Upward facing Lithium Flash Evaporator for NSTX_U*

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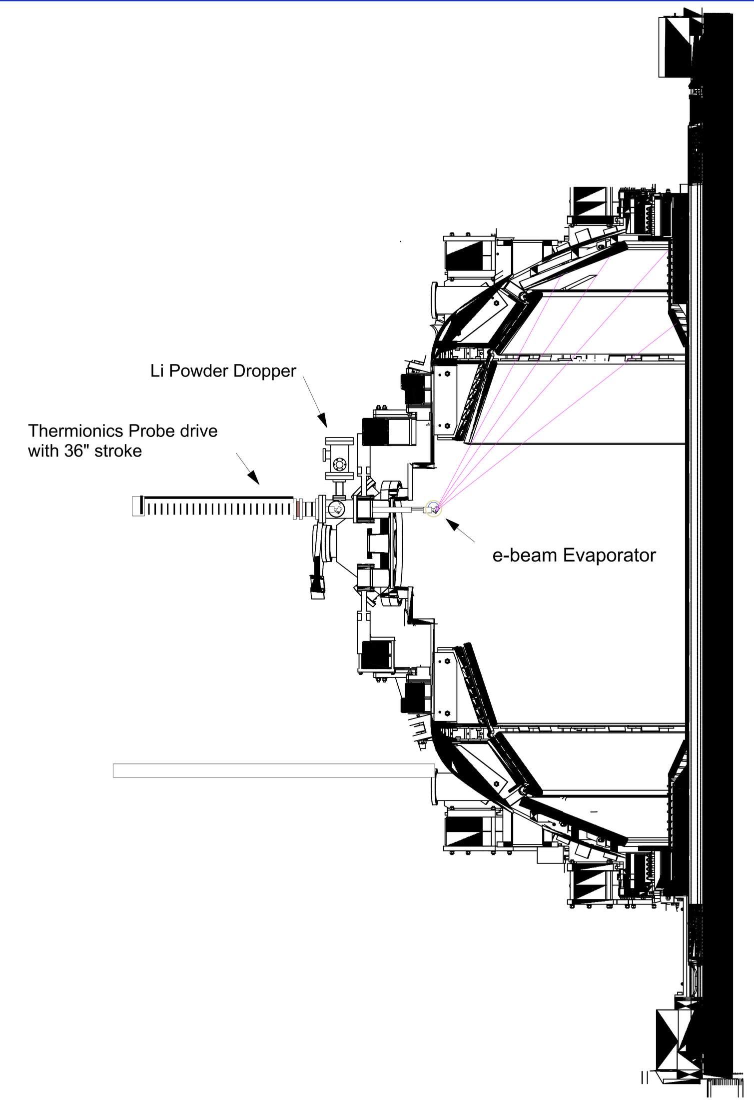
Abstract

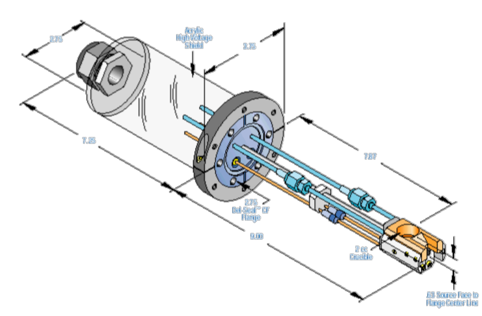
NSTX plasma performance has been significantly enhanced by lithium conditioning.[1]
To date, the lower divertor and passive plates have been conditioned by downward facing lithium evaporators (LITER) as appropriate for lower null plasmas. The higher power operation expected from NSTX _U requires double null plasma operation in order to distribute the heat flux between the upper and lower divertors making it desirable to coat the upper divertor region with Li as well. An upward aiming LITER (U-LITER) is presently under development and will be inserted into NSTX using a horizontal probe drive located in a 6" upper port of one of the large midplane port covers. The operation of the evaporator is designed to minimize coatings on diagnostic windows. In the retracted position the evaporator will be loaded with up to 300 mg of Li granules utilizing one of the calibrated NSTX Li powder droppers[2]. The evaporator will then be inserted into the vessel in a location within the shadow of the RF limiters and will remain in the vessel during the discharge. About ~10 seconds before a discharge it will be rapidly heated and the lithium completely evaporated, thus avoiding the complication of a shutter to prevent evaporation during the shot when the diagnostic shutters are open. The minimal time interval between the evaporation and the start of the discharge will avoid the passivation of the lithium by residual gases and enable the study of the conditioning effects of un-oxidized lithiated surfaces. The evaporator will be withdrawn, reloaded with Li granules and reinserted during the inter-shot interval.

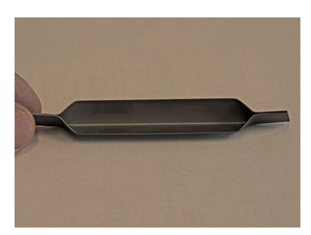
Two methods are being investigated to accomplish the rapid (few second) heating of the lithium. A resistive method relies on passing a large current through a Li filled tungsten crucible. A second method requires using a 3 kW e-beam gun to heat the Li. In this paper the evaporator systems will be described and the pros and cons of each heating method will be discussed.



Goals for the flash evaporator:

- Electron beam
  - It will require about 6.18 kJ to heat this from room temperature (20 °C) to boiling temperature
  - With a 3kV electron beam it will take about 2.7 s to achieve this.
    - A rough calculation of evaporation rate, gives 387 $gm^{-2}s^{-1}$
    - Intention is to evaporate approximately 300 mg of lithium (an aspirins worth)
      - So to evaporate this it will take about 0.7 s
    - Total time to melt and evaporate 3.5 s
- Resistive Heating
  - Tungsten boat m_W = 15 g
  - Current I = 500 A
  - Voltage V = 3 V
  - Power P = 1500 W
  - Requires about 2700 J to go from 20 °C to 1342 °C
    - It will take about 1.8 s to heat the tungsten boat to the boiling temperature of lithium.
  - Assuming that Li also melts to this temperature in roughly the same time and the evaporation rate is the same as above
    - 2.5 – 3 s to flash evaporate





Comparison between Resistive and e-beam heaters

Resistive Evaporator	E-beam Evaporator
Pros	Pros
Industry Standard	Industry Standard
Flash evaporate in ~2 seconds	Flash Evaporate in <1 sec
No concern about B-fields	No cool-down period
	Rough aiming by using deep crucible
	Power density is controllable
	Reload every ~4 shots
Cons	Cons
Difficult to aim to specific locality	Requires in-vessel Helmholtz coils
Requires high I in-vessel (500 amps)	
May evaporate crucible material	
Need to reload every discharge	

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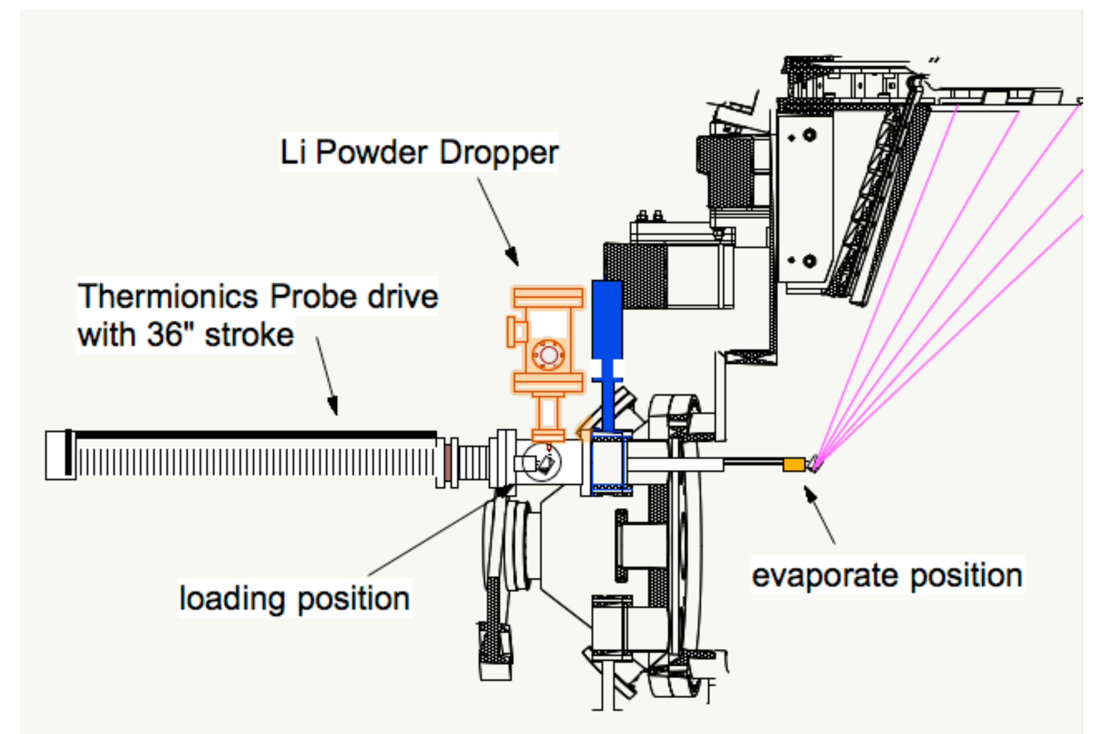
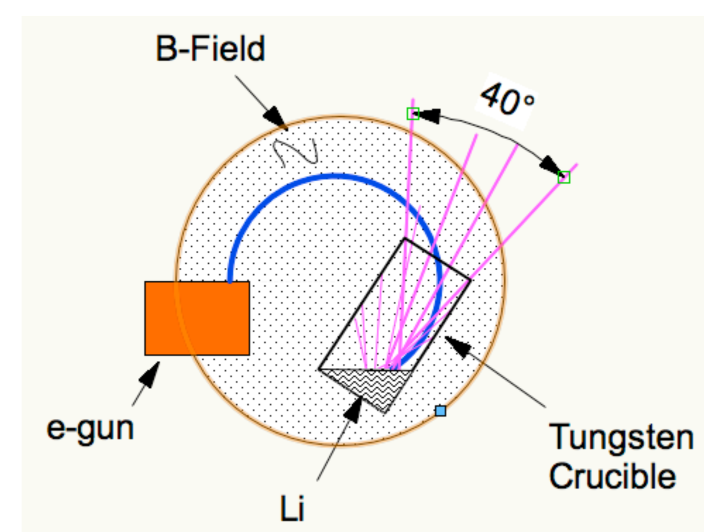
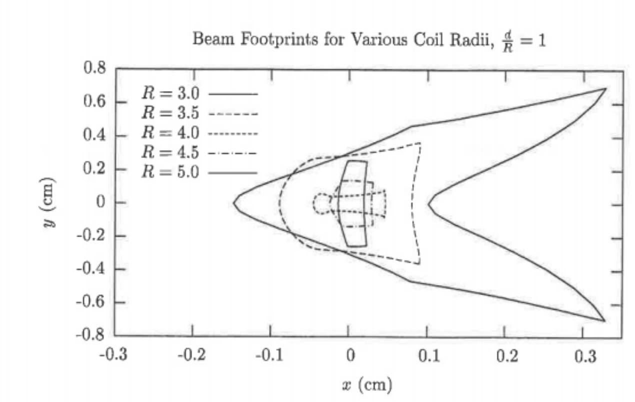




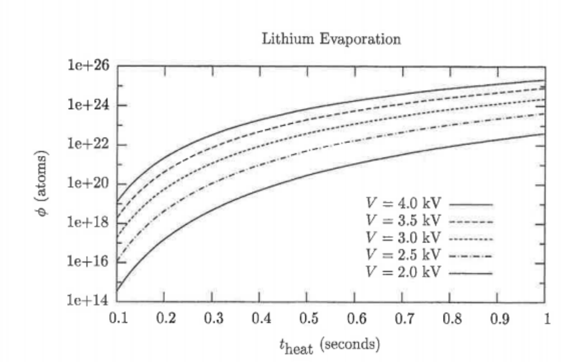
Crucible orientation to coat upper divertor. Ratio of crucible depth to opening is 2:1 and allows a 40 degree spray.

Beam Footprint as function of Helmholtz coil radius

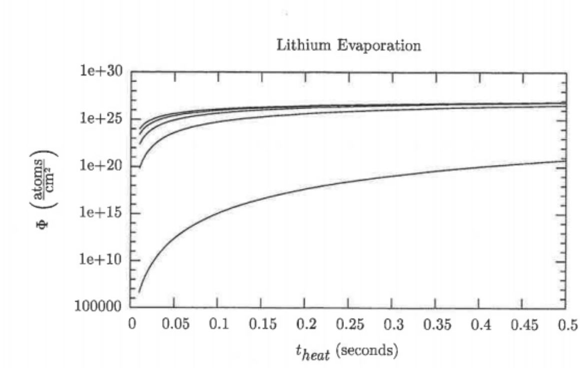


Larger footprint reduces power density and eliminates need for beam sweeping

Lithium Evaporation rate for different beam energy



Vary Accel Voltage, fixed current at .75 Amps

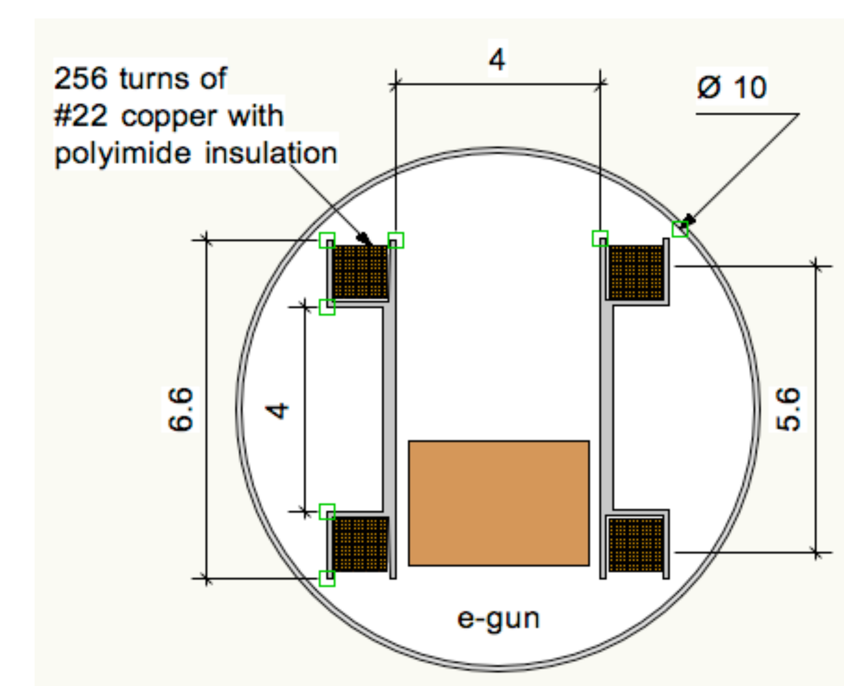


Vary Total Power density From 10, 80,150, 225 300 MW/m^2

- Cannot use permanent magnets inside NSTX-U
- Specifications for the magnetic field
  - E_e = 3-5 kV electron beam
  - Diameter d = 30 mm (1")
    - Upper limit
  - For a beam to be bent with a 30mm diameter will require a magnetic field of:
  - B = 90-150 gauss
- Magnetic field will be provided by electromagnets
  - Set of Helmholtz Coils
  - 57.15 mm (2.25") average diameter
  - 10 mm wide
  - Assume ~2 A to go through the coils. How many turns (N) are needed.
- Parameters
  - Current, I = 2 A
  - Resistance, R = 2.4 A
  - Voltage, V = 4.8 V
  - Power, P = ~ 10 W
- N = 216 turns required for each coil.

What is the over all temperature increase, ΔT, for a 10s pulse of the U-LITER (These are maximum parameters).

- Calculations show that, a rise of ΔT = 2 °C rise in the temperature
- A full run day:
  - 40 shots
  - 10 s to run the Helmholtz coils
  - Assume radiative cooling between shots
  - Will eventually have a 80 °C temperature rise
    - T_{tot} = 100 °C
  - Acceptable for vacuum compatible polyamide coated wire.



Helmholtz configuration

Comparison between Present LITER and U-LITER

	LITER	U-LITER
Probe Required	Yes	Yes
Shutter Required	Yes	Yes
Evaporation time	600 sec	<1 sec
Aiming direction	down only	Up/down
Cool-down time	120 minutes	0 sec (Surface heating only)
Efficiency (Li use)	60%	100 %
# shots/fill	250	250
Reload time	48 hours	4 hours
Evaporation stop time before onset of discharge	**2 minutes (time for Li to begin passivating)**	**5 seconds (time to open shutters)**

** E-beam calculations performed as partial fulfillment of Bachelor of Science degree at Drexal University