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MTA QUARTERLY PROGRESS REPORT

September, October and November, 1950

February 16, 1951

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TABLE OF CONTENTS

1. MTA Mechanical Design Studies

W. M. Brobeck

General Design Progress. At the beginning of the period the general design of Mark I accelerator was well established and principal remaining work was on detail design and drafting. The Laboratory engineering group had the responsibility for reviewing California Research and Development Company's designs of the tank, liner, water cooling, vacuum system, building and layout and handling arrangements. In addition the mechanical section was responsible for the design and procurement of the drift tubes, the oscillators, and injector. The major proportion of the engineering and drafting time devoted to the MTA work ran into these three items. In September approximately twenty-five people were working on drift tube design and drafting and by November an equal effort was being put on the oscillator design. The injector has had four to six engineers and draftsmen on it continuously. In November the total number of mechanical engineers and draftsmen on MTA work averaged about forty.

Drift Tube Design. Design of the drift tubes has been affected considerably by the magnetic forces and desired shape of the stray fields as mentioned in the last report. The estimates of the forces has been continually improved as a result of continuous model testing but have not yet definitely determined to the accuracy desired. Additional bolts have been put into the drift tube stems in order to handle the bending moments due to the magnetic forces, and in addition, the "flux leaders" intended to shape the stray field near the surfaces of the drift tube shells to reduce electron emission have been omitted on the first three drift tubes in order to reduce the magnetic forces. It is believed that with these changes the mechanical design will be adequate when the forces are finally known. If not, flux leaders may have to be omitted from some of the other tubes. One of the effects of the bending moment due to magnetic forces in the drift tube stems is to reduce the contact pressure at the joint between the drift tube and stem. A radiofrequency test set-up is being built to check the adequacy of this joint in handling the radiofrequency currents which cross it.

Liner Design. Details of the liner have been prepared by CRDC and reviewed by the Laboratory. The radio frequency joints between the liner shell and the end diaphragms have been made extremely rugged as has been indicated to be desirable from the tests of operation of the one megawatt oscillator resonant load at the Laboratory. Developments in the design of the liner from the first conception have increased the difficulty of manufacturing to the point where a cost plus fixed fee contract has been found necessary for its construction.

Current Measuring Target and Precessing Magnet. A preliminary design for the target to measure and absorb the output beam of the linear accelerator without attempting to produce useful material has been prepared and has been studied and modified by CRDC. Target shielding will require nine feet concrete compared to seven of the accelerator itself and the active parts of the target must be handled while protected by five inches of lead. Specifications for the "precessing" magnet which sweeps the beam in a circle over the

*Previous MTA Quarterly Report: UCRL-1009 face of the target in order to distribute the highly concentrated current in the beam have been agreed to and the magnet and its power supply are on order.

L-1 Test Facility. During the period a preliminary design of a test cavity for the purposes of experimenting with single drift tubes and testing oscillators was prepared and the detail design was started by CRDC. This L-1 test facility as it was called was originally conceived of as a test station for the Mark I oscillators to be used before the oscillators were connected to the main accelerator and for check tests after repair work. For this purpose it would have resembled the B-1 facility at UCRL. However, it appeared desirable to provide for tests of drift tubes as well as the oscillators which necessitated much more electrical power, larger tank and extensive shielding against x-rays. The project had grown to the point that the estimated cost was almost $7,000,000 and completion would be around January 1952 at which point it was felt that the cost and time would become so great that the project as planned was impractical. It was decided to drop the L-1 project and in its place to design an oscillator test facility primarily for Mark II and subsequent oscillators, to make special drift tubes for Mark I on which experiments could be performed, and to do all Mark I oscillator testing required at UCRL or on the accelerator itself. Preliminary design of the oscillator test facility to be called L-2 was just starting at the end of the period.

Mark III Design. During the period preliminary design and cost studies were made for a cyclotron type accelerator designated as Mark III. Experimental work had been proceeding for some six months on an electron model which has given very promising results. It was decided to convert the XC magnet based on the Oak Ridge Y-12 Beta design to the Thomas type cyclotron to study performance of the low energy region of the Mark III accelerator. A more complete description of this XC conversion is given in Section 15.

Mark II Target Design. Very little work has been done by the engineering group on the Mark II target but this is expected to count for larger portion of the effort after the first of the year.

2. Electron Model Tests and Wide Aperture Input Investigation

W. K. H. Panofsky

Electron Model. Considerable difficulties were encountered in the operation of the Mark I MTA electron model. The reason for the difficulties is the fact that the same operating voltage properly scaled for electron acceleration is also the critical voltage for rf loading by electron multiplication. These difficulties were overcome by grooving the faces of the drift tubes in order to reduce the geometry for electron multiplication. Also the oscillator power was increased to permit operation with a small amount of loading present. As a result, the electron model is now in satisfactory operating condition. As a result of this operation the following data have been obtained: 1) In optimum adjustment the acceptance phase angle of the machine is between 150° and 180°. This measurement was made by comparing the input current with the output current. These phase angle values are in excellent agreement with the predicted values. 2) The entire aperture of the linear accelerator input accelerates particles corresponding to the same range of phase angles. This point was checked by the use of diaphragms across the input aperture. This means that one can conservatively plan on having the full aperture of the Mark I MTA available for injection. 3) The output beam shape of the electron model exhibits the predicted central core maximum intensity. The beam profile was explored by moving a wolfram wire across the beam and observing the x-ray intensity as measured on a thin-walled Geiger counter as a function of wire position.

The only outstanding discrepancy on the operation of the electron model as compared to theory appears to be the magnet currents which are required to produce optimum performance. This descrepancy may be due to the uncertainty in the knowledge of the relation of measured currents and fields. This point is now under investigation.

Calculations and Model Tests on Wide Aperture MTA Input. Since the principal "commodity" which one is buying in the MTA is a certain aperture into which one can inject deuterons to be accelerated, it is clearly of greatest importance to study the limitations on this aperture. In particular one of the principal parameters defining values of wave lengths for future MTA development would be the relation governing feasible apertures for a given wave length.

As the aperture is increased the primary consequence is a decrease in voltage gain of the particle as compared to the voltage gradient in the tank. However, since the aperture problem is only a serious one for a relatively short distance in the tank, this loss in "pick-up efficiency" is economically insignificant.

Calculations have been made on suitable geometries with increased entrance aperture and consequent lower pick-up efficiency. The most extreme model in this direction which has been investigated is an opening of 9.6 in. diameter at 12.2 megacycles frequency. This results in an input pick-up efficiency of only 15 percent, but the overall increase in length is only 2 ft. One of these large aperture models has been scale modelled, and field runs indicate agreement with the field values used in the calculations. The principal remaining question is the detailed beam dynamics of such large aperture accelerators. It is clear that owing to the variation of pick-up efficiency with radial position large phase oscillations will be produced due to coupling between the radial and phase motions. This problem calls for numerical analysis, which is now being attempted with the aid of mechanical computing aids. The feasibility of such increased apertures will rest on the outcome of these calculations, and model tests in the electron model. These calculations are discussed further in Section 11.

<u>Calculations on Anticipated Mode Troubles Due to Reactive Ion Loading.</u> Calculations have been made studying the effect of reactive currents produced by residual ions in the MTA tank. It is concluded that with reasonable assumptions concerning sweeping fields and ion production rate that before such reactive effects would become troublesome the purely resistive loading due to the agents producing the ions to start with, would become excessive.

<u>Joint Tester.</u> The design and construction of a test facility permitting radiofrequency joints to be tested by a current density of 100 amps/linear inch is 50 percent completed.

3. Drift Tube Model Magnet Tests

Duane Sewell

Tangential Magnetic Fields. The investigation of the beam dynamics showed that 8-1/2 drift tubes are required for the Mark I machine instead of the 7-1/2 that were in the preliminary design. Therefore, the magnets have been redesigned to provide for the larger number. Also, the investigation of the rf loading from electrons emitted from the surface of the drift tubes indicates that it will be desirable to try to retard the motion of these electrons with magnetic fields tangent to the surface of the drift tubes. Tests were made on the 8 magnets with all of the steel return path removed in an effort to get higher magnetic fields tangential to the drift tube surface. It was found that the tangential field on magnets 4 through 8 was not increased sufficiently by this change; hence, steel cylinders were added to the ends of these magnets to lead some flux out to the drift tube surface. These cylinders, shown in Fig. 1, have been called flux leaders.

Forces Between Drift Tubes and Magnet Redesign. It was found that the magnetic forces on drift tubes 1 through 3 were too high when all of the steel was removed from these magnets; therefore, these three magnets have been redesigned with steel return paths. It was also found that steel cylinders for the inner and the outer diameters of the coil container on magnets 4 through 8 did not appreciably decrease the tangential field or appreciably increase the ampere turns required. Therefore, to simplify the mechanical design, these cylinders are being made of steel. Tests to determine the number of ampere turns required for each magnet have been completed and the results are given in Table I.

Measurements are now in progress to determine the forces between magnets.

TABLE I

Ampere Turns Requred for Full Scale Magnets

Drift Tube No.	Amp. Turns
1	$.240 \times 10^6$
2	.411
3	.582
4	.657
5	.687
6	.695
7	.719
8	.769

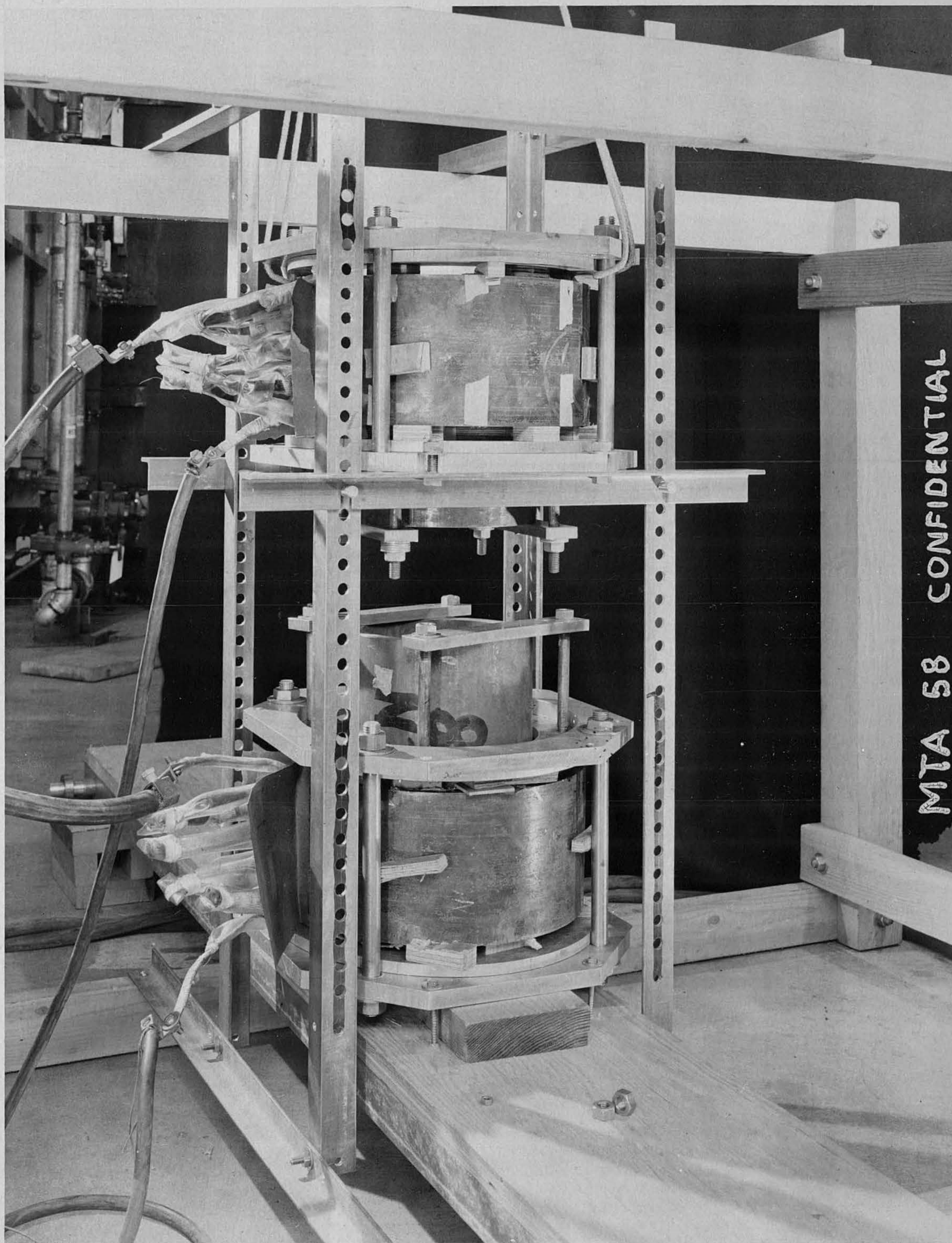


FIG. 1

OZ 1214

4. Model Cavity Tests

Duane Sewell

Measurements of Drift Tube Stem Positions. The 1/10 scale rf model of the Mark I machine has been converted to 8-1/2 drift tubes. Fig. 1 shows the cavity resting on its side and the drift tubes mounted on lucite stems.

The optimum positions for the metal drift tube stems have been determined on this model; the condition for the optimum position is for a minimum voltage across the outer end of the stem when the stem is perpendicular to the axis of the machine. The following table gives the final drift tube stem positions as determined by these tests:

Drift Tube Number	Full Scale Displacement from Drift Tube Center Line (inches)
1	+ 1-7/8 ± 5/8
2	+ 3-3/4
3	+ 4-3/8
4	+ 5-5/8
5	+ 5
6	+ 4-11/16
7	+ 2-1/2
8	- 1-1/4

A plus (+) sign indicates a displacement towards the exit end of the machine.

Cavity Frequency Measurements. The resonant frequency of the cavity was measured after the drift tubes were mounted on metal stems. This frequency was found to be 12.26 megacycles for the full scale machine.

The Q and shunt impedance (Z_s) for this 8-1/2 drift tube model have been calculated from the magnetic field measurements. The following are the full scale values: (5.8×10^7 mhos/meter was used for the conductivity of copper)

$$Q = 265{,}000$$
$$Z_s = 115 \times 10^6 \text{ ohms}$$

This gives the following value for the power loss in the cavity for CW operation:

$$P_L = \frac{V^2}{2Z_s} \quad \frac{(45 \times 10^6)^2}{2 \times 115 \times 10^6} = 8.8 \times 10^6 \text{ watts}$$

where

P_L = power lost in the cavity
V = total voltage across the cavity.

The following table gives a list of the relative losses in various portions of the cavity:

Losses (Relative)

	% Total
Cavity walls	50.3
Cavity entrance end	13.5
Cavity exit end	10.9
Drift tubes	14.5
Drift tube stems	10.9
Total	100.1

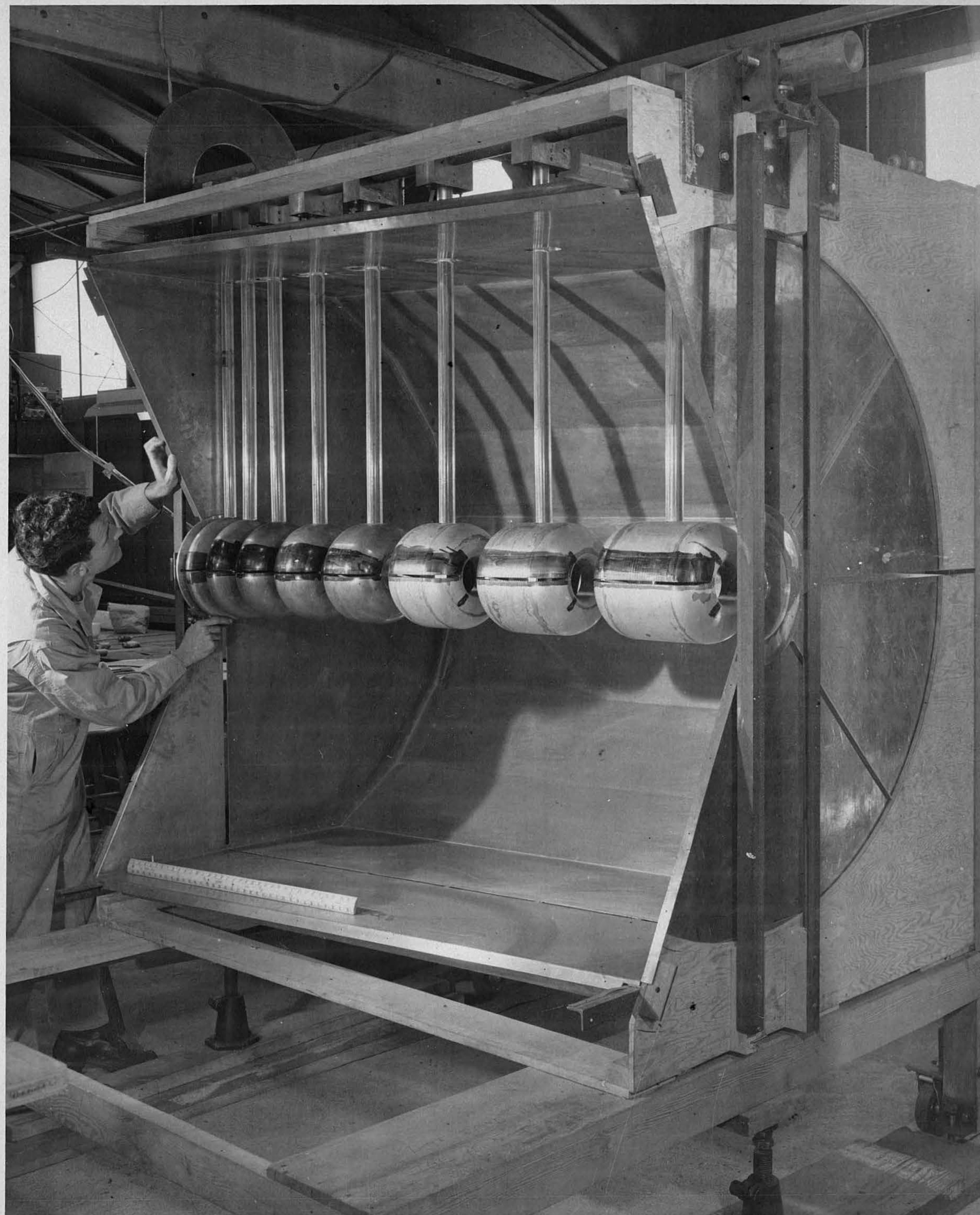
Itemized Drift Tube and Stem Losses (Relative)

DT No.	Drift Tube % Total	Stem Loss % Total
0	.3	1.3
1	.6	1.3
2	.8	1.3
3	.8	1.4
4	1.2	1.4
5	1.6	1.4
6	2.2	1.4
7	2.9	1.4
8	4.1	1.4
	14.5	10.9

The actual Q of the 1/10 scale cavity was measured and found to be 85 percent of that calculated from the magnetic field measurements. This was somewhat surprising since reasonable care had been used in cleaning and assembling the cavity. There was some worry that this discrepancy in Q might be caused by concentrated losses; therefore, it was deemed advisable to investigate this matter further.

Investigation of Losses. To separate the drift tube losses from the cavity wall losses, the drift tubes were removed from the cavity and the Q of the unloaded cavity was calculated from magnetic field plots. The actual measured Q of the unloaded cavity was found to be 98 percent of that determined from the magnetic field. Therefore, it was concluded that most of the 15 percent discrepancy in the previous measurements was associated with the drift tubes and their supports.

An effort was made to eliminate the additional losses in the drift tube assemblies. All of the cracks in the tubes and stems were carefully filled with soft solder. They were then copper-plated and polished to a mirror finish. A .0015 inch layer of silver was carefully plated on the drift tubes and stems just before they were reassembled in the cavity. The measured value of the Q of the loaded cavity was then found to be 93 percent of the value calculated from the magnetic field plots. From additional tests, it was concluded that this 7 percent discrepancy was caused by distributed losses and, therefore, would cause no trouble in the final machine.



$\frac{1}{10}$ SCALE MODEL CAVITY WITH 126° SECTION REMOVED TO SHOW DRIFT TUBES SUPPORTED ON LUCITE RODS

FIG. 1

OZ 1063

5. Linear Accelerator Electron Loading

Craig Nunan

Summary. Tests with d.c. voltages up to 70 kv have been discontinued because the results did not appear to apply in the case of rf voltages of the order of 1 megavolt. 12 mc/sec rf tests with surface areas comparable to MTA Mark I drift tube ends and at 2.2 megavolts (half the MTA gradient) indicate that the MTA electron loading will probably be above 1 megawatt. The surfaces were not heated or glow discharged but were wiped with rags soaked in C.P. acetone. Values of the x-ray intensity obtained in 200 mc/sec rf tests with 0.8 megavolts across approximately 1/16 scale gaps indicate MTA Mark I electron loads ranging from 0.3 to 15 megawatts with the usual value of about 3 megawatts. The 0.3 megawatt figure was obtained by glow discharging in Freon.

The 200 mc/sec rf tests with various shaped drift tubes indicate that the emission is the same function of electric field strength regardless of whether the field is varied by changing the electrode shape or by changing the gap voltage. However, the evidence on this point is not conclusive because of the large random variation of x-ray level with any particular geometry.

Normally the x-ray intensity is independent of pressure. The normal operating pressure is between 2 x 10^{-6} and 2 x 10^{-5} mm Hg. On a few occasions when the pressure was raised to 10^{-4} mm Hg the x-ray intensity increased by a factor of about ten.

Tests with lead collimated electroscopes indicate that 40 percent of the x-rays come from the end walls of the cavity and 60 percent from the drift tubes. Tests with fluorescent powder behind transparent absorbers indicate that electrons strike all parts of the rf cavity, but high energy electrons (above 200 kv) are confined to the region within 10 in. of the axis (cavity radius = 19 in., cavity length = 12 in.). A similar 200 mc/sec cavity having no drift tubes produced x-rays which were eliminated by glow discharge in air but which gradually returned over a period of two hours; such reduction and return of x-rays has never occurred in the cavity with drift tubes, even though glow discharging has been almost a standard routine with all tests. However, it is still possible that the cavity end walls in the test cavity with drift tubes may at times in the past have been emitting electrons that produced x-rays.

D.c. Tests. The d.c. tests at voltages below 70 kv and gaps less than 0.1 inch have been discontinued because the d.c. cold emission appeared to be produced by a different process than the rf cold emission (see Fig. 1):

As the d.c. voltage is raised, no cold emission is observed until the gap breaks down; after breakdown the voltage can be lowered and raised repeatedly and the curve of $\log_{10} I = K - 1/E$ is a straight line of about the same slope as with rf voltage. If the voltage is again raised to breakdown, and sparking is allowed to continue for several minutes, when the voltage is reduced below breakdown the emission is higher by a factor of 10 to 100. From 30 to 150 joules are dissipated with each spark (most of this energy being dissipated in a 50 ohm series resistor) and the surfaces of the electrodes are observed to become rougher. However, with rf voltage, cold emission occurs without ever breaking down the gap and continuous gap breakdown does not change the intensity of cold emission when the gradient is subsequently reduced to a value below breakdown. This may be due to the small amount of energy dissipated in the rf spark (about 2 joules).

With the electric field kept constant, the d.c. cold emission increases when the gap (and consequently the breakdown potential) is increased. All of the curves of d.c. cold emission current are lower than the lowest curves of rf emission, possibly due to the larger gap in the rf tests.

Surfaces found to be poor emitters at d.c. were tried at rf and were found to emit as copiously as copper.

(The d.c. data plotted in Fig. 1 was recorded before the last progress report was written but is presented here to better illustrate the above remarks. The d.c. emission density was determined by dividing total current by total electrode areas, although the spark breakdowns erupted the surfaces only near the outer edge of the electrode and the actual field and emission density are undoubtedly much higher than the values plotted in Fig. 1. The rf emission density plotted in Fig. 1 is the average over the rf cycle; it should be multiplied by 3.6 to get peak current density. See Fig. 9.)

<u>12 Mc/Sec Rf Tests</u>. Fig. 2(a) shows the 12 mc/sec system. The x-ray intensity has been measured with a field at the 5 foot diameter sphere equal to half the field at the MTA Mark I drift tubes. With a 25 percent duty cycle and 2.2×10^6 volts rf the x-ray intensity was 0.05 R/hr at 65 foot radius through 1 inch of steel. The x-ray attenuation by 1 inch of steel at 2.2×10^6 volts is comparable to the attenuation by 1/4 inch of steel at 784 kv. In the 200 mc/sec system the x-ray intensity through 1/4 in. of steel at a radius of 105 cm (3.45 feet) was 0.14 R/hr due to 10^{-6} ampere d.c. emitted from a wolfram needle protruding through one of the drift tubes with 784 kv across the gap. 10^{-6} ampere corresponds to $(3.45)^2/(65) \times 0.14 = 4 \times 10^{-4}$ R/hr at 65 feet radius. 0.05 R/hr at 65 feet radius corresponds to $0.05 / 4 \times 10^{-4} \times 10^{-6} = 1.25 \times 10^{-4}$ ampere average or 5×10^{-4} ampere during the rf pulse. This represents an electron loading of $2.2 \times 10^6 \times 5 \times 10^{-4} = 1.1$ kw on the 12 mc/sec system. The area of the inner sphere of the 12 mc/sec system is $4\pi(2.5)^2 = 79$ sq. ft. The outer hemisphere probably doesn't emit significantly. The emitting area of the curved end of the longer MTA Mark I drift tubes is about 50 sq. ft. Since emission occurs in both directions across the MTA gap, the total emitting area is comparable to the area of the 12 mc/sec system sphere. If the current increased no further when the field is doubled to full value, the MTA Mark I electron loading would be $47 \times 10^6 \times 5 \times 10^{-3} = 0.023$ megawatts. Using the curve in Fig. 3 which has the least slope, the electron loading extrapolated to MTA Mark I is 0.8 megawatts. The solid curve of Fig. 4 has a more typical slope for the 200 mc/sec system. At this slope the electron loading extrapolated to MTA Mark I is 20 megawatts. (See Fig. 10.) The foregoing discussion shows two things:

(a) It is not possible to extrapolate accurately over large changes in electric field.

(b) If the MTA Mark I drift tube surfaces are comparable to the surfaces of the 12 mc/sec system, the electron loading may be several megawatts.

The 12 mc/sec system has been cleaned with C. P. acetone but has not been heated to volatilize oil films. X-ray photographs have been made with a pin-hole camera. The films show about 35 small dark spots corresponding to the position of the 10 foot diameter hemispherical part of the outer conductor. The system has been operated for several days and the x-ray level remains fairly constant.

200 Mc/Sec. R.F. Tests.

(1) Metals. Aluminum, chromium, copper, anodized aluminum, and copper-oxide drift tubes had been tried before the last progress report. The list was extended by trying stainless steel and wolfram. The x-ray level with all metals was comparable, although the intensity with copper-oxide was a factor of 3 to 5 lower than with the other metals.

(2) Cleaning. Stainless steel and wolfram drift tubes were tested before and after leaching in sulfuric, nitric and hydrochloric acids. The cleaning produced no effect.

(3) Glow Discharge. When copper drift tubes were cleaned by rf glow discharge in Freon 12 for about 20 minutes the x-ray intensity dropped by a factor of four to a level equivalent to 0.3 megawatts loading on MTA Mark I (see Fig. 3). Further glow discharge in Freon 12 made no improvement. Glow discharge with 250 volts at 20 amperes d.c. was tried. After 5 minutes discharge there was no reduction in x-ray intensity. Longer glow discharge at 20 amperes produced blackening of the drift tubes and the x-ray level increased between 10 and 200 times after about 30 minutes discharge.

(4) Geometry. The drift tube shapes shown in Fig. 2 have been tried. Representative curves of extrapolated loading vs 1/cavity gradient are plotted in Fig. 3. Fig. 4 is a plot of j vs $1/E_{max}$ where E_{max} was varied by changing drift tube shape and the ratio of gap voltage to gap length was kept constant. J =amperes/cm^2 and E_{max} = maximum electric field in megavolts/cm. Also plotted in Fig. 4 are curves of j vs $1/E_{max}$ for copper and stainless steel hemispheres where the drift tube shape was kept constant and the gap voltage was changed. Note that the two types of curves have essentially the same slope. This suggests that the emission per unit area is the same function of electric field regardless of whether the electric field is changed by geometry or by total voltage. It also suggests that practically all of the cold emission is from the drift tubes. However, the points are scattered too widely to be conclusive and the assumption as to the emitting area is open to question. The emission per unit area was determined by assuming the emission to be uniform over the hemispherical ends of the 7/32 diameter tips, over the hemitoridal ends of the cylinders and over 0.4 of the hemipherical part of the hemispherical drift tubes.

Fig. 4 indicates that if the electric field were increased to infinity, the maximum current density would be 2×10^{-3} amp/cm^2. At first thought it would appear that a cylinder could be made with very thin wall, such that the area of the curved end would be very small and the total current would be reduced below present values. The fallacy is that the electric field is also increased on the cylindrical part back of the curved end so the area for emission is not reduced fast enough to overcome the increased emission density. This may explain why the points for 7/32 diameter nipples are so high. The distribution of emission density and the total emission have been calculated for cylindrical drift tubes with thin walls, approximating the wall cross section by hyperbolas. With this more accurate estimate of emission density distribution over the drift tubes the points still fall on the curve of Fig. 4.

Pressure. Normally, the x-ray intensity is independent of pressure. However, in a few cases a pressure dependence has been observed (see Fig. 5). In one set of cases the x-ray intensity was constant at pressures from 20 x 10^{-6} mm Hg to the transition value and a factor of 10 higher for pressures from the transition value up to the point of glow discharge. This was independent of electric field and was the same for air, argon, oxygen, helium and hydrogen. It was roughly the same for copper hemispheres and for stainless cylinders and the transition from low to high x-ray intensity occurred as the pressure either increased or decreased through the range from 70 to 100 x 10^{-6} mm Hg as measured with an ion gage. In the case of stainless steel hemispheres with a 15 inch diameter copper sheet between them to halve the electron path length, the transition was more abrupt and occurred from 45 to 52 x 10^{-6} mm Hg. In a later set of experiments mercury was placed in a flask attached to the vacuum system and kept cold by liquid air. When the mercury was vaporized by heating, the x-ray level did not change. Freon was introduced and the x-ray level did not change. Then an x-ray intensity vs pressure run was made and it was found that the x-ray intensity increased linearly with pressure from 48 to 86 mr/hr as the pressure was increased from 35 to 60 x 10^{-6} mm Hg. Mercury was again vaporized and the x-ray level varied from 31 mr/hr at pressures between 230 and 100 x 10^{-6} mm Hg to 320 mr/hr at 90 x 10^{-6} mm and back to 60 mr/hr at pressures between 70 and 45 x 10^{-6} mm. Afterwards several curves were run raising the pressure by letting air into the system and the x-ray intensity was always a maximum at about 100 x 10^{-6} mm, falling off at higher and lower pressures. The lowest pressure obtainable at the time was 30 x 10^{-6} mm. The system was heated to pump out the mercury, then the system was opened and cleaned. The pump oil (Litton oil) was replaced with Octoil S. Since that time the x-ray intensity has been independent of pressure, even though an effort has been made to repeat the original conditions by introducing mercury and freon. With the Octoil S pump oil and with more correct adjustment of pump heating power pressures of 10^{-6} mm Hg have been obtained, whereas, normal operating pressure had previously been about 20 x 10^{-6} mm. The x-ray intensity was not reduced by the improvement in vacuum. A glow discharge usually starts at about 200 x 10^{-6} mm Hg so it seems possible that the x-ray dependence upon pressure is connected with the preliminary phases of glow discharge.

Heating. Stainless steel cylinders with 1/8 inch thick wall were heated to bright red heat (about 1200°K) by d.c. electron bombardment from a wolfram filament placed between the cylinders. The filament was removed, rf voltage turned on and the x-ray intensity was observed as the cylinders cooled from cherry red ($\sim$1100°K) to room temperature. The x-ray level remained constant, indicating no thermal emission. In this case, heating reduced the x-ray level from 6.5 to 1.7 megawatts electron loading extrapolated to MTA Mark I. In general, heating the drift tubes for about a half hour to 300°C for copper and 800°C for stainless steel has no effect on the x-ray intensity. Occasionally the intensity is increased a factor of 2 or 3 and more often the intensity is reduced a factor of 2 or 3. Further heating makes smaller changes and the lowest loading obtained by heating repeatedly was 1 megawatt with copper hemispheres. The usually level after repeated heating is about 3 megawatts, and this value is often obtained with no heating. The rf cavity has never been heated, only the drift tubes.

Origin of X-rays. Fluorescent powder was blown on the end walls of the 200 mc/sec rf cavity and various thicknesses of polystyrene sheet were placed over the powder to determine incident electron energy by range. The powder fluoresced behind 0.020 inch polystyrene out to a radius of about 10 inches when the gap voltage was 750 kv between hemispherical drift tubes. The rest of the end wall fluoresced behind 0.002 inch polystyrene and the cylindrical part behind no absorber. Fluorescent powder was glued to a quartz rod running across the cavity half way between drift tubes. The powder fluoresced over the whole length of rod but a single layer of scotch tape stopped the fluorescence everyplace except within a radius of about 2 inches from the cavity axis; a layer of scotch tape also stopped the fluorescence everyplace on the end walls and everyplace on the drift tubes except the hemispherical fronts. The quartz rod cast a shadow in the fluorescence on the drift tube fronts. The highest gap voltage used when the quartz rod was in the cavity was in the cavity was about 300 kv.

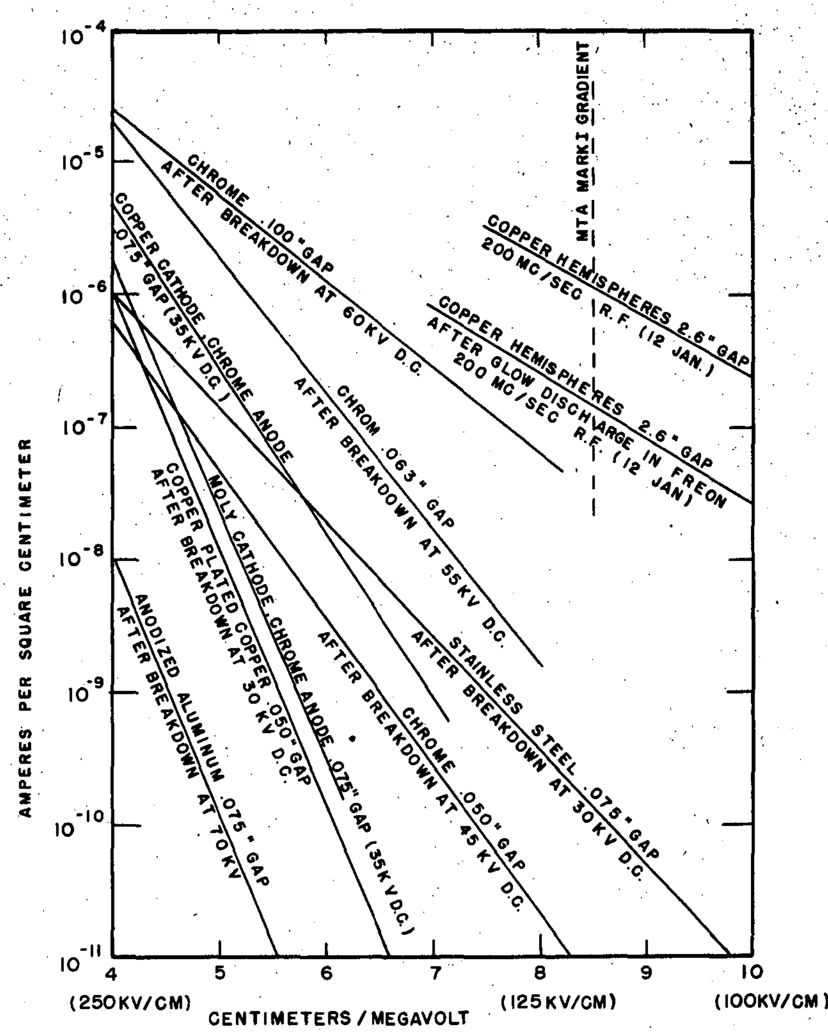
A lead collimator was built with two slots, each 1/2 inch wide, 16 inches long, and 12 inches high with an electroscope at the back of each slot. The slots were perpendicular to the cavity axis, arranged so that one electroscope measured x-rays from one end wall of the cavity and one electroscope measured x-rays from part of the face of one drift tube. Fig. 6 shows the arrangement and the width of view for each slot at the cavity axis. The end wall produced 100 mr and the drift tube face produced 170 mr. The total radiation with no collimation was 1800 mr, which is probably a factor of 3 too high because of scattering from the vacuum tank surrounding the rf cavity. Thus, the 200 mr from two end walls plus 340 mr from two drift tube faces probably constitutes almost all the x-rays.

A lead collimator was built, consisting of a series of 9/16 inch diameter, 16-inch long holes with an electroscope at the end of each hole. The holes were 2 inches apart and were arranged perpendicular to the cavity axis. Each electroscope had a field of view 1-1/2 inch in diameter at the cavity axis. Fig. 6 shows the electroscope readings. There was 160 mr from the tip of each drift tube, 30 mr from the center of the gap (due to overlapping of view of adjacent electroscopes, and about 10 to 20 mr on each of the other electroscopes (some of this being x-rays from the drift tube faces and end walls which are scattered in the vacuum tank wall at the front of each 9/16-inch hole).

Random Variation of X-ray Level. The 12 mc/sec rf system has been run for days a few hours at a time with only a few percent change in x-ray intensity. The 200 mc/sec system has been run at constant voltage for as long as 16 hours with the order of ± 30 percent change in x-ray intensity. However, when running voltage up and down to obtain the x-ray intensity vs voltage relation, the curves occasionally do not repeat within a factor of ± 3. Usually the points forming a single curve fit a straight line within a factor of ± 40 percent in current.

Unloaded Cavity. A new 12 inch long, 45 inch diameter rf cavity without drift tubes was installed. When it was first excited the x-rays were observed as indicated in Fig. 7. Glow discharge in air for 10 minutes eliminated the x-rays except at fields above 38 kv/cm. After an hour of continuous running the x-ray intensity (at 21 kv/cm) began to rise. Glow discharging again in air for 10 minutes eliminated the x-rays (except above 38 kv/cm), but they returned after a few minutes, rising slowly for 90 minutes, then remaining fairly constant. (See Fig. 8.) The cavity was taken apart, cleaned with a metallite sanding disk (92 percent aluminum oxide, 8 percent iron oxide) and then with C. P. acetone. The x-ray intensity was about the same as the first time the cavity was assembled. Glow discharge in Freon for 1 hour did not reduce the x-rays. Glow discharge in air for 20 minutes eliminated the x-rays again at 21 kv/cm.

The lowest gradient at the end walls of the unloaded cavity at which x-rays were observed was 16 kv/cm. The maximum gradient ever obtained at the end walls of the cavity with drift tubes was 14.5 kv/cm. Similar disappearance with glow discharge and return of x-rays was never observed in cavities with drift tubes.



GRADIENT = GAP VOLTAGE ÷ GAP DISTANCE (CURVATURES IGNORED)

FIG. 1

MU 1408

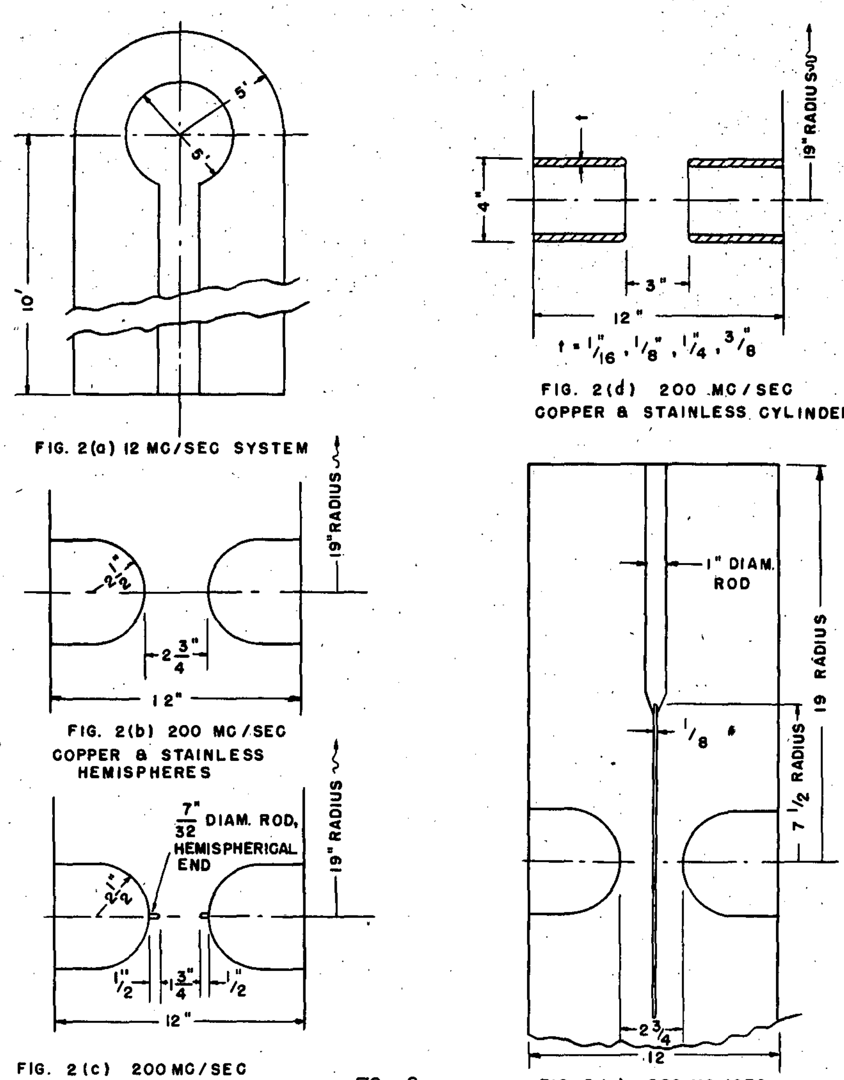


FIG. 2(a) 12 MC/SEC SYSTEM

FIG. 2(b) 200 MC/SEC COPPER & STAINLESS HEMISPHERES

FIG. 2(c) 200 MC/SEC COPPER & TUNGSTEN NIPPLES

FIG. 2(d) 200 MC/SEC COPPER & STAINLESS CYLINDERS

FIG. 2(e) 200 MC/SEC COPPER MID-SHEET COPPER & STAINLESS HEMISPHERES

FIG. 2

MU 1406

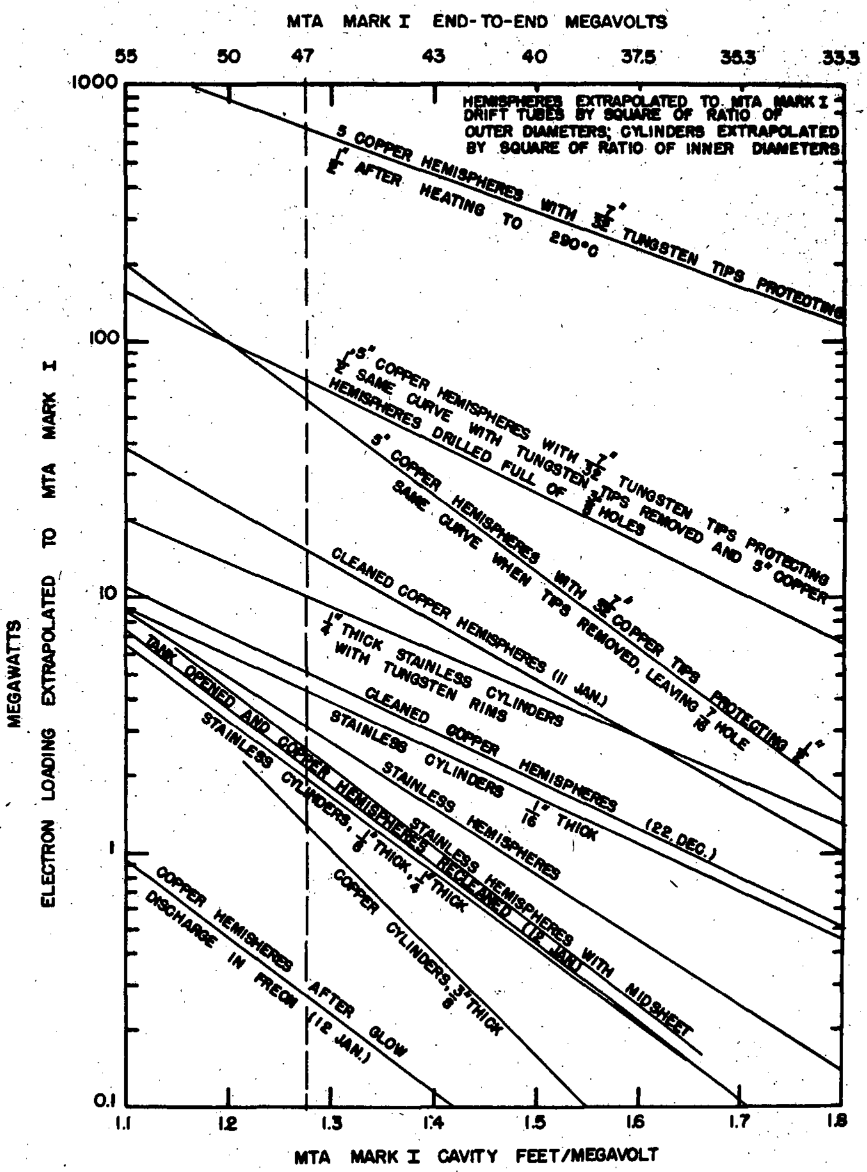

MTA MARK I END-TO-END MEGAVOLTS
55
50
47
43
40
37.5
35.3
33.3
HEMISPHERES EXTRAPOLATED TO MTA MARK I DRIFT TUBES BY SQUARE OF RATIO OF OUTER DIAMETERS; CYLINDERS EXTRAPOLATED BY SQUARE OF RATIO OF INNER DIAMETERS
5 COPPER HEMISPHERES WITH 7/32" TUNGSTEN TIPS PROTECTING 1/2" AFTER HEATING TO 290°C
5" COPPER HEMISPHERES WITH 3 7/32" TUNGSTEN TIPS PROTECTING 1/2"
SAME CURVE WITH TUNGSTEN TIPS REMOVED AND 5" COPPER HEMISPHERES DRILLED FULL OF 3/8" HOLES
5" COPPER HEMISPHERES WITH 7/32" COPPER TIPS PROTECTING 1/2"
SAME CURVE WHEN TIPS REMOVED, LEAVING 7/16" HOLE
CLEANED COPPER HEMISPHERES (11 JAN.)
1/4" THICK STAINLESS CYLINDERS WITH TUNGSTEN RIMS
CLEANED COPPER HEMISPHERES (22 DEC.)
STAINLESS CYLINDERS 1/16" THICK
STAINLESS HEMISPHERES
STAINLESS HEMISPHERES WITH MIDSHEET
TANK OPENED AND COPPER HEMISPHERES RECLEANED (12 JAN.)
STAINLESS CYLINDERS, 1/8" THICK, 1/4" THICK
COPPER CYLINDERS, 3/8" THICK
COPPER HEMISPHERES AFTER GLOW DISCHARGE IN FREON (12 JAN.)
1000
100
10
1
0.1
ELECTRON LOADING EXTRAPOLATED TO MTA MARK I
MEGAWATTS
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
MTA MARK I CAVITY FEET/MEGAVOLT

FIG. 3

MU 1419

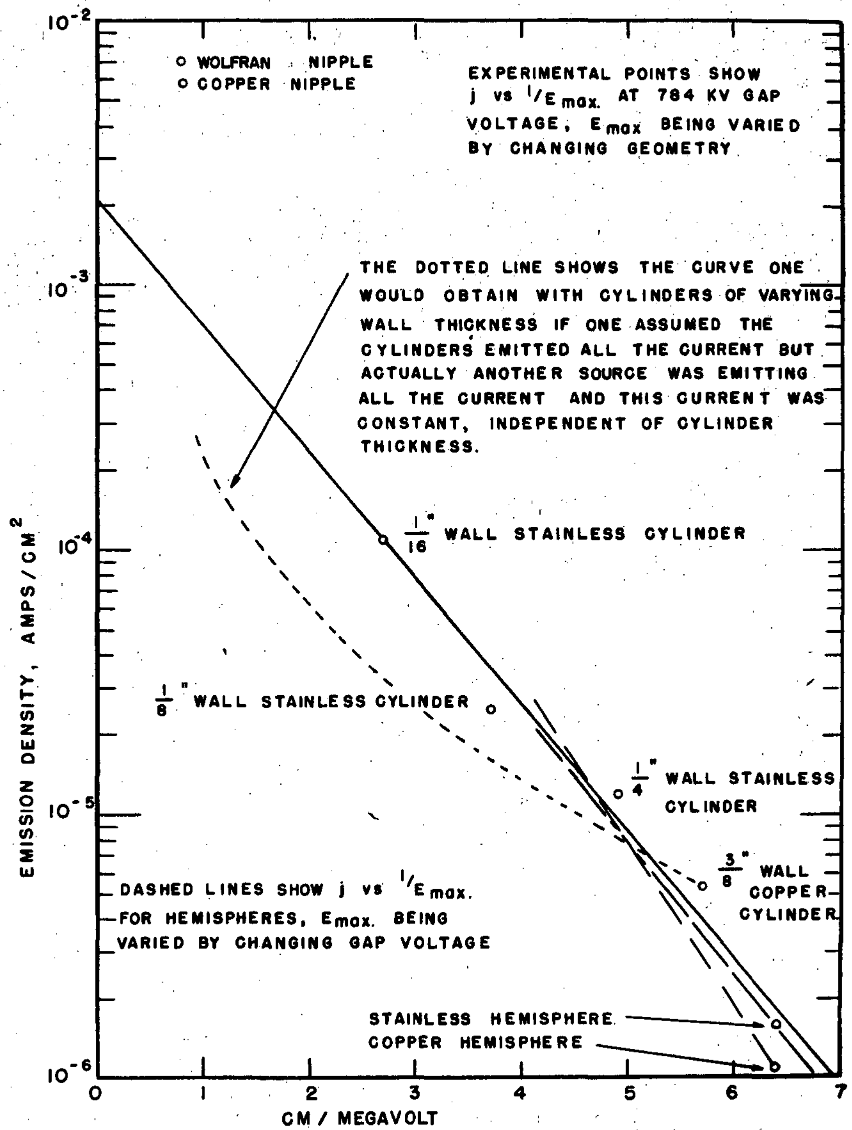

o WOLFRAN NIPPLE
o COPPER NIPPLE
EXPERIMENTAL POINTS SHOW j vs 1/E max. AT 784 KV GAP VOLTAGE, E max BEING VARIED BY CHANGING GEOMETRY
THE DOTTED LINE SHOWS THE CURVE ONE WOULD OBTAIN WITH CYLINDERS OF VARYING WALL THICKNESS IF ONE ASSUMED THE CYLINDERS EMITTED ALL THE CURRENT BUT ACTUALLY ANOTHER SOURCE WAS EMITTING ALL THE CURRENT AND THIS CURRENT WAS CONSTANT, INDEPENDENT OF CYLINDER THICKNESS.
1/16" WALL STAINLESS CYLINDER
1/8" WALL STAINLESS CYLINDER
1/4" WALL STAINLESS CYLINDER
3/8" WALL COPPER CYLINDER
DASHED LINES SHOW j vs 1/E max. FOR HEMISPHERES, E max. BEING VARIED BY CHANGING GAP VOLTAGE
STAINLESS HEMISPHERE
COPPER HEMISPHERE
EMISSION DENSITY, AMPS/CM²
CM / MEGAVOLT
10⁻²
10⁻³
10⁻⁴
10⁻⁵
10⁻⁶
0
1
2
3
4
5
6
7

FIG. 4

MU 1409

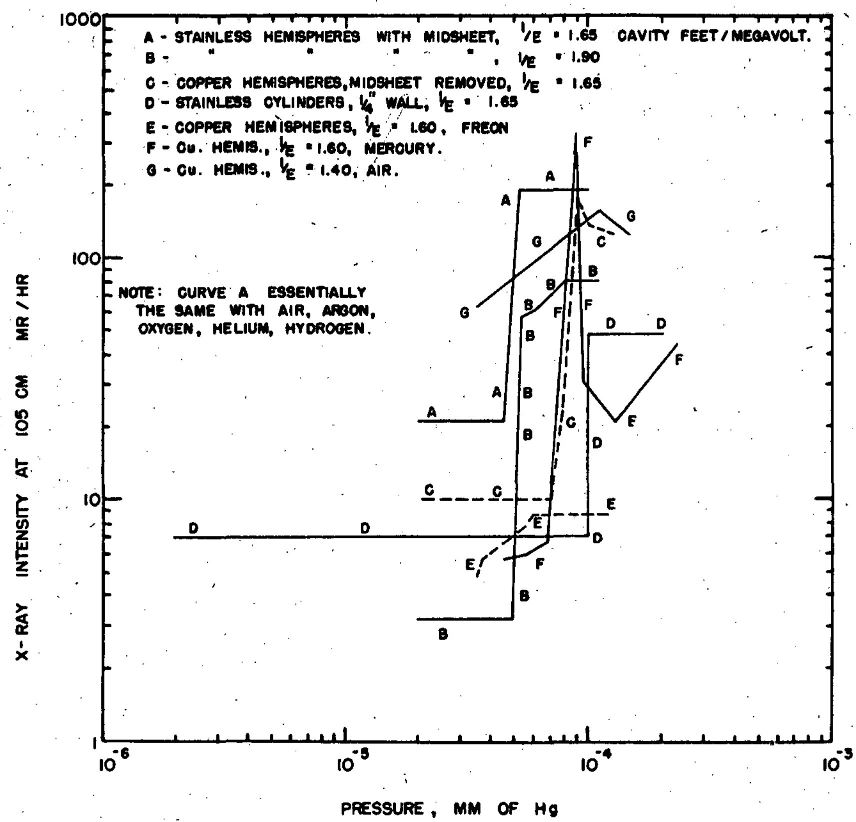
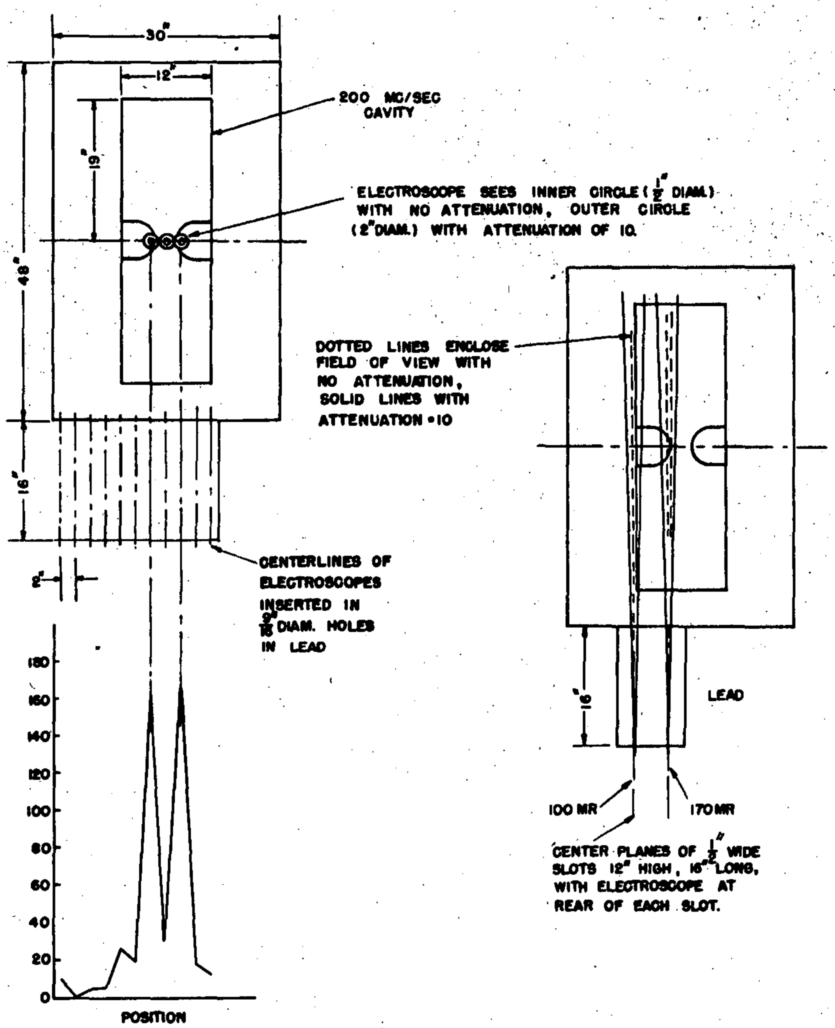


FIG. 5. X-RAY INTENSITY VS. PRESSURE

MU 1417



30"
12"
200 MC/SEC CAVITY
19"
ELECTROSCOPE SEES INNER CIRCLE (½" DIAM.) WITH NO ATTENUATION, OUTER CIRCLE (2" DIAM.) WITH ATTENUATION OF 10.
48"
DOTTED LINES ENCLOSE FIELD OF VIEW WITH NO ATTENUATION, SOLID LINES WITH ATTENUATION = 10
16"
CENTERLINES OF ELECTROSCOPES INSERTED IN 9/16" DIAM. HOLES IN LEAD
2"
LEAD
100 MR
170 MR
CENTER PLANES OF ½" WIDE SLOTS 12" HIGH, 16" LONG, WITH ELECTROSCOPE AT REAR OF EACH SLOT.
180
160
140
120
100
80
60
40
20
0
POSITION

FIG. 6

MU 1418

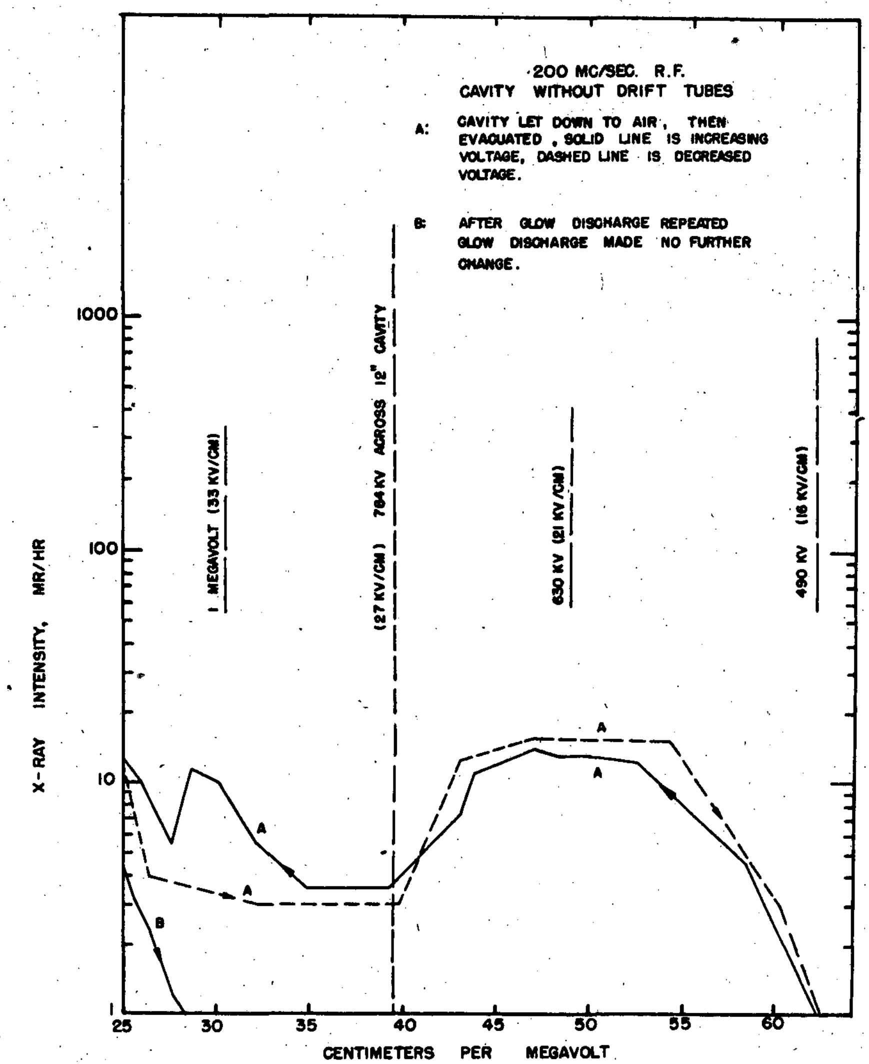

200 MC/SEC. R.F.
CAVITY WITHOUT DRIFT TUBES
A: CAVITY LET DOWN TO AIR, THEN EVACUATED, SOLID LINE IS INCREASING VOLTAGE, DASHED LINE IS DECREASED VOLTAGE.
B: AFTER GLOW DISCHARGE REPEATED GLOW DISCHARGE MADE NO FURTHER CHANGE.
1 MEGAVOLT (33 KV/CM)
(27 KV/CM) 784 KV ACROSS 12" CAVITY
630 KV (21 KV/CM)
490 KV (16 KV/CM)
X-RAY INTENSITY, MR/HR
CENTIMETERS PER MEGAVOLT
1000
100
10
1
25
30
35
40
45
50
55
60
A
A
A
A
B

FIG. 7

MU 1420

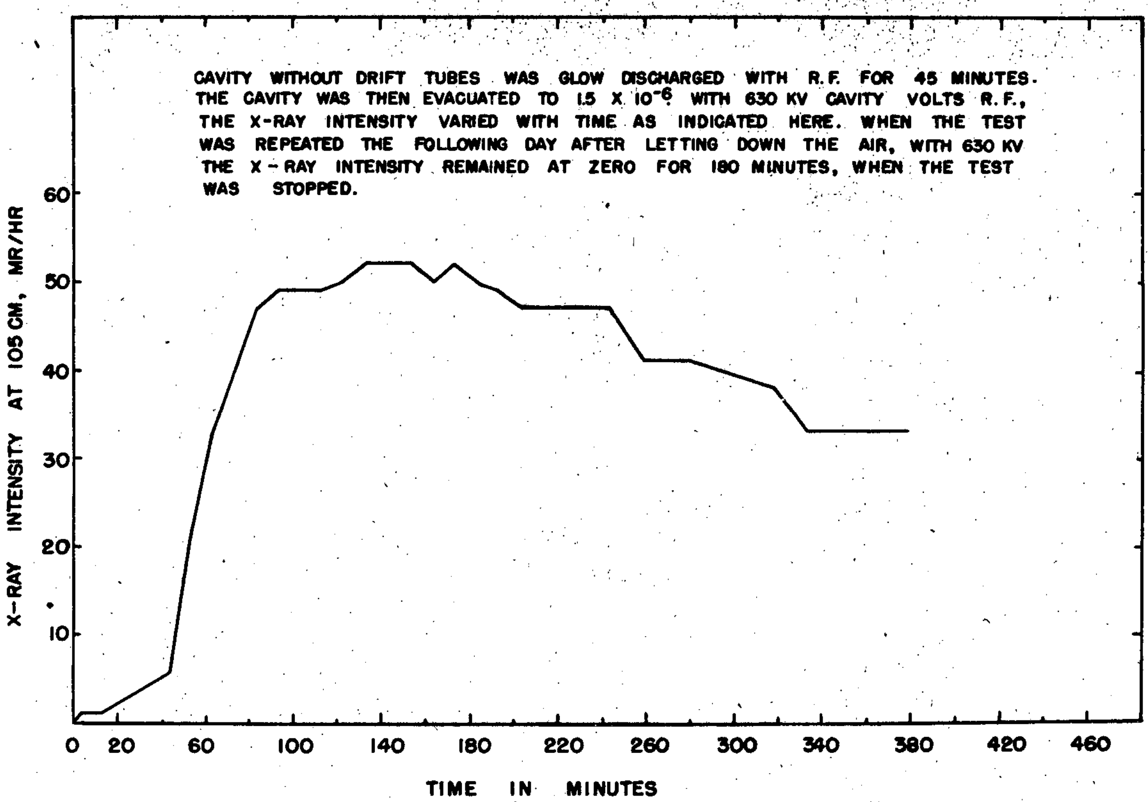

CAVITY WITHOUT DRIFT TUBES WAS GLOW DISCHARGED WITH R.F. FOR 45 MINUTES. THE CAVITY WAS THEN EVACUATED TO 1.5 X 10^-6 WITH 630 KV CAVITY VOLTS R.F., THE X-RAY INTENSITY VARIED WITH TIME AS INDICATED HERE. WHEN THE TEST WAS REPEATED THE FOLLOWING DAY AFTER LETTING DOWN THE AIR, WITH 630 KV THE X-RAY INTENSITY REMAINED AT ZERO FOR 180 MINUTES, WHEN THE TEST WAS STOPPED.
X-RAY INTENSITY AT 105 CM, MR/HR
10
20
30
40
50
60
0 20 60 100 140 180 220 260 300 340 380 420 460
TIME IN MINUTES

FIG. 8

MU 1410

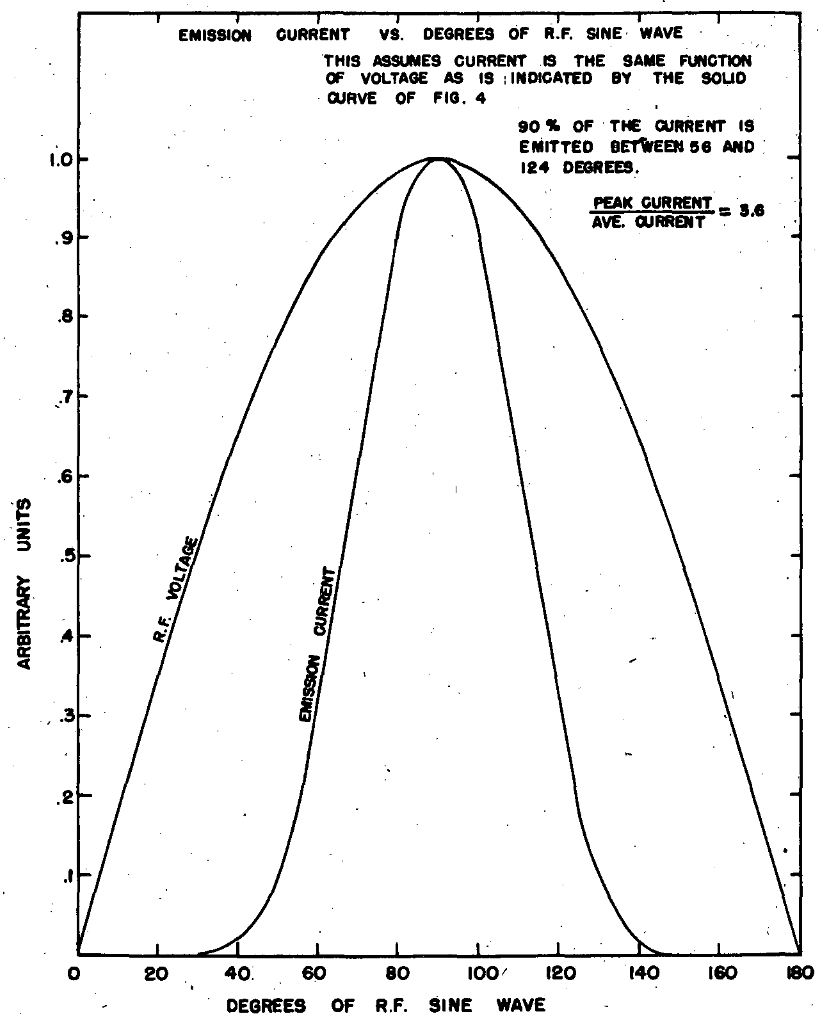

EMISSION CURRENT VS. DEGREES OF R.F. SINE WAVE
THIS ASSUMES CURRENT IS THE SAME FUNCTION OF VOLTAGE AS IS INDICATED BY THE SOLID CURVE OF FIG. 4
90 % OF THE CURRENT IS EMITTED BETWEEN 56 AND 124 DEGREES.
PEAK CURRENT / AVE. CURRENT = 3.6
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
ARBITRARY UNITS
R.F. VOLTAGE
EMISSION CURRENT
0
20
40
60
80
100
120
140
160
180
DEGREES OF R.F. SINE WAVE

FIG. 9

MU 1416

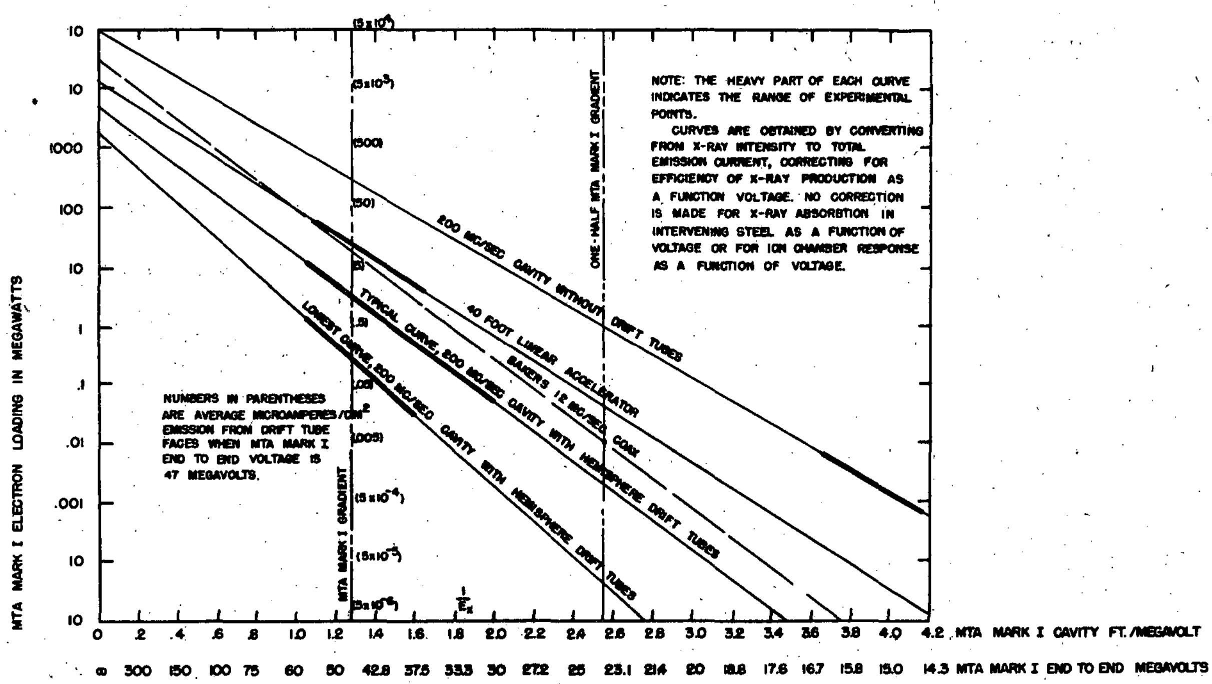


FIG. 10

MU 1421

6. Mark I Radio Frequency Equipment

Design and Development Program

W. R. Baker

Status of Pre-exciter. Plans for a lossy element type pre-exciter have been laid out and detailing is underway. The general system has been successfully modeled as previously reported.

A new system has been recently proposed, however, and the hope is that model work now in progress will show it to be superior to the lossy element method. The new system will use an rf amplifier-limiter that picks up the cavity frequency present at the ion lock point and raises it to a level to drive the pre-exciter power tube directly. This system should be much more efficient and easier to operate.

The general pre-exciter system now involves a sub-excitation (low level d.c.) of approximately 3 kv on the main oscillator. This is maintained continuously. A pulsed pre-exciter is then fed into a large rotable loop such that, when the rf level comes up enough, the sub-exciter takes over and the loop then turns to a position where it intercepts zero flux. With the sub-excitation started the main pulse can be applied at will.

Status of Cluster Oscillator. A six tube 50 kilowatt model of the cluster oscillator has been built and operated successfully at low load. Further tests involving a full resonant type load will be made on the Building 52 cavity when time is available. This system looks very practical.

Status of Resnatron. Plans for a vacuum furnace to do the copper brazing on a full size 12 mc Resnatron have been completed and actual construction should start soon. Experiments on a model of the electrode arrangement proposed have been delayed several times by insulator failure. An improved electrode arrangement and insulator system will be ready soon.

Status of MTA Protective Equipment. Preliminary design is being done on the anode current chassis, tank rf crowbar, and control chassis for the program bias supply. The circuits common to the program bias interlock, rf interlock, and rf permissive interlock are being tested. A 1-channel rf interlock of the new type has been working in Building 52 for several weeks.

Diagrams for the H. V. Divider resistor bank, simplified peak-reading voltmeter, and program bias power supply with transformer specs, have been developed. The peak-reading voltmeter is in drafting, the program bias power supply is ready to go to drafting. Transformers for the program bias supply are on order with Electro for delivery early in February. The parts list for the remaining items are being checked and those not stocked locally will be ordered.

Status of Rf Program. The grounded grid oscillator for use on Mark I has been operated under one megawatt resonant load conditions over a period of about two months. At present, it is giving an efficiency of 78-80 percent and operating at 17.5 kv anode voltage. The resonant load was pressurized with 15 pounds of a nitrogen-freon mixture for the initial tests but has recently been evacuated and the problems associated with ion-lock and vacuum "crow bar" protection successfully solved.

Problems now receiving attention include x-ray shielding, better vacuum, and a parasitic at 100 mc that occurs only under ion-lock conditions.

Oscillator No. 4, the RCA A2332 system has been completed and is ready for test when the resonant load becomes available.

Oscillator Production Status

J. C. Kilpatrick

Main Oscillators. All electrical components are on order for nineteen main oscillators and two pulsed pre-exciter oscillators.

Filament and interlock circuits are completed for eighteen main oscillators. Equipment layout drawings are being prepared by CRD.

Pre-Pulse Power Supply. Two pulse lines each rated 3 megawatts and 2.9 milliseconds will be used to supply plate power to the pre-exciter output tubes.

The pulse line capacitors are out for bids.

Two rectifier transformers are on hand to make a four ampere forty kilovolt charging supply.

Water cooled (GL 562) rectifier components have been ordered from Oak Ridge. Work is progressing on controls and auxiliary equipment.

7. Mark I Power Supplies and Mark II Power Plant Design

G. M. Farly

Oscillator Plate Supply. Details of the control and protective system were considered in discussions with Dr. Dunlap of the GE Company. Notes regarding changes were issued by UCRL and by the GE Company.

Discussions were held regarding changes that might be required for continuous operation of the recitifier. It was determined that it will be possible to add 7500 hp of additional motor capacity to the motor generator set to bring the average motor rating up to the average rectifier rating.

Magnet Supply. California Research Development has all necessary information.

Bias Supply. The arrangment of radiofrequency by pass and surge control apparatus was approved, and details concerning the physical arrangement of the equipment were decided in joint discussion with California Research Development and the manufacturer.

Emission limiting devices have been added to the bias output circuits. Schematic drawings for the three units are complete. All components are on order.

Beam Precessor. The method of controlling and regulating voltage was decided. Details of protective interlocking were also determined.

Sub Exciter. This equipment orginated and specifications were prepared in the current report period. As a result of experimental data which became available the power requirements were increased. Bids are due on the revised specifications in December.

Injector Supply (100 kv, 5 amps). This supply was also specified in the current period. UCRL requirements were incorporated in California Research Development requests for bids. Replies are due in December. According to present estimates, delivery promises will be unfavorable. As a result, this unit will be a critical item.

Mark II Power Plant Design. Phases of the Mark II power plant design were brought out in discussions between members of the Electronics division and technical representatives of the GE company and the Westinghouse Electric Corporation. The results were communicated to CRD in verbal discussions, and later amplified by visits from technical representatives of the above two companies. It is apparent that careful engineering planning will be required to co-ordinate the characteristics of proposed loads with the characteristics of typical power plants. Upon selection of a site for Mark II a definite engineering study of the power plant design should be undertaken.

Typical problems requiring solution.

1. Can conventional generating equipment be used with proposed pulsed loads?
2. What effect does load fluctuation have on boiler and turbine design?

3. How is turbo-alternator rating affected by rectifier harmonics?
4. Should synchronizing ties be used between generating units?
5. What percentage load will be dropped by oscillator protection devices?

8. Status of Mark I Control Equipment

J. C. Kilpatrick and Vern Denton

Control Room. The mechanical details of providing a foundation floor for the rack arrangement requested by the laboratory has been turned over to Standard Oil Engineering for detailing. A small start has been made toward laying out basic equipment on the control console. Fabrication of rack units is progressing with over 50 percent of the double racks delivered to the stores department for storage in Livermore. The console design was finished and delivered to the mechanical shops for fabrication.

Monitor Room for Oscillators. The preliminary flow diagram for the oscillator monitoring was completed and work is progressing on the units. A preliminary floor plan of the area was presented to Berkeley and to CRD for comments. Access to and from the area has been discussed with CRD and Rogers Engineering.

The general progress of the control system over the past three months has seen more general work turned over to CRD for their detailed handling. Rogers Engineering is handling several detailed jobs for them. UCRL has been overseeing the method and philosophy of controls with S.O.E., Rogers, and CRD. Preliminary control outlines have been turned over to CRD, Berkeley on the Program Bias System. Systems for P.S. 2,3,4, and the detailed work on the final prints for the oscillator controls and interlocks. The past three months has seen a large amount of indoctrination of outside personnel into the UCRL methods and reasons for wiring systems.

Standard Panels and Components. The orders for general standard panels and components was given to the mechanical and electrical shops during the past period. Work is progressing on these units with partial delivery on a few items to date. Special equipment will be required which is not on order or even designed as of now.

9. Mark I Ion Source Electrical Equipment

H. N. Owren

Introduction. The electrical equipment needed for the operation of the ion source consists of a group of power supplies, controls, and metering devices.

This equipment is in the process of construction or procurement, and is to be installed in Building 51. The majority of the power supply equipment will be located in a building which is to be constructed adjacent to Building 51 opposite bay 16. (Cooling tower area.)

Fig. 1 is a block diagram of the power supplies and their relative circuit locations.

100 kv dc Power Supply

Input: 2400 volts 60 cycle 3 phase

Output: Volts dc - 0-100 kv - adjustable
Amps dc (average) - 3.5
Amps dc (max peak) - 5.0
Min. pulse width - 4 x 10^{-3} secs
Max. pulse width - 50 x 10^{-3} secs or continuous
Repetition rate (max.) - 15 pps.

Fig. 2 is a block diagram of the 100 kv supply. The pulsing of this supply is accomplished by switching the 3 phase primary on and off with an ignitron contactor. This primary switching introduces some problems as the transformer inrush current may be many times the normal full load current. By proper phasing and timing of the "on pulse" this inrush current can be reduced to a safe value. This supply was modeled using thyratrons and a 240 volt 3 phase supply circuit. Because the exact impedance characteristics of the power supply components are not known, no attempt was made to scale the model. It was used, however, to verify our analysis of the circuits. The model illustrated that the inrush could be as much as 50 times normal current if proper precautions were not taken. As was expected, we found that if each successive pulse was started at the same relative phase position as the previous pulse stopped there was no excessive inrush current. It was also found that if approximately 5 percent of normal exitation was left on the transformer primary by shunting the switch tubes with resistors, the inrush was reduced to normal current. The model also illustrated that if the pulse was turned on at essentially the normal current zero point the inrush was not excessive. It is this latter method of timing that will be used as it requires only that the pulse gate be phased properly with the line supply. It is possible that the full scale supply will have characteristics which will prove this method to be inadequate. If this is the case, the first method can be used with only a modification of the pulse timing circuits.

As it will be noted from Fig. 1, the source and most of the supplies have one side electrically common to the 100 kv supply. These supplies are mounted in cabinets with smooth exteriors so as to be free from corona. The cabinets will be set on insulators and the cabinets and supplies will be at the high voltage accelerator potential. This requires some method of supplying power for the other units which may be at 100 kv potential with respect to ground. Special insulating transformers have been ordered which are designed to withstand the 100 kv pulses. Because of the nature of the source and its tank sparking, the class of insulation specified for these insulating transformers is higher than one would normally use for 100 kv dc. The transformers are being designed to withstand 275 kv rms 60 cycle for one minute. All transformers are to be tested at 250 kv rms 60 cycle for one minute before delivery. These transformers are oil insulated and are double shielded. The high voltage shield will be connected to the 100 kv potential.

Arc Supply

Input:	480 v 60 cycle 3 phase
Output:	0 - 600 volts dc
	100 amps dc
	continuous or pulsed. The pulse conditions are the same as the 100 kv supply except as noted below.

The arc supply is an ignitron rectifier (six phase, delta, double way circuit). This supply is also pulsed and model tests indicate that the minimum pulse length is approx. 2×10^{-3} sec. This supply is rated for continuous operation. Model testing of this circuit did not indicate that the on pulse would have to be timed with respect to the supply power voltage. This will allow the arc pulse to be turned on at any desired time. The controls and general construction of the unit are the same as that for the ignitron contactor.

Filament Supply and Magnet Supply. The filament supply (12 volts dc at 1000 amps out) and magnet supply (60 volts dc at 600 amps out) are dry disk type rectifiers of convential design. These supplies are mounted in corona free cabinets and will be at the 100 kv potential. The input will be 480 volt 3 phase 60 cycle.

30 kv Supply. This supply is a six phase, double wye rectifier of conventional design. It is rated 0.2 amps dc output continuous. This unit is also mounted in a corona free cabinet and sets on insulators.

Heater power for the palladium leak and other miscellaneous supplies needed at the high voltage level are provided in a like manner.

Controls. The power supply controls and metering are done on the line side at ground potential. This allows conventional Radiation Laboratory practice in control circuits and metering.

The trigger system consists of a circuit which supplies pulses scaled from the 60 cycle line. This trigger circuit provides signals for the scope sweeps etc. as well as the signal for the gate pulse circuits. When this system is used with the Mark I accelerator the initiating pulse will come from the pre-pulse put out by the main oscillator plate power supply (P.S. No.1). The gate pulse circuits gate the trigger signals for the ignitron contactor and the arc supply rectifier. This gate circuit has a built in delay to allow scope sweeps to start before the power pulses and to time the power pulses of the arc and high voltage supplies.

A circuit is provided for tuning off the trigger circuit in case of over load on the dc side of the 100 kv supply. This circuit uses a push button reset. No automatic reset is provided at this time but may be added at a later date.

Telemetering. Some of the signals which need to be monitored are at the 100 kv potential.

Means of bringing this signal down to ground potential will be provided. One method under development and which has completed preliminary testing consists of a carrier frequency of approx. 500 kc which is frequency modulated by the signal being monitored. This signal is picked up at ground potential by a shielded loop which is inductively coupled to a like loop at the transmitter. Tests indicate that sufficient signal is transmitted with the loops separated by three feet of air space. The frequency response of this system will be in the order of dc to 10,000 cps with an overall accuracy of approx. 2 percent. Other methods of telemetering signals are also being investigated.

Present Status of Ion Source Equipment.

Building 16

Cathode Investigation - Electrical equipment for the cathode investigation program was installed. New monitoring circuits with recording instruments have been recently installed.

Low Voltage Ion Source - A new supply to give 30 kv acceleration instead of 15 kv was installed.

D.c. Ion Source - This equipment has been operating with only some changes in the beam monitoring equipment. A one ohm pulse line is being constructed to supply a lower impedance source for the arc.

Building 51

1. The building to house power supply components is scheduled to be completed in December, 1950.

2. The enclosure in Building 51 - "C" area is approx. 75 percent complete.

3. The racks were installed in the control room and wiring started.

4. The design and drafting of the UCRL built equipment was completed.

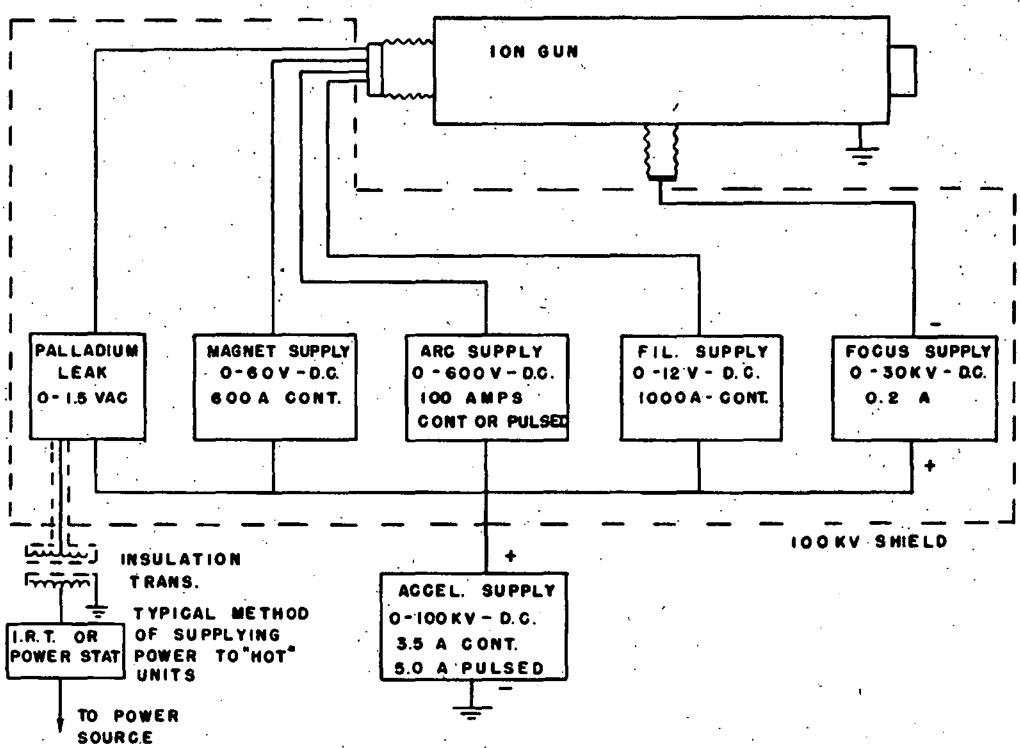
About 60 percent of this equipment will be constructed in December and the remainder scheduled for January, 1951.

5. Approximatley 75 percent of the electronic control chassis were constructed with the remainder scheduled for completion in December, 1950.

6. No High Voltage insulating transformers have been delivered. The manufacture of these transformers has completed the transformers except for bushings. These units are scheduled for delivery in December, 1950.

7. The 100 kv supply is scheduled for delivery the first part of December, 1950.

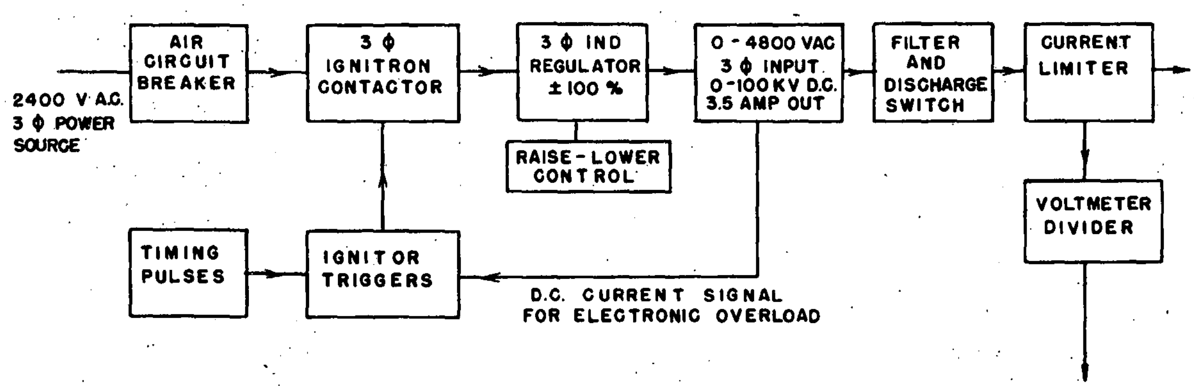
8. Approximately 90 percent of the material needed for UCRL built equipment and installation has been received.



MAJOR POWER SUPPLY COMPONENTS FOR MARK I ION SOURCE

FIG. 1

MU 1407



BLOCK DIAGRAM OF MARK I INJECTOR 100 K V D.C. SUPPLY
MAJOR COMPONENTS ONLY

FIG. 2

MU 1415

10. Ion Injector Development

E. J. Lofgren

Introduction. This report covers the ion injector development to about the middle of December and is a continuation of Section 6, UCRL-1009.* To avoid repetition it will be assumed that that report is available to the reader and a general statement of the injector problem will be omitted. No further work has been done on the Calutron Type Source. Most of the work has been done with the magnetically collimated, high voltage linear type source, generally called the high voltage source. It is depicted in Fig. 3, reference A. It has been run in two modes, i.e., with and without focusing potentials as will be described below. A subsidiary investigation of cathodes has been carried out, and a preliminary investigation has been made of another injection system characterized by repeated acceleration of the ions through grids with a few kilovolts across them.

It was once hoped that the first model of the plant injector would now be under test. Actually, it cannot now be completed before February. The governing delays have been procurement and design of electrical equipment. In view of this delay a description of the unit will be deferred to the next quarterly report.

High Voltage Source.

Modes of Operation. As originally operated, the ions are focused after extraction from the source by a deceleration and subsequent acceleration in electrodes E_2 and E_3. This scheme lends itself nicely to radiofrequency modulation as described in A. However, without modulation a simpler mode of operation becomes possible. An arc drift space at arch chamber potential (ground) is provided in the diverging field outside the magnet, then there is a single acceleration to the required high voltage. This is provided by simply grounding electrodes E_1 and E_2, (see Fig. 3, reference A) and applying a negative voltage to E_3 only. The arc plasma protrudes through the arc aperture, diverging with the magnetic field to the equipotential boundary at which the plasma electrons are turned back. This surface will be inside E_2 and concave towards E_3 and ions drawn from it will tend towards a focus at the collector. Adjustment of the plasma boundary, hence the focus, is made by adjusting the arc density and the magnetic field. Beams have been about three times larger with the drifting arc mode than with focusing lenses.

Beam Measurement and Magnitude. A new collector cup has been put into service. It is a deep shielded cup, the base of which is a copper plate with a thermocouple and calibrating heaters imbedded, allowing simultaneous measurements of the current to the cup and the temperature of the plate. The structure is shown in Fig. 1. The temperature can be related to energy dissipated in the collector by means of the calibrating heaters. From that data, the final accelerating voltage and the duty cycle the beam current can be computed. As usual a transverse magnetic field of about 200 gauss is provided to suppress secondary electrons and provision is made to bias the inner cup ± 500 volts with respect to the outer shield. All beam measurements are made with +500 volts on the cup unless otherwise stated. The bias effect, which is the increase

* This will be known as reference A.

in apparent beam as the bias is changed from + 500 volts to - 500 volts divided by the beam measured at + 500 volts bias is about 40 - 50 percent with this cup. If no magnetic field is used the effect is 300 - 400 percent.

Additional experiments have been carried out with a beam transformer, that is a permalloy core about 6 inches in diameter through which the beam travels and a secondary winding. The induced e.m.f. in the latter is integrated by a resistor to give the current. It has not been possible to get agreement with the directly measured beam. In general the induction measurements are high by 30 percent to 100 percent and depend upon the relative location of the transformer and collector cup. The disagreement is certainly due to secondaries and even if not corrected the transformer would still be a useful relative measure of the beam into the linear accelerator.

In operation with focusing potentials the largest beam obtained at 20 inches from the source magnet has been 1.0 ampere peak with approximately 1/1000 duty cycle. The operating conditions which are typical for high level performance are given in column 1 of Table 1. Using the new collector there is good agreement between the electrical measurement of current and the beam as calculated from the heating of the back of the cup although simultaneous electrical and thermal measurements in the first mode of operation were not carried out with a 1 ampere beam. In one case 650 ma and 670 ma were the electrical and thermal measurements respectively. The agreement to better than 10 percent is fortuitous.

In the second or drifting arc mode of operation the highest measured beam at 20 inches has been 3.0 amperes. In this case a thermal measurement was also made and indicated a current of 2.8 amperes. The chief operating variables are listed in column 2 of Table 1.

It should be remembered that all this work is done at a 1/1000 duty cycle and that these currents are total hydrogen ions. No further work has been done on analysis but from the experiments described in reference A and from other experience we believe the beam to be from 70 to 90 percent protons. There may also be a reduction to about $1/\sqrt{2}$ when deuterium is used due to the greater space charge. On the other hand when higher voltage is available a large increase in beam is expected since the beam varies approximately linearly with voltage in the range of operation at a rate of 600 to 800 ma per 10 kilovolts. At full duty cycle the beam will not be limited by available current but by the cooling and sputtering of the component parts of the injector.

<u>Beam Focus</u>. The new collector cup has an opening 4 inches by 4 inches and shutters which can be used to reduce this area any desired amount. This is shown in Fig. 1. The distance of the collector from the source magnet, distance D in Fig. 3, reference A, can be varied from 16 to 36 inches. These functions permit an investigation of the quality of the focus.

At a given distance D the focus can be determined by measuring the beam as a function of cup area. Typical data are plotted in Fig. 2, in which both curves A and C were taken with drifting arc operation under essentially the same condition except that in A the beam is 1200 ma and in C it is 2900 ma,

TABLE I

	1	2
Tank Pressure using hydrogen calibration of gage	5.8 x 10^{-5} mm	16.7 x 10^{-5} mm
Arc cathode	1-1/4" diameter Phillips	3 turn spiral of .125" dia.wolfram
Arc potential	325 volts	75 volts
Arc chamber pressure	3.5 microns of hydrogen	21 microns of hydrogen
Arc current	55	150 amperes
E_1 potential	80 kilovolts	0
E_2 potential	25 kilovolts	0
E_3 potential	60 kilovolts	52 kilovolts
Source magnetic field at the arc aperture	2000 gauss	1200 gauss
Beam at 20 inches from source magnet	1.0 ampere	3.0 amperes
Ratio: Total current / Beam current	Best values usually 3 - 4	3-1/3

and curve B is older data taken with the use of focusing potentials, E_1 and E_2. We see that both systems of focus are comparable and that 90 percent of the beam falls into an area corresponding to that of a hole about 3 inches in diameter.

We have adopted 20 inches as the standard distance from the source magnet to the collector opening because that is about the minimum distance at which it is physically possible to place a source of this kind from the center of the first accelerating gap. The variation of the beam with this distance is given in Fig. 3. Curve B is typical of operation with a drifting arc. Curve A represents a special circumstance in which an arc drift space of 3-1/2 inches was provided followed by electrodes E_1 at 76 kilovolts, E_2 at 30 kilovolts and E_3 at 60 kilovolts. This may be a promising system to investigate further since it gives the best beam vs. distance characteristic but the current is only one-half that of drifting arc alone.

Electrode Geometry. There have been no important changes in optimum arrangement of electrodes in the first mode of operation since the last report. In the drifting arc mode of operation the first runs were made by simply grounding E_1 and E_2. There have been variations since then resulting in the present simple geometry, (see Fig. 4) which has given 3.0 amperes. It seems to make no difference whether the drift space is closed or has openings to reduce the gas pressure. The accelerating gap also is not sensitive to changes as long as it is not so small so as to cause sparking. As the drift space, b in Fig. 4, is varied there is a flat optimum at 8 to 11 inches. If it is reduced to 4 inches the beam is only 1/3. This space is required to permit the arc plasma to blow up to the full electrode diameter.

The arc aperture has consisted of 48 holes each 0.120 inches in diameter in an annular array of 3/8 inch inside and 1-1/4 inch outside diameter. In this period enough work has not been done to say that it represents a real optimum, however there is no increase in beam if an additional ring of holes is added and there is a reduction of beam to 20 percent if a single 1/2 inch diameter hole is substituted.

A grid is necessary at the high voltage side of the accelerating gap, to cut out the defocusing half of the electrostatic lens. Without the grid the beam is only 250 ma. The grid wires are usually 0.020 inch tantalum wires or 1/16 by 0.010 inch ribbons spaced 1/4 inch apart. Any increase of spacing reduces the beam. Some experiments were made with curved grids. While not wholly conclusive it seemed that the beam could not be increased nor could the focus be improved at 20 inches, but with a grid convex towards the source the focus could be brought closer to the source.

It may be necessary to inject ions at an angle to the axis of the linear accelerator so that back bombarding ions can be kept out of the source. To investigate this possibility the accelerating electrodes were cut so that the gap made an angle of 12 degrees with the axis. The beam dutifully deflected by the same angle without great distortion of the focus.

Arc Cathode Development

General Program. Most of the development of the ion injector up to September, 1950, as mentioned in reference A, was conducted using directly heated tantalum cathodes. Typical of such cathodes was a flat spiral of 3/16 in. tantalum rod. This cathode, when operated at the temperatures required to sustain the arc, i.e., T 2300°C, was quite weak and easily distorted in the strong magnetic field. In addition, the rapid embrittlement of these filaments, due to the formation of tantalum hydrige, further reduced their life. The surface erosion of the emitter operating under bombardment by high energy negative ions and electrons at these temperatures is not negligible. Accordingly, an investigation has been undertaken to seek other cathodes which, when operating in the arc, have properties such that they will:

1. Emit uniformly from a continuous surface of tens of square centimeters to give effective illumination of arc apertures.
2. Yield high specific emission.
3. Continue to give effective service when the duty cycle is scaled by a factor of 200 (that is, from 1 pps at 10^{-3} to 8 pps at 25×10^{-3} sec.).
4. Render good service without suffering deleterious effects from periodic cycling from operating to atmospheric pressures.
5. Have emission efficiencies sufficiently high that the power input necessary to obtain the required emission does not cause undue heat dissipation in the injector.
6. Have activation periods in terms of minutes rather than hours.
7. Operate at temperatures such that their properties are not adversely affected when the emitting surface is bombarded by high energy negative ions and electrons.

These requirements are recognized to include the best features of the present day emitting surfaces.

To expedite the testing and development of arc cathodes, unhampered by concurrent development of ion sources, a portable vacuum system was designed and built. Measurements of the physical properties of the cathodes have been made, both pulsed and dc arc operation.

In pulsed service the cathodes have been operated under conditions of magnetic field and arc voltage such that the maximum arc current is drawn for a given cathode temperature and minimum gas pressure. In dc operation power supply limitations and anode dissipation set an upper limit on the amount of current that may be drawn by the arc. In the measurements to date, 25 amps and 40 volts are approximate test conditions. Any greater power to the anode results in rapid deterioration of the exit grid. Shortly, it will be possible to utilize a larger arc chamber and these dissipation limits will be considerably relaxed.

The investigations undertaken thus far might best be classified under cathode types. They include the following: metallic emitters, diffusion emitters, coated emitters, and compressed mixture emitters.

Metallic Emitters. The choice of metallic emitters is restricted to the refractory metals, wolfram, tantalum, molybdenum, and columbium. Of these four metals, only the first two are worthy of note. The high work function (4.2 volts) rarity and low melting point of columbium (2500°C) eliminate this metal from further investigation. The higher work function of molybdenum (4.3 volts) and the low melting point (2620°C) have postponed its immediate investigation. When hot, molybdenum is softer and more ductile than wolfram and may be structurally weak when operated at the temperatures required to get reasonable emission densities.

Tantalum. Tantalum filamentary cathodes have been used in the early development of the ion source. The melting point of tantalum (2996°C) and its lower work function 4.1 volts couples with its workability make it seem a natural choice for an emitter. When operated at the temperatures required to give the desired emission densities, tantalum is soft and easily shorts in configurations used to approximate large surface areas. The operation of tantalum in an atmosphere of hydrogen results in the absorption of large quantities of gas with the resultant formation of the brittle hydride. The surface erosion of tantalum at operating temperatures due to high energy ion back bombardment is of importance. It was the unsatisfactory performance of this emitter which led to these studies.

Wolfram. Having the highest melting point of the refractory metals (3370°C), wolfram, in spite of its high work function (4.52 volts), may be operated at temperatures such that its emission is sufficient. Even in hydrogen arcs the emission efficiency of wolfram is quite low. Where emission must come from large areas, the amount of power required can become several kilowatts. In addition, the major portion of the power input to the filament must be dissipated in the arc chamber. From the standpoint of insensitivity to emission poisoning, the wolfram filament is ideal. In experimental work it is frequently necessary to return to atmospheric pressure to make changes in the system. Most cathodes require reactivation after such treatment. The reactivation of wolfram filaments is slight.

Lanthanum Boride. Recently, Lafferty[1] of the General Electric Company, announced a new cathode of lanthanum boride. Because it obeys Richardson's equation it has been called a metallic emitter. Two of these cathodes have been tried in the ion sources. Other than outgassing, these cathodes require no activation time. They operate at temperatures between 1400 and 1600°C and have a work function of 2.66 volts.

The first cathode tested consisted of a layer of LaB_6 compacted to a surface of tantalum which has been prepared with a grid of 0.010 tantalum wires. It was 1-1/16 inches in diameter and heated by radiation. It was run under pulsed conditions for 4 hours in the 80 kv ion source at 14 microns of hydrogen and about 25 amp. arc current. The surface of the boride cathodes was found quite sensitive to bombardment by high energy ions. After the short test, inspection revealed that about half of the material had been sputtered away.

It is known that the boride materials are unstable when operated in contact with tantalum. The boron atoms diffuse into the metal lattice of of tantalum forming an alloy. This leaves the lanthanum free to evaporate. The hexaboride cathodes may be operated in a carbon base. Accordingly, a graphite holder was designed and compacted with LaB_6.

The cathode shown in Fig. 5 was designed for use with the lanthanum boride material compacted and sintered in a graphite holder. This cathode was run under pulsed conditions in the 80 kv unit for 2-1/2 hours and removed for inspection. The surface of the cathode was badly pitted and shrinkage had caused the boride annulus to break at several points. Approximately 25 percent of the LaB_6 had been sputtered away. The material remaining in the holder was LaB_6. There had been no breakdown of the compound as in the case of the tantalum backing. Although some experiments utilizing the diffusion properties of LaB_6 are planned, the general opinion is that these cathodes are not satisfactory for this application.

Diffusion Emitters. By far, the greatest success with developments to date has been with cathodes employing the diffusion principle. Diffusion emitters operating on the principle of diffusion of metallic oxides through porous media were described by Lemmens, Jansen and Loosjes.[2] Their cathode is similar to the usual oxide cathode except that the material is made to diffuse to the surface of a sintered wolfram button. These cathodes, containing a 1:1 mixture of $BaCO_3$ and $SrCO_3$ (by weight), are reported to give currents of some hundreds of amperes per square centimeter of surface when operated at temperatures of 1350°C and to have lives in terms of tens of hours. Using this lead, cathodes have been under development for possible use in the ion source.

Barium-Strontium Oxide Cathodes. A typical cathode 1-1/4 inches in diameter is shown in Fig. 6. Test cathodes operated in the 80 kv ion source gave plentiful emission and although the surface of the cathode was pitted by the high energy ions there was no noticeable deterioration in emission. Some cathodes, when run near the end of their life, gave hundreds of amperes of emission current from localized points. These points were visible on the surface of the cathode when removed for inspection. When these cathodes were recharged and returned to the source, they were found to be unaffected by this heavy sparking.

These cathodes are sensitive to oxygen poisoning. One cathode of the 1-1/4 inch size operated for 56 hours and was cycled to atmospheric pressure 8 times. Though each poisoning requires high temperature flashing for reactivation and though there is some doubt that the termionic properties recover completely, these cathodes can be returned to emitting condition in 15-20 minutes. Larger cathodes have been found to be more sensitive to frequent poisoning but have lasted as long as 21 hours.

Arc currents of 375-400 amperes have been drawn from the larger cathodes. This represents currents of the order of 20 amperes per square centimeter at temperatures of 1300 to 1400°C_B. Although this represents data from pulsed operation, there seems good reason to believe that this will be the same under dc operation.

When operated under continuous vacuum, these cathodes have furnished substantial currents for tens of hours at 1400°C_B. For example, a 7/8 in.

cathode gave 25 amperes emission in excess of 25 hours. The weight of mixed carbonates in the emitter was only 0.83 grams.

These cathodes have given uniform emission over continuous areas of the order of 20 square centimeters. There is little reason to doubt that they can be scaled to larger areas directly. Temperature measurements over the surface of the cathodes has shown them to have essentially no temperature gradient. The few degrees variation observed are probably as important from the standpoint of oxide diffusion as from the emission density due to temperature in the Richardson-Dushman equation.

The early success with small cathodes prompted the design and construction of larger cathodes. A typical example appears in Fig. 7. The first cathodes constructed to work in this holder failed mechanically due to warping. Opening of the gas-tight seal allows the oxides to evaporate at a very rapid rate. Other cathodes were designed to reduce the barium loss and have had varying degrees of success. These are the "waffle" and "Swiss cheese" forms. The names appended refer to the configuration used for oxide storage.

Other Diffusion Emitters. Emitters using the basic structure of the BaSrO cathodes have been tested. At present, the emitting properties of the BaSrO cathode have been equaled. It is desirable to reduce the evaporation rate of the material while keeping the emitting properties.

When the sintered wolfram disc is filled with BaO instead of the mixed carbonates, the outgassing time is reduced. Almost as soon as the water vapor is driven off the cathode is ready to operate. Because of the high vapor pressure of the oxide, this cathode must be operated at lower temperatures.

Yttrium oxide and cerium oxide have been tried in the sintered wolfram button. Yttrium will not diffuse sufficiently to operate in the desired fashion. Though the data on ceric oxide are not conclusive, it is probable that the diffusion rate is so low at the desired operating temperatures that it will not yield a satisfactory cathode.

Coated Emitters. In the investigation of other emitting surfaces, it was convenient to employ a coating of the emitting material on the surface of a filament. The filament was either tantalum or wolfram strip 1/16 x 5/16 inches bent in a U shape. These filaments present an emitting area of approximately 2-1/4 cm^2. The measurements on these cathodes are just beginning.

Mixed Wolfram and Thoria. Though some difficulty was experienced in getting a tenacious coating, these cathodes have given current densities of the order of 10 amperes per square centimeter.

Mixed Thorium-Zirconium-Magnesium-Calcium Oxide. This cathode gave currents of the order of 15 amperes. After a few hours operation, the metals alloyed with the tantalum ribbon.

Other Coated Emitters. Cathodes of cerium, lanthanum and yttrium oxide as well as eutectic barium aluminate cathodes are now ready for test. No data are available on their operation at this time.

Compressed Mixture Emitters. Directly heated cathodes of compressed thoria and wolfram powders are in the process of development. These cathodes are of the general type announced by Pomerantz[3].

Other Developments. The use of a carbon button for diffusion cathodes presents an interesting possibility. Buttons of sintered titanium and zirconium are to be tried. The investigation of surfaces to yield high secondary emission from positive ion bombardment while acting as a primary source of hot cathode emission are to be tested. An impregnated cathode in which the oxide has been soaked into the sintered wolfram button is also awaiting test.

Low Voltage Ion Source

General Description. This ion source was suggested by Professor Lawrence. The general idea that was proposed is shown in Fig. 8, and the first experimental approximation is shown in Fig. 9. Using two tantalum accelerating grids (E_1,E_2) we have obtained a reliable total ion beam of one ampere at a total voltage of only 15 kv. With careful adjustment, the drain on the high voltage is twice the beam current. This beam, which is a bundle of 265 small beams, is measured by a collector cup placed one inch away from the grid assembly. When this total current collector cup is removed, the beam travels through the vacuum tank, and its divergence can be measured by a small collector cup which is located about 30 inches from the grids. This cup is moved at right angles to the beam axis and hence gives a plot of current density across the axis of the beam. (See Fig. 10.)

Experiments show that the total ion beam current increases linearly with the number of holes used in the grid assembly, that is as the area of the array of holes. (See Fig. 11.)

The total beam then would be limited only by the arc plasma area. A large plasma area might be obtained by an arc from a large area cathode, or as in the case of the drifting arc operation described in Section 2 A, the arc cross section might be blown up by running it in a divergent magnetic field. The best intensity at present $\sim$0.6 amp/sq. inch of grid area. The beam could be brought to a focus if the grids were curved as in Fig. 1, provided space charge neutralization is fairly complete beyond the last grid. No focusing experiments have been undertaken yet. Application of this source to the linear accelerator would also require provision for additional acceleration from 15 kv to 80 kv.

The arc source is pulsed on for 10^{-3} secs once a second. D.c. acceleration voltages are used, with the source at high voltage. The magnet is pulsed by periodic connection to a charge condensed bank and allowed to oscillate for one cycle ($\sim$ 30 cycles/sec.). The arc is then pulsed at the peak of the magnet cycle.

Attention was focused on possible changes that would give the best combination of beam width and total beam. In addition, the success of the method depends on whether the power absorbed by the accelerating grids in continuous operation is low enough to be radiated. For this reason the drain currents were measured.

Accelerating Voltage. The total beam current increases linearly with total accelerating voltage, for any particular division of this voltage on the grids. (Fig. 12.) (This is also observed with other sources using a first accelerator without grid.)

Magnetic Field Variation. The total ion beam current increases with magnetic field as shown in Fig. 13. The present explanation for this effect has yet to be fully tested. The general idea is that due to the magnetic field, positive ions in the plasma move in small circles. If we consider the plasma within the thick exit grid E_o, we see that positive ions formed with large orbital radii can not survive. Hence the number of positive ions that survive to reach the accelerating field is increased at higher magnetic field. The effect is, of course, perturbed by changes in the energy distribution, the plasma to wall potential and so on. Fig. 13 also shows the effect for two different hole diameters in E_o. The dotted curves represent a very rough theoretical approximation which assumes a Maxwellian distribution of positive ions in the main body of the discharge. The ions are assumed to be filtered out by small holes in the E_o grid by geometrical considerations.

The Best Voltage Ratio. For a given voltage drop across the first accelerating gap, we find it requires about the same voltage drop in the next gap to pull most of the ions through. (Fig. 14.) This is the case when the spacings of the grids are equal.

Effect of Grid Spacing. Larger spacing in the first gap produces a more parallel beam of ions, and hence less focusing is required in the second gap. But if we have a fixed total acceleration voltage, then for a high value of total ion current, we find that the larger first gap requires more voltage across it. We can make up for the low voltage that is left for the second gap by using a small spacing which means a stronger lens. The above discussion shows that there is a definite voltage distribution for each gap setting. We have found a good combination of values, but they are not very critical. For instance: first gap 0.060 inch, second gap 0.030 inch ± 0.010 inch, with 70 percent ± 10 percent of the total voltage across the first gap. So far no attempts have been made to use tapered holes in the grids.

Grid Currents. The net currents to the various grids result from incident positive and negative ions, and secondary electrons emitted. Since only the former cause heating we have to know their ratio before heat calculations can be made. The secondary ratio involved here is not known, but one may expect ratios greater than 2:1. Fig. 15 shows the way these currents change with voltage distribution. At present, consideration is being given to the possibility of measuring the grid temperatures directly, with and without pulsed beam.

The measurement of beam width involves measurement of a few milliamperes of current over a 10:1 range and some degree of linearity is required. At present we are attempting to determine the major factors which influence collector cup readings. Some preliminary measurements have been started on the effects of beam magnitude and energy, magnetic fields and cup geometry.

The injector group during the last three months has consisted of: Paul Byerly, Warren Chupp, Bruce Cork, Warren Eükel, Forrest Fairbrother, Reinald Finke, William Lamb, E. J. Lofgren, Robert Richter, Howard Smith, Warren Watson.

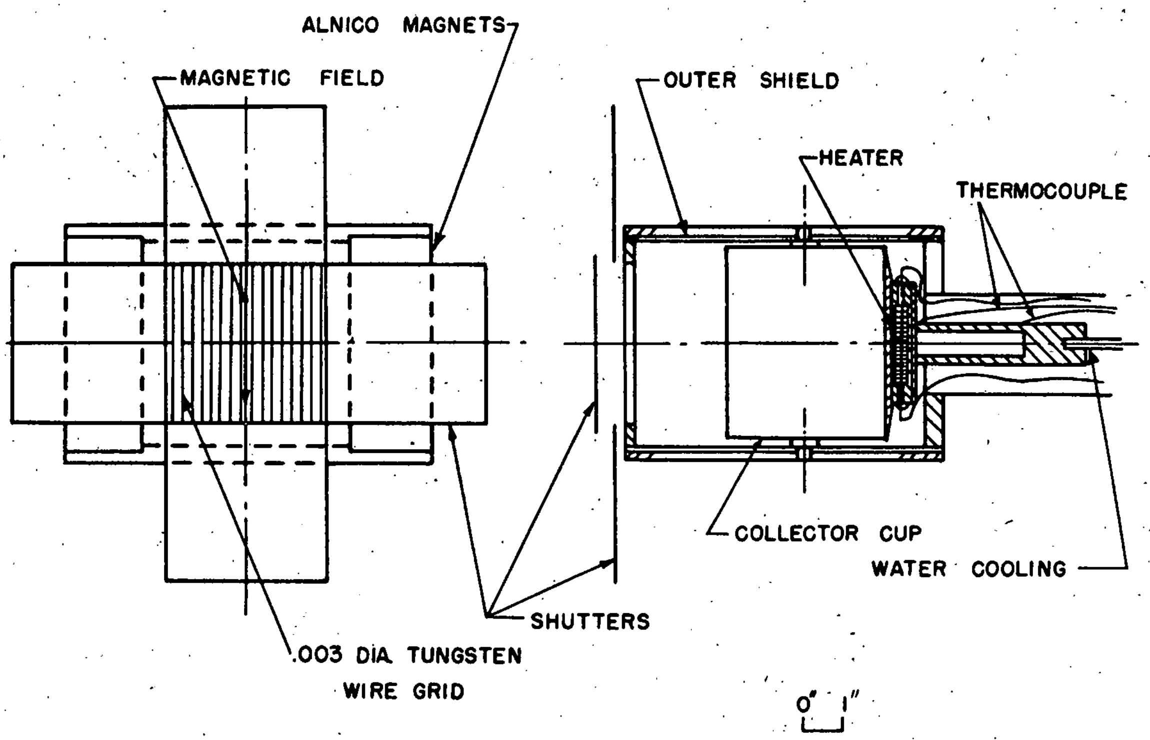
The investigation detailed in Section 4 was carried out by: John Foster, Frank Martina, Robert Teeters.

The developments described in Section 3 were in the hands of: Harry Heard, and John Woodyard.

The engineering has been done by: Clarence Harris, electrical; Robert Meuser, mechanical; and Harvey Owren, electrical.

References

[1]J. M. Lafferty, Phys. Rev. 79, 1012 (1950).
[2]H. J. Lemmens, M. J. Jansen and R. Loosjes, Phillips Tec. Rev. 11, 341 (1950).
[3]M. A. Pomerantz, NDRC 14-517.



COLLECTOR

FIG. 1

MU 1424

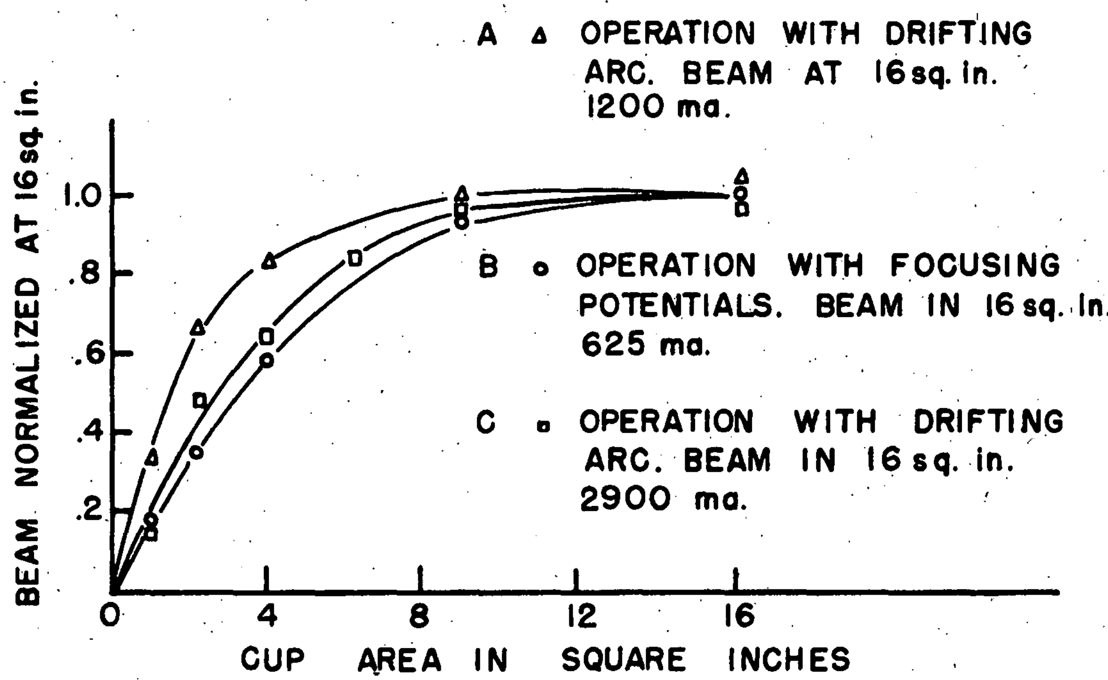


FIG. 2 TYPICAL CURVES, BEAM VS. COLLECTOR AREA AT 20 INCHES FROM SOURCE MAGNET.

MU 1426

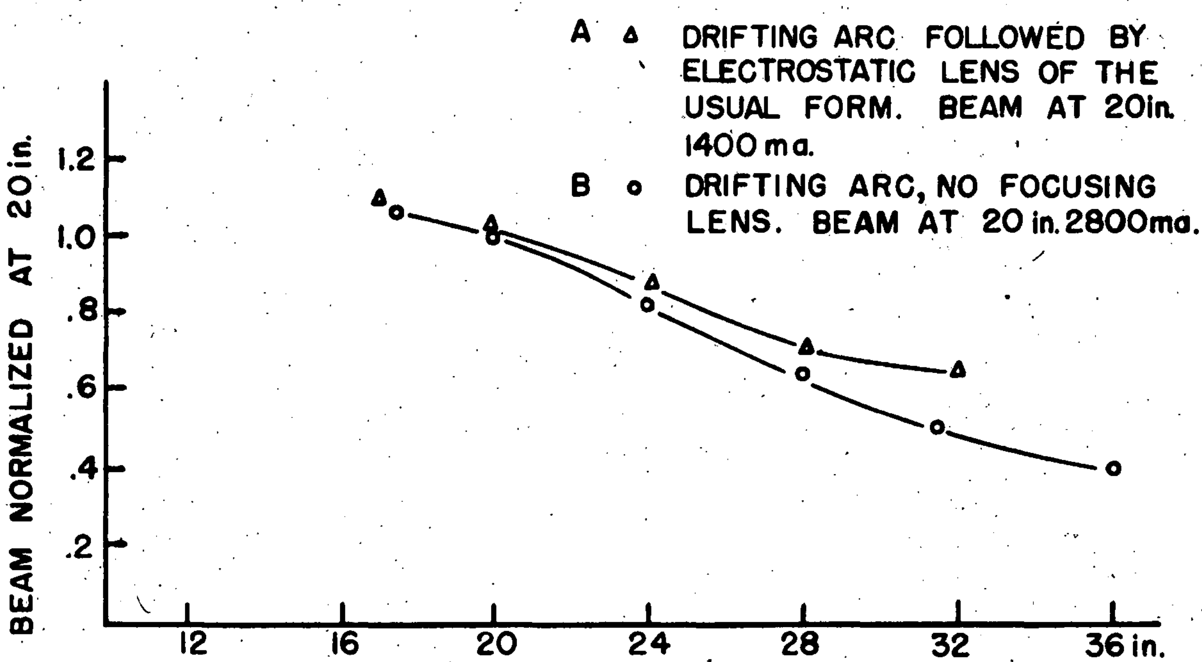


FIG. 3 RELATIVE BEAM IN 16 sq. in. COLLECTOR vs. DISTANCE FROM SOURCE MAGNET. DISTANCE D IN FIG. 3 REFERENCE A

MU 1425

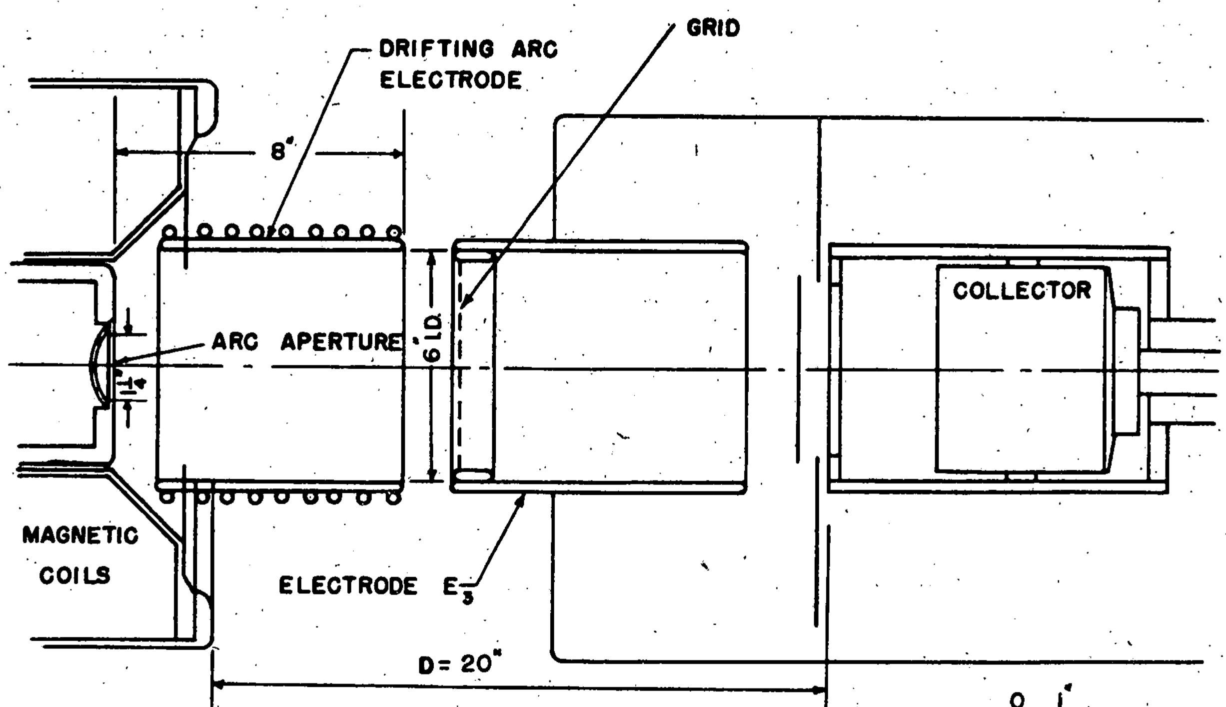


FIG. 4

DRIFTING ARC ACCELERATION

MU 1427

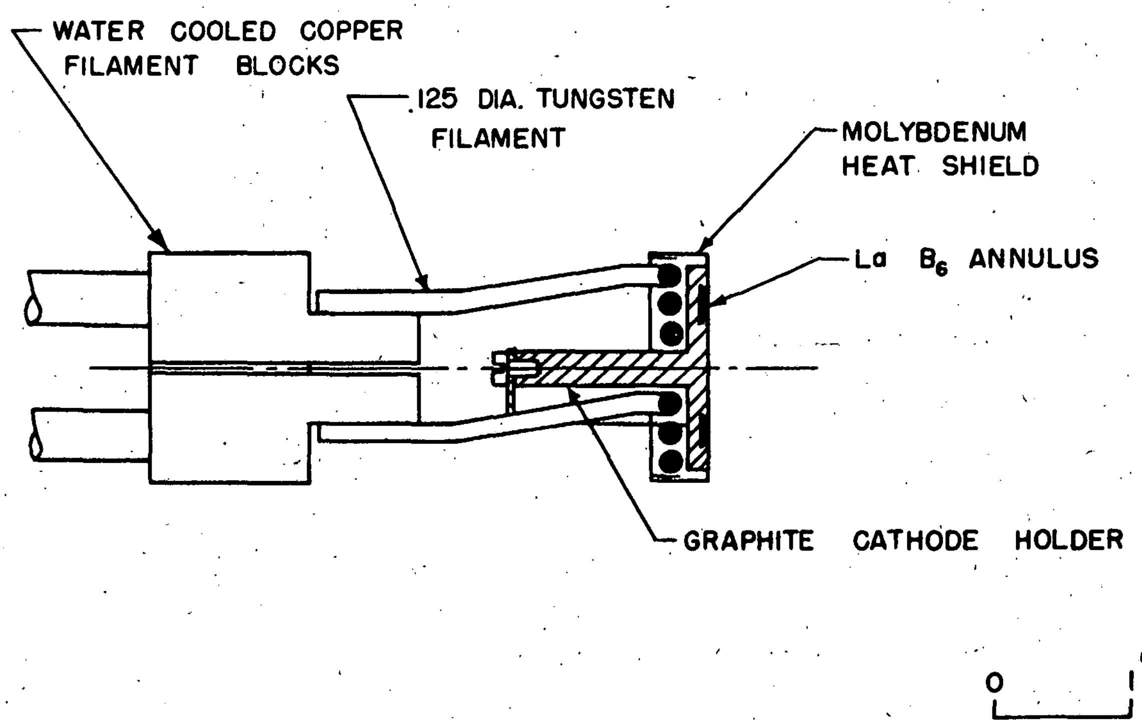


FIG. 5

LANTHANUM BORIDE CATHODE

MU 1428

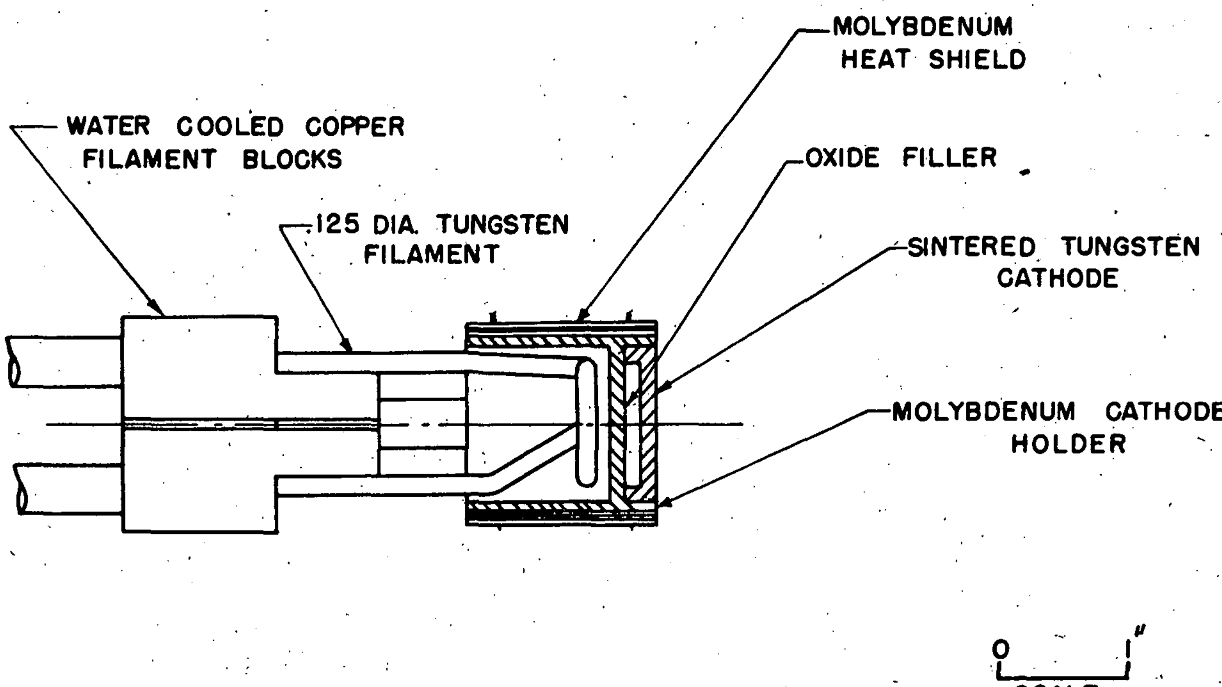


FIG. 6
SINTERED TUNGSTEN EMITTER

MU 1429

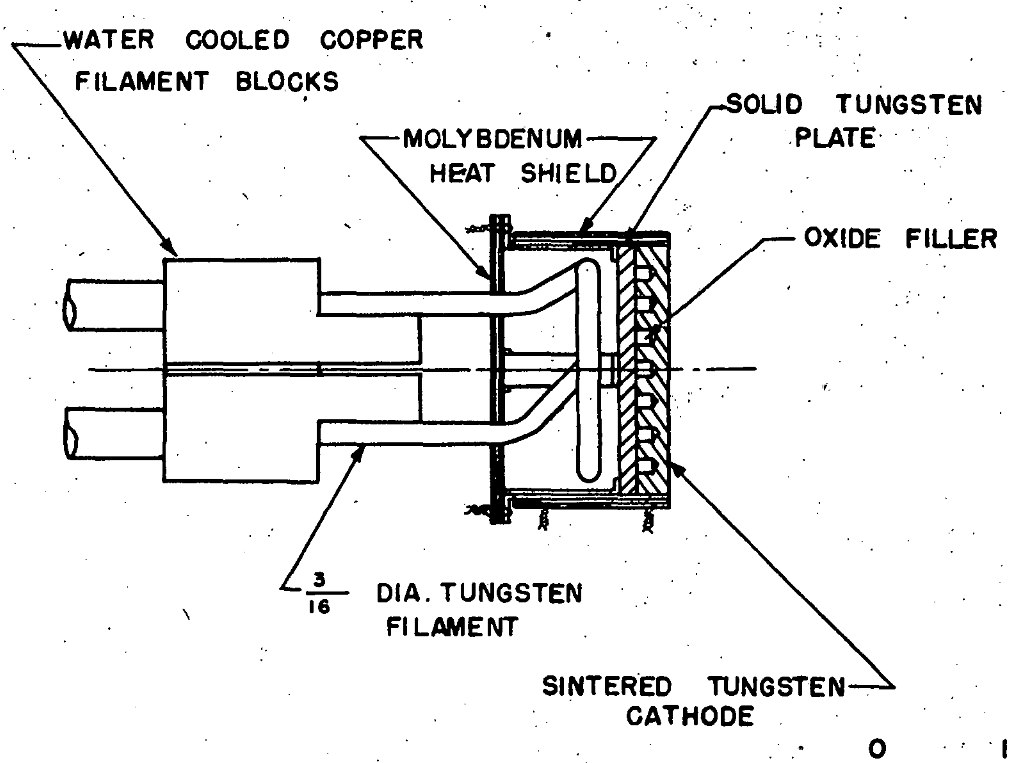


FIG. 7 SINTERED TUNGSTEN EMITTER

MU 1430

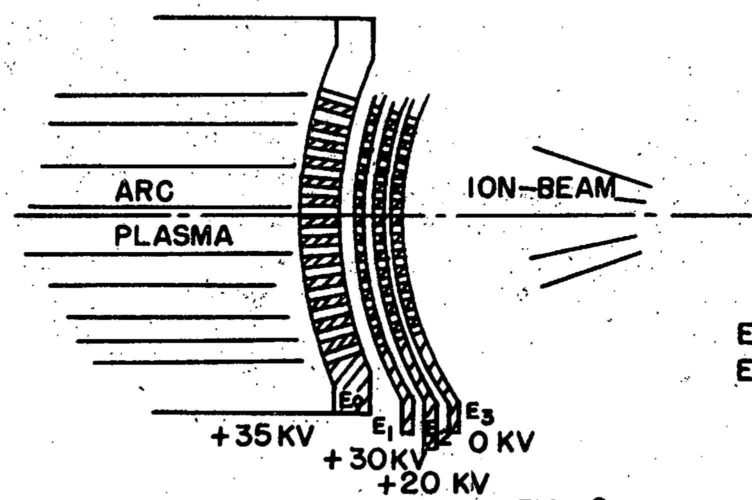

ARC
PLASMA
ION-BEAM
E0
E1
E2
E3
+35 KV
+30 KV
+20 KV
0 KV
E0 EXIT GRID
E1, E2, E3, ACCELERATING GRIDS

FIG. 8

MU 1431

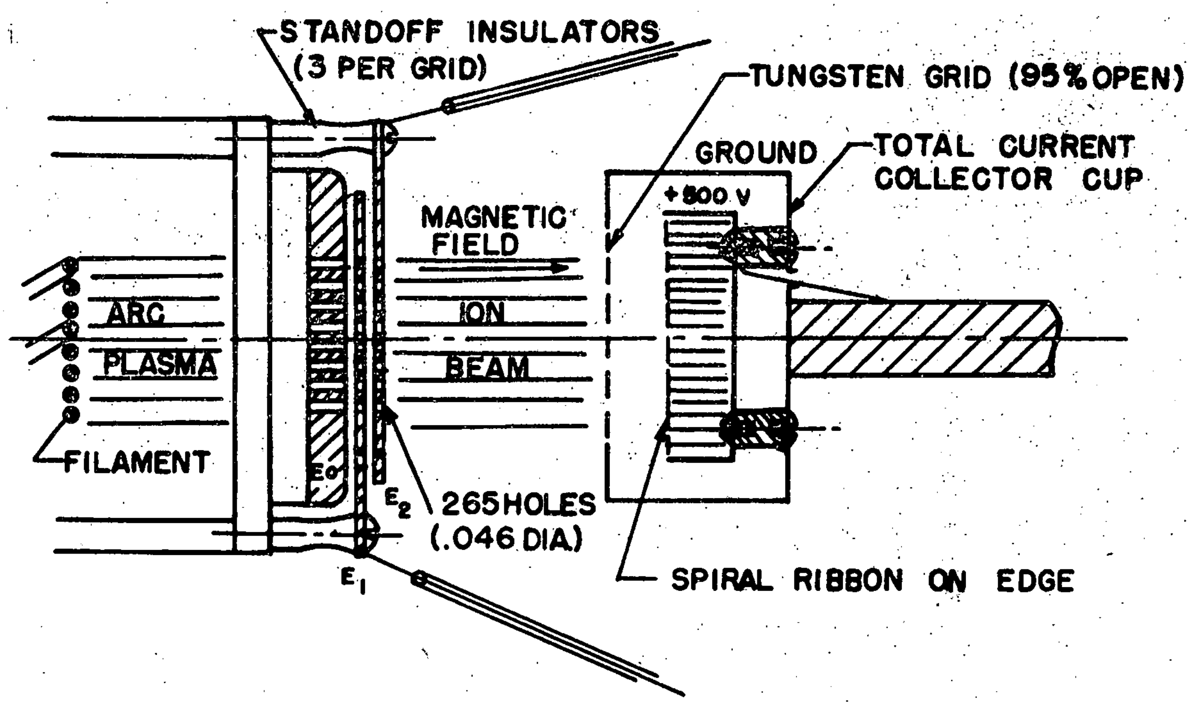

STANDOFF INSULATORS
(3 PER GRID)
TUNGSTEN GRID (95% OPEN)
GROUND
TOTAL CURRENT
COLLECTOR CUP
+800 V
MAGNETIC
FIELD
ARC
PLASMA
ION
BEAM
FILAMENT
E0
E2
E1
265 HOLES
(.046 DIA)
SPIRAL RIBBON ON EDGE

FIG. 9

MU 1432

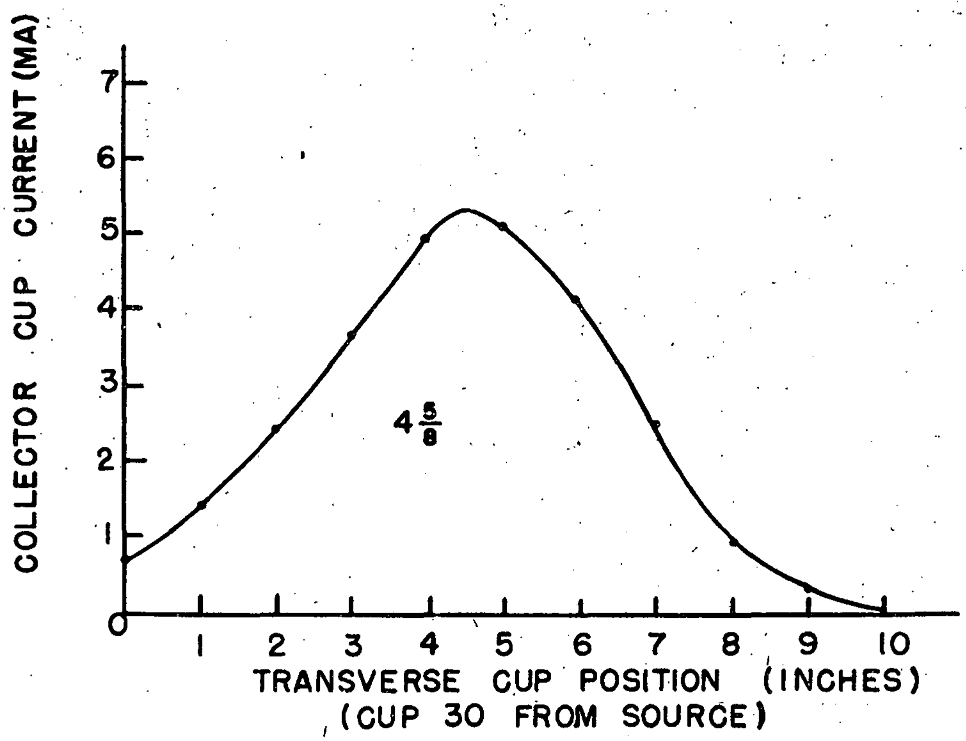


FIG. 10

MU 1433

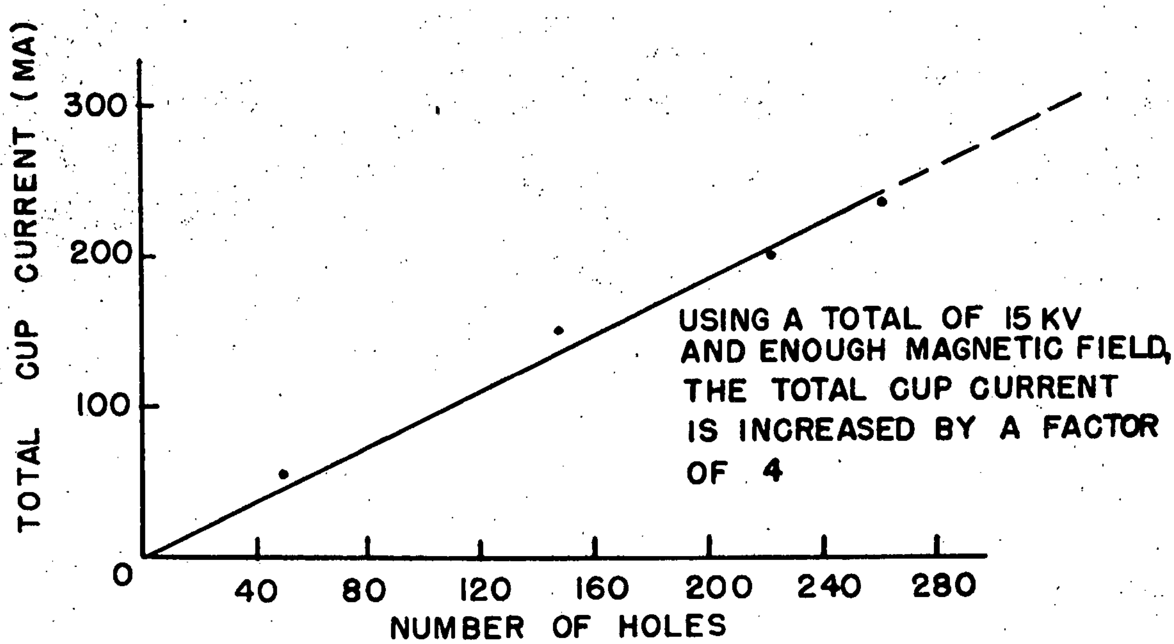


FIG. 11

MU 1434

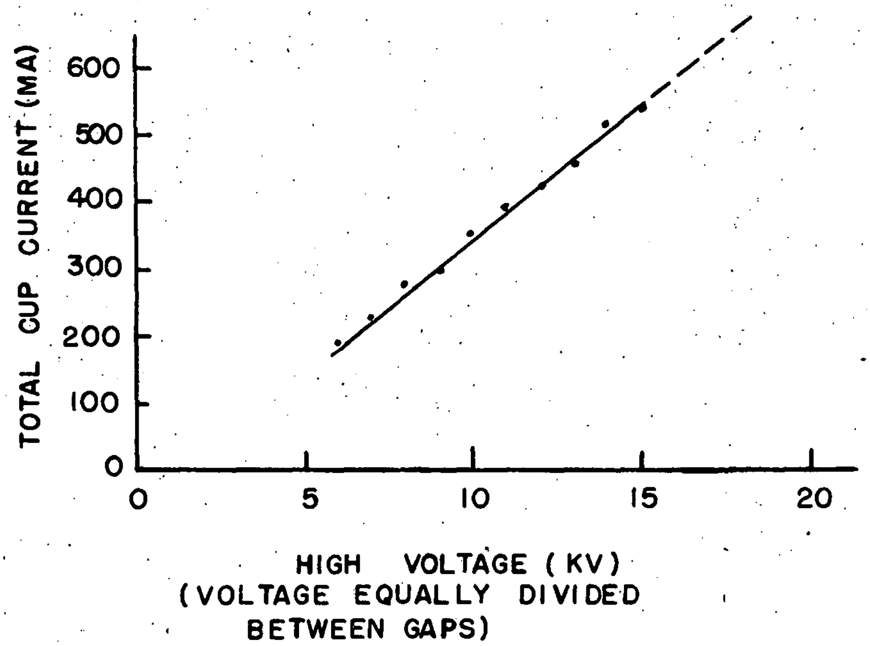


FIG. 12

MU 1435

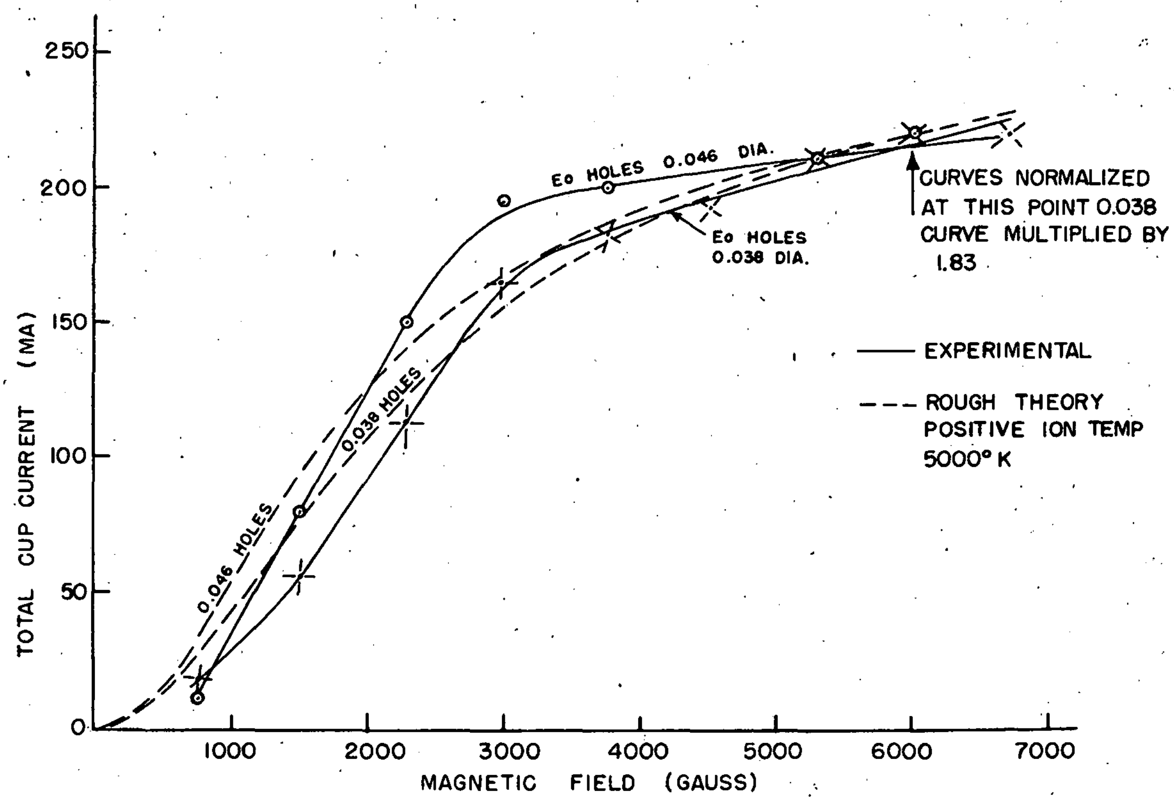


FIG. 13

MU 1436

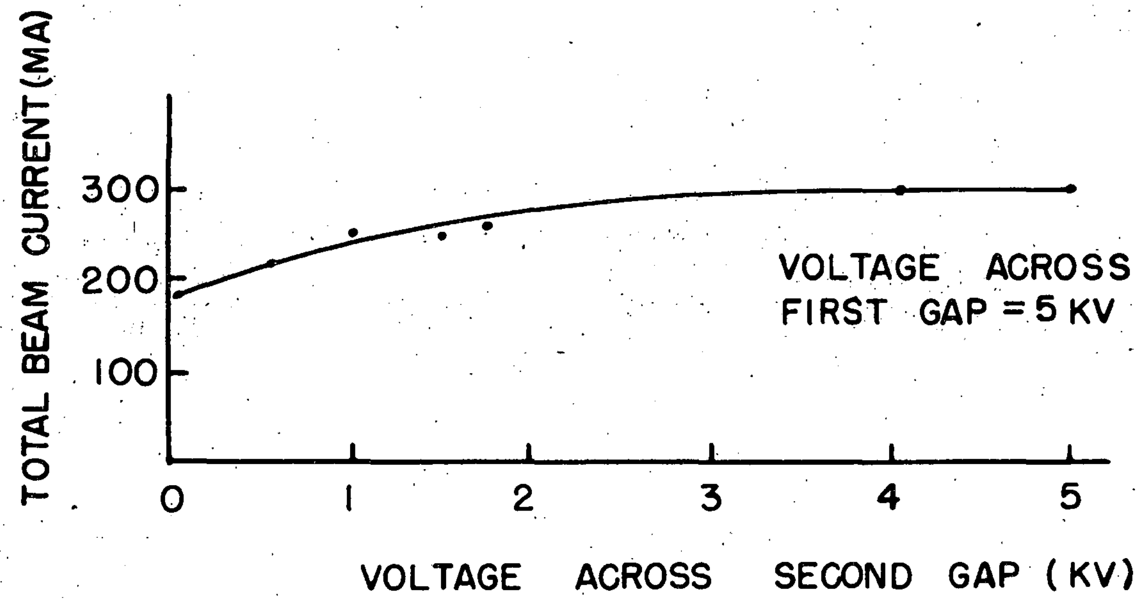


FIG. 14

MU 1437

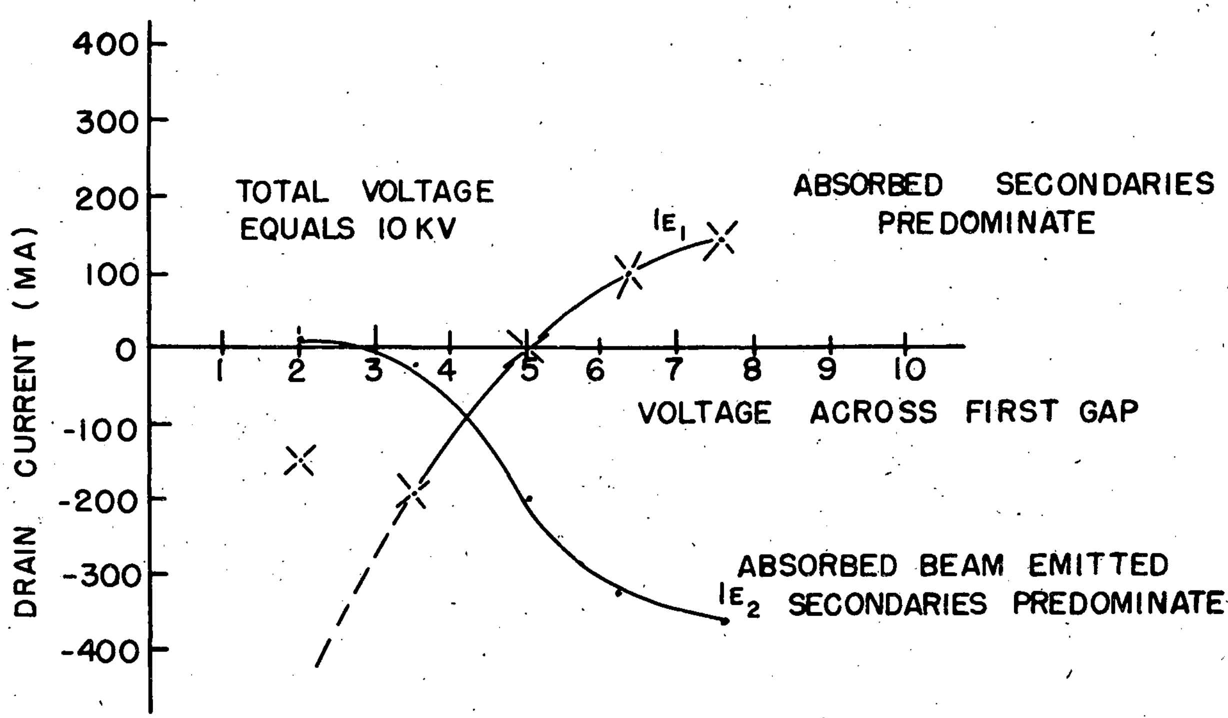


FIG. 15

MU 1438

11. Theoretical Studies

L. R. Henrich

Wide Aperture MTA Input. The problem of how much the input aperture can be increased to obtain the maximum current in the MTA is being investigated. This can be considered either under the condition of keeping the injection voltage fixed at about 80 kv or under the condition of varying the injection voltage. The latter method of treatment requires a much more expensive injector. Assuming that a high energy injector with high current density over a large aperture can be built, the radial and phase motion can be studied. As an indication of the desirability of going to higher injection energies, a comparison can be made by using the present Mark I design with the first unit of the machine eliminated. This provides a considerably larger area for injection. Some calculations are being made of the radial and phase motion to see whether there is a net gain in the number of accelerated particles. The indications are that some improvement is possible with this approach.

The first method of opening up the injection aperture but keeping injection voltage fixed requires the determination of additional fields between drift tubes. The calculations rather naturally divide themselves into two parts. The first is the calculation of the accelerating fields. These fields might be determined in two (or more) possible manners. The experimental method of constructing a model and then measuring fields has seemed unsatisfactory since the weak fields are rather poorly determined. The solution of Laplace's equation by the relaxation method for the actual machine would probably give the most satisfactory fields. However, by hand this is very slow. An attempt has been made to have the work done on the IBM 602-A but has run into various difficulties. It would be desirable to obtain solutions with high speed electronic computers. The second part of the calculation requires the determination of orbits after the fields are obtained. If a large fraction of the aperture is to be used, it becomes desirable to obtain solutions of the coupled equations. This again becomes rather a nasty computing job to which a satisfactory answer has not yet been found.

Power Losses in the Skin. The power losses in the skin will be related to the voltage gradient along the tank and the dimensions of the drift tubes. Minimizing this loss under various conditions have been studied. The voltage may be varied so as to give the minimum loss, the voltage may be kept fixed at some value to be determined, or the voltage gain by the particle can be chosen to be some fixed value, e.g., 0.5 Mev per foot. Calculation of the minimum power loss in these three cases indicated rather small variations. The conclusion was that other criteria--not power loss--should determine what type of voltage variation along the machine would be most desirable.

13. Mark II Target Program

C. M. Van Atta

Introduction. Since the previous progress report the effort of the MTA-Mk II target group has been mainly expended upon

(1) Additional experimental measurements on the 184-inch cyclotron of neutron yields;

(2) Computations of heat loads, heat dissipation and neutron yields of various primary and secondary target arrangements;

(3) Lattice computations for both non-multiplying and multiplying lattices.

Neutron Yields. The excessive growth of uranium due to thermal cycling and radiation damage suggests that the use of pure uranium as the primary target material may be impractical. Preliminary investigations of the known high-uranium content alloys (5-10 percent Mo-U, 2-5 percent Cb-U, Mo-Cb-U, etc.) does not indicate any great probability of the development of such an alloy within the time scale for the MTA-Mk II target which will be dimensionally stable against thermal cycling and radiation.

Present indications are that thorium does not have the property of excessive growth characteristic of uranium and, in addition, is a relatively malleable metal easily fabricated into plates or other shapes. In order to evaluate thorium as a primary target material the neutron yield as a function of thickness was measured for pure uranium and thorium and also for thorium as a primary target (one deuteron range or 1-inch thickness for 190 Mev deuterons) backed up with a uranium secondary target.

Fig. 1 gives results of recent measurements on uranium, thorium and thorium combined with uranium. For these experiments with 190 Mev deuterons the range in uranium is 0.63 in. and in thorium is 1.08 in. The target used for pure uranium was mostly built up out of 12 in. x 12-1/2 in. plates, whereas the target for pure thorium was made of 4-1/4 in. diameter round stock. From the few measurements taken with a 4-1/4 in. diameter uranium target, it appears that the difference in geometry is quite significant. To make a realistic comparison between the pure thorium and pure uranium targets the yield curve for the 12 in. x 12-1/2 in. uranium target is plotted as a solid line and the estimated curve for a 4-1/4 in. diameter uranium target is shown as a dotted curve based upon two measurements. The thorium yield is then compared with the dotted curve for uranium.

The uranium yield curves reach 92 percent (3.0 as compared with 3.25 neutrons/deuteron) of their maximum value at 1 inch beyond the deuteron range or at 1 in. + 0.63 in. = 1.63 inches. At this point the 4-1/4 in. diameter target yield is 2.75.

In order to compare the thorium yield with uranium we take a thorium thickness of 1.63 in. x 1.08/0.63 = 2.80 in., for which the yield is 2.15 neutrons/deuteron or 78 percent that of the comparable uranium yield.

For the combined target we take a one-range thickness of thorium (1.08 in.) and add 1 inch of uranium, which gives a yield of 2.45 neutrons/deuteron. Since in this case the uranium portion of the target was made up of 12 in. x 12-1/2 in. plates, this yield should probably be compared with the solid yield curve of uranium and is therefore 82 percent of 3.0 for straight uranium (12 in. x 12-1/2 in.).

This last comparison is not quite fair, however, if in using a compound target one can conveniently use a greater thickness of uranium. Whereas for the pure targets of either metal the points used for comparison are above the 90 percent yield points, the compound target yield curve continues to rise more rapidly with the result that as high as 90 percent of the pure uranium yield can be attained with the compound target using one range thickness of thorium and 3 in. to 3-1/2 in. of uranium.

The lower set of curves in Fig. 1 shows the yield data plotted against thickness of target in ranges for 190 Mev deuterons. The points used in the above comparisons are the points of intersection of the yield curves with the vertical dotted line. From this somewhat imperfect data we obtain the following relative yields:

U (one range + 1 in.)	100
Th (one range + 1.71 in.)	78
Th (one range)+ U(1 in.)	83
U (one range + 3.15 in.)	100
Th (one range)+ U(3.15 in.)	92
Th (one range + 5.42 in.)	75

These measurements clearly indicate that whereas the yield of thorium as both primary and secondary target is only about 75 percent of a solid uranium target of the same thickness measured in gm/cm^2, the yield of a combination target consisting of a deuteron range thickness of thorium backed up with uranium to the same total thickness in gm/cm^2 is 92 percent of the solid uranium target. This is all for a reasonable secondary target thickness of 3.15 in. of uranium or 5.42 in. of thorium. This combination seems promising as a means of obtaining yields very close to those of a practical uranium target (with its cladding and water cooling) and at the same time avoiding the probable difficulties of running uranium at high power concentrations.

In order to facilitate yield estimates for complex targets including cladding materials and coolant jackets the yield curves for one full range each of aluminum (13), copper (29) and molybdenum (42) as a function of uranium secondary target thickness were obtained. These data together with a similar curve for water are given in Fig. 2.

<u>Primary and Secondary Target Design Studies</u>. Because of the many alternatives which must be roughly evaluated, the primary and secondary targets are still in the design study stage.

A fairly detailed study has been made of the concentric uranium tube type of target described in the previous report in the form of a four-row tube bank. Each tube element is assumed to consist of three concentric uranium tubes of 0.160 in. wall thickness clad with 0.005 in. of zirconium. Sufficient uranium is contained in the four rows of concentric tube elements for both primary and secondary targets. This unit is contained within an aluminum tube of 4 in. O.D. and 0.050 in. wall, which defines the outer water cooling annulus, and also contains at the center an empty aluminum tube of 0.050 in. wall to define the inner water cooling annulus. The thickness of each water cooling annulus (inside, outside and between the three concentric tubes--four in all) is taken as 0.125 in.

The following table gives the average percentage deuteron energy loss in each of the materials of the target and the corresponding neutron yields.

	Neutron Yield Relative to Ideal Solid Uranium Target				
Target Material	U	Al	Zr	H_2O	Total
Average % E Loss	81.65	4.22	4.07	10.07	100.0 % E
f = Y (material)/Y(U)	1.0	0.39	0.54	0.25	
Yield = f x (% E Loss)	81.65	1.65	2.20	2.68	88.2 % Y(U)

From this study it appears that the overall yield of a water cooled concentric tube uranium target would be about 88 percent that of a solid uranium target. Whether such a target would in fact be feasible depends upon the extent to which the concentric uranium tube elements would grow and warp due to thermal cycling and irradiation. In any case, because of the relatively low temperature at which phase changes occur in uranium, the maximum temperature and therefore power concentration in such a target would have to be kept quite low and therefore the target itself would have to be large.

The indications are that thorium does not experience any phase changes between normal temperatures and its rather high melting point (probably about 1625°C). One advantage of thorium therefore as a primary target material is that the operating temperature and power concentration could be set quite high. Recently completed calculations indicate that a NaK cooled thorium primary target 6 feet in diameter can be designed for which the maximum temperature will be somewhat less than 1000°C while dissipating the full 35 megawatts beam energy of the Mk II accelerator. The deuteron energy loss in the NaK coolant is so small that the yield of this primary target when combined with an adequate uranium secondary target will be 98 percent of that for a solid thorium target backed with uranium, or 90 percent of that for an ideal pure uranium target. This compares very favorably with the 88 percent of U yield reported above for the water-cooled concentric uranium tube target and indicates that a combination thorium and uranium target may be at least as good as a practical water-cooled uranium target. The greater compactness of the thorium primary target is expected to yield additional advantages in higher lattice flux and neutron economy. The preliminary results on the thorium-uranium combination target are so favorable that engineering on the target will start with this design as a goal.

NEUTRON YIELDS OF URANIUM AND THORIUM FOR 190 MEV DEUTERONS

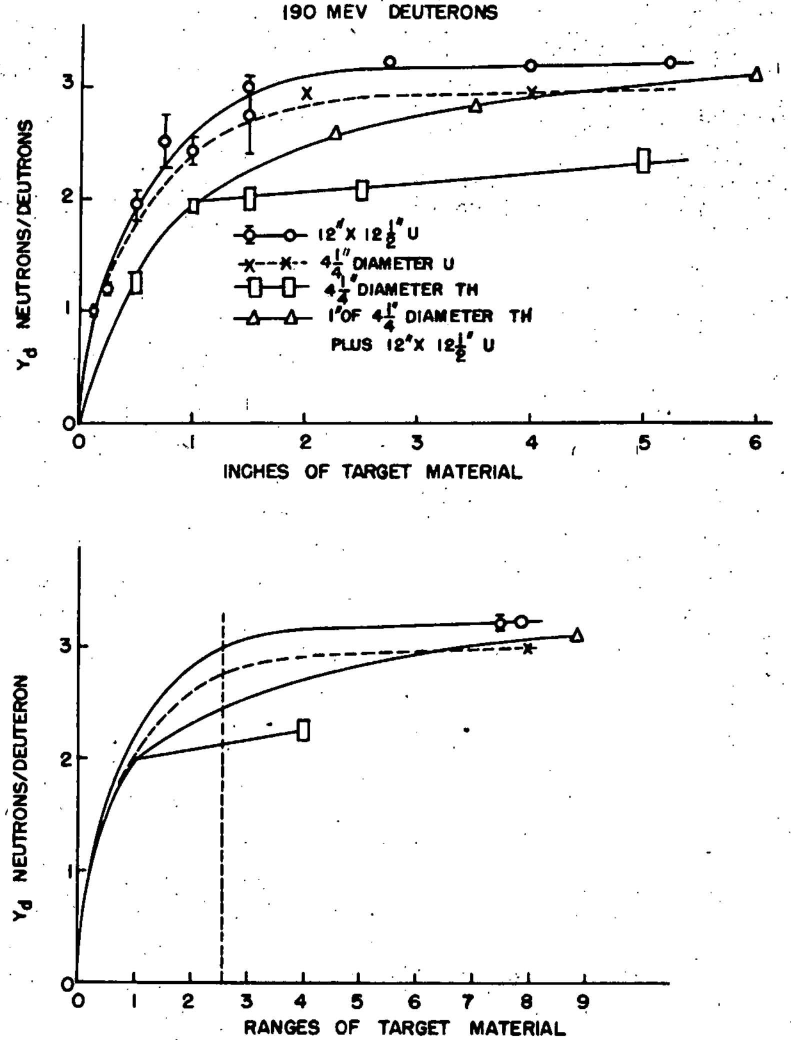


FIG. 1 MU 1412

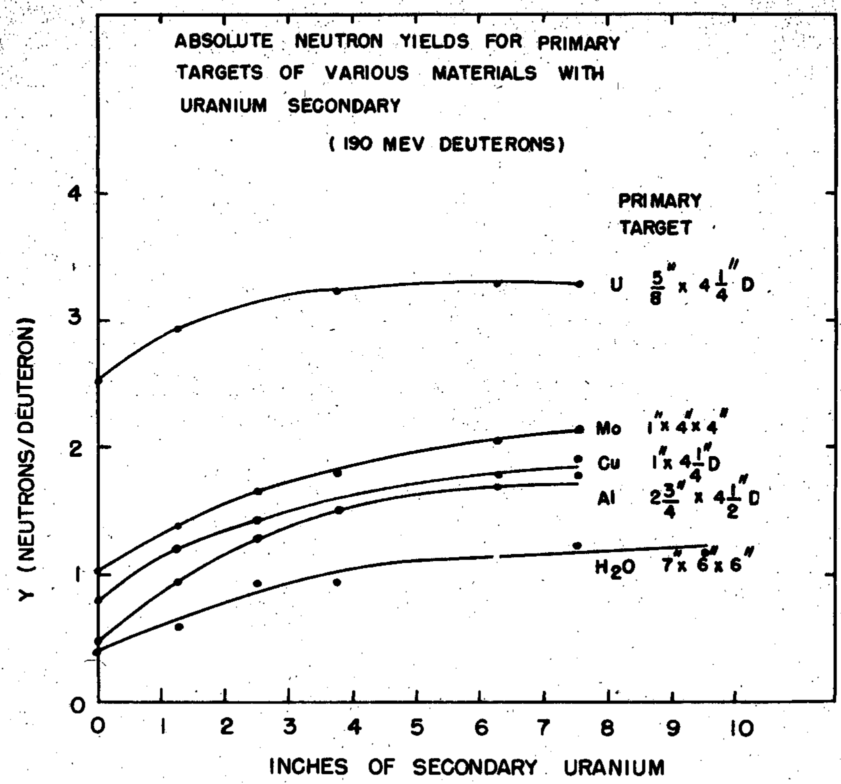

ABSOLUTE NEUTRON YIELDS FOR PRIMARY TARGETS OF VARIOUS MATERIALS WITH URANIUM SECONDARY
(190 MEV DEUTERONS)
PRIMARY TARGET
U 5/8" x 4 1/4" D
Mo 1" x 4" x 4"
Cu 1" x 4 1/4" D
Al 2 3/4" x 4 1/2" D
H2O 7" x 6" x 6"
Y (NEUTRONS/DEUTERON)
0
1
2
3
4
0 1 2 3 4 5 6 7 8 9 10
INCHES OF SECONDARY URANIUM

FIG. 2

MU 1411

14. Electron Model of the Clover Leaf Cyclotron

J. Reginald Richardson, John A. Jungerman, and Elmer L. Kelly

Introduction. The theory and mechanical construction of the cyclotron have been given briefly in a previous report (p 136 ff, UCRL-1009) and so need not be repeated here. A general idea of the pole shape and tank layout can be gained from Fig. 1 and 2. The single 180° rf dee was operated at negative bias. Since the dee bias was of the same magnitude as the rf voltage the beam orbit was constantly urged off center; this was compensated for by use of a dummy dee opposite the rf dee connected to the same bias supply as the rf dee. The dummy dee consisted of two insulated copper sheets fitted closely to the upper and lower pole faces and connected to a metal frame having the dimensions of the lip of the rf dee. This dummy dee is open around its periphery. Means were provided for inserting probes along a radius at three different positions: 120° (hill), 200°, and 240°(hill) measured from the center line of the rf dee in the direction of the electron beam (counter clockwise as seen from above). The 200° probe can be seen in Fig. 1. Some 26 trimming coils were installed on the pole faces for making slight changes in the magnetic field. In addition to the circular coils seen in Fig. 2 there was a flat spiral coil at the center of each poleface to produce axial focusing in this region and a flat spiral coil at the periphery of the pole faces on each "hill" and each "valley". The current in each coil could be varied continuously from 0.1 amp to 3 amps.

Establishment of the Beam. The existence of an accelerated beam of electrons in the electron model of the clover leaf cyclotron was first established on September 16, 1950. At that time x-radiation of energy 30 Kev was observed to originate in an aluminum target placed at a radius of 13-1/2 inches. The magnetic resonance was quite sharp, corresponding to a full width of the beam at half maximum of 0.5 percent in magnetic field.

The more accurate establishment of the energy and magnitude of the beam was gradually accomplished over a period of several months while other experiments were being done. The historical approach will not be used but rather our knowledge as of January 25, 1950 will be presented.

Energy of the Beam. The energy of the electron beam has been checked by the measurement of the x-rays produced and by the range of the electrons in aluminum foil.

A tantalum target was placed at a radius of 15 inches on a hill and the absorption curve of the x-rays in copper was measured. After going through 0.070 inch of copper, the absorption curve straightened out at a value corresponding to an energy of 57 Kev for the penetrating component of the x-radiation. This agrees well with the Kα radiation of tantalum (58 Kev) which can only be produced by electrons of energy in excess of 70 Kev. The possibility also exists that the agreement in energy between the measured x-rays and the tantalum Kα line is fortuitous and that the 57 Kev corresponds to the short wave length limit of the continuous radiation from 60 Kev electrons. In any case, however, the agreement with the predicted energy (65 Kev) of the electrons at this radius is quite satisfactory.

Current measuring probes shielded with various thicknesses of nylon and aluminum have been used in attempts to obtain the radial variation of the electron beam current. As one moves a shielded probe to smaller radii, the electron current at first increases somewhat, reaches a maximum, and then decreases rather rapidly as it is moved toward the center of the cyclotron. This decrease is interpreted as a failure of the electrons at smaller radii (lower energy) to penetrate the shield of the probe. A correspondence can then be drawn between the theoretical electron energy at the radius of this decrease in current and the thickness of the shield on the probe. For example, it is found that a probe shielded with 1.7 mg/cm^2 of Al shows evidence of losing current below 12 inches radius on a valley. An electron whose range is 1.7 mg/cm^2 has a mean energy of 28 Kev, while the theoretical electron energy at 12 inches radius is 36 Kev. Similar results have been obtained at other radii using other shields.

Magnitude of the beam. One of the most difficult problems in technique associated with the electron model has been the construction of reliable probes for the measurement of the electron current. It was found very early that there are fairly large numbers of electrons executing semi-cycloidal motion along the fringing magnetic field both along various radii and around the outer edge of the poles. These electrons have energies in excess of 1000 ev and must be kept out of the probe by shielding. The most satisfactory probes have been constructed using a combination of aluminum and either nylon or paper for insulation. The aluminum furnishes shielding from the radiofrequency voltage on the dee. Only the results obtained with shielded probes will be quoted in this report.

The amount of electron beam accelerated depends quite markedly on the dee voltage. For example, a beam of 5 microamperes near the maximum radius of 15 inches can be obtained at a peak rf voltage dee to ground of 800 volts. This will be reduced to 1 microampere at 600 volts, 0.2 microampere at 400 volts and finally to a negligible current at 280 volts. Efforts to determine the variation of the beam magnitude with radius have so far not produced trustworthy data, due primarily to lack of a satisfactory means of varying the probe shielding to match the changing electron beam range as the radius increases. However, by visual observation using a fluorescent beam clipper there is good indication that beam loss is considerably greater at a radius of 9 inches or 10 inches than it is in the neighboring regions. This is borne out by the fact that the difference in measured magnetic field and the theoretical field required is largest ($\sim$ 2 percent) in this region.

Threshold Dee Voltage. An important aspect of the electron model tests is a determination of the minimum radiofrequency voltage on the dees required for complete acceleration. This is the threshold dee voltage. Its exact value depends upon the minimum current chosen as threshold beam current. However, it is clear from an examination of a typical curve of beam current vs. dee voltage that the threshold dee voltage is not a very sensitive function of the value chosen for the threshold beam current.

A threshold dee voltage of 280 volts on the electron model means that the electrons have been accelerated through at least 120 turns. This figure would apply if the electrons remained in phase with the dee voltage throughout the acceleration. This will obviously not be the case near threshold, so that the number of turns involved is probably more like two or three hundred.

A peak voltage of 280 volts on the single 180° dee of the electron model corresponds to 520 kv on two 180° dees in a full scale accelerator for 250 Mev deuterons. For a three phase system using 120° dees the corresponding voltage would be 390 kv or for three 60° dees the voltage would be 670 kv. The desirability of further reducing this threshold dee voltage is therefore obvious.

There can be two principal reasons for a high threshold dee voltage:

1) A lack of correspondence between the actual radial and azimuthal variation of the magnetic field and that demanded by the theoretical expression

$$H = H_o \left[1 + A \left(\frac{\Upsilon\omega}{c}\right) \cos m\,\Theta + B \left(\frac{\Upsilon\omega}{c}\right)^2 \right]$$

2) Unsatisfactory starting conditions for the electrons near the center of the cyclotron.

We have strong indications that both of these causes are preventing the obtaining of lower thresholds. A great obstacle to our obtaining a good match on the magnetic field has been our inability to measure the field (of about 20 gauss) to better than 2 percent. The magnetic group have recently developed a method, however, which should allow accuracies of 0.1 percent to be obtained, and it is planned to use this method to tailor our field to better agreement with the theory.

The trimming coils which have been used so far on the magnetic field are spaced two inches apart on a radius and are circular in shape. When the individual currents through these coils are optimized, they produce a definite lowering of the threshold dee voltage over that obtainable without their use. However, it is felt that a much better job can be done with coils spaced closer together and shaped to follow the orbit of the electrons.

In regard to the second reason for a high required dee voltage, namely the starting conditions at the center, one would expect that electrons starting with an energy of only one or two hundred electron volts would be extremely subject to stray electric fields. These fields may arise, for example, from charges collecting on insulating films deposited on metal surfaces. An indication that this actually occurs is the observation that the optimum source bias was temporarily lowered by perhaps 40 percent when conducting paint was liberally applied to the metal surfaces in the region surrounding the source. In addition, operation with the dummy dee at rf dee bias instead of ground potential resulted in about a 30 percent reduction of the threshold dee voltage. There is also some evidence of reduction of threshold voltage with increased radius and consequently increased energy of source injection.

<u>Source Trials</u>. The original source consisted of a 5 mil wolfram wire shaped into a sharp V in order to eliminate magnetic field effects from the filament current. The height was about 1-1/2 inches. This filament was operated at a negative potential of about 100 V for optimum beam.

In order to increase the electric field in the filament region, various grounded structures were used to surround the filament. The best of these seemed to be a square box of molybdenum, 1/4 in. on a side with one side open. The filament used in this case was a single vertical wolfram wire with a current return close behind it. Spiral filaments were also employed, but were not as satisfactory possibly because they provide vertical electric fields when bias is applied to them. Finally, in order to get as simple a source as possible, the single wire filament was used without the box shield. However, it was found to be quite sensitive to filament position and bias voltages.

Next a source was designed with a grid of two vertical parallel wires which could be held at an arbitrary potential. By varying this potential it is possible to get a fairly well defined beam for a given choice of filament bias voltage. In fact, one could see the first three or four turns of the beam on a thin fluorescent probe. The source of electrons consists of a row of 0.020 inch holes in a molybdenum cylinder. The interior of the cylinder is made up of a spiral of 0.010 inch wolfram wire which is surrounded with barium aluminate. Thus the source of electrons is an indirect one and is quite ready in operation. The lifetime is about a month as compared with a few days with wolfram wire alone.

This source was used to make an investigation of the effect of starting electrons with various initial kinetic energies. This was possible since the electrons left the source perpendicular to the radius line. In particular the rf threshold for the full energy accelerated electrons was studied as a function of injection radius. The threshold was found to be 210 v r.m.s. at 2 inches, 218 v at 1-1/2 inches, and 227 at 1 inch injection radius.

Phase Measurements. Some preliminary work has been done to establish the feasibility of two types of phase measurement. In the first method rf voltage is placed on a probe in a known phase with respect to the rf on the dee edge. As the electron beam passes over the probe it will be deflected by the rf field unless the field is zero as the electron pulse passes by. Since the electron pulse is the sharpest near threshold rf voltages, this method will probably prove most useful in this region. Measurements with a d.c. field have shown that rf of the order of several hundred volts should produce an appreciable beam deflection after one revolution.

The second method for measurement of phase consists in observing the x-rays from a probe target with a photomultiplier tube some of whose elements are biased with rf voltage. This method appears practical without the use of a scintillation crystal. However, for either method, it is felt that a more stable oscillator is necessary in order to make useful measurements of the phase. This has been constructed and will be utilized in the 3 dee system.

Beam Trajectory Studies. The study of the electron paths may be conveniently divided into paths of the circulating beam and those of the external beam. Various techniques were used to find the trajectories in each case, i.e., by images of one probe on another, by measuring current decrease to a probe as another is inserted in the electron path, or by photographing electrons that had passed through a narrow aperture.

The circulating beam exists until about 15-1/2 inches on the hills and 14 inches in the valleys is reached. Near the center the orbits are nearly circular. As the radius increases the valley curvature decreases until at a 15 inch hill radius the corresponding valley radius is about 13-1/4 inches. This agrees quite well with the theory which predicts a 2 inch difference in radius at this point.

The first observations of the external beam were made with a fluorescent probe after the dee clearance for the beam was increased from 17 inches to 18-1/8 inches. Fig. 3 shows the beam as observed at the 240° hill. The leading edge of the probe shown there is at 16-1/2 inches. A characteristic constriction of the beam in the fringing magnetic field occurs as the radius increases followed by a fanning out again. The beam pattern at the 120° hill is similar except the latter fanning out does not occur. The magnitude of the external beam decreases as the rf dee voltage is reduced, the threshold voltage being about 350 volts. It is possible by reducing the magnetic field at one or two (but not three) hills to get an external beam at the same threshold dee voltage as is required to bring the beam out to the nominal 15 inch radius on a hill. The reduction might be due to improved magnetic field or it might be due to induced radial oscillations in the beam; observations indicate the latter explanation.

The external beam trajectories were studied in the region available outside the dee. The paths are described in a pinwheel fashion starting near the pole edge and ending on the tank wall. They are shown in Fig. 4. The trajectories were studied mainly by the window of one probe on another and the paths so determined agree quite well with angles found using photographs. By measurements of current to a probe at 200° (Probe B) as a function of the radius of another probe on a hill and preceding the former by 320° (Probe C), we were able to determine the region on a hill at which electrons that form the external beam spill out.

It was found that a region from 15-1/2 inches to 15-5/8 inches on the 240° hill produces external beam on Probe B (200°) for any radius of that probe greater than 14-1/4 inches. This is in agreement with visual observations that the circulating beam disappears after 15-1/2 inches on a hill or 14-1/4 inches 20° from a valley.

Efforts were made to get some idea of the current distribution associated with the external beam trajectories shown. Observations were made with a system of four collectors on the 240° plate at 19 inches radius and also with a group of eight collectors placed at a 16-3/4 inches radius and situated every 20° starting with 110° as shown in Fig. 4.

The four collector system showed that the external beam was concentrated in the 220° region of the 240° plate such that the current was some 12 times greater than in the 260° region. Measurements with the 8-collector system showed current concentrated in the region of the hills. Although more accurate trajectories would be necessary to describe the current distribution on the tank walls in detail, it may be said that the major part of the current from the 120° hill would be found in the region of 210°. Presumably a similar result would be obtained with the other hills. This experiment was not made because of the intervention of the dee. The results are sensitive to operating conditions and are therefore quite tentative. For example the ratio of the current to the 110° collector to the current to the 230° collector decreases a factor of 5 if the rf voltage is increased from 350 to 500 volts, i.e., high rf increases the spill out from the 240° hill.

Another measurement was made using large shielded probes to collect the external beam at the 120° and 240° hills. It was found that at least half of the internal circulating beam could be collected on these two collectors. This indicates that the loss in getting the beam out from between the magnet poles can be made quite small. By suitable adjustment of the various hill coils it was found possible to change the ratio between the currents collected on the two hills by more than a factor of 100.

Magnetic Lens Effects. After the electron path reaches about 15-1/2 inches on a hill, the Thomas magnetic focusing is reinforced by whatever focusing is provided in the fringing field. The focusing observed in the external beam at a hill is due to the fact that these electrons have traveled out from the preceding valley with a large radial component of velocity and therefore their path has been through a focusing magnetic lens field. This is able to constrict the beam to 1/4 inch vertical height at a radius of 18 inches as is shown in Fig. 3. In the valleys where the fringing field is weak, the transition from circulating beam to external beam is observed by an immediate vertical defocusing after 14 inches radius so that the external beam fills the entire height of a 2 inch fluorescent probe. The image cast on this probe as made by an object at the previous hill is inverted and magnified which shows that there is a focal point just beyond a hill. The images as seen by fluorescence on the tank wall are also inverted until the beam passes the next hill, at which point they are reinverted and appear erect. The constriction observed on the hills is also seen on the tank walls adjacent to a hill as a constriction which is a minimum 3 inches past the center of the plate. There is evidence that the position of the focal point of the magnetic lens can be altered by currents in the hill coils. This can be seen by lowered magnification as observed on the tank walls and in addition if sufficient current is employed (-2.4 amps in each coil) the constriction can be formed in the 150° region on the tank walls. As would be expected, the focal length of the magnetic lens is increased by increasing the field in the preceding valley or by decreasing the field at the hill. This indicates that the use of magnetic focusing may well be feasible for manipulating the external beam.

Electronic Developments. (Melvin Chun) Power supplies for accelerating grids in the electron gun were installed along with power supplies and controls for the compensating pole face windings. Special instrumentation was installed for monitoring the rf oscillator behavior. Numerous beam current probes were designed and tried for beam height measurements. Fluorescent probes and clippers were designed and tried in order to determine vertical oscillation of the beam as well as beam behavior at all radii.

Because of increased activity and scientific personnel, an additional 400 square feet of Building 43 (former storeroom) is being converted into laboratory working space, providing light, power, heat, and lab benches.

Work is being continued on internal magnetic field modifications and adjustments. A master oscillator power amplifier dee arrangement is being considered for use with a phase measuring device to be used on the accelerated beam. Close coordination with the theoretical and operating personnel continues.

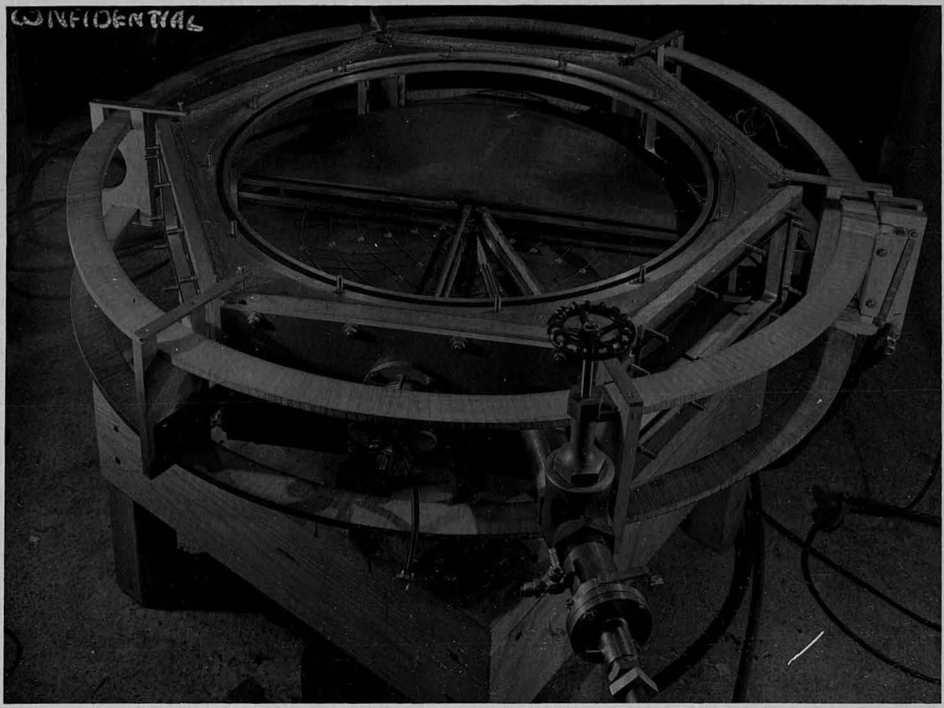


FIG. 1

FIG. 2

OZ 1025

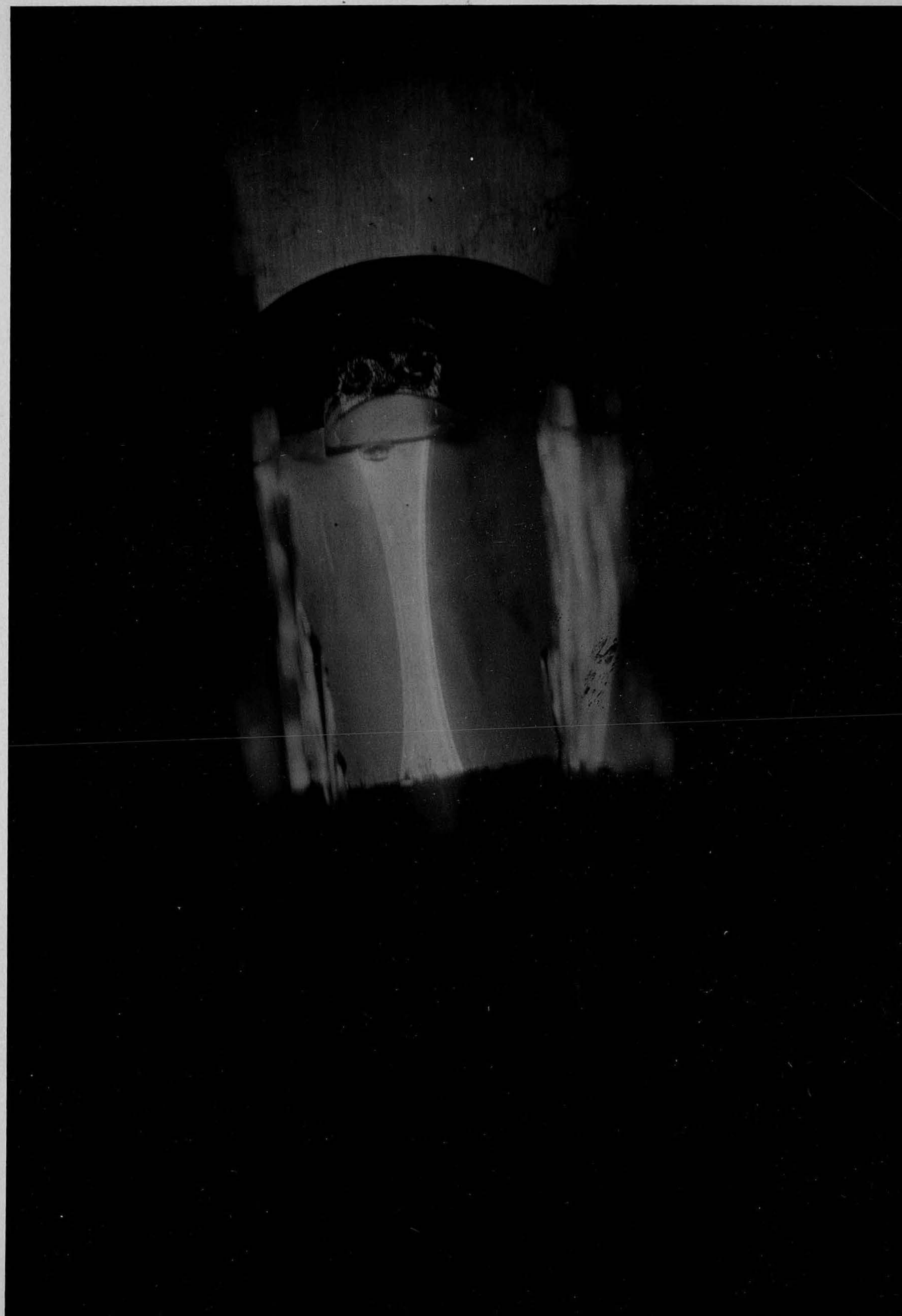
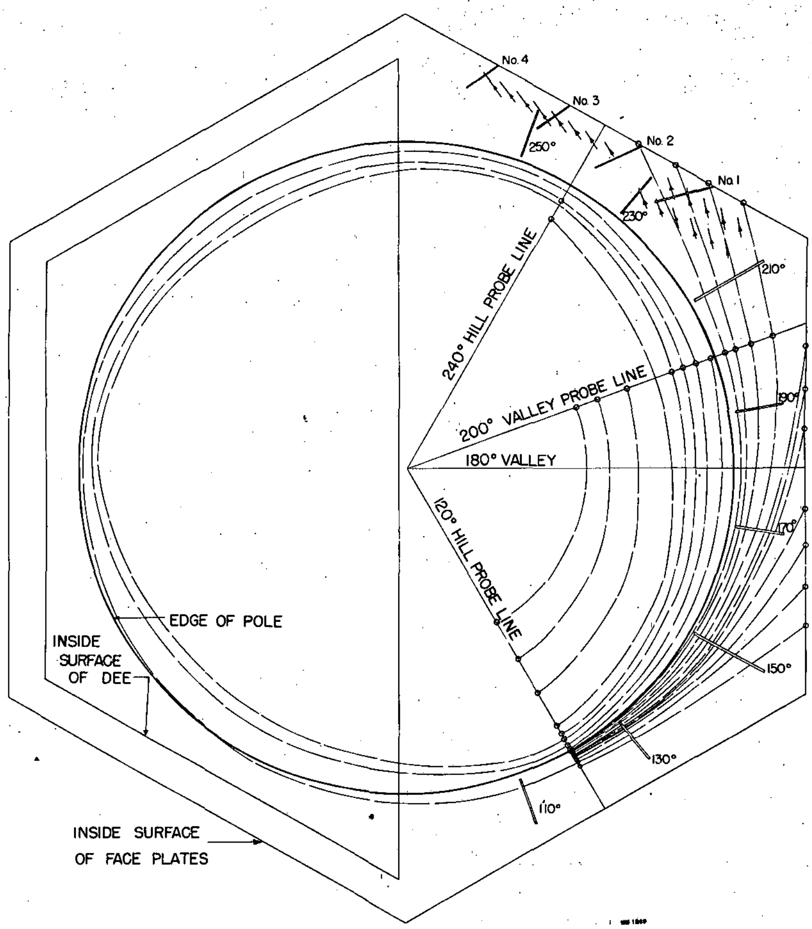


FIG. 3

CONFID.
OZ 1215


No. 4
No. 3
No. 2
No. 1
250°
230°
210°
190°
170°
150°
130°
110°
240° HILL PROBE LINE
200° VALLEY PROBE LINE
180° VALLEY
120° HILL PROBE LINE
EDGE OF POLE
INSIDE SURFACE OF DEE
INSIDE SURFACE OF FACE PLATES

15. XC Cyclotron Conversion

Marvin Martin

Introduction. Plans for converting the XC cyclotron to a Thomas type machine have been developed during the past quarter. A preliminary study indicates that it may be possible to use a great deal of the equipment originally planned for this machine, including the tank and vacuum pumps, the shielding and the dee stems. It is highly desirable in the interest of saving time to use the existing oscillator and model tests are now underway to determine its feasibility.

Rf Equipment Revision. The frequency tolerance on the existing oscillator is plus or minus 1/4 megacycle from the normal of 14 megacycles. If it is possible to obtain a properly shaped magnetic field at a value which corresponds to this frequency range for protons no revision of the oscillator or transmission lines will be necessary. Model tests of the XC magnet are underway to determine if this can be done. The tentative specifications include a magnetic field of approximately 9,000 gauss which at 30 inch radius gives a proton energy of 23-1/2 Mev.

It is planned to operate on a low duty cycle with beam pulse of 1 millisecond duration using not more than two pulses per second. A pulse line will be built to supply plate voltage to the oscillator. The design capacity of this line will provide four megawatts d.c. power during the pulse. It is planned to install only half the line at the present time since the existing oscillator has a rating of 1/2 megawatts cw. As operational experience is gained the oscillator power will be increased either by converting the present F 134 oscillator tubes to D 50's or providing MTA Mark I type oscillators.

Construction and Utilization of the Machine. Tentative internal dimensions have been selected as follows:

Clear opening inside dee	4"
Dee to ground clearance	3"
Minimum magnetic gap	12-1/2"
Maximum orbit radius	31"

A cost estimate and time study has been made on a preliminary basis which indicates that construction work will be completed some time in April and that the first stage of operation can be achieved under the existing budget limitations.

It is planned to use the cyclotron to study means for obtaining large circulating currents. The value of beta for 23-1/2 Mev is not large (0.23). Work on the electron model, however, has demonstrated that the principle of operation is sound for deuteron energies up to 250 Mev and it is believed that the most important question remaining is the ability of the cyclotron to produce a beam of the order of 50 milliamps or higher.

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