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Authors

Chintalpudi, S.
Clark, D.J.
Gavin, B.
et al.

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S. Chintalpudi, D.J. Clark, B. Gavin, H. Grunder,
W.R. Holley, R.M. Richter, F. Selph, E. Zajec

Lawrence Berkeley Laboratory
University of California
Berkeley, California

ABSTRACT

The continued improvement of heavy ion sources is of particular importance at Lawrence Berkeley Laboratory, as at present four heavy ion injectors are used in LBL accelerator operations. Two of these serve the SuperHILAC (a heavy ion Alvarez linac), another serves the Bevatron injector (a 20 MeV Alvarez linac operating in the $2\beta\lambda$ mode), the fourth is used at the 88-inch cyclotron. All of these injectors use PIG sources at present, with modifications in each case to suit the special requirements of the accelerator. At the SuperHILAC the need is for large duty factor (15-50%), long lifetime sources. The present source supplies 3.0μA, av. of Kr^{6+} at 16% duty factor, measured after acceleration to 9.5 MeV. At the $2\beta\lambda$ Bevatron injector requirements are for very high charge state of the lighter ions (up to Neon), with low duty factor operation. At present 1μA, peak of Ne^{6+} is achieved at 2.4 MeV. At the 88-inch cyclotron interest centers on usable beams of the highest possible charge state, because particle energy in the extracted beam varies as the square of the charge state. Currently 0.2μA, av.of 214 MeV Ar^{8+} is available.

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Introduction

The SuperHILAC will accept beam of 113 KeV/nucleon from either of two injectors. One is a pressurized high voltage generator designed to accelerate ions to 2.5MV(1) of mass A $\geq$ 40, while the other is a conventional 750 KV Cockroft-Walton supply used for accelerating the lighter mass ions (A $\leq$ 40). While Kr^{4+} (at 2.4 MV) and Xe^{6+} (at 2.5 MV) satisfy the linac acceptance requirements, the high voltage limitation of the injector necessitates higher charge states for the time being.

Both injectors use Penning type reflex discharges. Since emphasis lies with heavy ion production, and in as much as the low voltage, low mass injection system delivers adequate intensity beams (i.e. O^{3+}, Table 1), ion source improvement work is directed towards the 2.5 MV source. A test facility has been built to study source performance in an environment closely approximating that in the 2.5 MV source, and some results have been reported elsewhere.(2)

Recent emittance measurements made at the exit of the 2.5 MV injector, using $^{84}Kr^{6+}$ ions at (113 KeV/A), showed the areas to be 5.4 πcm-mrad and 7.0 πcm-mrad in the horizontal and vertical planes respectively.

Operation

Titanium cathodes are used in cold mode operation and allow for extended source lifetimes, typically, for Krypton at 18% duty factor, about 27 hours. Test stand data is being gathered on cold mode vs hot mode operation. In general, given equal power input, the hot mode operation appears to be superior for ions lighter than krypton with the exception of metallic ion production from anode sputtering. Also, hot mode operation permits higher duty factor and higher peak power input. On the other hand greater arc stability and longer lifetime is realized with cold mode operation.

Our ion source operation has been primarily with gaseous elements, however the acceleration of metal ions, particularly ^{48}Ca, will be realized after suitable power supply installation. While ^{44}Ca^{3+} has been analyzed at the test stand, ^{48}Ca has not been observed due to its low fractional level in natural calcium. Its intensity is expected to less than 0.3μamps (peak) at the test stand. Therefore when ^{48}Ca is ionized, it will probably be derived from a sputtering electrode enriched with ^{48}Ca metal. High sputtering efficiency is desirable. The consumption rate of calcium electrodes is about 60 mg/hr at 11% duty factor. In prior work at Dubna as much as one order of magnitude lower consumption rate was obtained(3). As this metal is extremely rare, it must be recovered by chemical reduction of the ion source. A 90% recovery efficiency is anticipated.

In an effort to simplify isotope separation and improve the beam intensity of Xenon, the SuperHILAC 2.5 MV source is using enriched Xenon gas stored in small volume at low pressure. Two solenoids are pulsed open in unison for 20 millisec, at rates of 1/sec to 1/min. The minute gas bursts are subsequently smoothed out by passing through a suitable length of porous metal rod. This gas source is in addition to and in parallel with a high pressure, high volume commerical proportional gas control device.

SuperHILAC performance data is shown in Table 1. The projected intensities of a few metallic ions are also included. Titanium, vanadium, and iron have also been accelerated from the 750 KV injector from cathode sputtering. Their intensities are expected to be increased sbout 50% upon installation of pulsed extractor power supply.

Bevatron Injector

The source used at the 200 MeV Bevatron injector is a side extracted PIG source of the cold cathode type developed at the Berkeley Hilac and later modified for use in the 20 MeV injector. (Figure 3). The source measures 3.5 inches high and is insulated from the tank walls by two alumina cathode insulators. The stainless steel anode has a 0.25 in. inside diameter, is 2.5 in. long, and is spaced on both ends by alumina insulators. The anode is machined to accept a replaceable thin (0.010 in.) tantalum plate having an exit aperture measuring .031 by 0.625 in. Anode and cathode cooling is provided by 0.125 in. diameter stainless steel tubing. The titanium cathodes are 0.325 in. diameter and fastened into position with screws to allow rapid replacement. The tungsten extractor jaws are 0.032 in. thick and are secured to the extractor body with screws that allow aperture adjustment. A typical width and gap spacing is 0.040 in. by 0.060 in.

A DC source magnet is used with an operating field of about 4000 gauss. Arc power is provided by a dual supply with an adjustable triggering spike of 0-8 KV and a pulse capability of 0-5 KV at 10 amperes. Operation at 8 KW, and a duty cycle of 1×10^{-3} will deliver 100 μamps of O^{5+}. Lifetime of the cathodes with this type of service exceeds 1000 hours. The extractor supply is regulated to 0.1% and is rated at 40 KV at 10 mA. Pulse rise time is 30 μsec.

Performance data of the source and acceleration through the 20 MeV linac is shown in Table 2.(5) For heavy ions the linac is operated in the 2βλ mode producing an ion velocity that is 1/2 that of a 20 MeV proton, or an energy of 5 MeV per nucleon. Acceleration is proportional to $T_f(q/A)E$, where T_f is the transit time factor, and E is the electric field gradient. Since T_f for particles with half normal velocity is about half the normal T_f, acceleration of particles with q/A = 0.5 to one-fourth energy requires the same E as for protons accelerated to full energy. In the case of the 20 MeV linac E can be raised considerably higher than this, making it possible to accelerate ions with q/A = 0.3.

Source Vacuum

Recent pressure and pumping speed measurements in the source region indicate that greater pumping speed is desirable to prevent excessive charge exchange losses in the extraction area. As an example, a gas flow of 1cc/min STP gives a resultant pressure in the source chamber 1.5×10^{-5} torr. which is marginal for good heavy ion operation. The pumping system at present includes a 650 l/sec turbo pump, a 800 l/sec diffusion pump, and a 400 l/sec vac-ion pump giving a net speed at the source box of only 125 l/sec. This low speed is due in part to the inadequate conductance of the accelerating tube (about 35 l/sec). Figure 4 displays a titanium sublimation pump system that is being installed.(6) This unit will give an additional 1700 l/sec. of pumping speed for N_2 at a Titanium sublimation rate of .12 grams/hour. The lifetime of a 35 gram ball of titanium would be 272 hours. Ultimate pressure in the source box would be approximately 5×10^{-6} torr.

The 88-inch Cyclotron

The LBL 88-inch Cyclotron is a variable energy, multiparticle, sector-focussed cyclotron which accelerates protons to energies up to 60 MeV, and heavier ions to 140 q^2/A MeV. It has an external polarized ion source for beams of polarized protons and deuterons which uses a quadrupole transport line to bring the ions down the pole axis of the cyclotron for injection. Heavy ion beams are run using a PIG source at the center of the cyclotron ("internal source").

The internal source is being improved to accelerate lighter mass ions, and to incorporate solid material feed systems with long lifetimes. Also an external PIG source test bench is being used to test improvements in internal source operation, and to develop better heavy ion sources for use externally with the axial injection system of the cyclotron. This work has been previously described.(7)

A cross Section of the internal PIG source is shown in Fig. 5. The anode and cathode holder are made of water-cooled copper. The cathode holder makes the electrical connection between cathodes, eliminating the need for an external connection to the top cathode. The upper cathode is now usually made with a shoulder and dropped in to the holder so a set screw is not required. The lower cathode is a cylinder dropped into the holder. The alumina base insulator forms a vacuum seal and makes insulated water connections to the anode and cathode circuits from two water lines coming through the source shaft. A drop-in boron nitride cover insulator protects the alumina, and is easily removable for cleaning. The electron dump provides a component of electric field, E, parallel to the magnetic field, B, causing electrons circulating around the cathode holder in an ExB mode to be dumped on the outer tantalum cover. Fig. 6.

Operation. Maximum stable beam is obtained with an arc power of about 2-3 kilowatts. To obtain a beam of lithium, a solid material containing lithium must be used in the source, since no gas contining lithium was available. Trials were made using 10-20% lithium flouride mixed with tantalum powder and pressed into a cylinder for use as a cathode. A $^{7}Li^{2+}$ beam was obtained. Later LiF was melted into a tantalum sleeve placed in the 3/8 inch diameter arc hole of the anode. This produced more lithium vapor near the beam exit slit and gave more beam. At present the sleeve and pressed cathodes are used together. This gives external beam intensities of about 1μA of 60-80 MeV Li^{2+} over periods of several hours between cathode changes. Nitrogen or argon support gas is used as needed.

The internal PIG source has been in operation about 2-1/2 years during which some maintenance problems have appeared. There has been some chipping of the 85% alumina base insulator, so copper inserts have been added at the water seals. When excess pressure appears inside the source, due to a water leak or vaporizing of some material, the electron dump region overheats and can damage the cathode holder or base insulator. Cathode changes take about 30 minutes and occur every 3-5 hours with oxygen gas. Cathode lifetime is usually 5-10 hours with nitrogen and other gasses.

Recent developments include the acceleration of $^{40}Ar^{7+}$ to 160 MeV. A tantalum sleeve is placed in the PIG anode bore with the opening on the extraction slit side. A few tests have been made to accelerate $^{40}Ca^{7+}$ to the same energy. Beam was obtained by putting calcium metal in the small hole in the sleeve used for argon. The best performance has been with nitrogen as the support gas. A list of the present external beams is given in Table 3. The internal beam at the source is 4-8 times larger, and the equivalent current using D.C. instead of RF extraction would be another 8 times larger, because of the beam phase with of 45^{o} out of 360^{o}.

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Figures

1. 3 MV Source Magnetic Gap Cross Section, XBL 728-3952.
2. 3 MV Terminal Ion Source and Beam Transport, XBL 712-6308.
3. Cross Section of the 20 MeV Injector Heavy Ion Source, XBL 745-800.
4. Titanium Sublimation Pumping System, XBL 745-801.
5. Cross Section of the 88-Inch Cyclotron Internal PIG Source, XBL 7110-1536.
6. Internal PIG Source, (disassembled), BBC 7110-4839.

TABLE 1 *

ION SPECIES	2.5 MV INJECTOR	750 KV INJECTOR	SUPERHILAC EXIT	TARGET
	μA	μA	ηA	ηA
$^{18}O^{3+/7+}$		800	30,000	25,000
$^{40}Ar^{6+/13+}$		6.5	1,500	200
$^{48}Ti^{7+/13+}$		6	90	5
$^{40}Ar^{3+/13+}$	50		3,200	600
$^{84}Kr^{6+/21+}$	12		1,900	500
$^{86}Kr^{6+/21+}$ (natural gas)	0.9		40	5
$^{132}Xe^{8+/29+}$	2.3		52	2.5
$^{40}Ca^{3+/}$	21	projected values based on test stand performance		
$^{48}Ti^{3+/}$	25			
$^{93}Nb^{5+/}$	23 (hot mode)			
$^{197}Au^{10+/}$	0.3 (hot mode)			

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* Average current values are given.

TABLE 2

ION	120 KeV/nucleon	q/A	Charge State In Linac	Linac Beam 5 MeV/nucleon*	Bevatron beam— 250 MeV/nucleon** Particles per pulse on target	Particles per second on targe
^{2}H	5 mA	.5	+1	250 μA	2×10^{11}	3×10^{12}
^{4}He	600 μA	.5	+2	70 μA	2×10^{10}	3×10^{11}
^{12}C	85 μA	.33	+4	4 μA	1×10^{8} 10^{10} ±	1.5×10^{9}
^{14}N	40 μA	.35	+5	1.0 μA	1×10^{7} 10^{10} ±	1.5×10^{8}
^{16}O	60 μA	.31	+5	1.6 μA	1.5×10^{7} 10^{10} ±	2×10^{8}
^{20}Ne	1. μA	.30	+6	0.01 μA	1×10^{5} 10^{9} ±	1.5×10^{6}

* Fully stripped ions at injection to Bevatron

** Pulse rate of 15/second

± Anticipated particles per pulse with SuperHilac injection.

TABLE 3

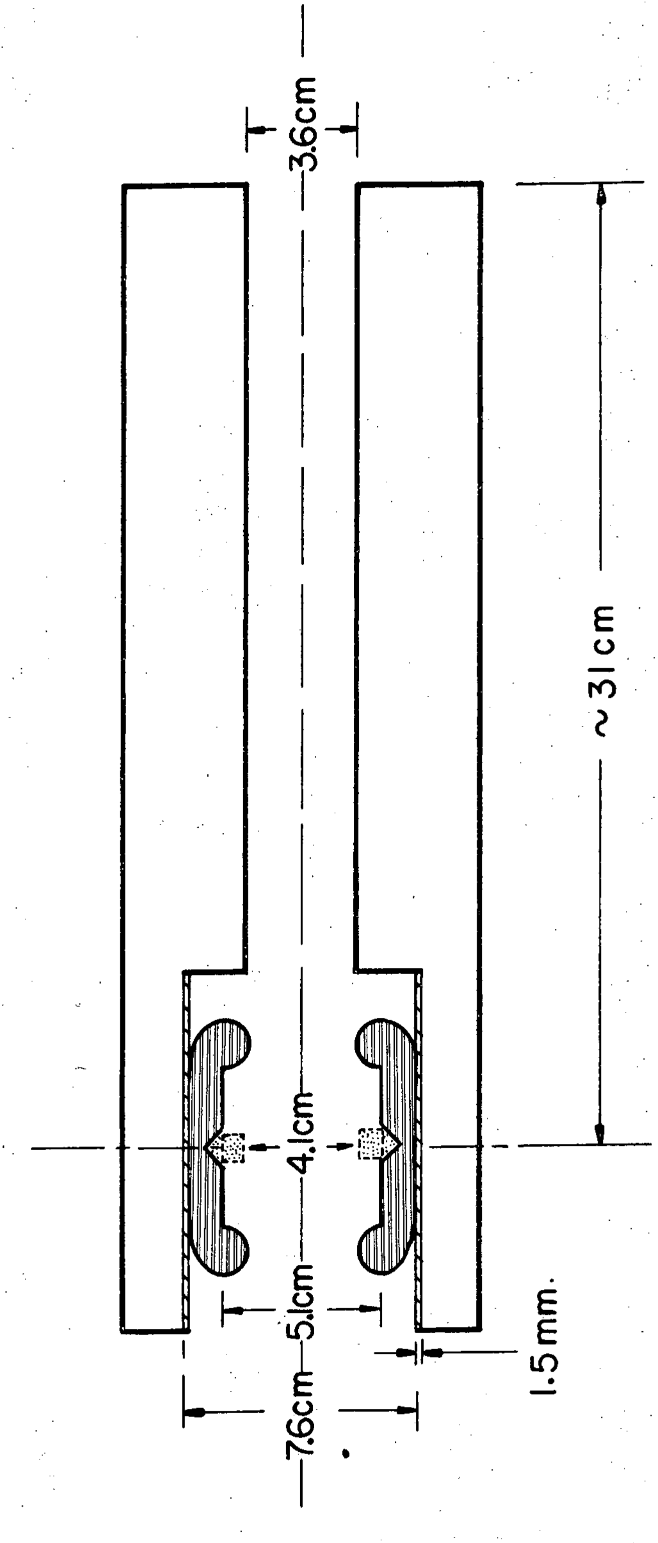
88-INCH CYCLOTRON HEAVY ION BEAMS APRIL 1974

ION	[+]ENERGY (MeV)	HARMONIC	[*]EXTERNAL BEAM
$^{6}\mathrm{Li}^{2+}$	80, 93	1	1 μA
$^{7}\mathrm{Li}^{2+}$	37- 80	3, 1	1 μA
$^{9}\mathrm{Be}^{3+}$	120, 140	1	0.2 μA
$^{11}\mathrm{B}^{3+}$	43-115	3, 1	2 μA
$^{12}\mathrm{C}^{3+}$	50-105	3, 1	5 μA
$^{12}\mathrm{C}^{4+}$	187	2	1 μA
$^{14}\mathrm{N}^{2+}$	34- 40	3	1 μA
$^{14}\mathrm{N}^{3+}$	50- 90	3, 1	5 μA
$^{14}\mathrm{N}^{4+}$	74-160	3, 1	5 μA
$^{14}\mathrm{N}^{5+}$	250	1	1 μA
$^{14}\mathrm{N}^{6+}$	360	1	10^{3} part/sec.
$^{16}\mathrm{O}^{3+}$	50- 75, 79	3	5 μA
$^{16}\mathrm{O}^{4+}$	85-140	3, 1	5 μA
$^{16}\mathrm{O}^{5+}$	218	1	0.5 μA
$^{20}\mathrm{Ne}^{4+}$	93-107, 112	3	1 μA
$^{20}\mathrm{Ne}^{5+}$	105-150, 175	3, 1	0.5 μA
$^{32}\mathrm{S}^{6+}$	120-150, 158	3	0.1 μA
$^{40}\mathrm{Ca}^{7+}$	163	3	.1 μA
$^{40}\mathrm{A}^{7+}$	130-163, 171	3	0.3 μA
$^{40}\mathrm{A}^{8+}$	170-214, 224	3	0.2 μA
$^{56}\mathrm{Fe}^{10+}$	180-220, 250	3	1 part/sec.
[†]$^{84}\mathrm{Kr}^{12+}$	207, 240	3	1 part/sec.

[‡] Energies run. Maximum if full magnetic field were used, is shown after comma, if higher.

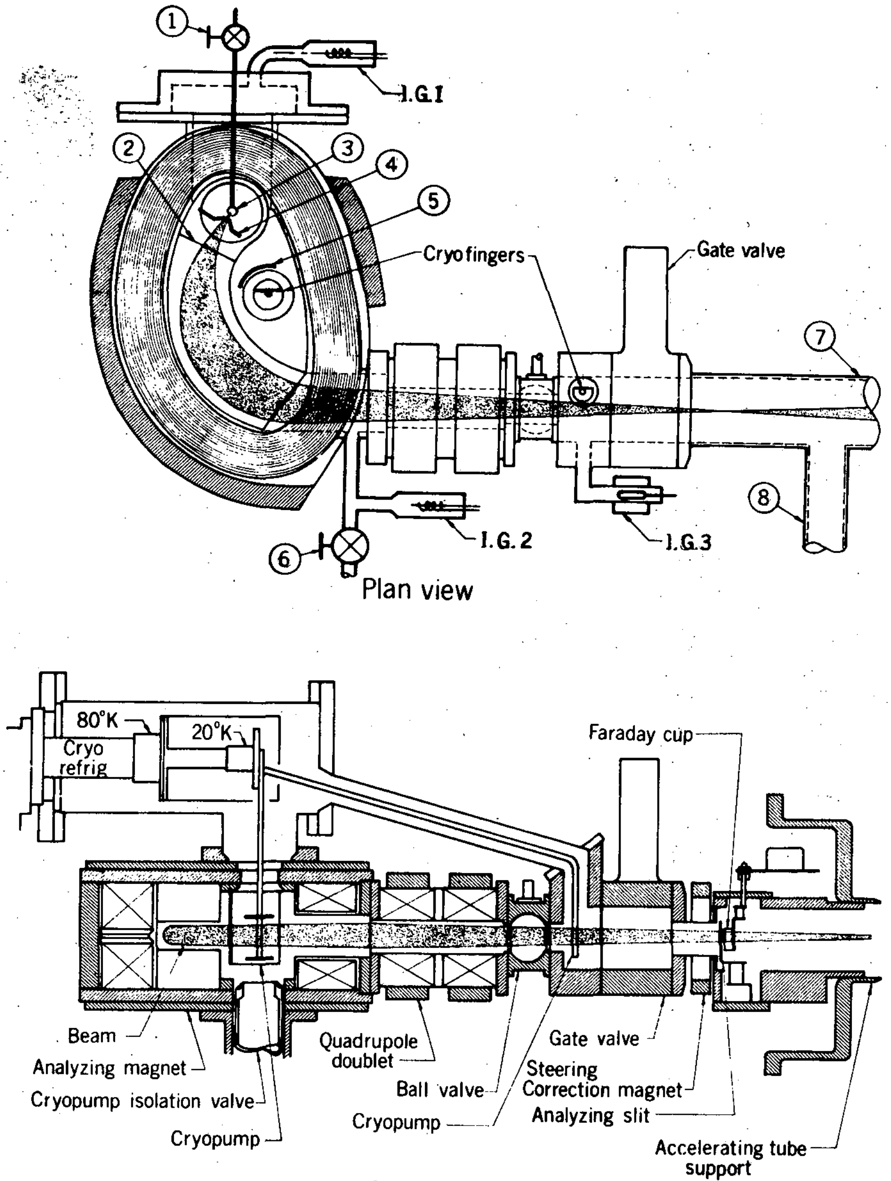
[*] Electrical microamps or particles/sec., total external.

[†] Filament source. Other beams used PIG source.



XBL728-3952

Fig. 1



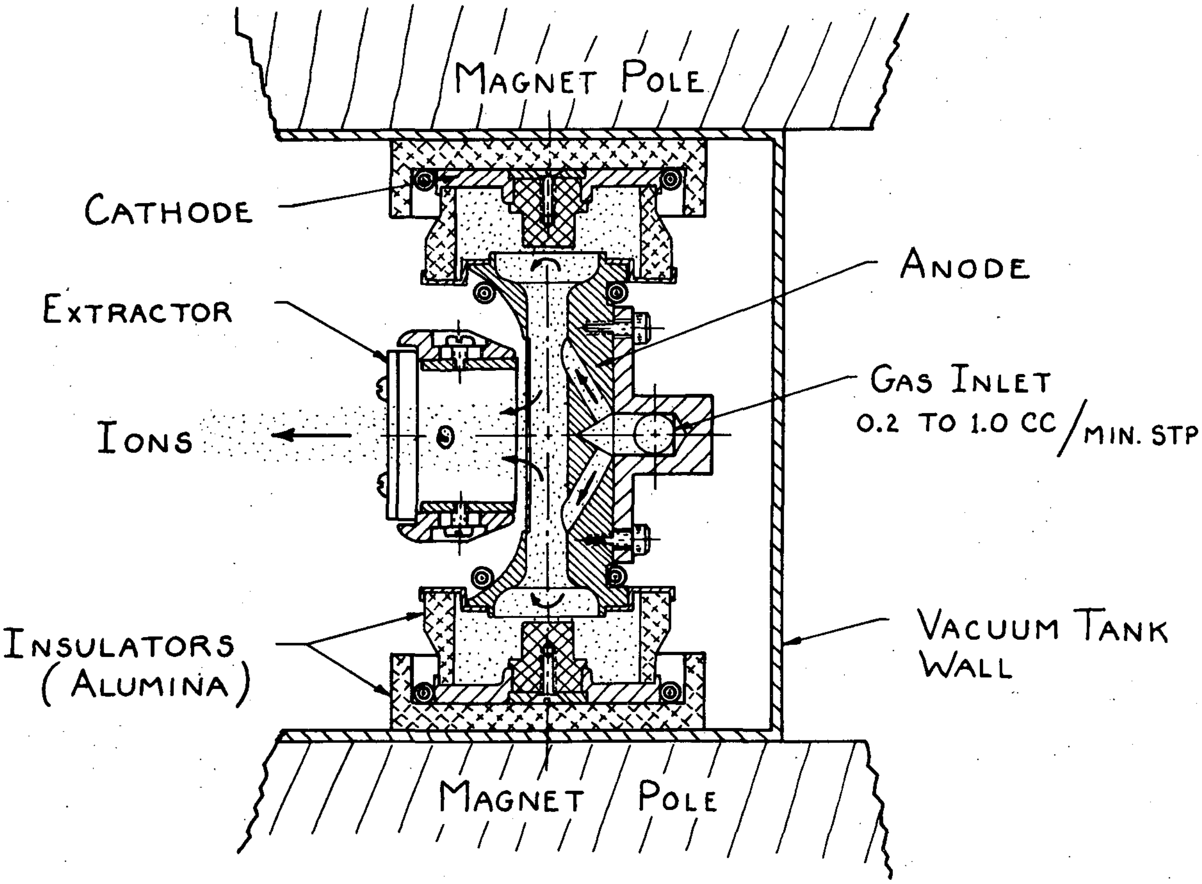
Plan view

Section

Ion source and beam transport

XBL 712 6308

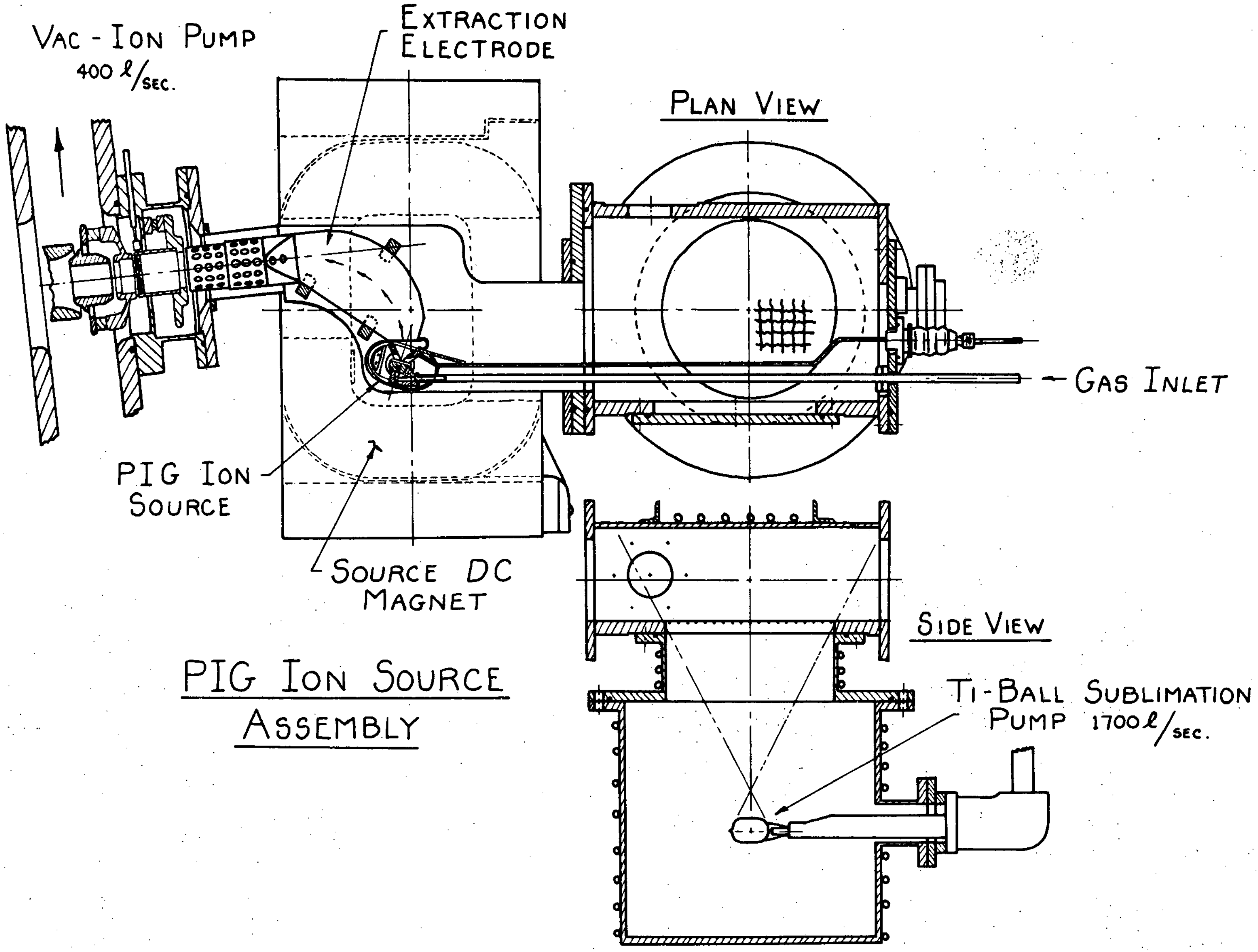
Fig. 2



PIG ION SOURCE

XBL 745-800

Fig. 3



XBL 745-801

Fig. 4

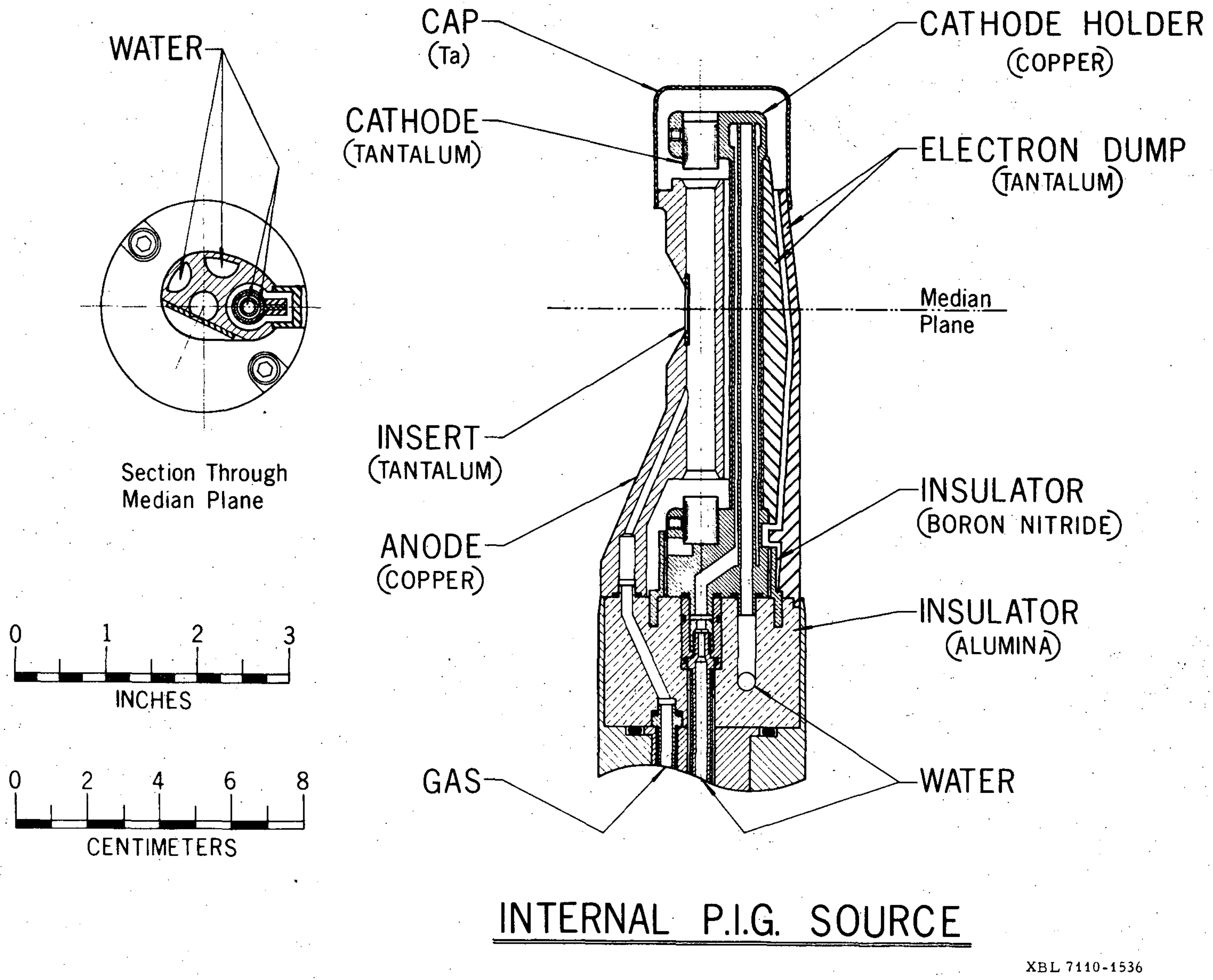

WATER
Section Through Median Plane
0 1 2 3
INCHES
0 2 4 6 8
CENTIMETERS
CAP (Ta)
CATHODE (TANTALUM)
INSERT (TANTALUM)
ANODE (COPPER)
GAS
CATHODE HOLDER (COPPER)
ELECTRON DUMP (TANTALUM)
Median Plane
INSULATOR (BORON NITRIDE)
INSULATOR (ALUMINA)
WATER
INTERNAL P.I.G. SOURCE
XBL 7110-1536

Fig. 5

CBB 7110-4839

Fig. 6

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