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RECENT DEVELOPMENTS IN RF PROTON SOURCES

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1. Introduction

An rf ion source of the Schneider type[1] was originally developed for Nimrod, but it suffered severely from internal breakdown when delivering intense beams with a pulse length of 1 millisecond. The onset of breakdown marked the end of the useful life of the source which was often short and unpredictable. The breakdown problem was never solved in spite of intense effort and eventually the Schneider source was abandoned in favor of an arrangement similar to that described by Thonemann and Harrison.[2] This source has been reliable in operation on Nimrod and some of its characteristics are given below.

2. Description of Nimrod RF Source

The source is shown in Fig. 1. It is mounted on a mild steel base plate, 1, which carries the invar cathode, 2, on an accurate register. The source pot 7 is made from a piece of standard 1" bore QVF pyrex pipe line with one end sealed, and ground parallel to the lower end. The pot is mounted on the dural extraction plate, 4, which is insulated from the cathode by the pyrex ring, 6. A pyrex disc, 5, almost completely covers the top surface of the extraction plate so as to reduce the area of metal exposed to the plasma to a minimum. Extraction of ions is achieved by pulsing the extraction plate (and therefore the plasma also) to a positive potential. To prevent discharges between the source pot and rf coil, which is "earthy", the insulating envelope, 10, is pumped up with compressed air to about 30 lbs/in^2. This also prevents breakdown from the extraction plate to the base plate over the outside of the ring, 6, at high extraction voltage.

The rf circuit consists simply of a 50 Ω coaxial line stretcher and stub connected directly to the coil, as shown in Fig. 2. The lengths of the line stretcher and the short circuited stub shown in Fig. 2 are typical values. When a 50 Ω power meter is connected in place of the tuner and source, a maximum pulse power of 20 kW can be obtained. The frequency is 125 Mc/s.

Hydrogen is fed into the source through a hole in the base plate via a nickel leak.[3]

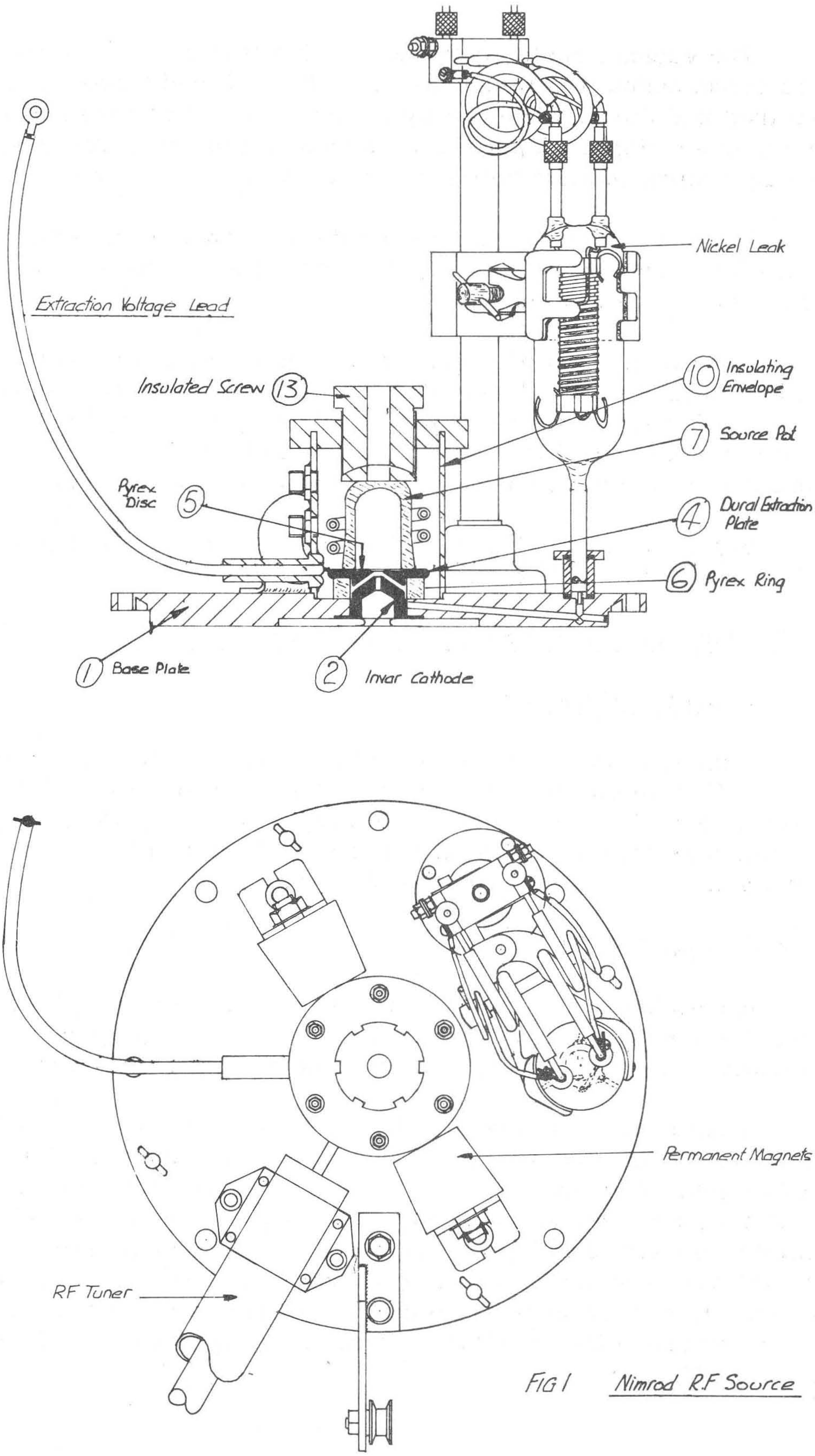


FIG 1 Nimrod R.F Source

The vacuum seals on the source itself are 1/32" diameter indium wire compressed to a thickness of 0.004". Considerable pressure is required and this is achieved by a strong insulated screw, 13, on top of the outer envelope. A pressure pad with a spherical upper surface takes up slight misalignment between the screw and source pot.

Two permanent magnets provide a roughly transverse magnetic field of about 50 gauss which greatly increases the ion density in the plasma, for a given rf power input.

The dimensions of the extraction gap used at present on Nimrod are shown in Fig. 3. Alignment of the extraction plate and cathode is critical. It will be seen that the insulating pyrex ring is well shielded from the beam and plasma and this is considered to be an important contribution to the high breakdown voltages achieved in operation.

Figure 4 is a photograph of a source assembly and Fig. 5 is a view of the source in position on the Nimrod preinjector.

3. Performance of the Source on a Laboratory Rig

3.1 Source Pressure

A special source pot was made up with a Pirani gauge head mounted on top. The variation of source pressure with the nickel leak current is shown in Fig. 6. The pressure readings are corrected for hydrogen. Normal operating pressure is about 10^{-2} Torr and the power consumption of the nickel leak at this level is 36 watts.

3.2 Output Current

A reliable current measuring device has been developed, which combines electrical and calorimetric methods, as shown in Fig. 7. The principle of the calorimeter is the same as that of Harrison.[4]

A collector cup, made in 2 mil copper foil to reduce its thermal capacity, is mounted on a double "stem" of copper strip 3/8" wide and 0.020 thick. A transverse magnetic field of about 200 gauss is applied to the cup, by permanent magnets, to suppress secondary electrons and a michrome wire heating coil is wound on it for calibration purposes. Thermistors are used for temperature measurement. Figure 8 shows a general view of the device. Both the calorimeter and the bridge circuit used to measure the resistance of the thermistors are well screened as shown in Fig. 10.

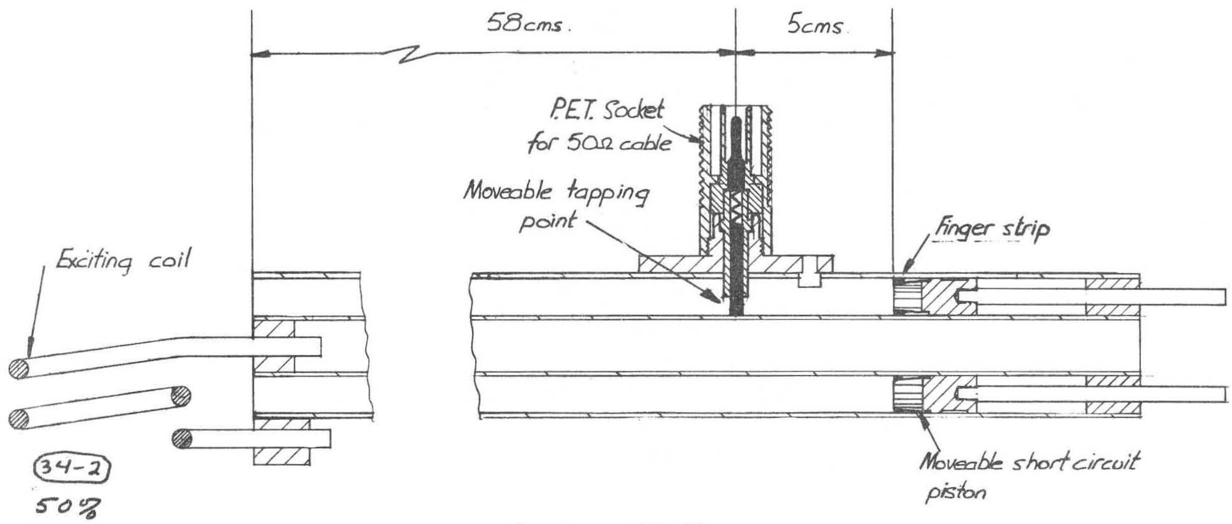


FIG. 2 R.F. Tuner

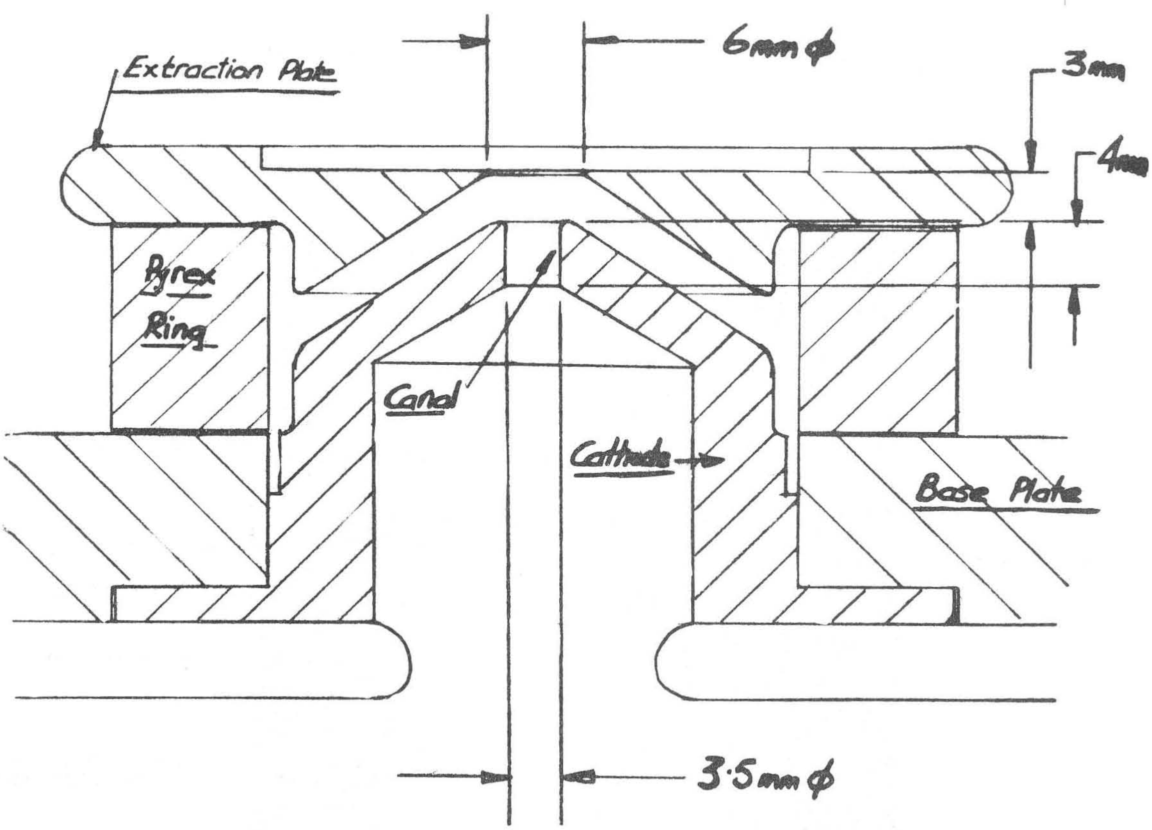


FIG. 3 Extraction Gap Dimensions

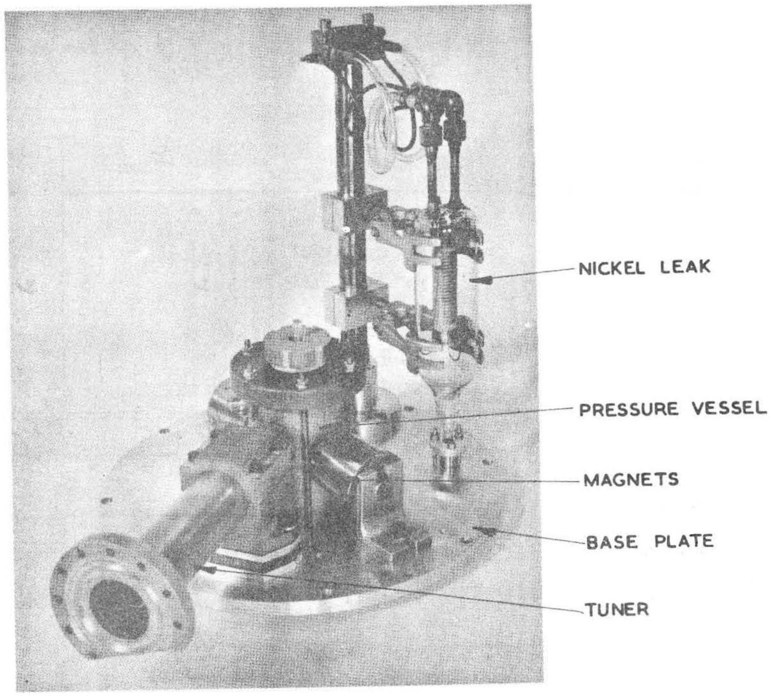


FIGURE 4 GENERAL VIEW OF SOURCE ASSEMBLY

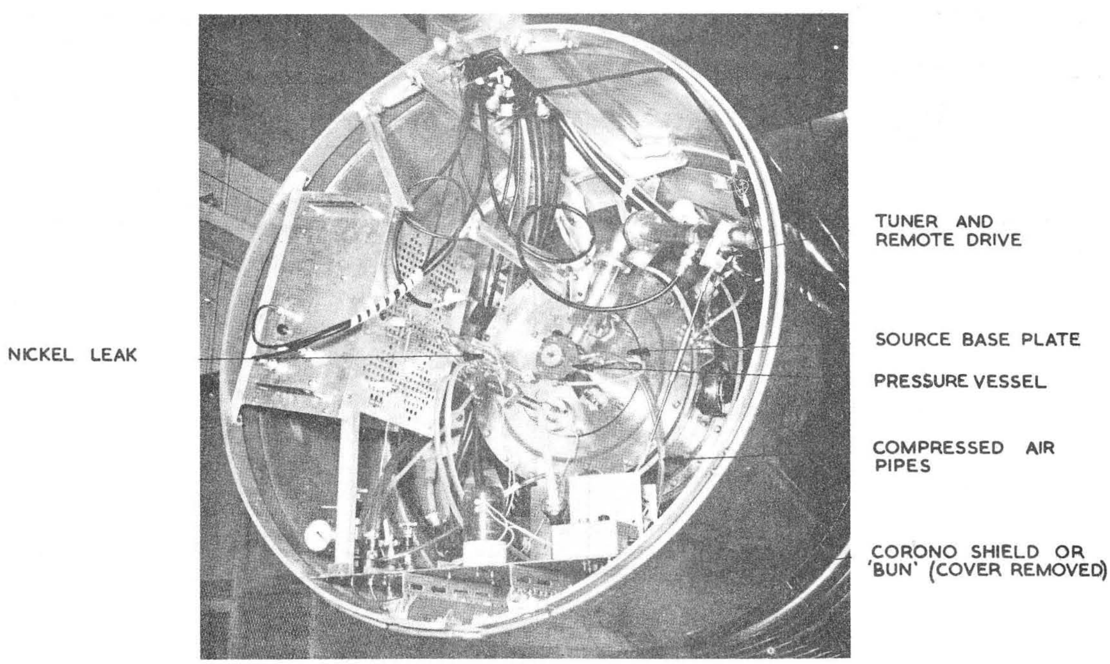


FIGURE 5 GENERAL VIEW OF SOURCE FITTED TO THE NIMROD PREINJECTOR

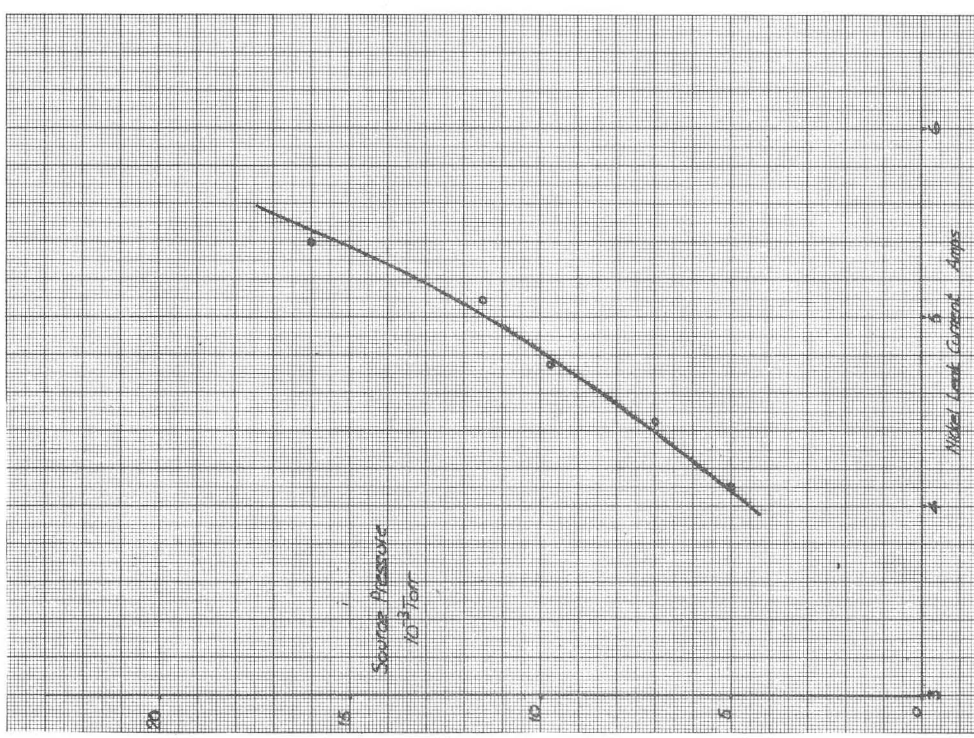


Fig. 6. Source Pressure as a Function of Nickel Leak Current

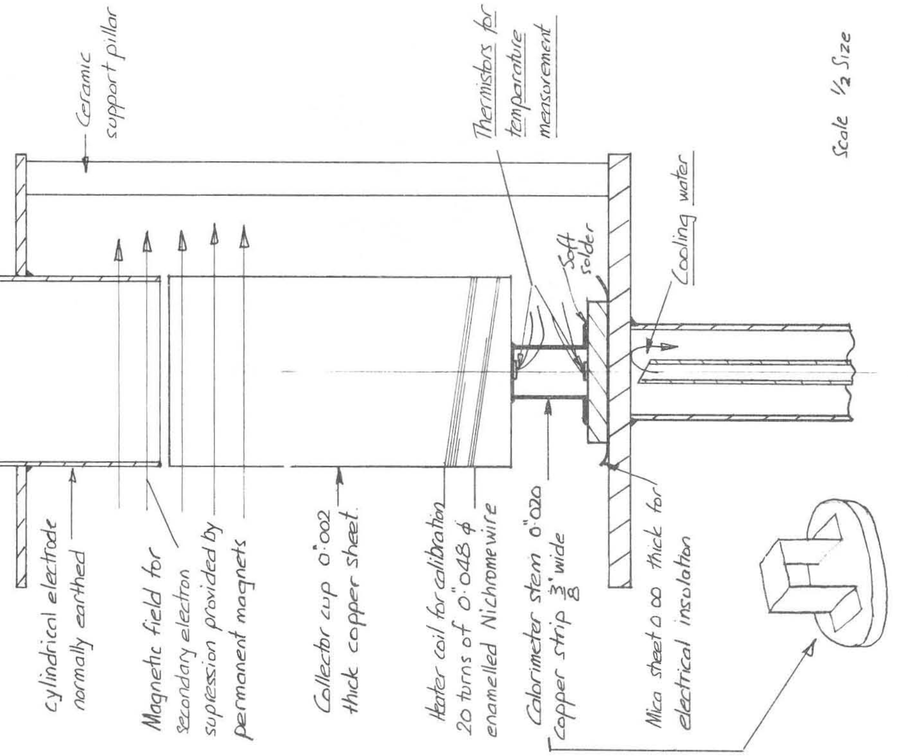


FIG. 7 Combined calorimeter & collector cup for beam current measurements.

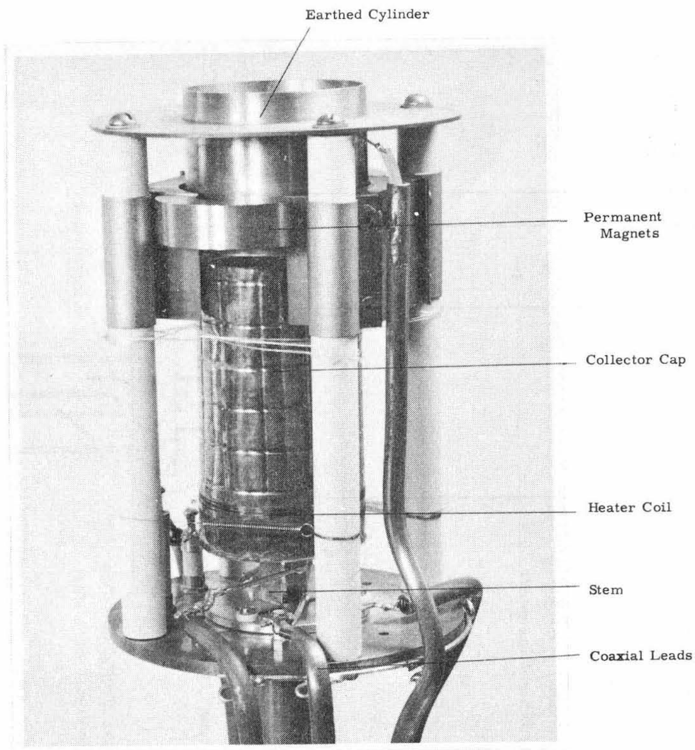


FIG 8 Current Measuring Device

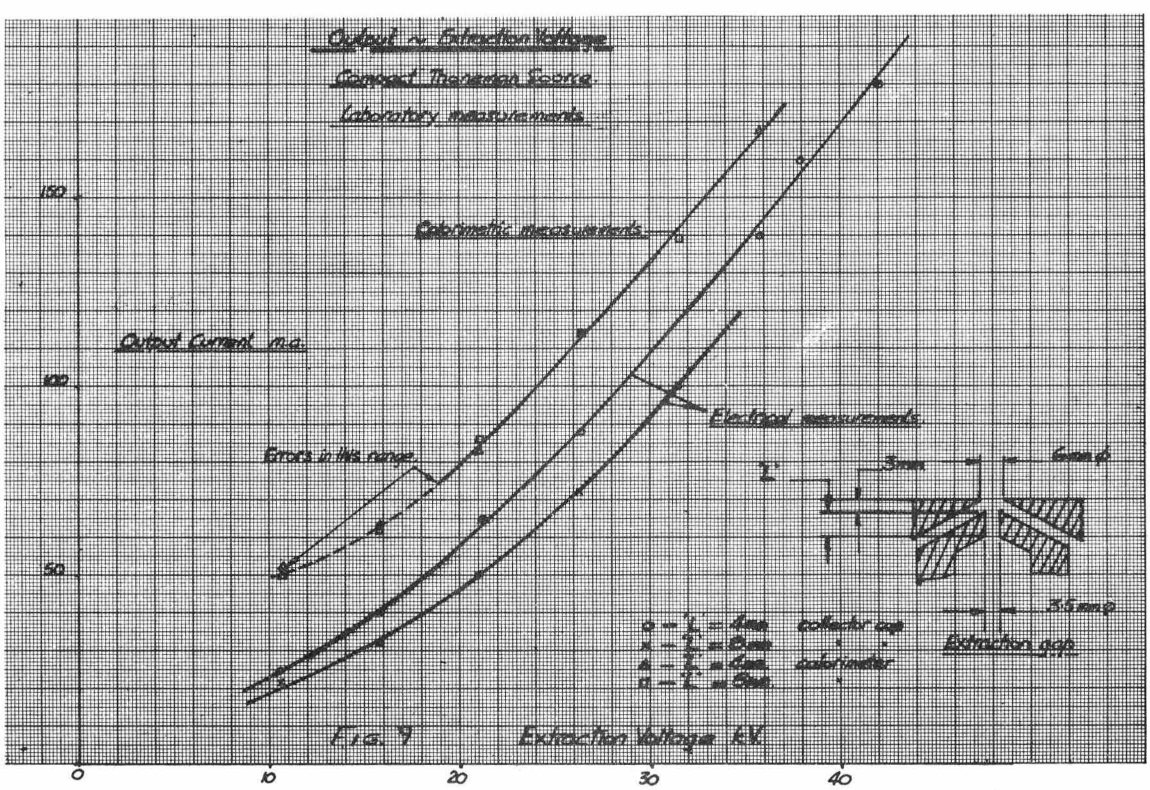


Fig. 9

Curves of output current against extraction voltage for two different canal lengths are shown in Fig. 9. The rf power level was adjusted to give a maximum output current at each value of extraction voltage. The difference between the calorimetric and electrical measurements is probably due to the neutral content of the beam, i.e. the total ion current crossing the plasma boundary under given conditions is the same for each canal length but the number of charge exchange events occurring in the beam is greater for the longer canal. Thus the charged component of the beam is smaller for the longer canal. The dotted part of the calorimetric curve in Fig. 9 is in error due to direct pickup of rf power by the thermistors--this result was obtained before the screening arrangements were fitted.

3.3 Multiwire Target

Preliminary experiments have been carried out using a technique for rapid measurement of beam properties such as diameter, current density distribution or emittance. The device is a target consisting of 25 tungsten wires, 0.2 mm diameter, spaced 2 mm apart and insulated from each other, each wire being connected to a condenser. When exposed to a beam, the charge collected by each wire produces a proportional voltage on its condenser. The latter are then "scanned" by a mechanical commutator which discharges each in turn through a resistor. Thus, a series of spikes is produced, the height of each one proportional to the charge collected by the wire in the first place.

This is illustrated in Fig. 11 where the target was used to measure the diameter of the beam at various axial distances from the source. The target itself is shown in Fig. 12.

Permanent magnets are built into the target to provide a magnetic field for suppression of secondary electrons, but they are not very effective and there is evidence that the space charge in the beam is at least partially neutralized by secondary electrons. Thus the dotted curve in Fig. 11 is not a real beam profile. The four positions of the target probably gave rise to four different beams, though the source conditions were the same.

It is hoped to extend this technique to the measurement of emittance.

3.4 Source Emittance Measurements

Some measurements of emittance of the beam immediately below the source have been made using the slotted plate and copy paper method.[5]

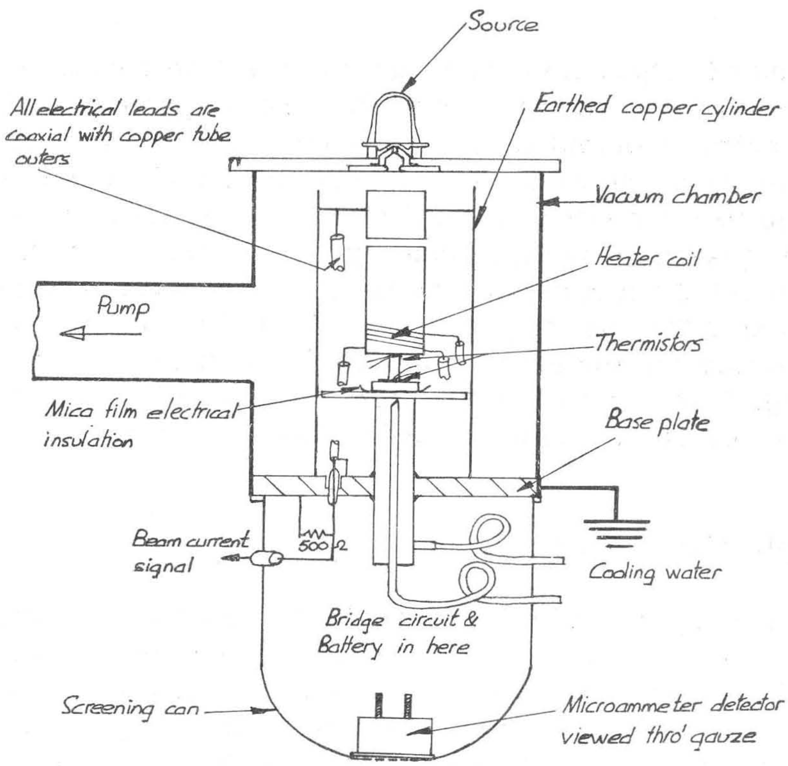
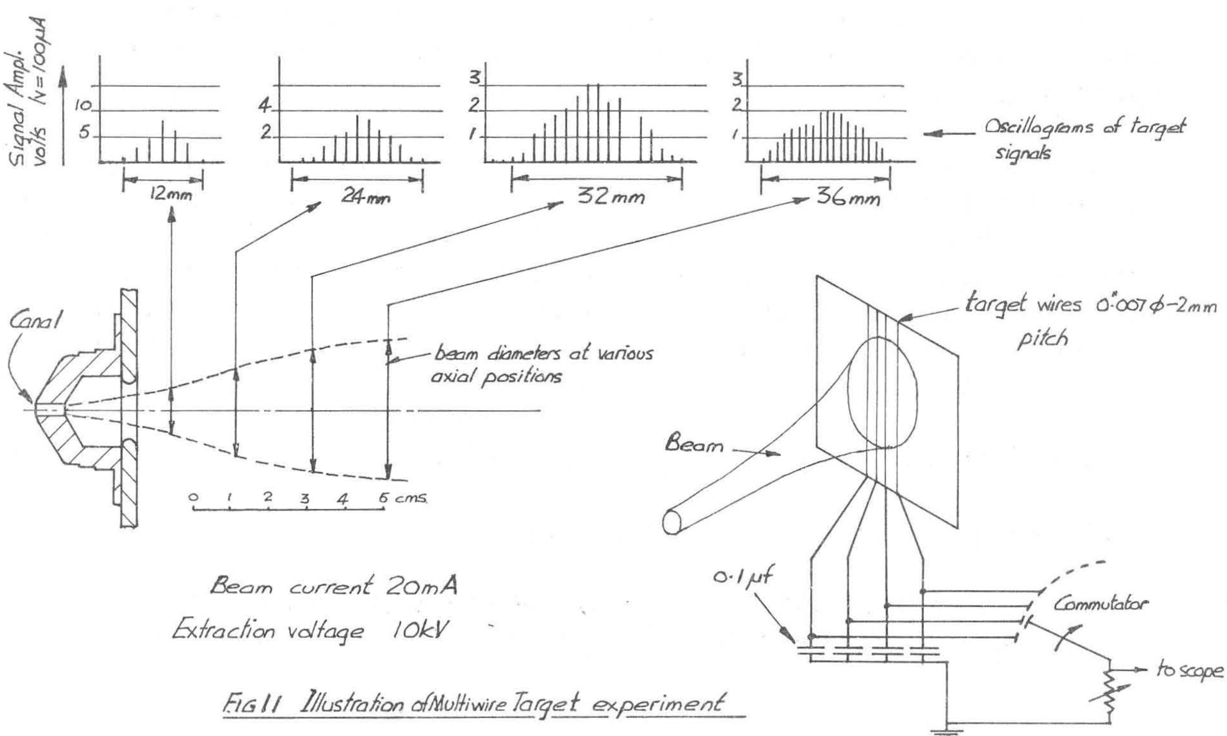


FIG 10 Screening arrangements for calorimeter



Beam current 20mA
Extraction voltage 10kV

FIG 11 Illustration of Multiwire Target experiment

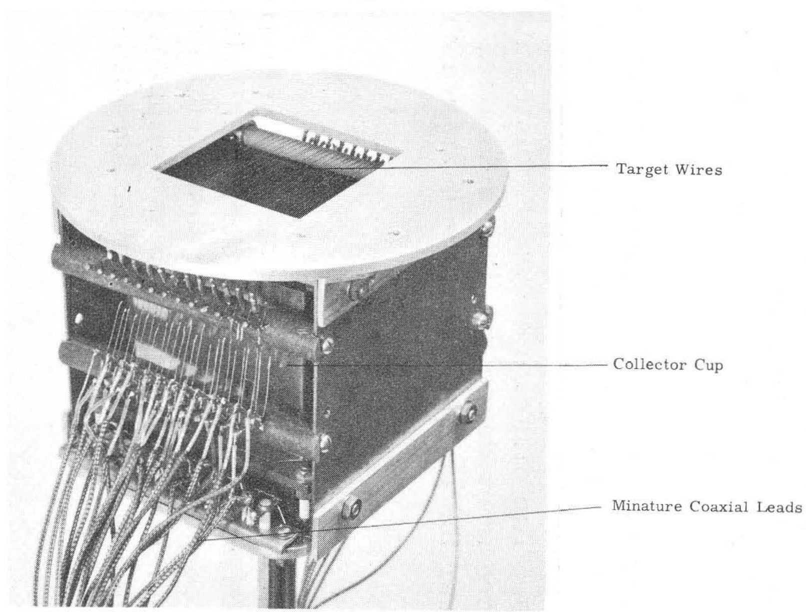


FIG 12 Multiwire Target

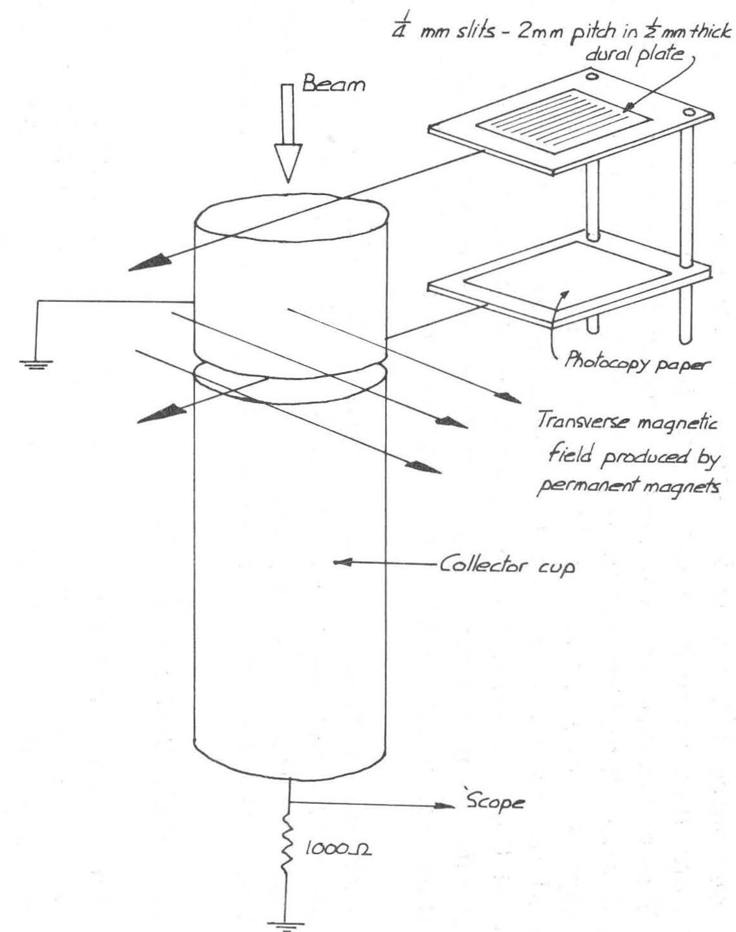


FIG 13 Emittance Measuring Device

The slits used were 1/4 mm wide, spaced 2 mm apart, in a 1/2 mm thick dural plate and they were built into a standard collector cup as shown in Fig. 13. The beam current was first measured with the plate and copy paper withdrawn, then they were pushed into the beam and the exposure made. A typical image is shown in Fig. 14 and preliminary plots of emittance are shown in Figs. 15 and 16. Both the area of the diagrams and the details of the images are closely similar to those obtained by Tallgren[5] with a Schneider type source. There seems to be a dense central region to each image which may well correspond to a large fraction of the beam.

Less dense markings, at larger values of divergence are often completely separated from the main "spectrum." The explanation of these effects is not yet clear, but they are not peculiar to the Schneider type source. They may well be common to all high intensity rf sources.

4. Source Performance on Nimrod

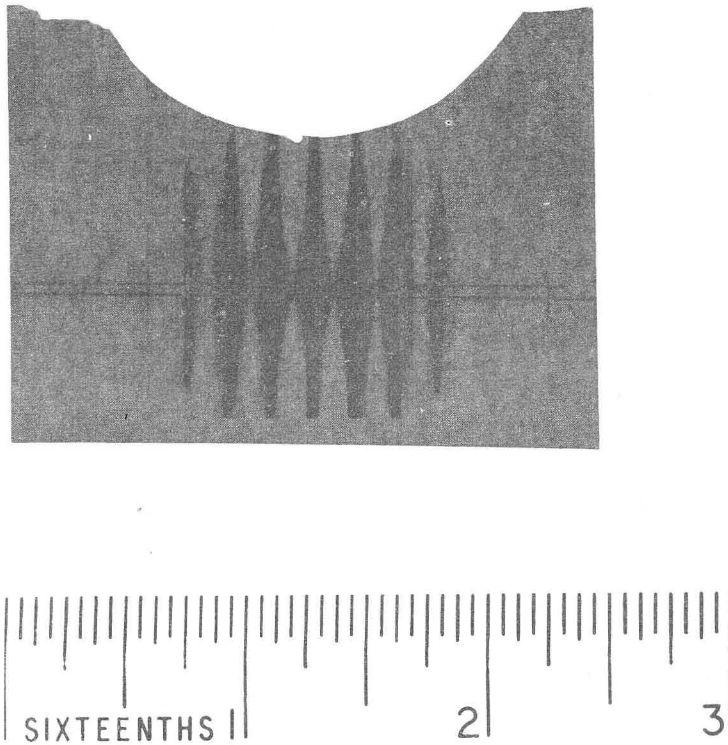
The source has proved reliable and consistent on Nimrod during a period of over a year. The present normal beam current is about 38 mA. At this level the useful life of the source is not yet known but a unit has been in service on Nimrod for four months of routine operation without detectable deterioration. The period of operation, to the time of writing, is about 1000 hours "beam-on" time.

The curve of output current against extraction voltage is shown in Fig. 17. The beam current was measured at 600 kV using the beam monitor system and the values shown were optimized at each value of extraction voltage.

Figure 18 shows an emittance diagram of a 40 mA beam which was obtained by using two 4-jaw apertures in the low energy drift space of the Nimrod injector as shown in Fig. 19. The apertures were set to 1 mm wide vertical slits. The diagram shows the distribution of current in phase space. There is evidence that the "side arms" on the diagram are due to the molecular ion component of the beam which was separated out by the quadrupole.

5. Future Developments

The present objective is to discover the upper limit of the performance of the source. Improved rf screening (with higher rf power inputs) is being incorporated and compressed sulphur hexafluoride is being substituted for compressed air so as to improve the external insulation. It is hoped to increase the extraction voltage to 50 kV.



BEAM CURRENT 100 ma. EXTRACTION VOLTAGE 20 KV.
O·5 ms PULSE LENGTH. EXPOSURE 120 PULSES.

FIGURE 14 IMAGE PRODUCED ON PHOTO COPY PAPER DURING EMITTANCE MEASUREMENT

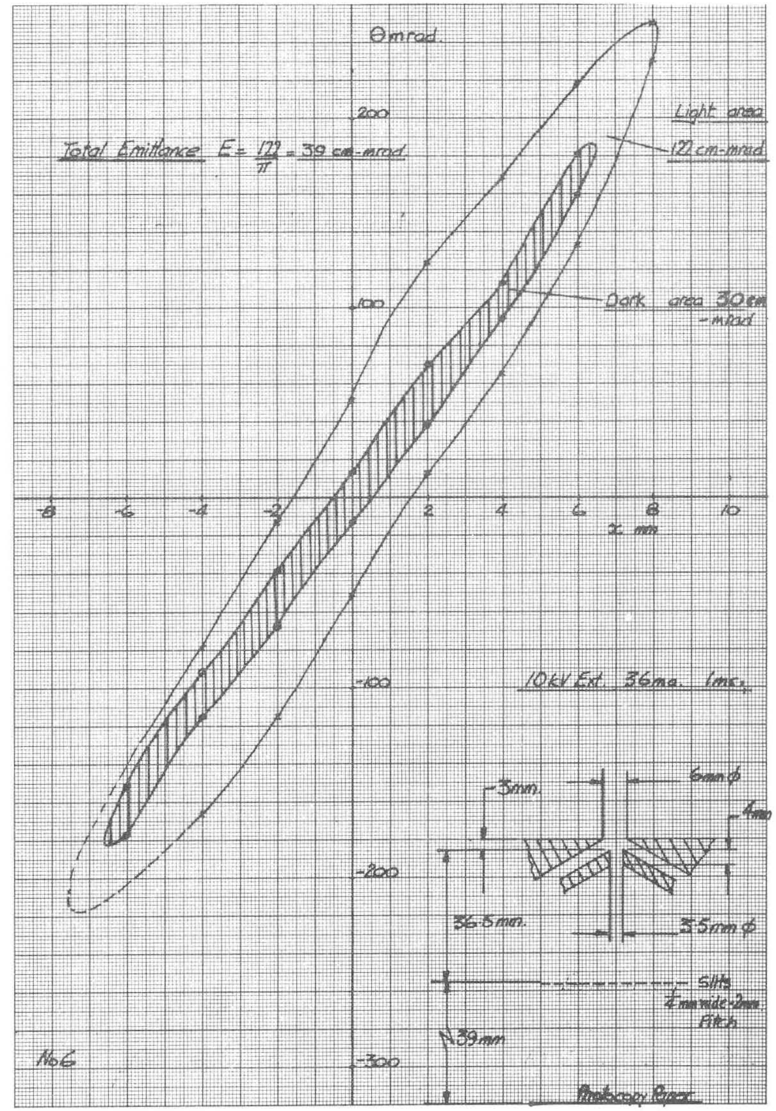
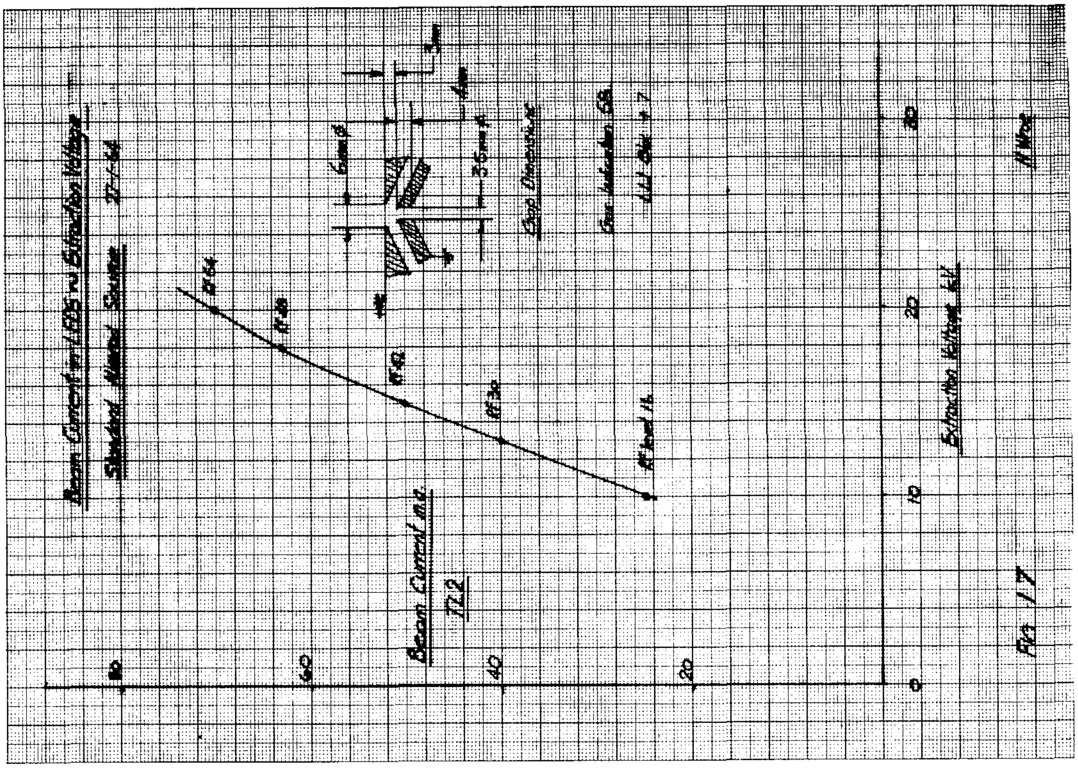
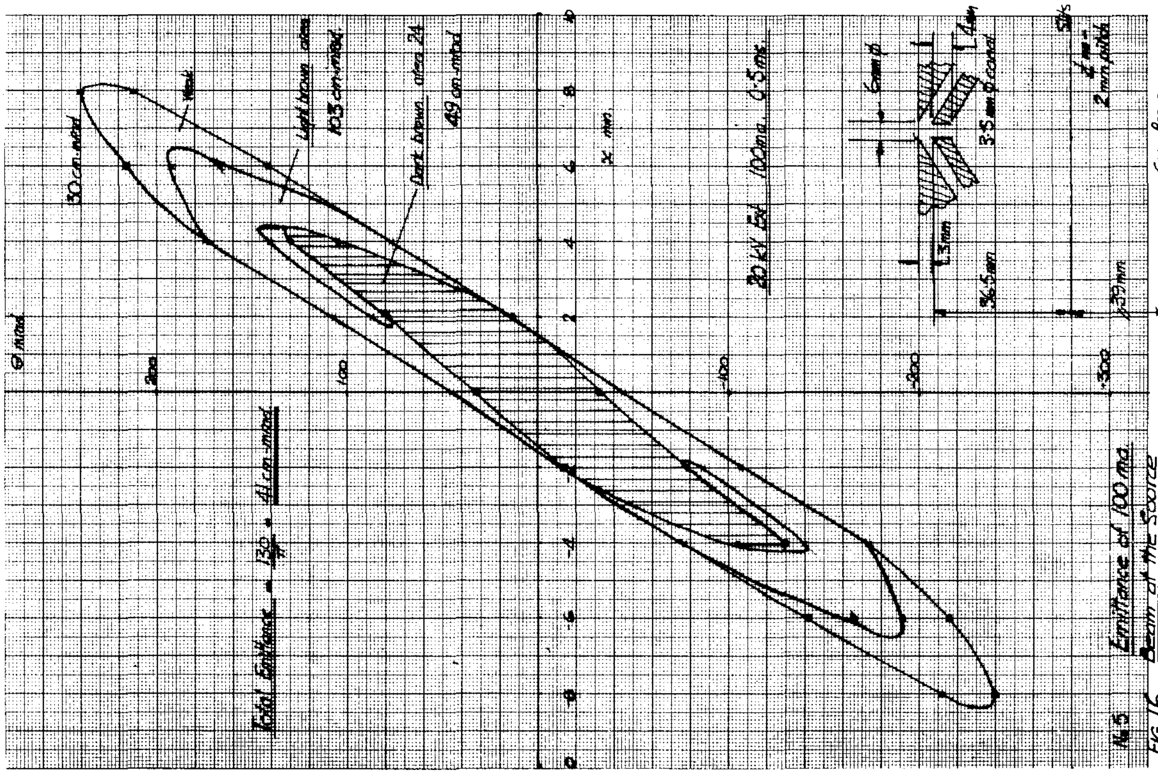


Fig 15 Emittance of 36 ma Beam at the Ion Source


Beam Current in I.O.S. v/s Extraction Voltage
Standard Mixed Source
Beam Current m.a.
Extraction Voltage kV
Fig. 17


Total Emittance
θ m.rad
x mm.
20 kV Ext. 100 ma. 0.5 ms.
Emittance of 100 ma.
Beam at the Source
FIG 16

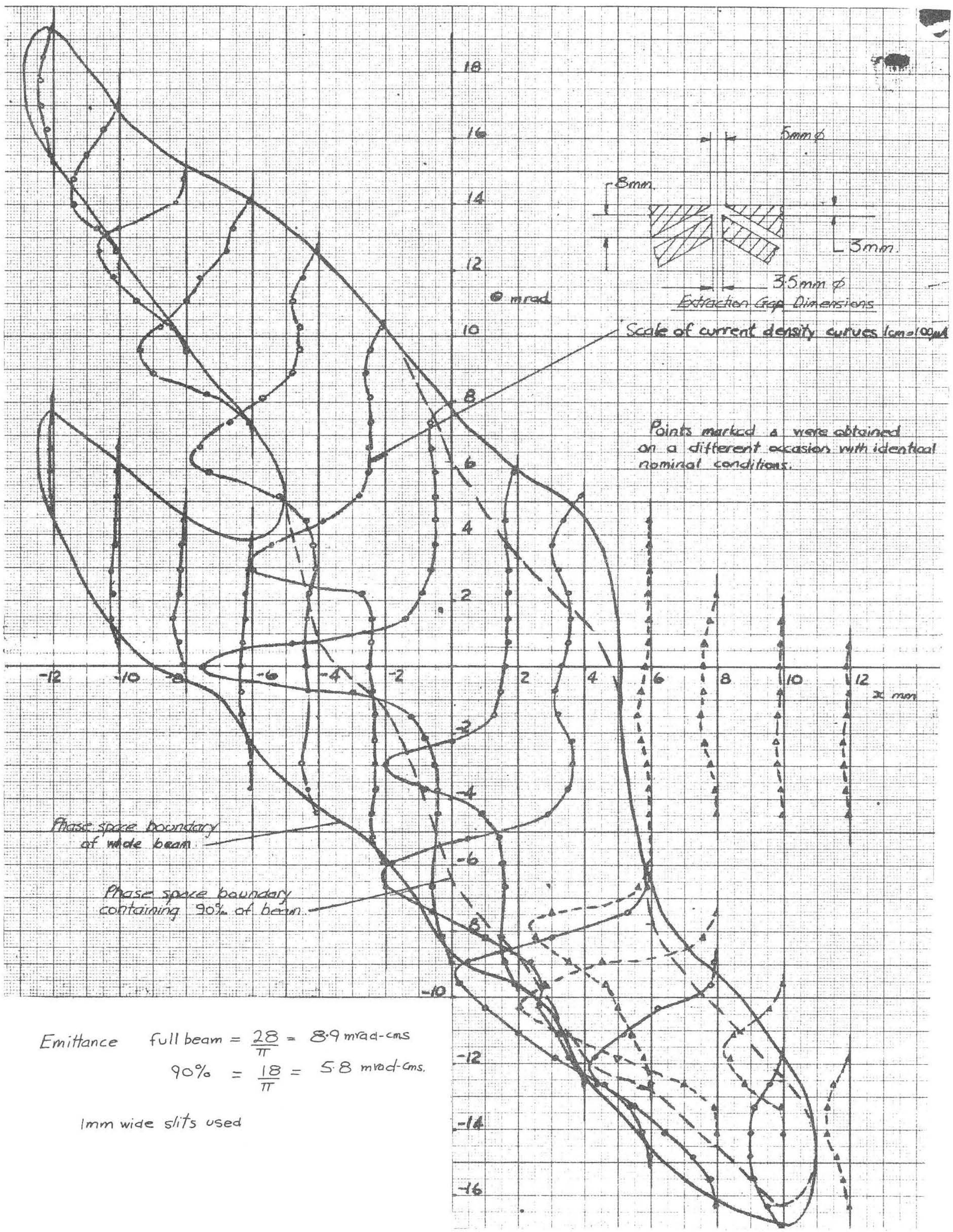


FIG 18 Emittance Diagram 40 mA Beam at 600 kV [Horiz Plane]

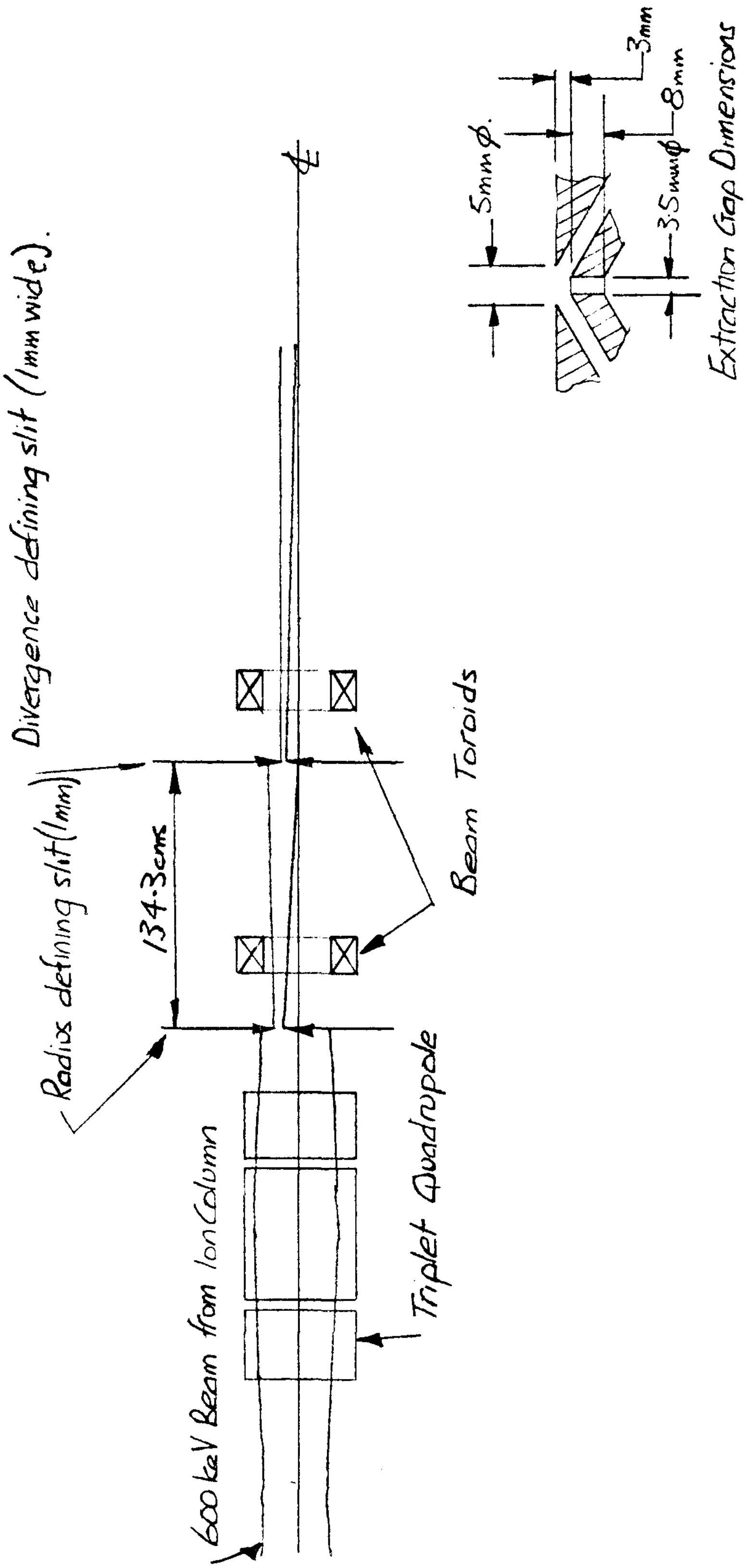


FIG. 19 Arrangement for Emittance Measurements at 600kV

LAPOSTOLLE: I would like to make a comment and ask you a question about the various parts in the emittance diagrams you have shown or, in other terms, the existence of several beams. First, I would like to say that what you observed in the rf source exists in many sources; it is for instance the same in the PIG source. Now I would like to ask, what is your explanation?

WROE: Well, I haven't got one of course. There are so many things it could be. For instance, this technique gives you the integrated beam which strikes the film. You cannot distinguish any changes with time. Now we have evidence that changes of emittance occur during a pulse. If you examine waveforms of beam pulses through a set of emittance measuring slits, they are hardly ever square and flat topped, though the waveform of the whole beam is. It looks as if beam is shifting about in phase space.

LAPOSTOLLE: You then think that it might come from different parts of the pulse?

WROE: Yes. We are going to look at this sort of thing in more detail on the source itself. This measurement I have just told you about was done at 600 kV. I really cannot offer any serious explanation yet.

HUBBARD: With respect to this wire target you use for measuring emittance, how do you handle the secondary electrons from the wires?

WROE: What we intended to do is just put the magnetic field along the wires. There is a field on this present target, a weak magnetic field. It doesn't seem to do very much good. What we are thinking of now is to make a target in the form of a stack of thin plates with insulation between and a fairly strong magnetic field along the plates. If the field falls off rapidly enough as you move away from the target, then it will not affect the trajectories of the ions. The idea is to cause an electron liberated from a plate to be returned to that plate and not a nearby plate.

SHAYLOR: I wondered if you could do anything successful in that line by putting a potential on the wires you are not using adjacent to the wires you are using?

WROE: I do not like electrostatic means of suppression you see, and we have got experience of incredible things that secondary electrons seem able to do in a field of this sort. I don't like it at all.

SHAYLOR: But you are quite happy with magnetic techniques?

WROE: Yes.

VAN STEENBERGEN: You have measured only current distribution, not emittance?

WROE: That is right.

HUBBARD: You measured the current distribution after a slit?

WROE: The idea of the wire target was simply to substitute it for the photocopy paper, so that you have a series of slits and you get out of the wire target a series of profiles in a single pulse, which you can interpret in terms of divergence angle. That is the idea.

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3. L. C. W. Hobbis and E. R. Harrison. Rev. Sci. Instr. 26, 303 (1955).

4. E. R. Harrison. Jour. Sci. Instr. 30, 242-244 (1957).

5. U. Tallgren. MPS/Int. LIN. 62-3, 1962.