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LMP DEVICE

Plasma Production Facilities

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The LMP device has been described earlier in the LRP 205/82 (1). This short note will summarize the main parameters. The device was first used to produce gas discharges - neon and argon -, it has been recently converted in order to produce also metal alkali plasmas such as barium plasmas.

MACHINE

The machine consists mainly of three parts :

- the vacuum vessel,
- the pumping group, and
- the magnetic field coils.

We present on Fig. I a schematic of the device.

Vacuum vessel

The total length of the vacuum vessel is of the order of 9.2m with an inner diameter of 0.40m. The vacuum vessel has a total of 9 sections. At each end, two Tee sections allow to couple it to the pumping groups. A total of 62 ports permit the availability of the diagnostics access at 88 different axial and azimuthal positions for plasma measurements and machine monitoring. Also these allow the connection to RF antennas inserted in the device. Divers specific ports have been adapted for optical purposes and insertion of anodes in order to modulate as desired the total length of the plasma.

The vacuum vessel is made of stainless steel (AISI 316L) which guaranteed a concentration of ferrite less than 1% after the welding and machining.

The seven sections underlying below the magnetic field coils are water cooled on the outer diameter as well than on the main flanges.

Pumping groups

Two pumping units are installed at the ends of the device. Each consists of a 5200 l/s diffusion pump - which reduces effectively to 2100 l/s after baffle and valve - backed by a 60 m^3/h roughing pump. A freon baffle is used to prevent oil back-diffusion. A base pressure, with all diagnostics and plasma sources installed, is a little over 10^{-7} torr. The ionization gauges, installed on the device are placed on an extension tube so that the measurement is less affected by the magnetic field.

Magnetic field

The linear homogeneous magnetic field is created by 44 identical water cooled copper coils. An air cooled heat exchanger of 200kW is used in a close circuit to maintain the input cooling water below 60° C. Each coil is formed from two independent two turn, nine layer pancakes which are sandwich together. Each of the pancakes is individually water-cooled. Table I shows the coil characteristics.

We are able to obtain a magnetic field of 0.3 tesla with an activating current of 850A. The current is regulated to compensate for long term drift.

The field homogeneity is $\simeq$ 0.3% over a central length of 4.75m and a diameter of 0.2m.

These parameters give the opportunity to use the LMP device in various applications of basic plasma physics research. To our knowledge there exists no other such long device with such a volume of homogeneous B field. Also the flexibility in changing plasma sources and adapting different arrangement with the vacuum vessel sections is very attractive.

PLASMA SOURCES

The plasma may be produced in different medium, gas discharge and alkali vapour, and in different regime, pulse or continuous.

Gas discharges

the initial experiments were performed in gas discharge produced plasmas : neon, argon, ... For plasma production we used, for most cases, radiatively heated electron emitting cathodes which were home made. A nickel disc is covered by Ba, Ar, Ca carbonates which react during increase of temperature and fully transform at ≃ 1000°C into oxides, mainly BaO, which are good electron emitters at 900°C. These cathodes in DC regime able to work with an emission current of 15A and in pulse regime up to 50 A reproducibly. The life time of these cathodes is reduced because of ion bombardment and so by using small currents the emissive layer lasts longer. Also the main problem remains that when the cathode is brought back to air after processing, it gets poisonned by the moisture contained in atmospheric air. The oxide layer then tends to crack.

The advantage of such source (Fig. II) is to work at relatively low temperature and the power supplies used for filament heating (12V - 100A) and for plasma production (350 V max - 100 A), mainly current controlled, have no specific requirements as high voltage isolation to mains. Only low ripple is a priority, mainly in case of continuous plasma discharge. In the case of pulse plasma, transistors circuitry may be used for fast switching. This switching supply was developped at CRPP. Plasma parameters obtained with BaO cathodes are shown in Table II.

Because of the life time and degradation of the oxides layer, dispenser cathodes with tungsten or nickel matrix as well as Lanthanum hexaboride cathodes were tested in a different schematic (Fig. III). These cathodes discs were adapted into a high temperature capability setting. Dispenser cathodes required 1100°C / 1200°C and Lanthanum hexaboride ~ 1600°C for good electron emission. Many problems of reproducibly and chemical reactions with insulators were encountered. so we kept to the solution of making our own cathodes.

The laboratory has also a good experience in the RF produced plasma either resonantly or non resonantly (2). Slow wave structures allow quiet plasma production with relatively low RF power, if required density is over $10^{11}cm^{-3}$ then high RF power is needed and plasma becomes turbulent. So this attempt, also, was left. One has to remind that laser diagnostic requires in many cases high density plasmas in order to get enough photons reemitted from the plasma - unless as with barium plasma intensity of light is important.

Alkali plasma source

Finally, the actual source of plasma which is used in the LMP device permits the creation of barium plasma in the so-called Q-plasma regime. This metal alkali plasma is produced by vaporising Ba and blowing homogeneously this vapour onto a hot tungsten rhenium coated disc (1800°C - 2100°C). This plasma gun (Fig. IV) was originally developed at the University of California at Irvine by N. Rynn and his team (3). It has been transfered to the CRPP through the joint collaboration INT (US) - Swiss National Found (Switzerland). At CRPP, this source received a number of transformation which improved the reproducibility of the plasma production and also facilitate certain operations such as: replacement of divers items, refilling the barium oven and restauring it in place, seal of the oven, resistive coaxial wire connectors, water cooled jacket which keeps the neutral vapour in the source region, heat shieldings, high voltage screen, which prevents arcing. (Fig. V).

The gun is fired by using a home made power supply which is programmable through microprocessor circuitry. It is basically composed of 5 partial power supplies (filament heating, filament cathode supply, cathode hot plate supply; oven supply and neck supply) (Fig. VI).

All power supplies are thyristors feedback stabilized. The philosophy of this arrangement lays on the principle of maximum automatisation for safety purposes and because of many potential users. It also allows data transfer to computer if needed.

The heating status of the gun is display on a T.V. screen, so one can, at any time, monitor all status of the device. Also are displayed : basic pressure, magnetic field current, temperature measurements, security, water cooling, plasma density detection through ion saturation current of a Langmuir probe ... (Table III).

Performances of the gun are subject to various parameters, so basically the power supplies are current regulated for keeping - in constant condition of pressure - stable incident power to hot plate. The plasma density will then be varied by total power on the hot plate and heating power on the vaporising oven, finally the heated neck will provide an optimum input of vapour in the effuser. The slotted effuser sprays over 360° the vapour in front of the hot plate. the plasma is created by contact ionisation and diffuses along the magnetic field lines. With Barium, ionisation efficiency is ~ 16% (4). The neutral vapour is collected on the water-cooled jacket, so the plasma leaving the production section is 100% ionised. Two heat shields avoid undesirable radiation losses from the effuser and keep it at an optimum temperature. Also the neck and the oven receive a heat shield which favorises a gain in the heating of ~30%.

The parameters of the barium plasma are given in table IV. Also typical radial and axial density profiles taken by Langmuir probe are shown on Fig. VII.

(1) The linear magnetized plasma device (LMP). M.Q. Tran, P. Kohler, P.J. Paris, M.L. Sawley. LRP 205/82
(2) M. Bitter, Ch. Hollenstein, P.J. Paris. Rev. Sci. Instrum. 47, 1209 (1976)
(3) V. Laub, N. Rynn, H. Böhmer. Rev. Sci. Instrum. 48, 1499 (1977)
(4) D.N. Hill, Ph.D. dissertation, "Wave-Modified Ion Distributions and Cross-Field Transport Measurements by Laser-Induced Fluorescence", UCI, 1983.

P.J. Paris, CRPP version of August 28, 1987

Coil inner diameter	.522 m
Coil outer diameter	.830 m
Coil thickness	.092 m
Number of turns	4
Number of layers	9
Conductor type	copper OF
Conductor size	20.83×15.75 mm^2
Cooling	water flow through a circular hole of diameter 6.35 mm
Typical coil electrical resistance at 20° C	4.58 mΩ
Total inductance of the solenoid	$5 \cdot 10^{-2}$ H
Max. input water temperature	60° C
Max. output water temperature	75° C
Water flow rate	120 l/min at 8.6 bars

TABLE I : Coil characteristics

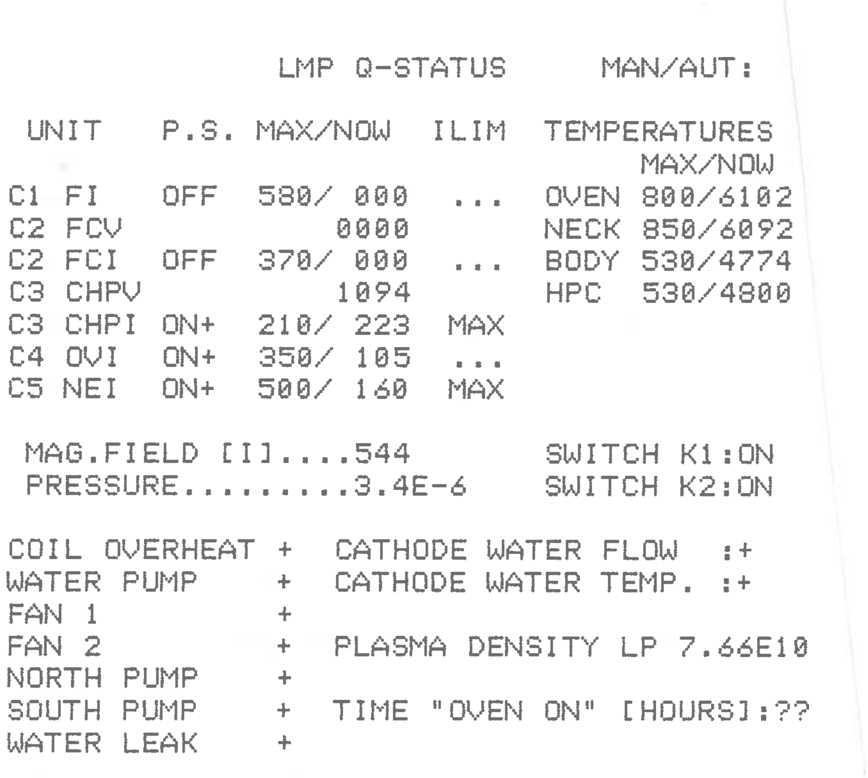
Plasma source :

Hot cathode (BaO)	
Cathode diameter	5 cm
Cathode current	~ 1 - 15 A continuous regime $\leq$ 50 A pulse regime

Plasma :

Plasma diameter	5 cm
Plasma length	4.75 m
Plasma density	$\sim 10^{10} - 10^{12}$ cm^{-3}
Ratio of plasma density to discharge current (Ne plasma)	6×10^{10} cm^{-3} A^{-1}
Neutral density	$\sim 10^{12} - 10^{13}$ cm^{-3}
Electron temperature	~ 6 - 15 eV
Ion temperature	~ 0.15 - 10. eV
Electron Larmor radius (T_e = 9 eV, B = 0.3 T)	2.38×10^{-3} cm
Ion Larmor radius (for a Ne_{20} ion T_i = 0.2 eV, B = 0.3T)	6.8×10^{-2} cm
Ion Larmor radius (for Ar_{40} ion T_i = 0.2 eV, B = 0.3 T)	9.6×10^{-2} cm

TABLE II : Design and plasma parameters of the LMP (with BaO cathode)



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                  LMP Q-STATUS     MAN/AUT:

 UNIT   P.S. MAX/NOW  ILIM  TEMPERATURES
                                 MAX/NOW
C1 FI   OFF  580/ 000  ...  OVEN 800/6102
C2 FCV           0000       NECK 850/6092
C2 FCI  OFF  370/ 000  ...  BODY 530/4774
C3 CHPV          1094       HPC  530/4800
C3 CHPI ON+  210/ 223  MAX
C4 OVI  ON+  350/ 105  ...
C5 NEI  ON+  500/ 160  MAX

 MAG.FIELD [I]....544       SWITCH K1:ON
 PRESSURE.........3.4E-6    SWITCH K2:ON

COIL OVERHEAT +  CATHODE WATER FLOW  :+
WATER PUMP    +  CATHODE WATER TEMP. :+
FAN 1         +
FAN 2         +  PLASMA DENSITY LP 7.66E10
NORTH PUMP    +
SOUTH PUMP    +  TIME "OVEN ON" [HOURS]:??
WATER LEAK    +
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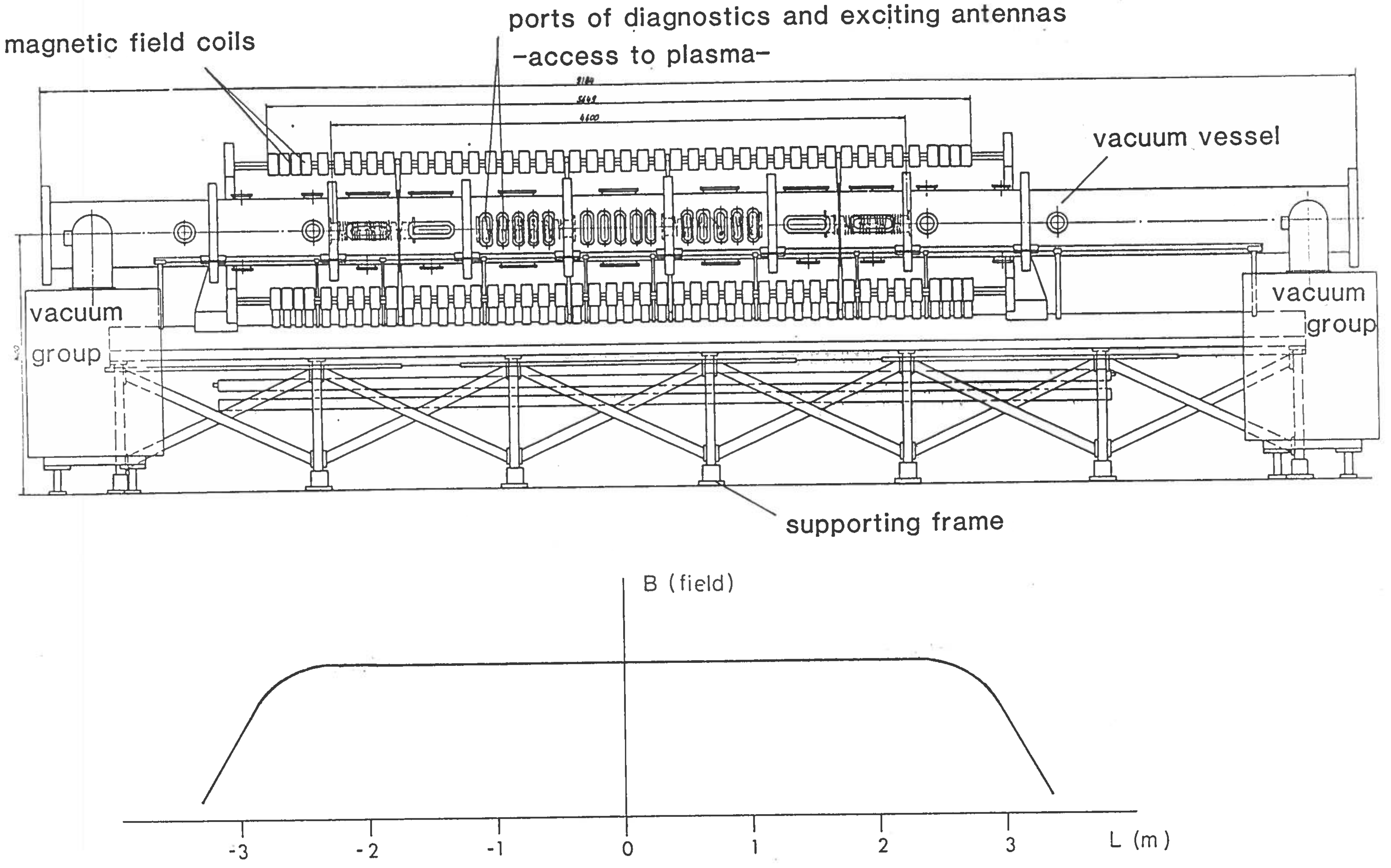
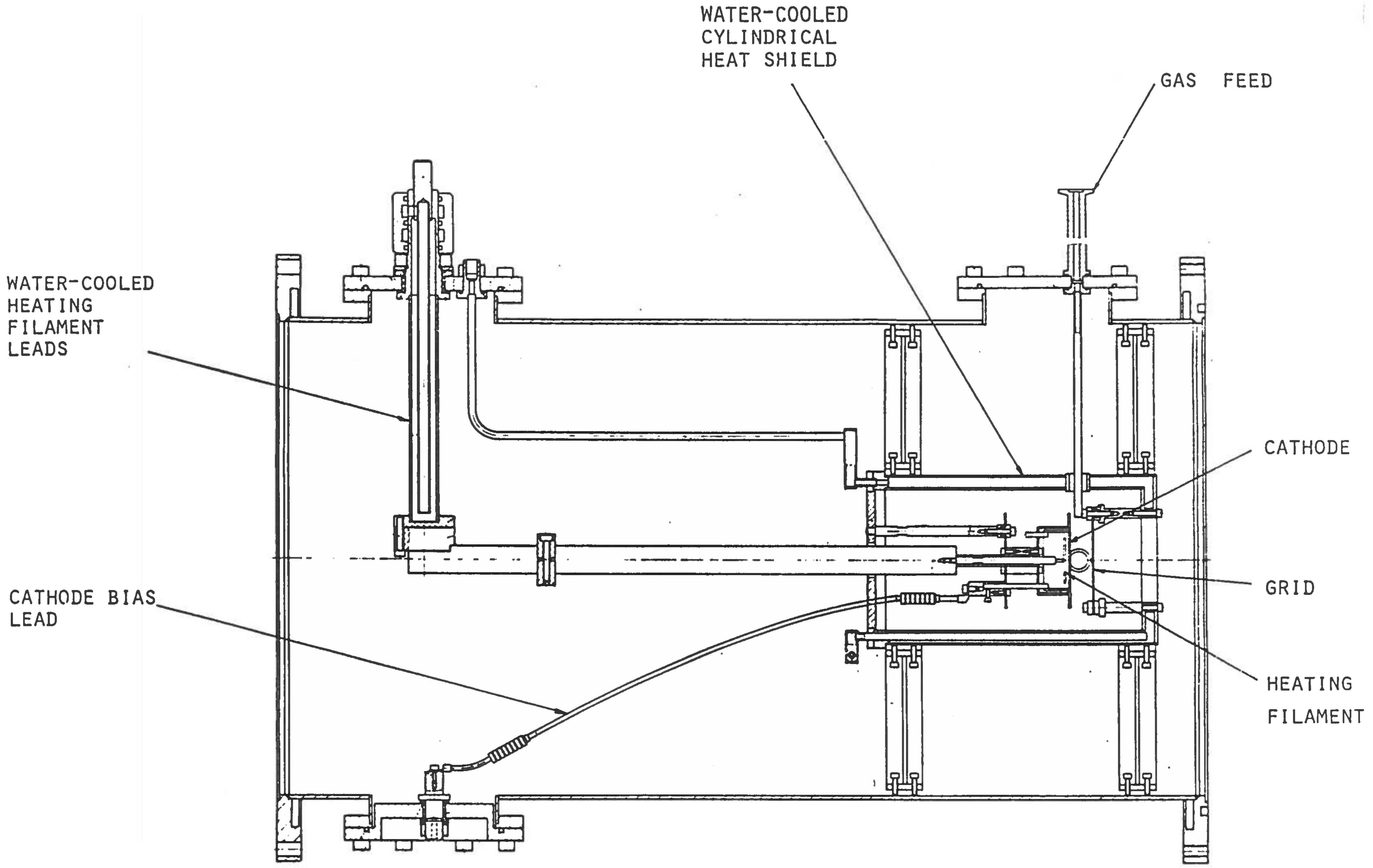
TABLE III : Lay-out of T.V. screen display

Barium	M = 138 a.m.v.	$M/m_e = 2.5 \times 10^5$
n_i	$10^8 < n_i < 10^{11}$ part/cm^3	
$T_i=T_e$	$T \approx 0.2$eV	
B field		$1 < B < 3$kGauss
Ion gyroradius	$r_{gi}=0.18$cm	for B=3KG and $T_i=0.2$eV
Electron gyroradius	$r_{ge}=3.67\times10^{-4}$cm	for B=3KG
Ion thermal velocity	$V_{thi} \approx 5.3\times10^4$cm/s	
Ion drift velocity	$V_{di} \approx 1.2\times10^5$cm/s	
Ion thermal energy	$T_i \simeq 0.2$ eV	
Ion drift energy	$E_{D\parallel} \simeq 1.0$ eV	
Ion plasma freq	$f_{pi} \approx 565$ KHz	for $n=10^9$cm^{-3}
Electron plasma freq	$f_{pe} \approx 284$ MHz	for $n=10^9$cm^{-3}
Ion collision rate	$\nu_{ii} = 4.8$KHz	for $n=10^9$cm^{-3}
Electron collision rate	$\nu_{ee} = 0.29$MHz	for $n=10^9$cm^{-3}

TABLE IV : LMP Q parameters
(after T. Good)

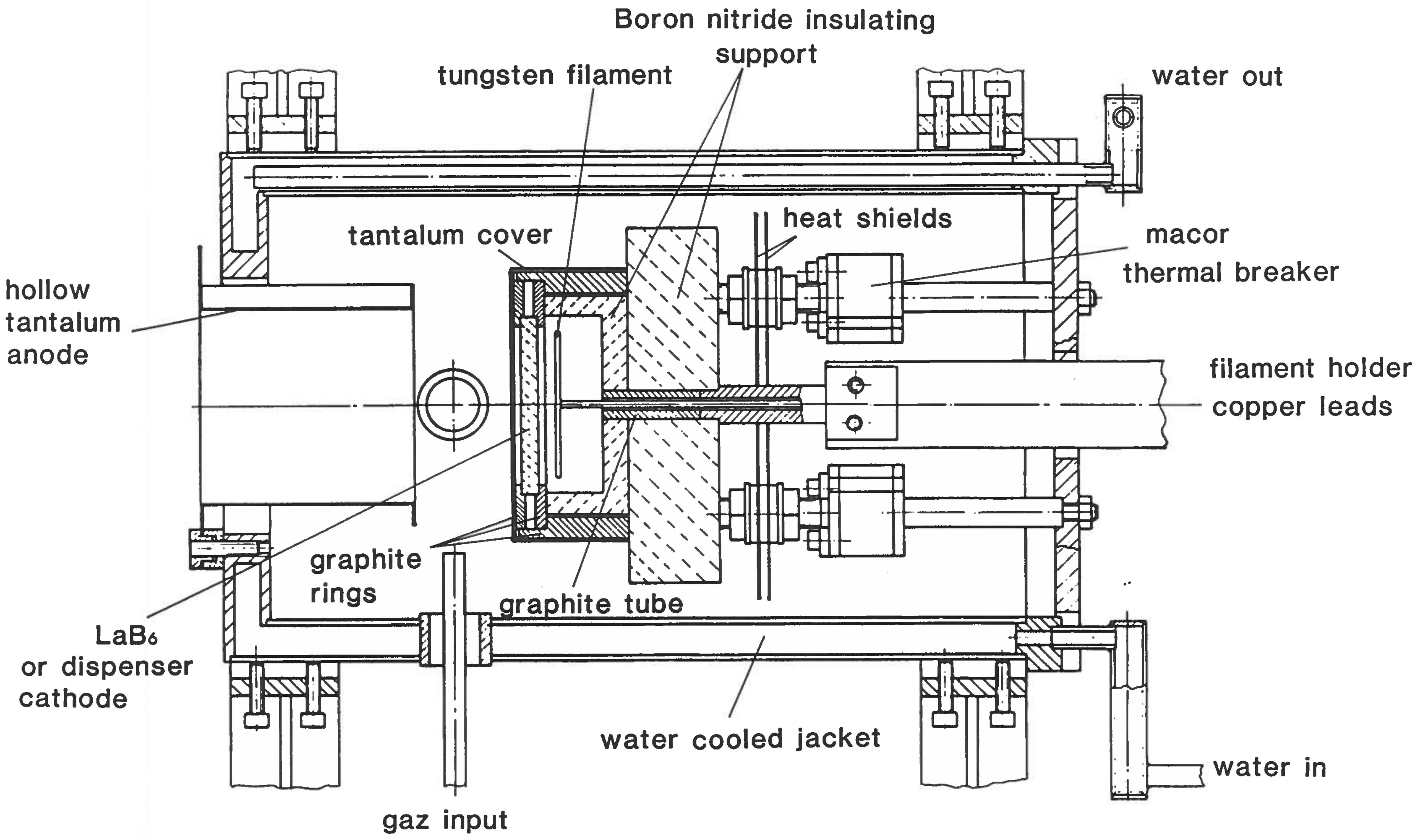


LMP – general view and B field graph –
Fig. I



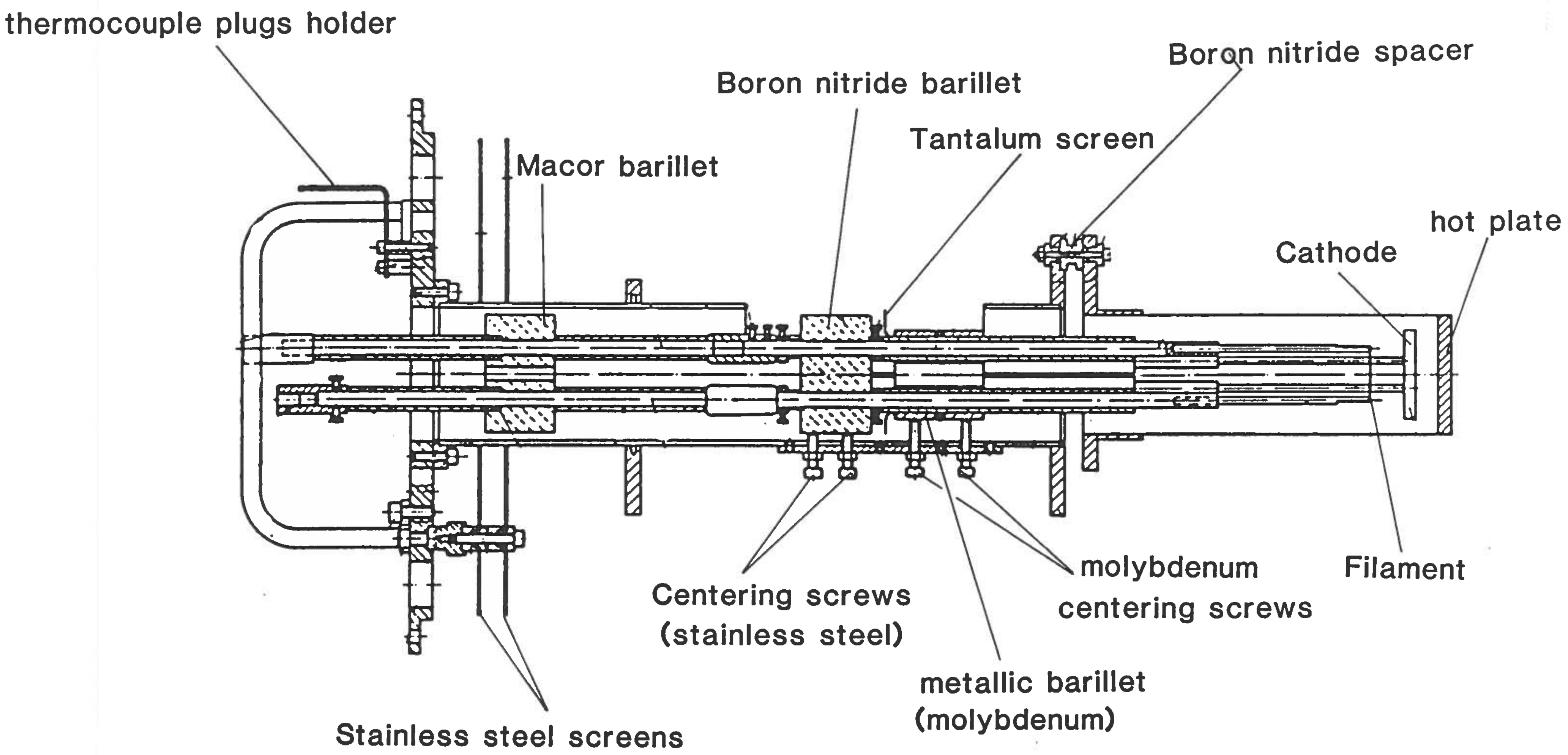
Oxide cathode source

Fig. II



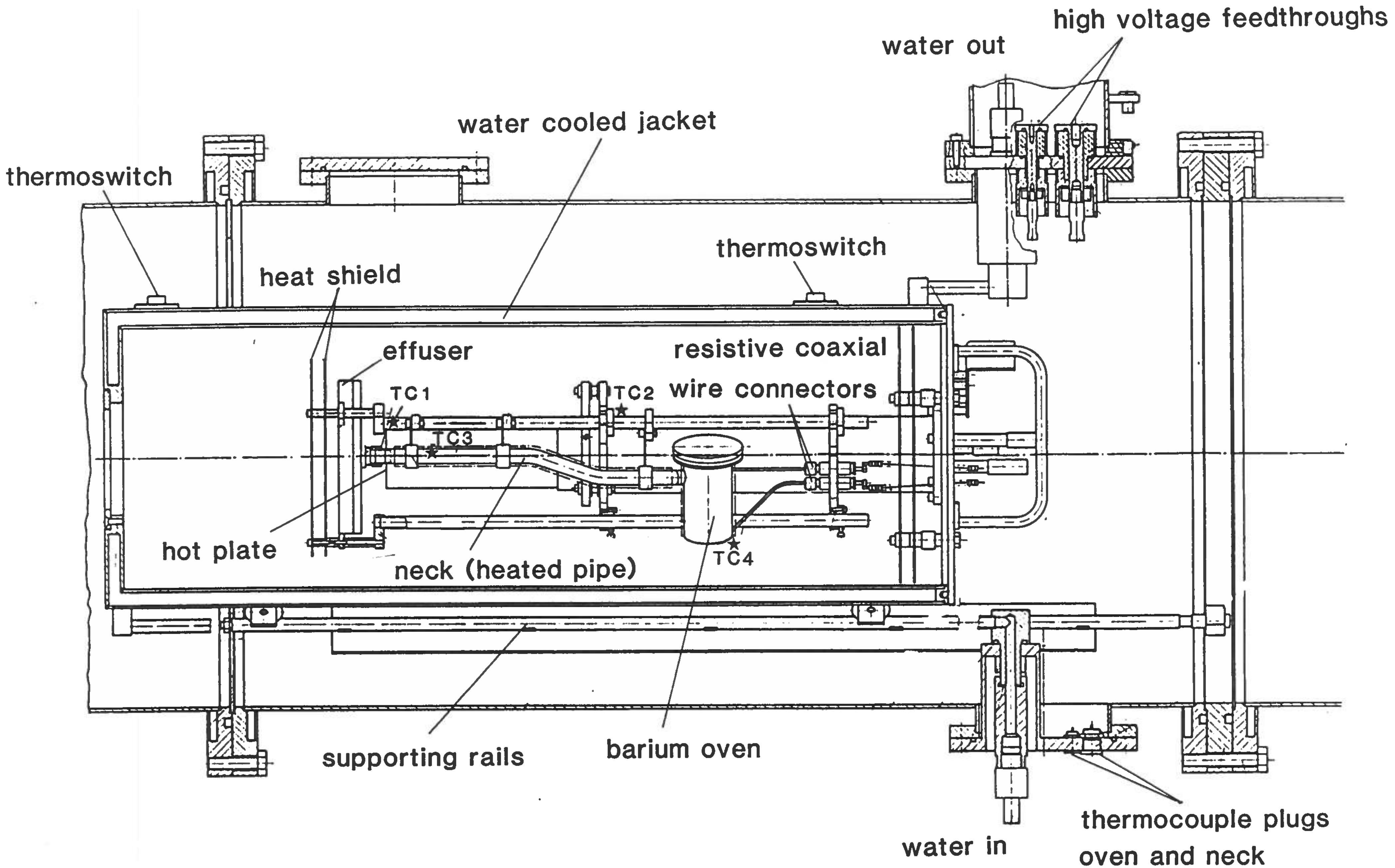
Lanthanum hexaboride cathode arrangement

Fig. III



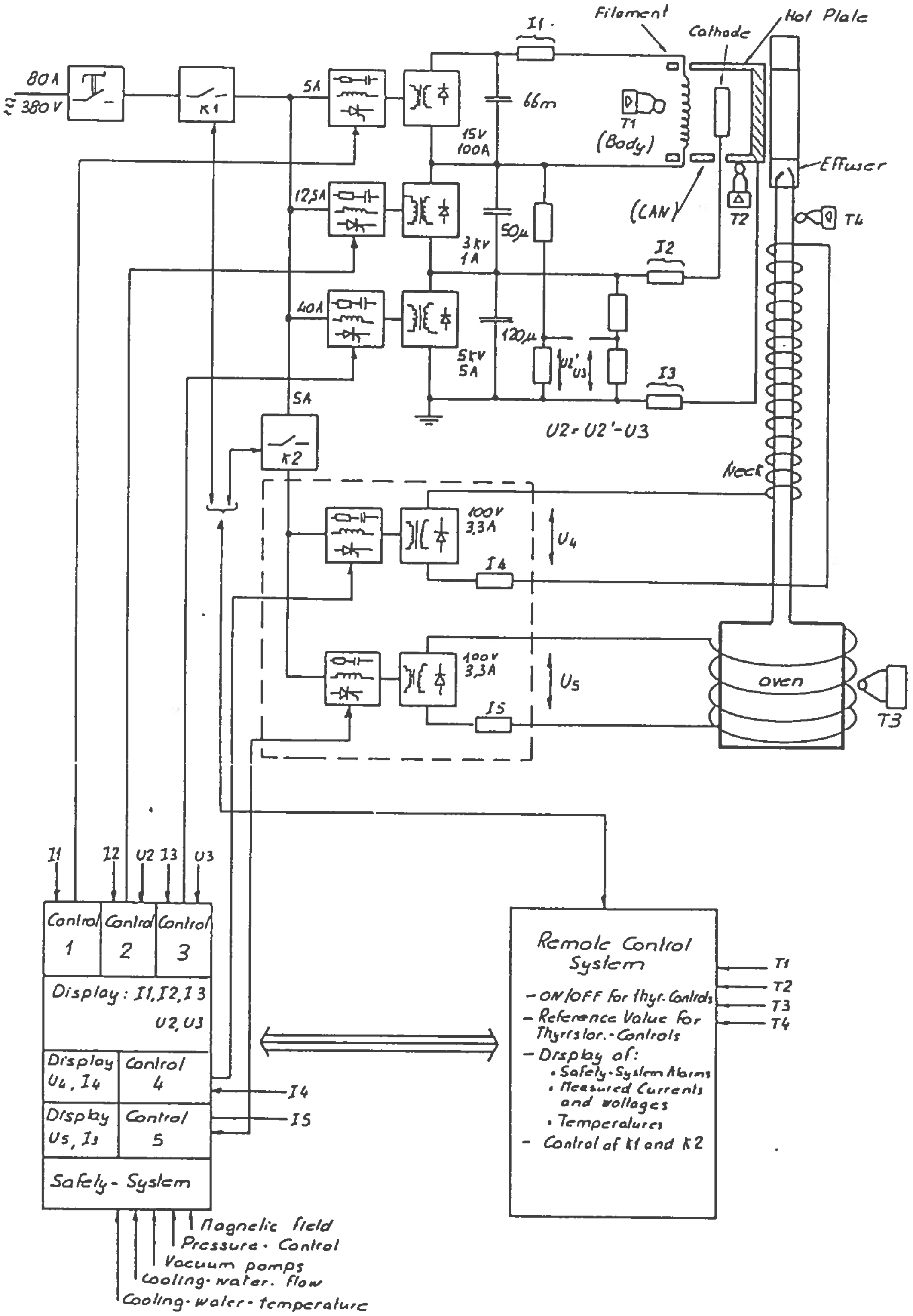
Q source gun

Fig. IV



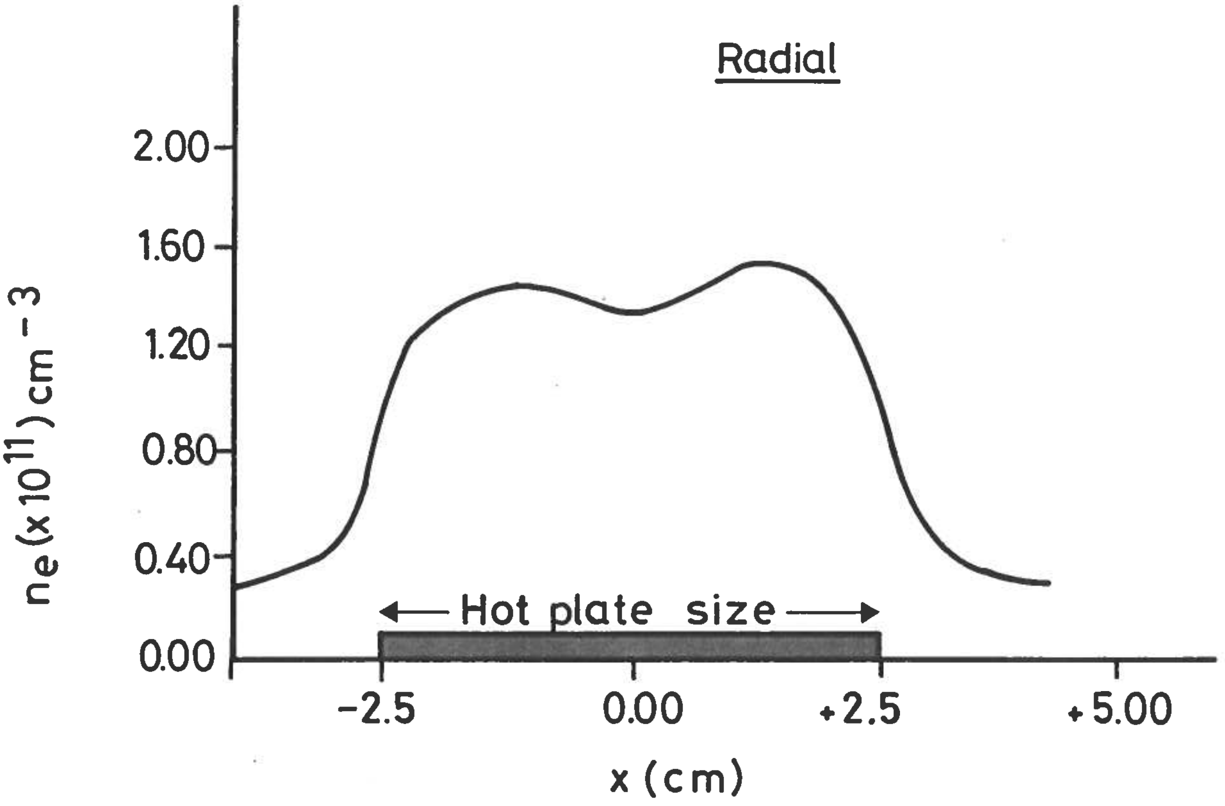
Barium Q,- plasma source inserted in LMP

Fig. V

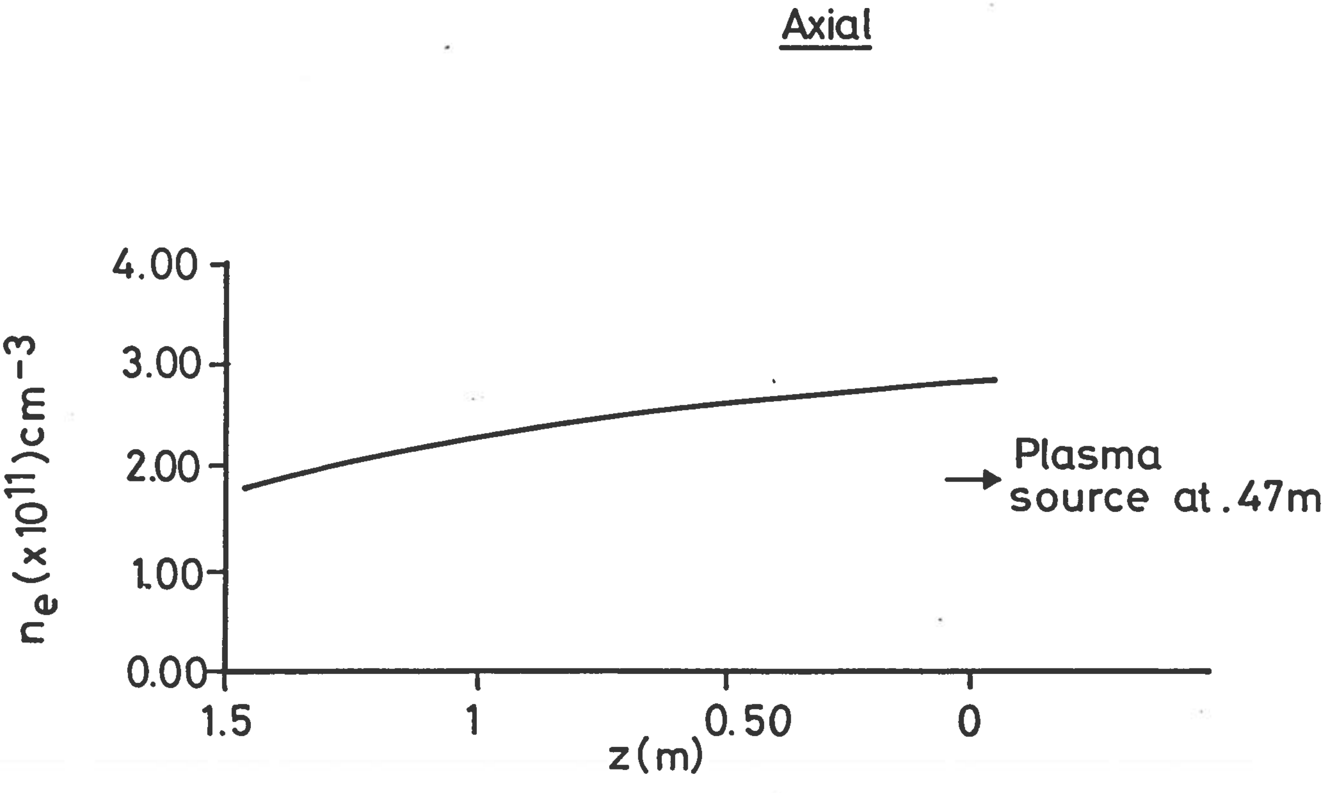


High voltage gun power supply
-schematic-

Fig. VI



Radial



Axial

Density Profiles

Fig. VII