IEEE Transactions on Nuclear Science, Vol. NS-26, No. 3, June 1979

THE HOLIFIELD HEAVY ION RESEARCH FACILITY - PHASE II

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Summary

The Holifield Heavy Ion Research Facility, with the completion of Phase I in late 1979, will include the Oak Ridge Isochronous Cyclotron (ORIC) and associated research areas, the new 25 MV tandem accelerator with new research areas for tandem beams, and modifications to utilize the ORIC as a booster accelerator. The combination of the tandem and ORIC will provide beam energies of 25 MeV/A for light heavy ions and 6 MeV/A up to A = 160. This paper discusses plans for a Phase II expansion of the facility to include an isochronous cyclotron with superconducting magnet and reconfiguration of the existing research areas and the ORIC vault to handle the higher energy beams from the new cyclotron. The new booster cyclotron is a low-flutter high-spiral design patterned after the MSU K = 800 design, with a central magnetic field of about 5 tesla and an extraction radius of 1 meter. The new beam transport system will incorporate an rf beam-splitter system that will be able to deliver successive beam pulses to two or three experiment areas.

Introduction

In 1975, Oak Ridge National Laboratory received funding for the first phase of a national heavy ion laboratory later to become known as the Holifield Heavy Ion Research Facility (HHIRF) in honor of Congressman Chester A. Holifield, long-time member of the Joint Committee on Atomic Energy. The Phase I construction, including the 25 MV folded tandem, research areas for tandem beams and a system for use of the ORIC as an energy booster, will be completed in late 1979. It is anticipated that construction of Phase II of the facility will begin in 1981.

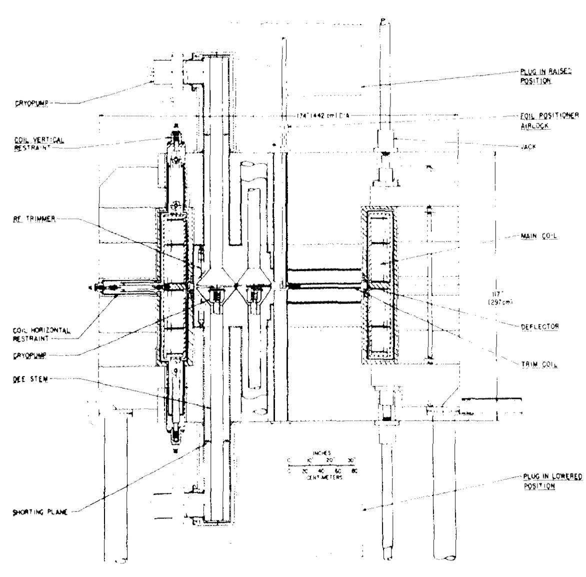

Fig. 1. Elevation cross section of proposed HHIRF cyclotron with superconducting magnet coils.

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Research sponsored by the Division of Basic Energy Sciences, U.S. Department of Energy, under contract W-7405-eng-26 with the Union Carbide Corporation.

The New Cyclotron

The new cyclotron is based on concepts and details of work at other laboratories, notably Michigan State University[1,2,3], Chalk River Nuclear Laboratories,[4] and the University of Milan.[5] It is presently planned that the iron and coil configuration of the magnet (Fig. 1) will be essentially identical with the most recent design of the K = 800 MSU magnet.[3] The principal departures from the MSU design will be in coil structure, cryogenics, radio frequency system, and vacuum system. The rf system will have a different and more optimum frequency range because there are no matching requirements for synchronous operation as at MSU where the K = 500 cyclotron is used as the injector. Figure 2 shows a comparison of ion mass/ion energy characteristics of Phase II with other facilities. The characteristics of the HHIRF 25 MV tandem provide superior performance for very heavy ions. The somewhat poorer performance for light ions is a result of injection limitations as revealed by preliminary and incomplete analysis. Further work may suggest improvements. The principal characteristics of the cyclotron are given in Table I.

Table I
Superconducting Cyclotron Characteristics
(Design Goals)

Energy constant, bending, K_B,[1] MeV/A	1200
Energy constant, focusing, K_f,[1] MeV/A	400
$B\rho_{max}$, tesla meter	5.08
Average beam radius, extraction, meter	1.02
Number of sectors	3
Magnetic field spiral, radians, cm	θ = R/33
Injection radius, cm, min, max	13-30
Energy gain ratio, E_f/E_i, min, max	10-60
Frequency range, MHz	36-54
Harmonic range	2-5, 7-8
Dee angle, degrees	60
Rf power (115 kV, 54 MHz), kW/dee	100
Magnet weight, U.S. tons	260
Magnet height, meter	2.97
Magnet diameter, meter	4.42

[1]The achievable energy may be limited by bending capability according to $E = K_B\, q^2/A^2$ or by focusing as $E = k_f\, q/A$.

Cyclotron Magnet

The operating magnetic field range is from approximately 3 to 5 tesla, thus the magnet pole tips and yoke will be fully saturated. The yoke will be cylindrical, with removable sections at the top and bottom for access to the gap. These plugs will be removable by means of permanently attached jacks. The main coils will be of stabilized NbTi superconductor immersed in liquid helium at atmospheric pressure.

To accommodate the desired range of particle energies it is necessary for the radial gradient of the field to vary from nearly flat to a profile that rises approximately 0.7 T from the center to extraction radius. Each of the two main coils is divided into two independently powered sections that are used to shape the field to the desired profile to within a small difference. The remaining difference field can

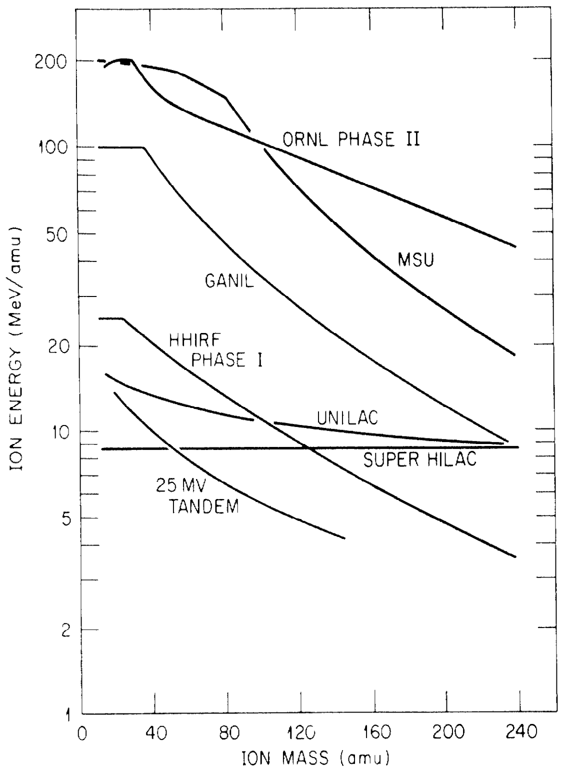

Fig. 2. Comparative performance of HHIRF Phase II and other heavy ion accelerators

be compensated adequately with trimming coils on the pole surfaces. By unbalancing the trim coil currents in the several sectors, first harmonic errors can be reduced to satisfactory levels. It is expected that higher order harmonics can be controlled by careful design and fabrication techniques. As in the Michigan State design, the trim coils will be at room temperature with the conductor wrapped around the pole tips. The total power will be about 60 kW in the 22 coil pairs per pole.

The computer program TRIM[6] is used to determine the azimuthally averaged magnetic field produced by the equivalent axially symmetric iron distribution. The program SATB[7] calculates the field of the 3-sector pole tips and iron distributions that influence the azimuthal variation in the magnetic field. Isochronism, focusing, and injection/extraction studies are made through use of the General Orbit Code (GOC).[8]

Radio Frequency System

The rf system operates over a frequency range of 36 to 54 MHz to accommodate the requirements of the energy range 5 to 200 MeV/A using harmonics (ratio of rf to orbit frequency) 2-5 and 7-8. Three accelerating electrodes are provided, one in each valley. The electrodes are spiral shaped with an azimuthal extent of 60°. The dees are mounted in the midplane of a double conductor $\lambda/2$ coaxial resonator. The double-line configuration gives a large conductor cross-section within the narrow space available but retains the simplicity of coaxial lines. This system provides a minimum voltage gain per turn of 600 kV with a dee voltage of 115 kV. Coarse tuning is provided by a moveable shorting plane system; fine tuning is by variable capacitors. The maximum power required is approximately 100 kW for each of the three dee-resonator systems. EIMAC 4CW100,000E tetrodes in Class AB_1 with broad-band drivers will be used.

Vacuum System

Design pressure for the accelerator region is 10^{-8} torr to avoid significant losses from charge exchange. A two-region system is used. The beam and rf space are pumped by cryosystems. Cryopanels above and below the median plane within each dee pump the beam space and nearby regions. The rf resonator stems are pumped by commercial 10-in. cryopumps. The outside of the rf liner and the trim coil spaces are pumped by a Roots blower system. The mechanical pumps and the 10-in. cryopumps are also used to evacuate the cryostat before cool-down.

Beam Injection and Extraction

The beam injection system depends on stripping to capture the beam into the correct orbit for acceleration. Typically the charge-change from stripping will be a factor of three or more. The system to be used on this cyclotron is based on reversing the spiral of the magnet pole tips near the center, as developed by Bellomo, Fabrici and Resmini.[9] That arrangement has the distinct advantage of placing the stripper on a hill (not in the rf electrode in the valley) with the attendant advantages of better accessibility and mechanical simplicity. It appears conceptually possible to inject from a common point to a stripper within the full azimuthal limits of the hill but this feature has not been investigated over the full range of injection requirements.

Precision extraction at $\nu_r = \sim 0.8$ will be used to develop turn separation. As in the MSU design,[2] three electrostatic and five passive magnetic elements will be used. The magnetic elements provide gradient correction to compensate the gradient of the fringing magnetic field of the cyclotron.

Beam Bunching

To achieve the desired energy resolution of $\sim 0.1\%$, the beam injected into the cyclotron should be bunched to ± 3°. This corresponds to 0.3 to $\sim$ 0.56 ns over the frequency range of the cyclotron. A three-stage beam bunching system will be used to achieve a bunching efficiency of about 70%. The three systems include a two-frequency double-drift buncher at the tandem entrance similar to the one developed for Phase I,[10] a terminal buncher operating at a high harmonic of this buncher frequency and a phase correction cavity following the tandem. The high-energy phase stabilizer is provided to correct small phase errors as may arise from microdisturbances in the tandem high energy accelerating tubes.

Research Areas and Beam Transport

The arrangement of the new facility is shown in Fig. 3. The beam transport system and research areas were designed to make maximum use of existing (Phase I) equipment and to minimize the impact on the research program during construction. It will be possible to construct the cyclotron vault and assemble and test the cyclotron with only minimal influence on the research programs using ORIC and the tandem. It is expected that the period of transition from operation with the ORIC to operation with Super-ORIC can be held to about a year.

There will be seven beam lines with several long enough to accommodate more than one target station. The "beam splitting" system (Figs. 4 and 5) is an important feature of the new transport system. It consists of a 2 m-long set of rf deflection plates and a 4 1/2-deg septum magnet. Two conventional bending magnets follow the septum magnet. Small steering magnets precede and follow the deflection plates. By operating the deflector plates on a subharmonic of the orbit frequency, beam pulses can be alternated between any two of the principal beam lines or shared among all three. For operation in a single beam line, the deflector plates are not used and displacement is provided by the steering magnets. This system, then, provides the capability for accommodating up to three simultaneous experiments. A deflector system on the beam line from the 25 MV tandem allows similar sharing of the beam from the tandem.

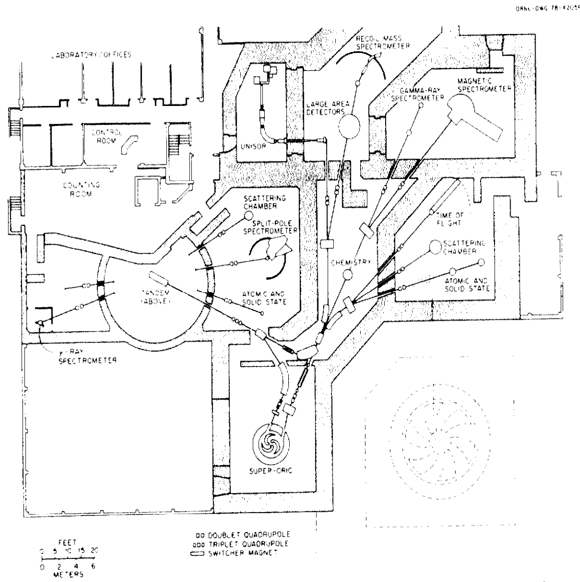

Fig. 3. Proposed facility layout for HHIRF Phase II and Phase III (dotted)

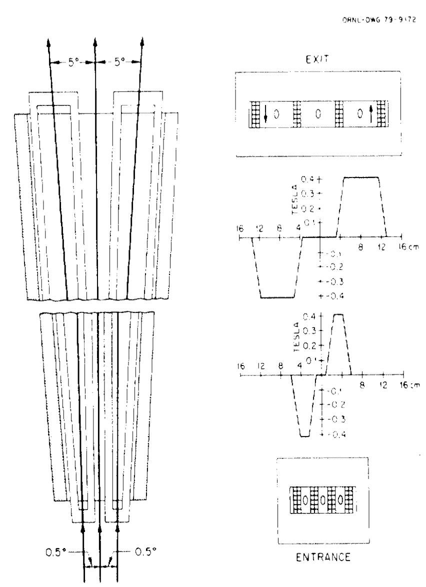

Fig. 4. Septum magnet with fields as calculated by TRIM

Possibilities for the Future

The Phase II facility described will provide capabilities to meet many of the present needs of nuclear physics and chemistry research. It is reasonable to anticipate that future requirements for higher energy, high intensity beams may develop. To meet that need, several possibilities for increasing the energy are being reviewed. One attractive option appears to be an additional cyclotron acceleration stage. The dotted lines on Fig. 3 outline the concept of a six-sector weak-spiral cyclotron with superconducting sector magnets providing a peak magnetic field of about 5 tesla and an average magnetic field of about 2 tesla. The cyclotron would provide light heavy ions to 600 MeV/A without stripping between the two cyclotrons. Maximum uranium energies would be 105 MeV/A ($\sim 10^{11}$ particles/sec) without stripping and 340 MeV/A ($\sim 10^{10}$ particles/sec) with stripping.

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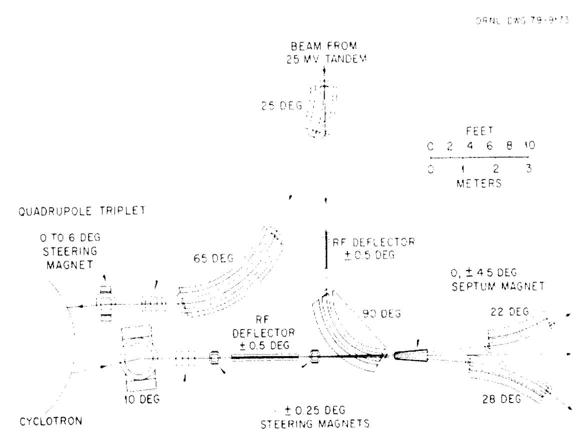

Fig. 5. Beam-splitting system with rf deflectors and systems magnets