STUDY OF ALTERNATE DESIGNS

for the

MODIFICATION

of the

MATERIAL AND STRESS BUILDING

SIXTY-INCH CYCLOTRON

for the

NASA LEWIS RESEARCH CENTER

Cleveland, Ohio

Contract Number NAS3-8146

Report No. 131-1-R1

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7019

September 3, 1965

File: 131-1, 4.1
Contract NAS3-8146

Mr. Myron A. Pollyea
National Aeronautics and
Space Administration
Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135

Dear Mr. Pollyea:

We are transmitting herewith 20 copies of the final submission of our Report No. 131-1-R2, "Preliminary Engineering Report for the Modification of the Material and Stress Building 60-Inch Cyclotron." Twenty additional copies will be forwarded on Tuesday, September 7.

We are also mailing separately reproducible sepia prints of the full-size drawings 131D8 through 131D14.

Very truly yours,

William M. Brobeck

William M. Brobeck

WMB:svb
Enc: As noted (20)

cc: Mr. M. A. Pollyea (4)

49-2

Bob - Johnny

For your info.

7007

Dayna 9/8

September 3, 1965

Dr. Henry G. Blosser
Michigan State University
East Lansing, Michigan

Dear Dr. Blosser:

We wish to acknowledge your kind permission for the use of information on the drawings of the Michigan State University 50 MeV cyclotron in planning and estimating the cost of the conversion of the 60-inch cyclotron at the Lewis Research Center, Cleveland, Ohio, to an AVF machine.

Mr. Myron A. Pollyea of the Research Center Facilities Engineering Division, who is the NASA technical representative on our contract for the study and Preliminary Engineering Report, expects to visit your laboratory sometime in the next few weeks.

With best regards,

William M. Brobeck

WMB:ys

CC: M. A. Pollyea

C NAS 3-8141

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APPROVALS

Issue	Contents	Prepared by:	Checked by:	Approved by:
Original				

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LIST OF DRAWINGS

SECTION I

Statement of Work

The following is the Statement of Work prepared by NASA in completion of which this report is submitted:

A. Description:

The present cyclotron was built and installed, starting in 1948, by the General Electric Company. Its specifications are as follows:

1. Particle and Energy: protons (accelerated as H_2^+) 10.5 MeV
   deutrons 21 MeV
   alpha particles 42 MeV
2. Internal deflected beam current 100 microamperes
3. External beam 5 microamperes
4. Energy stability 0.5%

It is the Government's intent in the proposed project to update this facility so that the research programs undertaken can be at the frontier of the state-of-understanding. The proposed modifications shall make this cyclotron more versatile by providing new particles, higher energy particles of a selectable energy, and more intense beam currents.

B. Nature of the Proposed Program:

Phase 1 - "Study of Alternate Designs" - The study shall consider the following alternates:

(a) A "close copy" of the existing Michigan State University (MSU) cyclotron using the maximum number of components of the present facility.

A "close copy" is herein defined as a cyclotron embodying the essential features of the original facility, but containing any changes that operating experience has shown to be useful.

(b) A two-dee cyclotron patterned after (a) above, but modified to have an oscillator and a resonant cavity that shall cover a frequency range of 10.75 to 21 MHz. One of the systems to be studied shall include tuning with a combination panel and shorting bar arrangement using an aluminum RF tank with no liner; the DC power input to the final amplifier is limited to 17.5 KV at 30 A.

(c) A cyclotron that shall be a scaling of the MSU magnetic field take advantage of the available pole diameter of the Lewis Cyclotron and the design of an RF structure capable of providing continuous coverage of all particle rotation frequencies.

(d) The designs (a), (b), and (c) shall be matched to the existing building and equipment. In all cases the existing magnet core, coils and power supply and the oscillator anode power supply shall be utilized.

(e) The study is intended to produce only the necessary costs and feasibility information required to permit the Government to make its selection of the alternatives.

SECTION II

Designs Considered

A. MSU Copy

The 60-inch cyclotron magnet has poles which conveniently accommodate the pole pieces of the design used at Michigan State University. As the MSU machine has an azimuthally varying magnetic field, the configuration of the magnet gap is, however, much different from that of the 60-inch machine. The 72-inch diameter of the existing poles will be reduced to 69 inches in the region of the gap. As the MSU gap itself is much less than that of the 60-inch machine, it is possible to excite the magnet to the required field strength with the existing main coils.

Drawing D1 shows the MSU design, including the MSU magnet. It is included for comparison with the drawings of the alternates.

In addition to the magnet core, coils, and power supply and the oscillator anode power supply, it is planned to use the ion source arc and filament and gas supplies and most of the vacuum-pumping and water-cooling systems. In this alternate no changes are assumed in the MSU design other than those required to adapt to the existing NASA equipment.

Drawing D2 shows a cross section through the cyclotron illustrating this design.

B. Two-Dee Designs with Full Frequency Range

The MSU cyclotron is limited in its range of energies and particles by the fact that the radio frequency is variable only through the comparatively narrow range of 13.5 to 21.5 megacycles per second. It is very desirable to cover the full two-to-one range of 10.75 to 21.5 megacycles to permit accelerating in both the first and second harmonic modes.

Change of the frequency range will require a change in the resonant system which includes the dee stems and their surrounding cavities. Increase of the range requires increasing the volume of the resonant cavity and increasing the radio-frequency power. Preliminary designs have been prepared for three methods of increasing the frequency range, designated alternates B1, B2, and B3. Computer calculations have been made to determine the frequencies and powers at both ends of the range of each alternate. All the alternates are capable of meeting the range requirements.

Alternate B1 uses the tuning method used at Michigan State. This is referred to as panel tuning because the boundaries of the resonator are formed by conducting panels which can be moved toward or away from the dee stems. Drawing D3 illustrates this alternate.

Alternate B2 uses a method being used at Brookhaven National Laboratory in which moving panels are supplemented by movable shorting bars. The shorting bars permit changing the lengths of the dee stems to permit the use of smaller panels than would be needed if the range were to be covered by panel motion alone. At Brookhaven a single dee is used, and, hence, a three-to-one frequency range is required. This is because second-harmonic operation is impossible with a single dee, making the next available mode that of the third harmonic. Covering the three-to-one range with panels alone is more difficult than for the two-to-one range, due to the higher power required so that the Brookhaven design is more attractive with a single dee than with two. Drawings D4 and D5 illustrate this alternate.

In alternate B3 each dee is tuned by a shorting diaphragm which can be moved inside a cylindrical resonator tank in contact with the dee stem and the tank wall. This system uses the least power. In the past, there has been a question as to the durability of the contacts required, but operation of the machines (at Oak Ridge and the University of Colorado) using this system has been entirely satisfactory, and this question no longer exists. However, it is still considered impractical to change the frequency while under power for fear of burning of the contacts. This limitation does not apply to panel tuning.

Drawing D6 illustrates this alternate.

The magnet changes required for the B group of alternates are the same as for alternate A.

C. Designs for Higher Energies

The alternates under category C are based on increasing the magnetic field or the exit radius or both over the values of the MSU design. Calculations of the capability of the magnet core, especially the limitation set by the 72-inch pole diameter, and the coils show that the magnetic flux through the magnet gap could be increased only 5% to 10% over that required by the MSU design. In view of the uncertainty of magnetic circuit calculations, the margin of 5% to 10% is only sufficient to ensure that the MSU flux requirement can be attained.

It is not possible to scale the design of a cyclotron in the sense that all linear dimensions change by the same factor. As the diameter increases, the particle mass increases, and, hence, the ratio of the exit to the central magnetic field must increase also. Linear scaling can only be done for the cases in which the magnetic field is the same at corresponding points on the model and prototype. Increase in the diameter by adding to the periphery of the MSU poles is also impractical without model testing because the field shape changes so rapidly with radius near the outer diameter that prediction of the effect of the additional iron would be very uncertain For the above reasons, even a small increase in diameter would require complete model testing at an additional cost of the order of $100,000. To this would have to be added the cost of a complete redesign of the machine.

In view of the fact that (a) only a very small increase, if any, would be possible, and (b) the costs would be large, no detailed consideration of increasing the size over that of the MSU design is justified.

To illustrate these points, the cost of a slightly enlarged design is included in the cost estimates.

D. Other Designs Considered

Although not required by the scope of work, it seemed desirable to consider a single dee as an alternate to the two-dee design. The Brookhaven 60-inch cyclotron conversion will use a single dee, and single dees are in use on the Oak Ridge (ORIC) and the Berkeley 88-inch cyclotrons.

Advantages of a single dee are simplicity of the dee structure, availability of space for extraction devices in the magnet gap, and the possibility of self-excited operation. Self-excited operation removes the requirement for servo tuning and considerably simplifies the operation of changing frequency.

Disadvantages of the single dee are, in most practical cases, the inability to obtain as high energy gain per turn as with two dees and the inability to operate on the second harmonic. Because the energy gain is, at most, twice the dee voltage, for the same energy gain the voltage on a single dee must approach twice that of the voltage on each two dees. This is generally impractical to reach, due to the clearance to ground and the power required. The reduced energy gain per turn makes it difficult, if not impossible, to obtain a well defined starting beam as is required for the best extracted beam quality.

Operation on the second harmonic, which is possible with two dees, permits the use of a two-to-one, instead of a three-to-one, frequency range to cover two modes of operation. Although experimental information is very incomplete, better performance is expected on the second than on the third harmonic.

Another disadvantage of a single dee in this particular case is that the two-dee MSU design exists, whereas a new design would be required for a single dee.

Consideration of all these points leads to a strong preference for the two-dee design in this application.

E. General

Radio-frequency parameters based on the computer calculations are presented in Table I.

All the estimated DC power requirements are within the capability of the existing 525 kW anode power supply. Due to the comparatively low voltage of 17.5 kV, however, the two Eimac 4CW50000 tubes used at MSU would be adequate for case B3 only. A larger tube such as the Machlett 8546 would be required for the other alternates.

TABLE I

RADIO-FREQUENCY PARAMETERS

	A ML8546	B1 ML8546	B2 ML8546	B3 4CW50k	C ML8546
Maximum Frequency - Mc/sec	22.1	20.9	21.6	21.6	21
Minimum Frequency - Mc/sec	13.7	10	10	10	10
Calculated Skin Loss at 100 kV Peak Dee to Ground - kW	76	94	80	46	125
Estimated Actual Skin Loss* at 75 kV Peak Dee to Ground - kW	129	159	135	78	210
Estimated Total RF Power Required - kW	221	251	227	170	302
Dee Stem Current at 75 kV Peak to Ground - Amps	--	--	5000	4700	--
Dee Stem Current Density RMS Amps per Inch	--	--	88	87	--

*Estimated actual skin loss is 1.5 x calculated skin loss.

Non-skin losses are assumed:

Coupling losses	22
Stray ions	30
Beam load	40
	92 kW

Oscillator anode efficiency assumed 60 per cent.

SECTION III

Cost Comparison

A. General

The comparison of the costs of the alternates considered is presented in Table II.

In estimating these costs, major attention was given to the items that differed between the alternates. The more detailed study of one alternate as would be made in a Preliminary Engineering Report can be expected to change the total cost of that alternate upward or downward. Such detailed study should not change the cost differences between alternates. These differences as presented in Table II can be used for the comparison of the costs of the alternates.

TABLE II

COST COMPARISON
(kilodollars)

Construction Cost	A	B1	B2	B3	C
			Alternate		
1. Magnet	184	184	184	184	242
2. RF System	195	226	266	224	268
3. Vacuum System and Tanks	75	91	101	101	96
4. Ion Source	13	13	13	13	13
5. Probe	18	18	18	18	18
6. General Controls	54	54	54	54	54
7. Extractor	64	64	64	64	64
8. Tools and Spare Parts	19	19	19	19	19
9. Cooling Water System	12	12	12	12	12
Total Construction Cost	634	681	731	689	786

Technical Services & Associated Costs	Alternate A	B1	B2	B3	C
1. Models & Model Testing	0	25	30	25	105
2. Full-Scale Testing & Startup	71	71	71	71	71
3. Supervision of Installation	30	30	30	30	30
4. Design	136	165	200	165	442
5. Other Engineering Costs	63	63	63	63	63
6. Travel & Subsistence and Miscellaneous	52	52	52	52	52
7. Computer Time	10	10	10	10	10
Total Technical Services and Associated Costs	362	416	456	416	813
Total Construction Cost	634	681	731	689	786
Total Cost - Engineering Estimate	996	1097	1187	1105	1599
Difference from Alternate A	0	101	191	109	603

All costs include installation assumed to be done by contractor's labor.

Costs are reduced where existing equipment is applicable. Allowance is made for the cost of reconnecting and checking existing equipment.

B. Discussion of Specific Cost Items Which Differ Between Alternates

Item 1. Magnet

The costs for the first four alternates include the following work on existing parts: Disassembly and reassembly of the magnet core and coils, boring a central hole through the top yoke and cutting off the lower pole piece to permit the attachment of the new lower pole tip. New parts included in this item are: pole tips and hills, pole face coils and their power supplies with operator's controls and instruments.

For alternate C, the cost of pole face coils has been increased to reflect an increase in magnetic field, radius, and beam energy.

Item 2. Radio-Frequency System

This item can be divided into mechanical and electrical costs. Mechanical costs include the dees, stems, shorting diaphragms, panels, trimming capacitors, and necessary mechanical drives and supports. The ion puller electrode and its mechanical parts are also included.

The electrical costs include the RF power chain from the anode power supply through to the dees, including the servo control of tuning and operator's controls and instruments.

This item in alternate A assumes the MSU RF system to be copied closely. The difference from MSU will be an increase in the distance from the magnet centerline to the resonator of about two inches and in the change in the power amplifier tubes to accommodate the output voltage of the existing anode power supply.

In the B alternates, the cost of the wide-range tuning system is included according to the particular method used in the alternate.

The cost of controls and servo equipment is increased over alternate A to provide for the general revision of these systems required for the greater frequency range.

In alternate C, the costs are increased to provide for the higher power and larger dimensions of the system.

Item 3. Vacuum System and Tanks

The differences in the vacuum tank costs reflect the differences in the size of the resonator tanks required.

Item 11. Models and Model Testing

The difference between alternate A and the MSU RF system is so small that RF model testing is not considered necessary. The B alternates include RF model testing and alternate C includes model magnet testing.

Item 14. Design

In the case of alternate A, this item covers the engineering and drafting costs involved in updating and completing the MSU drawings and preparing requests for bids. The cost varies with the amount of new design work required for the alternate.

Item 17. Computer Time

This item covers the cost of computing machine rent at commercial rates for the calculations required. Reduction of field measurements in the extraction region and determination of the beam path through extraction channel is required for all alternates.

For alternate C, extensive calculations based on the magnetic model measurements and calibration of the pole face coils are required.

SECTION IV

Summary & Conclusions

A series of alternate designs have been considered with respect to feasibility, performance and cost for conversion of the existing 60-inch cyclotron to an azimuthally variable field machine capable of accelerating protons from low energies to 50 MeV and other particles to corresponding energies.

The following conclusions can be drawn:

1. It is feasible to make the modification to the azimuthally varying field following the Michigan State design.

2. A wide range of frequency adjustment is practical and would cost about $100,000 more than the restricted range design.

3. It is not practical to increase the energy above that obtainable by copying the MSU design.

4. The cost of the combined panel and sliding short tuning as used at Brookhaven would cost about $90,000 more than either the panels or the sliding diaphragm alone. For this reason, and because there is a possibility of trouble with unwanted modes of oscillation, this design is not recommended.

5. The cost of panel and sliding diaphragm tuning is substantially equal. Panel tuning is recommended because it is in satisfactory use at Michigan State and because with suitable development it would permit changing frequency while under power.

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National Aeronautics and
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