"Plasma-Surface-Interaction Analysis of NSTX Lithium Module and Related Issues"

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· **Integrated NSTX lithium erosion analysis**

REDEP/WBC sputtering erosion analysis using:

1. UEDGE (Ronglien et al.) low-recycle plasma parameters
2. Lithium surface temperature (Ulrickson et al.)
3. T_s-dependent sputter yields (Allain et al.)
4. Li^+ transport model (Brooks, Allain et al.)

· **Sputtered Li^+ transport model**

Issue and 1st-order model defined, detailed work in progress (with UIUC).

· **Sheath superheat analysis**

BPHI-3D code analysis of NSTX lithium hot spot. Surface temperature limit analysis based on evaporation and superheat sheath theory.

· **DIII-D**

Work continues on DiMES Li 99 solid-phase experiment analysis via WBC code, IIAX/VFTRIM sputter yields. Good match with data. Integrated SOL analysis underway via coupling to MCI. (with D. Whyte, T. Evans, D. Ruzic, et al.).

Integrated NSTX lithium erosion analysis

- Geometry: divertor module, ~ 8 cm poloidal by 40 cm toroidal.

- 2-D Plasma profiles: UEDGE Case sn_34; core power into the SOL = 6.0 MW, core-edge density = 4 $x10^{19}$ m^{-3}. Peak heat load ~ 25 MW/m^2.

- Lithium surface temperature: SNL calculation for 10 m/s Li flow, UEDGE plasma heat loads: T_s varies from 220 to 471 °C.

- D^+, Li^+ sputter yields: UIUC data/model, Y=Y(energy, species, T_s) for 45° incidence.

- First-order charged sputtered particle transport model.

- WBC calculation of self-consistent lithium sputtering from module, lithium flux to SOL. Next step: coupling to UEDGE.

Sputtered Li^+ transport

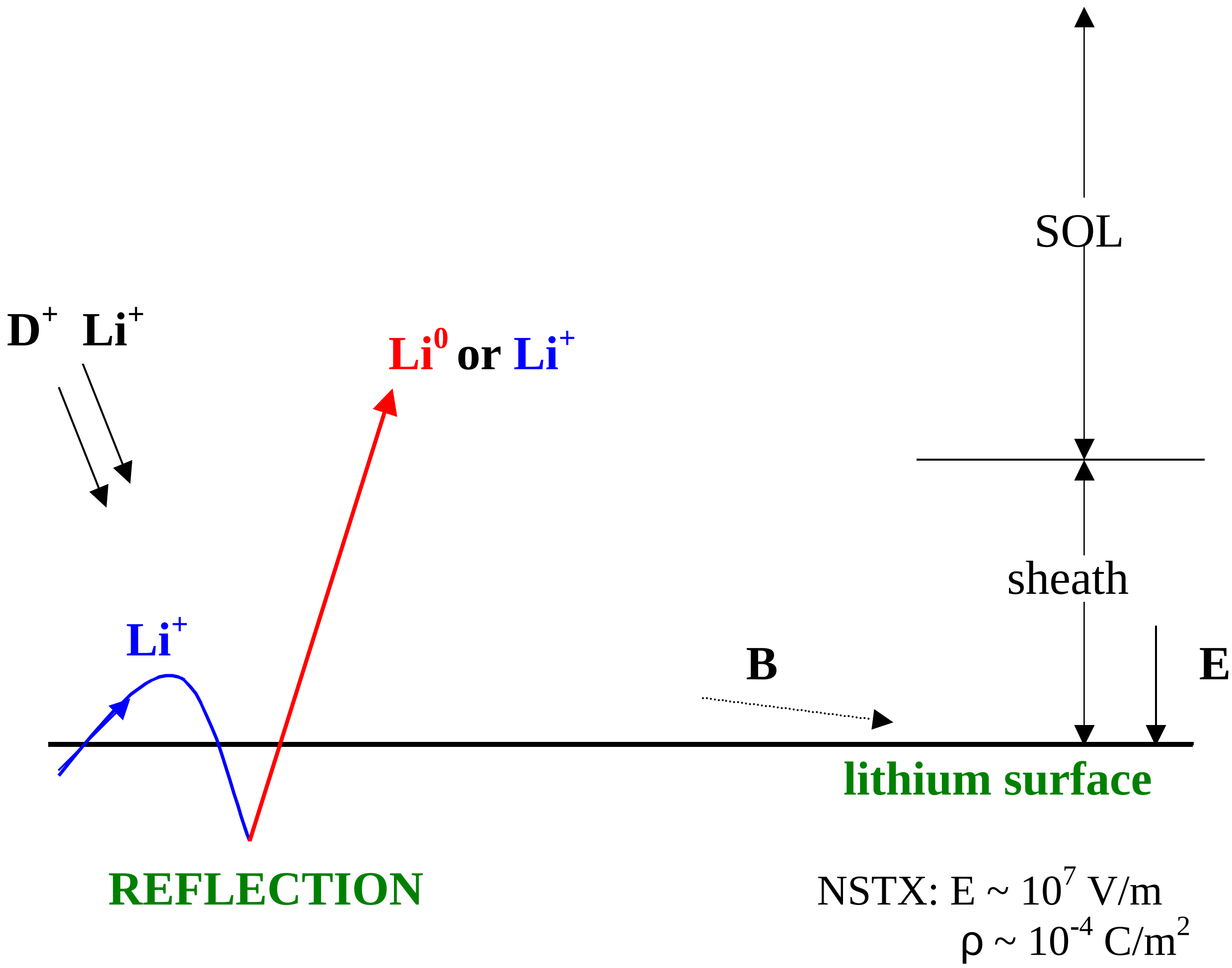
- Most (~2/3) sputtered lithium is in the form of ions (IIAX, PISCES, previous data). These are generally ignored in erosion analysis.

- What happens to the sputtered lithium ions?

- "Conventional wisdom" is that these ions are "invisible" to the plasma—they return to the surface immediately due to the sheath electric field and the near-tangential magnetic field, and have no further effect.

- That is true to zeroth-order but due to high neutral self-sputtering, we are concerned with more detail. *We need to consider transport of the sputtered charged lithium, and in particular, reflection and charge state of redeposited Li+ ions.*

Sputtered Li^+ Transport Model



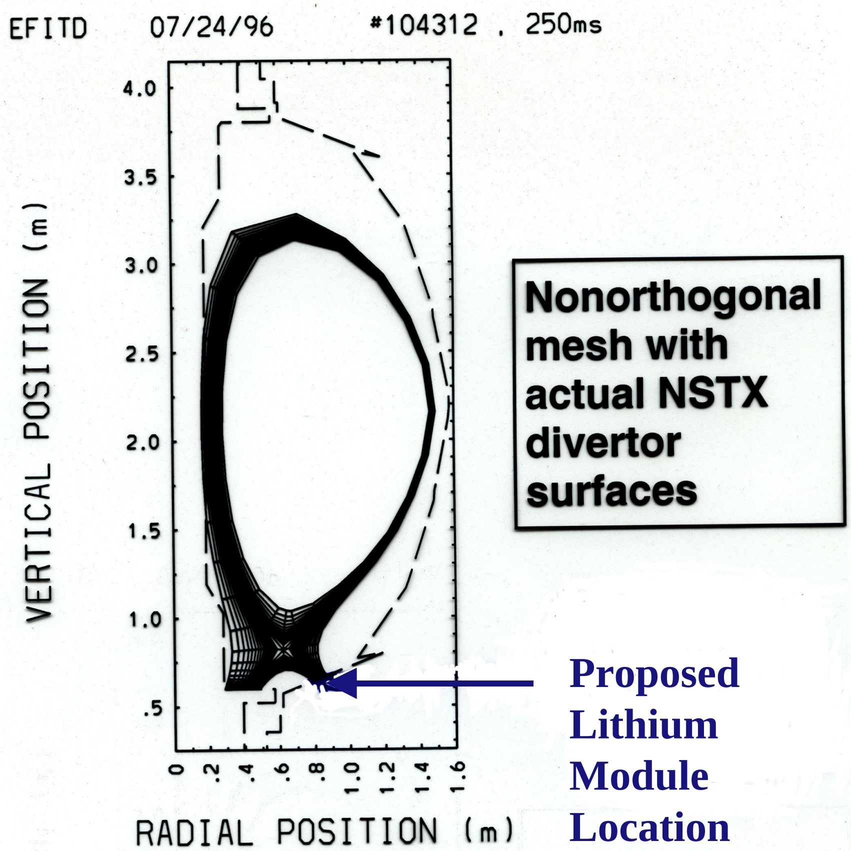
Parameters: R = Li^+ reflection coefficient
ε = charge fraction of reflected lithium
Y_0 = Li^0 sputtering coefficient

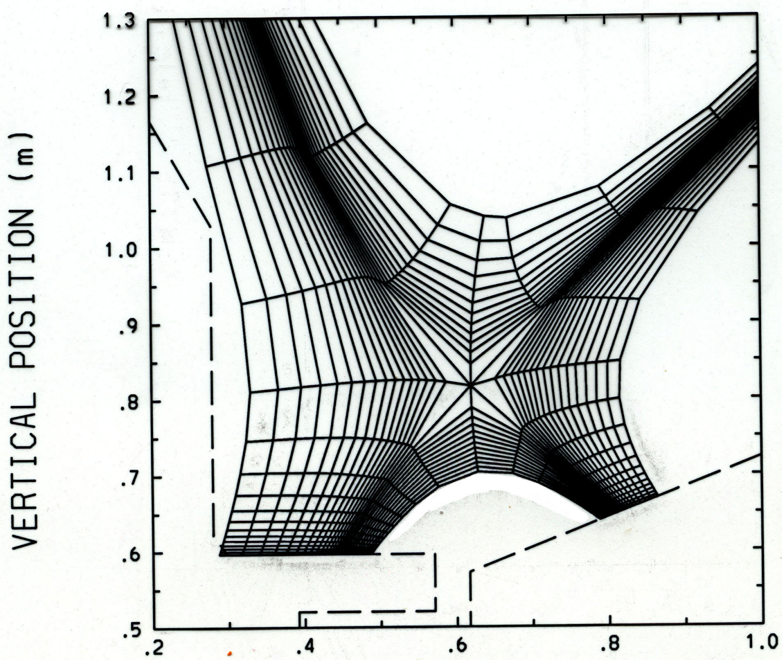
Then, Li^0 sputtering with reflection:

$$Y^{total} = Y_0 \, f(R, \varepsilon)$$

JNB 4/02

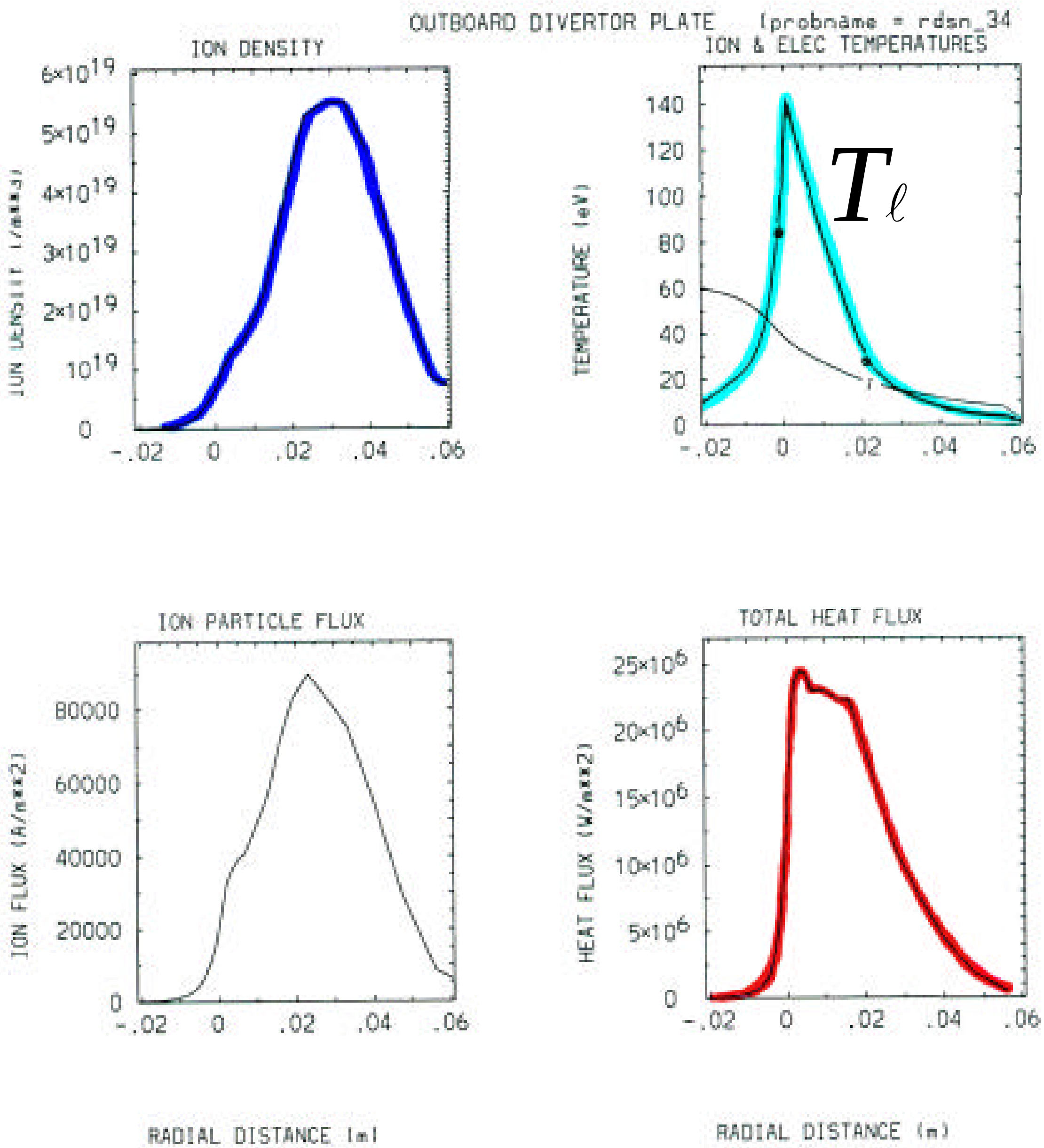
T. ROGNLIEN, LLNL





T. ROGNLIEN
LLNL
1/28/02

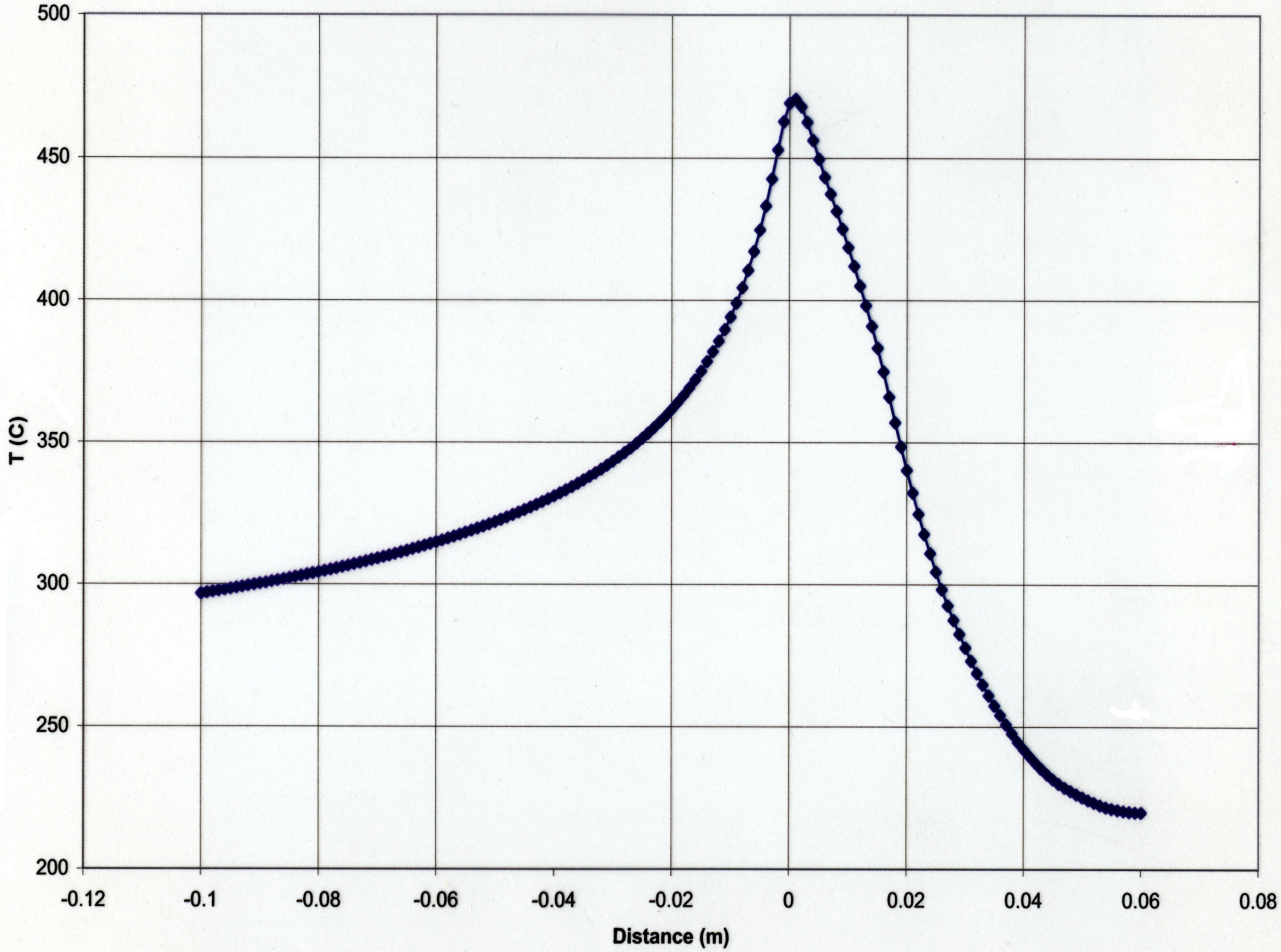
NSTX "HIGH POWER"



HIGH POWER
NSTX SN_34
CASE

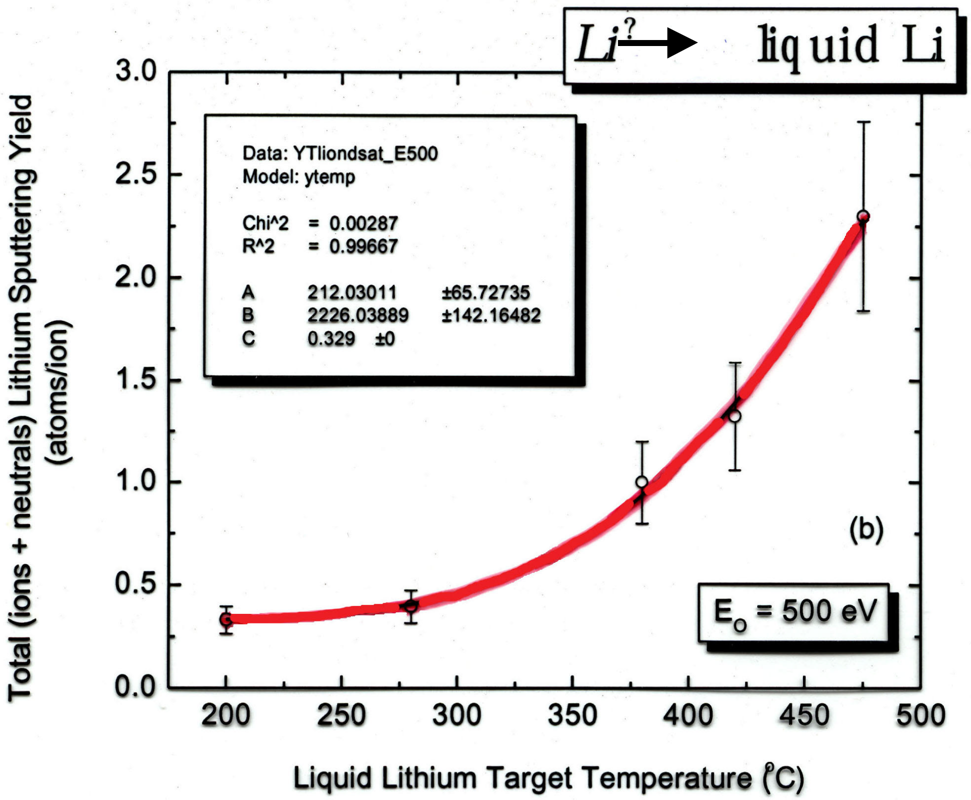
SNL
M. ULRICKSON
2/19/02

LITHIUM SURFACE TEMPERATURE



J.P. Allain
UIUC, 3/14/02

Figures 6 (a-d). Liquid lithium sputtering from Li^+ bombardment at 45-degree incidence plotted versus target temperature with empirical fits for a variety of incident particle energies.



$$Y(T) = C + A \exp(-B/T)$$

NSTX Lithium Module
Erosion/Redeposition Analysis

REDEP/WBC code simulation of 8 cm poloidal x by 40 cm toroidal flowing lithium module.

Using 2-D plasma parameters/profiles from UEDGE Case sn_34; Core power into the SOL = 6.0 MW, core-edge density = $4x10^{19}$ m^{-3}.

Temp-dependent lithium sputtering model (Allain).

Li^+ sputtered transport model with R=0.5, ε =2/3

Li atoms sputtered self-consistently from entire module surface by D^+ sputtering and self-sputtering.

VFTRIM-3D/random-collision-cascade sputtered velocity distribution (with cutoff energy determined by D^+ ion impingement energy and resulting maximum momentum transfer)

ADAS rate coefficients (Evans, Whyte) for electron-impact ionization of Li-I, Li-II, Li-III particles

[100,000 particles launched per simulation]

NSTX Li module erosion; Key Results:

- Self-sputtering yield exceeds unity at and near strike point.
- Overall self-sputtering is finite (non-runaway).
- Overall lithium sputtering is high.
- Lithium current to SOL/near-surface boundary is high.
- Module area < 1/10 divertor area helps.

WBC NSTX Lithium Analysis Case sn_34 Summary

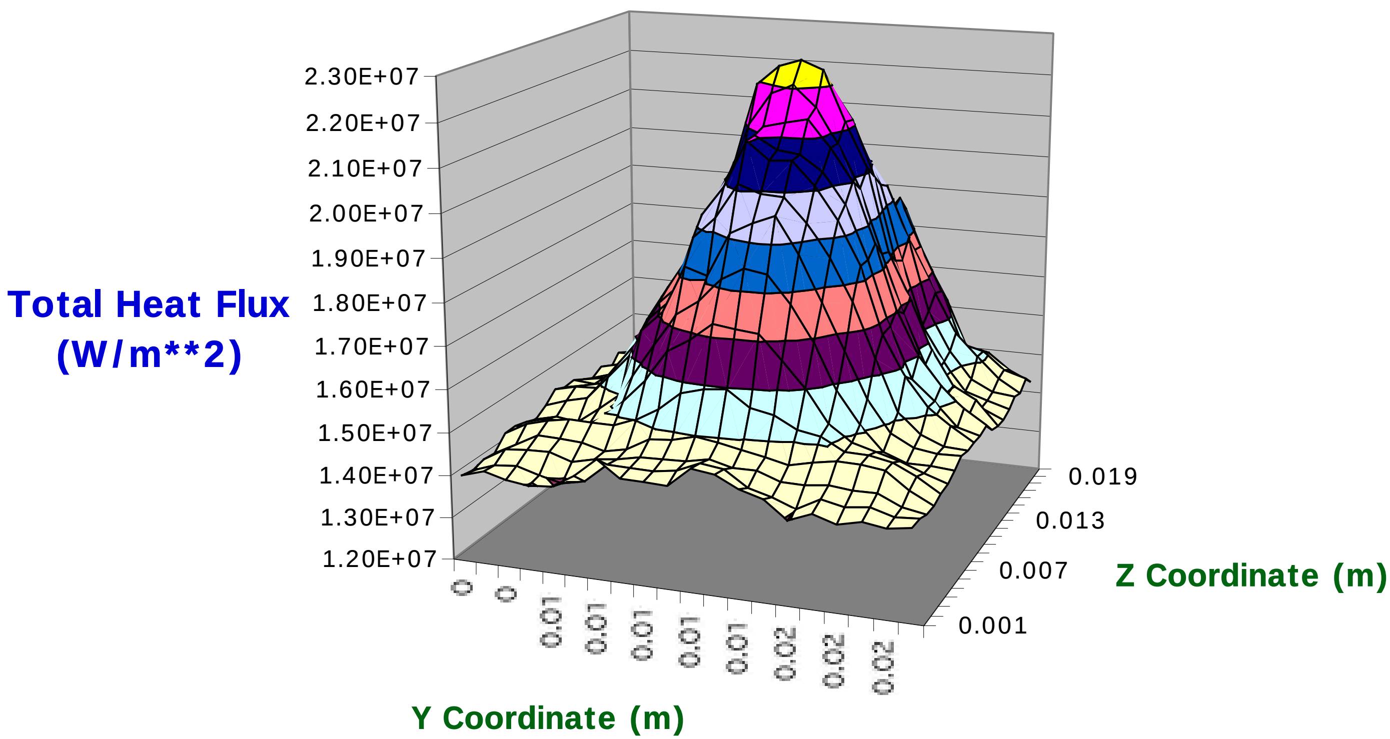
Parameter	Value
Peak electron temp., heat flux	~140 eV, 25 MW/m^2
Launch energy, average	10.4 eV
Charge state*	**1.002**
Angle of incidence* (from normal)	**20 ° (16°)**
Energy*	**85 eV (77 eV)**
Redeposition fraction on module	**0.63**
D+ sputtering fraction	**0.78**
Self-sputtering fraction	**0.22**
Fraction of sputtered lithium escaping the near-surface region (0-5 cm from plate)	**0.35**
Sputtered lithium atom current	**1.9×10^{21} Li/s**
D^+ ion current to divertor	**1.0×10^{23} D^+/s**
D^+ ion current to module	**7.5×10^{21} D^+/s**
Peak Li/D ion density ratio above module	**~ 0.5**

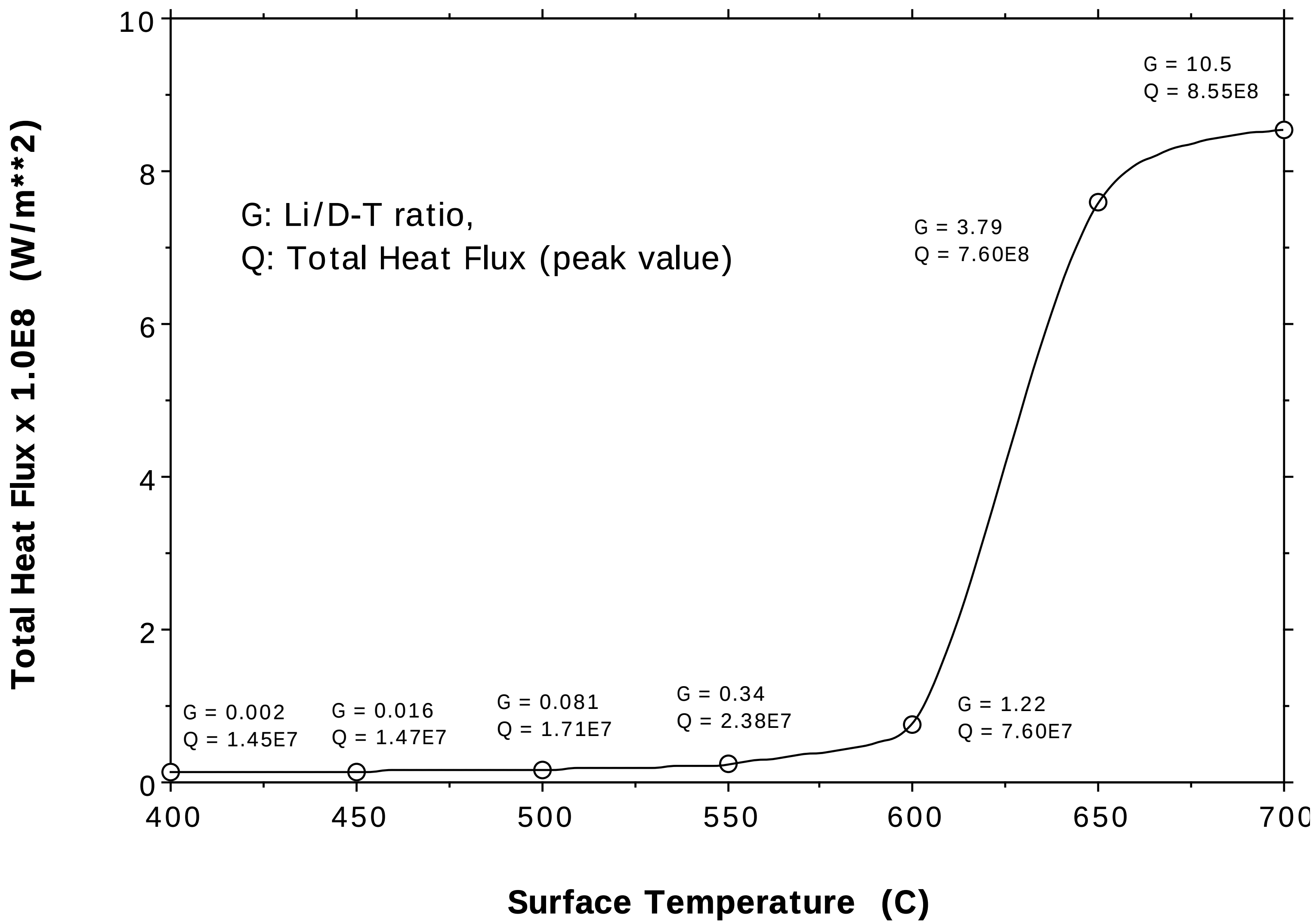
*average value (standard deviation) for redeposited ions

BPHI-3D Analysis: Lithium NSTX Module with 1 cm dia. circle hot-spot

Deuterium plasma, Te = 80 ev, Ti = 40 ev, Ts = 540 °C, B = 0.5 T,

Ne=1.e19 m-3, theta = 13 °, G = 0.25




G: Li/D-T ratio,
Q: Total Heat Flux (peak value)
G = 0.002
Q = 1.45E7
G = 0.016
Q = 1.47E7
G = 0.081
Q = 1.71E7
G = 0.34
Q = 2.38E7
G = 1.22
Q = 7.60E7
G = 3.79
Q = 7.60E8
G = 10.5
Q = 8.55E8
Total Heat Flux x 1.0E8 (W/m**2)
Surface Temperature (C)
0
2
4
6
8
10
400
450
500
550
600
650
700

Future Work

- Ongoing model improvements/coupling, e.g. MOLDYN results--WBC
- NSTX module, low power REDEP/WBC analysis, other high-power cases
- NSTX module coupled BPHI-3D/THERMAL-Code analysis of sheath/superheat
- Coupled WBC/UEDGE analysis of NSTX lithium transport in entire SOL
- CMOD lithium module analysis
- ARIES lithium divertor analysis

CONCLUSIONS

- **Sputtered lithium ion transport model developed.**

- **Integrated lithium erosion/redeposition analysis performed for proposed NSTX lithium module with high-power plasma case. Analysis shows high Li sputtering but probably non-runaway.**

- **Sheath superheat analysis initiated. Shows nature of sheath for NSTX low value, less oblique magnetic field. Shows possibly higher surface temperature limit for runaway-onset for NSTX plasma conditions.**

- **Next step = low-power cases, WBC/UEDGE coupling to compute sputtered lithium current to core plasma. Sheath analysis will further define temperature limits.**