RECENT PROGRESS ON THE ORNL Mc² CYCLOTRON

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Our approach to the planning of a facility such as Mc² is to develop a complete integrated system which to a high degree of confidence is workable. The system can then be improved by modifying the various components while, at the same time, taking into account the effect of the individual improvements on the overall system.

Last year at Los Angeles, we reported on Mc² as a workable system[1]. Since then we have been developing improved concepts for various features, such as: beam extraction, ion optics, material activation, magnet, RF cavities, vacuum system, and building layout. I will discuss some of the salient developments in these areas. Beam extraction, ion optics, and material activation have already been discussed in some detail by previous speakers at this Conference. However, these studies are significant enough to warrant comments on their overall relation to the project.

Extraction studies[2] have been made primarily on the Mc² Analogue with favorable results, and the translation of that extraction system to full-scale Mc² would require more than 700 kV/cm. However, a 3 kG reduction in the base magnetic field is equivalent to this. These values dictate the use of a magnetic extraction system. Two magnetic channel systems are being considered for the full-scale version. One is the ORIC type coaxial channel which has already been described at this Conference[3]. The other is a current sheet and iron combination as shown in Fig. 1. The current sheet would be formed of multiple conductors of about 0.3 cm radial thickness. The iron would be about the same thickness, so the total thickness, including mounting and insulation might be about 1 cm. This is a variation of the compensated-iron channel used in ORIC. The calculated field contribution is shown in the curves below the channel sketch. The cyclotron magnet field shape is shown by the medium dashed line, the contribution of the current sheet (105 ampere turns) is shown by the short dashed line; and the net effect is the solid line. These channels would need to provide a base magnetic field reduction of about 3 kG for a length of about 5 m.
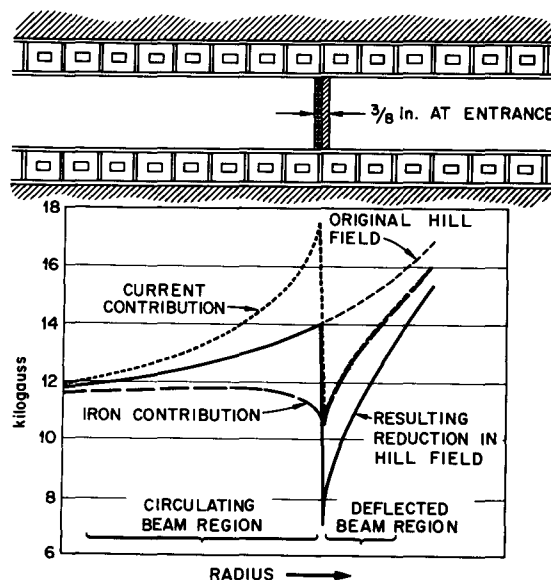

Fig. 1 Effect of iron and current sheet in a magnetic gap.

It is felt that the Analogue extraction system, including an adequately thin septum, can be scaled from the Analogue to Mc^2 by proper use of one of the two magnetic channel designs.

The increased interest in the use of Mc^2 for nuclear structure studies has made additional demands on the ion-optics system[4]. A drawing of one of the layouts studied is shown in Fig. 2. The need for high intensity and high resolution for protons suggests two beam paths into the proton room, since resolution and intensity are not, in general, compatible. The cyclotron is positioned to direct the deflected beam down the corridor with a minimum of bending so that the maximum intensity beam will be available. The intense beam of protons is then transported in to the proton room through a high transmission single 43° magnet.

The proton analysis system shown is calculated to provide an energy dispersion of 40 keV/mm at the image slit. This is accomplished in this study with a single n = 0.5 magnet with a radius of about 5 m and operating with a magnification factor of 2.7. The switching magnet, together with anti-scattering slits, will be used to clean up slit scattering. Future studies of the analysis system will examine alternate locations of slits, factors effecting optimum magnification, and more complex combinations of magnets.

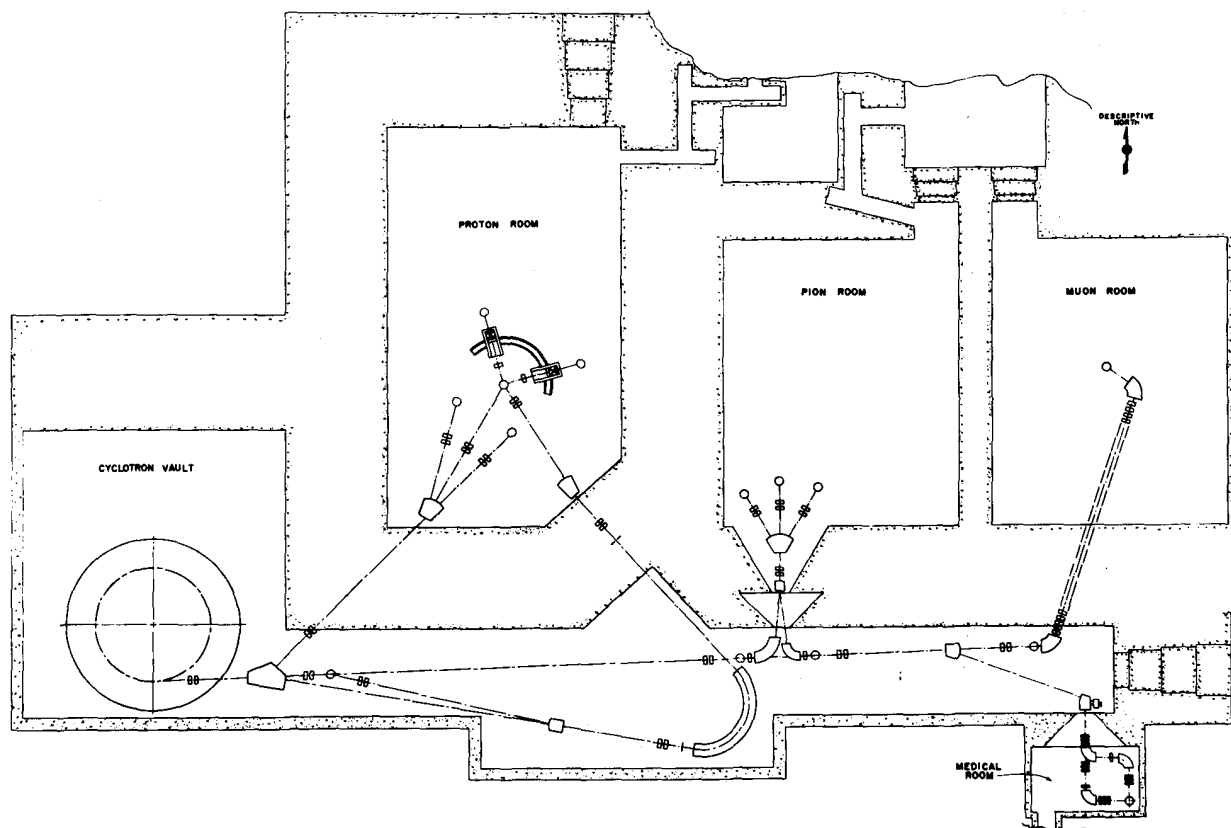For purposes of economy and simplicity, a polarized proton target is so

Fig. 2 Mc^2 ion-optics layout.

arranged that the polarized protons can be directed through the same analysis system.

Pions will be produced in the corridor and directed into the second shielded room with a reasonably short-path length to minimize loss by decay. Pions will also be produced in the corridor opposite the third shielded room and directed toward the room. A CERN-type muon channel will transport the decay muons into the experimental area. Provisions will be made for a medical facility which would provide pions to be utilized for medical purposes.

Several shielded-area arrangements have been studied, e.g., arrangements were considered with rooms on each side of the corridor and with the rooms fan-shaped around the cyclotron room. The arrangement shown here was selected as providing good flexibility and economy.

The technological advances resulting from the recent computations and experimental work of Toth, Fulmer, and Barbier[5,6] provides a very useful means of predicting residual activity levels and thereby a firm basis for developing new and novel solutions to the general radiation problem.

One essential part of the Mc^2 development program is a realistic appraisal of the radiation levels that will be encountered not only during operation of the cyclotron but after the machine is turned off for maintenance, repairs, and changes in the experimental setup. The beam intensity will be two to four orders of magnitude higher than in existing accelerators in the same energy range.

In the machine itself, the residual radiation levels will not increase in proportion to the beam intensity because the extraction efficiency (as indicated by tests with the Analogue) will be of the order of 80-90%. Protective coverings of carbon can be used in certain parts of the cyclotron to reduce the amount of induced activity. The indications are that with high beam quality and with advanced machine fabrication techniques, the residual radiation levels around the cyclotron will not be greatly higher than in existing machines of much lower beam intensity.

The high-intensity external beam will, however, present serious activation problems. The residual radiation studies have emphasized the need for careful planning of the external beam optics system. It is believed that a realistic appraisal, in the planning phase of Mc^2, of the residual radiation will enable us to meet these problems in such a manner as to permit necessary maintenance work without large delays due to residual radiation.

The Mc^2 magnet has been studied with particular interest directed toward increasing magnet efficiency. The concept as described at Los Angeles[1] was further studied with respect to the iron pole-tip gap and the pole-face conductor thickness, keeping the cyclotron aperture constant. A significant reduction in power over that for the first Mc^2 magnet model can be realized. Some of the results of this study are shown in Fig. 3. The Mc^2 magnet would fall near the 50% efficiency line. Because of the initial cost of copper, an iron gap of 25 to 30 cm would be chosen. A study
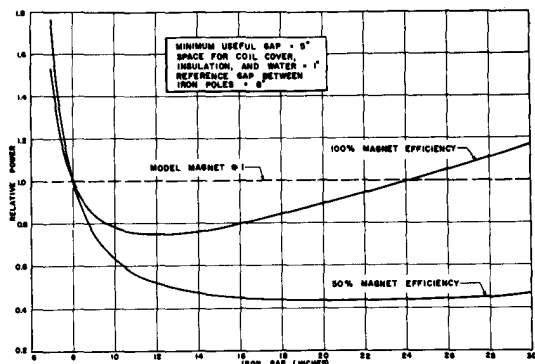
Fig. 3 Relative power for the Mc² magnet versus the iron-
pole-tip gap, keeping the cyclotron aperture
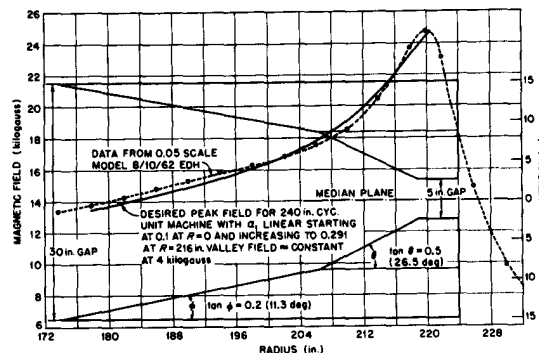constant and varying the pole face conductor
thickness.

Fig. 4 Model data of shaped pole tips designed to produce
the desired Mc² magnetic field.

was made of a magnet concept which would provide the desired field shape by shaping
the pole-tips; excitation coils would be located around the yoke of each pole-tip.
Model data, as shown in Fig. 4, indicates this can be accomplished. Detail design
studies may well use a combination of pole-face windings and pole-tip shaping.

Studies[7] of the Mc² acceleration system have resulted in a choice of what we
call a coaxial cavity. A photograph of a model cavity is shown in Fig. 5. This
cavity, full-scale, will enclose two pole-tips and be about 8 m high and 9 m along
one side.

There will be two such cavities to provide acceleration at four azimuths
amounting to 1 MeV/turn. This cavity would be driven by two 500 kW RCA 6949 shielded-
grid triode tubes operating in push-pull. The frequency would be 13.7 Mc/s, which is
the second harmonic of the ion-orbital frequency. The primary studies now under way
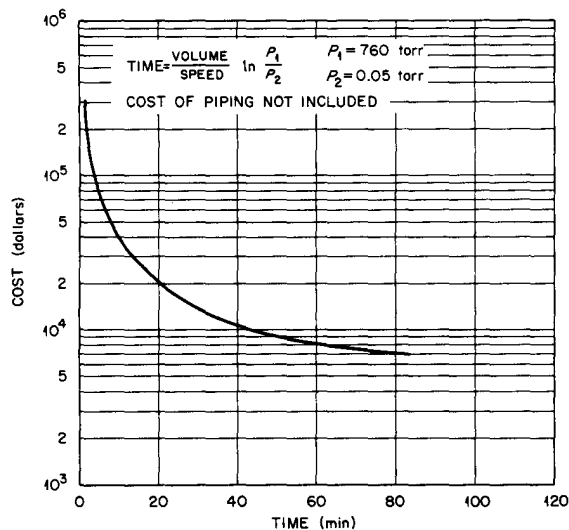concern methods of fabrication and assembly techniques.

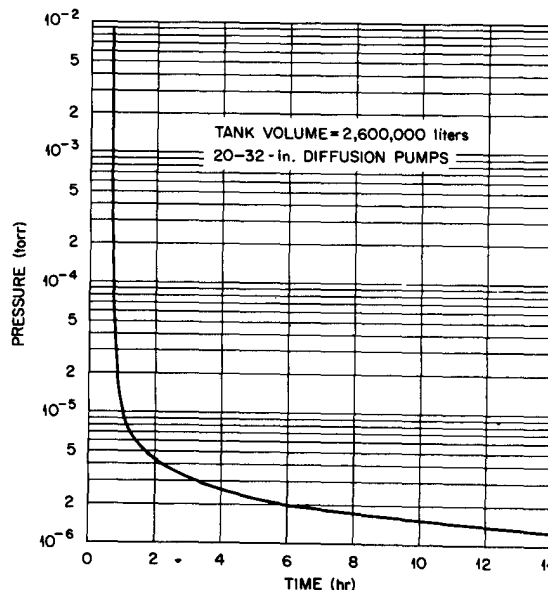Fig. 6 Cost of rough vacuum system versus time required
to obtain 0.05 torr.

Fig. 7 Time versus pressure for twenty oil diffusion
pumps of 32-in. diameter.

The vacuum system for Mc^2 is rather large. The volume of the vacuum tank is approximately 2.6 x 10^6 litres. A study was made of the pump-down system, and a cost versus pump-down time curve was developed, see Fig. 6. A pump-down time of about 30 min will be chosen.

The calculated pressure as a function of time for the Mc^2 tank is shown in Fig. 7 (30 min rough-down time is included). These data are based on tests in ORIC in which all mild-steel surfaces are nickel-plated. The nickel plating in ORIC is a significant factor in the ability to go from atmospheric pressure to a stable proton beam at full radius in less than 40 minutes.

The outside appearance of the building is essentially the same as one year ago. However, for continuity, a picture of a building model is shown in Fig. 8.

The office and laboratory building is shown at the front. This will provide space for about 100 technical people. The forepart of the building on the right is the shop, service, and staging area for the cyclotron. The back part of the building contains the cyclotron and shielding. The experiment rooms are underground and to the back of the office and laboratory building. The proton-experiment room has concrete walls 12 m thick. The roof is concrete arch construction with 10 m of earth. The pion and muon rooms have 5 m thick walls, arch roofs, and 5 m of earth.

The technology for the construction of an Mc^2 type cyclotron is now at hand. The need for a high-intensity beam of 800 MeV protons is well established. Our most pressing problem is a matter of the 0.4 pittances (p = 10^8) with which the facility can be realized.

References

1. R.S. Livingston, et al., Nucl. Instr. and Meth., 438, <u>18-19</u>, (1962).
2. J.A. Martin, et al., see paper II-2.
3. R.S. Lord, et al., see paper IV-9.
4. E.E. Gross, et al., see paper IV-4.
5. C.B. Fulmer, et al., see paper IV-7.
6. M. Barbier and C.B. Fulmer, et al., see paper IV-8.
7. S.W. Mosko, et al., see paper VI-9.

DISCUSSION

WRIGHT : Have you made any measurements of the flutter factor for the case of the coil-free pole-tip arrangement?

MARTIN : For the particular design shown we would have to include coils or saturated iron near the medium plane to obtain the proper flutter factor near the centre of the cyclotron.

WRIGHT : What are your plans for injection?

MARTIN : It is our intention to study d.c. injection systems, the exact energy at which we will inject is not yet decided. There are many advantages to such systems. It would give use greater control over the ability to change the injected phase, would permit pulsing of the beam, and would result in much lower radial amplitudes. We would like to inject with a d.c. accelerator probably under 1 MeV.
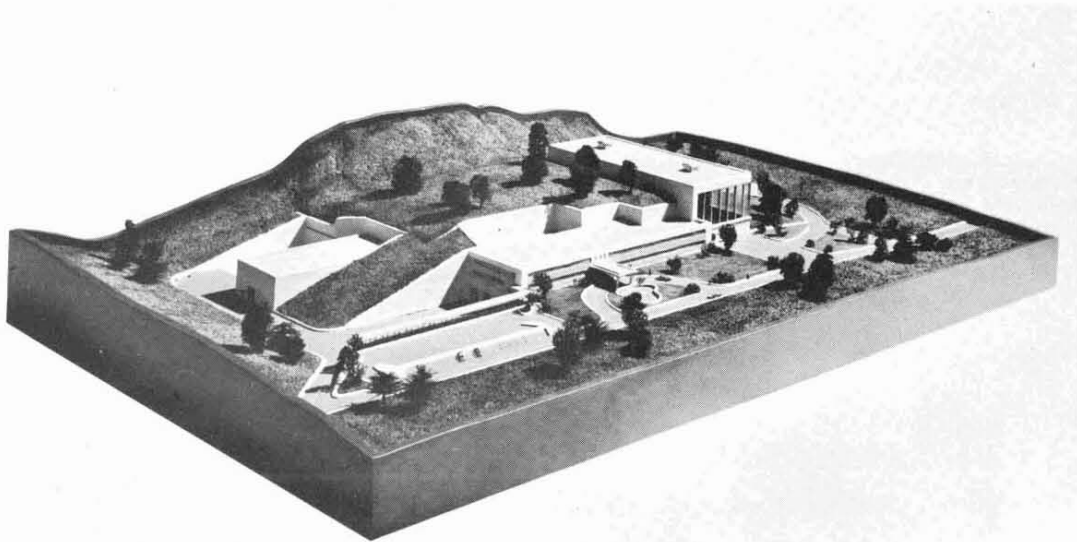
Fig. 5 Model of Mc² coaxial cavity.

Fig. 8 Scale model of the Mc² facility.

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BLASER : Regarding the current-sheet septum you sketched, what percentage of beam do you intercept with this 3/8" septum, and to what current densities are you obliged to go in the copper to get this 3 kG reduction?

JONES : The efficiency we would expect to get is 80-90%. This depends somewhat on being able to get a little bit more orbit separation or decreasing the 3/8" thickness a little bit. I think that we can do both if necessary. The current density, this is the total current in that section, is 100.000 A with a cross-section 3/16 x 5 in.

MARTIN : The current density is, in fact, quite high on the leading edge of that particular septum design. It need not be so thin except at just the beginning of the extractor.