforming wall**)**
  - **Hechler – Manufacturing and Reliability (Nygren also)**

Personal Observations

Not "official" Reviewer Comments

Approach: document concerns with existing design versus existing requirements.

General observations

- **Problems with design assumptions – "convective" heat loads to the FW have been ignored.**
- **Problems with process – detailed specifications not available in some areas, e.g., QA acceptance criteria for PFCs and many other sub-components will be in procurement packages not yet completed.**
- **Problems with design integration – some gross inconsistencies between objectives implicit in mission, such as changeout of the FW, and the resources available in space and hardware for remote handling.**

Personal Observations

Not "official" Reviewer Comments

Some Details

- **The definition of heat loads to the FW and port limiters was considered inadequate. (A. Loarte writer)**
- **Requirements related to tritium handling and dust were considered inadequate. Lack of risk-based decisions noted. (C. Skinner writer)**
- **Inconsistencies with remote handling (J. Palmer writer)**
- **Concerns about large number of tiles and definition of startup scenarios for port limiters (R. Raffray writer)**

Each section listed relevant ITER Issue Cards.

Personal Observations

Not "official" Reviewer Comments

Some Details continued

- **There were concerns about lifetime and (lack of) presumptions about operation with some failed or mising tiles, and about the specifications of heat loads for the FW. (R. Nygren – writer)**
- **The assessment of the divertor was very positive. (F. Escourbiac – writer)**
- **Incompleteness in design integration was an issue with relation to acceptance criteria, alignment of the FW, diagnostics for the FW/shield, inconsistencies between changeout of the FW and the resources for remote handling. (R. Nygren – writer)**

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Sandia & UCSD Effort

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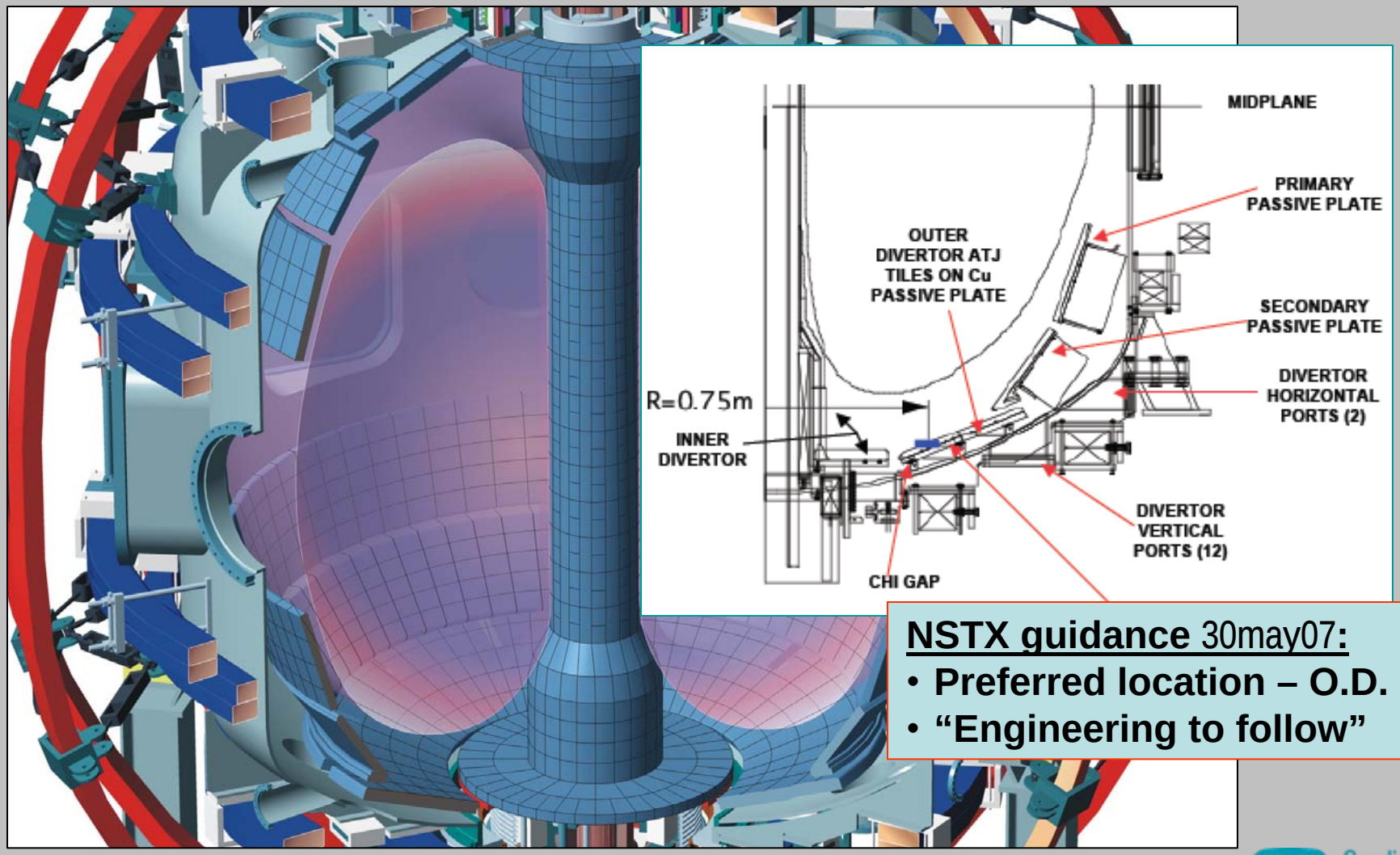
NSTX LLD (Liquid Li Divertor)



NSTX guidance 30may07**:**

- **Preferred location – O.D.**
- **"Engineering to follow"**

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Introduction: History - Background

NXTS Team found enhanced performance of plasmas in NSTX with Li present. LLD is 3rd Phase in NSTX 5-Year Li Plan for Particle Control & Power Handling. Collaboration with Sandia was funded via DOE Lab Collaboration (3-yr cycle).

Sep/Oct 06: **SNL proposal, with UCSD contract and Nov 06 start**

- *FY2007:* Design/fab a prototype for Li wetting tests at SNL, clean CDX-U Li injector & move to Sandia (PPPL/UCSD), wetting tests at SNL
- FY2008: Procure parts, build LLD hardware (+ Li injectors), deliver to PPPL
- FY2009: Install LLD in NSTX, fill LLD with Li, and perform experiments

Nov 06: **Proposal accepted with later start date**

Feb 07: **Meeting with NSTX Team; help on design concernsand hardware** (thermal analysis and SS-clad copper for tray)

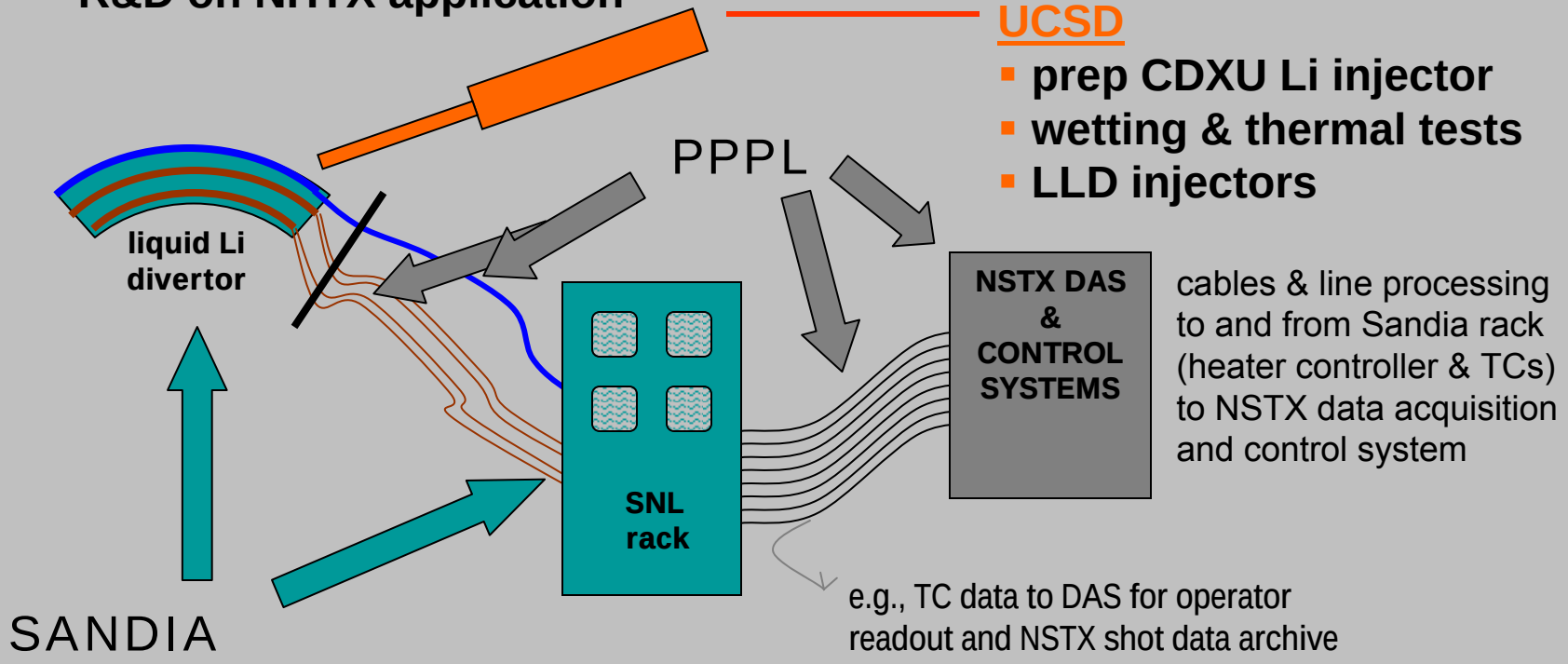
Apr 07: **Start of Funding**

Introduction - Responsibilities

SANDIA
- LLD design & hardware
- wetting & thermal tests
- installation (NSTX Team)
- participation, experiment
- R&D on NHTX application

PPPL
- assistance defining hardware interfaces
- labor during installation of LLD
- feedthroughs and cabling
- visual, spectroscopic & IR views of LLD

UCSD
- prep CDXU Li injector
- wetting & thermal tests
- LLD injectors



cables & line processing to and from Sandia rack (heater controller & TCs) to NSTX data acquisition and control system

e.g., TC data to DAS for operator readout and NSTX shot data archive

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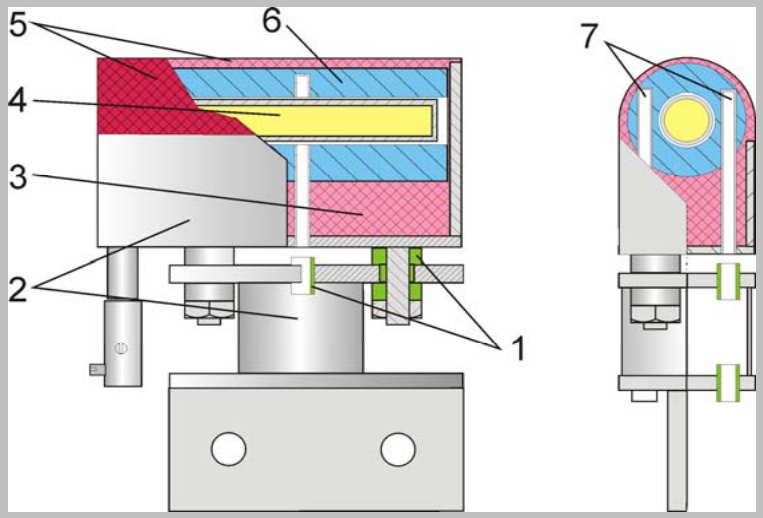
Basic Design Concept

- **Mesh holds Li surface.**

  This is based on Russian experience with various experiments on capillary systems and limiters in T-10 and in FTU as well as experience with the initial Li limiter in CDX-U.

- **Mesh can hold Li even during disruptions.**

  This is based on FTU experience published in SOFT and PSI and also presented in seminars here at PPPL.



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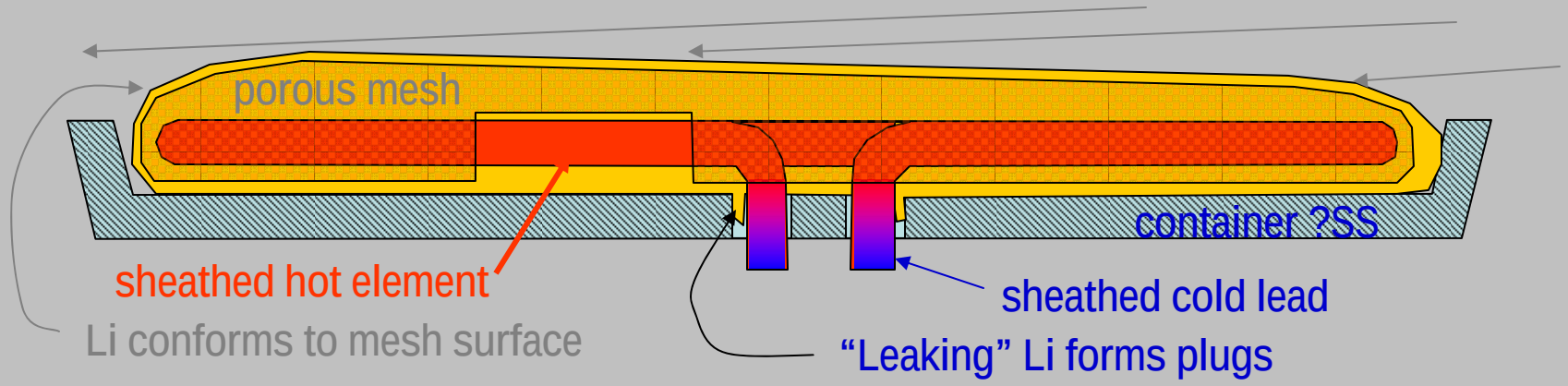
Basic Design Concept

- Mesh holds Li surface above container to reduce heat at the sides.
- "Tiling" of LLD sections reduces heating at the ends.
- Embedded heaters in "deep" mesh improve thermal control because mesh and Li are heated directly. Container can be cooler.



- **Embedded heaters in "deep" mesh improve thermal control because mesh and Li are heated directly. Container can be cooler.**
- **Sheathed heater contains both element and unheated leads.**

Introduction: Status

Apr 07: **Start of Funding, heavy BPO/ITER commitments for PI.**

- Nygren lead, add Sandia manpower for LLD (Joe Shelton, designers).
- Move wetting tests from spring to summer.
- Investigate flexibility in date for delivery/installation in NSTX.

Jun 06: **Status - some items slipped**

- Design specifications for equipment for wetting test
- Procurements for mesh (Ultramet) and Li injector (UCSD) for wetting test
- Specification of heat loads and LLD radial position

Jun 06: **Status – ongoing effort**

- Joe (Tre) Shelton (K-Tech) and designers (SNL) on board
- Thermal analysis and design in progress
- Laura Bersak (PPPL student, NASA Fellowship) will start Monday
- Other students and additional manpower available

Sandia Project Structure & Personnel

Fusion Technology
Sandia Dept **01658**
RE Nygren, mgr

Mike Ulrickson	(ITER)
Tina Tanaka	**(ITER +)**
Dennis Youchison	(ITER +)

Tom Lutz	**(diagnostics,LM)**
Jimmie McDonald	**(testing/facility)**
Fred Bauer	**(tech/LIMITs)**
Ken Troncosa	**(tech/LIMITs)**
Jim Bullock, Orion	**(CAD, designer)**

Pulsed Power
Center 01600

EM analysts	(ITER)
Thermal analysts	(ITER)
Stress analysts	(ITER)
Operator/tech	(ITER)

Nygren	(PI,LLD)
Tech	(LLD)
Designer	(LLD)

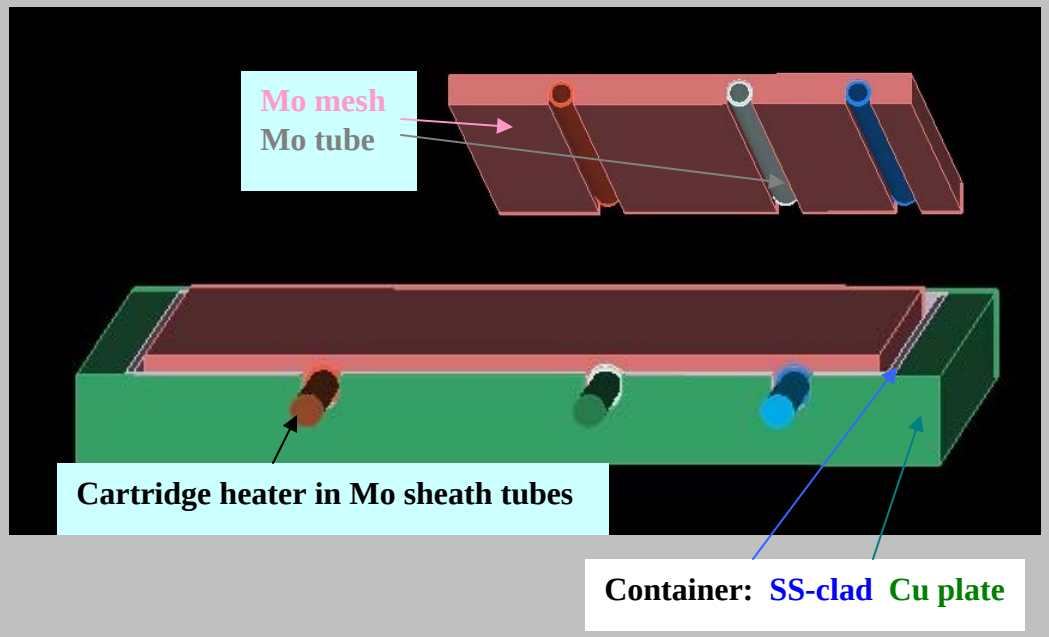
Introduction: Status

Ongoing effort

- **Site visit and discussions with Ultramet (May 9, 2007)**
- **Joe (Tre) Shelton (K-Tech) and designers (SNL) on board**
- **Thermal analysis and design in progress**
- **Laura Bersak (**PPPL student, NASA Fellowship**) will spend summer at Sandia and start Monday**
- **Other students and additional manpower available**

LLD Design Features

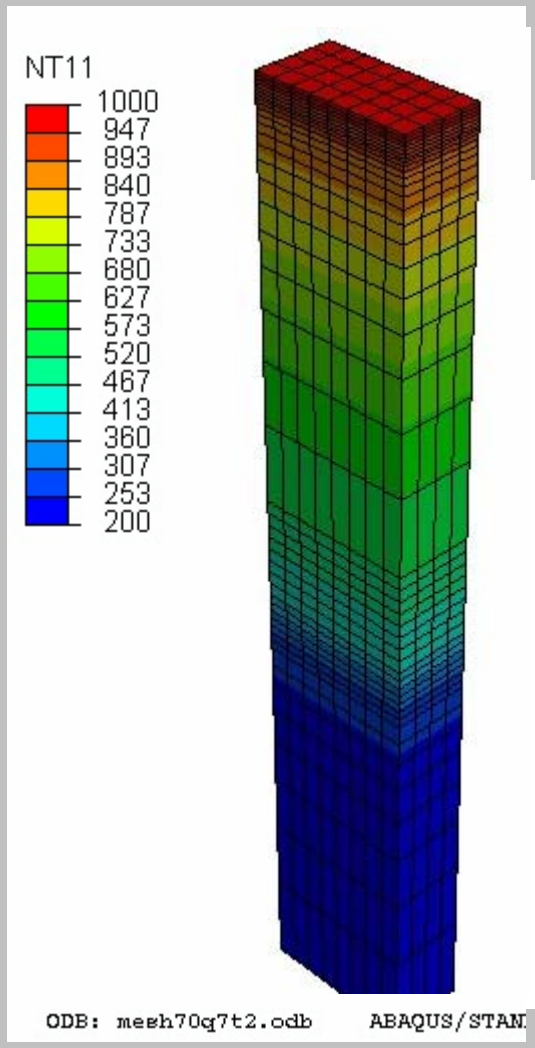
Wetting Test



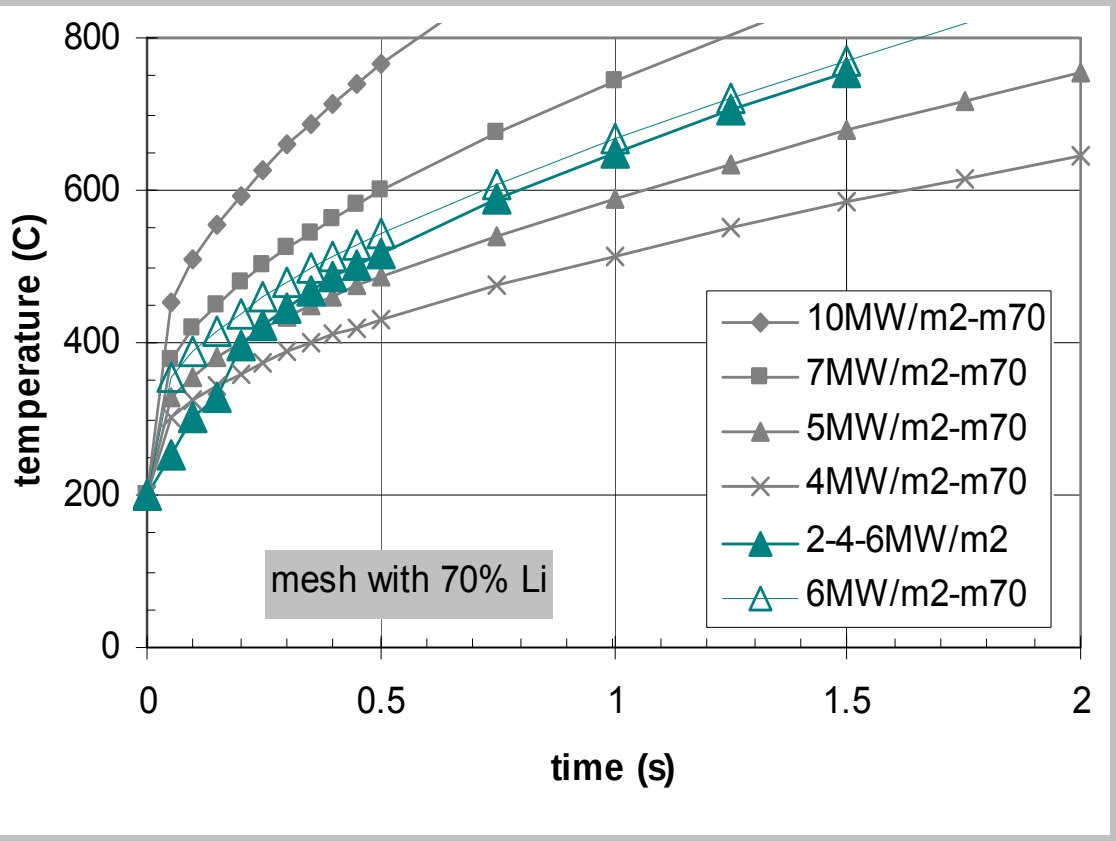
Mesh

- ~50-70% volumetric porosity
- mesh rises above edge of tray
- C skeleton, pyrolytic graphite (PG) added by CVD then Mo skin
- structure with high thermal conductivity, between PG and Mo
- Mo or SS tubes provide housing for heaters
- bond with Li

LLD Design - Thermal Analysis



1-D analysis with k-eff for mesh and temperature dependent properties



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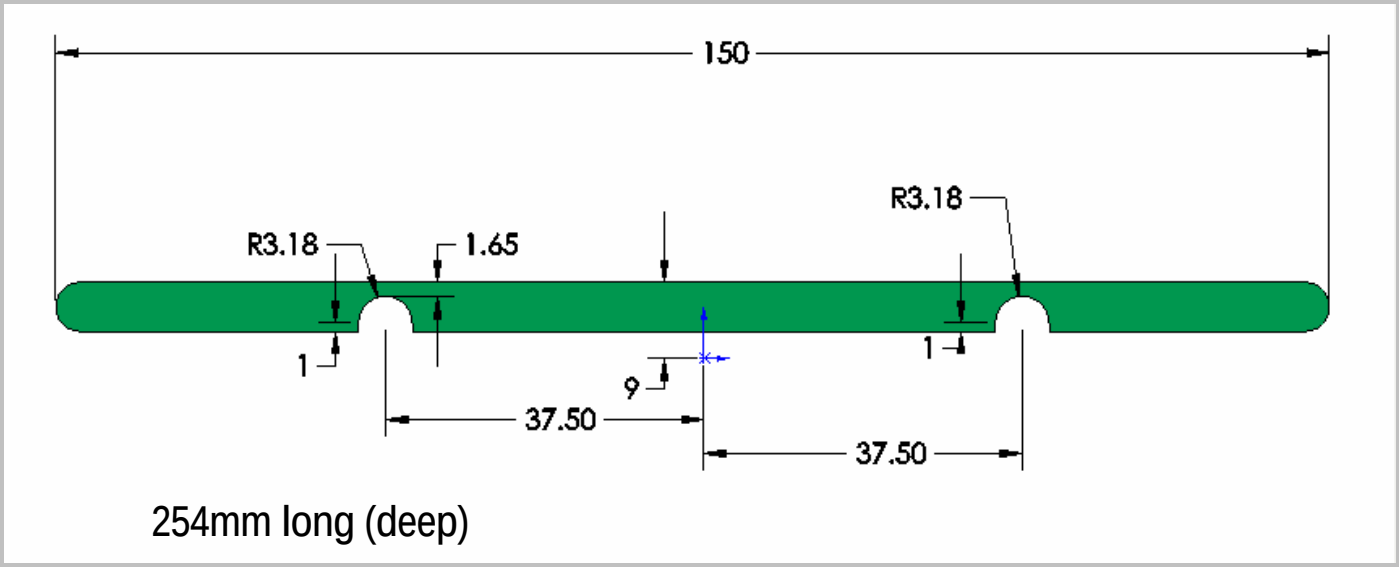
LLD Design - Thermal Analysis

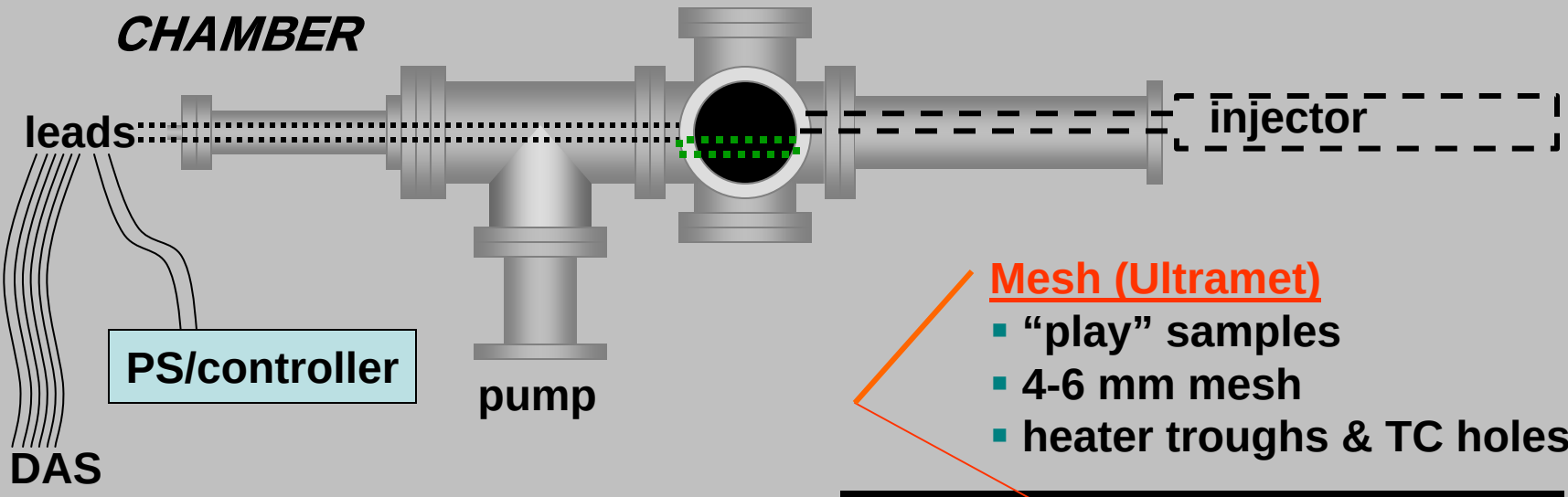
What heater power is required?



- volume ~2x10^{5}mm^3 with 70% porosity, 20% C, 10% Mo
- heat mesh and Li, melt Li, heat to 500˚C
- ~12 W of power 20 to 500 ˚C in 5 minutes.

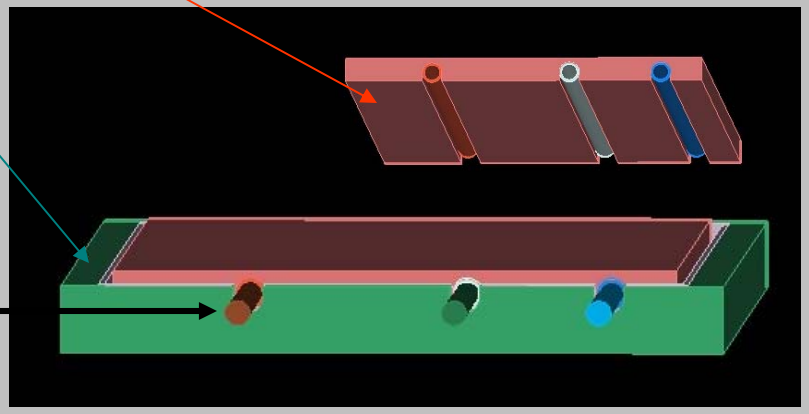
NEED further analysis with thermally-connected container.

LLD Wetting Test – Procurement



Mesh (Ultramet)
- "play" samples
- 4-6 mm mesh
- heater troughs & TC holes

SS/Cu container
- use SS-clad Cu (LTX)
- or SS/Cu brazed



Heaters (1/8" dia. ?)
- Mo – higher temp, $$ specialty item
- SS – more suppliers, sizes
- make leads/flange fit both wetting test and EB60

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