THE UNIVERSITY OF MICHIGAN

COLLEGE OF LITERATURE, SCIENCE, AND THE ARTS

Final Report

The University of Michigan 83-Inch Cyclotron

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I. INTRODUCTION

In January of 1958, the Department of Physics submitted to the U. S. Atomic Energy Commission a proposal for the construction of an 83-inch spiral-pole cyclotron and ancillary equipment to be used for research in nuclear spectroscopy. The initial request was for \$1,839,700. Funds for construction of the building to house the 83-inch facility, the 50-inch cyclotron and office and laboratory space were to be supplied by the State of Michigan.

In February 1958, the Michigan Memorial-Phoenix Project provided a grant of \$4,500 to permit preliminary planning of the facility. Between February and October of 1958, some \$2,871.79 was spent for this purpose, the balance eventually was returned to the Phoenix Project. Detailed planning ceased in October, due to the uncertain climate with respect to obtaining the necessary funding from the State and from the AEC.

In May 1960, the State Legislature authorized the construction of the building; and in June 1960, the U. S. Atomic Energy Commission authorized construction of the cyclotron facility. Ground was broken for the building in July 1960, and was accepted by The University in October 1961, the total cost being \$1,158,725. Detailed planning, design and construction of the cyclotron were begun in July 1960, under a total AEC appropriation of \$1,941,670. Of this, some \$90,362 was returned to the AEC in February 1964; and it is anticipated an additional amount of approximately \$16,000 will be returned when the books are closed. Thus, the construction cost of the cyclotron and ancillary equipment is very nearly \$1,835,308, and the total project cost approximately \$2,994,033.

The final report on the construction of The University of Michigan 83-inch spiral-ridge cyclotron facility summarizes the construction, the manpower employed, the cost breakdown by major categories, and the operational experience.

II. THE BUILDING

The cyclotron building consists of a two-story office and laboratory unit of 17,000 square feet gross, plus two underground machine rooms, each of which is connected to the office unit by a tunnel. One room of 4,420 square feet houses the

50-inch cyclotron and the other of 5,448 square feet houses the 83-inch cyclotron and its associated instrumentation. Of the total area, approximately 20,000 square feet is net useful space. A perspective and floor plan is shown in Figure 1.

III. THE CYCLOTRON

A detailed description of the cyclotron, beam preparation magnets, and reaction products analysis system as they existed in 1962 has been described in Nuclear Instruments and Methods, 18, 19, 93, (1962). A reprint is attached and forms part of this report. Deviations from the system as described in that paper are of minor nature. Views of the completed cyclotron are shown in Figures 2, 3 and 4; the control room is shown in Figure 5. Three views of the analysis equipment are shown in Figures 6, 7 and 8.

A brief chronology of the construction phase follows.

July 1960	Initiation of cyclotron design. Ground broken for building.
September 1960	Contract let for cyclotron magnet steel, coils, power supply.
February 1961	Cyclotron magnet steel delivered to site.
March 1961	Magnet steel assembled, coils and power supply delivered to site.
October 1961	Cyclotron building accepted from contractor by University, and personnel moved in. Power applied to cyclotron magnet and field measurements initiated.
February 1962	Spiral shims installed. Focusing magnet steel and coils delivered.
September 1962	Gradient coil assemblies completed.
November 9, 1962	First circulating beam (protons) obtained.
February 1963	Analyzer magnet steel delivered.
March 1963	R. F. power supply delivered and installed. First circulating beam under continuous power.
June 1963	Analyzer magnet assembly completed.
August 1963	Permanent plumbing and wiring of cyclotron completed. This completes construction phase of cyclotron.
December 1963	Beam transported to scattering chamber through beam preparation system.

April 1964	Analyzer magnets used for first time to analyze reaction products (deuteron elastic scattering on Au, Cr, Al).
August 1964	Installation of magnetic analyzer system completed.
January 1965	Overhead radiation shielding completed.

IV. MANPOWER

A summary of the manpower employed in the construction and testing and the list of personnel follows.

<u>Category</u>	<u>Man Years</u>
Faculty	11.0
Engineers	5.4
Design Draftsman	6.1
Cyclotron Technicians	12.5
Electronic Technicians	6.3
Shop	13.1
Secretary	4.2
Student Assistants	19.0 (Approx.)
Total	77.6

Consultants: 116 man-days

Personnel

Faculty

Bardwick, J.	9/64 - 3/65
Bruns, C. A.	9/61 - 8/64
Lambert, J. M.	9/61 - 8/64
Parkinson, W. C.	7/60 - 3/65
Tickle, R. S.	7/60 - 3/65

Engineers

Bardwick, J.	1/64 - 9/64
Bruinsma, P.J.T.	12/60 - 12/63
Unger, R.	9/64 - 3/65
Vogel, U.	7/62 - 8/63

Cyclotron Technicians

Downer, W. E.* (Supervisor)	7/60 - 3/65
Koenig, J. A.	7/60 - 3/65
Romine, J. C.	12/61 - 3/65
Wyman, J. S.	9/63 - 3/65

Design Draftsman

Franklin, C. H.	10/60 - 3/65
Keefer, R. D.	3/62 - 4/64

Electronic Technicians

Hanson, W. H.*	1/62 - 3/65
Sheldon, J. E.	8/63 - 3/64
Unger, R. G.	1/62 - 6/63
Willemssen, M. K.	2/62 - 3/65

* Part time on Project 04939.

Shop

Pittman, R. D.* (Supervisor)	7/60 - 6/63
Burch, K. L.	12/61 - 3/65
Prince, M. W.	12/62 - 3/65
Schleede, D. M.	11/61 - 3/65
Schnelle, G. F.	11/61 - 3/65

Secretary

Hedding, G.	10/63 - 3/65
Woodruff, P. M.	7/60 - 10/63

Student Assistants

Auer, I. P.	9/62 - 9/63	Koch, J. W.	8/61 - 9/63
Bardwick, J.	4/61 - 10/62	Koly, J. M.	12/61 - 3/63
Blaurock, A. E.	4/61 - 10/62	Kuhl, C.	10/61 - 11/62
Booker, S. A.	1/61 - 3/65		6/64 - 9/64
Brors, D.	6/62 - 12/63	Lillie, J. I.	2/63 - 8/63
Cole, T.	11/62 - 2/63	Laxon, J. L.	9/64 - 3/65
Courtney, R.	6/63 - 3/65	Madison, R.	8/64 - 10/64
Crane, B. H.	9/61 - 5/62	Myers, W. L.	2/62 - 5/62
Davis, J. G.	9/64 - 3/65		12/63 - 5/64
DuPlantis, D. C.	5/61 - 11/62	Natelson, M.	6/61 - 10/61
	6/63 - 3/65	Pattiwar, S. R.	1/62 - 10/63
Dzeguze, G. J.	9/62 - 6/64	Phillips, R. A.	6/61 - 10/61
Ekin, J. W.	1/64 - 6/64	Poltorak, A. S.	6/62 - 3/65
Fitzsimmons, W. A.	6/61 - 1/64	Sampson, J. A.	6/63 - 8/63
Fry, E. S.	9/61 - 6/63	Smelser, S. C.	8/62 - 10/62
Georgion, N.	2/63 - 8/63	Vandenbroek, J. A.	1/63 - 9/63
Graube, A.	2/63 - 5/64	Wegryn, W.	9/61 - 3/63
Graube, M.	7/63 - 12/63	Werner, P.	6/62 - 9/63
	9/64 - 3/65	Wessell, L.	6/64 - 9/64
Holton, C.	9/64 - 3/65	Weiffenbach, C.	8/64 - 3/65
Hildreth, R.	1/64 - 5/64	Wyman, J.	9/60 - 9/63

* Part time on Project 04939.

V. APPROXIMATE COSTS

An approximate cost breakdown for each of the major categories is given below.

I. Cyclotron

A. Magnet

Steel	\$133,288
Coils	49,960
Power supply	25,425
Installation	13,900
Spiral shims	5,043
Gradient coils	6,776
Power supply for gradient coils	34,200
Miscellaneous (regulator, field meas. equip., plumbing, etc.)	<u>20,190</u>

\$288,782

B. R. F. System

Oscillator	17,319
Dees and resonators	34,028
Ground sheets	9,811
Power supply	31,563
Tubes (including spares)	18,229
Insulators (including spares)	13,901
Miscellaneous	<u>13,875</u>

138,726

C. Vacuum System

Vacuum tank	18,610
Pumps and valves	26,596
Beam probes	9,005
Miscellaneous	<u>6,317</u>

60,528

D. Arc Source

7,182

E. Extractor

9,138

Cyclotron Total

\$ 504,356

II. Beam Preparation		
Steel	\$ 49,200	
Coils, mounts and plumbing	30,805	
Power supply and control	16,180	
Vacuum ducts	12,434	
Miscellaneous	<u>8,996</u>	
		\$117,615
III. Reaction Products Analysis		
Steel	97,260	
Coils	26,174	
Power supplies	22,890	
Vacuum ducts	3,596	
Magnet carriage	10,835	
Magnet track and drive	19,581	
Miscellaneous (regulators, controls, plumbing)	<u>15,351</u>	
		195,687
IV. Multi-angle Analysis		108,893
V. Scattering Chamber		6,812
VI. Shielding		64,179
VII. Radiation Monitoring		3,840
VIII. Salaries, Wages and Overhead		667,760
IX. Miscellaneous		
Closed water system	20,291	
Tools, instruments and stock	23,077	
Travel	7,657	
Postage, telephones, freight and express	5,993	
Consulting service	11,980	
Motor Control Center	6,969	
IBM card punch machine	2,514	
Stores	46,979	
Miscellaneous	<u>40,706</u>	
		<u>166,166</u>
Total Cost of Cyclotron Installation		\$1,835,308

The following table summarizes the costs for steel, copper and power supplies. The prices include machining and/or fabrication and delivery.

Steel, Copper and Power Supply Costs

Steel:

<u>Item</u>		<u>Weight (tons)</u>	<u>Cost</u>	<u>Cost/lb.</u>	<u>Cost/ton</u>
Main magnet		310	\$132,600	\$0.214	\$427
Analyzer magnets	(3)	117	97,260	0.416	829
Focusing magnets	(2)	52	49,200	0.473	947

Copper:

<u>Item</u>		<u>Weight/lbs.</u>	<u>Cost</u>	<u>Cost/lb.</u>
Main magnet		31,000	\$ 49,960	\$1.61
Focusing magnets	(2)	11,400	25,680	2.26
Analyzer magnets	(3)	9,048	26,174	2.90

Power Supplies:

<u>Item</u>		<u>Power/kw</u>	<u>Cost</u>	<u>Cost/kw</u>
Main magnet		360	\$25,425	\$ 70.80
Oscillator supply		360	30,045	84.70
Analyzer magnets	(3)	3x50	22,890	153.00
Focusing magnets	(2)	2x35	14,200	203.00
Gradient coil supply (12 units in one)		68	34,200	502.00

VI. TECHNICAL PERFORMANCE

A detailed technical paper is being prepared for publication, reprints of which will form a later addendum to this final report. Thus, only a brief summary of the operational quality of the facility will be given here.

The initial proposal was for a cyclotron designed to accelerate deuterons in the energy range 15 to 40 MeV, protons 7.5 to 35 MeV, and alpha particles 30 to 80 MeV. Because of the conservative design, it is actually possible to accelerate protons from 7 to 37 MeV, deuterons from 14 to 60 MeV and alpha particles from 28 to 120 MeV. It should be emphasized that these numbers come from the measured

magnetic field and r. f. frequencies. There has been no attempt, as yet, to accelerate protons above 28 MeV, deuterons above 40 MeV and alpha particles above 30 MeV.

The extraction efficiency varies from 25% - 45%, and depends on the particle energy. The use of harmonic bump coils, which remain to be installed, should permit more efficient extraction at all energies.

The radial phase-space density, or radial emittance is shown in Figure 9. Note that pairs of points are plotted to an expanded scale. The apparent source (radial) of the external beam is located approximately 6 inches upstream of the dee center line at the radius of 48 inches, and has an apparent width of 0.51 mm for that portion of the external beam used in the measurement.

The first beam preparation magnet which accepts about 60% of the extracted beam forms a dispersed image of the apparent source on adjustable slits midway between the two beam preparation magnets. The beam through the slit is brought to a focus at the center of the scattering chamber by the second magnet.

The ion-optical behavior of the two beam preparation magnets is very nearly that predicted by the first order theory of Judd, and as a result, the resolved beam to the scattering chamber does meet the design specifications of $R = E/\Delta E = 8 \times 10^3$.

The quality and performance obtained with the magnetic analysis system are best illustrated with results obtained. Spectra of $Al^{27}(d,p)Al^{28}$ at a deuteron bombarding energy of ~ 25 MeV, corresponding to a proton energy for the ground state of ~ 30 MeV, were obtained at the image surface of the first analyzer magnet using targets of two different thicknesses. These results are shown in Figure 10. The ground state doublet of Al^{28} , as observed at the image surfaces of the first, second and third analyzer magnets, is shown in Figure 11 for 15 MeV incident deuterons. These results are remarkably close to expectation. The target, which was completely non-uniform, had an average thickness of 6 kev for 15 MeV deuterons; thus, the maximum thickness must be somewhat greater than this, and is estimated to be about 8 kev. The energy spread on the target, corresponding to 1.25 mm slits, was 2.5 kev. The measured performance of the magnet regulators at the time the data were taken corresponded to approximately the same value. The 1.3° angular spread of the beam on the target results in a kinematic broadening of approximately 10 kev. (The kinematic broadening, due to the aperture of the analyzer magnets, is completely compensated by a shift in the location of the image surface.) The full widths of the lines are expected to be 13-14 kev, and the expected full width

at half-height, assuming a triangular line shape, is approximately 6.5-7 kev, in good agreement with the measured result.

VII. IMPROVEMENTS AND PROBLEMS

There remain several areas where future improvements are indicated. 1) Improved regulation of the magnetic fields and of the dee voltage. It is estimated that a factor of 5-10 increase in analyzed beam to the scattering chamber can be obtained by such improvements. 2) Installation of first harmonic "bump" coils. This should permit essentially the same extraction efficiency at all energies, and increase the quality as well as quantity of extracted beam. 3) Removal of parasitic modes in the R. F. system.

VIII. CONCLUSIONS

We believe that through the help and cooperation of many people and offices, we now have a unique facility for investigating the properties of individual levels of all stable nuclei. While the completion time was somewhat longer than estimated, four and a half years as compared to three years, the cost of \$1,835,308 is very nearly that estimated (\$1,839,000) in the initial proposal which was prepared in the fall of 1957, and more than \$100,000 below the \$1,941,670 funding authorized by the AEC. The operational performance of the completed facility certainly equals our expectations. The present users of the facility join us in expressing thanks to all the people, who in one capacity or another, have contributed to the success of this endeavor.

Figure 1. Perspective and Floor Plan of the Cyclotron Building.

Figure 2. View of the Completed Cyclotron.

Figure 3. View of the Completed Cyclotron.

Figure 4. View of the Completed Cyclotron.

Figure 5. The Control Room.

Figure 6. View of the Analysis Equipment.

Figure 7. View of the Analysis Equipment.

Figure 8. View of the Analysis Equipment.

Figure 9. The Radial Phase-space Density.

Figure 10. Results obtained at the Image Surface of the First Analyzer Magnet.

Figure 11. Results obtained at the Image Surfaces of the First, Second and Third Analyzer Magnets.