NOTICE
This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

CONF-771029--147

THE NEW ORNL NEUTRAL BEAM TRANSPORT SYSTEM*

W. L. Stirling, R. C. Davis, H. H. Haselton,
D. E. Schechter, and C. C. Tsai
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830

The Princeton Large Torus (PLT) neutral beam injection systems have proven themselves to be a solid foundation on which next generation systems can be based. There are two areas in the new systems receiving particular emphasis: (a) increased power per beam line and (b) higher beam transmission efficiency.

Increased power can be accomplished by increasing the current output of a single ion source and by increasing the number of sources per beam line. The PLT injector is a modified duoPIGatron which is rated as 60 A of extracted ions at 40 keV. We have already tested at Oak Ridge National Laboratory (ORNL) a plasma generator capable of producing 100 A of ion current. This generator can be extended with relative ease to a higher value of current since the magnetic multipole plasma confinement method is simple to scale. The basic PLT pumping system is able to handle the increased gas load. Thus, the 100-A source immediately increases the PLT beam line to a 2-MW transmitted neutral power capability. The addition of a second source to the beam line will again double the transmitted neutral power. Possible modifications to the pumping system are under study.

Two different methods are being investigated to improve the transmission efficiency. First the drift tube region, the region of the beam line between the vacuum chamber housing the ion source and the torus, is being enlarged. In this manner a second, large cryopump will be installed in the drift tube to lower the pressure to $\sim 10^{-5}$ torr. Thus, neutral beam reionization on the background gas will be significantly reduced from the measured losses at a few 10^{-4} torr of the PLT system. Second, the beam divergence will be reduced by application of one or more of three known techniques developed on a single aperture source in the laboratory. Each of these methods has shown a reduction in single beamlet divergence from $\theta_{HWHM} \sim 1°$ to $\sim 0.5°$. The low beamlet divergence coupled with a differentially pumped drift tube will effectively accommodate the larger ion sources under development. All future beam line systems will benefit either directly or indirectly from the experience gained operating and upgrading the PLT beam line concept.

Introduction

The neutral beam development program at ORNL has produced two neutral beam systems from which a third more efficient system is now emerging. The first was the ORMAK system which delivered about 500 KW of neutral power in three injector beam lines. A typical system is shown in Fig. 1. Two of the beam lines had ion sources with 10-cm-diam extraction grids, one co- and one counterinjector, capable of 10 A of power supply current at 30 kV. The third beam line contained a 15-cm-diam source operating at 20-22 A at 30 kV, also firing tangentially in the codirection. Because of the 50-msec pulse length, the beam line was relatively simple — consisting of an ion source, gas neutralization cell, movable beam stop, and entrance duct. Power delivered to the beam stop during a conditioning shot reached a peak value of 20-30 kW/cm² which required a change of beam stops after several months of operation. Power in the unneutralized beam (about 30% of the total power emerging from the neutralization cell) is deflected by the toroidal fringe field onto the wall of the entrance duct. Beam line simulation in the laboratory showed that about 70% of the extracted power (ions plus neutrals) was transmitted through the 40-cm-long, 8-cm-ID entrance duct from a 10-cm source and about 60% of the extracted power from the 15-cm source. The total beam line length from source grid to torus was 120 cm. The three beam lines were operating very reliably until termination of the ORMAK experiment at the end of 1976.

PLT Beam System

The second ORNL beam line design was for PLT at PPPL. The design criteria placed on the PLT injection system differed from ORMAK in several respects. The PLT system has a larger oval-shaped entrance duct, approximately 20 x 25 cm, and is about 50-cm long. In addition, the desired neutral power input was about 1 MW per beam line at 40 keV for a 300-msec pulse. To this end, a 365-cm long beam line[1] employing a 22-cm modified duoPIGatron[2] ion source capable of 60-70 A of extracted current at 40 keV was designed, fabricated, and tested. The 300-msec pulse length exceeded the characteristic thermalization times of the ion source grids and beam stops, and acceptable gas pressure rise time in the system. As a result, there was a significant change in the beam line concept from the simple ORMAK design.

First it became necessary to provide adequate pumping for the large neutral gas load flowing from the gas neutralization cell. This was accomplished with 4 M² of surface cooled to $\sim$4.2°K. Since the unneutralized portion of the beam amounts to $\sim$800 KW and could not be sprayed along the entrance duct, a deflecting magnet and beam dumps for the full, half, and third energy ion components were designed to remove this power. The movable beam stop also was changed radically into a collection of cooling tubes with high velocity water flow. The tubes were inclined at 11° incident angle with the beam. Finally, a smaller cryopump was designed and built to handle gas evolution in the drift space, which houses the beam stop (calorimeter) and the entrance duct which houses the isolation valve, ceramic break, and bellows. This beam line concept is shown schematically in Fig. 2.

New Beam Transport System

The desired characteristics for the next generation beam lines are already evident: more power transmitted more efficiently at lower cost. To increase the power per beam line, we are again scaling the ion source extraction area. In this way, the total extracted power will be increased to $\sim$1.7 MW for an increase in cost of $\sim$1.2 not counting some costs in engineering design. Figure 3 shows a schematic of the modified duoPIGatron ion source used on PLT. The new 100-A version will look identical except all components are a little larger. The line cusp confinement utilized in the plasma generator makes the scaling straightforward. However, there will be several modifications in the extraction grid and gas neutralizer cell.

We are considering two different grid designs. In one the diameter is scaled to a 27-cm-diam extraction area with a 100-cm long gas cell tapered down to $\sim$25 cm inner diam at the exit end. The alternate design is a 30-cm-diam extraction area with

*Research sponsored by the Department of Energy under contract with the Union Carbide Corporation.

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

a tapered gas cell down to ∿27 cm inner diam, also 100-cm long. In order to increase grid mechanical stability, the grids will have a support across a diameter of each grid. This will lower the extraction area ∿10%. In order to reduce gas conductance of the gas cell, a small axially concentric tapered rod will be employed. For molecular flow, the conductance is lowered ∿30%; for viscous flow, reduction is about a factor of three. We are in the transitional region. The rod will also intercept about 6% of the extracted beam. For either the 27-cm grid or the 30-cm grid system, the extracted beam is 100 A or better. The gas neutralization cell can be maintained at 100 cm in length as on PLT to achieve an equilibrium cell and no additional pumping is required in the main pumping chamber. The pressure should rise no higher than 1×10^{-4} torr to 1.5×10^{-4} torr for pulses on the order of a second in duration.

Operation experience on the PLT system has revealed that the pressure rise in the drift tube region is a major problem. The pressure rise is proportional to pulse time length varying from 10^{-4} torr to $\sim 8 \times 10^{-4}$ torr in 300 msec. Such a pressure rise will produce a 15-20% loss in neutral power due to reionization. Figure 4 shows a layout of the PLT beam line modified with a revised drift tube or front-end section to accommodate the pressure rise expected when operating the 100-A source. The drfit tube now has a cryopump comparable in size to the one pumping the source in the main chamber. We estimate a pressure of 10^{-5} torr in the drift tube region and 10^{-4} torr in the main source chamber. A second set of beam defining plates at the exit of the drift tube will limit the amount of beam striking the entrance duct which connects the modified drift tube to the torus.

We are also looking at the possibility of installing vertically two 100-A sources on a single PLT type beam line as shown in Fig. 5. Two components need close attention: deflection magnet and cryopump. The magnet poles will probably have to be extended vertically. The crypump will still be able to hold the pressure in the main chamber to $2\text{-}3 \times 10^{-4}$ torr, which will cause the pressure in the modified drift tube to rise to $3\text{-}4 \times 10^{-5}$ torr which is still acceptable.

Increased beam transmission efficiency will be effected in two ways: lower reionization losses as described above and reduced beamlet divergence. We are actively pursuing three methods to reduce the divergence; all show promise from a calculational standpoint.[3] The first method is one in which a precel voltage of a few hundred volts is applied between the anode No. 2 and plasma grid in the ion source generator. Tests with an ion source having a 10-cm-extraction grid revealed a 15-25% reduction in the entire beam profile composed of 365 beamlets. These tests will be extended to a 60-A source on a PLT-type beam line.

The second method involves reducing the noise level or plasma density fluctuation as low as possible, to less than ±1% from the present ±10% level. Plasma density fluctuations cause a corresponding fluctuation in the meniscus from which ions are accelerated and consequently, a fluctuation in the beamlet divergence. Reducing the fluctuation level improves operation both directly (by reducing the associated time varying divergence) and indirectly (by permitting operation at higher grid transparency or transmission which occurs under conditions which are more sensitive to the stability of the meniscus). We have designed and are fabricating a simple electron feed from an array of 60 filaments which will be located directly in the ion source plasma.[4] A schematic of this source is shown in Fig. 6. This filament arrangement is primarily for testing purposes. Other designs which will provide much longer filament lifetime are under development.

The third method utilizes shaped apertures in the extraction electrodes. Single aperture[5] studies with a shaped aperture reveal significant improvement over the cylindrical bore aperture presently in use. The half-width, half-maximum divergence angle was reduced from 1° to about 0.6°. A 22-cm-diam grid is being fabricated to provide a multiaperture test of the design by performing a full power accountability check on a PLT beam line. Should more than one of the three methods being developed to lower beam divergence be successful, they can be used in any combination on a future beam line to achieve maximum effect.

Conclusion

The beam line concepts described should permit increasing neutral power transmission in a present PLT-type beam line with a single 100-A source from 600 KW, reduced from 750 KW by a 20% reionization loss to ∿1.7 MW after considering a 5% reionization loss. Fabrication and assembly cost per beam line should not increase by more than 20%.

References

1. W. K. Dagenhart et al., "Development and Testing of the ORNL/PLT Neutral Beam Lines for the Princeton Large Torus, paper I4, this conference.

2. C. C. Tsai et al., "DuoPIGatron Ion Sources for PLT Injectors," paper E2, this conference.

3. J. H. Whealton, (Oak Ridge National Laboratory), private communication, 1977.

4. R. Limpaecher and K. R. MacKenzie, Rev. Sci. Instrum. 44, 726 (1973).

5. L. R. Grisham, C. C. Tsai, J. H. Whealton, and W. L. Stirling, Rev. Sci. Instrum. 48, No. 8, 1037 (1977).

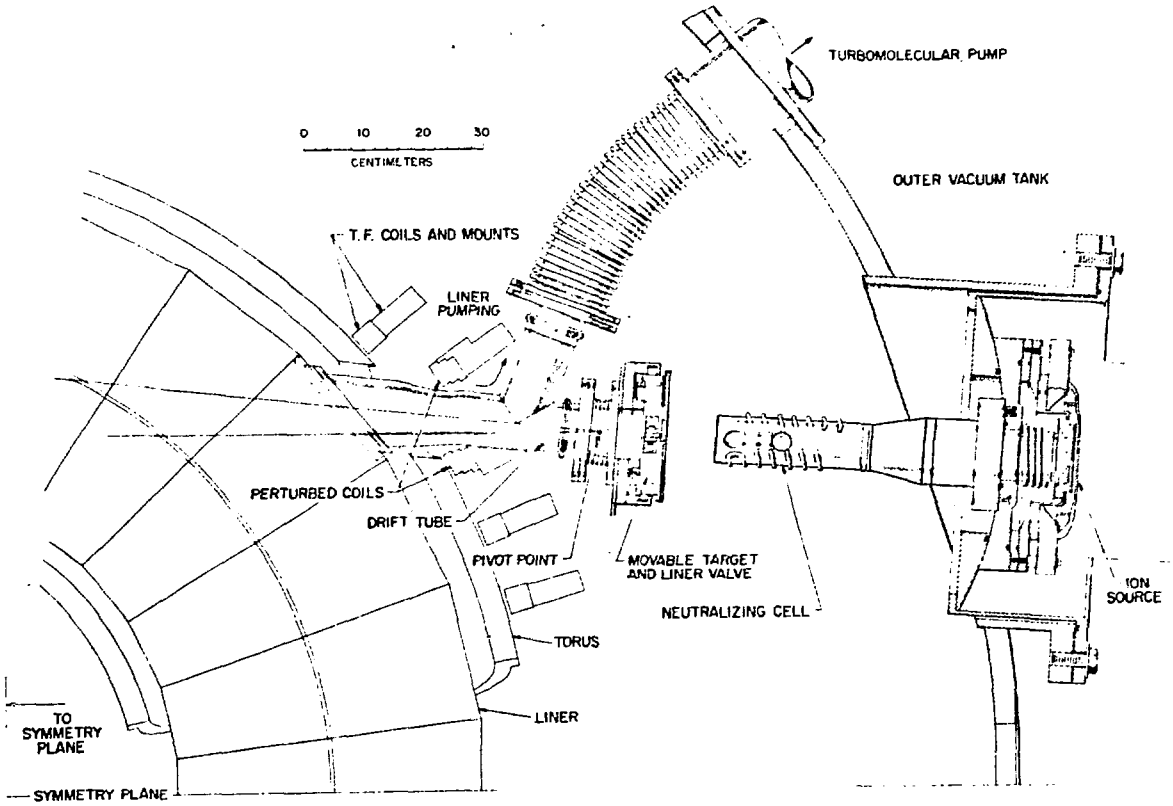

Figure 1. Plan View of ORMAK Injection System

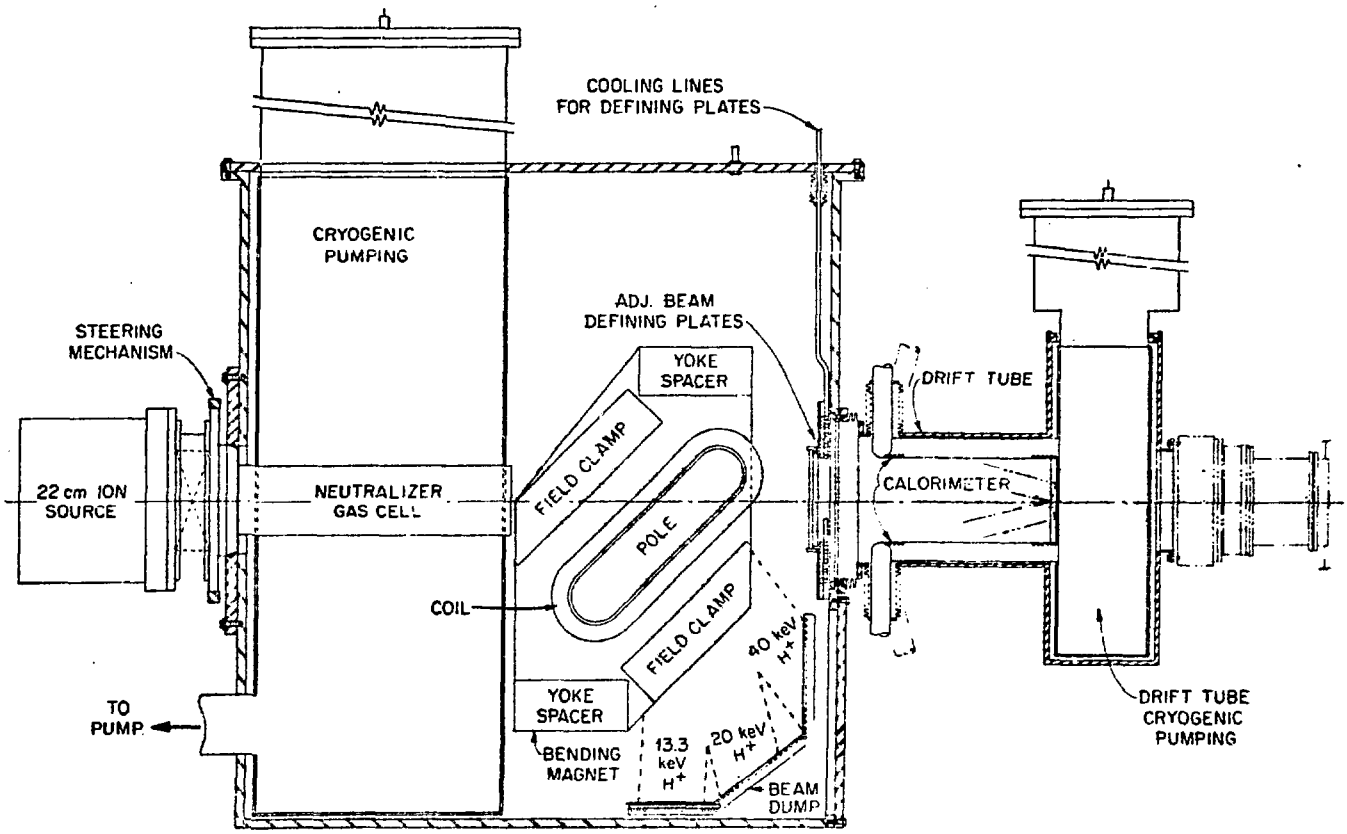

Figure 2. PLT Beam Line Concept

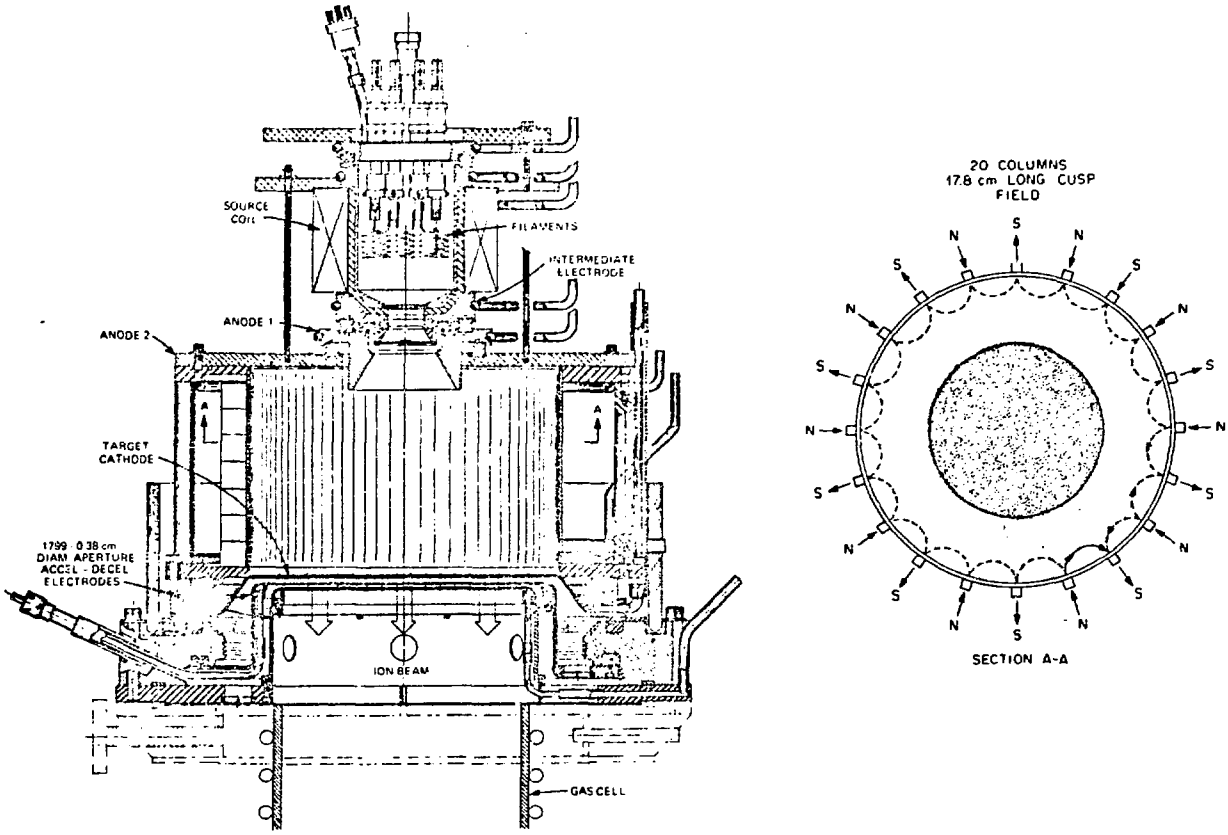

Figure 3. Modified DuoPIGatron Ion Source

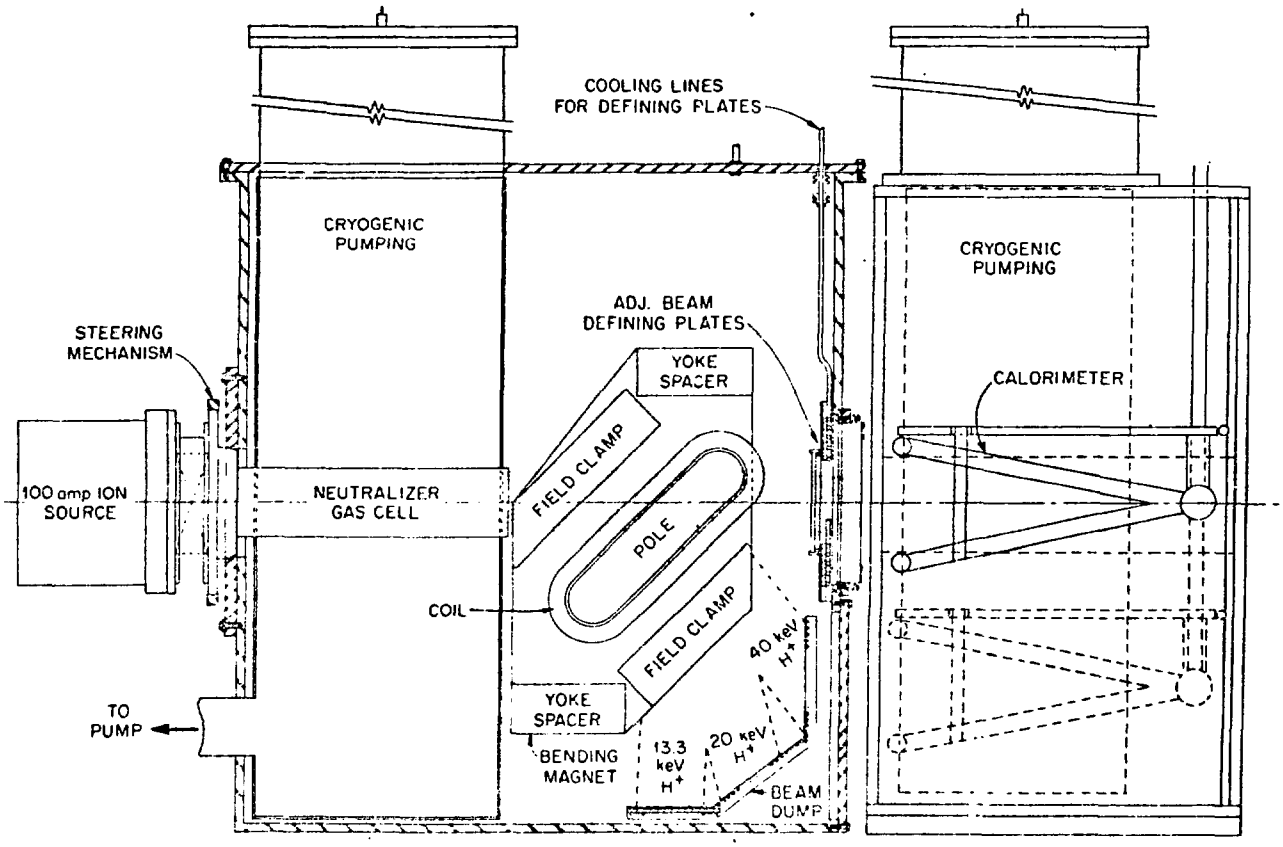

Figure 4. Beam Line with 100 A Ion Source

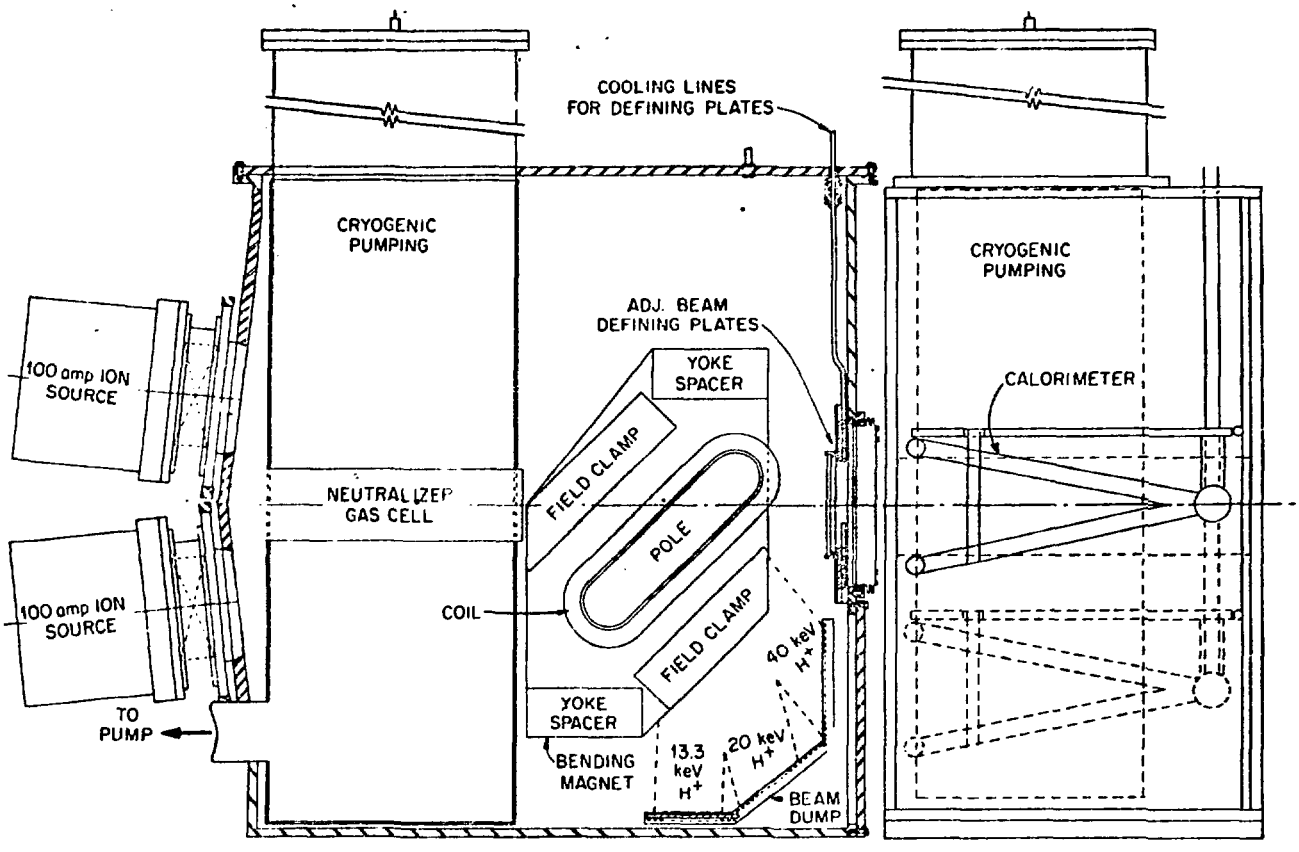

Figure 5. Beam Line with Two 100 A Ion Sources

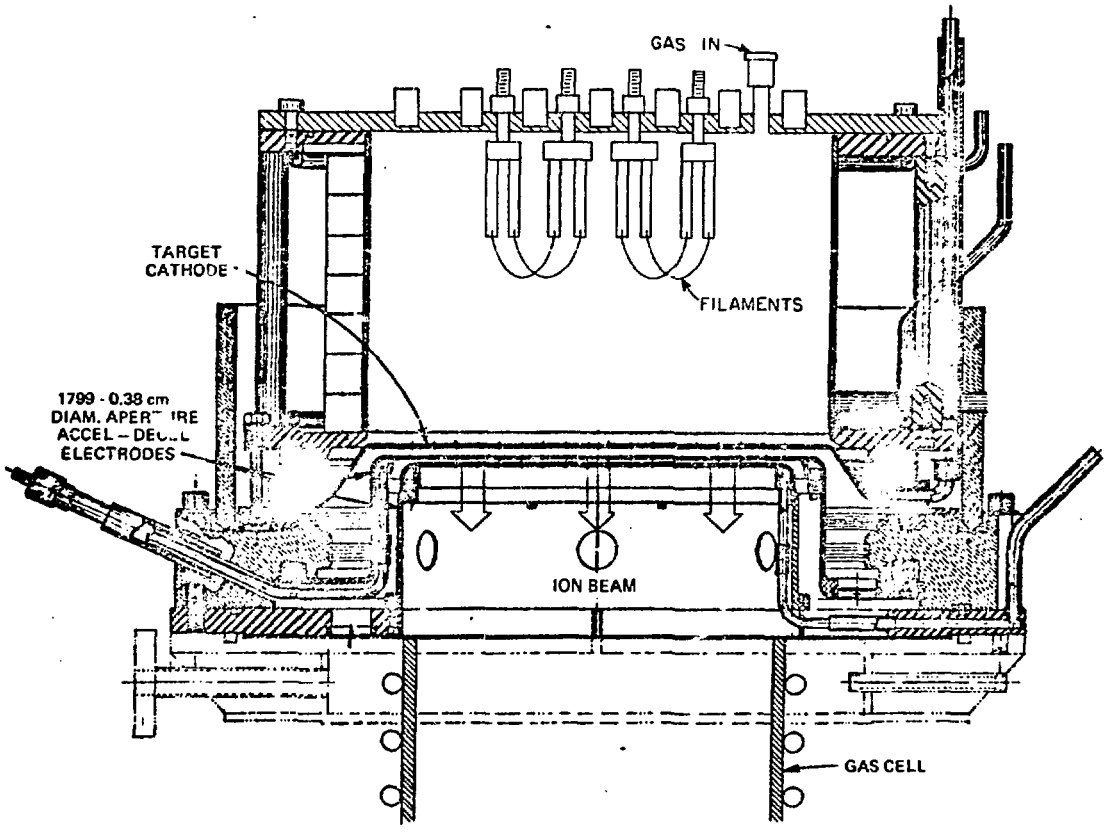

Figure 6. DuoPIGatron with Modified Electron Feed