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ORNL-1531
Progress
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ELECTROMAGNETIC RESEARCH DIVISION

SEMIANNUAL PROGRESS REPORT

FOR PERIOD ENDING MARCH 20, 1953

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OPERATED BY
CARBIDE AND CARBON CHEMICALS COMPANY
A DIVISION OF UNION CARBIDE AND CARBON CORPORATION
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for Period Ending March 20, 1953

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

DATE ISSUED

MAY 4 1953

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CARBIDE AND CARBON CHEMICALS COMPANY
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PAPERS PRESENTED DURING THE PERIOD

B. L. Cohen, *Angular Distributions of 21 Mev Protons Eleastically Scattered by Various Nuclei*, American Physical Society meeting, Cambridge, Mass., January 22-24, 1953.

A. Zucker, Invited Paper, *Nuclear Reactions with 25 Mev Nitrogen Nuclei*, American Physical Society meeting, Cambridge, Mass., January 22-24, 1953.

A. L. Boch, *Cyclotron Efficiency and Power Distribution Measurements*, American Physical Society meeting, Durham, N.C., March 26-28, 1953.

B. L. Cohen, *On the Statistical Theory of Nuclear Reactions*, American Physical Society meeting, Durham, N.C., March 26-28, 1953.

F. L. Green, *Electromagnetic Shims for Focusing in a Fixed-Frequency Cyclotron*, American Physical Society meeting, Durham, N.C., March 26-28, 1953.

R. J. Jones, *The Oak Ridge 44-Inch Cyclotron*, American Physical Society meeting, Durham, N.C., March 26-28, 1953

J. A. Martin, *Radioisotopes Production in the ORNL 86-Inch Cyclotron*, American Physical Society meeting, Durham, N C., March 26-28, 1953.

R. S. Livingston, *Recent Developments in High Energy Accelerators*, ORNL-ORINS Traveling Lectures, Alabama Polytechnic Institute, Tulane University, and Howard College, January 12-15, 1953.

ARTICLES FOR PUBLICATIONS

J. L. Fowler, W. H. Jones, and J. H. Paehler, "Fission Asymmetry as a Function of Excitation Energy of the Compound Nucleus," *Phys Rev* **88**, 71 (1952).

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L. D. Wyly and A. Zucker, "Activities in Light Nuclei from Nitrogen Ion Bombardment," *Phys Rev* **89**, 524 (1953).

W. R. Smith, "A Quick-Change Seal Opener," submitted to *The Review of Scientific Instruments*

B. L. Cohen, E. Newman, T. H. Handley, and A. Timnick, "Angular Distribution of Deuterons from $Be^9(p,d)Be^8$," submitted to *The Physical Review*

T. H. Handley and E. L. Olson, "Dysprosium-157," submitted to *The Physical Review*

R. S. Livingston and R. J. Jones, "High Intensity Ion Source for Cyclotrons," submitted to *The Review of Scientific Instruments*

B. L. Cohen, "Gallium-64," submitted to *The Physical Review*

"Laboratory Announces Achievement of Nuclear Fusion by 63-Inch Cyclotron," news release, February 20, 1953.

TOPICAL REPORTS ISSUED

R. S. Livingston, J. S. Luce, and J. A. Martin, *The Application of a New Type Ion Source to the Production of Enriched Lithium Isotopes*, ORNL-1380 (Dec. 24, 1952).

B. L. Cohen, *On the Statistical Theory of Nuclear Reactions*, ORNL-1504 (April 8, 1953).

B. L. Cohen and R. V. Neidigh, *Measurement of Angular Distributions of Nuclear Reaction Products with an Internal Cyclotron Beam*, ORNL-1512 (to be published).

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ELECTROMAGNETIC RESEARCH DIVISION SEMIANNUAL PROGRESS REPORT

ABSTRACT

A number of new reactions, some of them of a nuclear-fusion type, have been observed in the 63-in nitrogen cyclotron Angular distributions of particles produced in nuclear reactions have been measured extensively with the internal beam of the 86-in cyclotron Trial production of a number of radioisotopes in this cyclotron has revealed that significant reductions in the cost of cyclotron-produced isotopes can be expected New techniques are being developed which will contribute to the plans for the deflection of the beam of the 86-in cyclotron Preliminary design studies have been made for a variable-energy cyclotron and for an 80-Mev heavy-particle cyclotron The program for the separation of plutonium isotopes has advanced to the point where it is clear that such separation is feasible A study program involving small package-type reactors has been started

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THE 63-INCH NITROGEN CYCLOTRON

Triply charged nitrogen ions accelerated in the 63-in. cyclotron have produced some 20 new nuclear reactions. In many cases, there is evidence that a large portion of the nuclear matter of the target nucleus and the bombarding particles are fused. An internal beam of approximately 1 μa was measured by use of the known cross section of the reaction $D(N^{14},n)O^{15}$. The energy spectrum of the beam has a peak at 20 Mev and a maximum energy of approximately 26 Mev. The beam energy distribution was determined by measuring the ranges of nitrogen ions in Ilford C-2 emulsions.

The internal beam of the 63-in. cyclotron was used to bombard targets of deuterium, beryllium, and the separated isotopes of boron, carbon, nitrogen, oxygen, and sulfur The work reported previously[1] has been extended to include the measurement of the average cross sections of the observed nitrogen-induced reactions The cross sections were obtained by bombarding compounds of the elements under investigation and measuring the relative activity of the reaction products of the constituent elements For instance, the relative yields in carbon, nitrogen, and oxygen were determined by bombarding compounds such as AgCN, $Pb(NO_3)_2$, and $SrCO_3$ These yields were compared with an absolute cross-section measurement by the bombardment of di-deutero-cupreine $(C_2D_2)_n$ supplied by the Chemistry Division The average cross section of the reaction $N^{14}(d,n)O^{15}$ has been determined by Newson[2] as being approximately 10^{-27} cm^2 and, from the bombardment of di-deutero-cupreine, the average cross section for the reaction $C^{12}(N^{14},2p)Na^{24}$ has been found to be approximately 3×10^{-29} cm^2 Table 1 is a list of the reactions observed and shows the half life of the radioactive products, the ratio of the average cross section relative to an arbitrary value of 100 corresponding to 3×10^{-29} cm^2, the Q of the reaction, the energy available in the center-of-mass (C.M.) system, and the

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(1) L D Wyly and A Zucker, *Phys Rev* **89**, 524 (1933)

(2) H Newson, *Phys Rev* **51**, 620 (1937)

TABLE 1. NITROGEN REACTIONS IN LIGHT NUCLEI – THICK TARGET RELATIVE YIELDS

REACTION[a]	$t_{1/2}$	$\frac{Y}{Y_{C^{12}(N^{14})Na^{24}2H^{1}}}$	Q (Mev)	$E_{C\ M}$ (Mev)	$E_{barrier}$ (Mev)
$D^{2}(N^{14})O^{15}n$[b]	2 1 m	3600	+5 1	2 4	3 3
$Be^{9}(N^{14})Na^{22}n$	2 6 y	<200	+11 2	7 4	5 0
$Be^{9}(N^{14})F^{18}He^{4}n$	112 m	6500	+3 0		
$Be^{9}(N^{14})N^{13}B^{10}$	10 2 m	<1 0	-3 8		
$Be^{9}(N^{14})F^{17}He^{6}$	70 s	<2 0	-5 5		
$B^{10}(N^{14})Na^{22}H^{2}$	2 6 y	<400	+6 8	7 9	6 4
$B^{10}(N^{14})C^{11}C^{13}$	20 5 m	30	+1 1		
$B^{10}(N^{14})N^{13}B^{11}$	10 2 m	15	+0 90		
$B^{10}(N^{14})O^{15}Be^{9}$	2 1 m	60	+0 80		
$B^{10}(N^{14})F^{18}Li^{6}$	112 m	20	+0 20		
$B^{11}(N^{14})Na^{24}H^{1}$	15 0 h	20	+12 7	8 4	6 5
$B^{11}(N^{14})Ne^{23}2H^{1}$	40 2 s	0 5	+2 6		
$C^{12}(N^{14})Na^{22}He^{4}$	2 6 y	630	+5 4	8 8	7 9
$C^{12}(N^{14})F^{18}Be^{8}$	112 m	70	-2 8		
$C^{12}(N^{14})Na^{24}2H^{1}$	15 0 h	100	-3 2		
$C^{12}(N^{14})N^{13}C^{13}$	10 2 m	<0 2	-5 7		
$C^{13}(N^{14})Na^{25}2H^{1}$	62 s	140	+1 0	9 2	7 7
$N^{14}(N^{14})N^{13}N^{15}$	10 2 m	20	+0 23	9 5	8 6
$N^{14}(N^{14})O^{15}C^{13}$	2 1 m	40	-0 27		
$O^{16}(N^{14})Al^{28}2H^{1}$	2 3 m	250	+0 73	10 1	9 8
$O^{16}(N^{14})Na^{22}Be^{8}$	2 6 y	<90	-1 7		
$O^{16}(N^{14})F^{18}C^{12}$	112 m	9 0	-2 6		
$O^{16}(N^{14})P^{30}\gamma$	2 5 m	<25	+18 4-γ		
$O^{16}(N^{14})O^{15}N^{15}$	2 1 m	<25	-4 8		
$O^{16}(N^{14})N^{13}O^{17}$	10 2 m	<0 05	-6 4		
$S^{32}(N^{14})Ti^{45}H^{1}$	3 1 h	<30	+10 2		
$S^{32}(N^{14})Sc^{44}2H^{1}$	4 0 h	300	+1 8	13 2	18 5
$S^{32}(N^{14})Sc^{44*}2H^{1}$	2.4 d	150	+1 5		
$S^{32}(N^{14})Cl^{34}C^{12}$	33 m	10	+0 9		
or $S^{34}(N^{14})V^{47}n$	33 m	250	+7 5	13 5	
$S^{32}(N^{14})F^{18}Si^{28}$	112 m	<15	-2 6		
$S(N^{14})$??	2.7 m	50			

[a]The usual reaction notation has been changed slightly The first element represents the target nucleus, the bombarding particle is enclosed in parentheses All reaction products are listed on the right side of the parentheses, since, in many of the reactions, the products have approximately equal charge and mass and it would be meaningless to distinguish between them

[b]Average absolute cross section for this reaction for energy spectrum at 24 1/4-in radius (average energy 19 Mev) is 2×10^{-27} cm^{2}

energy necessary to penetrate the Coulomb barrier.

The photographic emulsion work has been continued, and a range-energy curve for nitrogen ions in emulsions has been obtained, the experimental method has been described previously[3] Figure 1 gives the curve as obtained from approximately 100 proton-recoil events.

The gamma-ray scintillation spectrometer was used to identify any doubtful reaction products listed in Table 1 Gamma-ray spectra of short-lived activities can be identified by means of a pulse-height analyzing scheme which involves the taking of successive photographs of an oscilloscope screen In fact, the half life of a photoelectric peak can be determined in this manner For example, the gamma-ray spectrometer was used successfully to identify Al^{28} as the short-lived activity from the oxygen target

The relative yields of the reactions $C^{12}(N^{14})F^{18}Be^{8}$, $C^{12}(N^{14})Na^{24}2H^{1}$, and $C^{12}(N^{14})Na^{22}He^{4}$ have been studied as a function of beam energy If the formation of Na^{24} is taken as a standard, the probability of the reaction leading to Na^{22} increases at lower energies, and the production of F^{18} becomes less probable More precise measurements will be made when the cyclotron beam is deflected

(3) *Electromag Res Quar Prog Rep Sept 30, 1952*, ORNL-1383, p 16

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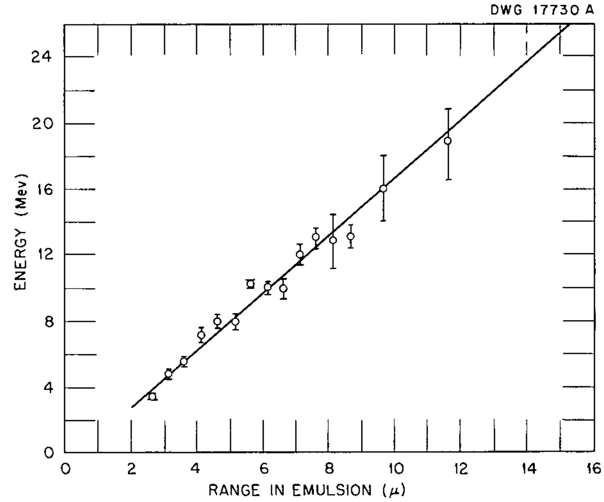

Fig. 1. Range-Energy Curve for Nitrogen Ions in Emulsion.

NUCLEAR PHYSICS RESEARCH WITH THE 86-INCH CYCLOTRON

The methods of measuring angular distributions with the internal cyclotron beam were further developed,[1] and a large amount of data was obtained The method of measuring target current for the determination of absolute cross sections was improved A water-cooled target holder was constructed to allow the use of higher bombarding currents, and protection of personnel from radiation was greatly improved. The measurement of angular distributions of elastically scattered protons was completed, and a paper is being prepared for publication. Difficulties with the use of lead were encountered in the chemical methods used in deuteron detection for heavy-element targets, other methods were only partly successful. A new method was developed in which sodium was used for deuteron detection, and a survey of deuteron yields and angular distributions was initiated. The measurement of the deuteron angular distribution from $Be^{9}(p,d)Be^{8}$ (ground state) was completed and the data were submitted for publication. It was found possible to measure triton angular distributions from targets other than beryllium, and measurements were also made for niobium and palladium. Further work

(1) B L Cohen and R V Neidigh, *Measurement of Angular Distributions of Nuclear Reaction Products with an Internal Cyclotron Beam*, ORNL-1512 (to be published)

on triton angular distributions is in progress. A method of detecting alpha particles with copper was developed, and the measurement of alpha angular distributions was begun. Preliminary experiments on the measuring of high-energy-neutron angular distributions proved unsuccessful and were discontinued. An attempt to measure the angular distribution of the high-energy gamma rays from $C^{12}(p,\gamma)N^{13}$ gave every hope of eventual success.

A considerable amount of work on methods of measuring excitation functions with the 180-deg probe proved to be only partly successful. The method finally developed consists in using the probe to provide a high-energy cutoff in the proton energy spectrum, and it is useful for rapidly decreasing excitation functions in which high accuracy is not required. Excitation functions for the reactions $Be^9(p,t)Be^7$ and $Fe^{54}(p,t)Fe^{52}$ were measured and are being used in connection with the project on triton angular distributions. Measurement of excitation functions for (p,d) reactions was undertaken but is progressing slowly because of experimental difficulties. Measurements of several (p,pn) and $(p,\alpha n)$ excitation functions were made because of their great interest, in the light of recent developments, in nuclear theory. Some theoretical work on the statistical theory of nuclear reactions was completed and a report was prepared.[2]

Experiments on the fission yield distribution from high-energy proton-induced fission in U^{235} were carried essentially to completion. Long-lived activities from this experiment and from a previous one on U^{238} fission yield distribution are still being determined.

A study was made of the variation of cyclotron energy with time and of methods for minimizing it. The variation has now been reduced to approximately 8% maximum difference in a three-month period. The variations seem to be gradual and take place over a period of several days.

Table 2 is a list of some previously unknown isotopes which have been identified with reasonable certainty.

The assignment of the proton-induced reactions was determined by measuring excitation functions, whereas the neutron reactions were differentiated from (n,γ) by cadmium ratios. In all cases, the possibility that the activities were from impurities was eliminated by measuring the reaction cross sections, these can be estimated theoretically with sufficient accuracy. Decay schemes were determined by scintillation

(2) B L Cohen, *On the Statistical Theory of Nuclear Reactions*, ORNL-1504 (April 8, 1953)

TABLE 2. RECENTLY IDENTIFIED ISOTOPES

ISOTOPE	HALF LIFE	PRODUCING REACTION*	DECAY SCHEME
K^{44}	22.1 m	$Ca^{44}(n,p)$	$\beta^-(1.9)$, $\gamma(3.0)$
Sc^{40}	1.6 s	$Ca(p,n)$	β^+, γ
Mn^{57}	1.55 s	$Fe^{57}(n,p)$	β^-
Ga^{64}	2 6 m	$Zn^{64}(p,n)$	$\beta^+(4\ 5)$, $\gamma(2\ 5)$
Dy^{157}	8 2 h	$Tb(p,3n)$	K, $\gamma(0\ 34)$

*Elements with atomic weights listed are enriched stable isotopes supplied by the Stable Isotopes Division spectrometry. The short-lived proton activity was obtained with a high-pressure pumping system employing water solutions of appropriate compounds. Potassium-44 and Dy^{157} were identified chemically.

THE 86-INCH CYCLOTRON

Operation of the 86-in. cyclotron has been very satisfactory during the past period. The machine was in operation a high percentage of the time, considering the very large number of runs of short duration, much time was spent in changing targets and waiting for them to "cool." There was a total of over 700 runs, an average of more than 30 per week. The machine was shut down once for planned modifications and three times because of of minor operational difficulties. A total of 11 radioisotopes has now been produced and their yields have been calculated.

CYCLOTRON OPERATION PROGRAM

The operating schedule adopted on July 28, 1952 of 15 shifts per week (18 shifts on a six-day week) was continued until January 1, 1953, when the night shift was discontinued. Since then, operation has been on a two-shift basis. The time is divided among four general programs nuclear-physics experiments, radiation-damage experiments, isotope production and bombardments for outside customers, and cyclotron development, including preliminary experiments for beam deflection.

During the period covered by this report, the following bombardments were made

Nuclear physics	474
Radiation damage	40
Isotope production	43
Biology	29
Experimental	155
Total	741

The Biology Division exposed both plants and animals (mice) to high-energy neutrons from a beryllium target. The number of runs indicated for the Biology Division in the preceding list is somewhat misleading. By local definition, a run begins and ends with a change of target. The Biology Division makes 12 to 15 exposures with the same target, the machine is merely shut down while organisms in the external exposure chamber are being replaced.

CYCLOTRON PERFORMANCE

On November 12, 1952, it was decided to try for a maximum proton beam while making a routine test run with a 6- by 10-in. aluminum target. After the machine had been operating steadily for about 1/2 hr at 500 μa and 22 Mev, the beam was increased in steps of about 500 μa until 3000 μa was obtained. The power on the target, measured calorimetrically, was 66.1 kw. Data for two readings are listed below

BEAM (μa)	INPUT TO OSCILLATOR (kw)	TARGET WATER (kw)	ION LOAD LOSS (kw)
2320	314	51 0	43 8
3000	370	66 1	54 0

During the past six months, the steady operation of the cyclotron was interrupted on only three occasions. On October 23, 1952, a large water main in the street broke and flooded the subbasement of the building, the first indication of flooding was the failure of the cyclotron. Over 19 in. of water was found in the cyclotron pit, all electrical conduits were flooded, and all motors located on the pit floor were inundated. It took about a day to pump approximately two million gallons of water out of the subbasement. Altogether, a week was spent in drying out the equipment and getting the cyclotron back into operation.

One of the insulators supporting the dee system failed on December 2, 1952. All four supporting insulators were replaced, and the machine was back in operation in 24 hours.

On March 19, 1953, a water leak developed inside the vacuum tank and was discovered to be in one of the rubber hoses supplying the dee system when the top of the tank was removed. The hose, which had an r-f burn where it had come in contact with the dee support plate, was replaced, and operation was resumed the following morning.

The average weekly innage for the past period, exclusive of the flood and down time for revisions, was 44%, with the best week having 59.8% innage. The time summary for a typical week is shown below

	HOURS	PER CENT
Attempted innage and baking-out time	10 4	7 2
Innage (beam on target)	72 1	50 1
Source – routine change of filament and adjustments	4 0	2 8
Targets – routine change and inspection	35 7	24 8
Electrical troubles	4 3	2 9
Utilities troubles	4 0	2 8
Weekly startup and shutdown	13 5	9 3

REVISIONS

Several external revisions were made to provide for the safe handling of highly radioactive targets. The concrete-block wall which protects personnel while targets are being handled was extended to a thickness of 42 in. and now includes a 42-in. water-filled window and a manipulator. The control valves for the target vacuum lock were replaced with electrically operated valves for remote control. A turntable was installed to simplify the handling of the target dolly.

A removable probe was inserted at the 180-deg position between the dees at a radius of 31 to 32 in., it is used to scatter the beam for nuclear-physics experiments. The variation in radius is made by using heads of different sizes on the probe, and when the probe is not in use, it can be pulled back into a vacuum lock or removed from the machine.

A liquid-flow target dolly has been developed with which a solution of the sample to be bombarded is pumped at high speed through a thin-walled target, the solution also serves as the coolant. A portion of the solution is trapped as it leaves the machine, and the activity is counted. Half lives of the order of 1/2 sec have been detected by this method. This half life is much shorter than that which can be measured from any sample that has to be removed from the machine in the conventional manner.

Until recently, a floating anode had always been used in the ion source. When the anode occasionally grounded, it was found that by increasing the arc current, operation could be continued. This was very convenient except that occasionally, when the grounded anode became cleared, the beam suddenly increased and damaged the target. After it was found that satisfactory operation could be obtained with a grounded type of anode, this design was installed and has been in use for several months.

ISOTOPE PRODUCTION

The past period has been one of readjustment to the termination, in August 1952, of the Po^{208} production program. Since then, 0.96 curie of the Po^{208} produced has been incorporated in a long-lived neutron source emitting 2.1×10^6 neutrons/sec.

The production of several other radioisotopes has since been investigated (see Table 3). It appears that with the use of the 86-in. cyclotron the cost of many radioisotopes now obtained from other machines can be substantially reduced. The isotope production work is done in cooperation with the Radioisotope Development and Radioisotope Sales Departments. The rate of development is limited by the time available to process targets and by the demand for cyclotron-produced radioisotopes.

ISOTOPE PRODUCTION TARGETS

The targets for isotope production were prepared in a variety of ways. The lead-coated target was produced by melting a small quantity of high-purity lead on the surface of a 6- by 10-in. aluminum blank, additional lead was added to give a coating approximately 1/16 in. thick and the excess was machined off. Lithium and sodium targets were produced in a similar manner, except that the process of coating the target was done in a helium-filled glove box. The targets were kept wet with mineral oil during the subsequent machining and bending operations, and just prior to installation of the target in the cyclotron, the mineral oil was removed with xylene. Then, until the target was installed, it was kept wet with xylene, which evaporated during evacuation of the target vacuum lock. The low average current on the sodium target was caused by the low melting point of the sodium and the small size of the targets (2 1/2 by 6 in.). The larger

TABLE 3. RADIOISOTOPES PRODUCED IN THE 86-in. CYCLOTRON AS OF MARCH 12, 1953

PRODUCT	HALF LIFE	TARGET	REACTION	YIELD (mc/ma hr)	MAXIMUM PROTON CURRENT (μa)
Be^7	54 d	Li^7	p,n	170	600
Na^{22}	2.6 y	Na^{23}	p,pn	7.8	50
Mn^{52}	6.0 d	Cr^{52} (83.7%)	p,n	1400*	1500
Mn^{54}	310 d	Cr^{54} (2.5%)	p,n	0.8*	1500
Co^{57}	270 d	Ni^{58} (67.9%) Ni^{58} (67.9%)	$p,2n$** p,pn**	6 9	1000
Zn^{65}	250 d	Cu^{65} (31.0%)	p,n	9.3	1000
Ga^{67}	78 h	Zn^{67} (4.1%) Zn^{68} (18.6%)	p,n $p,2n$	600	250
Bi^{205}	14 d	Pb^{206} (26%)	$p,2n$	170*	
Bi^{206}	6.4 d	Pb^{206} (26%) Pb^{207} (21%)	p,n $p,2n$	400*	
Bi^{207}	50 y	Pb^{207} (21%) Pb^{208} (52%)	p,n $p,2n$	0.3*	1000
Po^{208}	2.9 y	Bi^{209}	$p,2n$	9.8	800

*Estimated yields.

**Products of (p,pn) and ($p,2n$) decay to Co^{57}

(6 by 10 in.) target should dissipate approximately 5 kw (250 μa). The copper, nickel, and chromium targets used for the production of Cu^{65}, Co^{57}, and Mn^{54}, respectively, were produced by electroplating the metal on aluminum.

The production of Mn^{54} is an interesting case, since it is produced from Cr^{54}, which is only 2.5% of the natural material. Nevertheless, a production rate of approximately 1 mc/hr should be realized. This rate is considerably greater than that obtained in other machines in which the reaction used is (d,n) on Cr^{55}, which has an isotopic abundance of 9.5%. This also illustrates that large production increases could be obtained through the use of separated isotopes.

NEUTRON PRODUCTION TARGETS

The Biology Division now uses the cyclotron as a controlled source of fast neutrons. In their experiments, a beryllium target is bombarded with protons, approximately 1 neutron for 50 protons is obtained.

The beryllium target presently in use was fabricated by furnace brazing 0.015-in. beryllium sheet to the surface of a 6- by 10-in. aluminum target of the slotted-plate type. Eutectic 190 flux and an aluminum-silicon brazing alloy containing 11.5% silicon were used. The method of brazing is considered unsatisfactory because of the extreme probability of leaving large flux inclusions between the beryllium metal and the aluminum base, which would seriously impair heat transfer. The target now in use is only 40 to 60% efficient, since much of the beryllium has been removed from areas where it was poorly bonded to the aluminum.

Furnace brazing in vacuum seems the most promising of several alternative brazing techniques that have been considered, particularly since methods are available for eliminating the oxide coating from beryllium, aluminum, and aluminum-silicon alloy. This method of brazing beryllium to aluminum, in which the metals are sandwiched with 0.006-in. aluminum-silicon alloy, has been tested experimentally, and it was found that 100% bonding could be obtained without tinning the metal surfaces. The test specimens could be fluxed considerably without apparent loss of bonding. A vacuum furnace large enough for brazing 6- by 14-in. targets is 90% complete.

ELECTRONUCLEAR MACHINES

A beam deflector system is being developed and designed for installation in the 86-in. cyclotron in the fall of 1953. The successful operation of the 63-in. nitrogen cyclotron has led to a preliminary study of a cyclotron designed for the acceleration of heavy particles (boron through neon) to 80 Mev, which is sufficient energy to produce reactions with the heaviest of elements. In a preliminary study, it was found that it would be feasible to design a variable-energy cyclotron for the acceleration of protons, deuterons, and tritons in the 5- to 10-Mev range. The 44-in.[(1)] cyclotron is being modified to provide greater flexibility and larger proton currents for more effective use in the study of ion transmission.

BEAM DEFLECTOR FOR THE 86-in. CYCLOTRON

A number of cyclotron experiments have been made, and preliminary designs have been drawn in the development of a beam deflector system for the 86-in. cyclotron. Installation of the deflector system is scheduled for the

(1) Formerly referred to as the 22-in cyclotron, cf "The 44-in Cyclotron," this report

fall of 1953, however, so that the machine will be in operation while summer research participants are here.

One of the more serious problems is the design of a water-cooled septum that can be used with large ion currents without the septum being heated to the thermionic emission temperature. A mockup of a septum fabricated from stainless steel tubing (0.025-in. OD and with a 0.003-in. wall) has been exposed to the cyclotron beam. Ten 6-in. pieces of tubing were arranged with their axes parallel to the magnetic field and were oriented to simulate the septum. A centrally located tube of this water-cooled assembly burned through when operation was at a proton beam current of 1500 μa (20 Mev). In a bench test of a single section of this tubing, water-cooled at 7.7 in.^{3}/min, the energy dissipation was calculated to be 190 watts per inch of tube, an encouragingly large figure. The extreme radioactivity induced in type 304 stainless steel makes its use undesirable, the use of an aluminum alloy is now being investigated.

The space available for the external target room is so located with respect to the cyclotron that the deflector must be placed adjacent to the lower half of the north dee. The orbit for a beam of 31-in. radius is off center and is several inches from the periphery of this dee, therefore, tests have been made in an attempt to move the effective beam center to a position more favorable for beam deflection. The beam center can, in principle, be shifted by introducing a small, uniform gradient across the magnetic field. Such a gradient can be produced and controlled by means of "half-coils." One of these coils consists of an insulated conductor wrapped half-way around the magnet pole piece and attached so that the pole piece completes the circuit. From model magnet tests, it is estimated that, with 600 amp in an opposing set of half-coils, the gradient across the pole is 0.5 oersted/in. With such coils, the beam center has actually been shifted as much as 3.6 in., which varies the beam energy on a fixed target from 18 to 23 Mev. A 1000-μa beam at 20 Mev has been measured at 34 in. from the magnetic center, this is 3.5 in. beyond the normal position of protons of this energy. It is expected that half-coils will be very useful in controlling the deflected beam.

PRELIMINARY STUDY OF AN 80-Mev HEAVY-PARTICLE CYCLOTRON

The 63-in. cyclotron has produced many new and interesting nuclear reactions with 25-Mev nitrogen ions. In order to extend the range and the versatility of this type of accelerator, a preliminary study has been made for the construction of an 80-Mev cyclotron designed to accelerate ions ranging from boron to neon to energies sufficient to penetrate the Coulomb barrier of uranium. Such a machine would permit the study of nuclear reactions with target elements not now accessible to the 25-Mev nitrogen ions, the production of new isotopes, a study of nuclear scattering with heavy elements, and would make possible the production of transuranic elements beyond californium.

A set of specifications for the 80-Mev accelerator has been drawn up and preliminary design studies have been made. Since the proposed machine is designed to make maximum use of existing facilities, the final cost of the cyclotron would be very moderate.

Existing equipment could be used to provide a magnetic field of 14,000 oersteds in an 8-in. gap over an 86-in. pole diameter. The frequency of the r-f system would be variable from 3.0 to 7.5 megacycles/sec to make resonance possible for each of the various ions to be accelerated. This variation of frequency could be achieved by mounting variable condensers on the dee stems. The grounded-grid oscillator with a single triode would provide a maximum r-f output of 300 kw.

The controls and power supplies for this machine would be similar to the ones currently used on the 86-in. cyclotron, the ion source would be patterned after that of the 63-in. cyclotron. A 5-ft concrete shield would be required to protect operating personnel from neutron and gamma radiation produced by the cyclotron. A deflected beam would be brought through the shield into a separate experimental area.

PRELIMINARY STUDY OF A VARIABLE-ENERGY CYCLOTRON

A preliminary study has been made of the practicability of designing a variable-energy cyclotron which could be used as an alternative to a Van de Graaff type of accelerator in the energy range between 5 and 10 Mev. Essential specifications for such a cyclotron include provisions for quickly and conveniently changing the energy to any value in the design energy range, and for obtaining sufficiently well-defined energy to permit precise measurements of neutron cross sections.

The conclusions from the preliminary study are that such a cyclotron is feasible, that an energy definition of less than ±10 kev could be achieved, and that deflected beams would be in the range of 1 to 10 μa, or perhaps larger. A preliminary cost estimate that is based on complete conceptual designs but that does not include detailed engineering studies has been prepared. The total cost, exclusive of a building to house the project, would be about one million dollars.

Since cyclotrons with deflected beams are quite reliable in the region of 10 Mev, it would appear that solving the engineering problems of constructing a variable-energy cyclotron may be considerably more practicable than building Van de Graaff machines to go to 10 Mev. Although the energy spread of cyclotrons is rather large, their beams are also large so that by use of suitable energy selectors, for example, by collimation of the deflected beam and by analyzing with a magnetic field, a usable fraction with adequate energy definition could be selected.

Monoenergetic neutrons with energies up to about 13.5 Mev could be produced by means of such a cyclotron operating with D-D and H-T reactions. With the D-T neutron source, it would be possible to overlap this region and go up to 27 Mev. The cyclotron and the collimating system can be shielded, and the beam can be brought out through the shield wall, which will effectively eliminate the cyclotron background in the experimental area. Special techniques, for example, the use of the coincidence of the helium reaction products with the neutron-induced reactions, would make it possible to overcome other background difficulties which would also exist in the case of a Van de Graaff accelerator.

At present, one of the most needed neutron measurements, but also one of the most difficult, is that concerned with inelastic scattering. One technique which has been suggested for this measurement is to bombard normal hydrogen with tritons. The neutrons produced by this T-H reaction come out in a forward cone so that it would be possible, in principle, to use a detector for inelastically scattered neutrons in a region outside the cone where the background would be greatly reduced. Tritons in the energy region from 5 to 10 Mev would give neutrons from 2.5 to 6.3 Mev for such measurements.

A cyclotron in which the energy can be varied rapidly and continuously could be employed in the same manner as a Van de Graaff machine in experiments that involve the study of energy dependence of nuclear reactions. The reliability of 10-Mev deuteron cyclotrons is at least equal to that of Van de Graaff machines operating at 5 Mev.

Tentative specifications for the cyclotron are given in Table 4.

The proposed magnet would have a pole diameter of 54 in. and a gap of 13 in. (see Fig. 2). The exit radius would then be 22 in. corresponding to a position about 1 in. inside the $n = 0.2$ position. The system proposed for utilizing the external beam would consist of focusing magnets, analyzing magnets, and appropriate collimating slots. Additional features of the cyclotron would include dees mounted vertically, motorized variable-capacity adjustments on the dees, and electromagnetic focusing shims to permit modification of the magnetic field shape at different average magnetic field values.

THE 44-in. CYCLOTRON

The test cyclotron, assembled from available equipment in 1949 as a preliminary to the design and construction of the 86-in. cyclotron, provided for a maximum proton orbit of 22 in., hence this machine has been referred to informally as the 22-in. cyclotron. Inasmuch as the equivalent diameter of the pole pieces is 44 in., the machine is more appropriately identified as the 44-in. cyclotron. In order to provide a wider range of oscillator power and beam energies, appropriate modifications of the cyclotron are now under way.

Direct-Current Injection of Ions. Previous experience in focusing ions with a d-c electrode in a d-c field, as, for example, in the calutron, indicates that the geometry of the accelerating electrode is highly critical. The multiply accelerating r-f field of the cyclotron could be expected to increase this criticality. Qualitative consideration of the source problems indicates that the addition of a d-c accelerating electrode with the best geometry, which cannot be readily calculated because of complexity of plasma characteristics and the geometric shape of the region, should yield a proton beam somewhat more intense than that using only the r-f accelerating electrode.

Direct-current accelerating electrodes of several geometries have been tested, but none were found to accelerate the proton beam to maximum radius as well as the standard type of r-f accelerating electrode. A search for the optimum geometry is being continued.

TABLE 4. OPERATING SPECIFICATIONS FOR CYCLOTRON

PARTICLE	ENERGY (Mev)	RADIUS (in.)	MAGNETIC FIELD (kilo-oersteds)	FREQUENCY (megacycles/sec)
Protons	5 to 10	22	5 8 to 8 1	8 8 to 12.4
Deuterons	5 to 10	22	8 1 to 11.5	6 2 to 8 8
Tritons	5 to 10	22	10 to 14.2	5 1 to 7 3

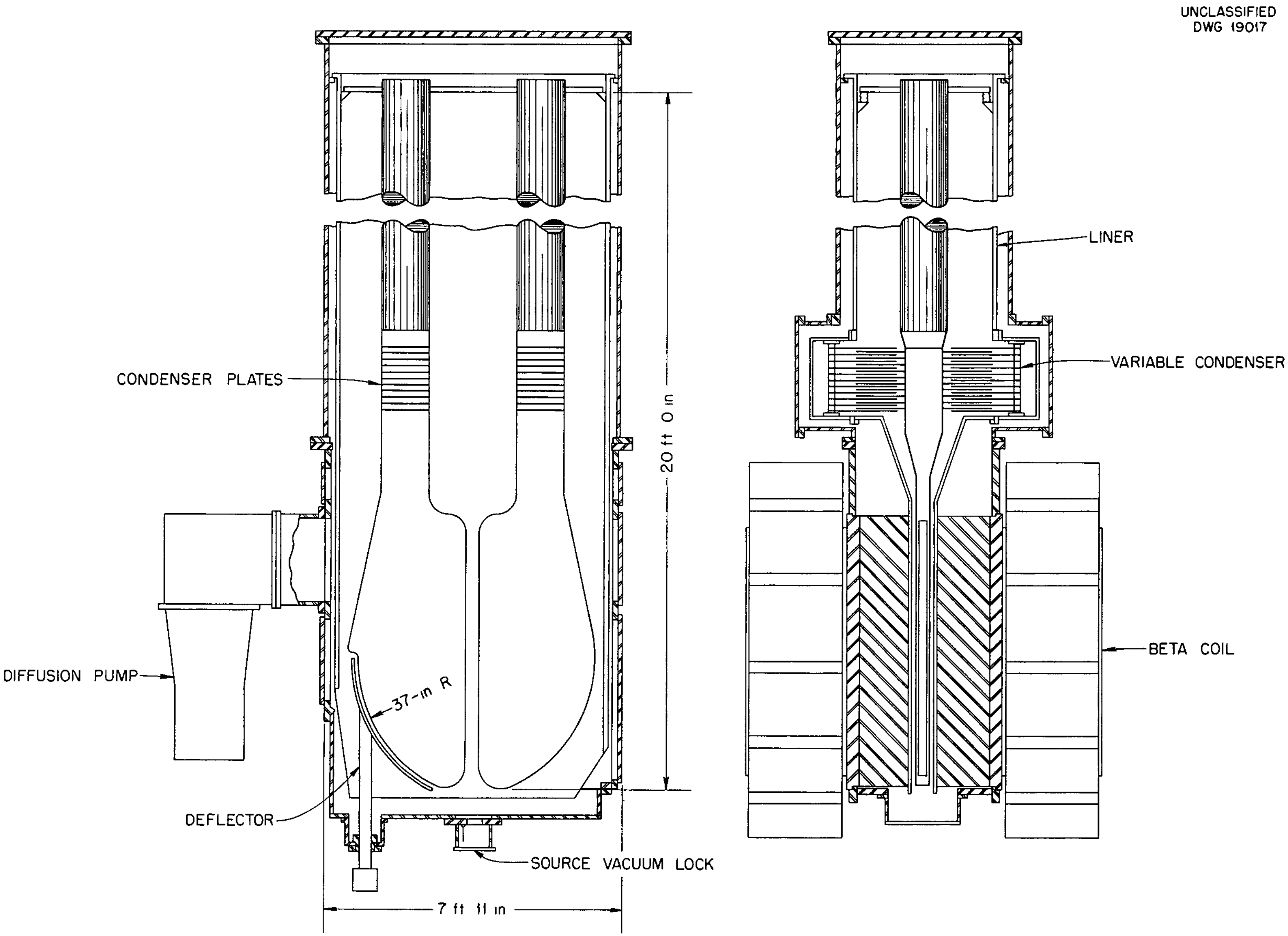

Fig. 2. Proposed 80-Mev Heavy-Particle Cyclotron.

SPECIAL SEPARATIONS

Safe methods for processing alpha-active elements in the calutrons and for recovering and chemically processing the materials have been developed and tested in the separation of thorium isotopes. The first two plutonium isotope separation runs were interrupted because of operational difficulties, but small quantities of the separated isotopes were collected.

IONIUM OPERATION

Thorium isotope separations that yielded 3 g of 90% Th^{230} (ionium) have been reported previously.[1] The calutrons used in these separations provided a means for pretesting, at intermediate levels of alpha activity, the facilities which were constructed for the plutonium program. Washing of the calutrons and recovery and purification of unseparated thorium isotopes were performed in the plutonium chemical-process equipment. Evaluation of airborne and other contamination hazards during operations and transfers indicated that the facilities provided sufficient contamination control to permit initiation of plutonium operations. An additional electromagnetic separation of thorium is planned which will provide an inventory of enriched ionium for future needs.

ENRICHMENT OF PLUTONIUM ISOTOPES

To date, two attempts to separate plutonium isotopes have been made by starting with feed material of 99.2% Pu^{239} concentration. Several hundred milligrams of enriched Pu^{239} and a few milligrams of enriched Pu^{240} have been collected. Effective separation performance has been curtailed by mishaps to the ion source unit. The need for design revisions in the source was shown, and these revisions have been incorporated in the source unit which will be used for the next separation.

A partial recycle of unseparated plutonium was accomplished with an operational ease sufficient to warrant optimism. The plutonium content of filtrates was low, although they were somewhat higher than corresponding uranium values. A test preparation of plutonium trichloride for calutron charges was completed with promising results by refluxing the oxalate with HCP.

Problems of airborne contamination became somewhat better defined as actual operations with plutonium provided data. As expected, those operations involving transfers of calutron units from one enclosure into another were the most troublesome, and airborne activities several times the permissible levels for operation without respiratory protection were often encountered. However, the present use of plastic bags for such transfers appears adequate for research-scale operations.

SHIPMENTS OF ENRICHED ISOTOPES

The distribution of electromagnetically enriched isotopes of heavy elements to various laboratories during the last six months is tabulated in Table 5.

(1) *Electromag Res Quar Prog Rep Sept 30, 1952*, ORNL-1383, p 23

TABLE 5. DISTRIBUTION OF ISOTOPES

TO	ISOTOPE	AMOUNT (mg)	PURITY (%)
Oak Ridge National Laboratory	Th^{230}	47	87 85
University of California Radiation Laboratory	Th^{230}	109	87 85
Oak Ridge National Laboratory	Th^{230}	301	87 85
Argonne National Laboratory	U^{234}	8	95 99
Oak Ridge National Laboratory	U^{234}	18	95 99
Brookhaven National Laboratory	U^{235}	43	99 994
Carnegie Institution of Washington	U^{235}	1	99 94
K-25 Laboratory	U^{235}	69	99 94
Oak Ridge National Laboratory	U^{235}	42	99 94
Florida State University	U^{235}	843	99 86
Oak Ridge National Laboratory	U^{236}	164	95 51
Oak Ridge National Laboratory	U^{236}	216	95 23
Argonne National Laboratory	U^{236}	8	96 65
Los Alamos Scientific Laboratory	U^{236}	93	96 65
Los Alamos Scientific Laboratory	U^{236}	896	28 92
K-25 Laboratory	U^{236}	2,010	16 58
Florida State University	U^{238}	850	99 996
Knolls Atomic Power Laboratory	U^{238}	5,094	99 996
Oak Ridge National Laboratory	U^{238}	847	99 996
Naval Research Laboratory	U^{238}	13	99 996
Los Alamos Scientific Laboratory	U^{238}	7,900	99 9993
Oak Ridge National Laboratory	U^{238}	740	99 992
Chalk River, Canada	U^{238}	15,000	99 992

THE APOTRON

The investigation of methods for plasma control by the Electromagnetic Fundamentals Group has resulted in the development of a 180-deg type of mass spectrograph that incorporates an ion source significantly different from the conventional calutron ion source and which yields very much larger ion throughputs. This mass spectrograph has been named the "apotron", "apo-" is from the Greek word meaning "to isolate." A report has been issued[1] in which the potentialities of the apotron for the separation of lithium isotopes have been evaluated.

The emitting surface of the ionizing arc in the apotron ion source is stabilized by a grid structure. The single accelerating electrode is a similar grid placed close to the arc grid. The grid structures are convexly curved to bring the ions emitted from a broad surface to a sharp focus at the collector. In contrast to the requirements in the calutron, the convergence of the ion beam near the ion source is now eliminated.

With 18-kv acceleration in a 4000-oersted magnetic field, the collector for lithium is placed about 10 in. from the ion source. This makes it possible to arrange the source and collector in a horizontal plane and to stack six apotrons in a single Beta vacuum tank (see Fig. 3).

A prototype of this multiple unit, with a single apotron in place, has been test-operated for several weeks. It is installed in a Beta magnet in Building 9204-3, and Beta power supplies have been joined to provide adequate power. With this single unit, more than 3 amp of lithium ion current has been measured in the collector and calorimetrically verified.

(1)R S Livingston, J S Luce, and J A Martin, *The Application of a New Type Ion Source to the Production of Enriched Lithium Isotopes*, ORNL-1380 (Dec 24, 1952)

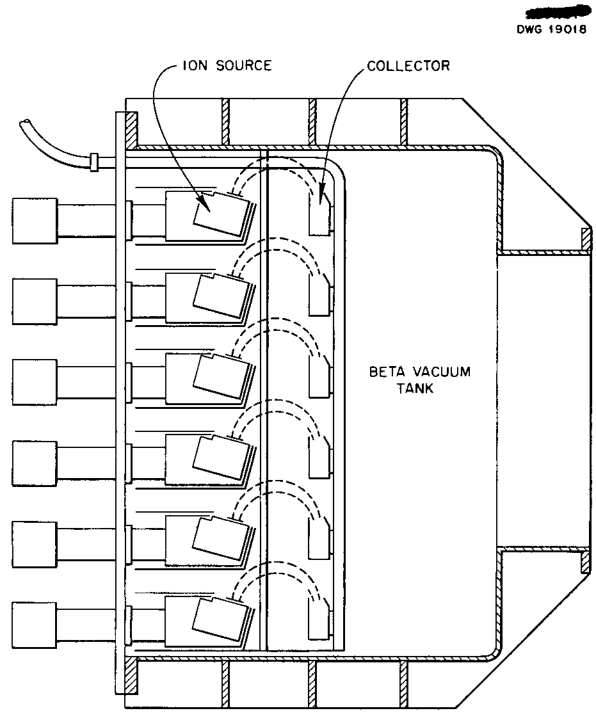

Fig. 3. Six Apotron Units Installed in a Beta Tank.

The assembly of a six-apotron unit is nearing completion (see Fig. 4), the unit is expected to be ready for initial tests in April. The rate of fabrication and assembly has been determined by the man power assigned to the project.

The more important problems encountered in the development of the new unit have been adequate cooling of the collector, control of electron oscillations in the vicinity of the positive-potential ion source, nonuniformity in the arc, and improvement of beam focus into the collector. The present collector is water-cooled by a flow of approximately 30 gpm at 80 psi, this has been found to provide good retention for a beam power of 54 kw. A new arrangement of electron dumping fins, which are built into the ion source and its ground shields,

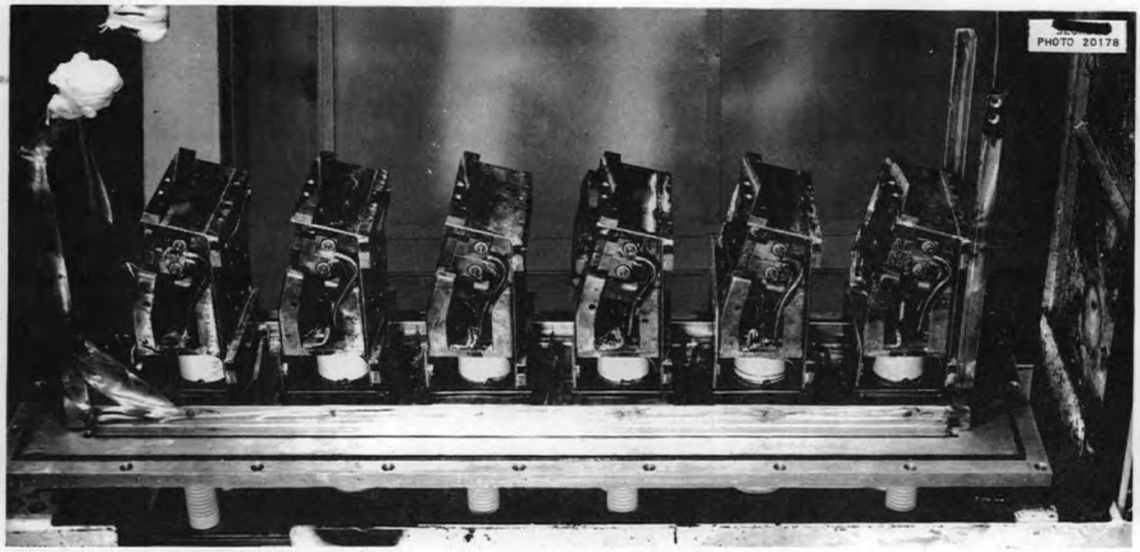

Fig. 4. Six Apotron Units Partly Assembled.

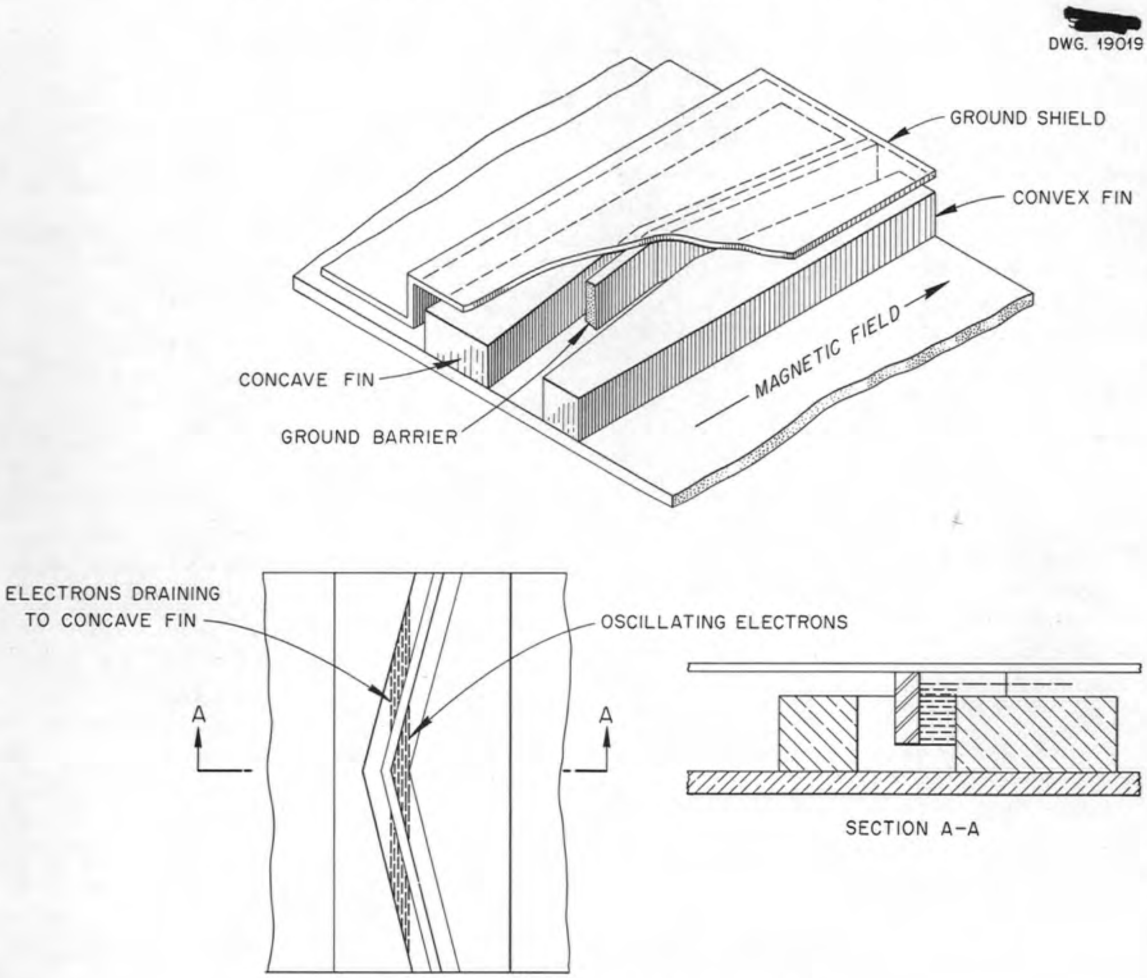

Fig. 5. Electron Dumping System.

minimizes the volume available to oscillating electrons and permits operation at low drain on the high-voltage system, even when the tank pressure is as much as 1.5 microns. It will be noted by reference to Fig. 5 that the oscillating electrons from the first (convex) section are dumped on the second (concave) section.

Greater uniformity of the ionizing arc is obtained in preliminary tests by the use of an arrangement in which the anode is indirectly heated to provide electron emission. A larger defining slot increases the number of ions striking a tantalum anode. Although the electrons emitted from this heated anode are of relatively low energy, they do help appreciably in making the arc more nearly symmetrical.

In the initial operation of the apotron unit, attention was first given to obtaining dependable operation of the ion source at high output. With reasonably steady operation at ion currents up to 3 amp, the problem of improving the beam focus into the collector can be investigated. The quality of the beam focus is determined from the ratio of ions entering the collector slots to the ions striking the collector face surrounding the slots (see Fig. 6). It has been found that this ratio is sensitive to electron oscillations in the source region and to vacuum-tank pressure. With the improved control of oscillations, the ratio has been increased. Recent tests have indicated that the optimum tank pressure is much greater than that for the calutron. Some good ratios - approximately 25 - have been obtained at 1.5 microns. Only very preliminary information is available on actual assay of product enrichment. From a recent run in which the results of several hours of experimental operation were combined with 7 hr of undisturbed isotope collection, the product collected in the light-isotope pocket assayed 78% Li^6. Such an isotope enrichment under these conditions and at this early stage is very encouraging. It is expected that with more attention to collector problems, for example, the proper placement of baffles, the isotope enrichment will be markedly increased.

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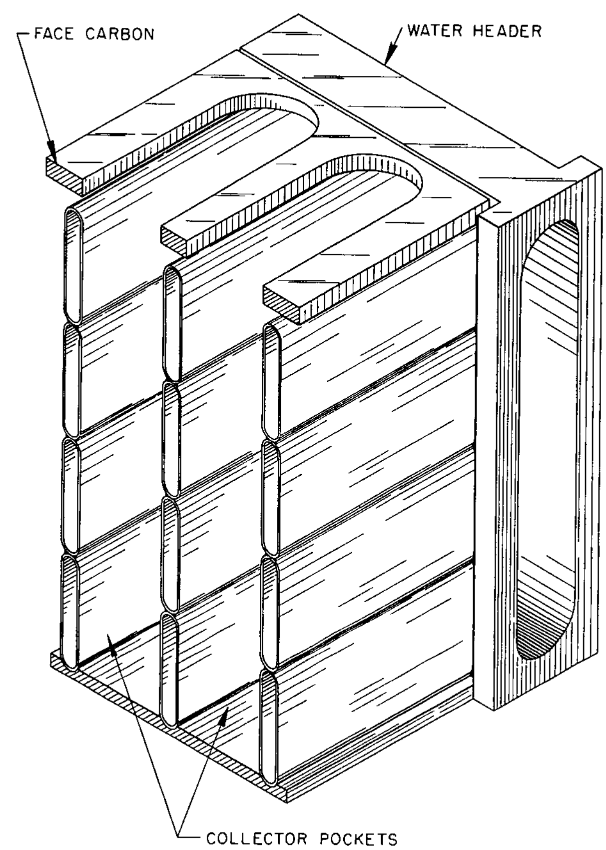

Fig. 6. Water-cooled Collector for Apotron.

CONTROLLED THERMONUCLEAR REACTIONS

A theoretical investigation of certain aspects of the feasibility of controlled thermonuclear reactions (CTR) has been under way at the Laboratory for some time. This Division is assisting in portions of work as described below.

One important problem which arises in work on the CTR is the determination of the potential distribution. The one-dimensional equation for this problem was set up by L. P. Smith, with the physical assumptions that (1) the ion distribution is Maxwellian, $n_+ = n_0 e^{-eV/KT}$, (2) electrons and ions are generated uniformly in the plasma at the rate g, (3) on the average, electrons and ions reach the walls at the same rate, and (4) the mechanism by which electrons reach the walls is electron-ion collisions.

Under these assumptions, Poisson's equation is

$$\frac{d^2V}{dx^2} = -4\pi\,|e|\left\{ n_0 e^{-|e|V/KT} - \frac{g}{\beta_-\, n_0\, \dfrac{dV}{dx}} \int_0^x \frac{d\xi}{e^{-|e|V(x)/KT}} \right\}, \qquad (1)$$

where

$$g = \frac{n_0^{\,2}}{d}\, e^{-2V_d|e|/KT}\, \beta_+ \left[\frac{dV}{dx}\right]_{x=d},$$

and

$$\beta_\pm \equiv \frac{|e|\,\sigma_\pm\,\bar{u}_\pm}{\dfrac{H^2\,e^2}{m}},$$

where $\bar{u}$ is the average velocity and σ is the collision cross section. The initial conditions are $V = dV/dx = 0$ at $x = 0$.

It is to be noted in particular that the constant g involves the value of the unknown potential and electric field at the wall, $x = d$. Hence, it is an unknown constant originally, and a solution of Eq. 1 must involve prescribing a value of g which will be consistent with its definition.

Considerable analytical work was done on the previous equation in order to gain some general understanding of the functional relationship between V and x and also of the magnitudes of the quantities involved. These considerations showed that the solution is parabolic in nature in the immediate vicinity of the origin, but the solution elsewhere is not clear. Hence, it was decided to use a numerical procedure.

The problem was transformed to

$$\frac{d^2z}{dy^2} = \frac{1}{k}\left(-1 + \frac{z^3y}{z'}\right) + \frac{z'^2}{z}, \qquad (2)$$

with the side condition that

$$\left.\frac{z^3y}{z'}\right|_{x=d} = \frac{\beta_+}{\beta_-} = 3660\ .$$

Here

$$\frac{eV}{KT} \equiv \phi \equiv \ln z$$

and

$$y = \sqrt{k}\,\gamma\, x\ ,$$

where

$$\gamma^2 = \frac{4\pi e^2 n_0}{KT},$$

k is chosen as an arbitrary constant. The problem was programmed and coded in this form for solution on the UNIVAC.

Solutions were obtained for several values of the parameter k in December

1952. Mathematical difficulties were encountered, as expected, with small values of k ($k < 1$), and the machine solutions had to be stopped. However, the solutions obtained, even though for small values of d ($d < 0.01$ cm), did clearly show that extremely high potentials were being obtained at the wall.

At this time, the physical setup of the problem was reconsidered, and one assumption was changed, namely, that the mechanism by means of which electrons reach the wall is electron-electron collisions. With this assumption, Poisson's equation becomes

$$\frac{d^2V}{dx^2} = -4\pi |e| \left\{ n_0 e^{-|e|V/KT} - \sqrt{\frac{g \cdot x}{\beta(e,e)\dfrac{dV}{dx}}} \right\} . \quad (3)$$

This equation is now being studied, and it appears that for the range of parameter values likely to be of interest (ones which will give solutions for d in the neighborhood of 50 cm), a serious "subtracting off" problem has been encountered in the numerical work.

RADIATION DAMAGE

The 22-Mev proton beam of the 86-in. cyclotron has been used in the investigation of radiation damage to materials of interest to the ANP Division. A series of bombardments of fluoride eutectic fuels in Inconel containers has been completed. The irradiated targets were examined by the Metallurgy Division for the radiation-induced effects on fuel stability and on the rate of corrosion of Inconel containers. Bombardments of as long as 92 hr with power densities up to 1700 watts/cc produced little radiation-induced corrosion, significant corrosion was found at 3300 watts/cc in a 46-hr run. Some progress was made toward the development of a helium-cooled capsule target.

The radiation-damage program was continued at a much reduced scale after November 1, 1952, because other more important investigations required a reallocation of ANP funds.

THE PACKAGE REACTOR

A limited program has been initiated for the purpose of investigating the development of relatively inexpensive nuclear reactor facilities for generating electric power for special applications. This program is aimed at achieving practical nuclear power in a minimum of time.

Present information suggests that a suitably designed "package reactor" would probably compete with existing power generation facilities in certain isolated localities. The Army is particularly interested in package reactors for remote military posts where the supply of fuel for conventional plants is of the greatest concern. The Military Planning Group of the Army is compiling a list of requirements and specifications for a package reactor that could be used at remote military bases.

The success of this program would unquestionably serve as a strong incentive to industrial power groups to enter the nuclear power field. Eventually, industrial competition would likely promote nuclear facilities of improved economy and reliability.

The initial task of the package-reactor group has been to evaluate the possibility of using a reactor similar to the STR Mark I for the production of electricity. The investigation of this proposal has shown that the cost of such a plant would probably be prohibitive. This is understandable because of the necessarily stringent requirements placed on the reactor components for submarine application. Much needed background information on components and costs was obtained, however, from the STR studies.

At present, a preliminary design and proposal study is under way on a package reactor of the MTR type which has the following tentative specifications

Reactor type	heterogeneous, water-cooled, moderated, and with reflector
Thermal power developed	6000 kw
Net power delivered	1000 kw
Fuel plates	flat, rectangular plates consisting of UO_2 fuel clad in a type 304 low-carbon stainless steel
Life of core	from one to three years

Every attempt would be made to use components which require a minimum of development and cost to construct.

At a later date, proposals will be undertaken which involve boiling reactors, homogeneous reactors, and, possibly, liquid-metal-cooled reactors as producers of electric power.

Assistance will be given to the Military Planning Group in establishing the desirability, feasibility, and selection of optimum areas for nuclear power applications and in developing needed information for making long-range plans for package power units.

OPERATION SUMMARY

A summary of operations in Buildings 9201-2 and 9204-3 from September 30, 1952 to March 20, 1953 includes the following experimental runs

Special separations	21
Electromagnetic fundamentals	87
Electronuclear machines	47
The 63-in cyclotron	105
The 86-in cyclotron	741

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 AND MACHINE SHOPS, OCTOBER 1, 1952 THROUGH MARCH 20, 1953

ACCOUNT NUMBER AND PROJECT		MECHANICAL SERVICE		MACHINE SHOP – CARBON		MACHINE SHOP – METAL	
		Hours	Per Cent of Total Time	Hours	Per Cent of Total Time	Hours	Per Cent of Total Time
33	Special separations	3,180.5	18.4	558.5	27.6	549.0	14.6
34-595	86-in cyclotron operations	3,809.8	22.0	67.0	3.3	380.0	10.1
34-596	86-in cyclotron special targets	1,129.0	6.5			145.0	3.9
		4,938.8	28.5	67.0	3.3	525.0	14.0
36	Electromagnetic fundamentals	4,534.2	26.2	744.0	36.7	1200.0	31.9
37	Electronuclear machines	545.0	3.1	126.0	6.2	198.0	5.3
38	Radiation damage	66.0	0.4	28.0	1.4	69.0	1.8
39	86-in cyclotron nuclear physics	242.0	1.4	8.0	0.4	148.0	3.9
40	63-in cyclotron physics and operations	2,012.9	11.6	213.0	10.5	390.5	10.4
4900-288	Labor and material for installation of radiation equipment in 86-in cyclotron pit	36.0	0.2				
4900-307	Labor and material for changing power supply to channel 509 – Aspen program	578.5	3.3	81.0	4.0	279.0	7.4
4900-309	Labor and material to move Chemistry Laboratory, 9201-2	7.0	0.1				
4902-281	Fabrication of 180-deg probe for 86-in cyclotron	221.0	1.3			27.0	0.7
4902-300	Fabrication of d-c injector for 22-in cyclotron	7.0	0.1				
4902-304	Aspen program	487.4	2.8	120.0	5.9	17.0	0.4
4902-308	Modification of handling equipment, 9204-3	356.5	2.1	74.0	3.6	112.0	3.0
4902-318	Deflect beam, 63-in cyclotron	47.0	0.3			246.0	6.5
43204-1	Building maintenance	43.0	0.2	8.0	0.4	2.0	0.1
	Total	17,302.8	100.0	2027.5	100.0	3762.5	100.0

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- **EQUIPMENT DESIGN**
  - V. O HAYNES
  - H. C McCURDY
- **OPERATIONS**
  - H KEESE
  - C GAULT

NUCLEAR PHYSICS
B L COHEN

- T. H HANDLEY(2)
- W H. JONES(3)
- R. V NEIDIGH
- E NEWMAN
- E L OLSON
- A TIMNICK(3)

63-INCH CYCLOTRON
A. ZUCKER

- M R DONALDSON(1)
- H C HOY
- R L KNIGHT
- R L QUINN
- H. L REYNOLDS
- F SCHUMAN
- D W SCOTT
- L D. WYLY(3)

ELECTRONUCLEAR MACHINES
R. S. LIVINGSTON(1)

- **44-INCH CYCLOTRON**
  - F. L GREEN
- **BEAM DEFLECTION**
  - E D. HUDSON
  - R. S LORD
  - J. E MANN
- **SPECIAL STUDIES**
  - M. R DONALDSON(1)
  - M. L. WINTON
- **DIRECT-CURRENT ION INJECTION**
  - N F ZIEGLER

86-INCH CYCLOTRON
A L BOCH(1)

- **OPERATIONS**
  - H L DICKERSON
  - M B. MARSHALL
  - E. G RICHARDSON, JR
  - A W RIIKOLA
  - C L VIAR
- **TARGET DEVELOPMENT**
  - J. A MARTIN
  - J. H. CUPP
  - M. L JENKINS(1)

RADIATION DAMAGE
R J JONES

- **PACKAGE REACTOR**
  - A. L BOCH(1)
  - F H NEILL

ELECTROMAGNETIC FUNDAMENTALS
J. S. LUCE

- **THE APOTRON**
  - H. B. BAINBRIDGE
  - G W BLUE
  - G F LEICHSENRING
  - R G. REINHARDT
  - W. R SMITH
- **THERMONUCLEAR STUDIES**
  - F. M RANKIN

(1)Dual Capacity
(2)On loan from Analytical Chemistry Division
(3)Research participant

March 20, 1953

Personnel	
Monthly	42
Weekly	11
Total	53