NSTX

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NSTX-U Physics Ops NBI Overview
(Part 2)

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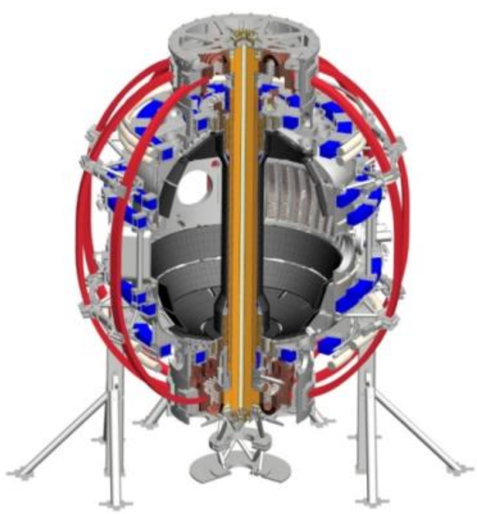
Timothy N. Stevenson

NBI



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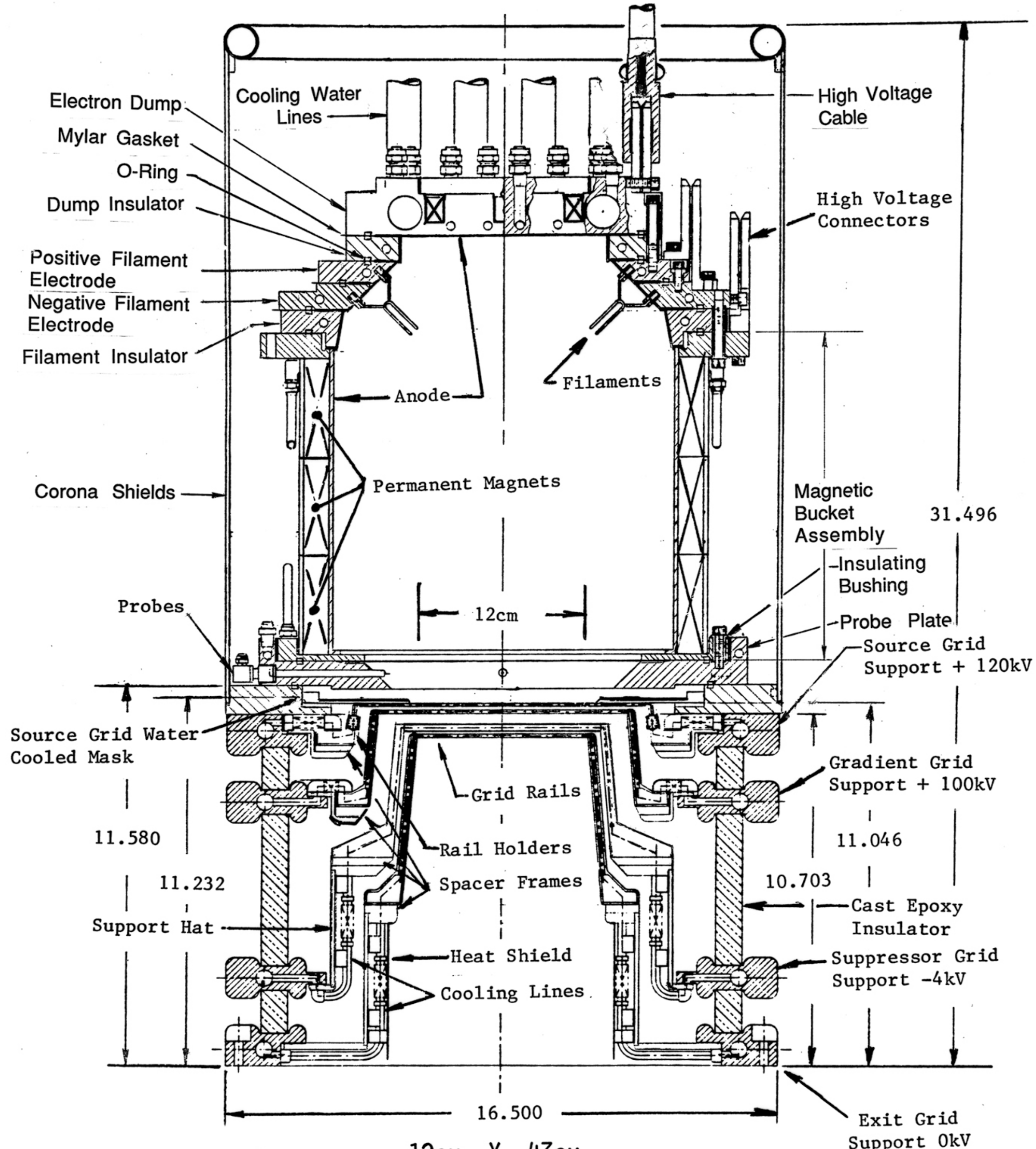


12CM X 43CM
LONG PULSE SOURCE ASSEMBLY


CAUTION

NBI Duct

Reionization Losses

There can occur losses due to reionization in the beam which is a function of background gas density, distance, and cross-section. This phenomena lowers the delivered power to the torus. Cryogenic pumping panels and large diameter ducts minimize this effect.

$$I_{remaining} = I_0 e^{-n \sigma L}$$

n = Gas density

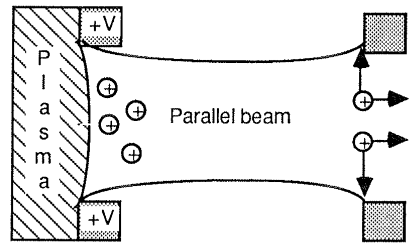
σ= Ionization cross-section

L = Path length

Tuning

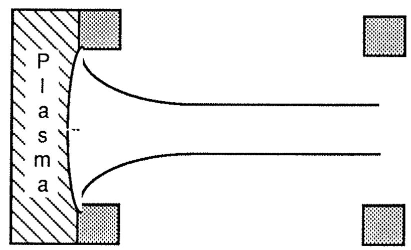
The process of tuning a beam can be physically described by imaging a balance between arc power and accel voltage. The balance is essentially between space charge blow-up effects at the plasma boundary and the electric field strength determined by the grid potential, grid shape, and grid spacing. It is important to note that the grid geometry represented in the following as square is actually a complex shaping used to establish field lines such that the extracted ion beam will be focused and not deflected. This occurs when the electric field creates a boundary condition such that ions near the boundary see the same field as if they were in the center of the aperture. This concept and resulting grid shaping is refered to as Pierce geometry, named for its originator.

Space Charge Blow Up for Ion Beam:



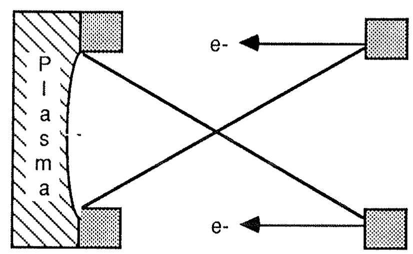
I. Flat or convex plasma surface

Space Charge forces a divergence of ion beam. The angle of deflection increases with distance up to the stalling distance.



II. Slightly concave plasma surface

Causes a compensating focus to offset the defocusing Space Charge effects. Beam is relatively parallel.



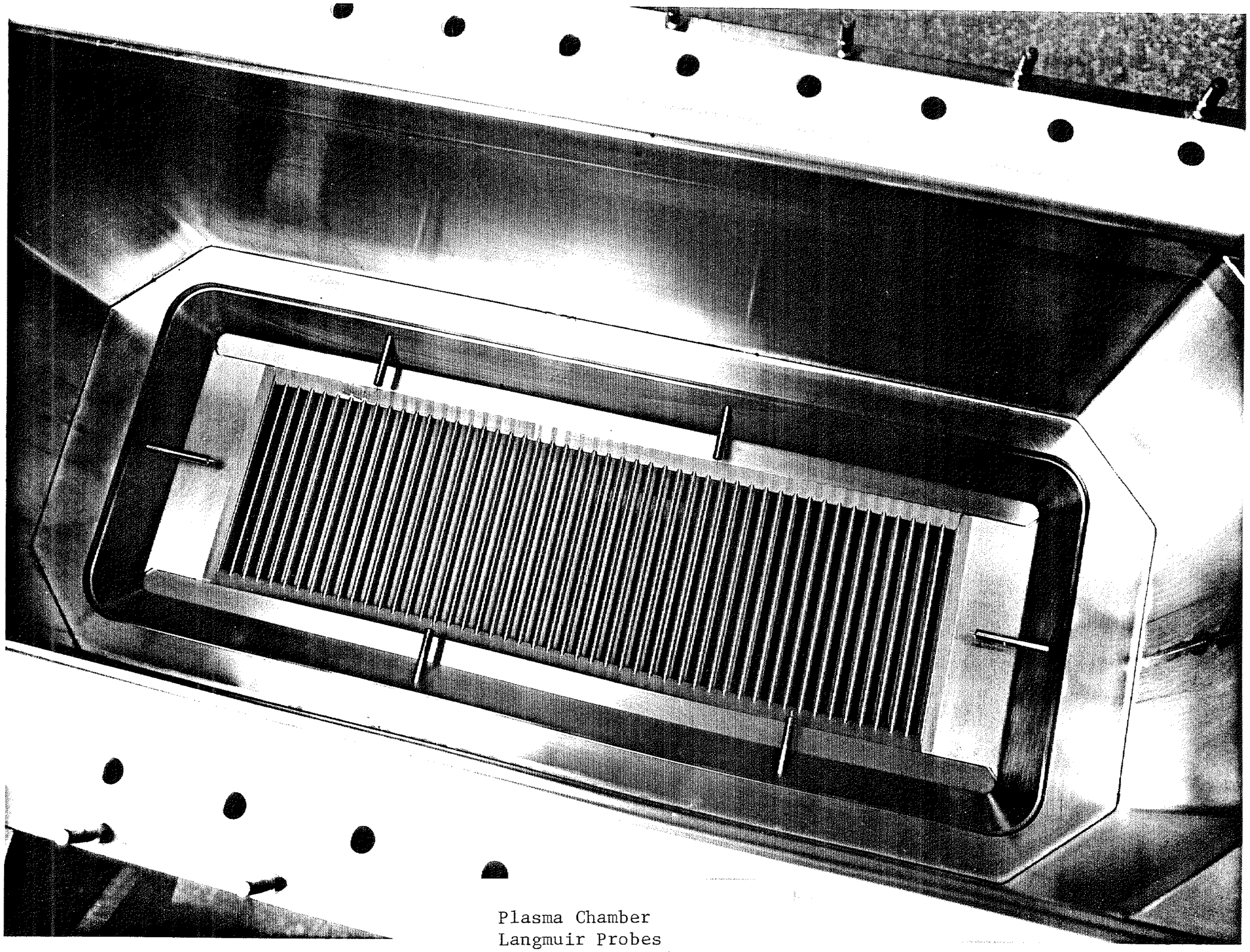
III. Very concave plasma surface

Causes overfocusing, resulting in worse divergence and higher secondary electron current (Igg).

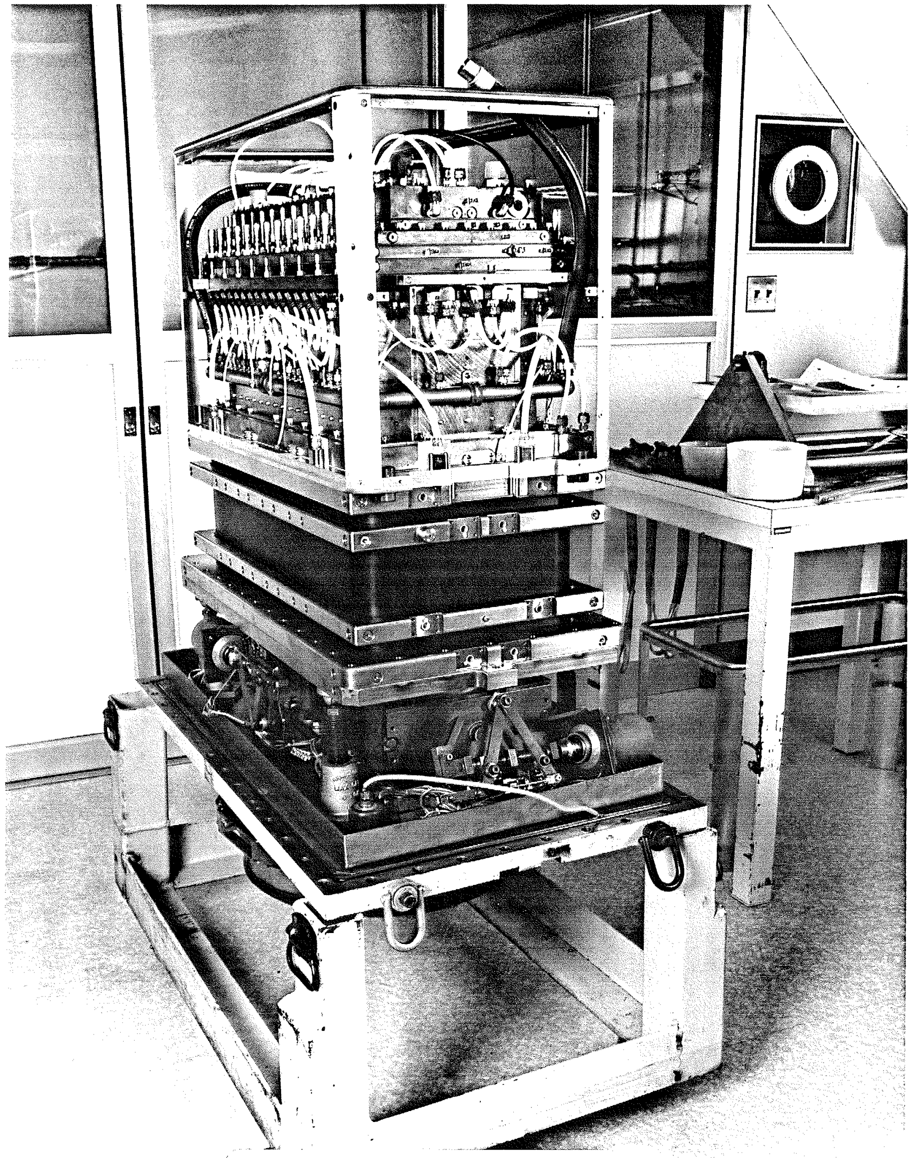
The resulting terminology corresponds to the plasma conditions which prevail at the surface.

FLAT or CONVEX plasma results from a higher density plasma than the grid can focus, hence OVERDENSE.

VERY CONCAVE plasma results from a lower density plasma that is unable to supply the appropriate number of ions to the grid potental extraction for proper focus, hence UNDERDENSE.

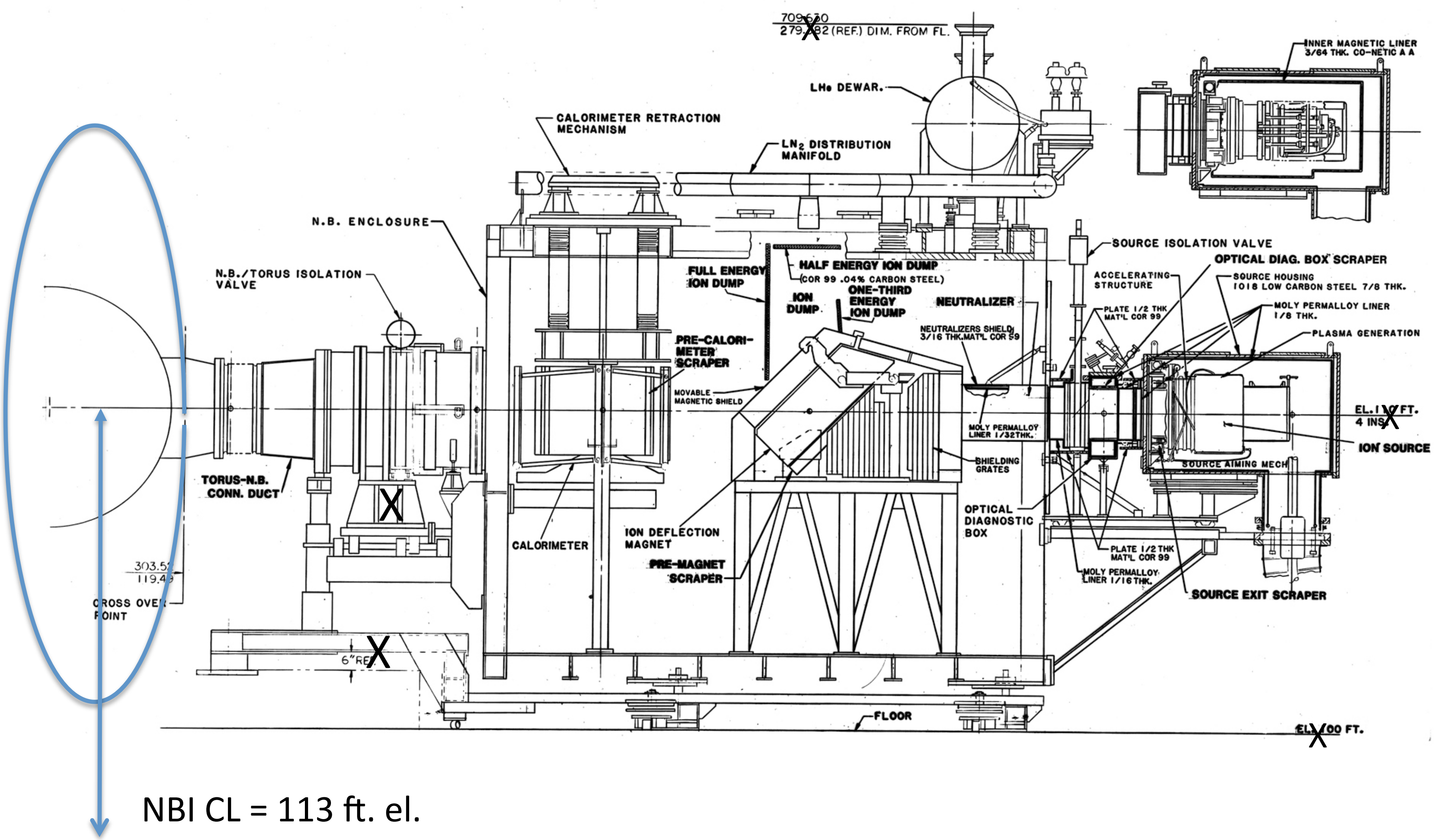


Plasma Chamber
Langmuir Probes
Accelerator Grids



Source Assembly
and
Steering Mechanism

NBI Beamline



NBI CL = 113 ft. el.

Beam Species Composition

e- + D_2 → D_2^+ + e- + *<u>e-</u>*		**D_2^+**
→ D + D + *e-*		
→ D^+ + D + e- + *e-*		**D^+**
e- + D → D^+ + e- + *e-*		**D^+**
e- + D_2^+ → D^+ + D + *e-*		**D^+**
D_2^+ + D_2 → D_3^+ + D		**D_3^+**

***e-* flow is essentially arc current**

The accelerator assembly of the LPIS produces an ion beam with a mix of the above species. As the beam traverses the neutralizer, a charge exchange probability exists such that a substantial fraction of the various species become charge neutral. Essentially the electric field of the fast ion attracts and captures an electron while passing through the background low energy gas. Likewise, there exists some probability that a neutral can lose its electron to another atom. These processes are represented by the following equations.

Neutralizer Charge Exchange:

$\underline{D}^{+} + D_2 \rightarrow \underline{D}^{o} + D_2^{+}$		Capture
$\underline{D}^{o} + D_2 \rightarrow \underline{D}^{+} + D_2 + e^{-}$		Loss

Equilibrium Fraction:

$$\frac{\sigma_{10}}{\sigma_{10} + \sigma_{01}}$$

Where:

σ_{10} = electron capture cross-section

σ_{01} = electron loss cross-section

This neutralization process makes it possible to produce a charge neutral beam which can penetrate the magnetic fields of the target. To more completely analyze the neutral beam made by the LPIS and NB beamline, the following equations detail the species composition and energy of a deuterium beam and deuterium background neutralizer gas. The underlined symbols represent fast or accelerated particles.

Neutralizer Charge Exchange

120 KeV Neutrals:

$$\underline{D}^+ + D_2 \rightarrow \underline{D}^o + D_2^+$$

60 KeV Neutrals:

$$\underline{D}_2^+ + D_2 \rightarrow \underline{D}^o/2 + \underline{D}^o/2 + D_2^+$$

$$\rightarrow \underline{D}^o/2 + \underline{D}^+/2 + D_2$$

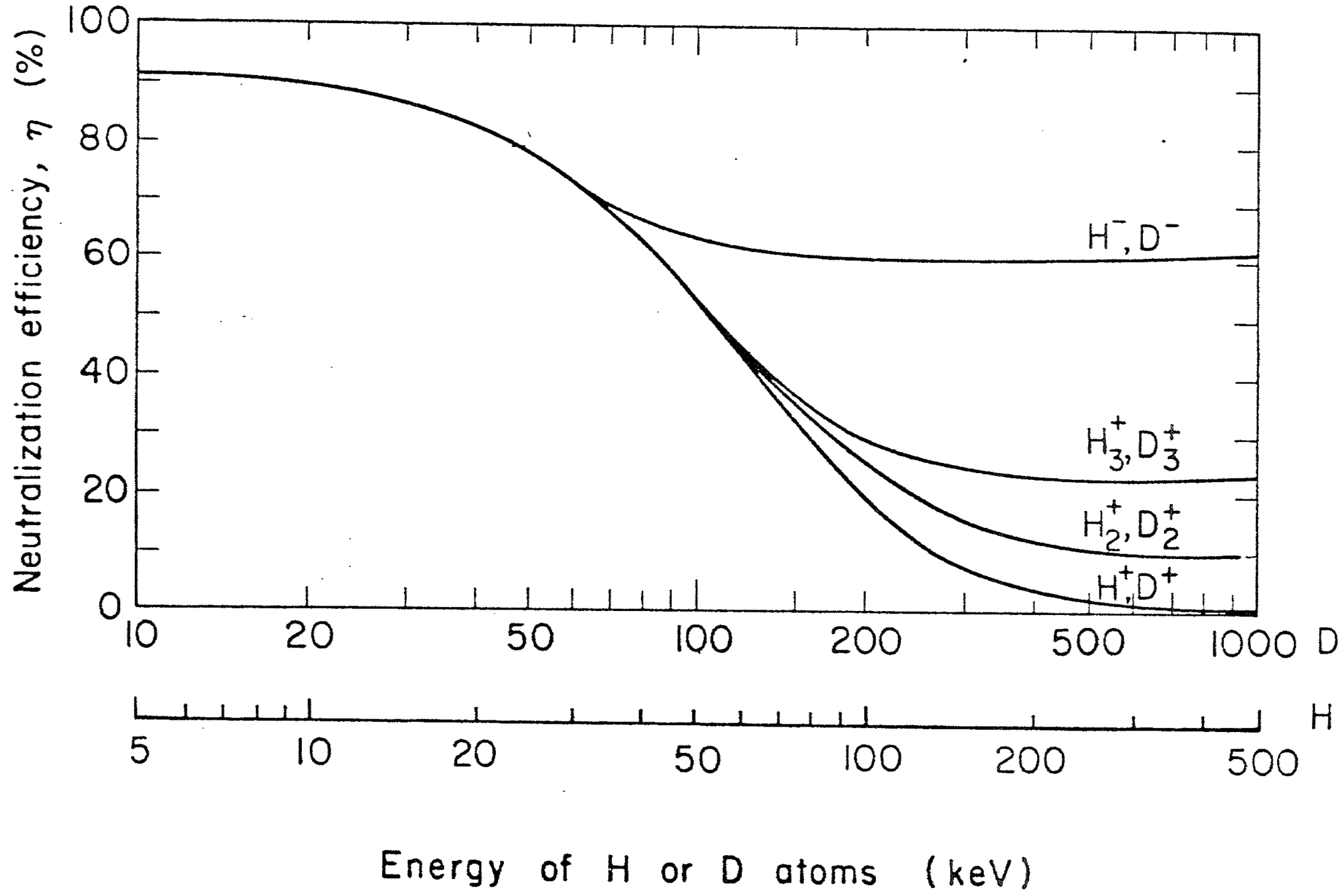
40 KeV Neutrals:

$$\underline{D}_3^+ + D_2 \rightarrow \underline{D}_2^+/3 + \underline{D}^o/3 + D_2$$

$$\rightarrow \underline{D}^o_2/3 + \underline{D}^+/3 + D_2$$

$$\rightarrow \underline{D}^o_2/3 + \underline{D}^0/3 + D_2^+$$

The following chart compares the neutralization efficiency of deuterium and hydrgen with respect to energy (accelerated voltage).



Neutralization efficiency, η (%)
100
80
60
40
20
0
H⁻, D⁻
H₃⁺, D₃⁺
H₂⁺, D₂⁺
H⁺, D⁺
10
20
50
100
200
500
1000 D
H
5
10
20
50
100
200
500
Energy of H or D atoms (keV)

Vaccel (kV)	Transmission Factor*
50	.57
55	.57
60	.56
65	.55
70	.55
75	.54
80	.52
85	.51
90	.49
95	.47
100	.45
105	.43
110	.41

* Includes transmission loss due to divergence, neutralization efficiency, and duct losses