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STATUS OF THE HOLIFIELD HEAVY ION RESEARCH FACILITY

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Summary

The Holifield Heavy Ion Research Facility presently operates the Oak Ridge Isochronous Cyclotron (ORIC). This accelerator provides heavy ions up to argon with energies useful for nuclear physics. The Phase I expansion of this facility, now a year away from completion, includes a 25-MV vertical folded tandem accelerator, beam transport and injection systems to use the ORIC as an energy booster, and additional experiment areas for the beams directly from the tandem. The tandem—cyclotron combination will provide heavy ions with energies up to 25 MeV/A for A < 35 and above 6 MeV/A up to A = 160, with intensities $\gtrsim 10^{11}$ particles/sec. Building construction for the project is essentially complete. The accelerator manufacturer, National Electrostatics Corporation, has completed installation and testing of the 10-m-diam by 30-m-high accelerator pressure vessel and has begun installation of the accelerator systems. The accelerator has previously been assembled at the NEC plant and the digital control system operated without voltage on the column. Voltage tests are expected to begin in Oak Ridge in January 1979 with beam tests to begin in March. Completion of the project, including acceptance tests of the tandem and the beam injection system for ORIC is presently scheduled for November 15, 1979. Construction of Phase II for the facility which will include a much larger booster cyclotron and additional research areas is expected to begin in 1982.

Introduction

Oak Ridge National Laboratory has a long association with heavy ion research. The first accelerator designed specifically for multicharged heavy ion acceleration, the ORNL 63-Inch Cyclotron, began operating in the spring of 1952. This machine provided 30 MeV N^{+3} ions. Design of the Oak Ridge Isochronous Cyclotron (ORIC) began in 1957 and the first extracted beam was obtained in 1962. In the early days of operation of the ORIC, the main emphasis was on acceleration of light particle beams: p, d, α, ^{3}He, to energies previously unavailable, but during the last several years there has been a strong resurgence of interest in research with heavy ions. These days, approximately 90% of the beam time of ORIC is devoted to heavy ions. The capabilities of the ORIC are limited, however, and generally useful for nuclear physics research to ions with A ≤ 40. Since the late sixties, we have been studying various heavy ion accelerator concepts to remove the energy limitation. The present project grew out of our 1972 proposal for a National Heavy Ion Laboratory which included a large tandem and a K = 400 separated sector cyclotron as an energy booster. In the summer of 1973 we proposed the beginnings of the present Phase I project, which included the concept of the tandem injecting into the ORIC as an energy booster, with the plan that a Phase-II project to include a more powerful cyclotron would follow. The energy-mass characteristics of Phase I are shown in Fig. 1.

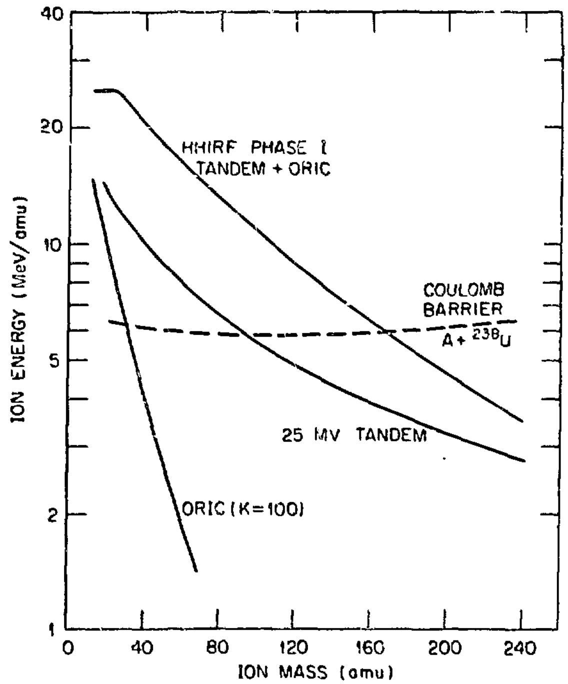

Fig. 1. Ion energy/ion mass characteristics for HHIRF Phase I. The curve for the 25 MV tandem is for gas stripper in terminal and foil stripper 1/3 down H.E. tube. Curves for tandem and tandem/cyclotron are for $\sim 10^{11}$ particle/sec.

Construction Status

Official groundbreaking for the construction of the new buildings was held April 5, 1975. The site preparation and foundation construction, done under a separate contract, were completed February 15, 1976. The building contractor began work May 5, 1976. Building construction is now nearly complete with only a few minor items and some cosmetic work remaining to be done. Figure 2 shows a recent photograph of the new facility. Installation of the beam transport systems, the ORIC injection system and the accelerator will be well underway in November. The elevation-section, Fig. 3, shows the arrangement within the building.

The 25 MV Tandem

The 25 MV tandem electrostatic accelerator is being manufactured by National Electrostatics Corporation to meet the construction and performance criteria[1] and specifications[2] developed by the HHIRF staff in consultation with prospective accelerator manufacturers and expert consultants. The selection of the manufacturer was by competitive bidding. The contract for the accelerator system includes construction and installation of the accelerator, its pressure vessel, the ion injector and ion source systems, the 90° energy analyzing system for the accelerated beam, and the design and equipment for the gas transfer and storage system. The principal characteristics of the accelerator and ancillary systems are given in Table I. A schematic drawing of the accelerator system is shown in Fig. 4.

The most notable departure from conventional practice is the folded design of the accelerator which makes the high voltage column significantly shorter

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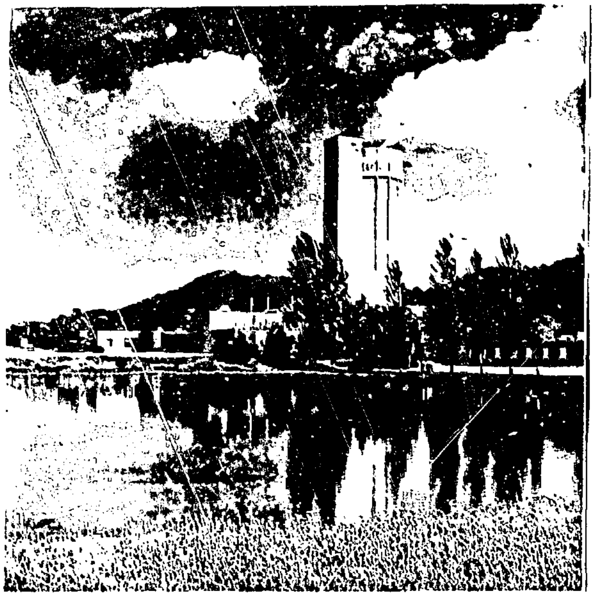

Fig. 2. The new facility as it appeared September 15, 1978

Table I

TANDEM ACCELERATOR PHYSICAL CHARACTERISTICS

PRESSURE VESSEL DIAMETER	33 ft
PRESSURE VESSEL HEIGHT	100 ft
COLUMN DIAMETER	11 ft
COLUMN HEIGHT	62 ft
TERMINAL DIAMETER	13.3 ft
TERMINAL HEIGHT	16 ft
INSULATING GAS	SF_6
MAX. OPERATING PRESSURE	125 psi (absolute)
PROBABLE OPERATING PRESSURE	80-110 psi (absolute)
CHARGING SYSTEM	DUAL "CHAIN BELT" WITH TOTAL CAPACITY IN THE ORDER OF 50 hp
SF_6 STORAGE VOLUME	6000 ft^3
STORAGE PRESSURE, MAX.	600 psig
COMPRESSORS	2 × 450 hp
VACUUM PUMPS	3 × 800 cfm (3 × 40 hp)
GAS TRANSFER TIME:	
STORAGE TANKS TO ACCEL. VESSEL	10 hr
ACCEL. VESSEL TO STORAGE TANKS	10 hr

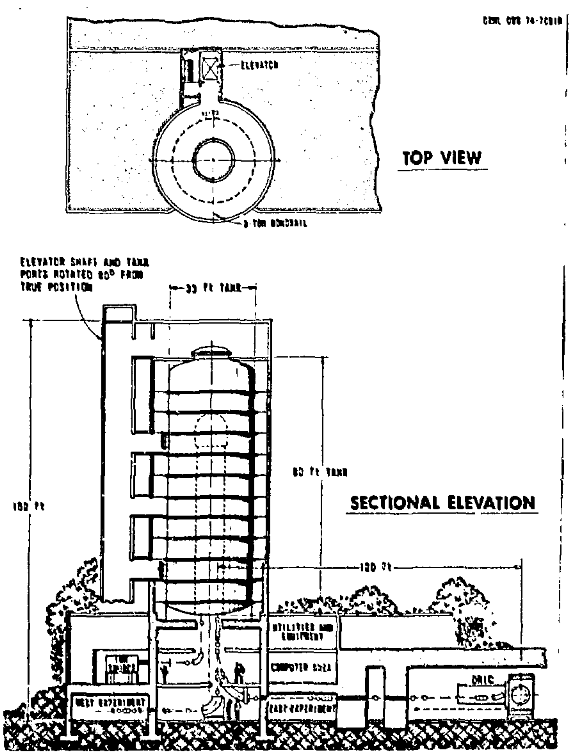

Fig. 3. Elevation section of the Phase I building addition

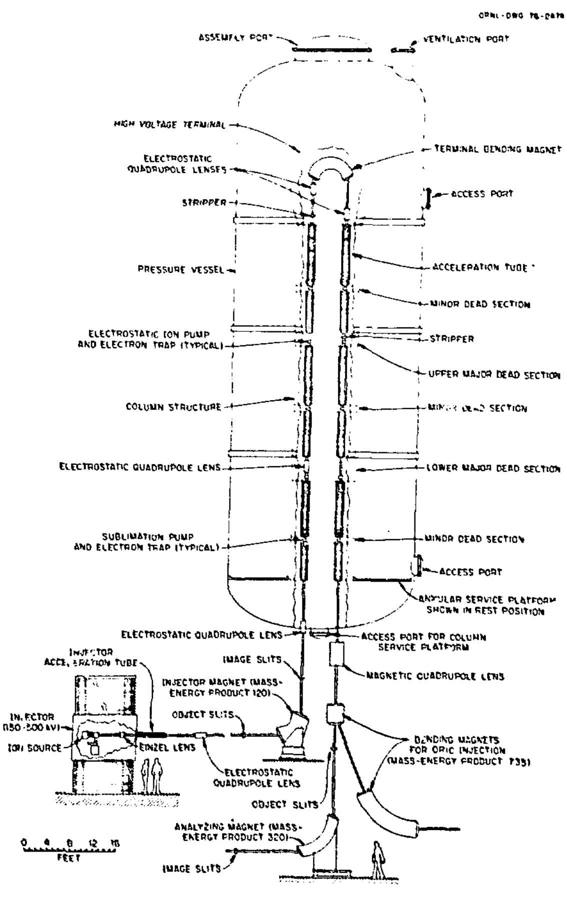

Fig. 4. Schematic drawing of the 25 MV folded tandem accelerator system

and reduces the pressure vessel and building size. The 180° magnet in the terminal will provide essentially perfect charge state separation following the terminal stripper. Performance characteristics of the accelerator are given in Table II. Reference 3 gives a detailed analysis of the phase space and emittance characteristics of the accelerator.

Table II

PRELIMINARY TANDEM PERFORMANCE CHARACTERISTICS

ION MASS	12 TO 250
ANALYZED BEAM INTENSITY	1.0 μA
MAXIMUM ANALYZED BEAM EMITTANCE*	0.4 [illegible]
OPERATING TERMINAL POTENTIAL	7.5 TO 25.0 MV
TYPICAL BEAM ENERGY STABILITY	[illegible] 2 keV × ACCEL. ION CHARGE NUMBER
MAX. INVARIANT EMITTANCE FOR INJECTED ION BEAM^b	0.2 × TANDEM TERMINAL POTENTIAL MV [illegible] mrad MeV
INJECTED ION ENERGY	150-500 keV
INJECTOR MAGNET	
a) mE/q²	120
b) MIN. MASS RESOLUTION	1/250 (FWHM)
ANALYZING MAGNET	
a) mE/q²	320
b) MIN. ENERGY RESOLUTION	1/1000 (FWHM)

*FULL AREA ($x_0 x_0'$ π)

^b FULL AREA ($x_0 x_0'$ π) MULTIPLIED BY (INJECTED ION ENERGY)[illegible]

A further departure from conventional practice is the digital control system which provides multiplexed communication between the accelerator and the operating console. The control system uses CAMAC serial highways, communicating with the control and supervisory computer and the control console through message switching and data storage units. The control system uses two Interdata Model 7/32 computers. One of the computers is used directly in the control function. The other computer has direct access to the data stored in the control computer and will be used for logging and surveillance as well as off-line program development.

Since the signing of the contract for the accelerator, the construction has progressed smoothly. Some key dates in the progress of the construction and installation are given in Table III. The most recent key achievement was the completion of testing of the accelerator column (in air) and the injector system under computer control. Those tests were completed on September 29; the accelerator is presently being disassembled and packed for shipment to Oak Ridge. It is anticipated that tandem installation will be at full activity in Oak Ridge by mid-November.

Photographs of the accelerator during various stages of manufacture and assembly in Madison are shown in Figs. 5-8.

Table III

TANDEM CONTRACT SIGNED	MAY 22, 1975
ACCELERATOR DESIGN/ENG. COMPLETE	NOVEMBER 1975
ACCELERATOR TUBES COMPLETED AND TESTED	JULY 1976
SUPPORT POSTS ASSEMBLED AND TESTED	SEPTEMBER 1976
FIELD ASSEMBLY OF PRES. VESSEL STARTED	JANUARY 1977
INSTALLATION OF PRESSURE VESSEL COMPLETED	JANUARY 1978
COMMISSIONING OF SF_6 STORAGE SYSTEM RECEIPT OF FIRST SHIPMENTS	MARCH 1978
TESTING OF ACCELERATOR IN NEC PLANT UNDER COMPUTER CONTROL	SEPTEMBER 1978
SHIPMENT OF ACCELERATOR COMPONENTS TO OAK RIDGE, INSTALLATION BEGINS	NOVEMBER 1978
COLUMN VOLTAGE TESTS BEGIN	JANUARY 1979
COMPLETION OF BEAM TESTS	SEPTEMBER 1979

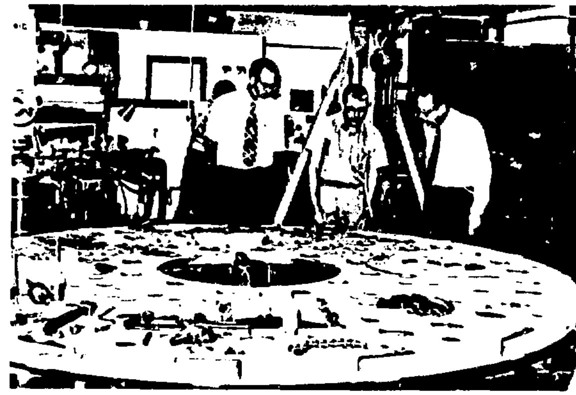

Fig. 5. One of the 11-ft-dia bulkhead castings of the high voltage column structure. The large center hole allows passage of the column service lift.

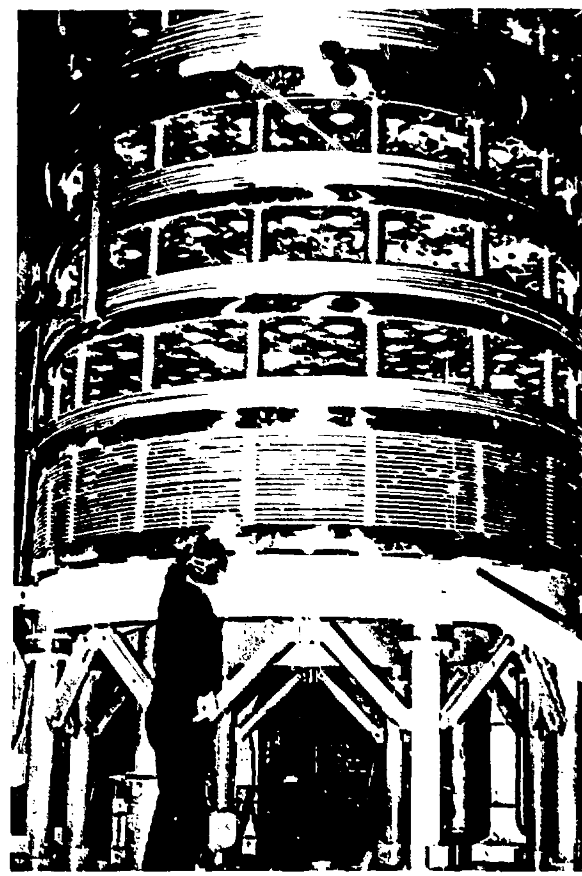

Fig. 6. The lower six sections of the high voltage terminal for the 25 MV accelerator. The structure seen under the hemisphere is the support for the 180° magnet.

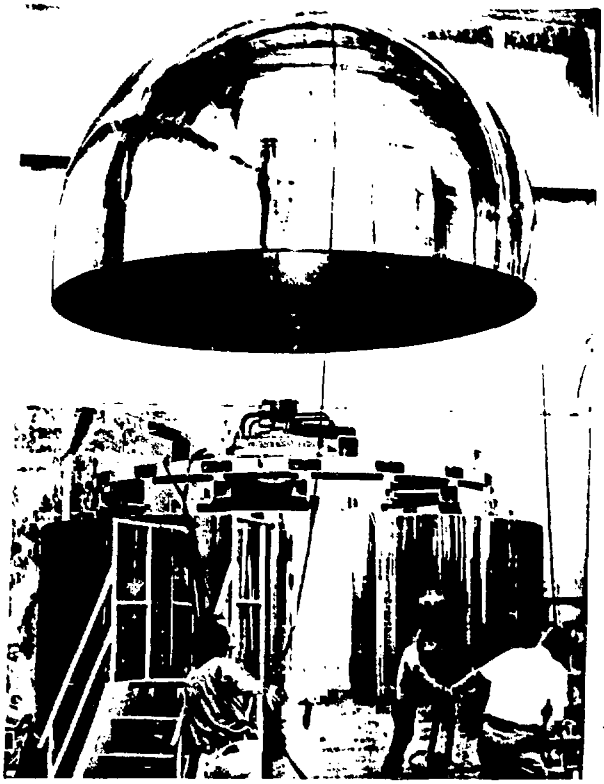

Fig. 7. The partially completed high voltage terminal for the 25 MV accelerator. The structure seen under the hemisphere is the support for the 180° magnet.

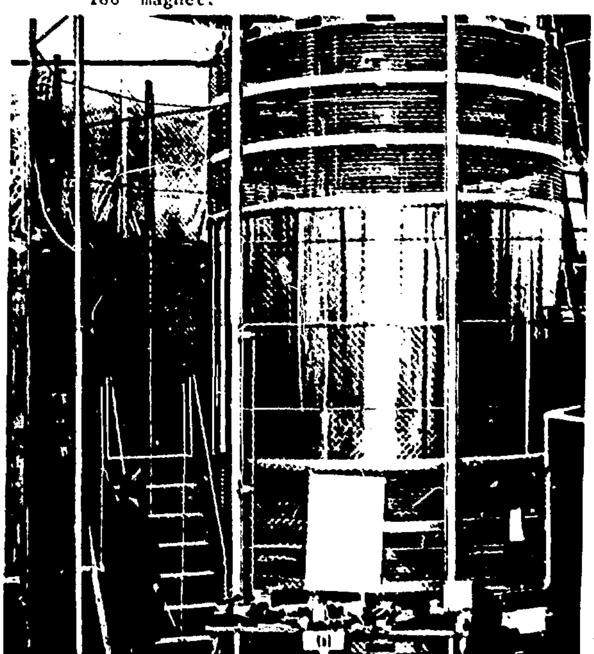

Fig. 8. The 500-kV injector and ground shield. The injector system is potential-graded, both top and bottom, using the same bulkhead-insulator system as the main column.

The pressure vessel for the accelerator was built by Chicago Bridge and Iron Company under subcontract to NEC. Preformed sectors of the vessel were shipped to Oak Ridge by rail and assembled into subsections at the site. The vessel was assembled within the completed tower during the last half of 1977; pressure testing of the vessel was completed in January 1978.

The installation of the gas transfer and storage system is complete and the system has undergone pressure and vacuum testing and some operational testing has been done using air. Final operational testing awaits completion of the connections between the accelerator pressure vessel and the gas transfer and storage facility. The first shipment of SF_6 was received in February; the final shipment, received in October, brought the inventory to 280,000 pounds.

Ion Sources

NEC will supply an off-axis direct extraction duoplasmatron for acceptance tests of the accelerator for iodine and lighter ions. For tests with heavier ions, notably gold, ORNL must supply the ion source. The Negative Ion Source Test Facility was developed in response to that need. The first use of the facility was the evaluation of an ion source using the Hortig-Mueller geometry.[4] More recently, as reported at this conference,[5] the ORNL version of the University of Aarhus sputter source and a new axial geometry sputter source have been completed and tested. The Aarhus source has produced an Au^- beam in excess of 25 μA continuously for 400 hours.

ORIC Beam Injection System

The beam from the tandem is delivered to the ORIC by a special transport system, Fig. 9, which begins in the vertical tandem output line with a 15° switching magnet and a 65° bending magnet to turn the beam horizontal.[6,7] The beam transport line following the bending magnets includes two triplet quadrupole lenses followed by a special injection magnet located within the ORIC rf resonator that serves to direct the beam to the correct radius and angle for stripping to a higher charge state and subsequent acceleration. The required foil stripper angle and radius both change with ion mass and energy. A foil positioning mechanism replaces the ion source and provides the needed precise adjustments of stripper angle and radius under digital control by the ORIC control computer. The ion path within the cyclotron is illustrated in Fig. 10.

Use of the tandem as the injector for the cyclotron required careful optics design to assure efficient and isochronous beam transport of a tightly bunched beam to the cyclotron. The buncher system is required to provide 6°-wide pulses (to match the phase window for $\Delta E/E$ of 1/1000 from the cyclotron). The systems developed[8] give 100% efficient beam transport with a time dispersion of 0.15 nanoseconds for a "reasonable" emittance of 2 π cm mrad $MeV^{1/2}$. The buncher produces the required pulse widths, for example 1.2 nsec at 14 MHz, with an efficiency above 50%.[8,9]

Modifications to the cyclotron for injection from the tandem included installation of the special magnet, Fig. 11, and a new dee and trimmer system with a slotted periphery to allow passage of the injected beam, Fig. 12. Other improvements will include provision of better vacuum in the resonator region by replacing a 20-in. diffusion pump with a cryopump of the same size. With the exception of the cryopump, all modifications to the cyclotron are complete. Testing of the foil stripper mechanism and installation of the new cryopump will be done during a shutdown scheduled for late this year.

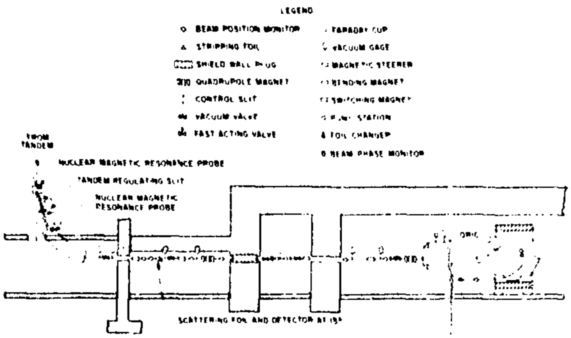

Fig. 9. Schematic drawing of the beam injection system for the ORIC

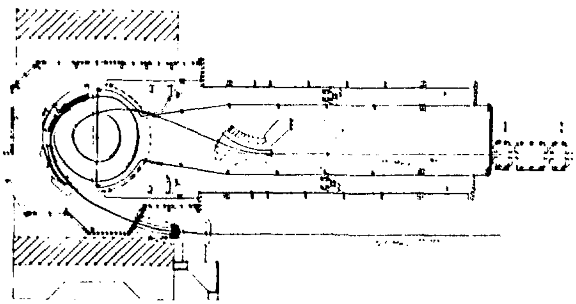

Fig. 10. The path of the injected beam within the cyclotron

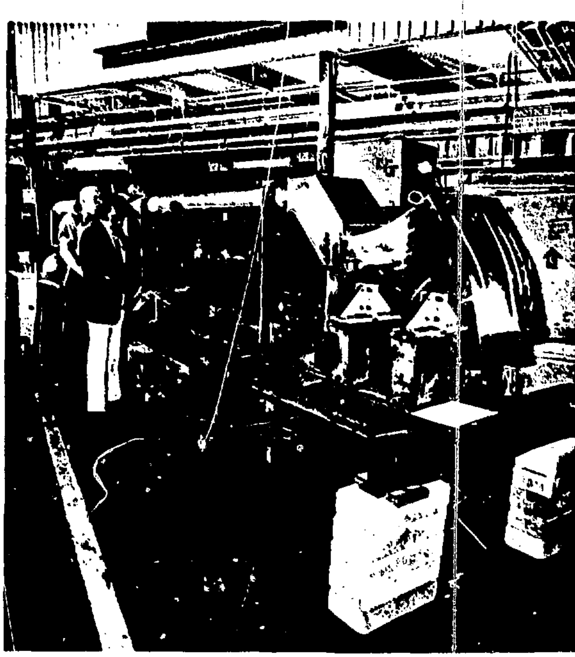

Fig. 11. The beam injection magnet being tested prior to its installation in the ORIC rf resonator

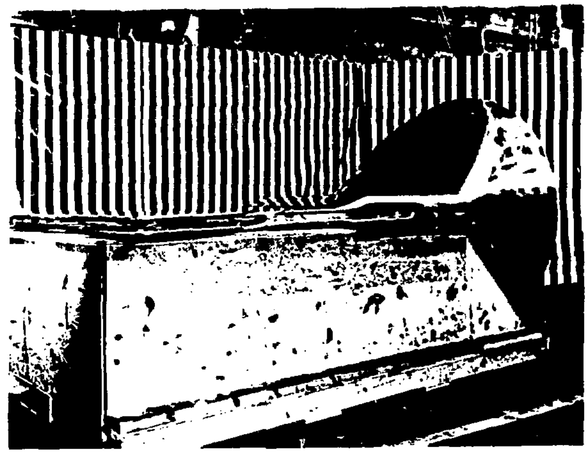

Fig. 12. The new ORIC dee is provided with a slot in the periphery to allow passage of the tandem beam

Experiment Areas and Beam Tesnsport Systems

The planned arrangement of the experiment areas and beams for the new facility is shown in Fig. 13. Initially, tandem beams will serve only the new East and West Experiment Rooms. The facilities served will be a gamma ray spectrometer in the East Experiment Room and an atomic and solid state research facility, the Enge Split Pole Spectrometer, and a multipurpose facility in the West Experiment Room. As the facility comes into operation, we hope to extend and modify the systems to the arrangement shown to permit major experimental areas in the existing facility to use beams directly from the tandem as well as beams from the cyclotron.

All of the new beam lines are of all-metal construction employing polished stainless steel pipe on Conflat flange systems. The multiport boxes for the attachment of pumps and diagnostic apparatus are based on the design used at GSI and supplied commercially by NTG. Cryogenic pumps are used exclusively throughout the systems. The arrangement of a typical line is shown in Fig. 14. The control of the beam transport is controlled via CAMAC serial highway to the tandem control computer.

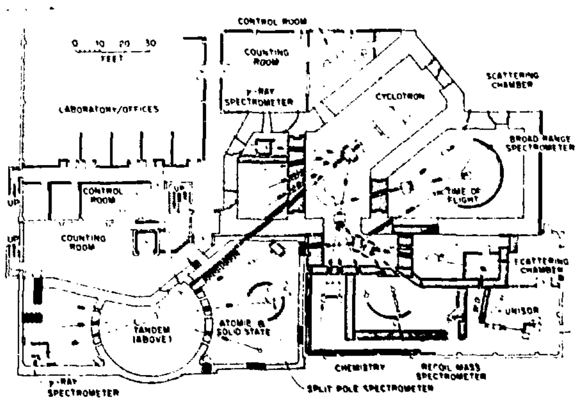

Fig. 13. The beam from the tandem to the new scattering chamber and UNISOR should be completed by early 1980. The rest of the plan will be completed about a year later.

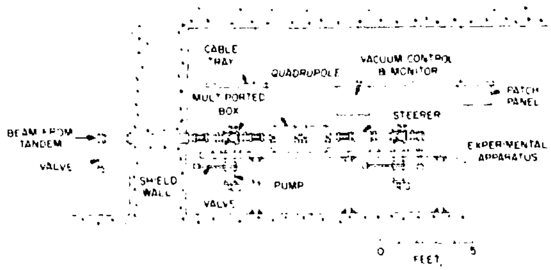

Fig. A typical beam transport system arrangement

Phase-II Plans

Following the approval of the Phase-I project in 1974, we continued to develop the Phase-II project concept of a separated-sector cyclotron, with an energy constant $K = ME/q^2$ of 400 MeV, designed to act as an energy booster for either the 25 MV tandem or the ORIC. This arrangement would have the advantage of allowing the use of either the ORIC or the 25 MV tandem to operate in stand-alone fashion as appropriate for the research program. The ORIC would be especially valuable as an injector for light heavy ions such as C, N, O because of the high current capability.

The continued development of the concepts of cyclotrons with superconducting magnets has made it possible to consider building machines with much higher energy capability at practical cost. Higher energy is also high on the list of researchers' needs. Early this year we decided to change our Phase-II ideas to incorporate a cyclotron with a superconducting magnet. The use of the ORIC as the injector for that type machine is not attractive and the new plan is to integrate all of the existing ORIC research areas and the cyclotron vault into a rearranged research area for higher energy beams. Such an arrangement for a K = 1200 cyclotron with superconducting magnet is shown in Fig. 15. Various designs of the cyclotron and research layout are under study. Design goals for the new facility are 300 MeV/A for light ions and 50 MeV/A for uranium.

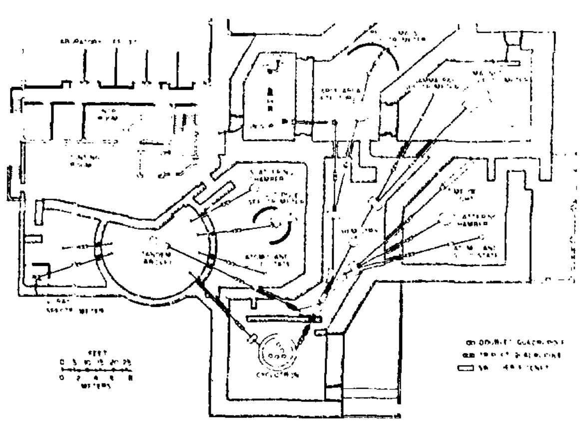

Fig. 15. One possibility for the layout of a Phase II facility with a K=1200 cyclotron with superconducting magnet. RF-driven electrostatic deflectors are provided to permit beam sharing among as many as three experiments for beams from the tandem or the booster cyclotron.

Conclusion

The completion of the present phase of development of the Holifield Heavy Ion Research Facility in November 1979 will provide beams up to about A = 160, with energies above 6 MeV/A. Scheduled operation for experiments will begin in January 1980. A Phase-II project to provide up to 300 MeV/A for light heavy ions and 50 MeV/A for the heaviest ions is planned.

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