THE POSITIVE ION PORTION OF THE LBL/LLL NEUTRAL BEAM PROGRAM*

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The positive ion portion of the Neutral Beam Development Program at the Lawrence Berkeley (LBL) and Livermore (LLL) Laboratories has two purposes: a) to carry out general research and development in a timely way to assure that users' needs can be met in principle, and b) to carry out specific development for users. To meet the first requirement, we have programs to develop sources capable of producing beams with high (85%) atomic fractions, long pulse lengths (10 sec to DC), and at beam energies up to 150 keV. We are also pursuing the development of on-line computer diagnostics and controls, the sophisticated high-power electronics required by neutral beam systems, and energy recovery. To meet the second requirement, we are developing prototype source modules to meet the requirements of the TMX and MFTF experiments at Lawrence Livermore Laboratory, the TFTR experiment at the Princeton Plasma Physics Laboratory, and the Doublet III experiment at General Atomic Co. The Lawrence Laboratories are also constructing and will demonstrate at LBL a complete prototype neutral injection system for TFTR, and are designing a similar system for Doublet III. This work is being done in a different division within the Laboratory, and is not the direct responsibility of the Neutral Beam Development Group.

Although positive-ion-based systems will be the main heating mechanism for confinement experiments for the next 8 to 10 years, to meet future needs we anticipate a shift in emphasis toward negative-ion-based systems in our research and development program within the next two years. In this paper we cover only topics relative to our positive-ion work. We describe our test facilities, discuss the status of our source development, mention our current problem areas, and describe some possible "new directions" within the positive ion program.

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I. Test Facilities

There are eight test facilities at the Lawrence Laboratories. All are presently used for positive ion research, although one (442) supports the negative ion program. The capabilities of these various test facilities are summarized in Table I. In most cases each facility has only one high-voltage supply, which can be connected in various ways to give the outputs shown in the table. All supplies are regulated, and have interrupt capability. This table also shows improvements in power supply capability and in pumping speeds that will occur within the next few months.

II. Status of the Positive-Ion-Based Neutral Beam Program

Our philosophy in ion source/accelerator development is the following: we test concepts on relatively small sources (typically with an accelerator grid cross-sectional area of about 10 x 10 cm) which are small enough to be easy to repair and modify, yet large enough to give realistic multiple-ampere beams. These test sources are identical to the larger prototypical sources in the critical aspects of grid dimensions, beam current density, and beam pulse length, and differ from the large sources only in the total grid area. Following (or more often, concurrent with!) successful demonstration of performance with one of these test sources, we construct full-sized prototype sources. In support of these efforts are programs for developing controls, diagnostics, direct-recovery techniques, and electronics. We will discuss each of these areas in turn.

A. Test Source Results

Table II shows the results to date of a variety of small test sources. A typical test source is shown in cross-section in Fig. 1. A "normal" plasma source of the type developed at LBL[1] is shown; the plasma is produced by a high-current, low-voltage discharge between hairpin-shaped tungsten filaments and a portion of the outer wall that serves as an anode. No attempt is made to confine ions or electrons in these sources.

In order to try to improve the fraction of the beam that is in atomic ions (D^+), as opposed to that in molecular ions (D_2^+, D_3^+), we have produced and are testing a series of "bucket" sources, following similar work at UCLA[2,3] ORNL,[4] and Culham.[5] These sources are characterized by rows of permanent magnets around the outer walls, which improve the ion and electron confinement times. We have measured the fraction of atomic ions in beams produced from plasma sources of varying axial lengths (along the beam direction), with and without magnets, and have observed that for a fixed ion current density, the fraction of atomic ions increases with increasing source depth. It appears, then, that the magnets do not directly affect the atomic ion fraction, but permit the source to be made deeper and still maintain tolerable ion and electron losses to the walls. An example of one of these bucket sources is shown in Fig. 2.

Both the 120 keV and the 80 keV test sources use the same sets of accelerator rails. Only the spacings are changed to maintain the highest ion current density consistent with breakdown at each voltage. A cross-section of the molybdenum grid rails used for 120 keV operation is shown in Fig. 3.

Low energy ion beams (1 keV) are also important to the magnetic fusion program. Low energy beams are used in the double charge exchange method[6] for production of negative ion beams [which are necessary for efficient production of high energy (150 keV) neutral beams]. This application for low energy ions beams requires high intensity (hundreds of milliamperes/cm^2) as well as good optics since in practical devices these beams may have to propagate hundreds of centimeters before being reaccelerated as negative ions. To produce intense beams, an electrostatic accelerator with a strong accel-decel grid configuration is used. This system is illustrated in Fig. 4. Current densities of .33A/cm^2 (deuterium) are easily attainable.

Good optics are quite difficult to achieve since the low energy beams are more severely affected by space charge blow-up. This, coupled with the fact that low energy ion beams cannot produce sufficiently dense background plasmas for space charge neutralization (or charge exchange), results in very poor propagation characteristics of the beam. Numerical calculations show that beam divergences on the order of 5-7° should be attainable for these low energy accelerators. In practice, due primarily to poor space charge neutralization, these beams have divergences of about 15°. Several techniques are being explored to reduce or eliminate this problem.

B. Full-size Source Status and Results

The status of a series of full-size sources developed for specific users' applications is shown in Table III. A schematic cross-section of a typical one of these sources, for TFTR, is shown in Fig. 5. This type of source has been described numerous times before, and is probably familiar by now to the neutral beam community.

A different approach was taken in the design of an 80-keV source for the MFTF experiment at LLL[7] (shown in Figs. 6 and 7). MFTF requires 48 neutral beams: twenty-four 80-keV, 80-A, 0.5 sec sustaining beams and twenty-four 20-keV, 80-A, 0.01-sec startup beams. Due to geometric constraints, these sources must be as compact as possible, so that they can be packed together very closely. Integration of the arc chamber and accelerator with the isolation valve and magnetic shield produces the required compact design. Compactness is achieved by immersing the arc chamber-extractor in high vacuum where high voltage can be held over smaller distances, by redesigning grid support structures, and by bringing services (water, deuterium, power) in only at the back plate thereby allowing close packing of sources. The magnetic shield also forms the vacuum wall. Reliability will be increased by reducing the electric fields everywhere else below those present between grids and by design innovations. The latter include techniques to reduce stray magnetic field and disperse gas uniformly, all metal-ceramic construction, and a 65-kV shield enclosing all 80-kV electrodes. Easier maintenance is obtained by a compact isolation valve and by modular construction that allows removing the arc chamber while leaving the accelerator and magnetic shield on MFTF. Curving both the grid wires and their holders provides focusing in two planes. The source module and the details of the arc chamber and extractor are shown in Figs. 6 and 7 respectively. Initial testing of the arc chamber revealed a density depression at the center. We plan to tailor the gas distribution and perhaps the anode current distribution to obtain a uniform plasma, before testing with the four-grid accelerator.

C. Controls

Test Facility IIIA at LBL has been equipped with a computer control system in a collaborative effort with the Charles Stark Draper Laboratory.[8] This system provides for controlling all power supplies, and also includes a "conditioning" or "polishing" algorithm for bringing a new accelerator structure up to operating voltage in the shortest possible time. The system can automatically produce a "tuning curve" of beam divergence versus beam current, and is adaptive in that it is capable of following slow drifts in the source perveance. The system has worked successfully although it is still being developed and we have only given it a limited amount of testing.

D. Diagnostics

Test Facilities IIIA and IIIB at LBL are the best equipped for beam diagnostics. Each beamline has a thermal-inertia type calorimeter for measuring total beam power to the dump and the beam divergences. The two beamlines share a set of diagnostic instrumentation consisting of a) thermal-inertia type ion dump and a sweep magnet for measuring the total ion beam power and the profiles of (selected) energy components on the dump, b) equipment for measuring the total energy deposited in the neutral dump, the neutralizer, and the accelerator grids by water-flow calorimetry, c) a bending magnet for momentum analysis of the remaining charged beam at the end of the beam line (or, with a stripping cell, the momentum distribution of the neutrals can be measured), and d) an optical spectrometer equipped with a 500-channel vidicon for measurement of the beam divergences of all energy components in the neutral beam, the beam aiming direction, and composition by Doppler-shift spectroscopy. Analysis of data from the ion and neutral dumps and from the spectrometer is performed on line by a computer. Additional optical diagnostics for measuring beam spatial profiles by total emitted light are being developed. Table IV summarizes some of our estimated diagnostic capabilities; we include also some information on variations observed during 0.5 sec operation.

E. Direct Recovery

The most recent direct recovery experiments were carried out with 8 A helium beams at 105 keV at LBL. The geometry of the experiment is shown schematically in Fig. 8. The maximum recovered ion power was only about 10% of the 170 kW expected; the electrical current collected dropped to zero in about 300 msec. We interpret this as due to electron production and collection at a rate sufficient to cancel the ion current. We believe the major problem is due to the desorption of gas from the electrodes and possibly from other surfaces. A gas analyzer showed that H_2 was produced in the direct convertor at a rate comparable to that of He from the beam. Preparations for the next test include the degassing of all electrodes, improved pumping, and improved shielding against the background plasma.

We are also investigating a second type of direct convertor. In this concept, each beamlet is neutralized in a short gas cell containing gas at low temperature (4 to 77 K) and then is introduced into a multiple-aperture direct-convertor section of approximately the same scale size as the accelerator section.

Some of the advantages of this scheme, if it is successful, are that it is compact, the ion source power supplies will operate near ground potential, and the design permits handling as high a beam current density in the direct convertor as can be handled in the accelcrator. We are building a single-slot cold neutralizer as a first step in testing this concept.

F. Electronics

A description of the high-voltage supplies for the major Test Facilities is shown in Table V. All supplies feature regulation to ±1% or better, and have the capability of rapidly switching the high voltage off in the event a spark is detected, then switching on again after a few msec for the spark to clear. A core stack[9] is used to dissipate capacitively stored energy; the energy to the grids in a fault is limited to 3J.

III. Prototype Beamline Construction

A prototype beamline for the TFTR experiment at PPPL, complete with a target tank and a computer control system, is being constructed at LBL. A similar, but less extensive, effort is also underway for the Doublet III experiment at General Atomic; in that case the design work is being done at LBL, but the beamline will be assembled and tested at General Atomic.

The design of the TFTR prototype beamline is shown in Fig. 9. This beamline, being built by the Division of Engineering and Technical Services of LBL, will be housed in a completely shielded test cell. Although three sources will be mounted on the beamline, only a single power supply will be available at LBL, restricting the testing to single-source operation. The facility will begin operation in December, 1978.

IV. Problem Areas

In this section we list and discuss briefly a number of problem areas--these are areas in which we either have already encountered difficulties, or anticipate difficulty in the near future. Our intention is to present our thoughts and experiences to those attending this Workshop, in the hope that our experience may benefit those about to encounter similar problems, and also that we can benefit from the experience of those who have already solved similar problems.

A. Source, Accelerator, Neutralizer, and Direct Recovery

Our principal problem in this area is the achievable atomic ion fraction in the beam. It is much more cost-effective to improve the heating of a confined plasma by increasing the fraction of full-energy neutrals, which penetrate better, than it is to add additional beam lines. Therefore, this topic now receives the highest priority within our research and development effort. As described earlier, the approach we are taking is to increase the length of the plasma source in the axial (i.e., beam) direction, to give a higher probability for D_2^+ and D_3^+ ions born in the discharge to dissociate to D^+ ions before they reach the accelerator. Operation at high gas pressures also enhances the atomic ion fraction. To maintain reasonable power efficiency, and especially to reduce radial losses (which otherwise would dominate if the source is made long enough) we use the bucket-type source. Test sources of this type have produced hydrogen beams with about 75% H^+ at a current density of 0.3 A/cm^2. The goals, however, are over 85% for sources for Tokamak injectors, and well over 95% for mirror machines. This is a challenge.

Long pulse operation is another major problem area. We are beginning to make calorimetric measurements of the power loading on the accelerator grids. Preliminary estimates indicate that while we may be able to achieve several second pulses with the present accelerator grid design, which has cooling only at the ends of the grid rails, such a design probably would not be able to run DC. We are taking two approaches to solve this problem: first, we are developing hollow grid rails that can be convectively cooled, and second, we are attempting to understand the sources of heating of the grid rails. We have made extensive computations of the trajectories of secondary ions and electrons born in the accelerator region but have not yet identified all sources of grid rail heating. The hope is that once we have identified the secondary particles responsible for heating the rails, changes in the design can be made to modify their trajectories so that they no longer strike the grid rails. We note that the requirements of a high atomic fraction together with a long pulse length may be contradictory; the fraction of atomic ions tends to increase with increasing gas pressure in the source, but we suspect (but have not yet measured) that the power loading on the accelerator grids will also increase with increasing pressure, as will beam loss due to charge-exchange in the accelerator.

Cathode lifetime will ultimately be a problem for long-pulse operation. While the filaments we now use are satisfactory for 5000 0.5-sec shots, they probably will not be satisfactory for 10 to 30 sec operation. We are therefore investigating two alternate cathodes, a commercial dispenser-type, and a LaB_6 hollow cathode of the type developed at UCLA.[10] The latter appears to be the more promising; we intend to modify a small bucket source to use this type of cathode.

The question of reliability of source operation should be raised. We do not in general find a sharply-defined limit in voltage above which a source will not operate; as the voltage is increased, operation simply becomes more and more difficult, due to an increasing frequency of faults (sparks in the accelerator structure). In spite of our best efforts we occasionally melt or otherwise seriously damage a set of grids, due either to improper operation of the source or to the failure of an electrical or mechanical component. A great deal of effort must be applied to this area before neutral beam systems will be suitable for use in reactors.

In a related area, we spend quite a bit of time "conditioning" a new or newly repaired source to run at its operating voltage. We have only very limited experience in how the choice of materials used in areas of high electric field strength affects source operation, and have never found any way to condition a set of grids other than actually running a beam through them.

The origins of beam divergences observed are not completely understood, either for very high or very low energy beams. The divergences observed with

120 keV beams are about double what we expected (i.e., 1.3 deg vs 0.6 deg in the direction perpendicular to the slots). We believe, but have not conclusively demonstrated, that the divergence is increased in the neutralizer by a beam-plasma interaction of the beam ions (which are moving faster than the electron thermal velocity) with the plasma in the neutralizer cell. Indications that this effect is occuring are the following: spectroscopic measurements of the beam divergence indicate that the beam divergence increases with position down the neutralizer; there is an indication of an energy spread in the beam that is larger than can be accounted for by the power supply regulation; and numerical simulation with presumed neutralizer plasma properties give estimates of an increased divergence which agrees plausibly with that observed. If this instability occurs, and some means cannot be found to damp it, it will limit the minimum attainable beam divergence for high energy beams. We are building a very short, cold (liquid nitrogen temperature) neutralizer section for a single beamlet. This design, if an adequate neutralizer thickness can be obtained at an acceptable gas flow, should inhibit wave growth by greatly increasing the plasma density gradient in the neutralizer and by placing conducting planes between adjacent beamlets. We plan to test this neutralizer this summer.

In the 1 keV beam development, the beam divergences are also observed to be larger than expected (15 deg., vs 5 deg.). It appears in this case that the beam does not produce a sufficiently dense plasma in the neutralizer to neutralize the beam space charge. The most difficult problem in producing these intense low energy beams is therefore overcoming the space charge forces of the beam itself. One method which has been discussed and used with moderate success is to place electron emitting filaments in the beam. This method is now being tested on the low energy ion beam at LLL. Other ideas for improving propagation characteristics of low energy beams include magnetic guide fields, and electrostatic or magnetic lenses. From the results of research carried out to date, it is apparent that some scheme is necessary for overcoming the deleterious space charge effects of the low energy beam.

We also anticipate problems with direct recovery. So far our direct recovery experiments with large beams, while partially successful, have not yet performed as successfully as earlier experiments at the kilowatt level.[13] Once direct recovery at the MW level has been demonstrated on the test stand, there still remain difficult problems in retrofitting sources equipped with direct recovery units to existing neutral beam systems.

B. Electrical

One of the principal problems in the electrical area is in tailoring the transient response of the entire system of source plus power supplies during the beam turn-on phase. It appears that the beam can be turned on with minimum opportunity for sparking if the beam current is made to vary approximately as the 3/2 power of the instantaneous beam voltage. This variation will tend to maintain optimum beam optics during the turn-on phase. We have been forced to develop programmable modulators to vary the power into the plasma source (and therefore, the available beam current) in a prescribed manner. With our present high voltage supplies, operation above about 50 kV is very difficult or impossible without these "arc modulators".

Another major problem area, one that will become increasingly severe as beam energies increase, is that of the capacitively stored energy available to be dissipated in a spark in the accelerator structure. Several experiments between 40 and 120 keV indicate that source operation is drastically downgraded following deposition of more than about 5 joules in the grids by a spark. We solve this problem now by use of a stack of transformer cores through which all leads to the source are threaded. In the event of a spark, inductive coupling to these cores inserts a resistance of several hundred ohms in series with the spark and absorbs most of the stored energy. At the 120-kV level, the energy stored in the 65A accelerator structure is only 2 to 3 joules. This energy cannot be absorbed by the "core stack" just described, and may present serious problems for us as we raise the beam energy to 150-200 keV.

High power tubes for series regulators present a problem. Two tubes capable of 1- to 2 MW of plate dissipation are being developed, by RCA and Eimac, but neither has yet been demonstrated to operate successfully with a neutral beam source in a switching and regulating mode.

Finally, an important, but rather mundane problem: It is necessary to telemeter certain information from the high-voltage "deck" to ground. We have had considerable difficulty using a digital telemetry system in the presence of electrical noise generated by sparks. We are developing a frequency-modulated analog system that we hope will be more immune to electrical noise.

C. Mechanical

Sources designed to operate in an environment of high radiation flux must be designed with all hard seals, and with a minimum of organic materials. We have had difficulty in developing large rectangular ceramic-to-metal seals suitable for use in the high voltage insulating structure of a source. Our best, and most recent success, has been in vacuum brazing alumina (Al_2O_3) insulators to thin rectangular titanium pieces, with a thin alumina "backing" piece. After a successful braze, the thin titanium is fusion welded to a more massive titanium ring. We have produced full-size insulator assemblies this way that are vacuum tight and mechanically sound. We have had less success in fabricating insulator sections from MACOR, a commercially available machineable glass ceramic produced by Corning Glass Co. Our first attempts to machine insulator rings from large pieces of this material and braze them to thick titanium sections were not successful. We have recently stress-relieved the MACOR billets before machining, following instructions from Corning, and have obtained much more satisfactory results. We have not yet re-attempted to braze these ceramic section to titanium.

We use molybdenum rather than copper in high voltage areas because of its superior voltage-holding ability. This presents difficulties in fabricating accelerator parts, though. Molybdenum grid rails are fabricated by rolling (for small cross sections) and by drawing (for large cross sections). We are now attempting to have fabricated molybdenum grid rails that are fabricated hollow, so that we can cool them by forced convection if necessary. We have also experienced considerable difficulty in fabricating stable high-voltage shields of molybdenum sheet. This problem is not yet solved satisfactorily.

We anticipate that the mechnical design of beam dumps will prevent problems as the beam pulse length is increased. We will probably be forced to convectively cooled systems, with some loss in diagnostic capability.

D. Computer Control and Diagnostics

Development of our computer system for control and diagnostics has not progressed nearly as rapidly as we would have liked. The main reason is that the system software was inadequate, and we did not provide adequate support in this area. It was considerably more difficult to bring a multiple-user network into operation than we had anticipated. Now that the system is more or less operational, we are beginning to appreciate another type of problem, that of the interface between the human test stand operators and the computer system. The simplest type of interface to implement is a conventional keyboard, and this is very unsatisfactory from the point of view of a person attempting to operate the test stand.

V. New Directions

Several topics remain, which are neither descriptions of hardware already built nor problem areas; they indicate changing directions within the positive ion neutral beam program.

A. System Economy

It may be possible to reduce the complexity and cost of neutral beam systems substantially. For example, if the "arc modulator" developed to give a prescribed time dependence to the beam current as the high voltage is switched on could be used in an active system to make the beam current track variations in the high voltage (power supply ripple), all the while maintaining optimum beam divergence, then it might be possible to eliminate the high voltage regulator, at a considerable cost saving.

As another example, there may be enough degrees of freedom left in the design of the accelerator structure to permit development of designs with reduced mechanical tolerances, thus making them easier to make and align.

B. Industrial Source Fabrication

Neutral Beam source development was judged sufficiently mature by the U.S. Department of Energy that industrial participation was invited, in the form of two contracts to industrial firms to fabricate one each complete neutral beam source for TFTR, with all hard seals and able to be remotely maintained. This work is just beginning, but from the experience we have had so far, it appears promising that industry will be able to contribute substantially to solving our difficult fabrication problems.

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TABLE I. TEST FACILITIES

FACILITY	SITE	REGULATED VOLTAGE (kV)	CURRENT (A)	PULSE LENGTH (SEC)	OPERATIONAL	VOLUME (ℓ)	PUMPING SPEED (ℓ/SEC)	SHIELDED ?
I	LBL	40	20	0.01	now	700	1,000 (air)	no
IIA	LBL	11	7	DC	now	2,000	7,000(air)	no
		20	20	~2	now			
IIB	LBL	40	80	0.01	now			
IIIA	LBL	150	15	0.5	now			
		100	40*	0.5	now			
		50	60*	0.5	now			
		50	15	10	now			
		120	15	1.5	6/78	170,000	30,000 (air)	no
		120	15	30	1/79			
		150	15	30	4/79		500,000 (O_2) 9/78	
IIIB	LBL	80	80	0.05	now			
		120	80	0.025	now			
		120	15	0.5	1/79			
442	LLL	20	20	0.01	now	6,000	7,000 (air)	no
HVTS	LLL	200	20	DC	1979			
		120	65	30	debugging	20,000	650,000 (D_2)	yes
		80	80	30	debugging			
NBSTF	LBL	120	65	0.5	12/78	40,000	3×10^6 (D_2)	yes
		165*	34*	DC				

* TRANSFORMER/RECTIFIER CAPABILITY

TABLE II. RESULTS FOR VARIOUS TEST SOURCES

BEAM ENERGY (keV)	BEAM CURRENT (A)	GAS	PLASMA SOURCE	PULSE LENGTH (SEC)	1/e HALFWIDTHS (DEGREES)	COMPOSITION $\%H^+/\%H_2^+/\%H_3^+$
120	14	H_2	NORMAL	0.5	1.24 x 0.76	
120	10	D_2	NORMAL	0.5	1.28 x 0.42	
105	12.2	H_2	BUCKET	0.5	1.28 x 0.5	66/27/7
80	11.2	H_2	NORMAL +2.5 cm	0.5	1.4 x 0.7	63/26/11
80	11.[illegible]	H_2	NORMAL	0.5	1.4 x 0.7	70/20/10
85	13.5	D_2	NORMAL	0.5	1.4 x 0.5	
1	10	D_2	NORMAL	0.03	~15	70/20/10

TABLE III. FULL-SIZE SOURCE STATUS AND RESULTS

USER	BEAM ENERGY (KEV)	BEAM CURRENT (A)	GRID DIMENSIONS (CM)	GAS	FOCAL LENGTH (m)	PULSE LENGTH (SEC)	INTRINSIC 1/e HALF-WIDTHS (DEGREES)	COMPOSITION $\% D^+/ \% D_2^+ / \% D_3^+$	STATUS
TFTR	120	65	10 x 40	D_2	∞	0.01 0.5	1.2 x 0.5	70/20/10	Achieved Expected 8/78
HFTF	(80)	(80)*	10 x 44	D_2	7 x 7	(0.5)*	(<1.5 x 0.5)		Plasma Source Being Tested Accelerator Being Assembled
DOUBLET III	(80)	(85)*	10 x 40	H_2	4.8 x 5.5	(0.5)*	(<1.5 x 0.5)	(70/20/10	Being Assembled

*Number in Parentheses represent anticipated performance

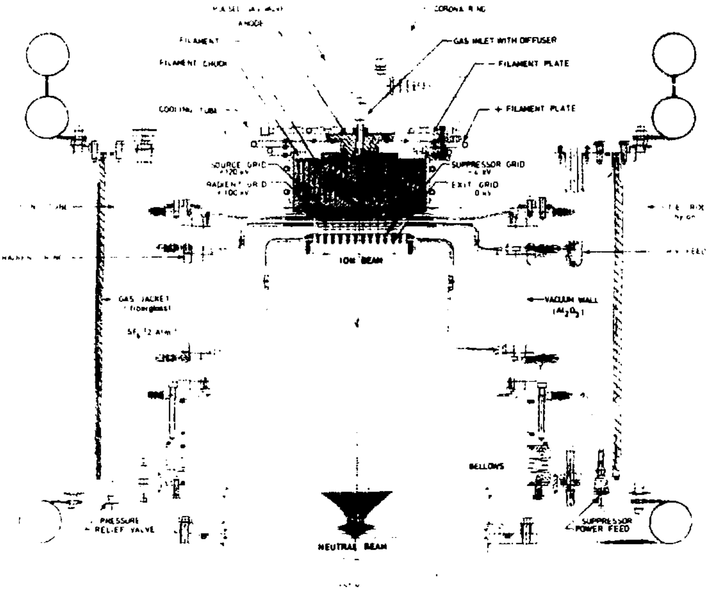
TABLE IV
ESTIMATES OF BEAM DIAGNOSTIC CAPABILITIES
(BASED ON 120 keV TEST STAND DATA)

BEAM PROPERTY	REPRODUCIBILITY SPECTROSCIPIC	CALORIMETRIC	ACCURACY	DRIFTS
DIVERGENCE	≤ 0.05° (0.02 Typical)	~0.02°	~15%	~25% During 500 ms Pulse
Aiming Direction	≤ 0.05° (0.02° Typical)	< 0.01°	0.1°? (May depend on ∫ndl, etc.)	<0.015° If Well tuned ~0.2° during tuning
Composition	Few % Points	Few % Points	~5% Points	Few % Points

TABLE V. POWER SUPPLY CHARACTERISTICS

SUPPLY	V (kV)	I (AMPS)	τ (SEC)	REGULATION %	REGULATOR	SWITCH	OPERATIONAL
III A	150	20	0.5	± 1	Shunt (Machlett DP-15's)	SCR	NOW
III A*	150	15	30	± 1	Shunt (Machlett DP-15's)	SCR	4/79
III B	120	80	0.025	± 1	Switching of Small Banks	SCR	NOW
HVTS	120	65	> 1	± 1	Series (RCA A 3012)		7/78

*This supply, in another configuration, will also be used to test the TFTR Prototype beamline.

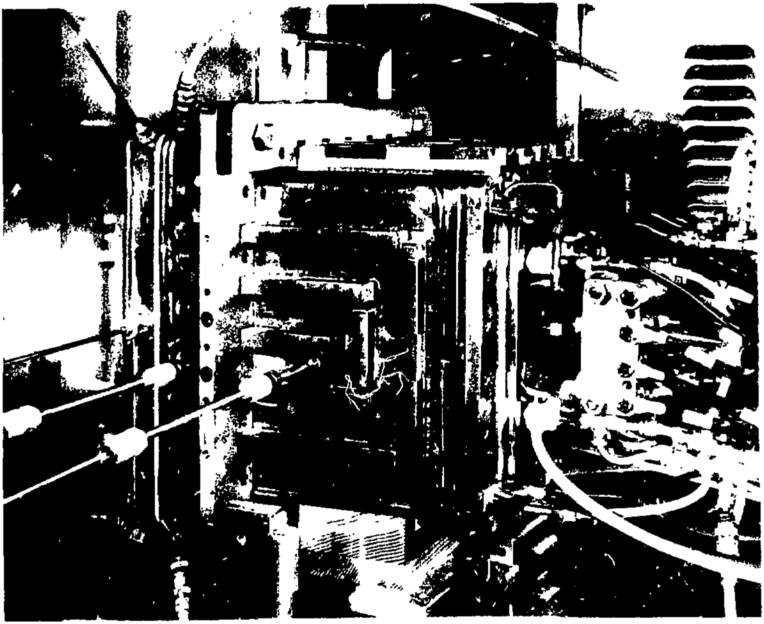


LBL 15-A NEUTRAL BEAM SOURCE MODULE

(15-A 120-keV 0.5-sec)

CBB 770 12659

Figure 1. Cross section of a typical test source.



CBB 781-230

Figure 2. Photograph of a "bucket source" on the test stand.

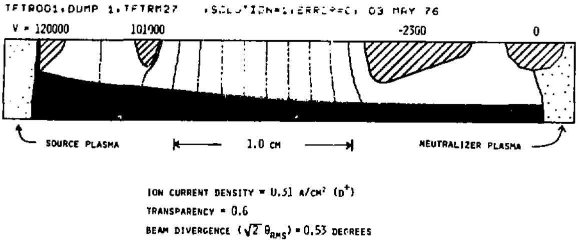


Figure 3. Cross section of the molybdenum grid rails used in the 120-keV accelerators

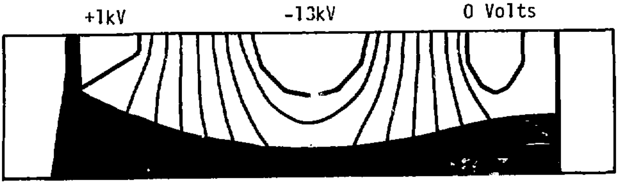
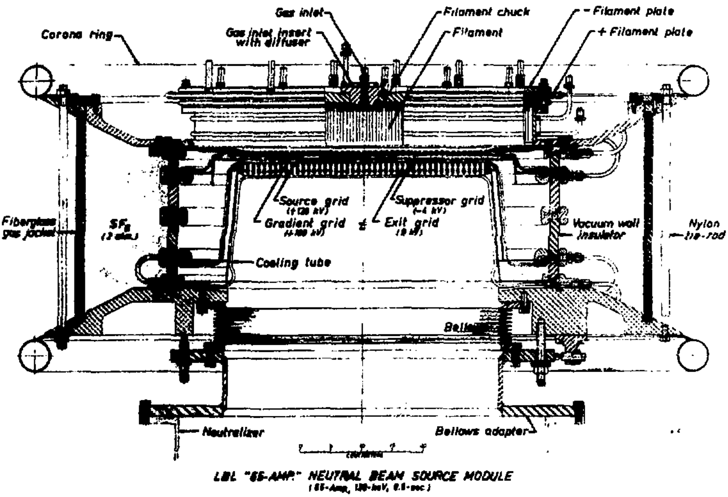


Figure 4. Accel-decel accelerator grid design used for producing 1-keV beams.



CBB 775-5125

Figure 5. Cross section of a 120-keV 65 A source for TFTR.

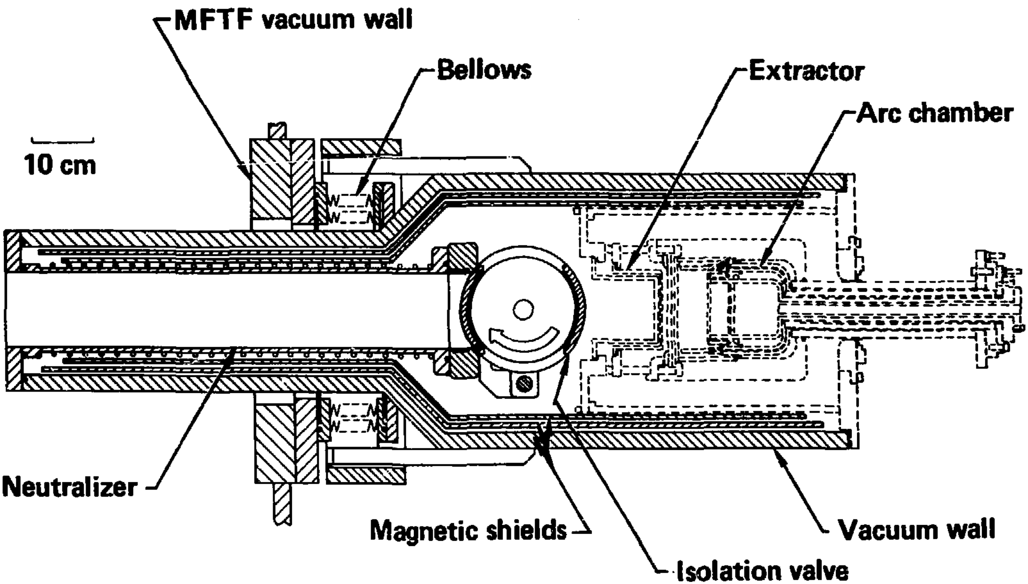


Figure 6. 80 keV MFTF source and injector module.

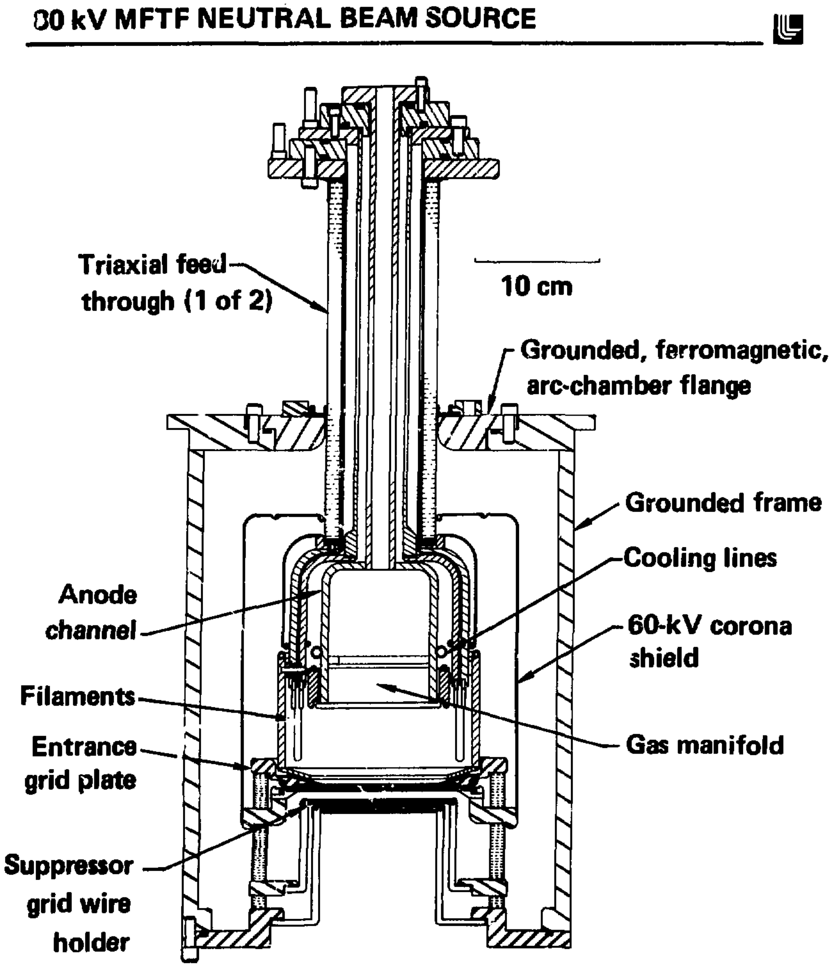
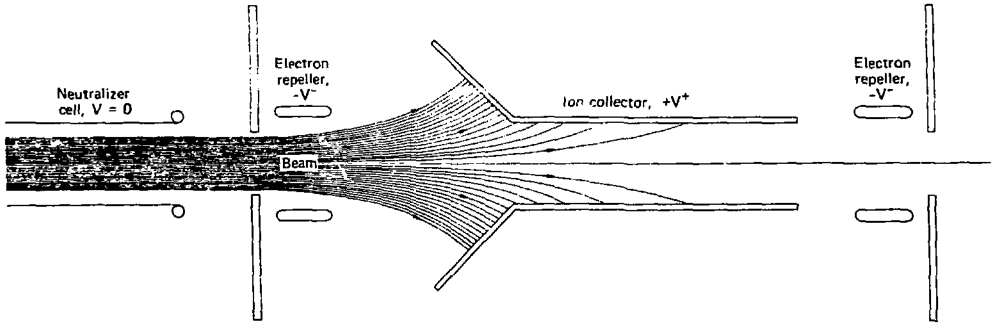
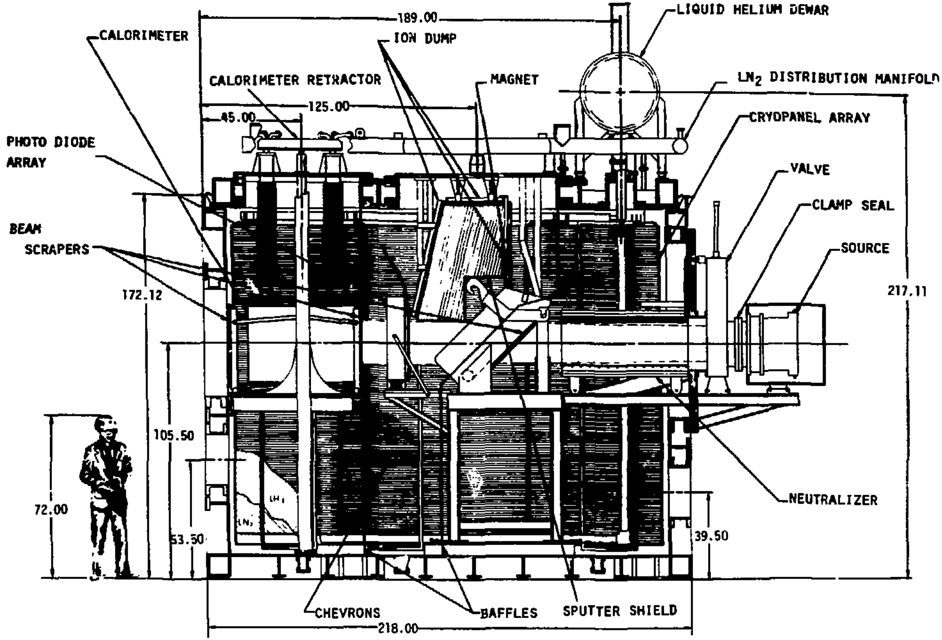


Figure 7. 80 keV neutral beam source.



XBL 789-10843

Figure 8. Schematic of direct recovery experiment.



NOTE: DIMENSIONS IN INCHES

Figure 9: Design of the TFTR Prototype Beamline.

XBL 788-10014