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XP "NSTX-2011 performance with a pumping Liquid Lithium (LiLi) layer"

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Contents

1 Thickness of the LiLi layer

Reference parameters of the SoL strike zone:

	Value	
L_m	2.5	length (circumference) of the strike line
$q_{MW/m^2} \propto exp(-x^2/w^2)$	5-8.5	heat deposition profile
$2w_{cm}$	4-8	effective width of the strike zone
$P_{SoL,MW}$	0.4-1.5	Heating power from the SoL
$\frac{dN}{dt}$	10^{22}	Reference particle flux from the core, assuming $\tau_D \simeq 50\ ms$
$m_g \simeq 1.92_g \frac{dN_{22}}{dt} \Delta t^{pump}_{sec}$		Total amount of LiLi for pumping D$^+$, assuming 6 atomic % $m_g \simeq \frac{1}{0.06} \frac{A_{Li}}{6 \cdot 10^{23}} \frac{dN_{22}}{dt} \Delta t^{pump}_{sec}$
$d_{\mu m} \simeq \frac{145}{2w_{cm}} \frac{2.5}{L_m} \frac{dN_{22}}{dt} \Delta t_{sec}$		Corresponding thickness of the LiLi layer $d_{\mu m} = m_g/(0.53 \cdot 2w \cdot L)$

Performance of LITER evaporators

The basic requirement for evaporation is

$$m_g \simeq 1.92_g \frac{dN_{22}}{dt} \Delta t^{pump}_{sec} \qquad (1.1)$$

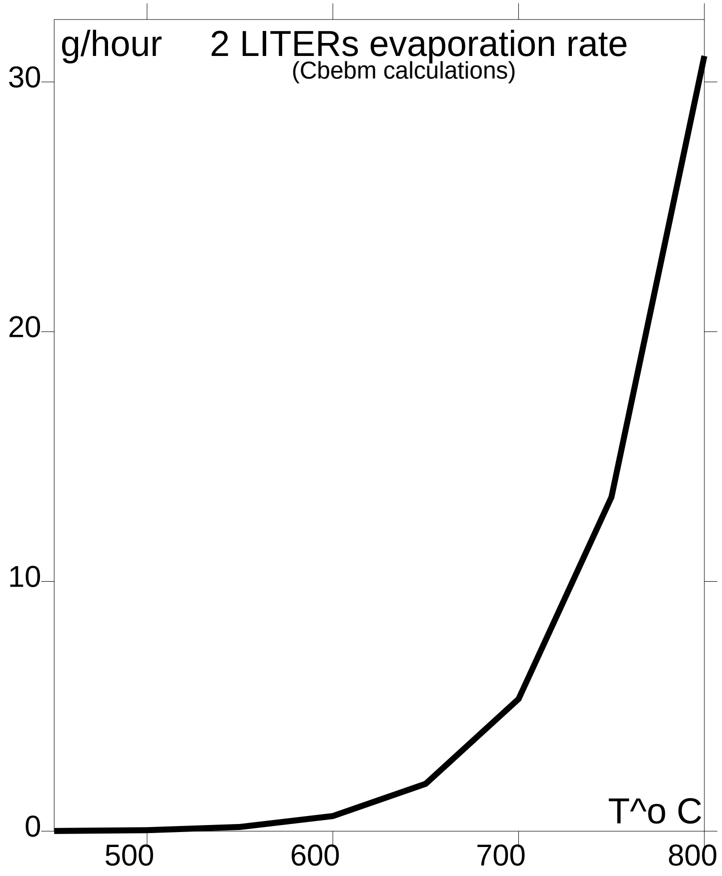


Fig.1. Total evaporation rate $R^{LITER}_{g/hour}$ of 2 NSTX LITER evaporators.

Only a small fraction of evaporated Li is delivered to the strike point zone. The necessary evaporation amount M_g from the LITERs

$$M_g \simeq \frac{m_g}{0.05} \frac{dN_{22}}{dt} \Delta t^{pump}_{sec},$$
$$t^{evap}_{hour} = \frac{38}{R^{LITER}_{g/hour}} \cdot \frac{15}{2w_{cm}} \frac{dN_{22}}{dt} \Delta t^{pump}_{sec} \qquad (1.2)$$

Technically it is doable

2 Thermal regime of the plates

The LiLi layer is costly in all aspects. It should be preserved for many shots.

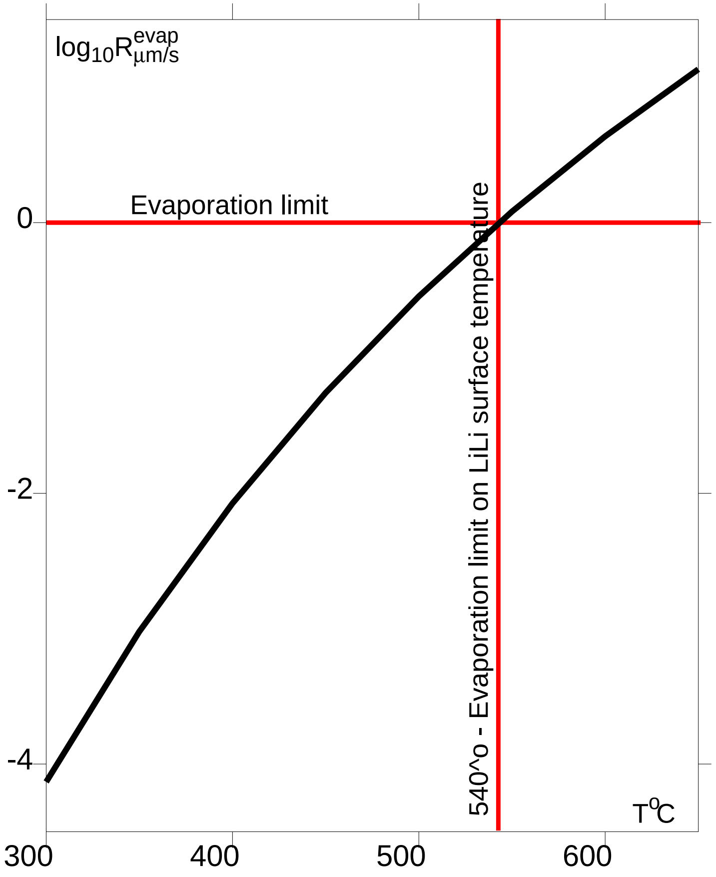


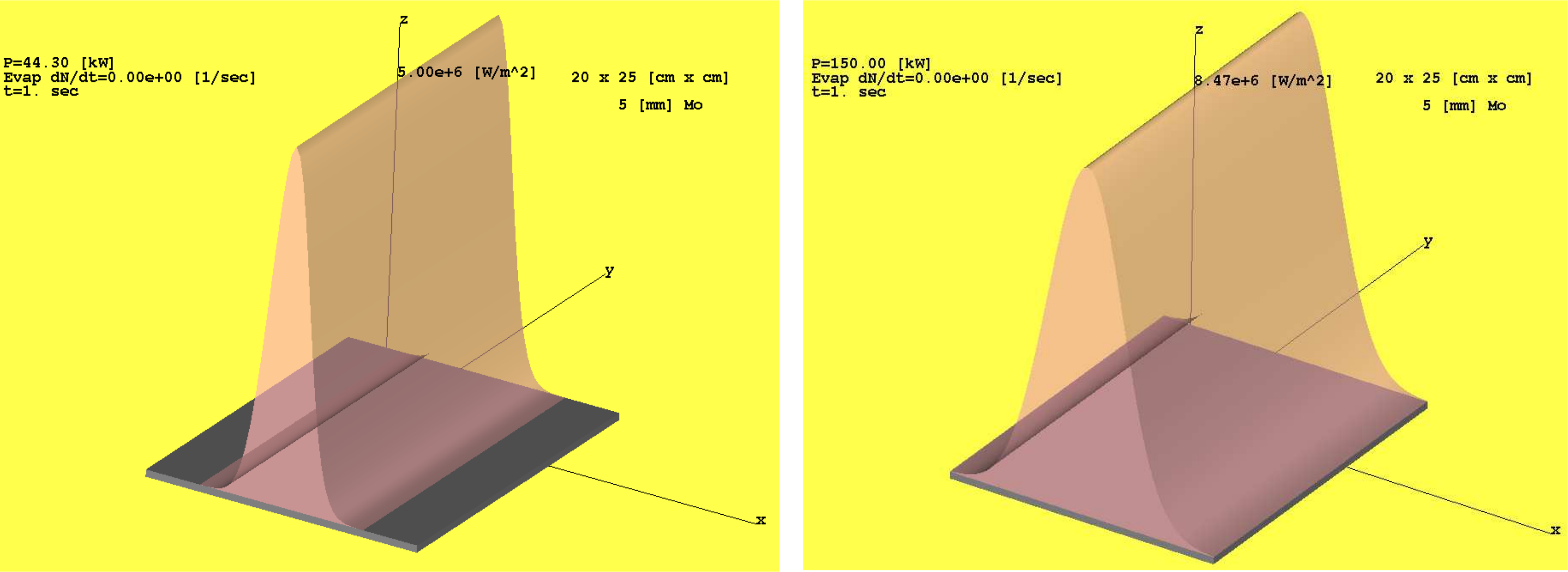
Fig.2. Log of evaporation rate $\ln_{10} R^{plate}_{\mu/s}$ from the LiLi surface as function of T^oC.

Evaporation becomes a concern when it can erode about 1 μm of LiLi per shot.

LiLi surface temperature should be kept below 540^o C

$$T^{LiLi} < 540^o\ C. \qquad (2.1)$$

Two cases of power deposition



(a) $\boldsymbol{P^{SoL} = 0.44}$ **MW,** $\boldsymbol{2w = 4}$ **cm**

(b) $\boldsymbol{P^{SoL} = 1.50}$ **MW,** $\boldsymbol{2w = 8}$ **cm**

Fig.3. Power deposition profiles

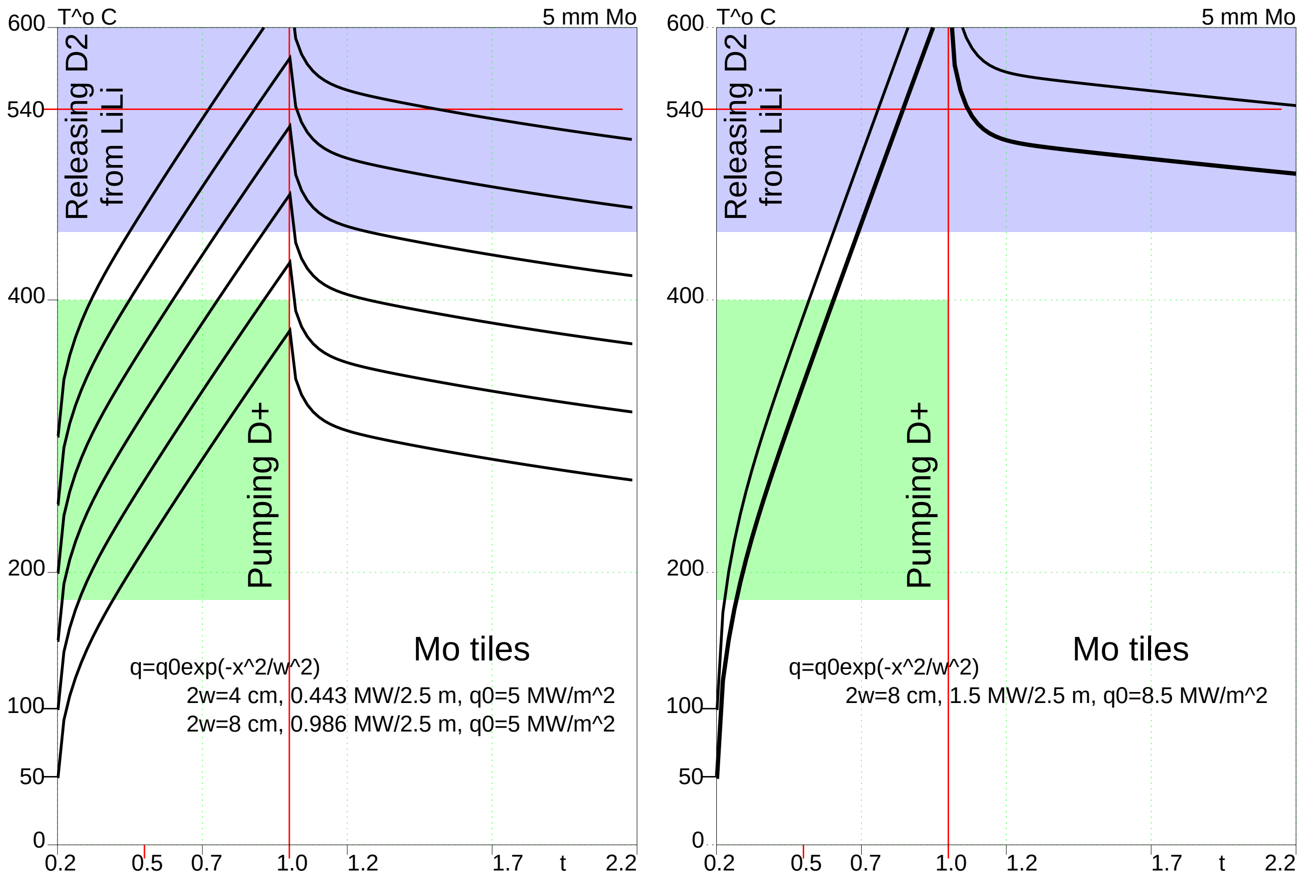
No gigantic heating power $P^{SoL} > 1.5$ *MW (for 2.5 m long strike zone) was considered. Allowable* $P^{SoL} \propto 2w$.

Thermal regimes of Mo tiles

Evaporation limitations leave a room for:

(i) pumping D^+ at $T^{LiLi} < 400^o$ and

(ii) releasing D_2 at $400^o < T^{LiLi} < 540^o$



(a) $P^{SoL} = 0.44$ MW, $2w = 4$ cm   *(b)* $P^{SoL} = 1.5$ MW, $2w = 8$ cm

Fig.4. Waveforms of LiLi temperature on the top of the Mo tiles for different initial temperatures ($\Delta T_0 = 50^o$ C) and heating interval 0.8 sec.

(a) $P^{SoL} = 0.44$ MW, $2w = 4$ cm

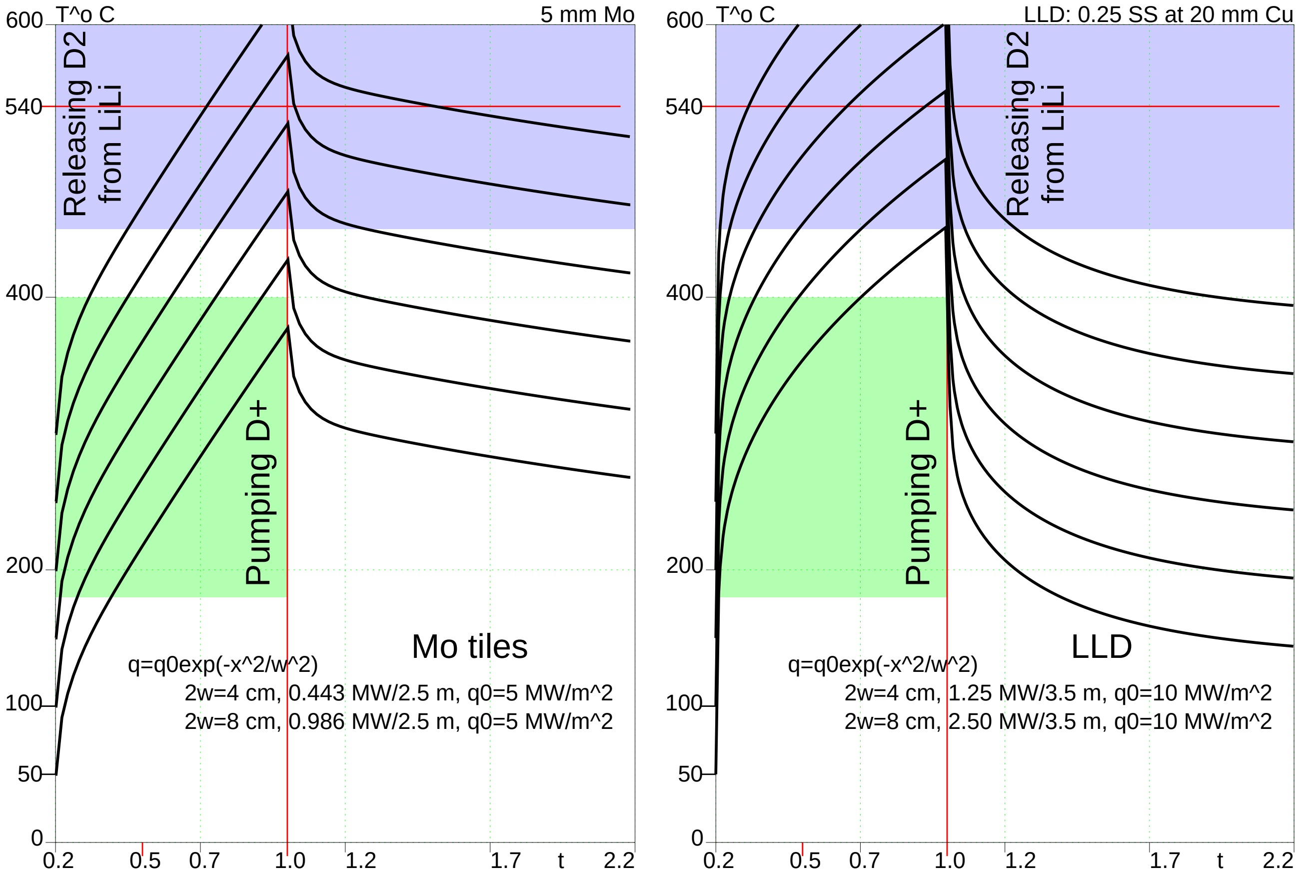
(b) $P^{SoL} = 1.50$ MW, $2w = 8$ cm

Both pumping D^+ and releasing D_2 can be combined either.

The real rate of releasing D_2 is unknown to me. It should be determined for designing the shots!!!

Thermal regimes of LLD

LLD has different than Mo tiles characteristics of the thermal regime



(a) Mo tiles $P^{SoL} = 0.44\ \mathrm{MW}/2.5\ \mathrm{m}$ *(b) LLD* $P^{SoL} = 1.25\ \mathrm{MW}/3.5\ \mathrm{m}$

Fig.5. Waveforms of LiLi temperature on the top of LLD for different initial temperatures ($\Delta T_0 = 50^o$ C) and heating interval 0.8 sec.

(a) Mo tiles $P^{SoL} = 0.44$ MW/2.5 m

(b) LLD $P^{SoL} = 1.250$ MW/3.5 m

SS of LLD makes combination of pumping/releasing more difficult than for Mo tiles.

3 Expected plasma performance

Recycling and the gas influx, NOT the core turbulence, determine the best possible confinement in tokamaks

Pedestal temperature (end of the confinement zone)

$$\frac{T_i^{edge}+T_e^{edge}}{2} \geq \frac{1-R^*}{1+(\Gamma^{gasI}/\Gamma^{NBI})} \cdot \frac{\left\langle E^{NBI}+P^{aux}/\Gamma^{NBI}\right\rangle}{5}, \qquad (3.1)$$

$$\left(\text{where} \quad R^* \equiv \frac{R_i^{ecycl}+R_e^{ecycl}}{2} + \frac{R_e^{ecycl}-R_i^{ecycl}}{2}\frac{P^{aux}}{P^{NBI}+P^{aux}}\right)$$

In simulations assessing the expected performance:

$$R_{eff}^{ecycl} \equiv \frac{1-R^*}{1+(\Gamma^{gasI}/\Gamma^{NBI})},$$

$$\frac{T_i^{edge}+T_e^{edge}}{2} \geq R_{eff}^{ecycl} \cdot \frac{\left\langle E^{NBI}\right\rangle}{5}, \qquad P^{aux}=0, \qquad (3.2)$$

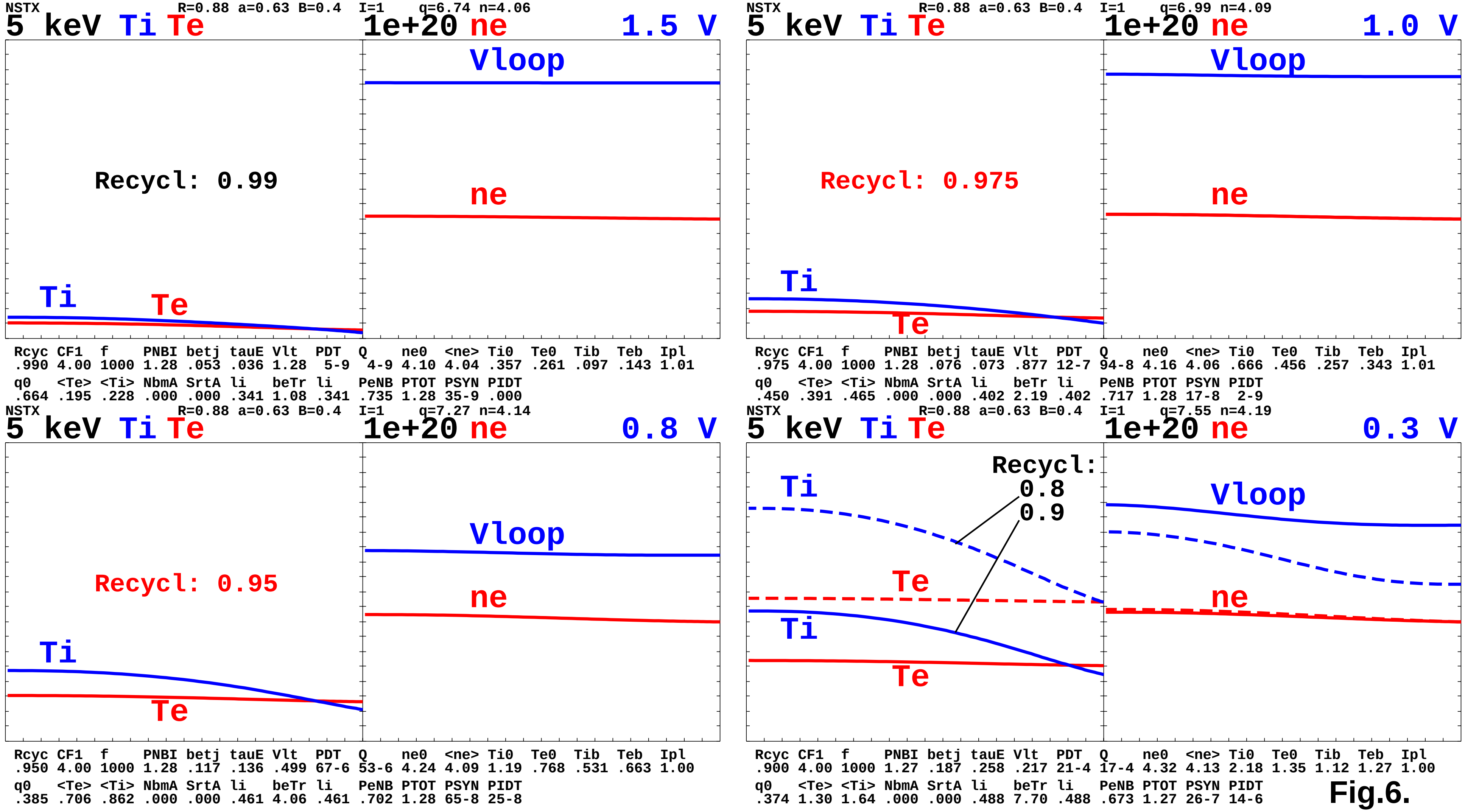
together with a Reference Transport Model

$$\chi_i = D = \chi_i^{neo}, \qquad \chi_e = 20\ m/s^2. \qquad (3.3)$$

Results of simulations (ASTRA)

R_{eff}^{ecycl} is the crucial parameter for performance: LiLi can provide $R^* \simeq 0.5$.

$\Gamma^{gas}/\Gamma^{NBI} \simeq 1$ is a challenge.



```
NSTX                R=0.88 a=0.63 B=0.4  I=1     q=6.74 n=4.06
5 keV Ti Te                              1e+20 ne          1.5 V
Rcyc CF1  f    PNBI betj tauE Vlt  PDT  Q    ne0  <ne> Ti0  Te0  Tib  Teb  Ipl
.990 4.00 1000 1.28 .053 .036 1.28  5-9  4-9 4.10 4.04 .357 .261 .097 .143 1.01
q0   <Te> <Ti> NbmA SrtA li   beTr li   PeNB PTOT PSYN PIDT
.664 .195 .228 .000 .000 .341 1.08 .341 .735 1.28 35-9 .000
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NSTX                R=0.88 a=0.63 B=0.4  I=1     q=6.99 n=4.09
5 keV Ti Te                              1e+20 ne          1.0 V
Rcyc CF1  f    PNBI betj tauE Vlt  PDT  Q    ne0  <ne> Ti0  Te0  Tib  Teb  Ipl
.975 4.00 1000 1.28 .076 .073 .877 12-7 94-8 4.16 4.06 .666 .456 .257 .343 1.01
q0   <Te> <Ti> NbmA SrtA li   beTr li   PeNB PTOT PSYN PIDT
.450 .391 .465 .000 .000 .402 2.19 .402 .717 1.28 17-8  2-9
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NSTX                R=0.88 a=0.63 B=0.4  I=1     q=7.27 n=4.14
5 keV Ti Te                              1e+20 ne          0.8 V
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.950 4.00 1000 1.28 .117 .136 .499 67-6 53-6 4.24 4.09 1.19 .768 .531 .663 1.00
q0   <Te> <Ti> NbmA SrtA li   beTr li   PeNB PTOT PSYN PIDT
.385 .706 .862 .000 .000 .461 4.06 .461 .702 1.28 65-8 25-8
```

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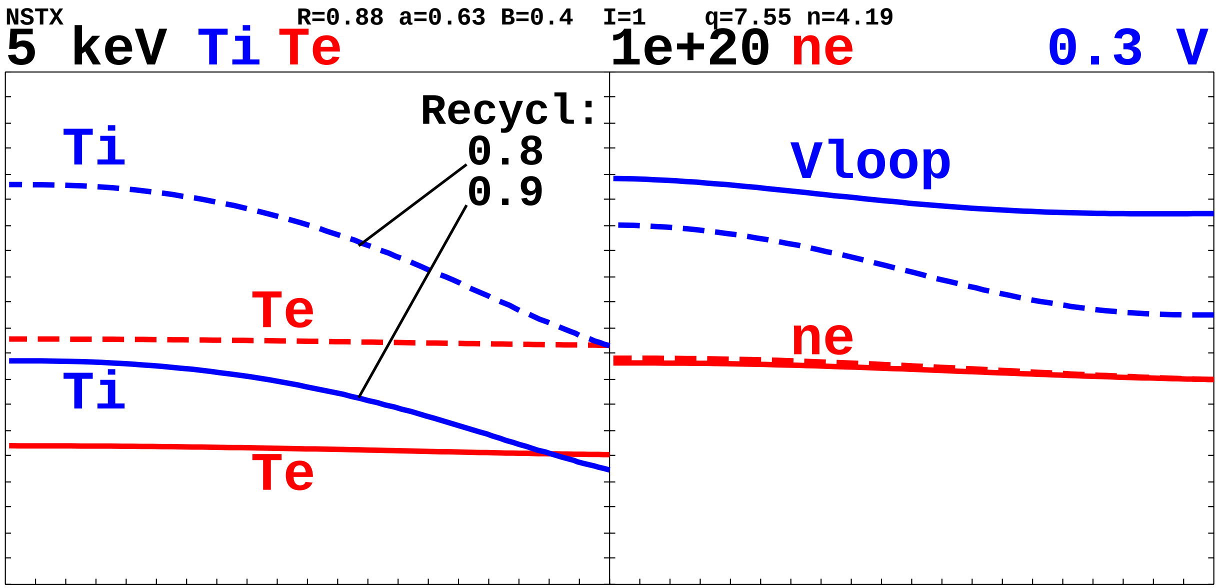
NSTX                R=0.88 a=0.63 B=0.4  I=1     q=7.55 n=4.19
5 keV Ti Te                              1e+20 ne          0.3 V
Rcyc CF1  f    PNBI betj tauE Vlt  PDT  Q    ne0  <ne> Ti0  Te0  Tib  Teb  Ipl
.900 4.00 1000 1.27 .187 .258 .217 21-4 17-4 4.32 4.13 2.18 1.35 1.12 1.27 1.00
q0   <Te> <Ti> NbmA SrtA li   beTr li   PeNB PTOT PSYN PIDT
.374 1.30 1.64 .000 .000 .488 7.70 .488 .673 1.27 26-7 14-6
```

Fig.6.

4 Summary: XP objective

For high plasma performance the reduction of R^{ecycl}_{eff} (low recycling and gas influx) is much more important than the high P^{NBI} of core turbulence studies.



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Rcyc CF1  f    PNBI betj tauE Vlt  PDT  Q    ne0  <ne> Ti0  Te0  Tib  Teb  Ipl
.800 4.00 1000 1.27 .292 .492 .078 .033 .026 4.42 4.17 3.90 2.40 2.33 2.33 1.00
q0   <Te> <Ti> NbmA SrtA li   beTr li   PeNB PTOT PSYN PIDT
.375 2.36 3.08 .000 .000 .513 14.4 .513 .630 1.27 99-7 38-5
```

Fig.7a. High performance with $P^{NBI} = 1.5$ MW

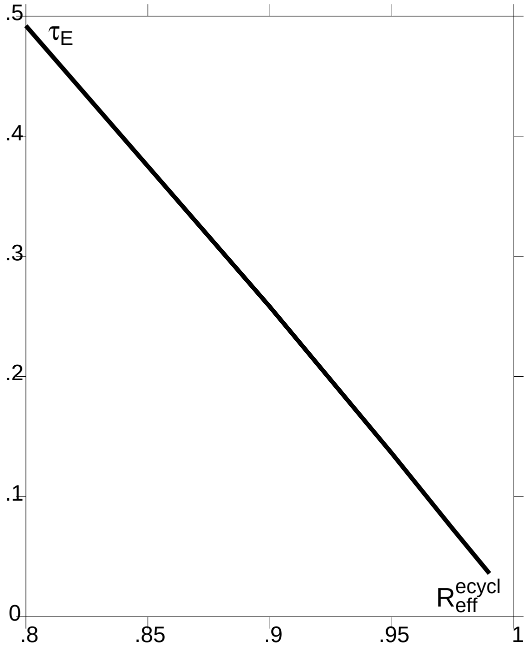

Fig.7b. τ_E vs R^{ecycl}_{eff}

The current XP, synchronized with others and potentially affecting the entire physics of NSTX, can introduce new physics and LiWF regimes in tokamaks.