Density Control in NSTX by In-vessel Cryopumping

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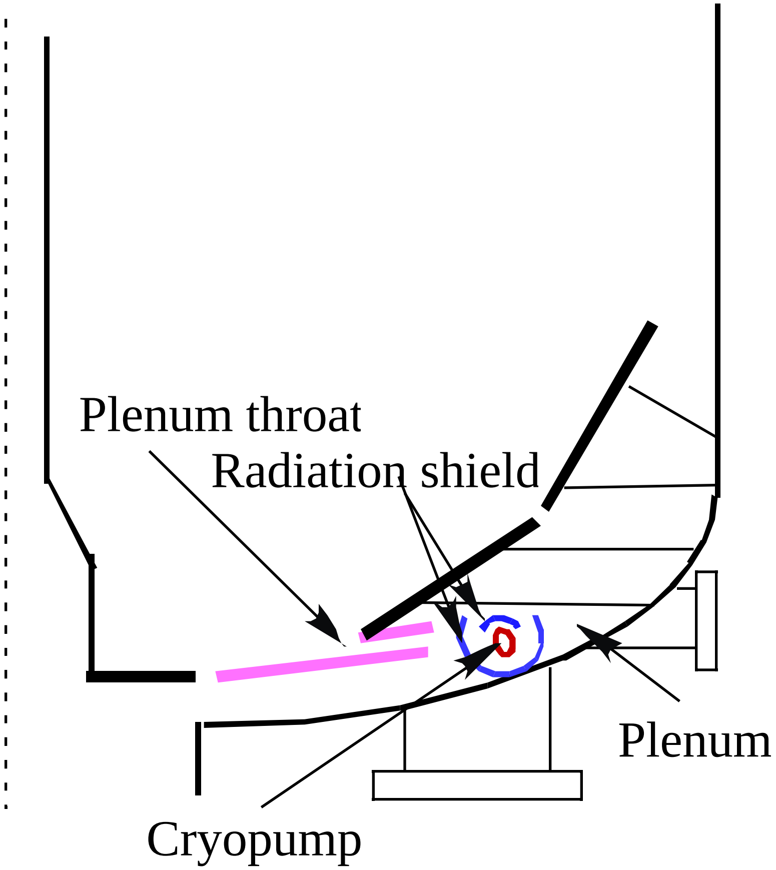
How much particle exhaust is needed in NSTX?

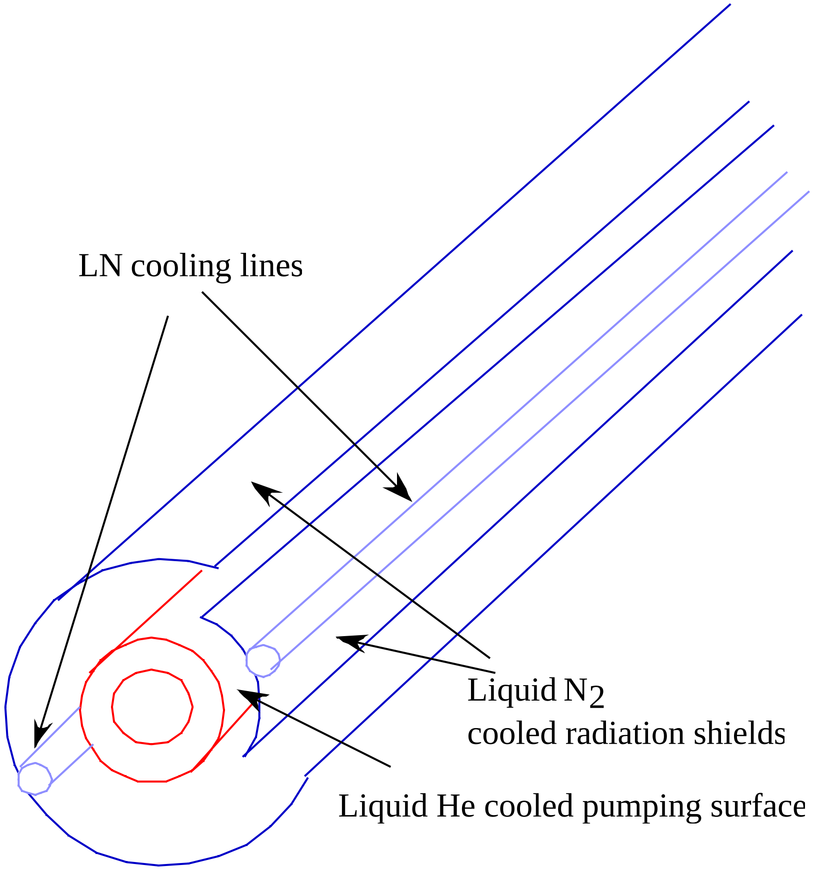
- The minimum exhaust needed would be equal to the NBI fueling rate, since the gas puff, in principle, can be reduced to zero.
- The NBI fueling is proportional to the injected current (0.174 torr l.s^{-1} per A).
- At 80 keV, assuming 80% full energy, 15% half energy, and 5 % one/third energy species mix from the ion source, 5 MW of injected power would correspond to 14 torr l s^{-1} of deuterium atoms.
- Assuming 100 % recombination inside the pumping plenum, a minimum of 7 torr l s^{-1} of deuterium molecules would be the goal.

In-vessel cryopumping is attractive because it would provide efficient, reliable, and uniform pumping.

A toroidal liquid He cooled loop, similar to the DIII-D ADP, at R = 1.2 m would provide a pumping speed of > 24,000 l/s.



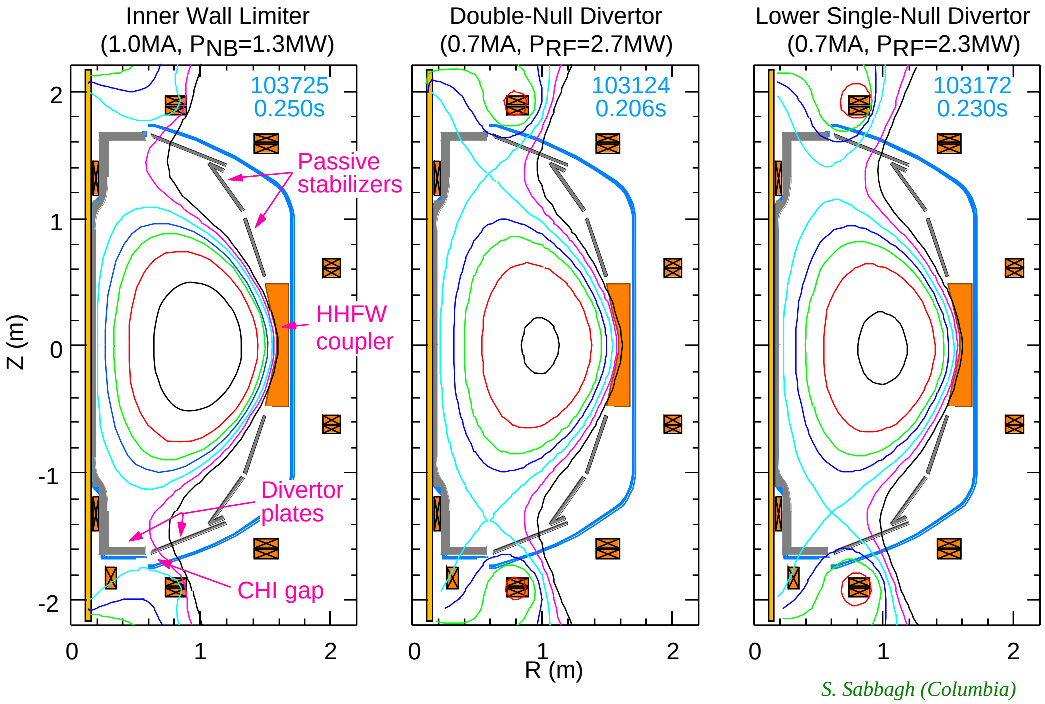
Essential components of the cryopump



There are some concerns with the current divertor configuration, from particle exhaust point of view.

- The separatrix strike point of the outer divertor appears to be too far from the plenum throat.
- The ability to move the strike point closer towards the divertor throat seems limited.

Variety of Configurations Produced


Inner Wall Limiter (1.0MA, P_{NB}=1.3MW)

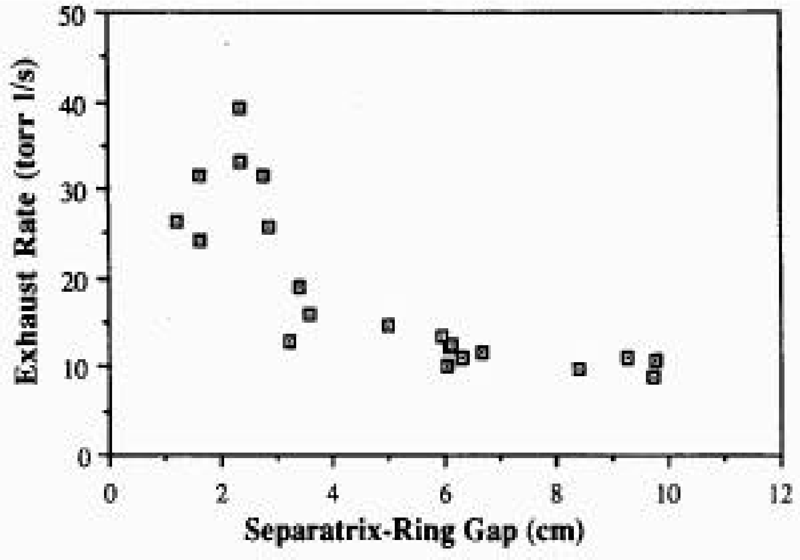
Double-Null Divertor (0.7MA, P_{RF}=2.7MW)

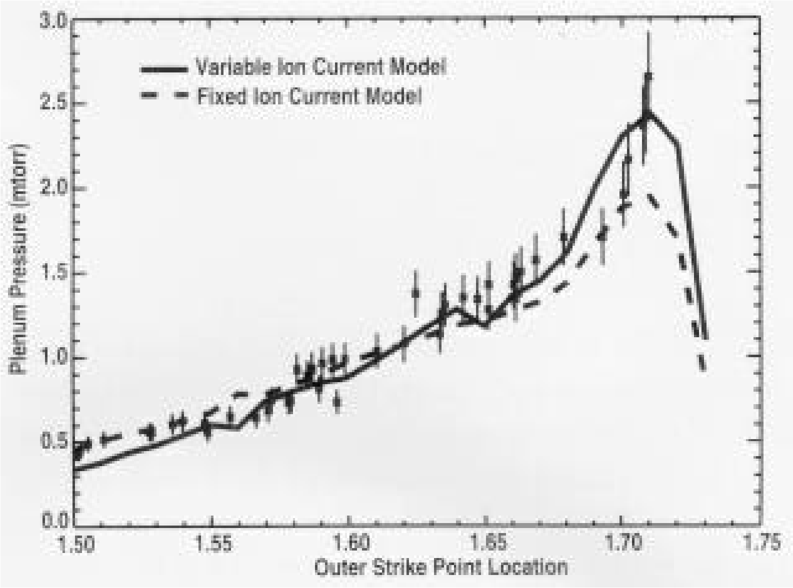
Lower Single-Null Divertor (0.7MA, P_{RF}=2.3MW)

S. Sabbagh (Columbia)

M. Bell et al., "Fuelling and Wall Conditioning Issues in NSTX", in Proceedings of the IEA workshop:http://www.pppl.gov/~mbell/IEA-W45/.

Experimental and modeling works in DIII-D show strong dependence of plenum pressure on separatrix strike position.



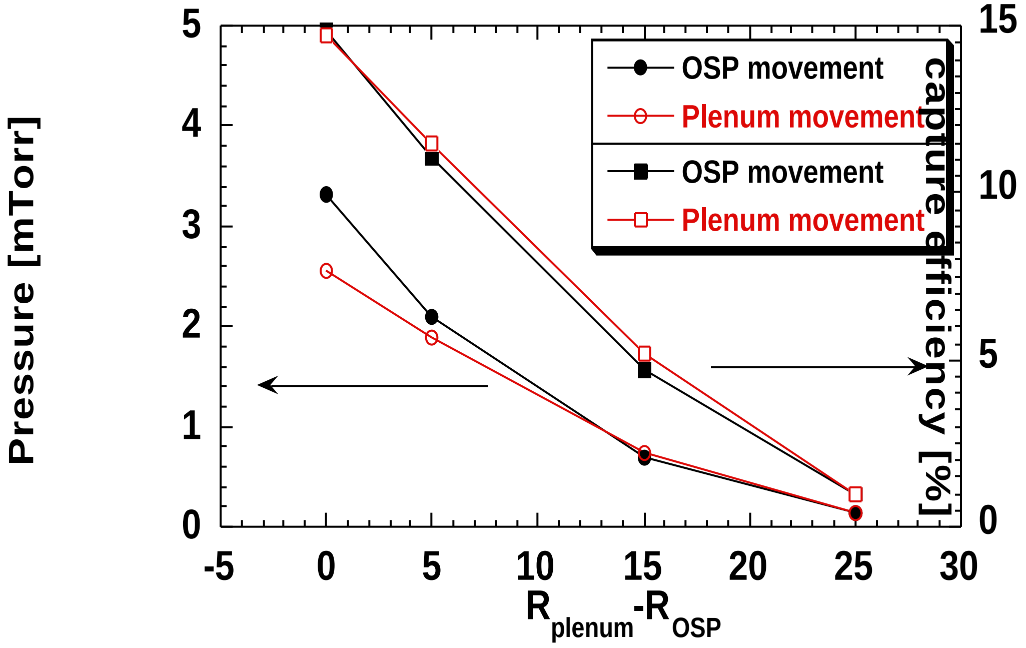


M. M. Menon, et al., Fusion Technology, 37, 355 (1995)

R. Maingi, et al., Nuclear Fusion, 39, 1187 (1999)

A simplified simulation in NSTX shows strong dependence of exhaust efficiency on separatrix position.

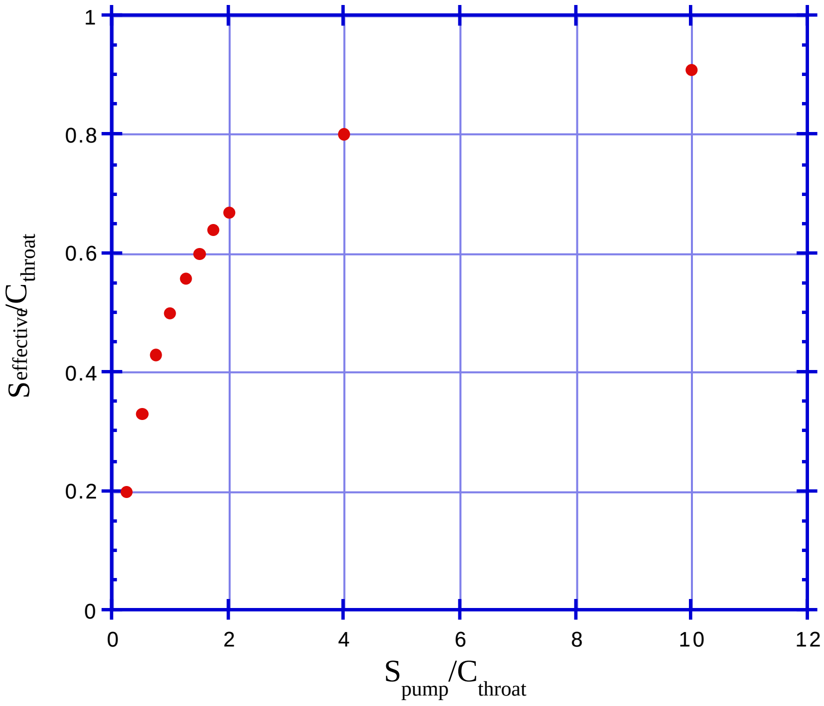
(conducted by R. Maingi & L. W. Owen)



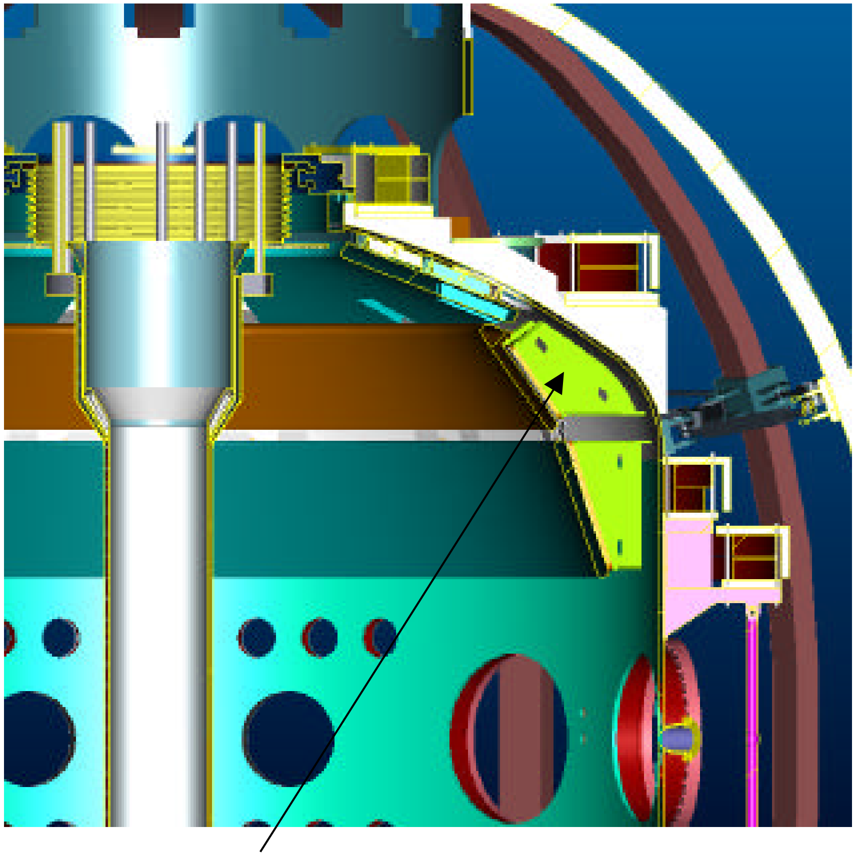
- EFIT from Shot # 104316 @ 230 ms
- Same ne/Te profiles as in DIII-D.
- Throat conductance (C) is 20,000 l/s.
- No pumping. Pumping will reduce pressure by the factor (C/C+S), S being the speed of the pump.

The pumping speed of the in-vessel pump should be at least equal to the plenum throat conductance of 21,000 l/s

- The effective pumping speed is decided by the combination of the throat back conductance and the pumping speed of the pump.
- Due to the asymptotic nature of the curve on the right, designing a pump with a pumping speed much higher than the plenum throat conductance does not make much sense.



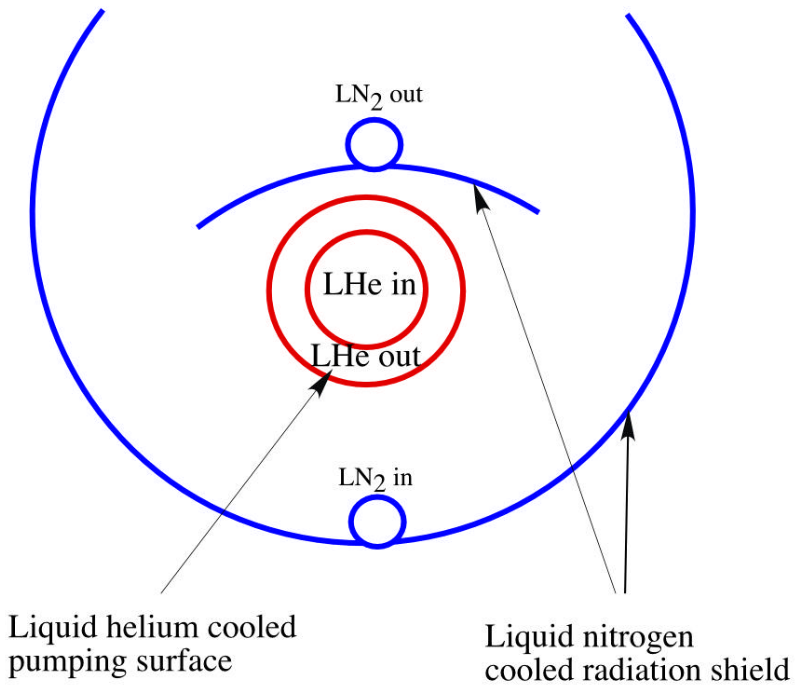
Required mechanical modifications



Passive plate support

- There are 12 supports for the passive plates blocking the path of the pump in the plenum chamber. A redesign of these supports is necessary.
- The plenum should be closed at all places except at the throat. Any opening needed for diagnostics should be small compared to the divertor throat opening of 2000 cm^2.
- The throat, being narrow (2.8 cm) and long (13.6 cm), has a conductance of only 21,000 l/s. The conductance of any other opening would compete with the pump.
- A new closed plenum enclosing the pump and the secondary passive plate?

A configuration, similar to the DIII-D ADP, is suitable for particle exhaust in NSTX

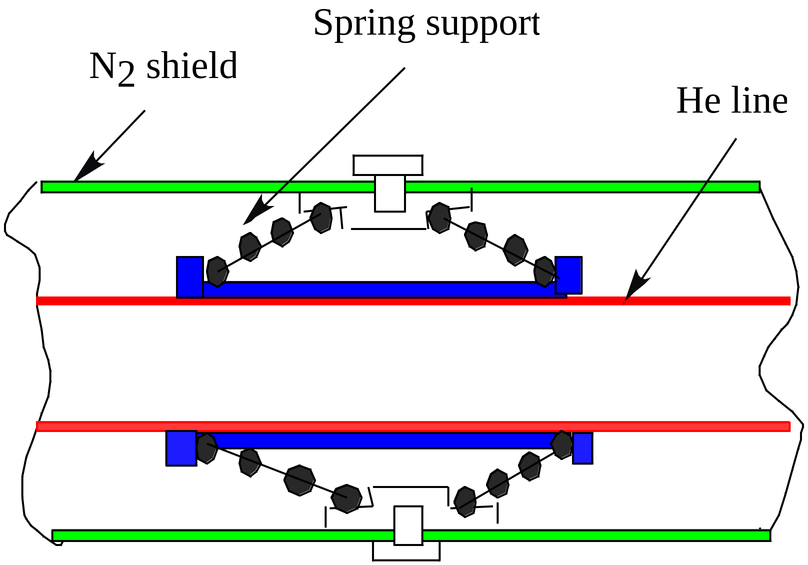


Cross-section of the pump (10 cm outer dia.)

- Proven design base.
- Simplicity in construction.
- High pumping speed.
- Easy to regenerate.
- Easy to turn on and off.
- Ability to pump in a wide range of pressure (up to tens of millitorr).
- D_2 pumping speed of 24,000 l/s (2.5 cm OD, 750 cm long, 0.9 mm thick wall Inconel 625 pumping surface, surrounded by 10 cm OD shield)

In the DIII-D pump, special metallic springs were used to suspend the LHe line within the LN cooled radiation shield

- Low thermal heat leak to He.
- Shock-proof support.
- Permits differential expansion/contraction during thermal cycling.
- Baking and UHV compatible.



Two design approaches may be considered

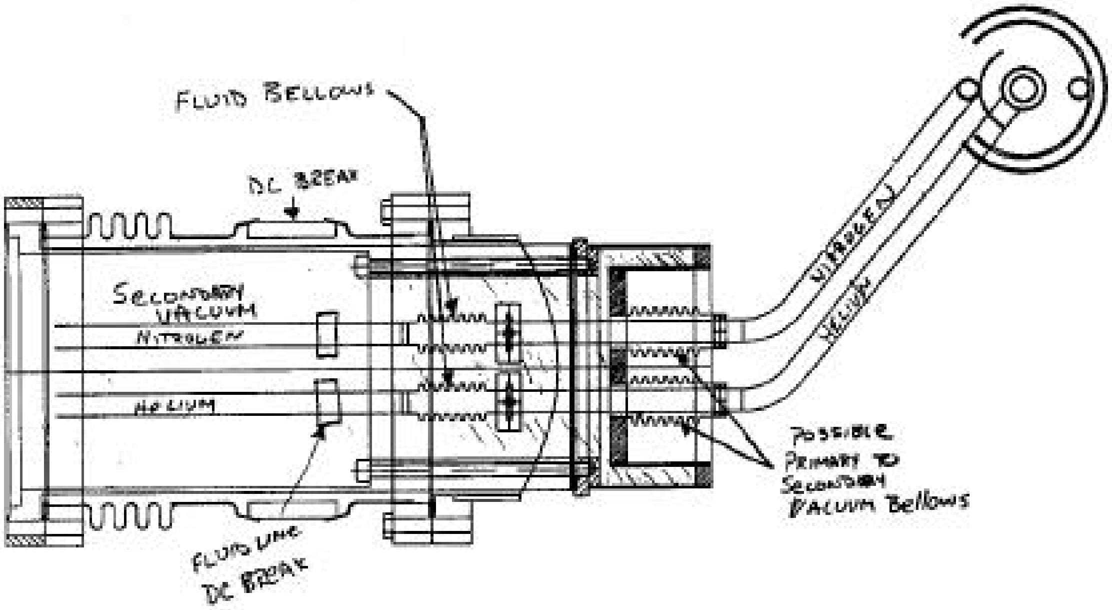
- A closed loop inside the torus
  - Proven design.
  - Induced currents in the loop during plasma ramp-up would introduce significant heat loading to the cryogenic circuit.
  - Induced currents during disruptions would introduce significant electromagnetic forces.

Complicates the design and increases the cost.

- An open loop in the torus
  - Significantly lower heat loading.
  - Possibility of arcing during plasma disruptions if voltage buildup in the pumping loop exceeds the Paschen minimum.
  - The uncertain effects on arcing due to the magnetic field, coupled with the possibility of charged particles inside the plenum.

Simpler design and perhaps increased risk.

Cryogens can be introduced through single port using an appropriate feedthrough



- Liquid helium requirement per pump would be about 5 g/s (2.4 l/m) or less depending on the pump design.

Summary & conclusions

- In-vessel cryopump is attractive for particle exhaust in NSTX.
- A toroidal pumping loop made of a thin walled inconel tube of 2.5 cm diameter, surrounded by a radiation shield of about 10 cm diameter, located at R = 1.2 m, would provide a pumping speed of 24,000 l/s.
- The particle exhaust is decided by the product of pressure and pumping speed. Plenum pressure is strongly dependent on the separatrix position relative to the plenum throat. By bringing the separatrix close to the plenum throat, an exhaust rate of 10 - 20 torr l/s appears possible.
- All gaps between the passive plates should be closed as any such gap would compete with the pump.
- The supports for the secondary passive plate (outer divertor) blocks the installation of the pump, and hence needs redesign.
- Evaluate a new plenum (sub-chamber) integrating the pump and the secondary passive plate.