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UCRL-1359
Technology - Materials
Testing Accelerator

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UNIVERSITY OF CALIFORNIA
RADIATION LABORATORY
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MINUTES OF MEETING OF MTA REVIEW COMMITTEE HELD JUNE 12, 1951

Russell H. Ball

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RESEARCH SERVICE BRANCH
Atomic Energy Commission
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Berkeley, California

MINUTES OF MEETING OF MTA REVIEW COMMITTEE
HELD JUNE 12, 1951

Present: UCRL: Alvarez, Brobeck, Cooksey, Lawrence, Lofgren, Norton, Reynolds, Richardson, Thornton

CR&D: Davis, Hildebrand

AEC: Ball, Fidler, Fleckenstein

Richardson said the pole faces of the electron model of the cloverleaf cyclotron have been improved by the addition of shims. Measurements of the magnetic field indicated an improvement although accurate measurements of the field are difficult to obtain because of its low average value--namely, about 20 gauss. The pole radius is 16½ inches and the design calls for the electrons at 15½ inches to have the same velocity as do deuterons of 250 Mev. The threshold dee voltages required with the improved magnetic field are shown in Table 1.

Mev	Radius in Inches	(Single Dee Operation) Threshold Dee Voltage	(Two Dee Operation) Dee Voltage to Ground (Full Scale)
250	15½	340 v	--
220	14½	170 v	310 KV

Table 1.

The shape of the external beam has been investigated by the use of probes coated with fluorescent material. The pattern of the external beam has been changed by the improvement of the magnetic field as indicated in Figure 1.

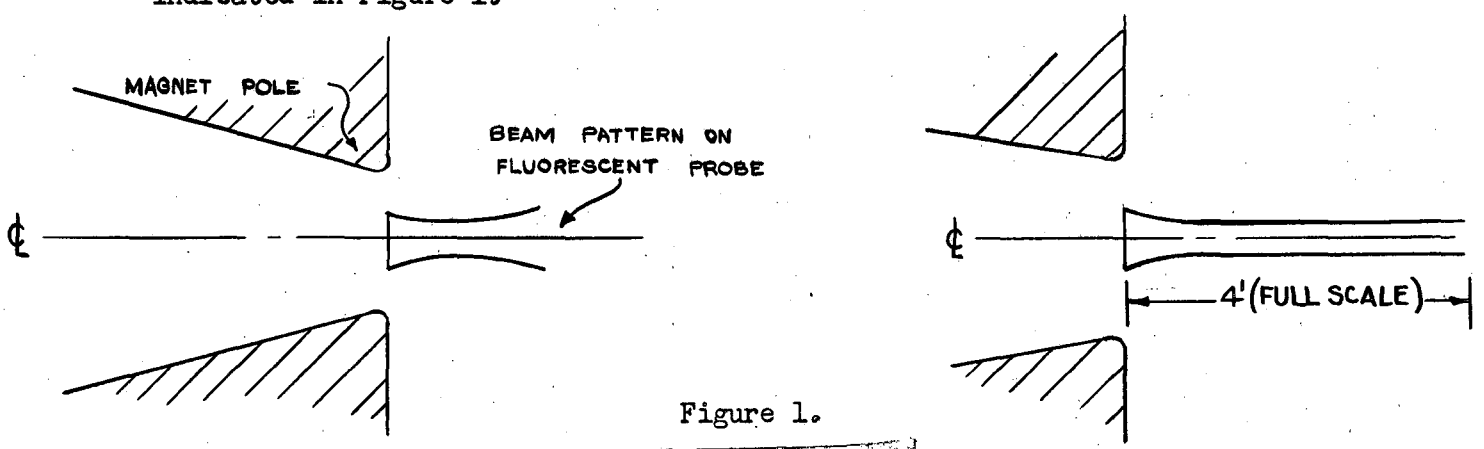

Figure 1.

The pattern shown extends a distance equivalent to 4 feet, full-scale. By juggling the currents in the hill-and-valley trimming coils it is possible to make the beam come out essentially completely at any one of the three hills. It now looks quite feasible to have a single target and to provide for switching the beam to an alternative target at will.

Concerning the loss of the beam during acceleration, Richardson said they have placed radial clippers on the electron model which correspond on the full-scale machine to restricting the beam to a 7-inch aperture out to a radius where the deuteron energy would be 220 Mev. These clippers are coated with fluorescent material. It has been found that by proper adjustment of the magnetic field a negligible loss of beam occurs on these clippers. On going to higher threshold voltages, in order to get the beam out to $15\frac{1}{2}$ inches, there is an increase in the beam lost to the clippers. This loss, however, can presumably be controlled by proper adjustment of the magnetic field. Lofgren pointed out that with these low magnetic fields it has never been possible to make measurements with sufficient accuracy to determine whether the median plane is flat.

Alvarez questioned the pattern obtained for the external beam. Lawrence said that one has here a magnetic lens formed by the stray field outside the magnet. One revolution of the particles corresponds to a distance of about 100 feet so that the observed focusing of about one inch per revolution is quite reasonable. Alvarez said that he could not understand the focusing unless the beam has a large amplitude in the vertical direction and this possibility was ruled out by the presence of the beam clippers. Lawrence and Richardson contended that one simply has here a magnetic lens having a focal length of the order of 100 feet. Alvarez said that this beam pattern is different from what one would have predicted and therefore involves some principles that are not fully understood. He recommended continued investigation of the beam pattern and the causes responsible for it. It was agreed that these studies would be conducted.

Richardson said the theoretical people are still progressing in their understanding of the proper magnetic field for a cyclotron of this type. The required field is obtained from a series expansion of the function $\frac{1}{\sqrt{1-\beta^2}}$. The first calculations included corrections for the first term involving β^2. β is approximately proportional to radius and one introduces a term $A(r)\cos 3\theta$ to correct for the β^2 term. Further refinement of the magnetic field requires correction for the term involving β^4 and requires the inclusion of a correcting term $C(r^3)\cos 3\theta$. The correction term for β^4 is appreciable for particles

of 250 Mev and it should therefore be included. It is planned to make new pole faces which involve the so-called C or r^3 term. It is possible to introduce some of the effect obtained from the C term by proper adjustment of the hill-and-valley coils.

Removal of the beam requires the proper adjustment of the A and C terms to reduce the radial focusing at the edge of the magnet.

Alvarez asked about space charge effects. Lofgren said that the space inside the dees is field free so that one has an appreciable degree of neutralization. He said the time required for electrons to more to some spot to neutralize the space charge is approximately the same time that the electrons have to move away from the spot after the space charge has disappeared. By the time this has happened there is another bunch of particles on its way which requires neutralization. Richardson said that from an experimental point of view this looks right. He said they now obtain electron currents of the order of 1 microamp. The equivalent deuteron current is obtained by multiplying this figure by 40,000.

Alvarez asked if there were many ions lost in the center of this machine during the first few turns and whether it would be possible to make up these losses by the use of a more intense ion source. Thornton said in the center of this machine, the space charge problem is at least as bad as in other sections. He said with the 20-inch injector cyclotron used for the quarter-scale bevatron no trouble was experienced in getting a beam of 20 milliamps in a space of dimensions small compared to what we are after. Therefore, for the same dee height there is no doubt but what one could get the same currents. Lofgren said they did not attempt to go beyond the beam current of 20 ma with the injector cyclotron because there was no pressing need for such a development; therefore the 20-ma beam obtained does not represent the limit obtainable.

Richardson said the ion source for the full-scale machine will probably be about 3 inches in diameter and about 6 inches long and dee voltages of several hundred kilovolts will be available to pull the beam out of the ion source. With the large area obtainable from such an ion source it is not conceivable that the ion source could constitute a limit on the beam current obtainable.

Hildebrand asked what was the relation between the 250-Mev beam chosen for the cloverleaf cyclotron and the 350-Mev chosen for A-12. Thornton said that the choice for the cyclotron is based on an estimate of the ultimate value of β for which correction can be obtained by tailoring the magnetic field. It is anticipated that this will impose a limit of about 300 Mev for deuterons.

Hildebrand said CR&D is now trying to assemble the best available

knowledge to make an economic analysis of Mark III; that is, they are trying to tabulate the cost of product in dollars per gram versus the beam energy. Alvarez said that in the linear accelerator the neutrons become cheaper at higher energies because of the improved yield in the target. This improvement is offset in part by the fact that the shunt impedance at the high energy end of the machine diminishes, thereby increasing the cost per unit length; and, secondly, one requires a longer machine to attain the higher energies. Our best estimates at the moment are that the economic curve will have a plateau between 250 and 350 Mev and we can design for the low voltage end of the plateau. Hildebrand said their figures are not yet in final form but it appears that the plateau may occur at higher energies than estimated by Alvarez.

Brobeck asked if the energy limit of the cyclotron were not also influenced by resonant effects which result in a transfer of energy from radial to axial oscillations and hence result in loss of the beam. Richardson said that both limits exist but the limitation of the magnetic field shape is the more limiting one.

Thornton said they are planning to redesign the 20-inch injector cyclotron and equip it with 3-phase dees to test two specific points. The first of these is to test 3-phase dee operation at somewhat higher power than is possible with the electron model--that is, in the many kilowatt region rather than the few watt region--and, secondly, they will be able to investigate the ion currents that can be started off and captured into reasonably stable orbits with the field configurations one will have at the center. The redesign and conversion work will be completed about the end of July. This cyclotron will accelerate protons.

Hildebrand asked if there were any work contemplated now that would supply knowledge regarding the degree to which the beam can be brought out at specified points. Richardson said this work is continuing with the electron model. Richardson said that future work planned for the electron model consists of improvements in removing the beam--that is, studies of how and where the beam comes out and angles of emergence, and beam focusing.

Lawrence said that he and Fred Powell are going east tomorrow morning to discuss the Mark III proposal with the Commissioners. He said it would be his recommendation that work begin immediately on construction of Mark III at Livermore and that the Mark II engineering be carried on at the same time. By next Christmas or January we will know how Mark I operates. If its operation is successful he would recommend extending it and building Mark II at Livermore. This would save both money and time. Should Mark I run into trouble it would not interfere with the Mark III schedule and should Mark I prove inoperable much of

the power equipment for Mark I could be used for Mark III. Following this program we can be assured of being into production within two years. Thornton said that one aspect of building a high-energy cyclotron here in relation to the Mark II program was that there are quite a few problems associated with materials in the target end of Mark II and a few milliampere beam from such a cyclotron would be very valuable for testing materials for the Mark III target. Both types of machines will probably succeed and it will probably be found that each will have its place in the production program.

Alvarez said that successful operation of Mark III removes from further consideration the 12-megacycle, 60-foot diameter tank for Mark II because Mark III will be much more economical than the 12-megacycle Mark II. He said if you grant that the cyclotron is a sure thing, then a linear accelerator must be made quite efficient in order to compete economically with the cyclotron. Lawrence said that if Mark II is loaded down with a high beam current the unit cost of the product will be cheap enough to be inviting even with 12-megacycle operation. Lawrence said he agrees with Alvarez that at the present time emphasis should be placed on Mark III and we should consider designing a cyclotron having a beam current in the range between 50 to 300 milliamps. We should feel confident to guarantee a beam of 50 milliamps. Lawrence said in building Mark III one would start initially with small rf power supply and add to it as it became possible to go to higher beam currents.

Lawrence said that the optimum dee voltage is about 10% above the threshold and that the present electron model is more efficient at low dee voltages due to the increased vertical oscillations caused by the higher dee voltages but this latter effect would not be noticeable in a full-scale machine. Lawrence said that 200-300 KW are required for excitation of the dees to 310 KV to ground. Thornton said the exciting power will be 3 or 4 times that required for the 60-inch cyclotron.

Alvarez said that in the cyclotron the beam load will be of the order of 100 times the excitation power. Alvarez said that experiments with the electron model should include measurements of the beam outside the cyclotron to determine the amount of beam spreading. Thornton said that the full-scale machine will have positive damping as the beam goes out radially. The electron model does not provide for compensation for the 4th order terms in β and consequently is unstable in this regard. Alvarez said that it would be preferable to have the beam spread out in a slit since the solid angle through a slit hole is smaller than that through a circular hole for the same total beam and beam density.

Davis suggested that it might be advantageous to build Mark III with the pole faces vertical.

Lawrence stated, and Hildebrand agreed, that Mark II and Mark III should be built at Livermore and designed to produce tritium only, since the production of any other product would require more water than is available at Livermore unless a pipeline is run from the Mendota Canal. Reynolds said the cost of a 6-inch pipeline to bring additional water from the Mendota Canal would be approximately $500,000.

Hildebrand said that at the time the Mark II engineering report was prepared there was more optimism about a variable target than there is today. He suggested it would be advisable to call this shift in emphasis to the attention of the Commission.

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