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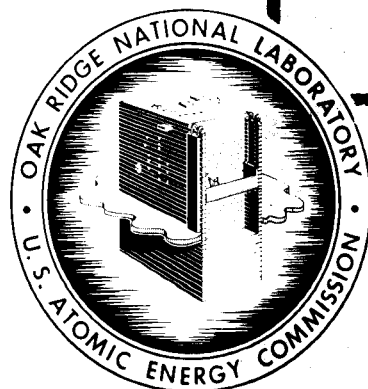
SEMIANNUAL PROGRESS REPORT

FOR PERIOD ENDING SEPTEMBER 20, 1954

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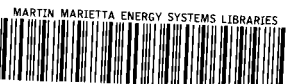
for Period Ending September 20, 1954

R. S. Livingston, Director
Edited by F. T. Howard

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PREVIOUS PROGRESS REPORTS

The following progress reports have been issued by the Electronuclear Research Division for the indicated period-ending dates:

Y-495	September 30, 1949
Y-548	December 31, 1949
Y-584	March 31, 1950
Y-637	June 30, 1950
Y-676	September 30, 1950
Y-722	December 31, 1950
Y-767	March 31, 1950
Y-795	June 30, 1951
ORNL-1173	September 30, 1951, Part I
ORNL-1269	December 31, 1951, Part I
ORNL-1339	March 31, 1952, Part I
ORNL-1345	June 30, 1952, Part I
ORNL-1383	September 30, 1952
ORNL-1531	March 20, 1953
ORNL-1663	September 20, 1953
ORNL-1670	March 20, 1954

PAPERS PRESENTED DURING THE PERIOD

B. L. Cohen, D. J. Coombe, and B. L. Ferrell, "Recent Progress in Fission Fragment Angular Distribution Measurements," American Physical Society meeting, Washington, D. C., April 29-May 1, 1954.

B. L. Cohen, G. H. McCormick, T. H. Handley, and E. Newman, "The $(p,2n)$, $(p,2p)$, (p,He^3) , and (p,f) Cross Sections and Excitation Functions," American Physical Society meeting, Southeastern Section, Oak Ridge-Knoxville, Tennessee, April 1-3, 1954.

B. L. Cohen, "Research in Nuclear Physics with 22-Mev Protons," Vanderbilt University, April 8, 1954.

F. L. Green and J. A. Martin, "High Intensity Beam of Low Energy Protons in the ORNL 86-Inch Cyclotron," American Physical Society meeting, Southeastern Section, Oak Ridge-Knoxville, Tennessee, April 1-3, 1954.

T. H. Handley and B. L. Cohen, "New Isotope Identification Program on the Oak Ridge 86-Inch Cyclotron," American Physical Society meeting, Washington, D. C., April 29-May 1, 1954.

F. T. Howard, "A Model for Demonstrating Motion of Ions in a Cyclotron," American Physical Society meeting, Southeastern Section, Oak Ridge-Knoxville, Tennessee, April 1-3, 1954.

R. S. Livingston, "Recent Developments in High Energy Accelerators," University of Alabama, April 21; University of Miami, April 23; and University of Texas, April 27, 1954.

H. L. Reynolds and A. Zucker, "Excitation Function for the Reaction $Be^9(N^{14})F^{18}He^5$," American Physical Society meeting, Southeastern Section, Oak Ridge-Knoxville, Tennessee, April 1-3, 1954.

H. L. Reynolds, "Primary Cosmic Radiation," University of Miami, April 6; Clemson College, March 23, 1954.

A. Zucker, "Nuclear Reactions Produced by 25-Mev Nitrogen Ions," University of Miami, April 1; Vanderbilt University, May 6, 1954.

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A. Zucker, "The Acceleration of Heavy Particles to 25 Mev," Georgia Institute of Technology, April 27, 1954.

A. Zucker, "Cross Section Measurements with 29-Mev Nitrogen Ions," Invited paper, American Physical Society meeting, Seattle, Washington, July 7-10, 1954.

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B. L. Cohen, "Potassium-44," *Phys. Rev.* **94**, 117 (1954).

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H. L. Reynolds and A. Zucker, "Equilibrium Charge Distribution of Stripped 26-Mev Nitrogen Ions," *Phys. Rev.* **95**, 1353 (1954).

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B. L. Cohen, H. L. Reynolds, and A. Zucker, "A Comparison of Nitrogen- and Proton-Induced Nuclear Reactions," to *The Physical Review*.

T. H. Handley, "Neutron Deficient Activities of Praseodymium," to *The Physical Review*.

T. H. Handley and E. L. Olson, "Holmium-167," to *The Physical Review*.

W. H. Jones, A. Timnick, J. H. Paehler, and T. H. Handley, "Bombardment Energy and Fission Product Yield Pattern for Protons on Natural Uranium and Uranium-235," to *The Physical Review*.

G. H. McCormick and B. L. Cohen, "Fission and Total Reaction Cross Sections for 22-Mev Protons on Th^{232} , U^{235} , and U^{238} ," to *The Physical Review*.

J. A. Martin, R. S. Livingston, R. L. Murray, and M. Rankin, "Isotope Production Rates in the ORNL 86-Inch Cyclotron," to *Nucleonics*.

H. L. Reynolds and A. Zucker, "Excitation Functions for Nitrogen-Induced Nuclear Reactions," to *The Physical Review*.



H. L. Reynolds and A. Zucker, "Range of Nitrogen Ions in Emulsion," to *The Physical Review*.

H. L. Reynolds, L. D. Wyly, and A. Zucker, "Equilibrium Charge Distribution of Energetic Nitrogen Ions," to *The Physical Review*.

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Part I

UNCLASSIFIED WORK

ELECTRONUCLEAR RESEARCH DIVISION SEMIANNUAL PROGRESS REPORT

ABSTRACT

Nuclear physics research with 22-Mev protons in the 86-in. cyclotron included angular-distribution measurements of neutrons from (p,n) reactions in nine target elements; measurement of the angular distribution of fission fragments from proton-induced fission of U^{233} , U^{235} , U^{238} , Th^{230} , and Th^{232} ; measurement of alpha-particle angular distributions from (p,α) reactions; a study of the neutron-deficient isotopes of terbium; and completion of an extensive program of the measurement of activation cross sections. Two new targets for cyclotron production of isotopes were developed, and the production yields for 14 radioisotopes are summarized. A new record for continuous beam power on a production target, 36 kw for 5 hr, was achieved. The design of a beam-deflector system for the 86-in. cyclotron has been completed, and several of the components have been fabricated; a shutdown for installation is scheduled for October 8.

The deflected N^{+++} beam of the 63-in. cyclotron was used in a study of the gain and loss of electrons by nitrogen ions passing through thin foils, and the equilibrium charge distribution of ions as a function of energy was thus obtained. The excitation functions were measured for nitrogen-induced reactions on both nitrogen and oxygen.

Assembly of the 44-in. cyclotron is approaching completion. Studies of the magnetic and radio-frequency requirements of the proposed 114-in. heavy-particle cyclotron were continued, and an investigation of the possibility of converting the 44-in. cyclotron was initiated.

THE ORNL 86-INCH CYCLOTRON

NUCLEAR PHYSICS RESEARCH

Angular distributions of neutrons from (p,n) reactions induced by 20-Mev protons were measured for Mg, Al, Cu, Mo, Ag, Ta, Au, Th, and U. The neutrons were detected by silver and aluminum activation, which detect neutrons of 12- and 6-Mev average energy, respectively. The angular distributions are very sharply peaked in the forward direction; thus it is indicated that direct, rather than compound, nucleus interaction is the predominant process. Many interesting conclusions may be obtained from the shapes of the curves. Yield studies accompanying these measurements indicate that emission of neutrons is a very improbable process in light elements.

Measurements of fission-fragment angular distributions from 22-Mev proton-induced fission were extended to include U^{238} , U^{235} , U^{233} , Th^{232} , and Th^{230} as targets and to include Ag, Zr, Sr, Ba, and Br as detected fragments. All angular distributions are symmetric about 90 deg, with maxima in the forward and backward directions. In general, the angular distributions are more

anisotropic for asymmetric fission than for symmetric fission.

Measurements of alpha-particle angular distributions from 22-Mev proton-induced (p,α) reactions were made until it seemed quite certain that the angular distributions are essentially symmetric about 90 deg but that they have a small component ($\sim 15\%$) which is distinctly in the forward direction. It was decided to discontinue this work until the deflected beam is available.

An extensive program for the measurement of activation cross sections was completed. A study of (p,pn) vs $(p,2n)$ cross sections in medium-weight elements indicated that the (p,pn) cross sections are much larger in most cases. This finding would seem to practically invalidate the compound-nucleus hypothesis. A study of $(p,pn) + (p,2n)$ vs $(p,2p)$ cross sections indicated that, in many cases, the latter cross sections are much larger; this cannot be easily explained by compound-nucleus interaction, either. Measurements of (p,α) cross sections showed that these cross sections were considerably larger than expected

and were surprisingly insensitive to the energetics involved. The (p, He^3) and (p, t) cross sections were found to be quite small (~ 0.1 to 1 millibarn). Cross sections for (p, γ) reactions were also found to be quite small (~ 1 millibarn), which indicates that the lifetime of the intermediate state must be rather short. A survey of (p, n) cross sections at 13-Mev incident energy was completed.

A photographic recording magnetic spectrograph was constructed for measuring the energies of internal conversion electrons in the range of 50 to 500 kv.

A study was made of the neutron-deficient isotopes of terbium produced by the proton bombardment of enriched isotopes of gadolinium. The terbium was chemically separated by ion-exchange methods. Two isotopes previously reported, 4.7-d Tb^{157} and 190-d Tb^{155} , were not observed. When analysis of the data is completed, it is expected that the decay scheme of several of the isotopes will be clarified.

APPLIED PHYSICS

The Applied Physics program includes the production of radioisotopes, the development of production targets, ion-transmission studies, and service bombardments for other divisions of the Laboratory.

Isotope Production

Several routine production bombardments were completed: a 5-hr bombardment of lithium metal produced 520 mc of Be^7 ; a 25-hr bombardment of chromium produced approximately 15 mc of Mn^{54} ; and a 4-hr irradiation of RbCl in the capsule target produced 8 mc of Sr^{85} . Gallium-67 production for the ORINS Medical Division continued, with a bombardment being made every third week and each bombardment producing approximately 350 mc. A new program was begun in cooperation with the UT-AEC Agriculture Research Program. Fluorine-18 (1.87-h half life), which is produced by the $(p, 2n)$ and (p, pn) reactions on F^{19} , is being used in a study of the uptake and distribution of

TABLE 1. CYCLOTRON-PRODUCED ISOTOPES

Isotope	Half Life	Radiation	Nuclear Radiation	Target	Production Rate	
					(mc/ma-hr)	(mc/hr)
Be^7	54 d	No β^+ ; 0.48-Mev γ	(p, n)	Li ; 6×10 in.	170	120
F^{18}	1.87 h	0.65-Mev β^+ ; no γ	(p, pn) $(p, 2n)$	NaF ; capsule	7500	1500
Na^{22}	2.6 y	β^+ ; 1.28-Mev γ	(p, α) $(p, \alpha n)$	Mg ; 6×10 in.	0.4	0.4
Na^{22}		(Not carrier-free)	(p, pn) $(p, 2n)$	Na ; 6×10 in.	3.1	1.3
Mn^{52}	6.0 d	β^+ ; 0.7- to 1.5-Mev γ	(p, n) $(p, 2n)$	Cr ; 6×10 in.	80	80
Mn^{54}	310 d	No β^+ ; 0.84-Mev γ	(p, n)	Cr ; 6×10 in.	0.5	0.5
Mn^{54}		(Not carrier-free)	(p, pn)	Mn ; 6×10 in.	20	20
Fe^{55}	2.9 y	No β^+ ; no γ ; 100% E.C.	(p, n)	Mn ; 6×10 in.	10	10
Co^{56}	80 d	β^+ , E.C.; 0.85- to 3.25-Mev γ	(p, n)	Fe ; 6×10 in.	70	70
Co^{57}	270 d	0.3% β^+ ; 0.120-Mev γ	(p, pn) $(p, 2n)$ $(p, 2p)$	Ni ; 6×10 in.	50	50
Zn^{65}	250 d	β^+ , E.C.; 1.12-Mev γ	(p, n)	Cu ; 6×10 in.	9.3	9.3
Ga^{67}	78 h	No β^+ ; 75% 0.182-Mev γ	$(p, 2n)$ (p, n)	Zn ; 2.5×6 in.	600	120*
As^{73}	76 d	No β^+ ; 0.067-Mev γ	(p, n) $(p, 2n)$	Ge ; capsule	8	1.6
As^{74}	17.5 d	β^+ , β^- ; 0.6-Mev γ	(p, n)	Ge ; capsule	50	10
Y^{88}	105 d	E.C.; 1.85- and 0.9-Mev γ	(p, n)	SrO ; capsule	20	4
Po^{208}	2.93 y	5.11-Mev α ; no γ	$(p, 2n)$	Bi ; 6×10 in.	9.8	9.8

*A production rate of 600 mc/hr could be expected with the larger target.

fluorine in sheep. A 30-min bombardment of sodium fluoride in the capsule target produces approximately 750 mc of fluorine activity, together with 20 μ c of Na^{22} . In the experiments now under way, the presence of Na^{22} causes no difficulty.

Yield Summary. A summary of the production rates which have been obtained with the 86-in. cyclotron is given in Table 1. Generally, a serious effort has been made to obtain the highest possible production rates. In a number of instances the capsule target was used because the demand for the isotope at the time did not justify the development of a coating method for the larger target. In most cases the results are based on several development runs. The data for Co^{56} and Zn^{65} , however, are based on a single run. It is believed that with further operating experience their yield can be materially improved.

Service Bombardments

Use of the 86-in. cyclotron as a neutron source by the Biology Division has continued at a rate of 8 to 10 hr a week. A neutron flux density of approximately 1.6×10^9 neutrons/cm²·sec is produced in a lead-shielded exposure chamber by the proton bombardment of a beryllium target.

Numerous short bombardments were made for other divisions. One high-level bombardment of molybdenum was completed for the Chemistry Division; an average current of 1 ma was sustained for an 11-hr period. This target will allow the separation of relatively large amounts of long-lived technetium isotopes to be used for half-life and decay-scheme studies.

Target Development

A new target assembly, Fig. 1, was developed for use in the high-current bombardment of medium- and high-melting-point metals. It consists of a 6 × 7 in. rifle-drilled flat plate which is clamped between two header blocks containing seal rings. The weight of the target is approximately one-third that of the standard 6 × 10 in. grazing-incidence target used previously. All seals are provided with cam-lock devices to allow easy disassembly after bombardment. Use of this smaller target should greatly facilitate target processing when remote manipulation is necessary. Target plates of Be, Al, Cu, Mg, and Ag have been fabricated for use in the assembly. The copper target has successfully dissipated 36 kw of beam power for 5 hr.

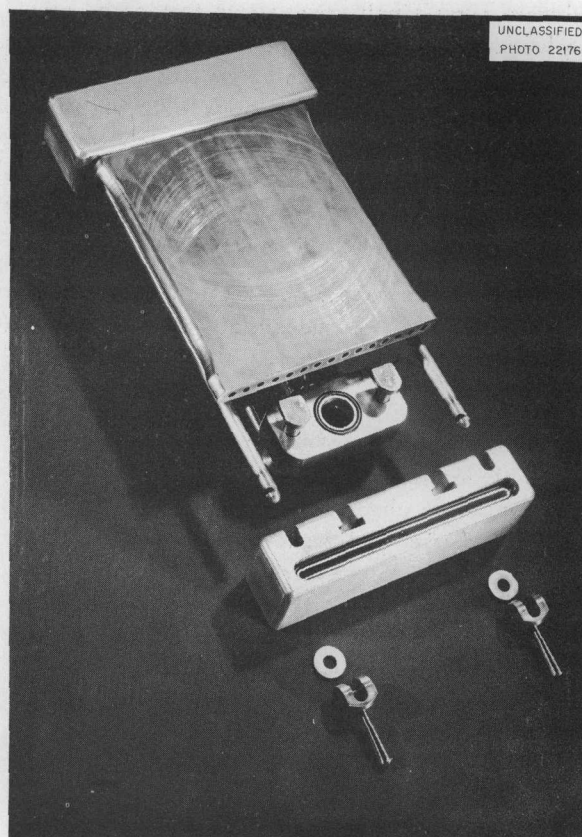


Fig. 1. New Isotope-Production Target Assembly with 6 × 7 in. Removable Water-Cooled Target.

The thin-walled tube target was completely redesigned to simplify removal of the irradiated capsule, to simplify component fabrication, and to allow easy opening of the irradiated capsule. Aluminum, rather than nickel and Inconel, is being used successfully for both the capsule and the outer tube. Figure 2 is a photograph of the target assembly with the capsule partially removed. The capsule is opened by breaking at a pre-scribed point by means of long-handled tongs (see Fig. 3).

Ion-Transmission Studies

In continuation of the ion-transmission tests, highly charged nitrogen ions were accelerated in the 86-in. cyclotron. Triply charged nitrogen ions were accelerated on the fifth mode to an energy of 10 to 12 Mev. Total beam currents of the order of 30 μ a were obtained momentarily; currents up to 5 μ a were easily attained. At a target current of approximately 1 μ a, the 12-Mev triply charged nitrogen beam is accompanied by a very small

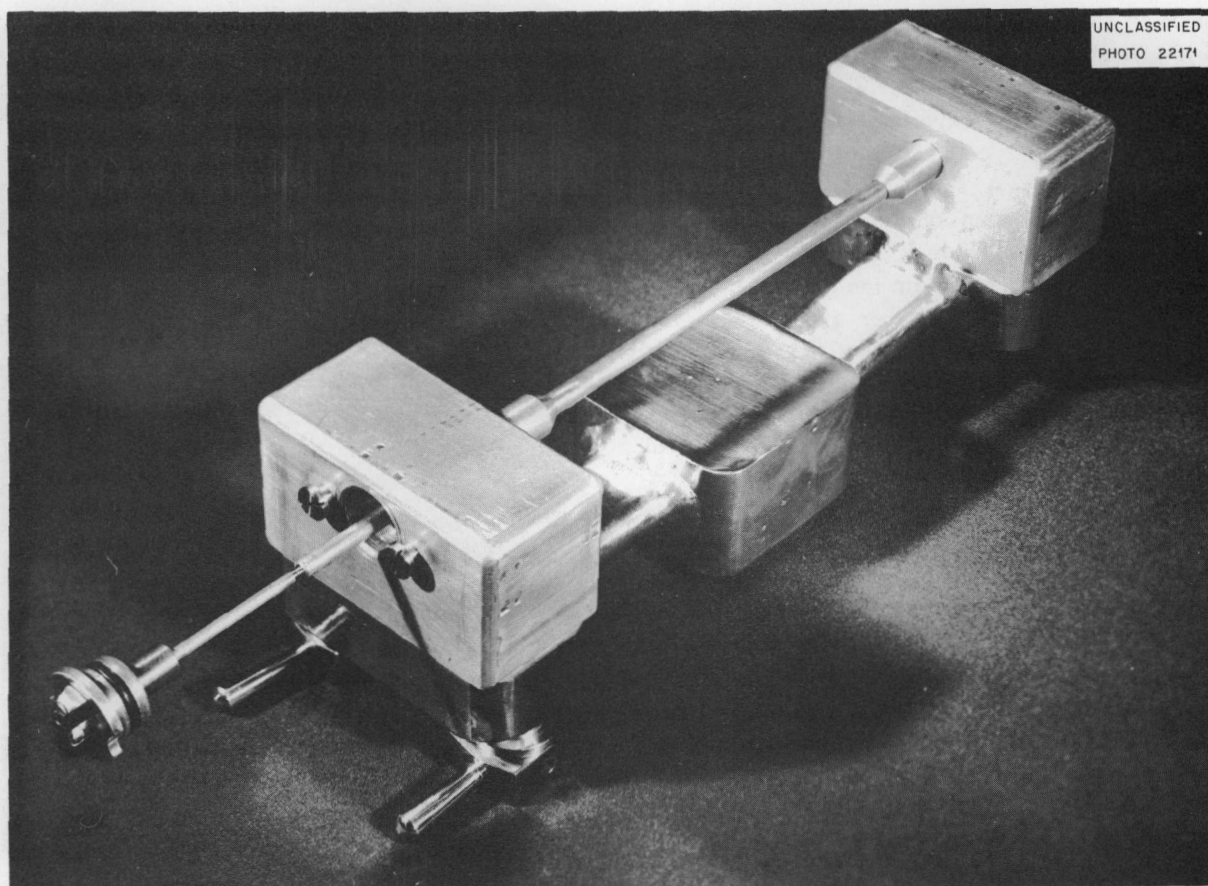


Fig. 2. Capsule-Type Isotope-Production Target Assembly with Removable Capsule.

current ($\sim 10^{-3} \mu a$) of nitrogen ions with energy greater than 30 Mev. This was demonstrated by the production of the 112-m F^{18} activity in a beryllium target bombarded through a nickel absorber (5.18 mg/cm) which stopped nitrogen ions of less than about 19 Mev. An estimate of the energy was also obtained from the ratio of F^{18} and Na^{24} activities produced in a carbon target; the ratio was greater than 1, and, based on data supplied by the 63-in. Cyclotron Group, an energy in excess of 29 Mev is indicated. There would be an acceleration of N^{5+} ions to an energy of about 35 Mev in the third mode at the same frequency and magnetic field at which triply charged nitrogen ions are accelerated. Because of the extremely low current, it is reasonable to assume that these ions originated in the ion source. Efforts to increase the N^{5+} ion beam have been unsuccessful thus far.

BEAM-DEFLECTOR DEVELOPMENT

The major design work for the beam-deflector system for the 86-in. cyclotron was completed. Several components have been fabricated, and a schedule has been established which will permit a shutdown on October 8 for the conversion. It is estimated that a period of from four to six months will be required for the installation of the deflector system.

A prototype magnetic channel coil was constructed and tested in a magnetic gap which approximates the cyclotron conditions. The 32-turn coil requires a 50-v, 5000-amp supply and 60 gal of cooling water per minute at 65 psi. Tests indicate that the field, normally 8800 oersteds, is reduced to about 500 oersteds at the center of the channel, while outside the channel the disturbance is less than 1% except for a local

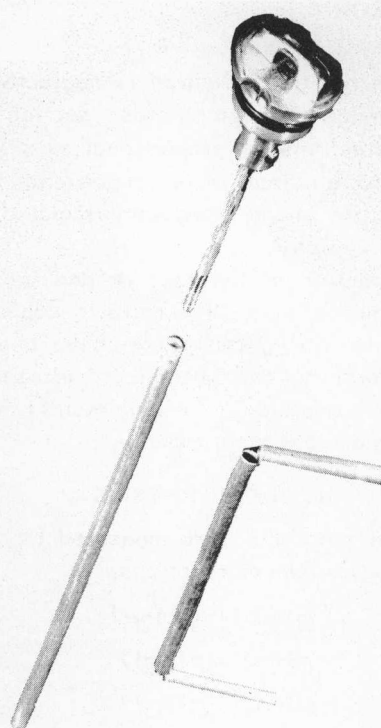
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Fig. 3. Target Capsule, Showing Method of Opening.

region near the entrance end of the coil. A further reduction in the field disturbance was not warranted because the final shimming of the channel will be done in the cyclotron magnet gap.

Aluminum tubing with a 0.062-in. diameter and a 0.010-in. wall thickness was substituted for the 0.050-in.-dia, 0.003-in.-wall tubing in the septum design because of the difficulties of securing a bond that was not subject to corrosion by the flux. Preliminary tests indicate that the heavier-wall tubing can be successfully Heliarc welded. A target test on 0.010-in.-wall tubing was run in the cyclotron at beam currents up to 1200 μ a. A closed, distilled-water system of 35 gpm at 500 psi will be used for cooling the septum tubes; this will permit a beam intensity in excess of 1 ma at the septum. The closed water system is used in order to reduce corrosion of the septum tubes.

CYCLOTRON OPERATION

The 86-in. cyclotron was operated continuously, 80 hr a week, during the past six months except for a few periods of 12 to 14 hr when it was necessary

to shut down in order to repair leaks. The work schedule was continued at two shifts a day, five days a week, until late August; a third shift was then added to take care of the bombardments scheduled to be carried out before the machine is shut down on October 8 for installation of the beam deflector. The following bombardments were completed for the indicated projects.

Nuclear physics research	589
Isotope production and experiments	94
Neutron production for Biology Division (1093 exposures)	55
Operational and developmental tests	12
Total	750

This considerably exceeds the total of 528 bombardments made during the previous six-month period.

The average innage (actual beam on target) was 37.7%, or 30.2 hr for each 80-hr week. The time summary for the period is shown below:

	Hours	Per Cent
Innage (beam on target)	827	38
Attempted innage and bakeout time	266	12
Ion source - routine change of filament and adjustments	60	3
Targets - routine change and inspection	594	27
Equipment failure and troubles	244	11
Standby (waiting for target)	127	6
Radiation hazard	12	<1
Weekly startup and shutdown	40	2
Scheduled shutdown	27	1

A new record for continuous beam power was achieved on September 10. A steady proton current of 2000 μ a at 18 Mev was maintained for 5 hr; a 6 x 7 in. copper target was used for the production of Zn⁶⁵. This steady operation at higher power was obtained when the beam energy was reduced to 18 Mev by the effective center of the beam orbit being moved toward the target. The beam center is controlled by means of so-called "half-coils" wound on the pole pieces. The beam power on the target, 36 kw, was measured by calorimetric methods. This is the largest amount of sustained power ever put on a production target in the 86-in. cyclotron.

THE ORNL 63-INCH CYCLOTRON

Research conducted with the high-energy nitrogen ions accelerated in the 63-in. cyclotron may be conveniently separated into the two categories of atomic physics and nuclear physics.

ATOMIC PHYSICS

Further studies were made on the penetration of nitrogen ions through matter in the velocity region where orbital electrons are captured and lost. The equilibrium charge of ions in thin Formvar foils was measured as a function of ion energy. After passing through a thin foil, about $25 \mu\text{g}/\text{cm}^2$, the beam was analyzed into its component charge groups by the fringing field of the cyclotron and was detected with nuclear emulsions. The equilibrium distribution of ionic charge is given as a function of energy in Fig. 4. Over most of the energy region investigated, only the first three electrons play a part in the capture-and-loss process.

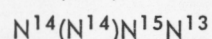
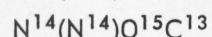
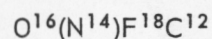
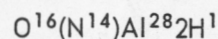
Capture-and-loss cross sections cannot be determined from measurements of this type, but the ratio of the capture-to-loss cross section can be obtained. For example, the ratio of the loss-to-capture cross section for the first electron is just the ratio of N^{7+} to N^{6+} , if the contribution that

results from the third electron is neglected. The ratio of the loss-to-capture cross section for the first two electrons is proportional to $v^{3.9}$, and for the third electron it is proportional to $v^{2.7}$ over the entire energy range investigated, where v is the ion velocity.

A determination of the capture and loss cross section requires very thin foils. Zapon foils, approximately $3.5 \mu\text{g}/\text{cm}^2$ thick, have been made at this laboratory, and preliminary measurements have been completed. Final results will be available in a subsequent report.

NUCLEAR PHYSICS

Excitation functions were measured for the following nitrogen-induced reactions:



The last two reactions in particular have almost identical excitation functions (see Fig. 5). If some mechanism such as neutron or proton cross-

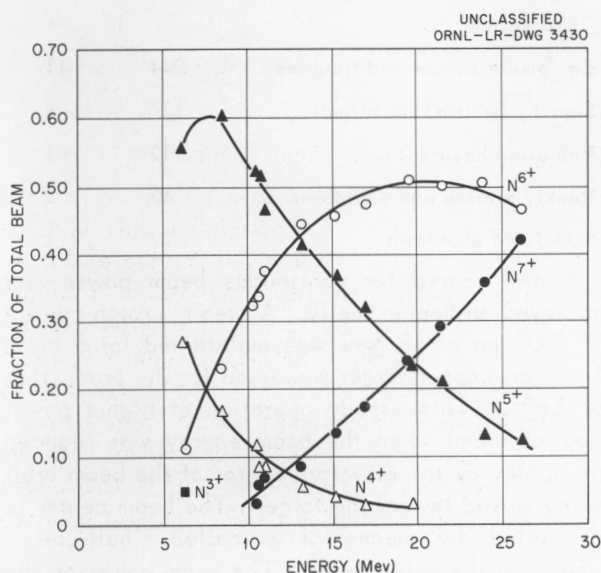


Fig. 4. Equilibrium Charge Distribution of Nitrogen Ions as a Function of Energy.

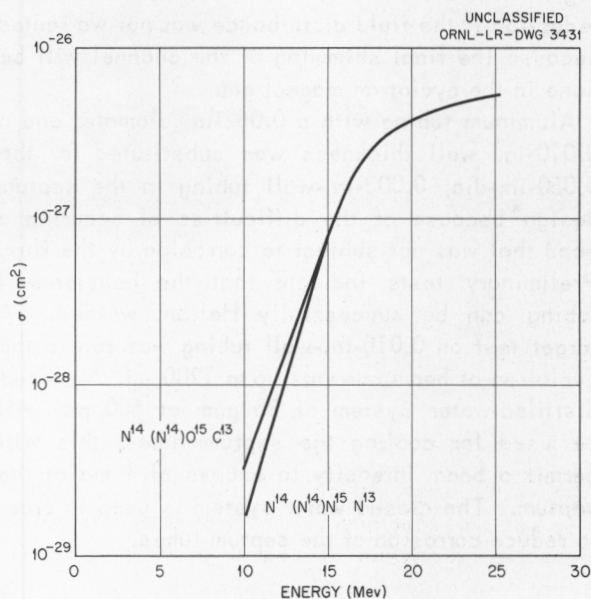


Fig. 5. Excitation Functions of Nitrogen-Nitrogen Reactions.

over were of primary importance, there should be a difference in the thresholds for these two reactions. The similarity between the two curves is an indication of a compound-nucleus mechanism for the two reactions.

Nitrogen-induced reactions in aluminum were studied by radiochemical means. Both N^{13} and C^{11} were found to be included in the reaction products. The presence of these two nuclides

throws doubt on the recent "buckshot" hypothesis for heavy-particle reactions, at least below 30 Mev.

A double-focusing 90-deg magnetic analyzer was designed for the identification of reaction products from nitrogen-induced nuclear reactions.

Preliminary results were obtained for the excitation functions of nitrogen-induced reactions in boron.

THE ORNL 44-INCH CYCLOTRON

The design work for the revision of the 44-in. cyclotron was completed, and fabrication and assembly of components are approaching completion. This machine is being redesigned for the acceleration of large currents of protons to 1.5 and 5 Mev. The oscillator, vacuum system, ion source, and target-probe are ready to be installed. The existing power supplies are being enlarged.

The dee stem and dee-stem housing have been assembled and are ready for mounting of the dees. The dees were delivered by the contractor, but

several leaks in very inaccessible locations have delayed final assembly. In order to repair the leaks in the internal water-cooling tubes it was necessary to cut windows through the sides of the dees. The windows were then closed by Heliarc welding. The liner for the vacuum tank and for the dee-stem housing has not yet been delivered.

Grinding and shimming of the tank walls to produce a flat magnetic field was continued. The magnetic field is now uniform to within 0.05%.

MULTIPLE-PARTICLE HEAVY-ION CYCLOTRON

A proposed variable-frequency 114-in. cyclotron for the acceleration of heavy particles, carbon through neon, to energies sufficient to penetrate the Coulomb barrier of the heavy elements was briefly described in the previous progress report.¹ Studies of the magnetic and radio-frequency requirements for this machine have been continued. As a possible alternative proposal, the feasibility of converting the 44-in. proton cyclotron to a 48-in. heavy-particle machine is being explored.

PROPOSED 114-INCH CYCLOTRON

A small-scale model of the 114-in. magnet, Fig. 6, was designed to provide answers to the essential questions of magnet geometry. A full-scale electrical model of the dee system was constructed and tested. In conjunction with the

electrical model, a pneumatic-pressure, movable, r-f joint was developed.

Quarter-Scale Model

The one-quarter-scale model magnet is of the closed-yoke type. The completed unit will be $75 \times 46.5 \times 45$ in., with a maximum gap of 4.6 in. and a minimum gap of 2.875 in. Its total weight will be 14.4 tons; 12.7 tons will be iron and 1.7 tons will be copper. The magnet gap will be in a vertical plane to provide the greatest access for making field measurements. The pole tips are removable so that shims of any shape can be inserted readily. A central field of 20,000 gauss will require an excitation of 6775 amp at approximately 50 v.

The yoke was designed to be constructed of new iron from commercial sources, but, with slight design changes, available surplus iron can be used instead. The magnet is of laminated design,

¹Electronuclear Research Semiann. Prog. Rep. March 20, 1954, ORNL-1670, p 13.

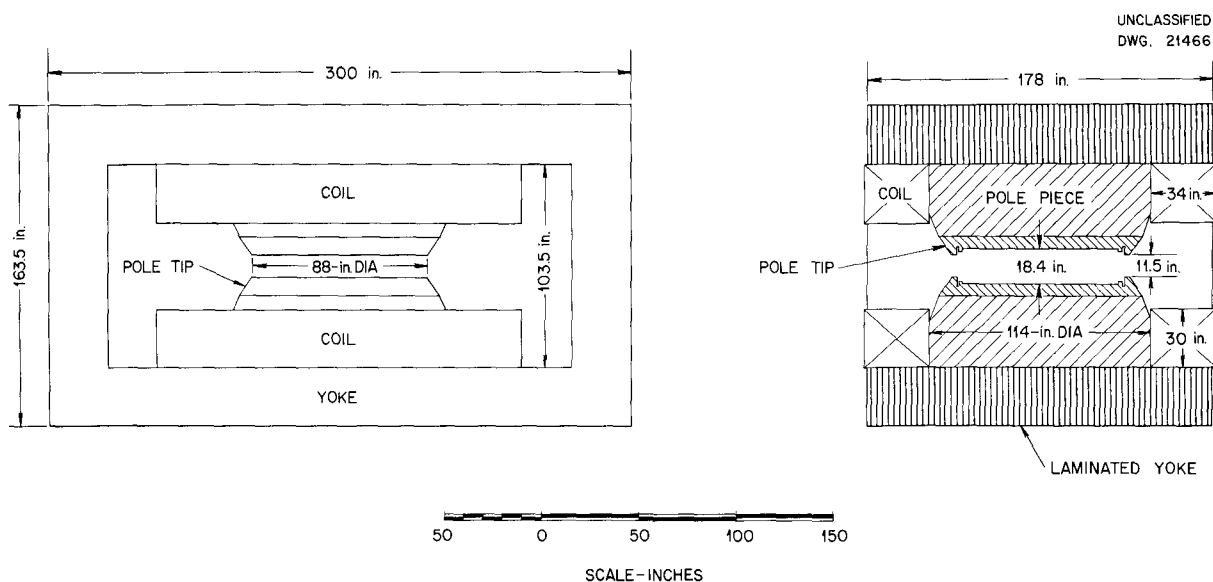


Fig. 6. Magnet for Proposed 114-in. Heavy-Particle Cyclotron.

with each layer tack-welded to the next, and it has four corner bolts for added strength. The pole pieces are 2-in.-thick iron disks that are secured to the yoke by bolts.

The coils are made up of two "pancake" windings that are connected in series electrically and have parallel coolant passages. The conductors are made from 3×0.42 in. available surplus copper ribbon and are water cooled by a copper tubing brazed to one edge.

Electrical Model

A model of the radio-frequency system, Fig. 7, was constructed in order to check the computed frequency range and the voltage distribution along dee stems that have variable parallel-plate capacitors connected to ground. Although the actual cyclotron would have been mounted with the dee stems vertical, it was necessary to construct the model with horizontal dee stems because of space limitations and accessibility. The horizontal mounting necessitated the use of dee-stem supports, which degraded the Q of the system considerably.

Measurements were first made on the model without the variable capacitors on the dee stems and with the spider arbitrarily placed 227 in. from the dee tips. This position is not the one computed for the spider in the original design, but

the decision was made to leave the spider there for all measurements except those of frequency range because it might be damaged by repeated movement. Under the above conditions the resonant frequency of the system was 8.07 megacycles, with a Q (measured on a band-width basis) of approximately 3400. Voltage probes were installed at 20-in. intervals along the dees and dee stems to measure the standing wave (Fig. 8). A further check on the Q of the system was made by computing the effective series resistance of the dee stems from voltage and impedance measurements and comparing it with the resistance computed from Q . The two values differed by less than 10%; thus it was indicated that the band-width Q is approximately correct.

Measurements on the system with the variable capacitors in place are not fully completed. Data thus far obtained indicate that the Q of the system has been lowered considerably - to 1160. This lowering is probably due to wooden braces on the capacitor. A standing-wave curve was also obtained with the capacitors unmeshed; it is shown in Fig. 9 along with the measured standing wave from Fig. 8 for comparison purposes. A preliminary measurement of the frequency tuning ratio, with the spider still in its arbitrary position, gives a value of 1.44 (5.5 to 7.9 megacycles), compared with the design value of 1.5.

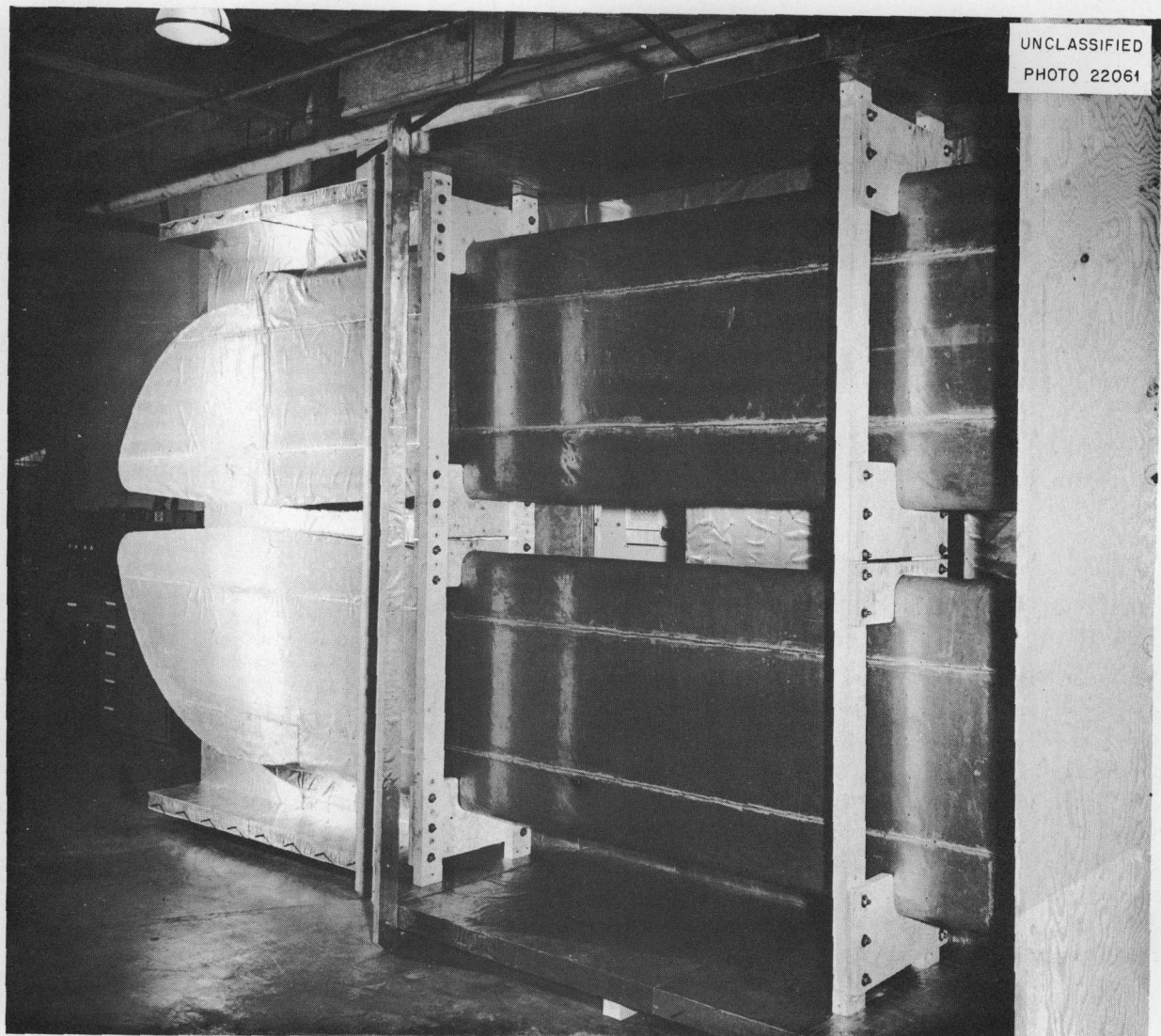


Fig. 7. Radio-Frequency System for Proposed 114-in. Cyclotron.

Pneumatic-Pressure Radio-Frequency Joint

In the design of the 114-in. cyclotron, the frequency of the dee system must be varied over a wide range, and the use of a parallel-plate variable condenser seems to be the most practical way of accomplishing such variation. One set of plates is fixed to the dee stem, and the other set is movable along the inside of the r-f shield. The connection to the movable plates must permit the plates to be moved while under vacuum and must carry an r-f current of approximately 100 amp per lineal inch. The pneumatic r-f joint, shown in

Fig. 10, was tested as a possible solution to this problem.

The pneumatic tube is soldered to the condenser plates and fitted loosely into a long C-clamp which holds a knife edge just above and along the tube. When the tube is inflated, contact is made between the tube and the C-clamp by means of the knife edge. (The knife edge profile is shown to scale in Fig. 10.) When the air pressure in the tube is released, the tube is free to slide along in the C-clamp.

Tests have been conducted on copper, copper-plated brass, and copper-plated stainless steel

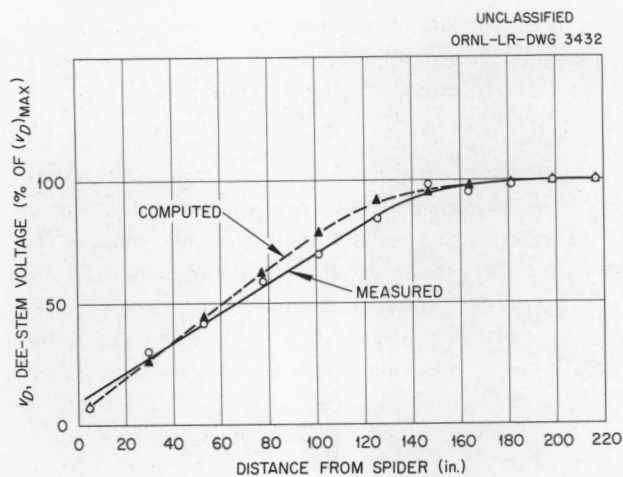


Fig. 8. Standing Wave on Dee Stem.

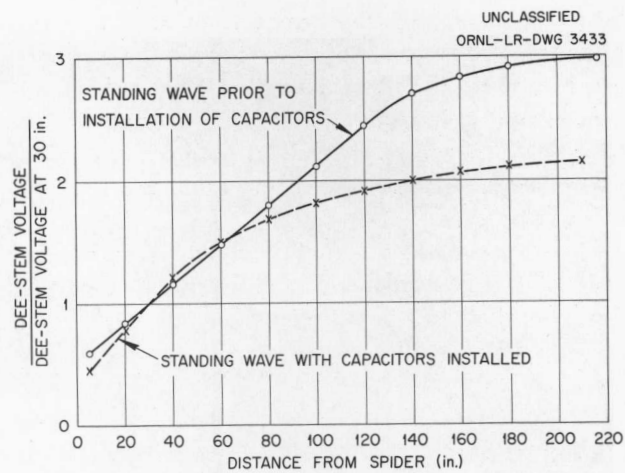


Fig. 9. Normalized Standing Wave on Dee Stem.

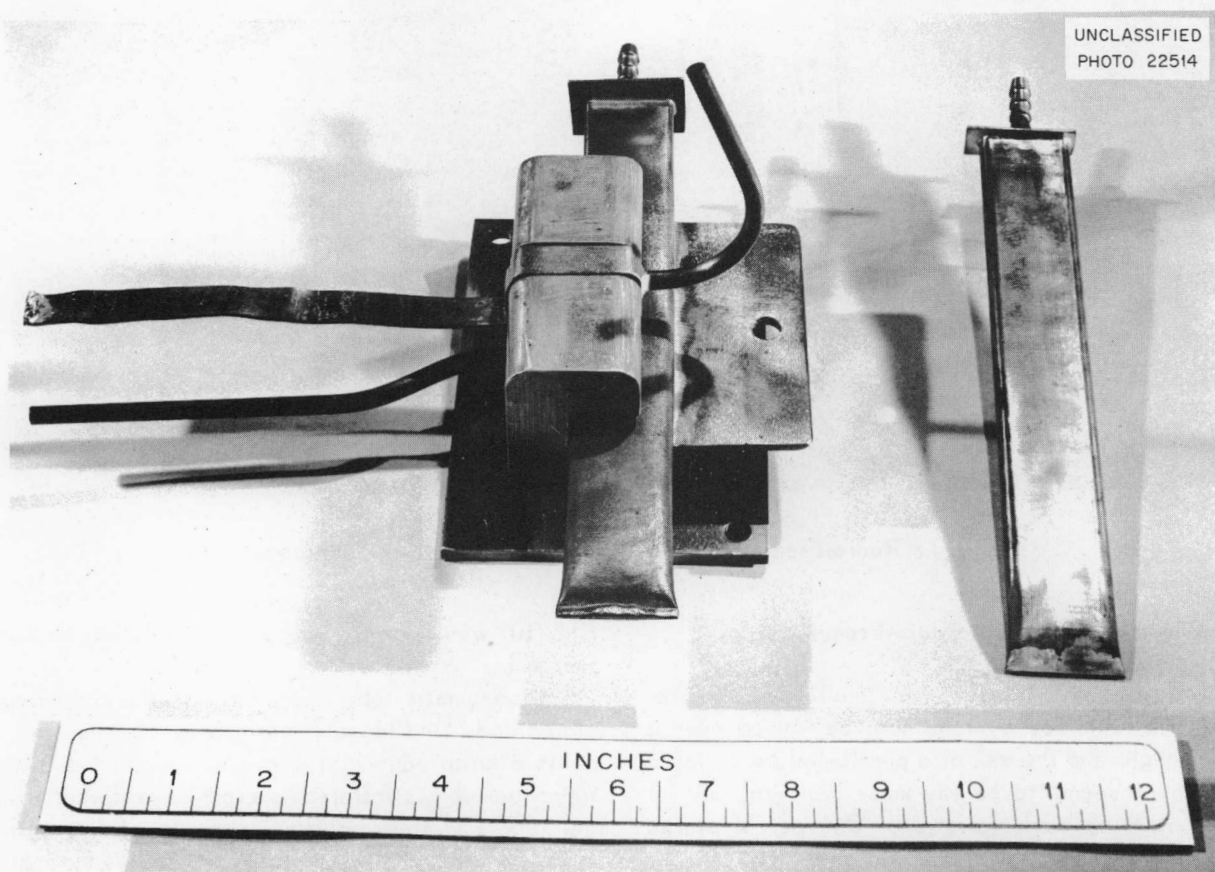


Fig. 10. Pneumatic Radio-Frequency Joint.

tubes to determine the temperature rise and resistance of the joint as functions of the current, air pressure, and cooling-water flow. Measurements were also made of the force exerted by the tube on the knife edge, the deflection of the tube vs pressure, the stresses in the tube, and the life of various tubes.

The results of the study indicate that, of the materials tested, copper-plated stainless steel is the best choice. It was found that, at an r-f load of 100 amp per lineal inch, the temperature rise could be held to less than 10°C by a water flow of only 0.5 gpm. Once the joint had been made, the temperature rise was rather insensitive to air pressure in the tube. For the application described above, the tests demonstrate that this type of joint is quite feasible.

PROPOSED CONVERSION OF THE 44-INCH CYCLOTRON

A possible alternative proposal for a heavy-particle cyclotron is being explored. The present 44-in. cyclotron has dees 44-in. in diameter and is operated in a beta magnet at a magnetic field of 6350 gauss. Preliminary investigation has

shown that, with a properly designed magnet, this cyclotron could be adapted for use as a heavy-particle cyclotron for the acceleration of N^{5+} to about 89 Mev.

Conversion of the 44-in. cyclotron to a heavy-particle machine would require the construction of a new magnet and a new vacuum tank. The 48-in. pole pieces would be incorporated in the walls of the vacuum chamber. All other components of the present 44-in. cyclotron, oscillator, dee system, vacuum system, ion source, target-probe, and power supplies, would be utilized. It would be necessary to provide a properly shielded room for operation at this energy and to reroute all utility connections to this new location.

The new magnet would be of the closed-yoke type with a magnetic field of 20,000 gauss at the center and a pole-tip diameter of 48 in. At the design frequency, 11 megacycles, the magnetic field could be varied to obtain resonance for highly ionized carbon, nitrogen, and oxygen (see Table 2). The cyclotron would require a room approximately 20 × 40 ft in size and with shielding walls of 3 ft of poured concrete.

TABLE 2. CHARACTERISTICS OF ACCELERATED PARTICLES AND OPERATING QUANTITIES

	Ion			
	C^{5+}	N^{5+}	N^{6+}	O^{6+}
Atomic number	6	7	7	8
Mass	12	14	14	16
Kinetic energy, Mev	76.4	89.0	89.0	102.0
Kinetic energy per nucleon, Mev	6.37	6.37	6.37	6.37
Magnetic field gauss	17,000	20,000	16,700	19,050
Threshold voltage dee-to-ground, kv	46.8	54.5	45.4	52.0
Radio frequency, megacycles	11	11	11	11

Part II

 WORK

100

ABSTRACT

Relatively high enrichments of the heavier isotopes of plutonium were obtained in an electromagnetic separation run in which 12.7% Pu^{240} was utilized as the feed material; the Pu^{240} and Pu^{241} products exceeded 85% and 60%, respectively.

The ORNL design study for the Army Package Power Reactor was completed, and the Chicago Operations Office has issued invitations to 33 prospective prime contractors for lump-sum bids.

SPECIAL SEPARATIONS

PLUTONIUM PROGRAM

The laboratory-scale separation of plutonium isotopes was continued, both for the production of enriched isotopes to be used in nuclear measurement and for the evaluation of the suitability of the electromagnetic process in larger-scale operations of interest in special-weapons applications. The feed bank for the program presently consists of 477 g of plutonium that assays 5.6% Pu^{240} and 140 g that assays 12.7% Pu^{240} .

Calutron Performance

Isotope-separation results for the second and third plutonium runs with the 5.6% feed are given in Table 3. The Pu^{240} product was recovered from the collector in two batches, which are listed separately. These separations completed the initial processing of the material containing 5.6% Pu^{240} , and recovery of the unseparated material is in progress. The recovered 5.6% material will be put through an additional separation cycle after

completion of the initial separation runs with the 12.7% feed.

Relatively high enrichments for the heavier isotopes of plutonium were obtained in the fourth separation run, which utilized the feed material that contained 12.7% Pu^{240} (see Table 4). The Pu^{240} product was selectively removed from the collector pocket in two batches and assayed separately. The enrichments of Pu^{240} and Pu^{241} , relative to Pu^{239} , were 48 and 126, respectively. The average separation rate during the run was 370 mg/hr, and the efficiency of conversion of PuCl_3 vapor to well-focused Pu^+ ions was 7%.

In recycle operations, 70 g of the plutonium that was vaporized but not separated was recovered and converted to PuCl_3 charge material to be used in future separation runs.

Chemical Recycle and Feed Preparation

Seven batches of plutonium chloride (PuCl_3) were prepared for calutron feed, and a total of

TABLE 3. SEPARATION RESULTS OBTAINED WITH FEED CONTAINING 5.7% Pu^{240}

Run Number	Collector Pocket	Isotopic Composition (at. %)			Weight of Plutonium (g)
		Pu^{239}	Pu^{240}	Pu^{241}	
2	Pu^{239}	99.42*	0.53	0.05	6.48
	Pu^{240}	38.52	61.01	0.47	0.42
	Pu^{241}	63.23	20.65	16.07	0.18
3	Pu^{239}	(Not assayed)			
	Pu^{240}	23.59	75.83	0.58	0.51
	Pu^{240}	41.52	57.61	0.87	0.76
	Pu^{241}	61.8	15.3	22.8	0.12

*Isotope desired.

TABLE 4. SEPARATION RESULTS OBTAINED WITH FEED CONTAINING 12.7% Pu^{240}

	Isotopic Content (at. %)				Plutonium (g)
	Pu^{242}	Pu^{241}	Pu^{240}	Pu^{239}	
Feed vaporized	0.22	1.71	12.7	85.4	120
Pu^{242} product	<u>4.5*</u>	20.9	30.0	44.3	0.06
Pu^{241} product	0.6	<u>62.1</u>	12.8	24.5	0.16
Pu^{240} product	0.10	0.71	<u>80.1</u>	19.1	0.37
Pu^{240} product	0.04	0.58	<u>87.2</u>	12.2	0.74
Pu^{239} product			1.0	<u>99.0</u>	7.0

*Isotope desired.

TABLE 5. DISTRIBUTION OF ISOTOPES

Isotope	Receiver	Amount (g)	Purity (%)
U^{235}	Oak Ridge Institute of Nuclear Studies	0.030	99.94
	Oak Ridge National Laboratory, Y-12	0.427	99.86
	Columbia University	0.102	99.08
	Oak Ridge National Laboratory, X-10	30.480	97.34
	Oak Ridge National Laboratory, Y-12	22.052	97.34
U^{236}	Argonne National Laboratory	0.003	96.65
	University of California Radiation Laboratory	0.015	96.65
U^{238}	Phillips Petroleum Company	0.017	99.99992
	Brookhaven National Laboratory	102	99.9997
	University of California Radiation Laboratory	0.500	99.9997
	North American Aviation, Inc.	2.147	99.994
	Brookhaven National Laboratory	101.8	99.957
	Dow Chemical Co.	5.088	99.946
Th^{230}	University of California Radiation Laboratory	0.212	90.02
	Oak Ridge Institute of Nuclear Studies	0.003	87.85
	Emory University	0.025	87.85
Pu^{240}	Oak Ridge National Laboratory, X-10	0.491	75.83
	Los Alamos Scientific Laboratory	0.162	62.80
	University of California Radiation Laboratory	0.060	62.80
Pu^{241}	Los Alamos Scientific Laboratory	0.063	14.30
	University of California Radiation Laboratory	0.022	14.30

1428 g of the chloride is represented in these preparations. The preparation method has been standardized to give theoretical yields of chloride suitable for calutron operation. The technique consists in producing the oxide from the oxalate at a low temperature (less than 350°C); the oxide is then dissolved in HCl, evaporated to crystals, and refluxed with hexachloropropene for 12 to 18 hr. Complete chlorination is achieved by reacting the last traces of oxide with phosgene at 500 to 550°C.

Wash solutions obtained in the recovery of plutonium from calutron units were evaporated in a tantalum evaporator with a capacity of 12 gph. Processing for purification to the oxide consists in the removal of copper by means of an ammonia precipitation of the plutonium; iron is removed by an oxalate precipitation. The final chlorination at

high temperature with phosgene serves to remove trace impurities as volatile chlorides.

Salvage solutions, for example, filtrates and condensates, have remained sufficiently low in plutonium content to permit them to be discarded. Solid salvages present a difficult processing problem in that heating in a muffle furnace and fusions are required in order to permit plutonium to be recovered. Limited facilities and personnel have resulted in a backlog in salvage operation that must be eliminated before a meaningful material balance can be obtained.

ISOTOPE SHIPMENTS

The distribution of electromagnetically enriched isotopes of heavy elements to various laboratories since March 1954 is shown in Table 5.

ARMY PACKAGE POWER REACTOR

The Army Package Power Reactor (APPR) project is being administered by the Chicago Operations Office (COO) of the AEC in conjunction with the Army Reactors Branch, Division of Reactor Development, AEC. The latter group is composed of military personnel loaned from the U. S. Army Corps of Engineers.

More than 100 industrial firms expressed interest in undertaking the design and construction of a prototype plant based on the feasibility report prepared by the Laboratory.¹ On July 8, 1954, an amplified and revised edition² of the previous report was issued on limited-distribution basis. The revised edition contains the conceptual design for a 10-Mw, heterogeneous, water-cooled and moderated reactor suitable for the generation of 1000 kw of net electric power and 3535 kw of steam for heating purposes. The plant is designed for use at a remote military installation (Fig. 11).

On August 19, 1954, invitations to bid on the plant were sent by COO to 33 private firms. The

interested contractors were requested to submit bids based on the following seven major requirements:

1. The contractor will be completely responsible for the design, construction, and testing of a 10-Mw reactor which will reliably produce electric power at approximately 1700-kw net output. The basic system will be that described in the above-mentioned report.

2. The proposed site is Fort Belvoir, Virginia.

3. Stainless-steel-clad, highly enriched fuel assemblies will be used. The contractor has the choice of either furnishing appropriate fuel assemblies or obtaining them from the Oak Ridge National Laboratory.

4. The contractor will be responsible for obtaining the approval of the Reactor Safeguards Committee for the safety of the plant.

5. The contractor will guarantee the performance of the plant for a 700-hr test period, with not more than 40 hr of outage permissible. An additional six-month operating period may also be required; if so, the contractor will be paid an amount commensurate with the reliability of operation.

6. A period of three years will be allowed for the completion of the project, not including the six-month operating test.

7. The contractors will submit bids for the

¹A. L. Boch, W. R. Gall, and W. H. Jordan, *A Ten-Megawatt Pressurized-Water Package Reactor and Associated Power Plant*, ORNL CF-53-10-106 (Nov. 2, 1953).

²A. L. Boch, W. R. Gall, G. F. Leichsenring, and R. S. Livingston, *A Conceptual Design of a Pressurized-Water Package Power Reactor*, ORNL-1613 (July 8, 1954).

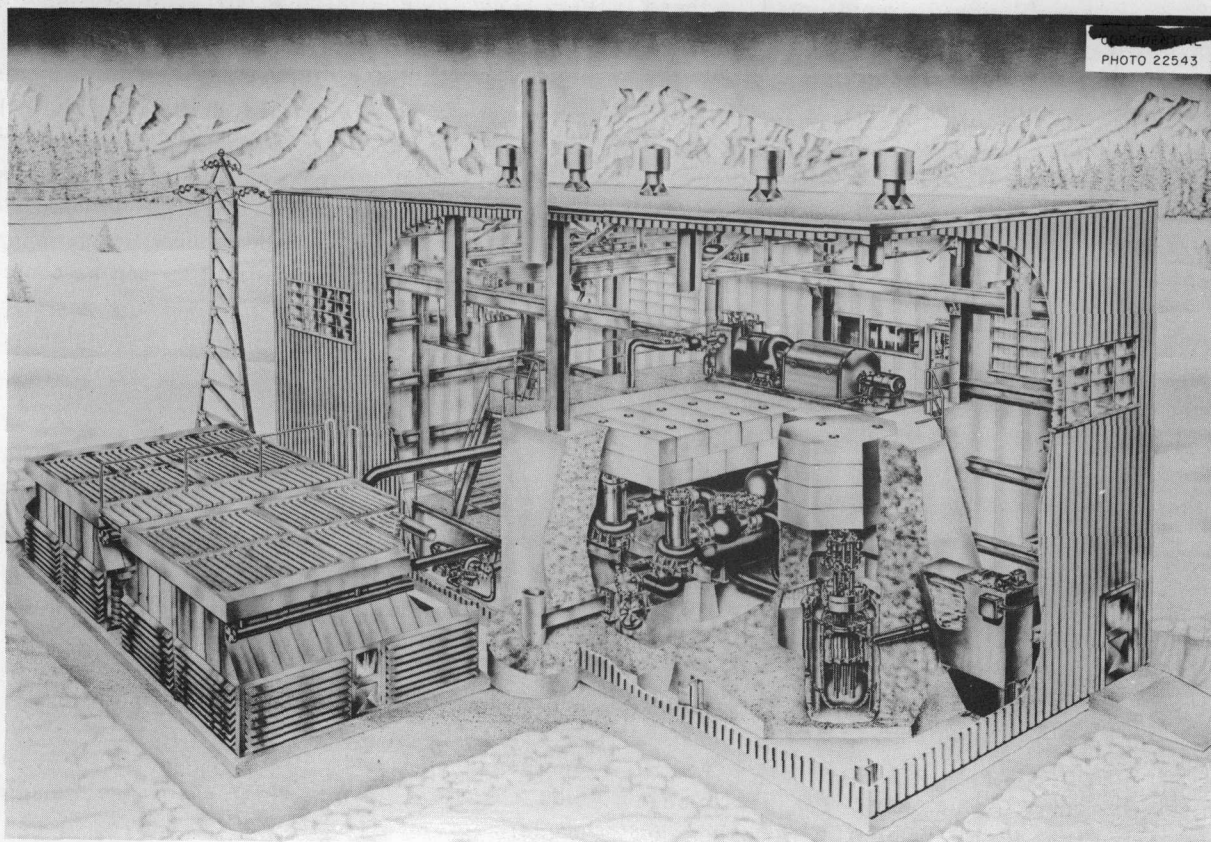


Fig. 11. Artist's Sketch of Army Package Power Reactor; Based on ORNL Design Study.

design, construction, testing, and performance of the plant on a lump-sum basis.

The contractors are expected to return the bids to the Chicago Operations Office by November 19, 1954. The Contractor Selection Board will then analyze the bids and will award the contract approximately one month later.

APPR DEVELOPMENT PROGRAM

Although the design of the package reactor was intended to utilize existing technology and to require a minimum of development work, the Laboratory has continued a modest development program.

Fuel-Plate Fabrication

Work is continuing on the development of suitable fuel plates to be fabricated of a UO_2 -stainless steel-ZrB₂ matrix clad in type 304L stainless steel. At present the major effort is being devoted to the brazing of the fuel plates to stainless steel side plates. A complete summary of this work will

be reported in the progress report of the Metallurgy Division.

Fuel-Plate Irradiations

Plans have been made for the irradiation of a package reactor fuel assembly in the lattice of the MTR. The assembly will be irradiated to 50% burnup of the U^{235} ; this will be equivalent to approximately 30 Mwy of operation for the package reactor. Tentative plans are being made for a similar irradiation in the core of the STR. The STR test is more desirable because of the close approximation between the operating conditions in the STR and in the APPR.

Reactor Simulator Tests

The package reactor will be re-examined, with the latest reactor parameters and by means of the ORNL Reactor Plant Simulator, for the effect of changes in load and reactivity on the stability.

Control-Rod Drive Mechanism

The mechanism has been operated for more than 70,000 cycles and 500 scrams. The high-pressure seal has operated very satisfactorily with a recorded leakage rate of 4.5 lb/hr at the specified conditions of temperature and pressure. The anticipated leakage rate was 10 lb/hr. Examination of the components after testing disclosed very little wear of the metal parts. Accelerations of the rod of up to 27 ft/sec² were achieved under scram conditions. Tests of the mechanism which involve cycling, scrams, and corrosion effects will continue.

Nuclear Calculations

Criticality calculations have now been made by three methods: (1) modified 2-group diffusion theory, with multiplication in the fast group, performed with desk calculators; (2) 3-group, 3-region diffusion-theory calculations, coded for the ORACLE computer; and (3) 30-group, 9-region diffusion-theory calculations, coded for the UNIVAC. The third method is a modification of a previous UNIVAC program and now employs the Goertzel-Selengut method for describing neutron-energy loss in hydrogen collisions. The method has yielded very satisfactory results when applied to a number of aqueous homogeneous critical assemblies. All three methods give comparable results for critical mass for the cold, clean reactor; the hot, poisoned reactor; and the hot, fully loaded reactor with boron burnable poison. The greatest difference is about 10% in critical mass, or about 4% in reactivity. The discrepancies are qualitatively understood in terms of approximations made in one or another of the methods. Results of the modified two-group calculations were reported in the revised feasibility report;² results of the automatic computer calculations are being reported in a supplement.

Control-rod calculations were made in two ways. (1) Modified two-group calculations were made for an equivalent bare cylindrical reactor, employing a fast-group boundary condition, at the rod surface,

based on diffusion of the fast neutrons into the moderator within the rod. (2) The ORACLE program was used to perform three-group, three-region calculations, on a central control rod. These methods, applicable at present only to a central rod, give results appreciably different from the Nordheim-Scallettar method and are used to apply corrections to Nordheim-Scallettar calculations of the multirod system.

The 30-group, 9-region UNIVAC program was used to obtain spatial distributions of fuel, boron, and neutron fluxes at various times in the burnup cycle of the reactor.

APPR INFORMATION MEETINGS

Four information meetings dealing with various pertinent aspects of the APPR have been arranged for the prospective contractors. The schedule and purpose are as follows:

1. **September 21, 22, and 23.** The prospective contractor will visit the proposed site, Fort Belvoir, Virginia, for a briefing on the pertinent data involving geographical and geological considerations.

2. **September 24.** The contractors have been invited to the Bettis Plant of the Westinghouse Electric Corporation, Pittsburgh, Penna., for a general question-and-answer period on topics pertinent to the APPR.

3. **September 27, 28, and 29.** A comprehensive metallurgy information meeting has been arranged at ORNL for the contractors. The meeting will cover primarily fuel plate design and development, including irradiation effects and chemical processing.

4. **September 30 or October 1.** A demonstration and information meeting on the APPR control-rod drive mechanism will be conducted by the American Machine & Foundry Co. at their laboratory in Greenwich, Conn. The American Machine & Foundry Co. is under subcontract to ORNL for the evaluation of the drive system.

OPERATIONS SUMMARY

A summary of operations in Buildings 9204-3 and 9201-2 from March 20 to September 20, 1954 includes the following experimental runs:

Special separations	26
Electronuclear research	112
Electronuclear machines	16
The 86-in. cyclotron	745

The 63-in. cyclotron	87
The 44-in. cyclotron	47

The distribution of shop time charged to each of the various projects is given in Table 6.

Assignment of personnel to the various projects is indicated in the organization chart.

**TABLE 6. TIME DISTRIBUTION - MECHANICAL SERVICE AND MACHINE SHOPS,
MARCH 20 TO SEPTEMBER 20, 1954**

Account Number and Project	Mechanical Service		Machine Shop			
	Hours	Per Cent of Total Time	Carbon		Metal	
			Hours	Per Cent of Total Time	Hours	Per Cent of Total Time
33 Special separations	3,258.5	19.43	1264.7	61.61	333.0	9.98
34 86-in. cyclotron, applied physics	1,497.0	8.92	4.0	0.20	8.0	0.24
35 86-in. cyclotron, operations	4,250.9	25.34	67.0	3.26	603.8	18.10
37 Electronuclear machines	919.0	5.48	3.0	0.15	95.0	2.85
39 86-in. cyclotron, nuclear physics	104.0	0.62			212.0	6.35
40 63-in. cyclotron, physics	196.0	1.17	56.0	2.73	512.0	15.34
41 63-in. cyclotron, operations	1,141.9	6.81	87.0	4.24	120.0	3.60
43 Package reactor	3.0	0.02				
44 44-in. cyclotron	1,810.2	10.79	12.0	0.58	1177.0	35.27
46 Electronuclear research	3,548.7	21.15	558.9	27.23	276.0	8.27
1 Building maintenance	45.5	0.27				
Total	16,774.7	100.00	2052.6	100.00	3336.8	100.00

