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DOUBLET III BEAMLINE - AS-BUILT

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Summary

Doublet III is a large noncircular tokamak (R = 1.4 m, a = 0.45 m, plasma elongation 3:1). It has a toroidal magnetic field of 2.6 T, an ohmic heating flux swing of 5 V-sec and should deliver plasma currents of up to ~3 MA for a 300 msec flat top. An upgrade to $B_T \simeq 4$ T, $\Delta\theta \simeq 10$ V-sec, $I_p \simeq 5$ MA with a 1 sec flat-top is currently underway.

In order to fully exploit Doublet III capabilities and to study new plasma physics regimes, a Neutral Beam Injector System has been constructed. Initially, a two beamline system will supply 7 MW of heat to the plasma. The system is currently being expanded to inject ~20 MW of power (6 beamlines). Each beamline is equipped with two Lawrence Berkeley Laboratory type rectangular ion sources with 10 cm × 40 cm extraction grids. These sources will accelerate hydrogen ions to 80 keV, with extracted beam currents in excess of 80 A per source expected. The first completed source is currently being tested and conditioned on the High Voltage Test Stand at Lawrence Livermore Laboratory.

This paper pictorially reviews the as-built Doublet III neutral beamline with emphasis on component relation and configuration relative to spatial and source imposed design constraints.

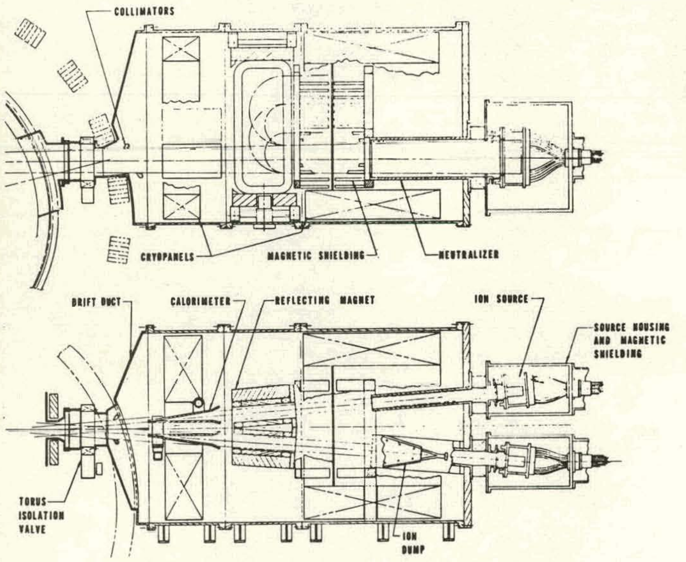

Figure 1. Plan and Elevation Views of the Doublet III Neutral Injection Beamline.

DESIGN CONSTRAINTS

The layout of the Doublet III beamline is shown in Figure 1. The major as-built components and assemblies to be reviewed in this paper are schematically depicted. The design was basically fixed by the anticipated parameters of the ion source and by constraints imposed by the Doublet III machine and space about the machine itself. A photograph of the Doublet III machine is shown in Figure 2 with arrows indicating the injection ports to be utilized for beamline units one and two. It should be noted that the injectors are not aimed at the mid-plane of the torus but rather above and below. This alignment is a consequence of the Doublet geometry and a desire to inject equal amounts of energy into the upper and lower lobes of the machine. Injectors are therefore added in pairs.

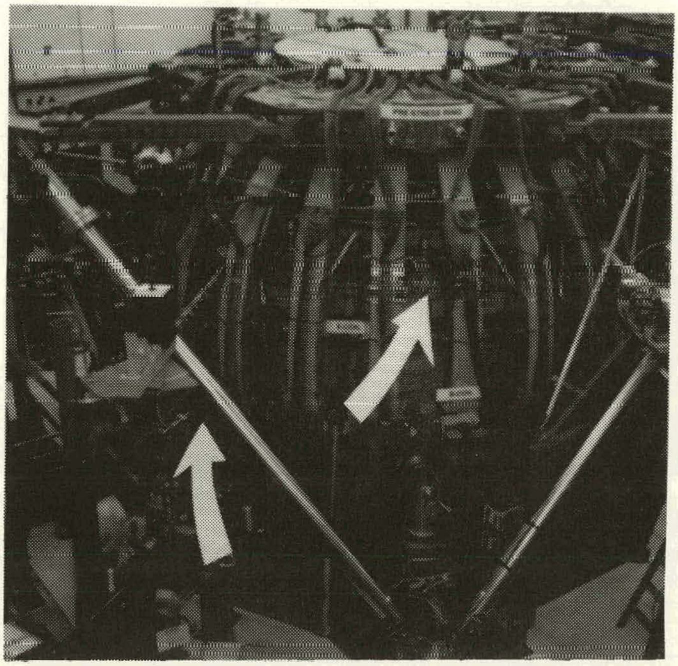

Figure 2. Photograph of the Doublet III Tokamak Illustrating Injection Ports.

The anti-torque structure exterior to the B-coils constraints the azmuthal position for either upper or lower injection. The beamlines (for quasi-perpendicular injection) will be located at 120° intervals on each of the upper and lower injection planes, and 60° out of phase from upper to lower.

The Doublet III entrance apertures for neutral injection are defined by the location of the toroidal field coils (B-coils) and the plasma field-shaping coils (F-coils). As can be seen in Figure 2, the maximum clear aperture in the horizontal plane for the beam is about 32 cm wide between the B-coils. The horizontal focus of the ion source is chosen to be here, 48 m from the acceleration grids. The ion source is focused vertically at 5.5 m where the F-coils limit the aperture to 18 cm. The beams from the two sources intersect in this plane.

The overall length of the beamline assembly and focal length of the source are defined by the proximity of the pit wall at the 270° location as illustrated in Figure 3. This figure illustrates the Doublet III facility with six (6) beamlines located about the machine. The arrows again indicate the position of the first two (2) beamlines.

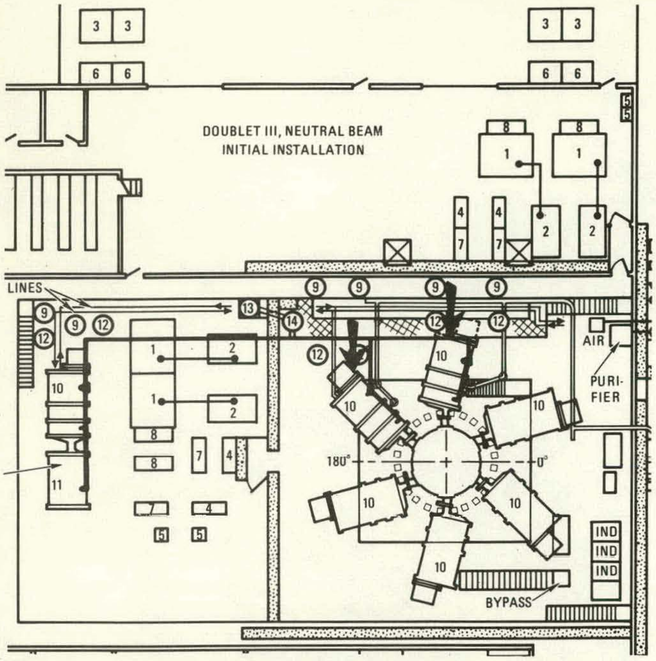

Figure 3. Doublet III Facility Diagram Illustrating Beamline Configuration.

BEAMLINE AS-BUILT

The neutral beam injector includes all components needed to produce and transport neutral beams to the entrance port of Doublet III. Each injector contains two (2) source lines fitted with Lawrence Berkeley Laboratory (LBL) type rectangular aperture ion sources with 10 cm × 40 cm extraction grids. The extracted energetic ions are neutralized by electron capture in a gas neutralizer. Unneutralized ions are swept out of the beam with a reflecting magnet and deposited on an ion dump. The neutralized component is either intercepted by the beamline calorimeter or transported through a series of collimators to the target plasma in Doublet III. To minimize neutral beam losses due to reionization after exiting the neutralizer cell and to establish the initial vacuum conditions, large cryopump arrays are located and baffled in a manner which allows for differential pumping. The physical arrangement of the components cited is illustrated in Figure 1.

The remainder of this paper will present a brief description and as-built photograph of each component or sub-assembly contained in the beamline. The order of presentation is not necessarily according to function, as outlined in the preceding paragraph, but rather according to its geometrical placement within the beamline. The order of presentation is prompted by component assembly considerations.

The beamline injector as depicted in Figure 1 is assembled in three (3) stand-alone spools, each of which for ease of maintenance, can be disconnected and rolled away from the others on tracks. There are no connections between spools other than a cryogenic feed line which connects the fore and aft cryopanels. Sub-assemblies are therefore grouped and assembled according to spools and are most easily illustrated in this context. The order of presentation will begin at the ion source and proceed through spools numbered one, two and three. The spool number sequence is from right to left as viewed in Figure 1. The nose cone section and drift duct, which mates the beamline to the machine injection port, is the final segment to be discussed.

ION SOURCE ASSEMBLY

A side view of the completed ion source assembly is shown in Figure 4. Depicted are the plasma generator, the accelerator structure and the adjustable base assembly which allows for source steering and alignment. The design parameters of the Doublet III Ion Source are given in Table I.

TABLE I
NOMINAL DESIGN PARAMETERS FOR THE
DOUBLET III ION SOURCE

Extraction voltage	80 kV
Extracted beam current	85 ± 15A
Accelerated ions	Hydrogen
Pulse length	0.5 sec. min.
Duty cycle:	
plasma heating pulse	0.0017
source conditioning pulse	≤0.0083
Extraction grid size	10 cm × 40 cm
Grid transparency	∿60%
Extracted current density	∿0.25 A/cm^2
Extracted species mix	60% H_1^+, 30% H_2^+, 10% H_3^+
Hydrogen gas input	∿42 Torr-ℓ/sec
Hydrogen gas efflux	∿30 Torr-ℓ/sec
Extracted beam divergence ($\theta_{1/e}$)	± 0.5° × ± 1.5°
Focal length of source (40 cm direction)	4.8 m
Focal length of source (10 cm direction)	5.5 m

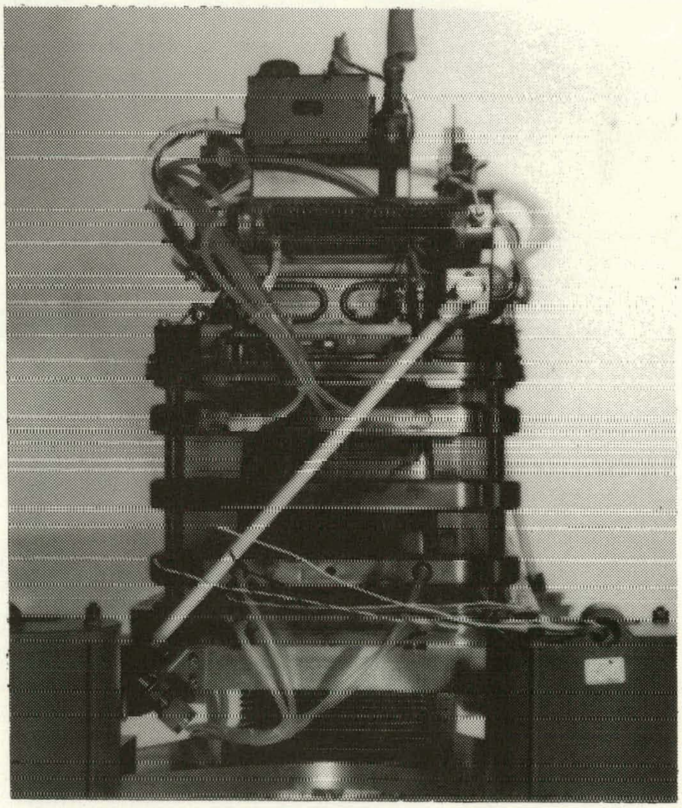

Figure 4. Side View Photograph of the Doublet III Ion Source.

SPOOL (1)

Spool number one (1) contains the aft cryopanel, the neutralizer cell and ion dump assembly, portions of the magnetic shielding and the differential pumping baffle. The spool itself, which serves as a portion of the vacuum tank, is a cylindrical aluminum structure about 2 m in diameter with walls approximately 1.9 cm thick. Aluminum was selected for this structure based on magnetic perturbation analyses (induced field error = 1×10^{-3} T with time constant τ = 450 msec.).

The aft, cylindrical, cryopanel uses a modified "Santeler" type of liquid nitrogen cooled shield geometry. The LN shield is made from extruded aluminum shapes welded into a cylinder. These extrusions are serrated so as to minimize room temperature reflection to the helium cooled surface. The helium cooled surfaces are copper sheets brazed onto stainless steel tubes. Flow paths are tubular and spaced in such a manner that there is ample opportunity for penetrations for beam diagnostic ports and mechanical support for internal components. The pumping surface presented is ~ 8.0 m^2 with a calculated hydrogen pumping speed of 7.8×10^5 ℓ/sec.

The completed aft cryopanel, in place in Spool 1, is shown in Figure 5, as seen from the upstream end.

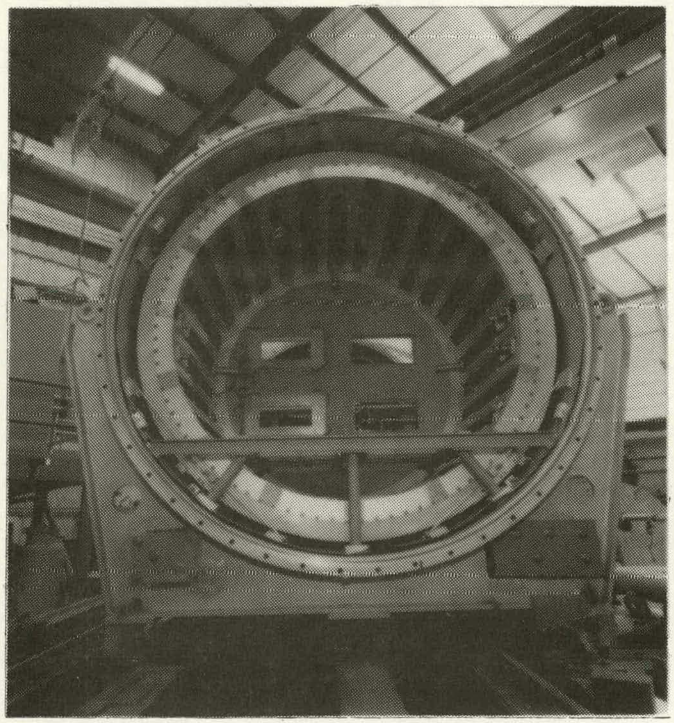

Figure 5. Spool #1 Assembly Viewed From Upstream End. Cryopanel and Gas Baffle Shown.

The neutralizer and ion dump assembly is positioned inside the aft cryopanel. The completed assembly with magnetic shielding fingers mounted in shown outside the spool in Figure 6. The neutralizer cell is a rectangular duct (15 cm × 45 cm), 105 cm long. Excess thermal hydrogen gas escaping from the source is used as the charge exchange medium for partially neutralizing the positive ion beam. The neutralizer is fabricated as a double shell structure. The exterior shell is made of AST-A253, Alloy 2 steel to magnetically shield the exterior to a value of less than 2×10^{-4} T.

Figure 6. Neutralizer and Dump Assembly With Magnetic Shielding Fingers Attached.

The positive ion dumps which are part of the same subassembly are approximately 2 cm thick copper plates used as inertial targets with heat removed via water cooling during the interpulse period. The target surfaces are inclined to the beam by 7.5° to reduce the peak power density to ~ 2 kW/cm^2. This power density assures that copper will remain below its melting point for a pulse of 1.0 sec duration. Each of the dump plates is instrumented with thermocouples and the cooling water input and return lines are fitted with flow meters and ΔT blocks.

The magnetic shielding fingers, also illustrated in Figure 6, extend from the end of the neutralizer-ion dump assembly to the gas baffle. The shielding reduces the anticipated tokamak fringe field from $\sim 2 \times 10^{-2}$ T to a value of $(2\text{-}5) \times 10^{-4}$ T. The fingers are AST-A253, Alloy 2 steel structures about 6 cm × 3 cm cross section and ~ 50 cm long spaced on 12 cm centers. This configuration allows for the field attenuation required while minimizing gas flow impedance to the cryopumps.

The differential pumping baffle, shown in Figure 5, is a simple aluminum plate which spans the entire cross section of the spool downstream of the first set of magnetic shielding fingers. Beam apertures fitted with collimators have been cut into the surface at the appropriate locations.

SPOOL (2)

Spool number two (2) which is itself a continuation of the vacuum envelope contains the reflecting magnet, the continuation of the magnetic shielding fingers, and a devious ion shield. The magnetic shielding fingers are the same as those described for Spool #1.

The ions remaining in the beam after passage thru the neutralizer are swept out of the beam by a 180° reflecting magnet. The magnet is shown in Spool 2 in Figure 7. This scheme also has the advantage of keeping the gas load due to the reflected ions in the high pressure section of the beamline, i.e., upstream of the gas baffle. The magnet has two 18 cm gaps for the twin source beamline, each operable up to ~ 0.1 T for 80 keV injection and capable of being operated at full field when the other gap is off. A beam collimator is mounted at the exit plane of each gap. Field clamps are used to reduce fringing fields between the magnet and neutralizer.

Figure 7. Spool #2 Assembly Viewed From Downstream End. Magnet and Devious Ion Shields Shown.

Molecular ions (∿30 kW at H_2^+ and H_3^+) are deflected, but not reflected, by the magnet. These plus about 30 kW of negative ions are stopped on water cooled copper surfaces which shield the magnet and forward cryopanel. As a group these surfaces are called the devious ion shields. The devious ion shields are shown mounted on the magnet in Figure 7.

The magnetic shielding fingers are shown mounted to the magnet in Figure 8. The magnet is viewed from the upstream end as opposed to the view shown in Figure 7, which is the downstream end which mates to Spool #3.

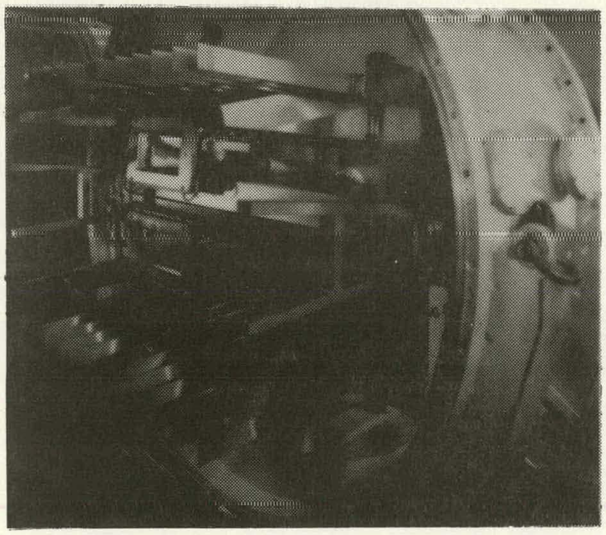

Figure 8. Spool #2 Assembly Viewed From Upstream End. Magnetic Shielding Fingers Attached to Magnet.

The large mass of ferromagnetic material used in the yoke of the magnet (∿8000 kg) will tend to modify the $\sim 2 \times 10^{-2}$ T fringe field and cause a dipole perturbation at the plasma edge ∿2.5 m away. The magnitude of this perturbation is estimated to be $\sim 3 \times 10^{-4}$ T which is not troublesome. Other soft iron components give much smaller contributions.

SPOOL (3)

The third and final spool contains the forward cryopanel and the movable beam calorimeter.

The forward cryopanel is a 3-layer disk shaped structure which acts as a baffle as well as supplying pumping capability on two sides. The two outer surfaces are aluminum weldment, LN cooled chevrons. Liquid nitrogen flows around the outer rings and along the internal frames. The helium cooled copper panel is mounted between the two chevron panels. Stainless steel tubes which carry the liquid helium are brazed to the copper panel. The total pumping surface presented is $\sim 6\ m^2$ with a calculated hydrogen pump speed of 5.8×10^5 ℓ/sec. The cryopanel is shown mounted in Spool #3 in Figure 9.

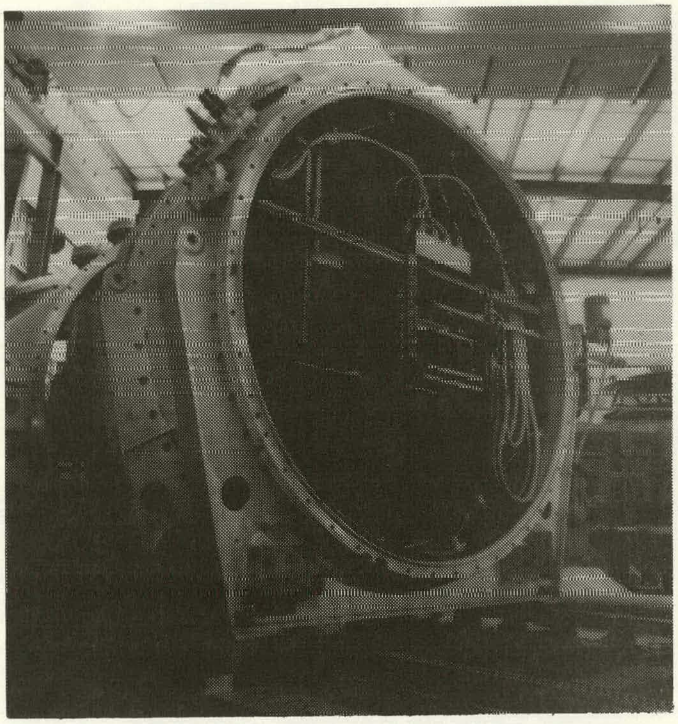

Figure 9. Spool #3 Assembly Viewed From Upstream End. Cryopanel and Calorimeter Shown.

The rectangular hole in the center of the cryopanel is designed to accommodate a movable calorimeter or to allow for beam passage into the drift duct region and finally into Doublet III. The calorimeter is likewise shown in-place in Figure 9. Like the positive ion beam dumps, the calorimeters are made of approximately 2 cm thick copper plates which are water cooled via tubes brazed to their back surface. The target surfaces are inclined to the beam by 4.6° to reduce the peak power density to less than 2.5 kW/cm^2. Again, each of the plates is instrumented with thermocouples and total beam energy monitors (ΔT blocks and flow meters).

Spool #3 is again shown in Figure 10, this time from the upstream side. The cryopanel mounts are clearly visible about the circumference.

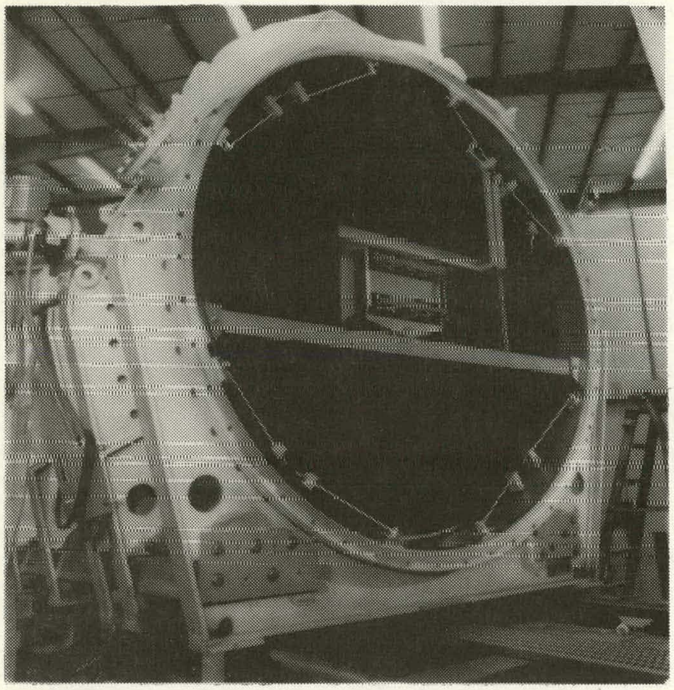

Figure 10. Spool #3 Assembly Viewed From Downstream End. Cryopanel Supports Shown.

NOSE CONE AND DRIFT DUCT

The contoured nose cone and drift duct assembly serve to mate the neutral beam injector to the Doublet III device. The nose cone, which was fabricated from 304 stainless steel, is shown in Figure 11.

The complex shape of the nose cone results from two (2) criteria, namely, 1) to position the beamline as close to Doublet III as possible, thereby reducing the length of the drift duct, and 2) to maximize the pumping conductance of the structure so as to minimize beam reionization losses. A final double picture frame collimator is mounted within the structure. The section attaching the snout of the nose cone to the Doublet III device is called the drift duct (not shown in Figure 11).

The drift duct is made of stainless steel to minimize magnetic field perturbations at the plasma. It incorporates flexible metal bellows to allow for the thermal expansion of the Doublet III vacuum vessel under bakeout and discharge cleaning conditions. The bellows also isolate the injection system from the very high accelerations which the torus experiences during pulses. A ceramic break is incorporated in the drift tube to isolate the torus electrically from ground.

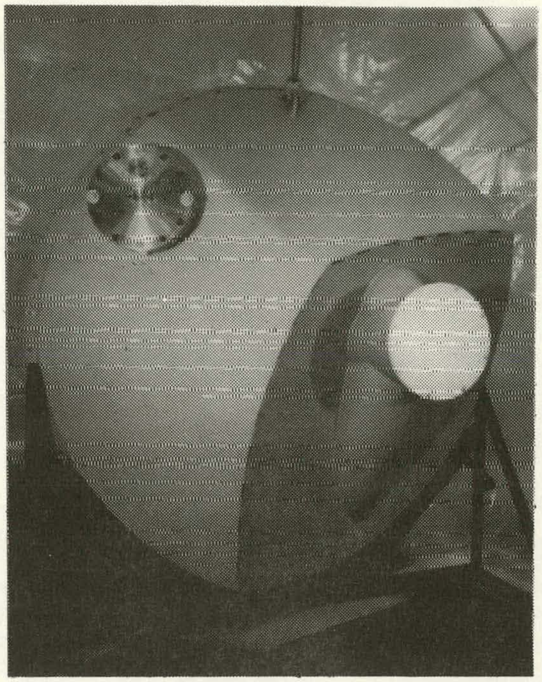

Figure 11. Nose Cone Structure. Contoured for Maximum Pumping Cond. and Close Positioning to Doublet III.

STATUS

Fabrication of the first beamline for Doublet III is completed. The beamline is assembled in the beamline test area and attached to the test tank for checkout and full power source testing before being mounted on Doublet III. A mock-up of the drift duct and entrance port to Doublet III has been fabricated and installed on the test tank. A rectangular aperture magnet is being designed to simulate stray tokamak fields near the entrance aperture.

System testing of the power supplies, ion sources, beamline and instrumentation and control systems is scheduled to commence in early 1980. Components of the second beamline are in various stages of fabrication. Drawing packages for beamlines three and four are being readied for review and vendor quotation.

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