Liquid Lithium Surfaces for Particle Control in NSTX

Prepared by

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Outline

- Particle Pumping by Liquid Surfaces
- Plasma Edge Effects Due to Strong Pumping
- MHD Experiments on Flowing Liquids
- MHD Modeling of flowing free surface liquids
- Conclusions

Objective

- The objective of this project is to provide a fusion device with a tool for particle control.
- Specifically, we will provide a module capable of removing about 10^{23} particles/sec for the full duration of the plasma.
- A secondary objective is to demonstrate the power handling capability of liquid surfaces in contact with a fusion plasma (an innovative PFC solution for the future).

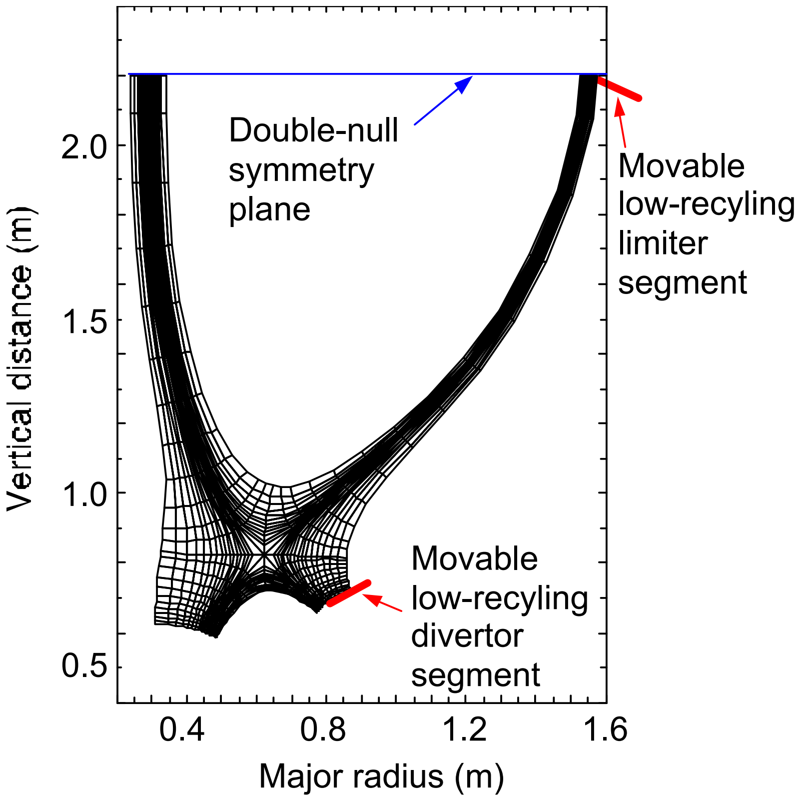
NSTX Particle Pumping Needs (R. Maingi)

- **Particle content of the plasma ~5 x 10^{20}.**
- **Typical gas fueling rate 50-100 Torr l/s (3.5-7.0 x 10^{21} H/s).**
- **The beam fueling rate is about 30 Torr l/s.**
- **Fueling from wall recycling is important particle source.**
- **Recent analysis shows net core outflux of 100-150 Torr l/s (7-10.5 x 10 21 H/s).**
- **Implies a need to pump about 10^{22} H/s.**

Particle Pumping by Liquid Li

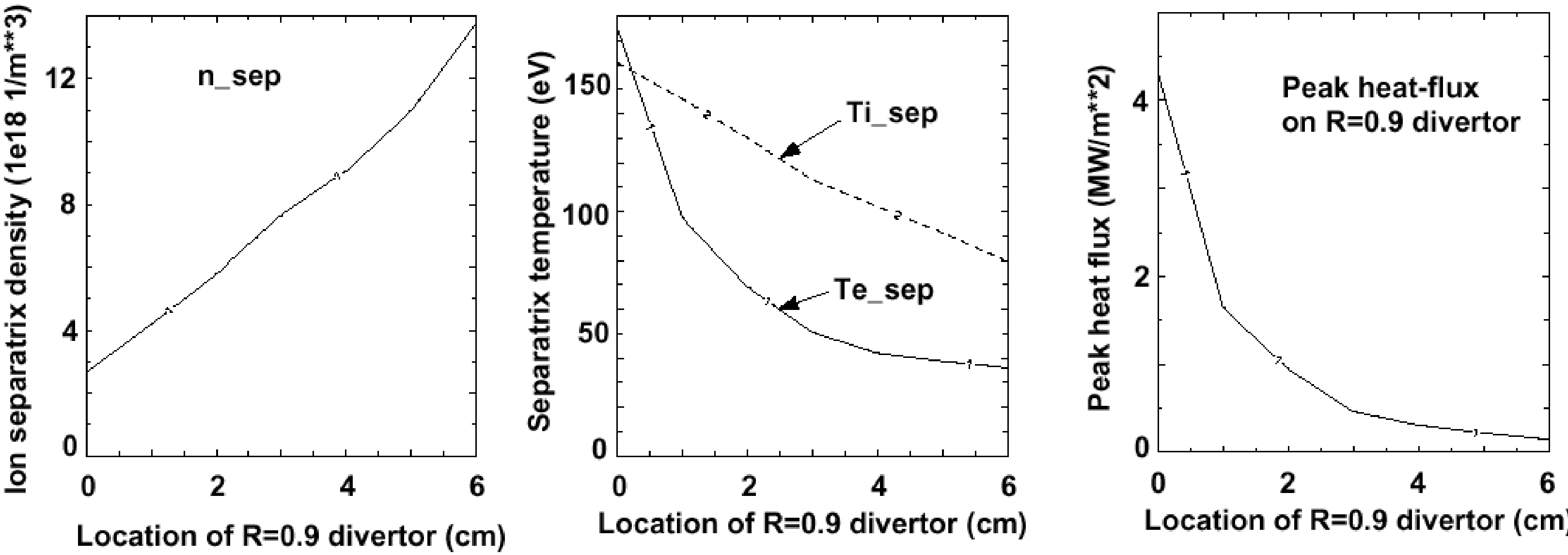
- The range of H in Li is 10-90 nm (100-1000 eV)
- H atoms have a diffusivity of about 10^{-4} cm^2/s
- The recombination rate for H on Li is the product of the rate coefficient and the square of the near surface concentration
- The rate coefficient can be estimated from the models of Baskes or Pick and Sonnenberg (predicted values 10^{-27} to 10^{-31} cm^4/s depending on the temperature)
- Retention measurements have been conducted at fluences between 10^{19} and $10^{22}/cm^2$ with 100% retained (Ehrents, Causey, and Doerner)
- A 1 m^2 area of Li flowing at 10 m/s can pump 10^{23} H atoms/s

UEDGE Modeling of Plasma Edge



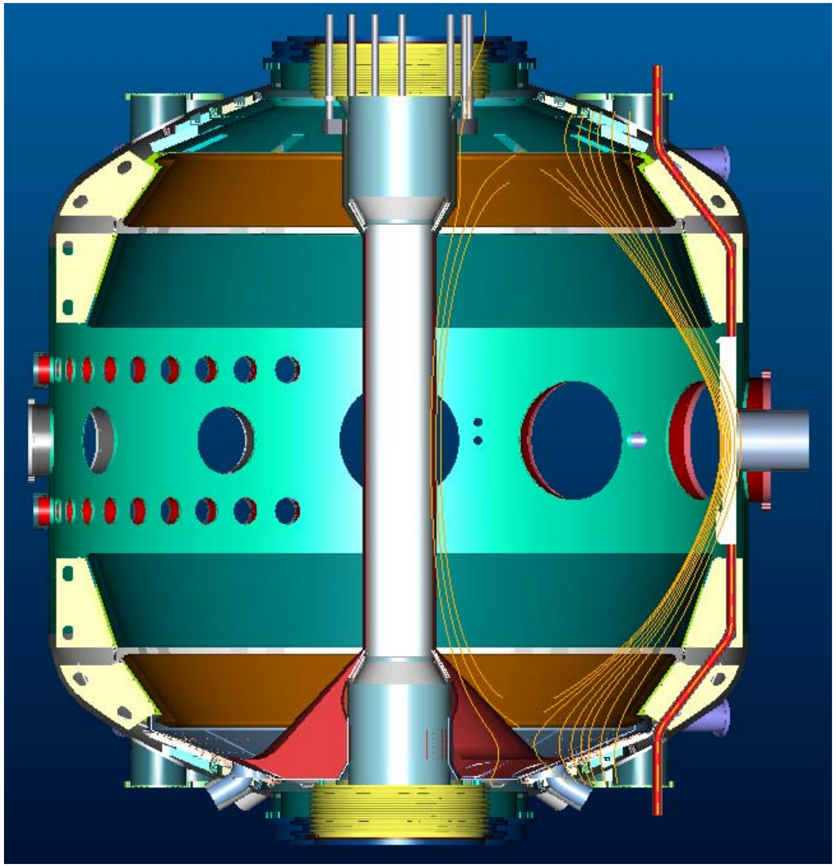
- **Regions having low recycling were placed either near the mid-plane or in the divertor.**
- **The position of the plates determined how many particles were pumped.**
- **The results for the divertor plate are shown on the subsequent slides.**
- **Tom Rognlien, LLNL**

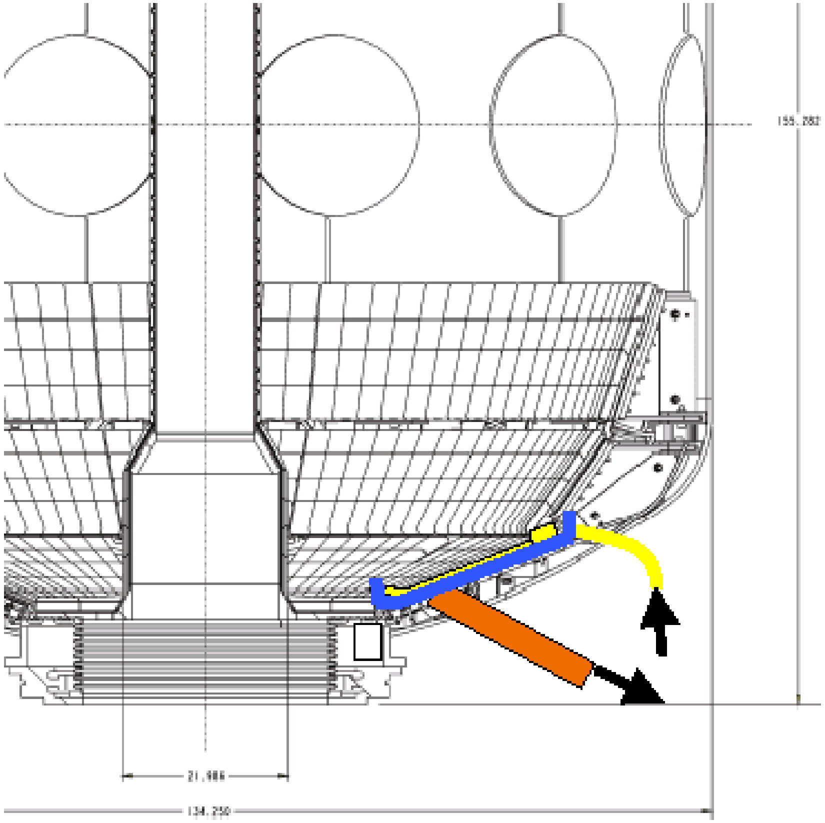
UEDGE Modeling Results (LLNL)



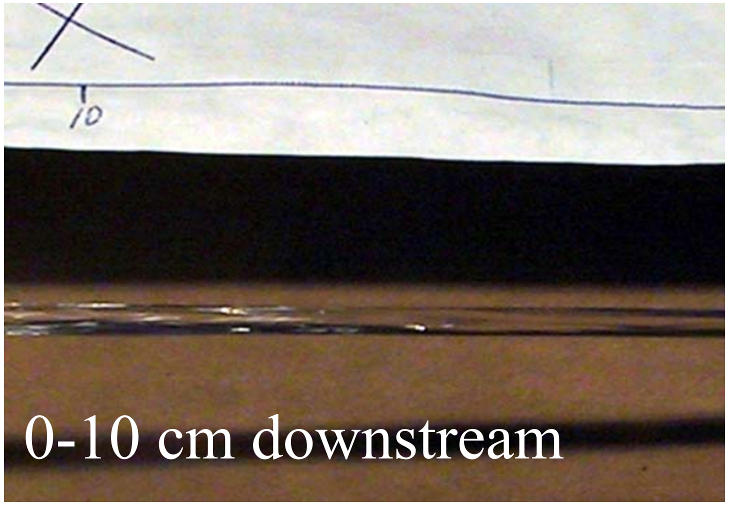
- Pumping increases edge temperature
- Pumping decreases edge density
- Divertor heat flux increases with pumping

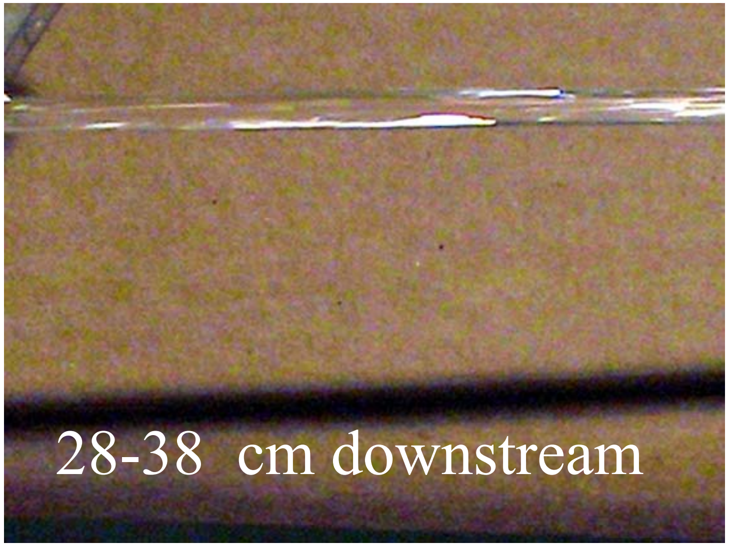
Module Sketches (ORNL)





Nozzle Development





- **Water was used to simulate Liquid lithium**
- **Nozzle L/D = 1**
- **Stream diameter = 4.8 mm**
- **Flow velocity = 10 m/s**
- **Only slight surface waves observed.**
- **Surface waves stable over 38 cm flow length.**
- **No observable side spray.**

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Laboratory Studies of MHD Effects

- Because of the need for experiments to validate the MHD modeling of flowing free surface liquids, we have constructed two new experimental devices (LIMITS and MTOR)
- MTOR is a toroidal coil facility constructed from the TARA coils. Initial experiments on liquid Ga have started in the last month at UCLA.
- LIMITS is a permanent magnet system with flowing Li at Sandia. Experiments will start in July.

MHD Test Facilities

- MTOR at UCLA
- Toroidal Magnetic Field (0.2 to 0.6 Tesla)
- Vertical field from permanent magnets
- Can increase B with iron inserts
- Liquid Ga or GaInSn only
- T< 100C
- Flow ~2l/s up to 400kPa
- Flow speed <10 m/s

- LIMITS at Sandia
- Iron yoke permanent magnet system (0.1 to 0.8 Tesla)
- Vertical field by pole face shaping
- Liquid Lithium flow system
- T< 450 C
- Flow ~2.5 l/s up to 600 kPa
- Flow speed up to ~15 m/s
- Heat removal studies without B field.

Planned MHD Experiments

- MTOR (UCLA) will focus on film flow down a ramp in gradient magnetic fields
  - Constant crossed fields, 1D and 2D gradients
  - Effects of externally applied currents
  - Time varying fields
- LIMITS (SNL) will focus on jet flow in gradient fields.
  - Constant crossed fields, 1D and 2D gradients
  - Effects of externally applied currents
  - Multiple jets
- The first round of experiments will be completed by November 2002 and reviewed at the ALPS/APEX group meeting.

MHD Modeling Efforts

- UCLA is using FLOW3D with added MHD effects modules to study the influence of induced currents on free surface flow (a parallel effort by Hypercomp is using adaptive meshes and volume of fluid method)
- Large volumes of physical space must be modeled because of the B fields produced by induced currents
- Optimization of the solving method and necessary equations is still in progress
- The experiments will provide important calibration and validation of the models

Conclusions

- Proposed liquid surface module has the potential of addressing particle control needs in the 5 year plan.
- Several R&D issues have been resolved over the past 15 months
- The key remaining issue is MHD effects on the flowing liquid metal
- Experiments are beginning to provide the data needed to validate the MHD modeling
- MHD modeling is progressing with key issues about boundary conditions and computational schemes being optimized.
- We anticipate making a decision to implement a flowing liquid surface in a fusion device in Fall 2003.