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ORNL-1884
Progress
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ELECTRONUCLEAR RESEARCH DIVISION

SEMIANNUAL PROGRESS REPORT

FOR PERIOD ENDING MARCH 20, 1955

OAK RIDGE NATIONAL LABORATORY

OPERATED BY

CARBIDE AND CARBON CHEMICALS COMPANY

A DIVISION OF UNION CARBIDE AND CARBON CORPORATION

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ELECTRONUCLEAR RESEARCH DIVISION

SEMIANNUAL PROGRESS REPORT

For Period Ending March 20, 1955

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

CLASSIFICATION CHANGED TO: DECLASSIFIED
BY AUTHORITY OF: AEC List #6
BY: D. Morrison 7/26/57

DATE ISSUED

JUN 3 1955

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Part I

UNCLASSIFIED WORK

ELECTRONUCLEAR RESEARCH DIVISION SEMIANNUAL PROGRESS REPORT

ABSTRACT

The ORNL 86-in. cyclotron is being modified to provide for deflection of the proton beam. It is expected that operation will be resumed late in the spring. Nuclear physics work was limited, for the most part, to interpretation of previously collected data and to making preparations for utilizing the deflected beam. It was found that for certain isotopes the production rates could be almost doubled by operating at a slightly reduced energy and a much larger current.

With the use of the ORNL 63-in. cyclotron, the absolute values of the electron capture and loss cross sections for 26-Mev nitrogen ions were obtained. The angular distribution of the cross sections for elastic scattering of nitrogen by nitrogen was measured at energies from 13 to 22 Mev. A double-focusing 90-deg magnet is being planned for use in identifying stable reaction products from nitrogen-induced reactions.

The major components of the revised 44-in. test cyclotron were assembled and are being tested. Consideration is being given to the use of these components, along with a new 20,000-oersted magnet and a shielded cyclotron room, and if the tests are satisfactory the Laboratory will have available a machine which will accelerate N^{5+} ions to 81 Mev.

THE 86-INCH CYCLOTRON

The 86-in. cyclotron has been shut down since October for the installation of a beam-deflector system. The shutdown was delayed several weeks to permit stock-piling of certain radioisotopes and to complete committments for service bombardments for other projects. During the last weeks of operation the schedule was increased to a three-shift, 120-hr week. The machine is expected to be available again for nuclear physics and isotope production work late in the spring.

INSTALLATION OF BEAM-DEFLECTOR SYSTEM

Immediately after the cyclotron was shut down, the complete vacuum and resonant dee systems were thoroughly decontaminated. Considerable alpha activity had accummulated on these interior surfaces some two years before as a result of several Po^{208} production runs. Also, before any alterations were made in the vacuum-tank walls, the magnetic field was carefully measured for azimuthal variations. These measurements will serve as a basis of comparison after the deflector system is installed. The azimuthal variation in the field did not exceed ±0.1%. The field was essentially the same as when measurements were made four years ago.

The temporary beam-centering coils were replaced with permanent coils, and new bus bars for the generator were installed. These coils consist of half-coil windings on the pole piece. Upper and lower half-coils shift the beam center vertically, and the north and south half-coils shift it horizontally. (The median plane of the magnetic field is vertical in the 86-in. cyclotron.) The magnetic-field measurements made after the installation indicate that the two sets of coils will produce a resultant first harmonic in the magnetic field whose phase angle and magnitude are continuously variable over a 90-deg sector of the pole.

Extensive modifications of the stainless steel vacuum tank were made to provide space for the magnetic channel and for the channel and deflector controls. A partly assembled view of the magnetic channel is shown in Fig. 1. The channel has been installed, and force measurements indicate that the vertical forces on the channel iron are less than 20,000 lb and that the horizontal forces are approximately 4000 lb. Adjustments in the magnetic field to compensate for the channel disturbance and "tight"-wire studies for plotting the deflected beam path are in progress.

The septum, which separates the circulating beam from the deflected beam, consists of water-cooled aluminum tubes, 0.062 in. in diameter and with 0.010-in. walls, spaced on ¼-in. centers

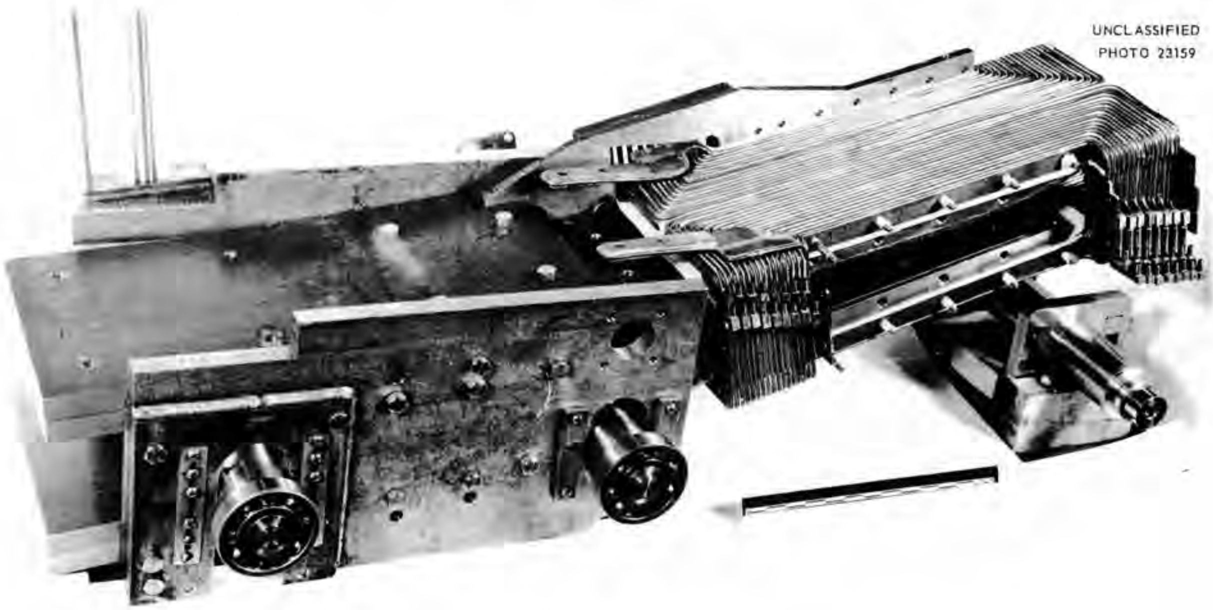

Fig. 1. Magnetic Channel for Deflected Beam.

(see Fig. 2). This septum can be operated in a 22-Mev proton beam of 2.5 ma without excessive temperature rise when each tube is carrying cooling water at a velocity of 70 fps. Bonding of the 0.010-in.-wall aluminum tubes to the headers was obtained by a two-step Heliarc welding process in which argon gas and Eutectic 190 welding rod were used. First, a continuous bead of Eutectic 190 was welded along the entire length of the inside of the header plate. The bead was then drilled through to receive the $\frac{1}{16}$-in.-dia tubes and was machined into individual cones. The tubes were inserted in the holes, extending through to the tops of the cones. The cones of weld material were then heated with an arc from a tungsten electrode in an argon atmosphere until they became welded to the tubes. This method avoids the use of welding flux, which corrodes the tubes and, in time, causes leaks. One side of the header was completely welded before the other side was started, so that tubes which had closed during welding could be drilled out from the far end. Drilling was required for only a small fraction of the tubes. Header-plate covers are also attached by Heliarc welding.

Installation of the dees, liner, and associated equipment should begin shortly, and, under favorable circumstances, the cyclotron should be in operation late in the spring.

NUCLEAR PHYSICS RESEARCH

Inasmuch as the cyclotron was shut down for a greater part of the report period, most of the attention was given to the following: interpreting and examining the theoretical implications of previously collected data, improving instrumentation, and making preparations for utilizing the deflected beam.

Excitation functions for various proton-induced nuclear reactions on Na^{23}, Al^{27}, and Si^{29} were measured with the Berkeley linear accelerator, and the results were compared with studies of N^{14}-induced reactions on B^{10}, N^{14}, and O^{16} performed with the ORNL 63-in. cyclotron. If these reactions proceed by a compound nucleus interaction, the results of the two experiments should be comparable, since the same compound nuclei, Mg^{29}, Si^{28}, and P^{30}, are involved in both sets of reactions. It was found that (1) in all reactions in which only neutrons, protons, or alpha particles are emitted the cross sections are similar, both in corrected energy dependence and in absolute magnitude, but that (2) the reactions in which fragments of approximately equal mass are emitted are at least 100 times more probable in the nitrogen-induced reactions. This indicates that these latter reactions are caused by direct interactions rather than by fission of a compound nucleus.

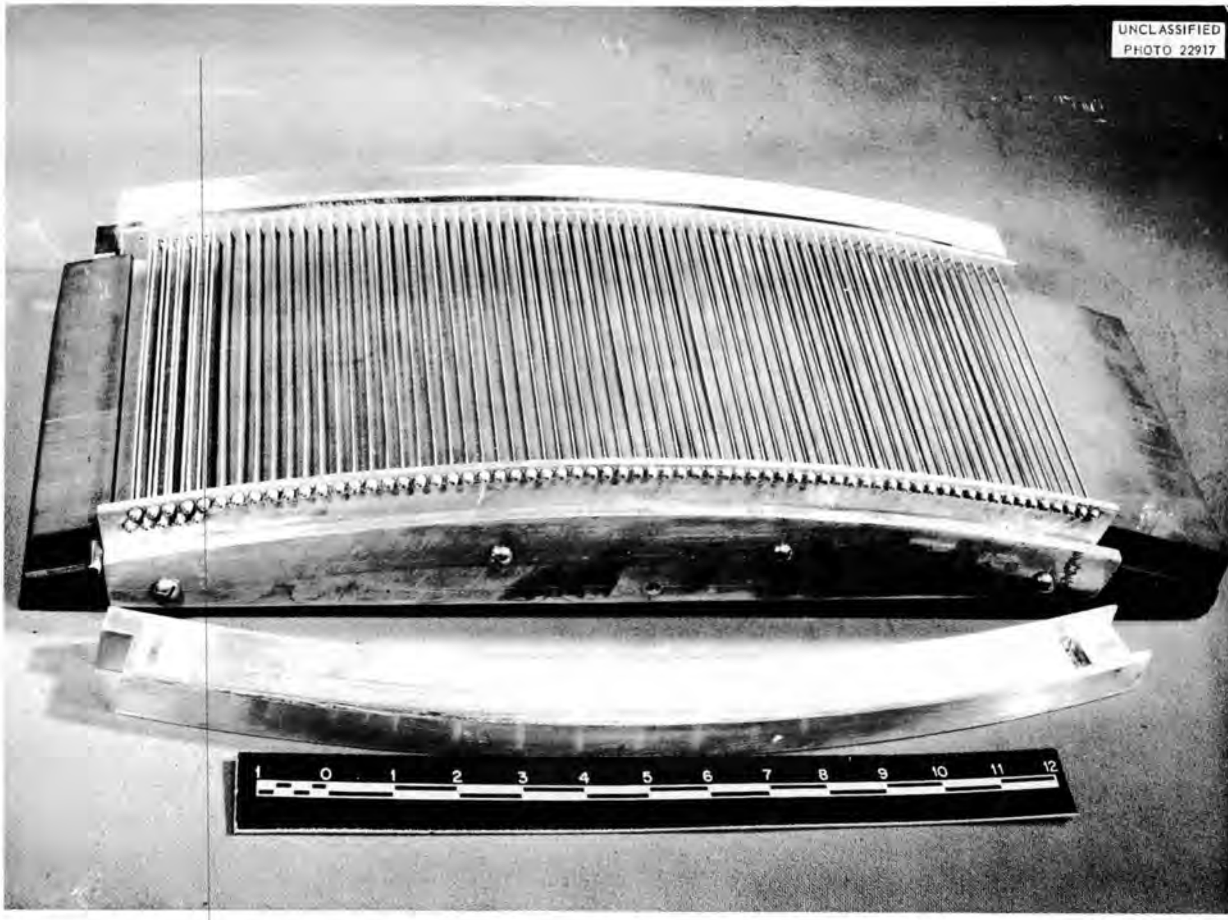

Fig. 2. Deflector Septum, Showing Water-cooled Tubes.

The theoretical aspects of experiments on cross sections for (p,pn), $(p,2n)$, $(p,2p)$, (p,n), (p,γ), (p,α), and (p,He^3) reactions, of angular distributions of neutrons from (p,n) reactions, and of fission fragments from (p,f) reactions were worked out, and papers were submitted for publication.

A general-purpose reaction chamber was constructed for use with the deflected beam of the 86-in. cyclotron. Special-purpose chambers were built for measuring angular distributions of fission fragments from (p,f) reactions and angular correlations between protons emitted from $(p,2p)$ reactions. A particle-selective spectrometer consisting of proportional and scintillation counters was designed and constructed. Various other electronic and mechanical details associated with the use of the deflected beam were planned.

Construction of an internal-conversion spectrograph and associated equipment and facilities was completed, and calibration studies were made. The accuracy of energy determinations was found to be within about 0.2%.

A spectrometer for measuring the energy distributions of fragments of specified mass from thermal-neutron fission was planned, and the cost was estimated.

APPLIED PHYSICS

It has been found that over 2 ma of beam can be obtained steadily if the beam energy in the 86-in. cyclotron is reduced to 18 Mev by reducing the effective beam radius. This increased beam current at somewhat reduced energy gives a net increase in the isotope production rate from (p,n) reactions. The thick-target yield for (p,n) reactions on medium and heavy elements is relatively insensitive to energy ($\sim$3.7%/Mev) in the region of 20 Mev. Operation at 2.0 ma and 18 Mev rather than at 1.0 ma and 22 Mev increases the production rate by a factor of 1.7. New records were established in the production rate for Zn^{65}, Mn^{54}, and Cd^{109}; production data are given in Table 1.

Three bombardments of magnesium, totaling 93 hr, were made for the production of Na^{22}. The beam energy used for Na^{22} production was 22 Mev, the average current was 860 μa, and the estimated production was 35 mc.

Enriched stable isotopes are now being used in the cyclotron for the production of some radioisotopes; production data for I^{125}, I^{130}, and Mn^{54} are given in Table 2. The enriched isotopes can be used advantageously because (1) the yield of the desired isotope is markedly increased, (2) the contaminating activities produced in other isotopes of the target element are much reduced, and (3) the unused material in the target is recoverable by

TABLE 1. HIGH-CURRENT PRODUCTION OF RADIOISOTOPES

	Product		
	Mn^{54}	Zn^{65}	Cd^{109}
Half life, days	310	250	470
Nuclear reaction	(p,n)	(p,n)	(p,n)
Target	Cr*	Cu	Ag
Run length, hr	30.0	5.0	28.7
Average target current, μa	1960	1910	2000
Total production, mc	25.1	74.8	147
Production rate, mc/hr	0.84	15	5.1

*Natural chromium; results obtained from enriched chromium are given in Table 2.

TABLE 2. RADIOISOTOPE PRODUCTION WITH ENRICHED-ISOTOPE TARGETS

	Product		
	I^{125}	I^{130}	Mn^{54}
Half life	60 days	12.6 hr	310 days
Nuclear reaction	(p,n)	(p,n)	(p,n)
Target isotope	Te^{125}	Te^{130}	Cr^{54}
Natural abundance, %	7.0	34.4	2.4
Enriched abundance, %	80.5	48	65
Amount, mg	388	912	700
Fraction recovered, %	96	91	~80
Target type	Capsule	Capsule	6 × 7 in.*
Average target current, μa	181	160	2030
Run length, hr	8.3	2.5	10.75
Total production, mc	13.5	50.8	36.1
Production rate, mc/hr	1.63	20.3	3.34

*Chromium-54 was electrodeposited on the target by Stable Isotope Research and Production Division.

chemical means. In the production of Mn^{54} the target contained only 700 mg of Cr^{54}, and the yield was increased by a factor of 3.8; in addition, the product contained very little Mn^{52} and Cr^{51}, which would ordinarily have complicated target handling and processing. The recovery of the target material is possible because products of (p,n) reactions are chemically different from the target; this economic advantage does not hold for the (n,γ) reactions obtained in nuclear reactors.

A study of the feasibility of Ca^{47} production in the cyclotron was completed; this is the only calcium isotope with a suitably short half life (4.7 days) for use in humans. Production of Ca^{47} by the (n,α) reaction is unattractive because the Ca^{45}/Ca^{47} production ratio is large even when the best enriched Ca^{46} is used. In the cyclotron, Ca^{47} is produced by the reaction $Ca^{48}(p,pn)Ca^{47}$, and the other isotopes of calcium do not lead to the production of undesirable isotopes. In the yield measurements, calcium oxide was bombarded in the capsule target used in the 86-in. cyclotron. For normal calcium, only 0.18% Ca^{48}, the yield was 15 μc/hr. The irradiation of enriched Ca^{48} will yield over 3 mc/hr.

CYCLOTRON OPERATION

During the last months before the cyclotron was shut down, the work schedule was stepped up from two shifts to three shifts a day, five days a week, in order to complete the bombardments for which commitments had been made. In spite of the increase in scheduled time, it was necessary to postpone the date of shutdown from October 8 until October 22, 1954, to complete all the last-minute requests. The machine has not been in operation since October 22.

The average innage (beam on target) for the five weeks of actual operation was 44.3%, or 53.2 hr for each 120-hr week. The time summary for the five weeks is shown below:

	Hours	Per Cent
Innage (beam on target)	271.0	44
Attempted innage and bakeout time	59.7	10
Ion source – routine change of filament and adjustment	13.8	2
Targets – routine change and inspection	129.1	21
Equipment failure and troubles	116.9	19
Standby (waiting for target)	3.7	<1
Radiation hazard	5.3	1
Weekly startup and shutdown	11.0	2

Proportionally more isotope production runs were made during the period in order to meet commitments and to stock-pile a few long-lived isotopes for which there is a demand. During one calendar week several long bombardments (10 to 30 hr) increased the total hours of actual operation to 90.7; this is 76% innage.

The following bombardments were completed for the indicated projects:

Nuclear physics	36
Isotope production and experiment	19
Biology (65 exposures)	4
Operational and developmental	20
Total	79

THE 63-INCH CYCLOTRON

During the past six-month period the high-energy nitrogen ions produced in the ORNL 63-in. cyclotron were used in investigations in atomic and nuclear physics. The performance of the cyclotron was improved by the installation of new bushing seals to replace old ones which leaked frequently. The ion source was also modified so that more reliable operation is now attained, along with larger internal and deflected beams.

ATOMIC PHYSICS

The absolute values of the electron capture and loss cross sections by 26-Mev nitrogen ions were determined. Nitrogen-ion charge groups separated by the fringing magnetic field of the cyclotron were passed through Zapon foils ranging in thickness from 2.5 to 6 $\mu g/cm^2$. Such thin foils were required in order to produce nonequilibrium charge distributions. After passing through the foil, the ions are detected with photographic emulsions. When the mass of an average atom in Zapon was assumed to be approximately 14, the following cross sections, in square centimeters per atom, were obtained:

$$\sigma_{56} = 7.6 \times 10^{-18}$$
$$\sigma_{65} = 2.0 \times 10^{-18}$$
$$\sigma_{67} = 2.9 \times 10^{-18}$$
$$\sigma_{76} = 3.8 \times 10^{-18}$$

Here, σ_{ij} is the cross section for the change of the atomic charge from i to j. In Fig. 3 the percentage of ions in a given charge state is plotted as a function of $\sigma_{56} \cdot X$ (X = foil thickness) and as

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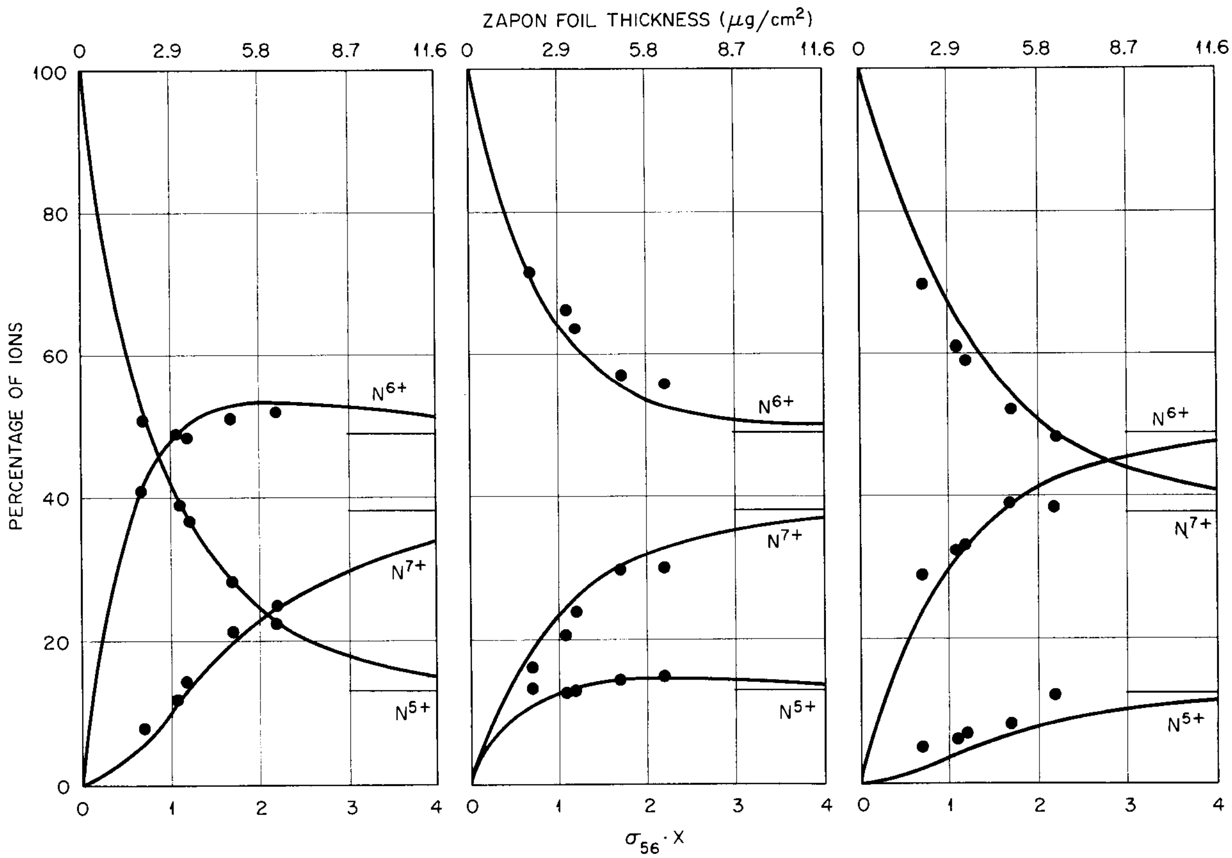

Fig. 3. Distribution of Ionic Charges as a Function of Foil Thickness.

a function of Zapon thickness alone. The plots from left to right represent the charge distributions for initial beams of N^{5+}, N^{6+}, and N^{7+}, respectively. Experimental points are shown as dots, and calculated "best fits" are shown as solid lines.

NUCLEAR PHYSICS

The measurement of excitation functions leading to radioactive residual nuclei is continuing. The elastic scattering of nitrogen from helium, nitrogen, carbon, oxygen, neon, and argon is being studied. Angular distributions of the differential cross sections for elastic scattering of nitrogen by nitrogen were measured at energies from 13 to 22 Mev. A gas target at a pressure of approximately 0.5 cm Hg was used, with Ilford D-1 nuclear emulsions as particle detectors. By normalizing the angular distributions to the calculated coulomb cross sections at small angles, where nuclear effects are negligible, absolute values for the differential cross sections were obtained. The interference terms predicted by the Mott formula for scattering of identical particles appear clearly at low energies, as is shown in Fig. 4. The smooth solid line is the classical Rutherford cross section. The wavy solid line is the cross section according to the Mott scattering formula for identical particles of spin 1 and even parity. The dots are the experimental points which confirm the previously known spin and parity assignments of the nitrogen nucleus. At high energies the elastic scattering cross section for large angles drops below the theoretical coulomb cross section. For example, at 22 Mev the elastic cross section starts to deviate from the coulomb cross section at about 25 deg, and at 45 deg in the laboratory system it drops to about one third the coulomb cross section.

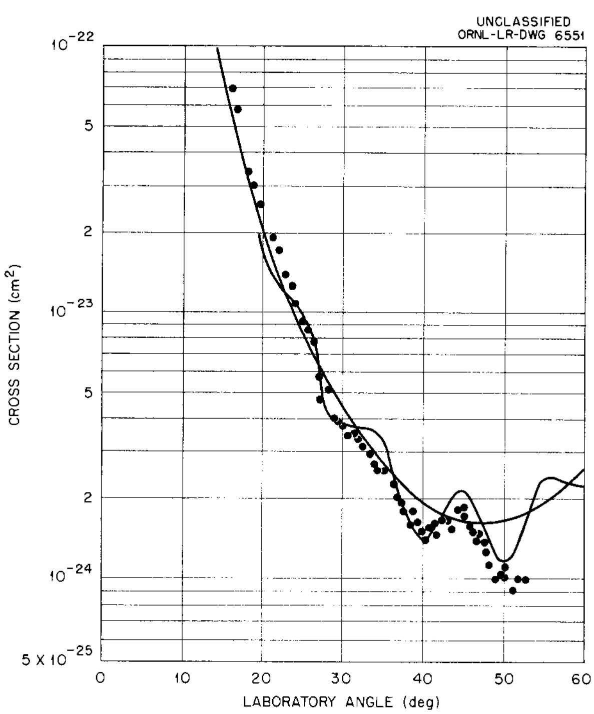

Fig. 4. Differential Cross Section for Elastic Scattering of Nitrogen by Nitrogen.

CYCLOTRON OPERATION

The performance of the 63-in. cyclotron has been improved in the last six months. A leak which had caused trouble in the operation for a long time was finally traced to a faulty bushing seal. This seal was replaced, and no vacuum troubles have been encountered since that time. A new version of the ion source was developed in which the reentrant insulator was replaced by a standoff insulator. The source now operates more reliably. In many instances the anode of the old ion source shorted out after only an hour or so of operation. The current model usually lasts an average of 14 hr. Failure is caused by the filament burnout, and work is in progress to lengthen the filament life.

ANALYZING MAGNET

A double-focusing 90-deg magnet is being designed for use in identifying the reaction products from nitrogen-induced nuclear reactions. An analyzing magnet is essential for the identification of heavy particles which cannot be differentiated by the usual techniques of range, energy loss, and energy measurements. A combination of momentum and range, together with the known charge of a particle whose velocity is given, should bring about identification of reaction products. A magnetic field, variable from 3000 to 10,000 oersteds, will be used to focus particles approximately 34 in. from the exit face. The object distance is 32 in., and the radius of curvature provided is 21.6 in. The usable magnetic field over the 2-in. gap will be 3 in. wide. Double focusing is provided by a 45-deg incidence into the magnetic gap. The magnet coils have been designed, and the design for the yoke and pole pieces is 80% complete.

CYCLOTRON DEVELOPMENT

The 44-in. cyclotron is being revised to provide for the acceleration of protons to 1.5 and 5 Mev. The major modifications include new 44-in. dees and stems, a larger oscillator, and enlarged power supplies. The machine is to be used in a continuation of the study of problems associated with the acceleration of large ion currents.

The major components have been assembled and vacuum-tested (see Fig. 5). The whole dee system is supported by a cantilever mounting at the outer end of the dee stems. This mounting is supported on insulators in order to permit the application of a bias potential to the dees. In initial inspections this support system has been found to be satisfactory.

Some work remains to be done on the ion source, the handling equipment, the oscillator auxiliary equipment, and magnetic field shimming. The fabrication of the liner for the dee-stem housing was delayed because of brazing errors made by the contractor. The electrical work necessary for revision of the existing power cubicles that supply the oscillator, ion source, dee bias, and deflector progressed as rapidly as the availability of funds and the status of other work in the Division would permit.

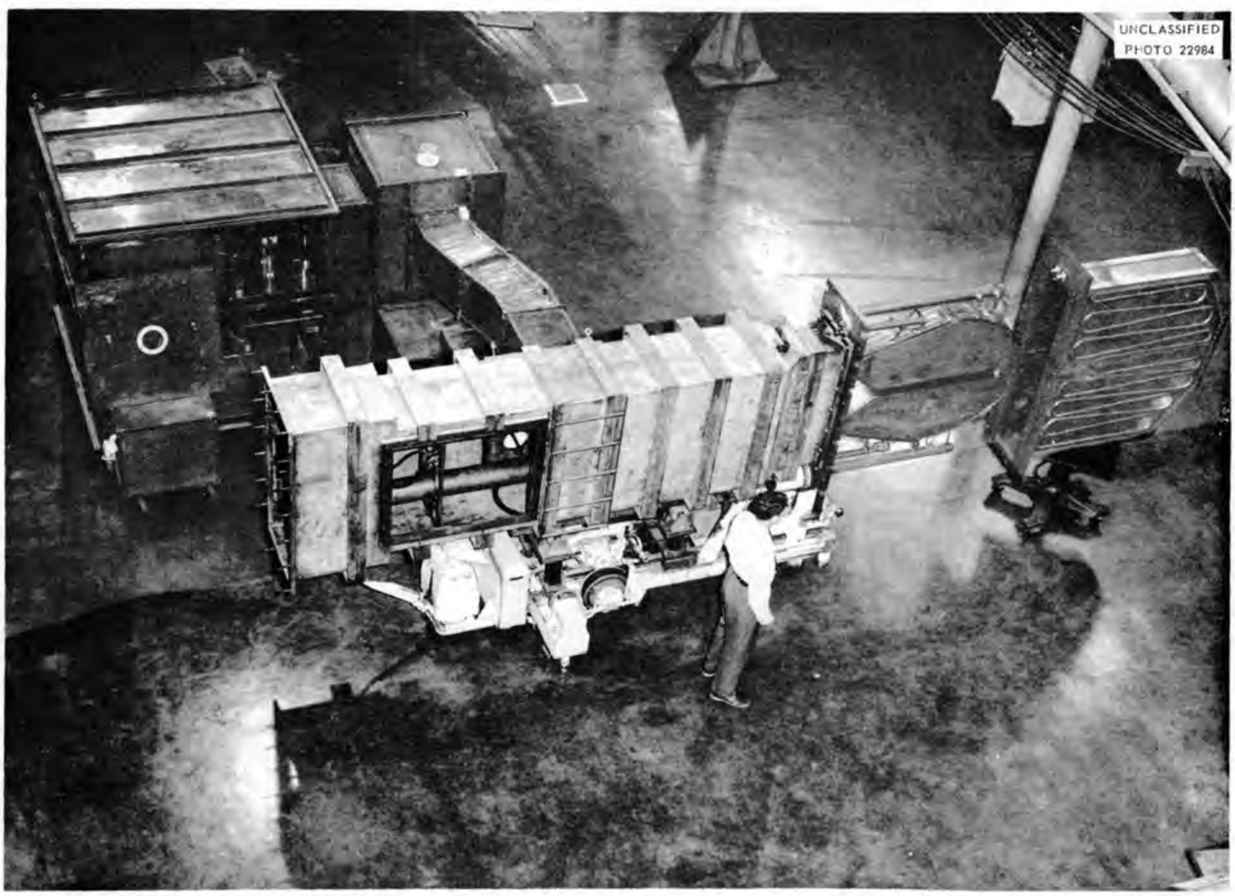

Fig. 5. Assembled Components of the 44-in. Cyclotron.

HEAVY-PARTICLE CYCLOTRON STUDY

In view of the increasing interest in, and importance of, the field of heavy-particle physics and because of the serious limitations of the ORNL 63-in. cyclotron, there is increased interest in obtaining at ORNL a modern, permanent, heavy-particle accelerator. A fixed-frequency cyclotron designed to accelerate large currents of nitrogen, carbon, and oxygen ions to energy levels approximating the coulomb barrier of heavy elements would be particularly useful in basic nuclear physics research.

Due to the limitations, in time and costs, under which the 63-in. cyclotron was constructed, a large amount of existing equipment was adapted for use in the accelerator, and many design compromises were accepted. Consequently, this machine lacks the versatility and reliability which are essential in a heavy-particle accelerator adequate to meet the continuing needs of the Laboratory. There are several limiting features of the machine which cannot readily be corrected:

1. The cyclotron is not and cannot be shielded in any economical or reasonable manner.
2. The quality of the magnetic field is only marginally adequate; the median plane shifts with time, and it is very difficult to keep the field properly shimmed.
3. The dee stems are outside the vacuum chamber and must enter the vacuum through bushing insulators. This limits the maximum dee-to-ground potential to about 40 kv, which, in turn, seriously limits the ion current and the flexibility in operation of the machine.
4. The magnetic field gap is only 6 in., less than half of what it should be to obtain the desired output.
5. The resonant system was designed specifically for N^{+++} ions, and its available frequency range does not permit the acceleration of heavy particles of any other charge or mass.

The study of the feasibility of converting the present 44-in. test cyclotron to a 48-in. heavy-particle cyclotron has received further attention. The new machine would be designed to accelerate N^{5+} ions to 81 Mev; the design specifications are given in Table 3. This modern cyclotron, with wide-aperture dees, high voltage, a precise 20,000-oersted magnet, and completely adequate shielding, would not have the limitations now experienced with the 63-in. machine. All the major components of the recently revised 44-in. cyclotron could be utilized. The dees, the dee stems and housing, the coupling circuits, the vacuum pumping system, and the 250-kw oscillator

TABLE 3. DESIGN SPECIFICATIONS FOR PROPOSED 48-in. HEAVY-PARTICLE CYCLOTRON

Nitrogen (5+) energy, Mev	81.5
Carbon (4+) energy, Mev	66
Diameter of magnet pole tips, in.	48
Maximum radius of orbit, in.	20
Magnetic field at center of gap (maximum), oersteds	20,000
Magnetic field drop-off at maximum radius, oersteds	400 (or 2%)
Magnetic field gap (minimum), in.	13.5
Radio frequency (maximum), Mc/sec	10.5
Radio frequency (minimum), Mc/sec	7.5
Dee-to-dee r-f voltage (design), kv	200
Threshold voltage for N^{5+}, kv	110
Dee-stem length, ft	7
Dee-stem diameter, in.	7
Dee diameter, in.	44
Dee width (inside), in.	6.5
Dee-to-dee gap, in.	2
Q of dee system (unloaded)	10,000
Grounded-grid oscillator output, kw	250
Oscillator tube (Federal-134),	One

with its power supply could all be adapted for use in the new machine with only a small amount of rearrangement required. The major new requirements would be a 48-in. magnet and a shielded cyclotron room.

A preliminary design study has been made for a 48-in. magnet (see Fig. 6). The magnet is of the conventional closed-yoke design, with the median plane of the magnetic field in the vertical plane. The pole diameter is 48 in., the gap 13.5 in., the pole base diameter 76 in., the maximum field intensity 20,000, and the field drop-off is 2% at a radius of 20 in. Approximately 29 tons of copper is required for the two coils. The coils have a total of 10.5×10^6 ampere-turns, and the power required is 1050 kw.

The area immediately adjoining the east end of Building 9204-3 is being considered as a site for the cyclotron room (see Figs. 7 and 8). This location will result in a minimum extension of the existing utilities in the building. Being mostly below ground level, the room will be easy to shield. Placing the room at the basement floor level will make it convenient to transfer heavy equipment. The control station for the 44-in. cyclotron can be used without moving it from its present location in Building 9204-3.

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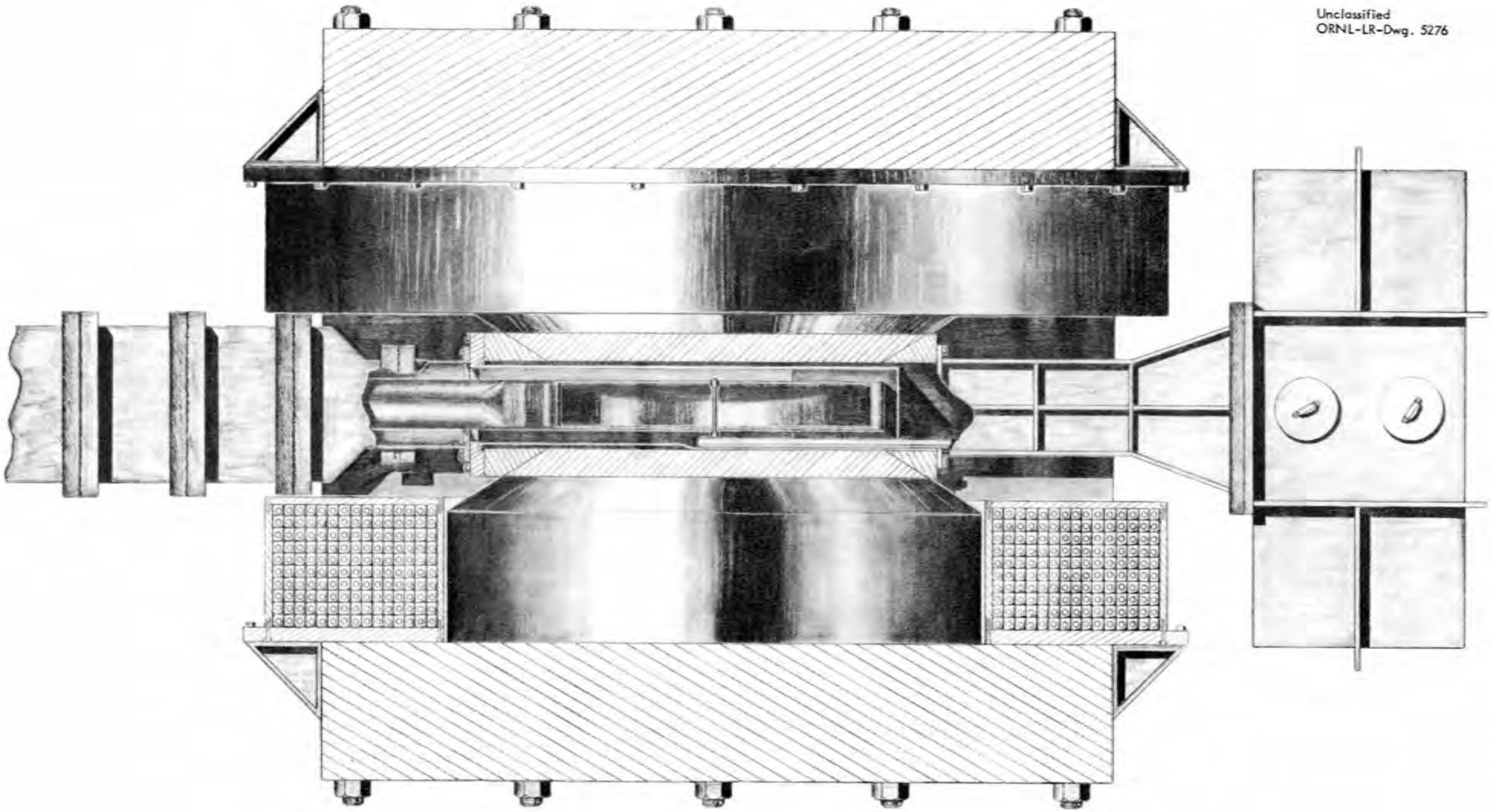

Fig. 6. Artist's Sketch of 48-in. Cyclotron Magnet, Plan View.

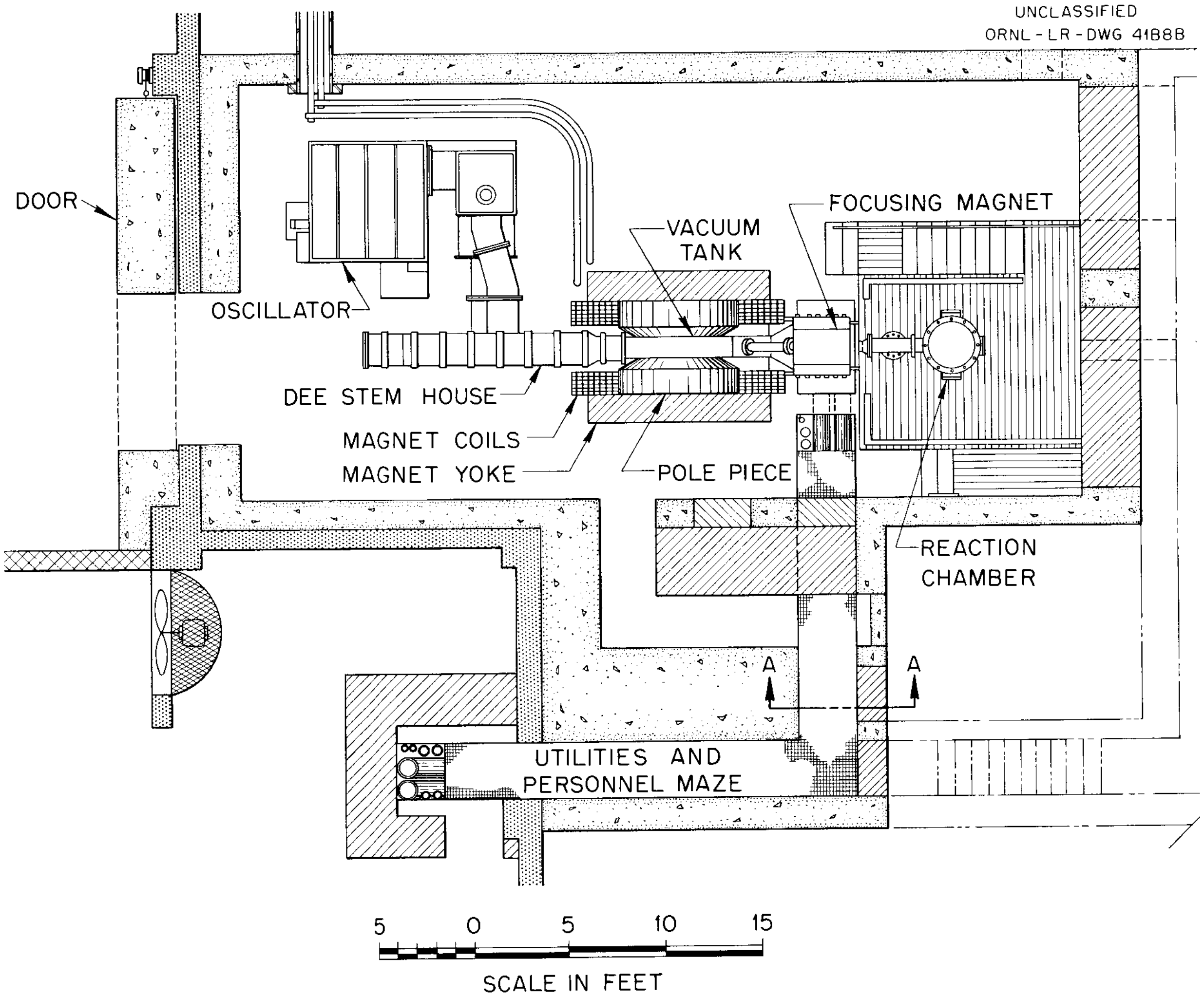

Fig. 7. Plan View of Cyclotron Installed in Shielded Room, Adjacent to Building 9204-3.

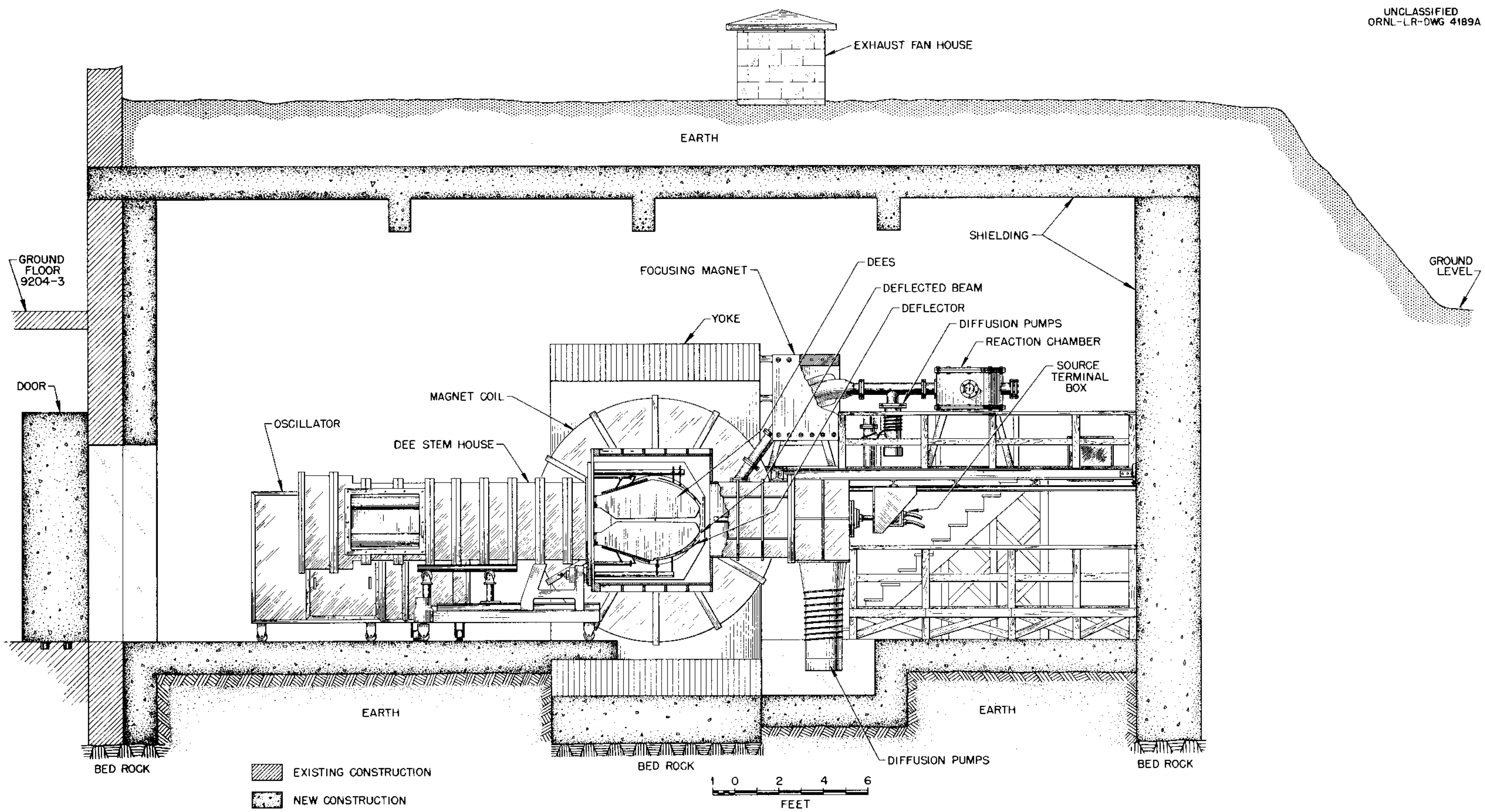

Fig. 8. Vertical Section of Proposed 48-in. Cyclotron.

Part II

[redacted] WORK

Declassified

ABSTRACT

In the electromagnetic separation of plutonium isotopes, an additional run provided milligram quantities of Pu^{240} and Pu^{241} assaying 81.3 and 48.5%, respectively. Plans are under way to obtain more highly irradiated plutonium as feed material.

The Laboratory is continuing to provide the Army Reactors Branch with assistance relative to package reactors. The construction contract for the APPR, based on the ORNL conceptual design, was awarded to the American Locomotive Company. As was agreed at the time the contract was awarded to ALCO, the Laboratory is continuing with a developmental program concerning certain features of the reactor core.

Studies are being made of a fixed-frequency accelerator that will operate in the 1-bev energy range. It now appears that this energy range can be achieved by the introduction of azimuthal variations in the magnetic field which serve to overcome the relativistic effect and provide appropriate beam focusing.

SPECIAL SEPARATIONS

PLUTONIUM PROGRAM

The heavier isotopes of plutonium are separated from highly irradiated feed for distribution on a commission-wide basis. In addition to making purified isotopes available for accurate measurement of their nuclear properties, the experience gained in handling plutonium in the electromagnetic facilities will allow continuing appraisal of the suitability of the process for large-scale plutonium separations of interest for special weapons applications and for combined operation with high-burnup plutonium-producing reactors.

The feed bank consists of 477 g of plutonium (1200 Mwd/ton) assaying 5.6% Pu^{240} and 130 g of plutonium (3000 Mwd/ton) assaying 12.7% Pu^{240}. An additional 300 g of the higher-level material, produced in the NRX Reactor, has been requested.

Calutron Performance

A fifth separation of the plutonium isotopes was made from 3000-Mwd/ton plutonium containing 12.7% Pu^{240}, 1.7% Pu^{241}, and 0.22% Pu^{242}. The feed material was obtained by a selective recovery of part of the unresolved plutonium chloride vaporized in the fourth separation reported previously. A single-arc calutron was used, since only 70 g of feed was available. The efficiency of conversion of $PuCl_3$ vapor to well-focussed Pu^+ ions was 6%. The production and product assay data for the run are given in Table 4.

Chemical Recycle Operations

At the present stage of development of plutonium isotope separations, the process efficiency (grams collected per gram vaporized) is about 7%. For every 100 g of plutonium vaporized as $PuCl_3$,

TABLE 4. RESULTS FOR ISOTOPE SEPARATION FROM 3000-Mwd/ton PLUTONIUM

	Isotopic Content (at. %)				Total Weight of Plutonium (g)
	Pu^{242}	Pu^{241}	Pu^{240}	Pu^{239}	
Feed vaporized	0.22	1.71	12.67	85.4	63.2
Pu^{241} product	0.8	48.5*	26.9	23.7	0.101
Pu^{240} product	0.4	0.88	81.3	17.8	0.352
Pu^{239} product			1.0	99.0	3.2
Pu^{241} salvage	0.41	20.56	51.23	27.75	0.051

*Isotope desired.

93 g must be recovered, purified, and rechlorinated to provide feed material for subsequent runs. In this way reasonable utilization can be achieved; this is of particular importance where only small quantities of special feed materials are available.

Salvage operations connected with plutonium recycle chemistry have proved to be more time consuming than was originally anticipated. In the first step, the salvage materials are burned in a muffle furnace. This produces a refractory plutonium oxide which can be dissolved only by lengthy leaching with HF-activated nitric acid. Extraction with tributyl phosphate is used for recovery of plutonium from concentrated wash solutions and salvage leach solutions; a series of five batch extractors arranged for countercurrent operation is used. In the extraction phase of the process, no operational difficulties have been experienced; reasonable time cycles are being maintained, and raffinates have a sufficiently low plutonium content to permit discard.

A 120-g batch of 3000-Mwd/ton plutonium which was recovered from the fourth and fifth separations is presently being processed. This will be the first material to be carried through the complete recycle in the recovery facility.

The recovery and purification of the 450 g of 1200-Mwd/ton plutonium, used as feed for the first three Pu^{240} separations, are nearing completion. The remaining work consists primarily of the time-consuming salvage processing, which has been temporarily deferred to permit the recycling of the higher-level material. As soon as practicable, the 1200-Mwd/ton material will be removed from the system. With only one assay level of material being processed, recycle operations will be considerably facilitated, since inadequate glove-box space has proved to be a serious limitation.

Air-borne alpha activity continues to be below tolerance levels in the chemical recycle laboratory. Measurements of alpha activity, assumed to be plutonium, in the filter duct system have shown an increase in activity level in the past several months. No hazard is expected to result from this increase, but changing of filters will become more difficult if the increase continues. Minor contamination on the outside of glove-box surfaces was noted in dry chemistry operations and has been controlled by occasional painting.

Preparation of rare-earth chlorides used as a substitute for plutonium chloride in calutron development runs was continued on a routine basis.

Product Processing

During purification of the Pu^{241} products from the fourth and fifth separations, iron was found to be present as an impurity in larger amounts than could be explained by pickup from the graphite of the collector pocket. The iron is presumably introduced by use of steel scraping tools to remove the products from the collector pocket surfaces. Consideration is being given to the use of a more wear-resistant material such as tungsten carbide in the scraping tools to minimize the introduction of undesirable impurities. Re-evaluation of the production data indicates that the retention of plutonium in the Pu^{241} pocket is 70 to 80% rather than nearly 100%, as previously supposed. As time permits, products from all collector pockets are being purified. Future shipments will be made from purified stock only.

ISOTOPE SHIPMENTS

The distribution of electromagnetically enriched isotopes of uranium and plutonium to various laboratories since September 20, 1954, is shown in Table 5.

TABLE 5. DISTRIBUTION OF ISOTOPES

Isotope	Shipped To	Amount (mg)	Purity (%)
U^{235}	Columbia University	94	99.90
	Tracerlab	834	99.80
U^{236}	Brookhaven National Laboratory	304	95.36
U^{234}	Argonne National Laboratory	25	96.30
	Brookhaven National Laboratory	186	95.99
	University of California Radiation Laboratory	30	94.00
U^{238}	California Research Corporation	505	99.9997
	Phillips Petroleum Company	425	99.9997
	Tracerlab	1,000	99.9997
	Westinghouse Atomic Power Division	47,920	99.9997
	Oak Ridge National Laboratory, X-10	10,000	99.9988
		5,028	99.9988
Pu^{239}	Oak Ridge National Laboratory, X-10	3	99.796
		204	99.796
Pu^{240}	Argonne National Laboratory	26	87.2
	General Electric Research Laboratory	2	87.2
	Los Alamos Scientific Laboratory	22	87.2
		478	57.6
	Oak Ridge National Laboratory, X-10	3	87.2
	University of California Radiation Laboratory	35	87.2
		28	87.2
	Knolls Atomic Power Laboratory	92	62.8
		415	61.0
Pu^{241}	Knolls Atomic Power Laboratory	105	62.1
		40	48.5
	Argonne National Laboratory	5	62.1
	Los Alamos Scientific Laboratory	8	62.1
	University of California Radiation Laboratory	6	62.1
		1	62.1

ARMY PACKAGE POWER REACTOR

On August 19, 1954, invitations for proposals on the Army Package Power Reactor (APPR) were sent to 33 qualified contractors. A period of 90 days was allowed for the preparation of proposals, November 19, 1954, being the date established for the opening of the bids. The ORNL conceptual design report[1] was furnished to all bidding firms for their information and guidance.

On November 19, 1954, 18 companies submitted detailed, well-thought-out proposals for the APPR. After a thorough review of the proposals by the Contract Selection Board and extensive comparisons of the technical features of the various proposals, the contract was awarded on December 10, 1954, to the American Locomotive Company (ALCO) for the sum of $2,096,753. Their proposal was judged to be the most favorable to the government from the standpoint of price, excellence of design, and responsiveness to other terms of the bid invitation. The prices submitted by the various companies ranged from $2,096,753 to $6,900,000. Twelve of the proposals were under $4,000,000; the second and third from the lowest being $2,462,355 and $3,037,586, respectively. None of the proposals differed very markedly from the ORNL concept, except in the feature of containment and in building facilities.

At the present time, ALCO is engaged in the design of the plant, with particular emphasis on preparing for a formal presentation of the APPR plant to the Reactor Safeguards Committee. The Stone & Webster Engineering Corp. is the subcontractor for ALCO.

DESIGN STUDIES

The Army Reactors Branch has recently commenced studies of nuclear power plant systems of much lower capacity than that of the APPR. Previously, little attention has been given to reactors specifically for low-power applications. These applications would be expected to satisfy the electrical and space-heating loads of the Air Force Distant Early Warning (DEW) Stations; therefore a thorough study for the purpose of selecting an appropriate reactor system is warranted.

It is understood that this chain of radar sites is a part of the Air Defense Command's Aircraft Control and Warning (AC & W) Stations, extending about 2000 miles across northern Canada and in the range of 1500 to 2000 miles north of Chicago. Its purpose is to give the U.S.A. about 3 hr warning in the event of a potential attack by enemy aircraft, and its importance may be gaged solely upon this function. The normal operating complement of each station is about ten men. The site locations are all extremely remote and desolate.

The specifications and other factors relative to the operation of a package reactor plant suitable for DEW line power stations would be as follows:

1. 100 kw of net electric power,
2. 400 kw of steam suitable for space heating,
3. plant operation under ambient temperature conditions of −60 to +90°F,
4. water available in the form of seasonal ice and snow or salt water – well-drilling would not be possible,
5. all construction materials would be transported to the site,
6. construction season would be from June through September,
7. the nearest railroad would be 750 miles,
8. airlift from railhead to site possible but limited to 10-ton loads,
9. the reactor would be completely automatic in operation,
10. the reactor core life would be a minimum of one year.

Early in January several private firms were asked to undertake conceptual design studies of advance-type reactor plants which would meet the above requirements. The assignments are as follows, with the study completion date to be June 1, 1955:

1. General Electric Guided Missile Division to study the circulating-fuel homogeneous reactor type,
2. Walter Kidde & Company, Inc. to study the gas turbine reactor type,
3. Le Tourneau–Westinghouse Co. and The Fluor Corp., Ltd. to study an advanced APPR type,

[1]A. 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).

4. Babcock & Wilcox Co. to study the homogeneous boiling reactor type,
5. The Glenn L. Martin Co. to study a nuclear power plant which would furnish 100 kw of electric power and be the ultimate forseeable in packaging.

In addition, the Argonne National Laboratory was asked to study the heterogeneous boiling reactor type.

The Laboratory is assisting the Army Reactors Branch in preparing specifications for these small reactors and will assist in reviewing and evaluating the proposals.

APPR DEVELOPMENT PROGRAM

At the time the contract for the construction of the APPR was awarded to ALCO it was agreed that the Laboratory would continue with a developmental program concerning certain features of the reactor core.

Critical Experiments

Preparations are being made for a series of critical experiments to support and supplement the criticality calculations described in the last progress report. The experiments planned will include determinations of (1) the cold clean critical mass, (2) the critical amount of burnable poison required to compensate the reactivity of the initial fuel inventory, (3) the worth of various configurations of control rods, (4) the effects of external structures such as the fuel-element end boxes and the assembly grids, and (5) the power distribution in several of the above critical assemblies. The geometry of the design reactor will be accurately reproduced. The moderator and reflector will be water, at room temperature. Fuel will be in the form of 0.002-in. uranium foils and will be somewhat less homogeneously distributed than in the design reactor. The effect of temperature on reactivity can, at best, be determined over a limited range, and the extrapolation to design operating temperature will have to be made analytically.

The detailed engineering of the critical experiment and the acquisition of materials are in progress. It is expected that preparations for the experiment will be completed around the first of June and that the experimental program will be completed by the first of September.

Reactor Simulator Tests

A series of tests has been planned to determine the effect on the fuel and water temperatures and on the reactor period of such forcing functions as the injection of cold water into the core, step and ramp changes in $\Delta k/k$, and changes in load demand. Six differential equations describing the thermal kinetics of the power plant were derived. Four of these are based on heat balances which were written for the fuel and the coolant in the reactor and for the coolant and steam in the steam generator. Two equations involve the time lags between the reactor and the steam generator. The ORNL reactor-plant simulator will be used in solving the equations.

ALCO design data were used in the derivation of the equations. All the circuit constants have been re-examined and recalculated for ALCO design data.

Fuel-Plate Melting Experiment

An experiment is being planned in which an irradiated package reactor fuel plate will be melted in order to determine the amount of radioactive material that is released in gaseous form. The purpose of the experiment is to obtain a realistic estimate of the hazard involved in a reactor accident in which the fuel plates are melted.

In order to simulate the reactor fuel plates, miniature fuel plates will be fabricated in exactly the same manner that the prototype fuel plates have been made, that is, with UO_2 dispersed in a matrix of stainless steel and roll-clad with stainless steel. Since the concentration of fission products in the actual reactor will be a maximum at the end of the design life of the fuel plates, the sample plates will be irradiated with an equivalent integrated flux. Once the plates have been irradiated they should be melted in such a manner that it will be possible to determine fairly accurately the amount of activity associated with the material (1) released as a gas, (2) expelled from the molten mass and subsequently condensed, and (3) retained in the melted fuel plate. It is not proposed that specific radioactive materials be identified in this experiment but rather that, through a simple procedure, a rough idea of the amount of radioactivity released to the atmosphere by the melting of a fuel plate can be obtained.

In order to obtain experience and to acquire a better understanding of the problems involved in this experiment, it is tentatively planned to make a number of preliminary runs with samples of very small size, each containing only 5 to 10 mg of fuel. The irradiation and melting of these samples can take place over a relatively short length of time, and the amount of shielding and the need for special equipment can be kept to a minimum.

At the present time, work is in progress on the development of suitable equipment for use in the induction heating of the sample.

Fuel-Assembly Irradiation Experiments

To test the reliability of the fuel element design proposed for the APPR, two series of in-pile irradiations have been undertaken. The first of these irradiations is of a six-plate stainless steel fuel assembly having the same composition as that proposed for the APPR but modified slightly in physical dimensions to fit the removable sub-assembly hole in the STR Mark I core (see Fig. 9). The specific aims of this irradiation are as follows:

1. to investigate the general behavior of the APPR-type composite fuel plates, consisting of wrought stainless-steel-clad UO_2-SS-B_4C sintered-powder core combination, under irradiation,
2. to test the mechanical stability of the stainless steel element under combined hydraulic, thermal, and irradiation conditions present in the STR core,
3. to determine the compatability of clad stainless steel in contact with high-velocity cooling water at high temperature (460°F) and pressure (2000 psi) under irradiation.

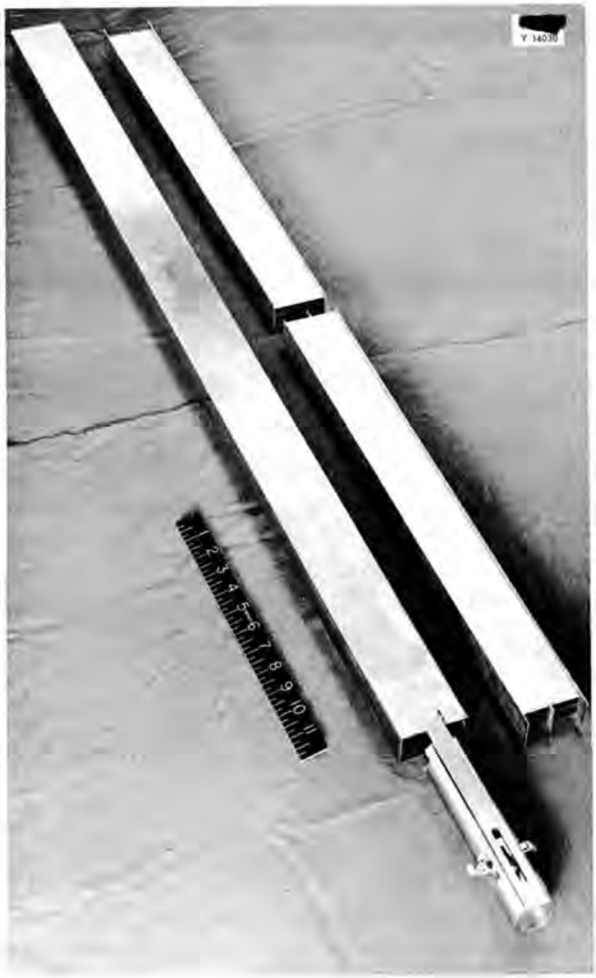

Fig. 9. APPR-Type Fuel Assembly for Irradiation in the STR.

The fuel assembly was fabricated by the ORNL Metallurgy Division and delivered to WAPD at Bettis Field, Pittsburgh, on December 30, 1954, for the final preirradiation test and inspection. A summary of these tests follows:

1. *Bettis Mockup Test.* The fuel assembly was tested at STR temperature, pressure, and flow in the Bettis mockup for a period of 1900 hr. No unexpected corrosion resulted.

2. *Corrosion Test.* The fuel assembly was tested for three days at 685°F in static water. Results of the test indicate normal weight gains and demonstrated that the brazing alloy was satisfactory.

3. *Danger Coefficient Test Facility Test.* The range of the facility was not sufficient to determine the exact reactivity of the stainless steel fuel assembly; however, by extrapolation of the experimental data it was estimated that the assembly had a negative reactivity of 20×10^{-4}. This apparently means that the positive reactivity effect of the uranium is not sufficient to override the negative reactivity of the stainless steel housing on the fuel assembly.

In addition to the above tests, several additional tests were made on dummy samples as follows:

1. *Vibration Test.* A five-plate dummy assembly having a depleted uranium core and dimensions similar to the enriched fuel assembly was provided for a series of vibration tests in order to check the integrity of the braze joints. The assembly was tested at rated flow in low-pressure, room-temperature water. The results indicated that the

amplitude of deflection was approximately 1 mil with a natural frequency of about 1200 cps.

2. *D-Loop Tests.* A three-plate dummy assembly was also provided for a long-term corrosion test. The assembly was placed in the Bettis D-loop facility and operated at rated temperature, pressure, and flow for three periods of approximately one week each, with satisfactory results.

3. *Plate Corrosion Test.* The enriched fuel plates were corrosion-tested before being brazed in the fuel assembly. The result showed normal weight gains.

4. *Braze-Joint Corrosion Test.* Small-specimen T-joints of fillet-brazed stainless steel were tested at 680°F in a static autoclave for a total of three weeks. They showed no weight change, flakiness, or roughness.

Subsequent to the testing at Bettis Field, the fuel assembly was delivered to the STR facility at Arco, where, prior to installation, the heat transfer characteristics of the assembly were determined by the cyclic method. The fuel assembly was installed in the STR the week of March 6, 1955, and will be operated in the reactor for approximately 280 hr at full power; this will result in a maximum fuel burnup of approximately 10%.

The second series of irradiations, to be done in the MTR, has been proposed in order to:

1. investigate the general behavior of the APPR-type fuel plates under high burnup (40 to 58%),
2. obtain a plot of fission-fragment damage in the matrix as a function of UO_2 particle size,
3. evaluate random-sized and selected controlled-sized UO_2 particles in initial makeup of core section,
4. test mechanical stability of fuel assembly,
5. check the compatibility of MTR coolant and fuel assembly material.

For this investigation three in-pile irradiations have been proposed:

1. Small samples (1 × 3 in.) of APPR-type fuel plates with varying UO_2 particle sizes are to be irradiated to 20 and 40% burnup. The samples will be examined metallurgically to determine the most suitable particle size.

2. A complete APPR fuel assembly modified to fit into the MTR core and having a matrix composed of a single fuel-particle size (44 to 88 μ) will be irradiated to a high burnup.

3. A complete fuel assembly, similar to the one above, except that each plate will contain a different UO_2 particle size, will also be irradiated to a high burnup.

A tentative schedule indicates that the above series of irradiations could be completed by January 1956. A summary of specifications for these test elements is shown in Table 6.

TABLE 6. SUMMARY OF POWER SPECIFICATIONS

	Test Fuel Assemblies			ORNL Package Power Reactor Design
	MTR-APPR		STR-APPR	
	Type I	Type II		
Heat flux, av Btu/ft^2-hr	449,000	461,000	442,000	55,900
Specific power, kw/kg	9000	9000	7150	550
Fuel concentration in matrix, g/cm^3	1.240	1.240	1.04	1.31
Fuel loading, g/cm^2	0.0315	0.0324	0.039	0.066
Fuel in each plate, g	10.36	10.67	10.767	23.65
Maximum temperature of fuel, °F			580	566

ACCELERATOR STUDIES AT 1 bev

Studies of the feasibility of a fixed-frequency accelerator in the 1-bev energy range are being made in collaboration with the Physics Division. A fixed-frequency machine should yield sufficiently large proton currents at this energy to be very useful in meson physics research. The theory of an azimuthally varying magnetic field cyclotron, first proposed by Thomas in 1938, is being extended to several different magnetic field configurations; calculations are being made with the Oracle. It is planned to make preliminary designs for magnets appropriate for the most promising configurations. The effects of spiraling the axes of the hills and valleys, as suggested by the Midwestern Universities Research Associates (MURA) group, are being investigated.

The radius and the magnetic field patterns were calculated for machines having 4, 5, 6, 8, 10, and 12 hills and valleys (poles). Some calculations were made for the design requirements of an eight-pole machine. The machine would have eight wedge-shaped pole pieces, with the coils wound in such a manner that the magnetic field in the valleys would be reversed for the larger radii (see Fig. 10). The magnet specifications for a 1-bev cyclotron of this design are given in Table 7.

An important problem encountered in the theoretical work is the effect of the "imperfection"

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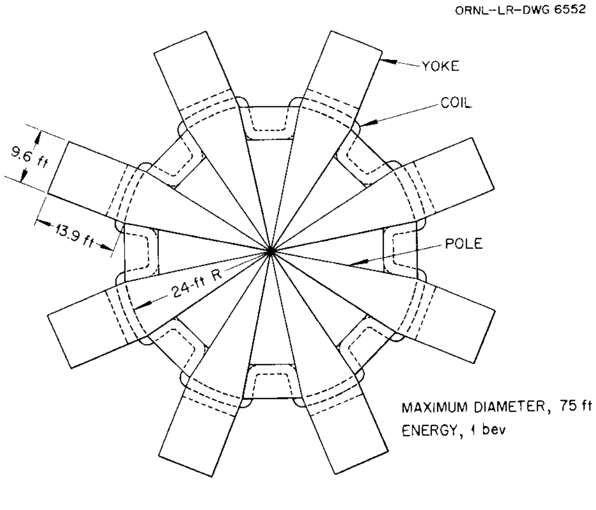


Fig. 10. An Eight-Pole, 1-bev, Fixed-Frequency Cyclotron, Plan View.

TABLE 7. MAGNET SPECIFICATIONS FOR A 1-bev CYCLOTRON

	Closed Yoke	Open Yoke	The Bevatron
Excitation, 10^4 amp-turns	65	242	
Current density, amp/in.^{2}	1000	1000	
Power, Mw	2.5	8.5	3.5
Copper, tons	100	400	350
Iron, tons	9700	6200	9500

resonances. The ions, as they gain energy, are continually undergoing focusing oscillations about an equilibrium orbit. The frequency of these oscillations is a function of the energy – equal to the ion frequency at zero energy and increasing in frequency with increasing ion energy. Therefore, at certain energies the focusing oscillation will complete an integral number of cycles in either one or two ion revolutions. When this condition exists, any slight imperfection in the fields will cause the radial focusing oscillation to increase in amplitude, and, hence, the ions may be lost. Resonance energy levels for different pole configurations are given in Table 8.

The success with which ions can be accelerated through these energy levels is not known. It is thought that by careful construction the resonances can be passed without excessive loss of ions. Plans are being made for an electron-model accelerator to be used in assessing the importance of imperfection resonances and the feasibility of their penetration. These resonances serve one useful purpose, however, in that the radial beam spread at these radii can probably be used to an advantage in deflecting the beam.

The MURA group has suggested the use of spiral poles, the hills and valleys spiraling outward from the magnet center. This has two advantages: the imperfection resonances occur at higher energy levels, and a more compact magnet structure is possible. Some data have been calculated for an eight-pole machine which indicate that the first and second resonances would occur at 456 and 880 Mev, instead of at the 415 and 720 Mev listed

TABLE 8. RESONANCE ENERGY LEVELS FOR FOUR POLE CONFIGURATIONS

Pole Configuration	Resonance Energy Levels (Mev)			
	First Resonance	Second Resonance	Third Resonance	Fourth Resonance
4-pole	275	360		
6-pole	370	570	750	800
8-pole	415	720	960	
12-pole	440	810	1120	1380

in Table 8. Also, the variation in the magnetic field from hill to valley would be less, with the result that the average magnetic field would be higher, and the over-all magnet structure would be reduced in size by a factor of approximately 2.

The practical problems encountered are the design of the coils and pole faces and the design of the r-f accelerating system. The large magnetic field variations and the accuracy with which the field must be constructed add to the difficulty. For a machine in the bev energy range, the conventional cyclotron dee system is unsatisfactory. The requirements for a practical r-f electrode system are being studied.

[redacted]

OPERATIONS SUMMARY

A summary of operations in Buildings 9204-3 and 9201-2 from September 20, 1954, to March 20, 1955, includes the following experimental and production runs:

Special separations	12
Electronuclear research	132
Electronuclear machines	18
The 86-in. cyclotron	69
The 63-in. cyclotron	100
The 44-in. cyclotron	8

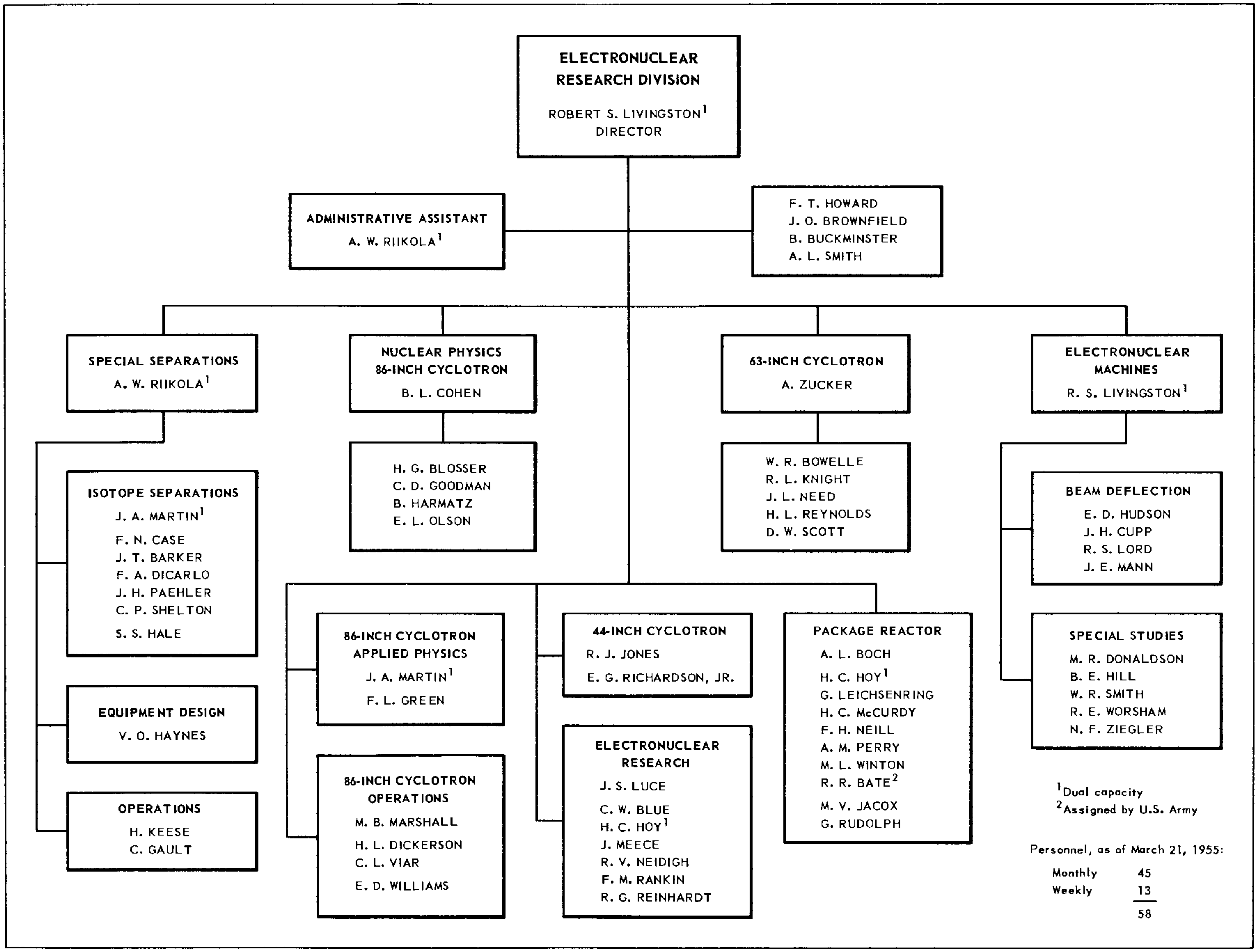
The distribution of shop time charged to each of the various projects is given in Table 9.

The assignment of personnel to the several projects is indicated in the organization chart.

TABLE 9. TIME DISTRIBUTION – MECHANICAL SERVICE AND MACHINE SHOPS, SEPTEMBER 20, 1954, TO MARCH 20, 1955

Account Number and Project	Mechanical Service		Machine Shops			
			Carbon		Metal	
	Hours	Per Cent of Total Time	Hours	Per Cent of Total Time	Hours	Per Cent of Total Time
33 Special separations	2,952.8	17.79	578.0	31.17	332.0	15.16
34 86-in. cyclotron, applied physics	1,537.3	9.26	83.0	4.48	72.0	3.29
35 86-in. cyclotron, operations	4,721.9	28.45			298.0	13.61
37 Electronuclear machines	311.0	1.87			8.0	0.36
39 86-in. cyclotron, nuclear physics	142.5	0.86	69.0	3.72	292.0	13.33
40 63-in. cyclotron, physics	187.5	1.13	42.0	2.26	48.0	2.19
41 63-in. cyclotron, operations	1,261.5	7.60	150.7	8.13	156.0	7.12
43 Package reactor	19.0	0.11	64.0	3.45	8.0	0.36
44 44-in. cyclotron	689.0	4.15	28.0	1.51	136.0	6.21
46 Electronuclear research	4,743.4	28.57	839.8	45.28	840.4	38.37
1 Building maintenance	34.5	0.21				
Total	16,600.4	100.00	1854.5	100.00	2190.4	100.00

 [redacted]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[1]Dual capacity
[2]Assigned by U.S. Army
Personnel, as of March 21, 1955:
Monthly 45
Weekly 13
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