NCSX Port Access Requirements for Neutral Beam Injection System and Torus Vacuum Pumping System

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Synergies Accrue From Combining The Respective Duct Requirements Of The NBI And TVPS Systems

- **The port access requirements for the Neutral Beam Injection (NBI) systems and Torus Vacuum Pumping Systems (TVPS) are usually approached as separate and independent design problems.**

  - **The Neutral Beam Injection (NBI) System port access requirements for NSCX are usually determined by neutral beam physics and engineering constraints.**

  - **The Torus Vacuum Pumping System (TVPS) port access requirements are usually determined by vacuum science and engineering constraints.**

- **This Report discusses synergies that accrue from combining the respective duct requirements of these systems.**

NCSX Port Access Requirements for Neutral Beam Injection

- **NBI System Port Access Requirements**

  1) **Provide the Desired Aiming (RTAN)**

  2) **Maximize Injected Power**

  3) **Maximize the Desired Injected Species**
     [H^0(E), H^0(E/2), H^0(E/3), or D^0(E), D^0(E/2), D^0(E/3)]

  4) **Allow Far-Wall Armor for Beam Shine-thru**

  5) **Minimize Beam Duct Conditioning**

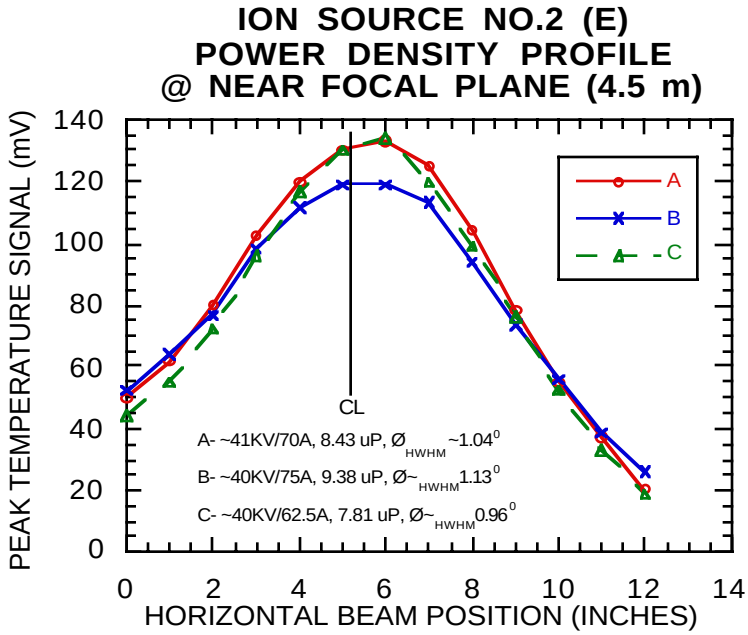
  6) **Provide for NBI & Physics Diagnostic Requirements**

  7) **In-Vessel Constraints**
     (Diagnostics, RF Antennas, Far-wall)

  8) **Ex-Vessel Constraints**
     (Nearby walls, Diagnostic equipment,..)

ION SOURCE OPTICS EFFECT PORT ACCESS REQUIREMENTS

- Injected Beam Optics depends on Ion Source operation



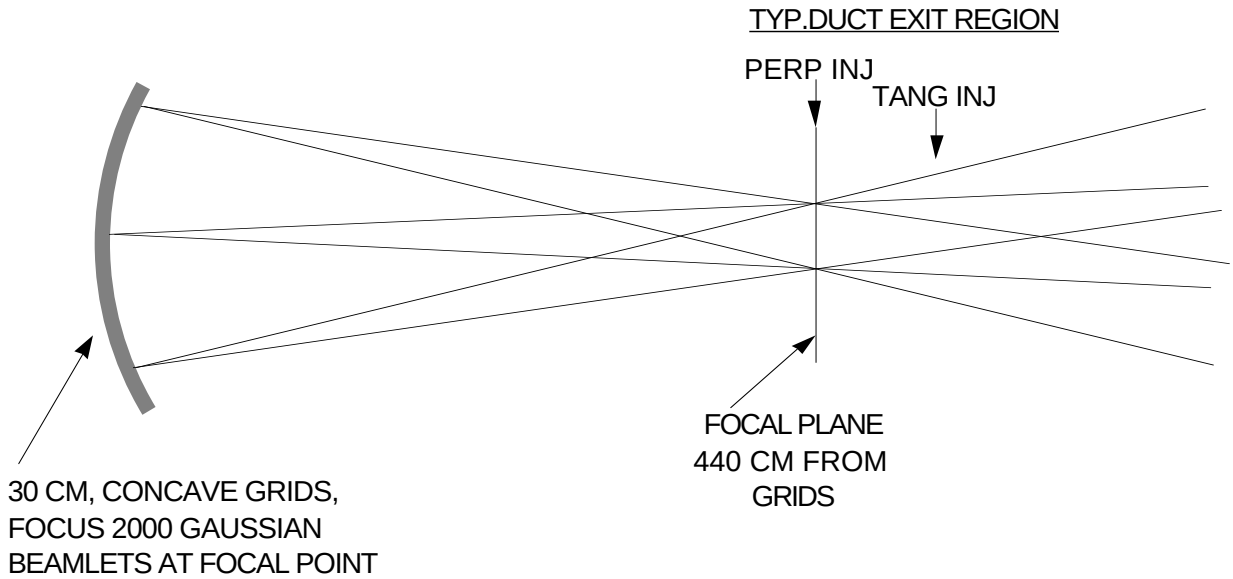
- Summary Of NBI Optics

$\theta_{HW@HM}$ [b]	NBI System [a]	$W_{HW@HM}$ [c]	$\theta_{HW@1/e}$ [d]	$W_{HW@1/e}$ [e]
1.5°	S	11.58 cm	1.8°	13.9 cm
1.13°	E	8.75 cm	1.36°	10.5 cm
1.2°	NW	9.25 cm	1.44°	11.1 cm
0.94°	SW	7.25 cm	1.13°	8.7 cm

[a] NBI System listed in order of Ion Source fabrication and testing at ORNL.
[b] Angular Divergence from centerline to edge at one-half of full power.
[c] Angular Divergence from centerline to edge at 1/e of full power.
[d] Beam Half-width from centerline to edge at one-half of full power.
[e] Beam Half-width from centerline to edge at 1/e of Full Power.

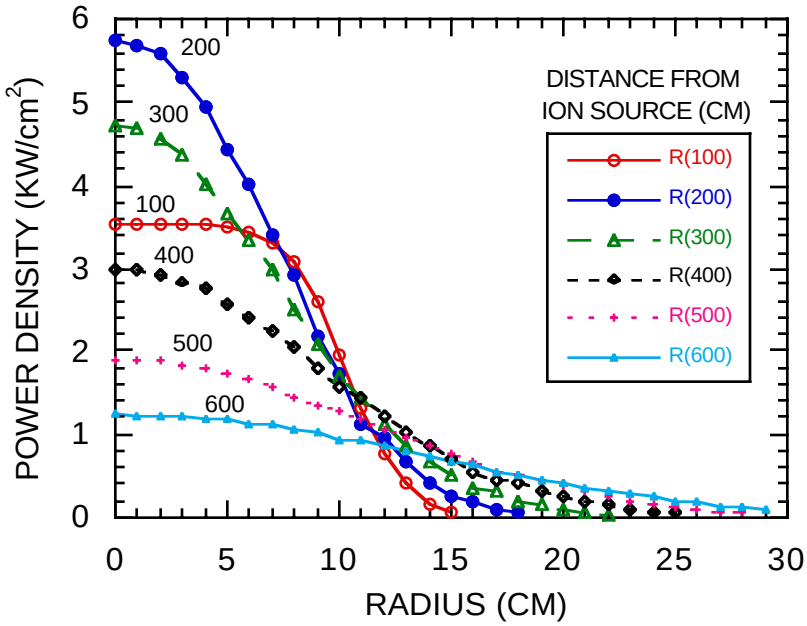
- Power Density Profile is Gaussian down to ~0.1 of Max
- Beam diagnostics are needed to measure centering

Ion Source Optics Determine Duct Size and Achievable Aiming Angles



- **Simulated Power Density Along Beam Axis**

P_0 = 1500 KW, FL = 440 CM, 1/e half-angle = 1.80^0



INJECTED POWER IS MAXIMIZED BY REDUCING TRANSITION DUCT REIONIZED POWER LOSSES

- System gas pressure in the Transition Duct causes reionization of neutral particles

- The deflection of reionized beam particles into the Duct walls by the fringe magnetic field causes additional gas load from out-gassing

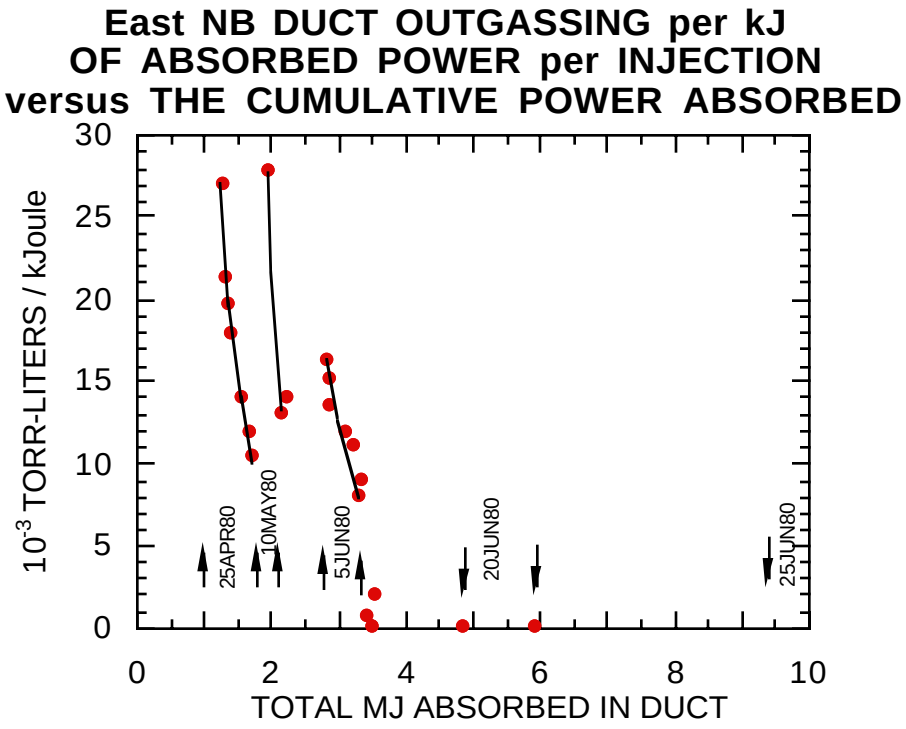
- Neutral Power Reionization Loss Fractions in PBX-M Due to Duct Neutral Gas (~1-4x10^{-4} T)
  - Perpendicular Ducts $\rightarrow$ 0.88 P_0 (12% loss)
  - Tangential Ducts $\rightarrow$ 0.83P_0 (17% loss)

- PBX-M Injected Power Capability
  - ORNL Qualification (No Fields)
    - $H^0 \rightarrow$ = 6 MW (1.5 MW x 4)
    - $D^0 \rightarrow$ = 8 MW (2.0 MW x 4)
  - PDX Testing (No Fields)
    - $D^0 \rightarrow$ = 8.3 MW (4 NBI @ > 52 KV)

- ***Reduction of Transition Duct neutral gas pressure to the ~10^{-5} T regime significantly increases injected power***

TRANSITION DUCT CONDITIONING REDUCES REIONIZATION LOSSES

- **Reduction of Duct outgassing by conditioning increases injected power and provides more reproducible results**



- **Duct outgassing can be reduced by a duct design that includes a high conductance geometry, walls far from the beam, appropriate materials, baking, and HeGDC between discharges.**

HIGH DUCT PRESSURE MAY CHANGE THE SPECIES RATIOS MEASURED UPSTREAM IN THE BEAMLINE AND BROADENS THE BEAM POWER PROFILE

- Typically, Neutral Beamlines are operated with the neutralizer cell at ~90-95% equilibrium gas pressure to optimize the yield of the full energy component

- The additional gas target through the Transition Duct for different port access geometries can change the fractional ionic yield of the low energy components and produce small differences in the species ratios of injected beam

- Small reductions in the percentage of the full energy component have been measured at the edges of beams in a narrow duct

- Species Measurements

  H^0 @40 keV
  (ORNL, using ion dump yields)
  - $H^0(E):H^0(E/2):H^0(E/3) = 63:20:17$
  - $P^0(E):P^0(E/2):P^0(E/3) = 80:13:7$

  D^0 @ 47 keV,100 ms, 1.6 MW
  (PDX using RBS on injected neutrals)
  - $D^0(E):D^0(E/2):D^0(E/3) = 53:32:15$
  - $P^0(E):P^0(E/2):P^0(E/3) = 72:21:7$

POWER TRANSMISSION TO TORUS FAR-WALL AND THE REQUIRED NB ARMOR ARE ISSUES FOR PORT SELECTION

- **A handy formula for calculating the approximate fraction of beam that will "shine-through" a PDX plasma (R. Goldston) is:**

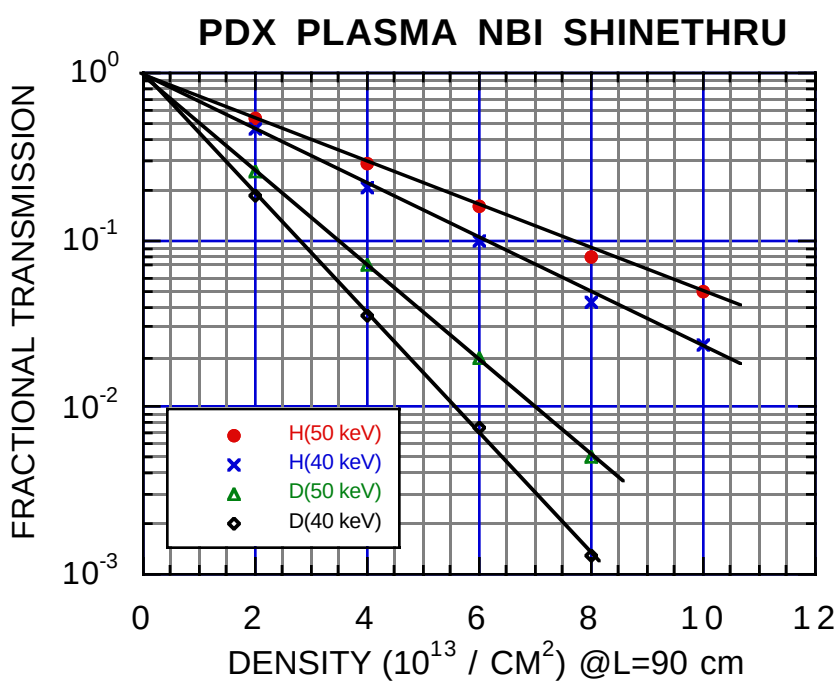
H^0: 50 keV/nucleon $\sigma_{tot} \sim 3.4 \times 10^{-16}$

Shine-thru $= \exp(-n_e \cdot 90 \cdot 3.4 \times 10^{-16})$

$= \exp(-n_e / 10^{13} \cdot 0.31)$

D^0: 25 keV/nucleon $\sigma_{tot} \sim 7.4 \times 10^{-16}$

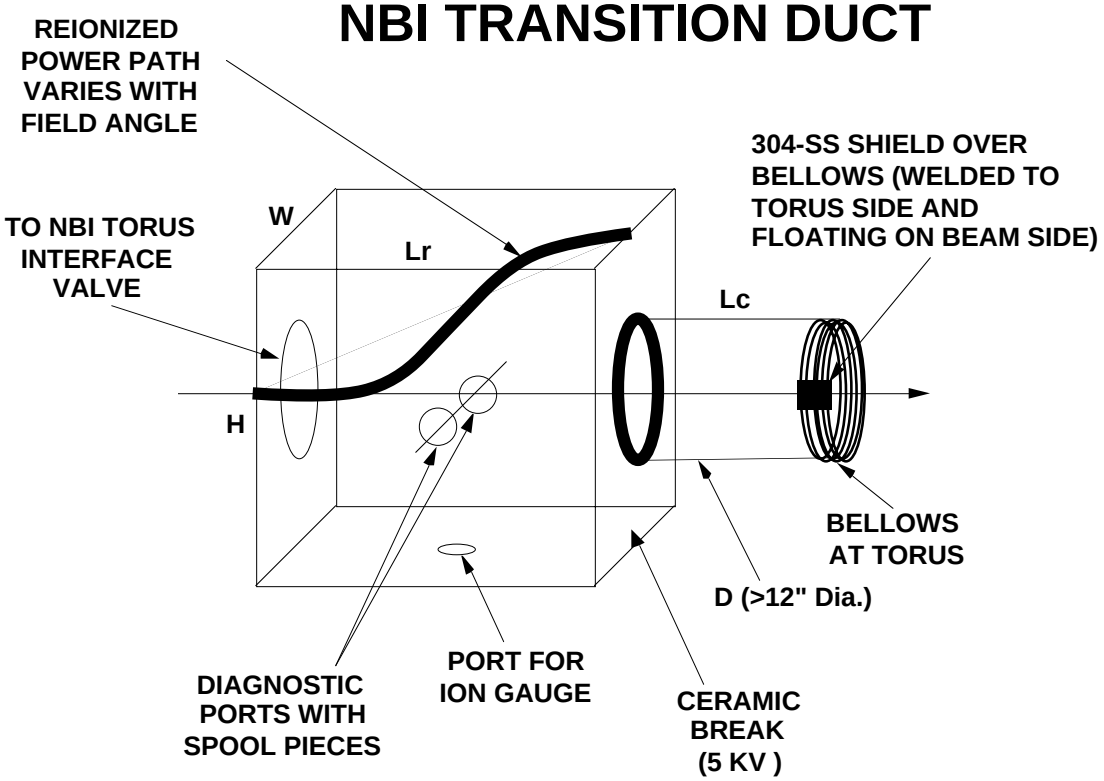
Shine-thru $= \exp(-n_e / 10^{13} \cdot 0.67)$



- **Far-wall beam armor should be capable of absorbing full power in the absence of plasma and be instrumented to provide beam diagnostics**

NBI DUCT DESIGN OPTIMIZATION and PORT ACCESS REQUIREMENTS

HIGH CONDUCTANCE NBI TRANSITION DUCT



- Maximize dimensions W, L, H, D.
- Use electropolished 304-SS.
- If possible, use rectangular ceramic break and rectangular bellows to maximize conductance.
- All vacuum seals bakeable to 150°C.
- Provide 150°C bakeout capability.
- If possible, useful to operate at 150°C.
- Provide ion gauge port.
- Provide diagnostic ports with spool pieces.
- Provide port for GDC electrode.
- Far-wall beam armor should have beam diagnostics

TORUS VACUUM PUMPING SYSTEM PORT ACCESS OPTIONS

- **Four Options for Torus Vacuum Pumping System Port Access are:**

  1) Suspend the <u>four</u> PBX-M, 1500 L/s turbomolecular (TM) pumps from the bottom of the torus
  (PBX-M method, 2600 L/s for H_2)

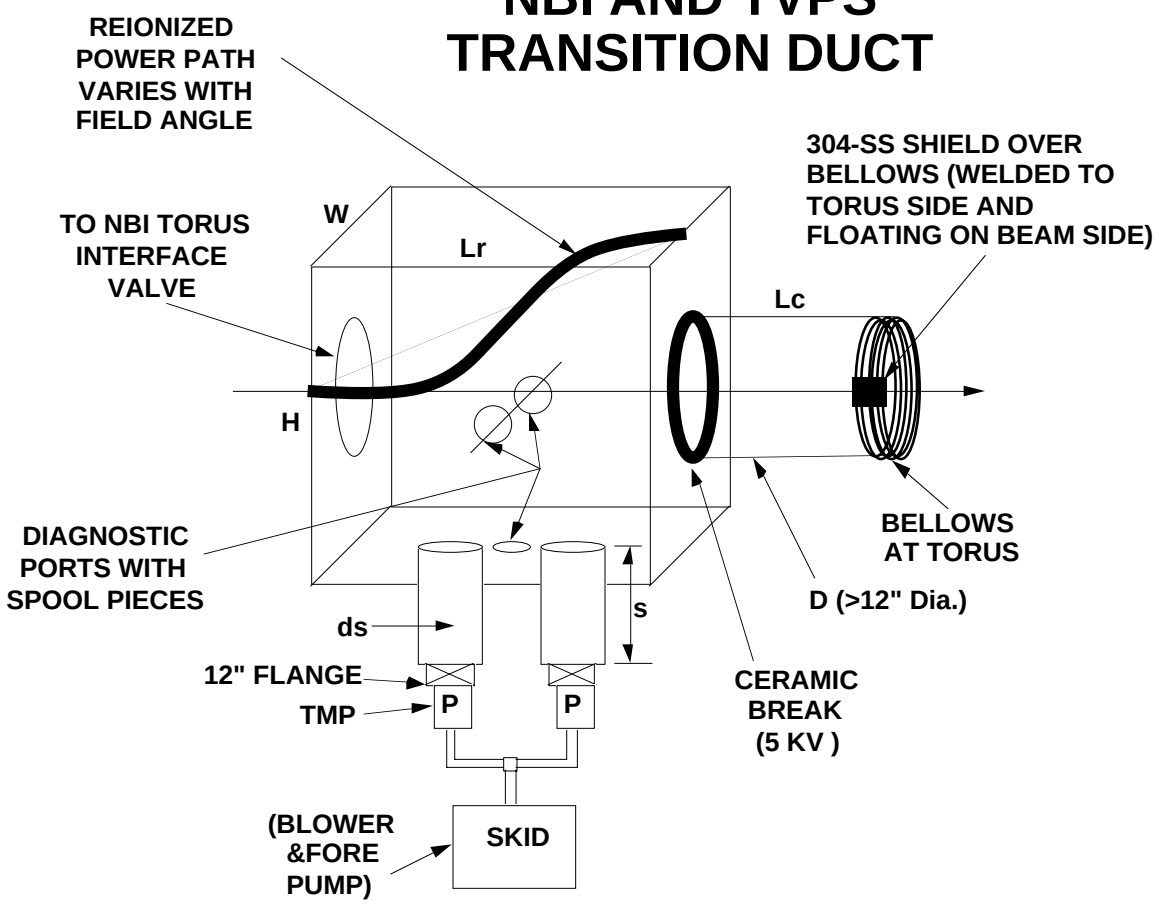
  2) Suspend <u>four</u> PBX-M TM pumps from a large midplane Pump Duct
  (TFTR, NSTX) for ~ 3000 L/s

  3) *Suspend 2 TM pumps from each of 2 Neutral Beam Transition Ducts for ~3000 L/s*

  4) Suspend 2 TM pumps from each of 4 Neutral Beam Transition Ducts for ~4-6000 L/s

SYNERGIES ACCRUE FROM COMBINING DUCT REQUIREMENTS OF THE NEUTRAL BEAM AND TORUS VACCUM PUMPING SYSTEMS

HIGH CONDUCTANCE NBI AND TVPS TRANSITION DUCT



- **Port Access and external constraints need to be varied to:**
  - **Maximize dimensions of H,W, D, d_s**
  - **Minimize dimensions of Lc, Lr,S**
  - **Select S for high conductance, B-field operation, and occlusion from beam sputtering**
  - **Provide Bakeability**

CONCLUSIONS

- The port access requirements for the Neutral Beam Injection (NBI) systems and Torus Vacuum Pumping Systems (TVPS) are usually approached as separate and independent design problems.

- Combining the respective duct requirements of the Neutral Beam Injection (NBI) and Torus Vacuum Pumping Systems (TVPS).
    - Eliminates separate port access requirements for NBI and TVPS
      (more access for RF and diagnostics)

    - Provides high conductance geometry for NBI and TVPS

    - Minimizes NBI gas loading of torus during NBI conditioning, and minimizes duct gas at start of next shot