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ORNL-1663
Progress
4A

ELECTRONUCLEAR RESEARCH DIVISION

SEMIANNUAL PROGRESS REPORT

FOR PERIOD ENDING SEPTEMBER 20, 1953

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 September 20, 1953

R. S. Livingston, Director

Edited by F. T. Howard

DATE ISSUED

FEB 18 1954

OAK RIDGE NATIONAL LABORATORY

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CARBIDE AND CARBON CHEMICALS COMPANY

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PAPERS PRESENTED DURING THE PERIOD

B. L. Cohen, R. V. Neidigh, and E. Newman, "Measurement of Angular Distributions of Nuclear Reaction Products with an Internal Cyclotron Beam," American Physical Society meeting, Washington, D.C., April 30 – May 2, 1953. Abstract: *Bull. Am. Phys. Soc.* **28**, 62 (1953).

E. Newman, B. L. Cohen, and T. H. Handley, "(p,pn) and $(p,\alpha n)$ Excitation Functions," American Physical Society meeting, Washington, D.C., April 30 – May 2, 1953. Abstract: *Bull. Am. Phys. Soc.* **28**, 62 (1953).

H. L. Reynolds and A. Zucker, "Range-Energy Relations of Nitrogen Ions in Emulsion," American Physical Society meeting, Washington, D.C., April 30 – May 2, 1953. Abstract: *Bull. Am. Phys. Soc.* **28**, 72 (1953).

B. L. Cohen and T. H. Handley, *Experimental Studies of (p,t) Reactions*, American Physical Society meeting, Rochester, N. Y., June 18-20, 1953.

ARTICLES PUBLISHED

B. L. Cohen, "Theory of the Fixed Frequency Cyclotron," *Rev. Sci. Instr.* **24**, 8 (1953).

H. L. Reynolds, D. W. Scott, and A. Zucker, "Nuclear Reactions with Energetic Nitrogen Ions," *Proc. Nat. Acad. Sci. U.S.* **39**, 975 (1953).

ARTICLES SUBMITTED FOR PUBLICATION

B.L.Cohen, "On the Statistical Theory of Nuclear Reactions," submitted to *The Physical Review*.

B. L. Cohen, "Potassium-44," submitted to *The Physical Review*.

B. L. Cohen and T. H. Handley, "An Experimental Search for a Stable Dineutron," submitted to *The Physical Review*.

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B. L. Cohen and R. V. Neidigh, "Measurement of Angular Distributions of Nuclear Reaction Products with an Internal Cyclotron Beam," submitted to *The Review of Scientific Instruments.*

B. L. Cohen and T. H. Handley, "Experimental Studies of (p,t) Reactions," submitted to *The Physical Review.*

B. L. Cohen and R. V. Neidigh, "Angular Distributions of 22-Mev Protons Elastically Scattered by Various Elements," submitted to *The Physical Review.*

T. H. Handley and E. L. Olson, "Erbium-163 and Thulium-165," submitted to *The Physical Review.*

R. J. Jones and A. Zucker, "Two Ion Sources for the Production of Multiply Charged Nitrogen Ions," submitted to *The Review of Scientific Instruments.*

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Part I

UNCLASSIFIED WORK

ELECTRONUCLEAR RESEARCH DIVISION SEMIANNUAL PROGRESS REPORT

ABSTRACT

Nuclear physics research with 22-Mev protons produced by the 86-in. cyclotron included investigation of (p,t) reactions, measurement of angular distributions of fission fragments produced by (p,f) on thorium, investigation of proton diffraction patterns, measurement of (p,pn) and $(p,\alpha n)$ excitation functions, and identification of several new isotopes. In an investigation of the long-range prospects for the production of neutron-deficient isotopes in the 86-in. cyclotron, yield calculations were made for (p,n) and $(p,2n)$ reactions, and new types of targets were developed. The magnetic field of the 63-in. nitrogen cyclotron was modified to improve the deflected beam; a C^{+++} beam was used to determine the range energy relation for carbon ions in emulsion. The 44-in. test cyclotron is being modified to permit operation with larger currents at higher energy. A preliminary study was made of an r-f system suitable for use in a variable-energy heavy-particle cyclotron.

THE 86-INCH CYCLOTRON

NUCLEAR PHYSICS RESEARCH

The project on experimental studies of (p,t) reactions was completed. It was concluded that the (p,t) reactions proceed principally by compound nucleus interaction, with the "double neutron pickup" contributing significantly only when the target nucleus contains two loosely bound neutrons (for example, Nb^{93} with 52 neutrons) and that the intrinsic probability of triton emission from a compound nucleus is approximately equal to that for the emission of neutrons or protons.

The measurement of angular distributions of barium, silver, and strontium fission products from thorium fission induced by 22-Mev protons was completed. It was concluded that the angular distributions are approximately symmetric about 90 deg and can be adequately fitted by

$$I(\theta) = a + b \cos^2 \theta$$

and that the value of b is about 0.26 for barium and strontium (asymmetric fission) and about 0.10 for silver (symmetric fission).

Analysis of data obtained on the elastic scattering of 22-Mev protons by 15 different target elements shows all the characteristics of diffraction scattering, including at least two maxima and two minima for each element, Fig. 1.

A project on the measurement of angular distributions of alpha particles from (p,α) reactions was initiated. The distributions show a very pronounced forward structure, indicating that some process other than compound-nucleus interaction is responsible for the reactions.

Excitation functions for several (p,pn) and $(p,\alpha n)$ reactions were measured from the thresholds to 23.5 Mev. The principal conclusions were:

1. The Coulomb barriers encountered in emission of protons or alpha particles from a compound nucleus are not significantly lower than should be expected for spherical nuclei; this conclusion is contrary to the predictions of the collective model.

2. The previously known phenomena of excessive emission of charged particles from nuclear reactions were again observed in an energy region where some previous explanations of the phenomena are not valid.

Measurements of $(p,2n)$ excitation functions were undertaken to obtain estimates of nuclear temperatures.

A search for fission in medium-weight elements has thus far proved to be fruitless. The upper limits for the cross sections for $Cu^{63,65}(p,f)Na^{24}$ and for $Al^{27}(p,f)N^{13}$ were determined to be 10^{-7} and 10^{-3} barns, respectively. Work is continuing on the latter reaction. The measurements of fission yield distributions from 22-Mev proton-induced fission on U^{238} and U^{235} were completed.

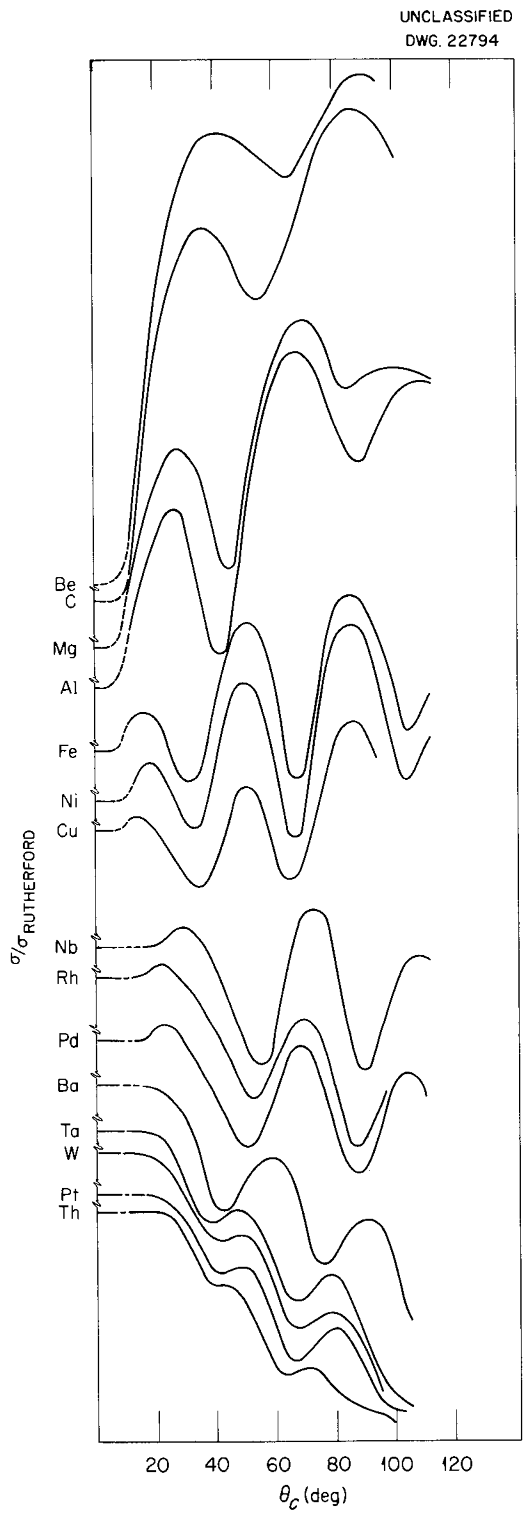


Fig. 1. Angular Distribution of 22-Mev Protons Elastically Scattered by Various Elements. There is no significance in the spacing between the various curves.

Measurements of the excitation for $U^{238}(p,\alpha)Pa^{235}$ indicate that the identification of Pa^{238} may be in error. This problem is being studied; the major difficulty is in protactinium chemistry.

All previous identifications of isotopes were reinvestigated, and some errors were uncovered. The identifications in the following tabulation are considered certain; the beta- and gamma-ray spectra have been investigated in all cases. All identifications have been submitted for publication.

New Isotope	Half Life	Producing Reaction
Ga^{64}	2.5 m	$Zn^{64}(p,n)$
K^{44}	22.0 m	$Ca^{44}(n,p)$
Dy^{157}	8.2 h	$Tb(p,3n)$
Er^{163}	75 m	$Ho(p,3n)$
Tm^{165}	24.5 h	$Er(p,2n) + (p,3n)$
Yb^{167}	18 m	$Tm(p,3n)$
$Er^{160,161}$	3.6 h	$Er(p,2n)$ or $(p,3n) + \beta$
$Ho^{160,161}$	2.5 h	Daughter of 3.6-h $Er^{160,161}$

A search for the activity of long-lived Mg^{22} is being made with a detection sensitivity that is expected to be fruitful. A search for the activities of Ca^{38} and Ne^{18} proved to be unsuccessful; the Ca^{38} half life must be less than 1 sec or more than 3000 years. Survey searches for short-lived (1 sec to 2 min) activities induced by both protons and neutrons are being made, and a few promising results are being further investigated.

Additional data became available which confirmed previous theoretical work on nuclear reaction theory. All data were reanalyzed and the work was submitted for publication. The theory of (d,p) and (p,d) reactions (stripping, pickup) was investigated in great detail. A simplified presentation was prepared, and previous data on (p,d) angular distributions were analyzed. Calculations of angular distributions of 22-Mev protons elastically scattered by heavy elements were set up and are now being made on IBM machines.

A magnetic-lens beta-ray spectrometer was rebuilt and put in operation; calibrations are now in progress. The construction of a scintillation-pair spectrometer was begun. Apparatus for measuring beta and gamma spectra of short-lived activities by oscilloscope photography was put into operation.

APPLIED PHYSICS

The work of the 86-in. cyclotron applied-physics program has centered on the long-range aspects of the isotope-production program. The thick-target yields for over 100 radioisotopes were calculated; target fabrication techniques were improved and a new capsule-type target was developed which allows the bombardment of targets in powder form at currents as high as 200 μa. The use of the cyclotron by the ORNL Biology Division continued at the level of one-half day per week. The production of Ga^{67} for the ORINS Medical Division was continued but at a reduced rate.

Yield Calculations

The (p,n) and $(p,2n)$ reactions have large yields when thick targets are bombarded with 22-Mev protons. Since the products of these reactions can be separated chemically from the parent element in a carrier-free state, they may be used with advantage in many applications in which specific activity is an important consideration. The thick-target yield for these reactions has been estimated for over 100 radioactive species produced from target elements of atomic number greater than 25 and from isotopes of over 10% natural abundance.

The calculations were based on the statistical theory of nuclear reactions. The total proton cross sections were taken from Blatt and Weisskopf,[1] as were the nuclear temperature data used in calculating the $(p,2n)$ cross sections. The (p,pn) competition, which is particularly large for the medium-weight elements, was taken into account through the use of experimentally determined values, for example, the data of Ghoshal[2] for Cu^{63} and the values for Cu^{65}, Pd^{110}, Ag^{107}, and Ta^{181} determined with the 86-in. cyclotron. Reaction thresholds were approximated through the use of the Metropolis form of the Weisacker-Fermi mass formula.

Figure 2 gives the thick-target yields from (p,n) and $(p,2n)$ reactions from 22-Mev protons. The decrease in $(p,2n)$ yield at low atomic number is caused by the increasing competition of the (p,pn) reaction.

Target Development

The vacuum-brazing technique described in the previous semiannual report[3] has proved to be a satisfactory method for the fabrication of large beryllium targets. A 4 × 10 × 0.045 in. sheet of beryllium was brazed to a 6 × 10 in. aluminum target base by using aluminum-silicon brazing alloy containing 11.5% silicon. The brazing was done in vacuum without the use of flux, the oxide film on the aluminum base, on the beryllium sheet, and on the brazing alloy having been removed chemically just prior to the brazing operation. A target fabricated in this manner has been used intermittently for the past four months at currents occasionally exceeding 1 ma.

A capsule-type irradiation target was developed to allow the bombardment of small quantities of oxides or other materials which cannot be easily applied to a grazing-incidence target or which cannot be placed directly in the proton beam. The present design consists of a 0.186-in. Inconel capsule of 0.005-in. wall thickness which is centered within a 0.250-in.-dia tube also having a 0.005-in. wall thickness. The material to be bombarded is tightly packed into the capsule which is then sealed by heliarc welding. Both the capsule and the outer tube are cooled by water flowing at high velocity in the annulus between them. The use of thin-walled tubes and a small

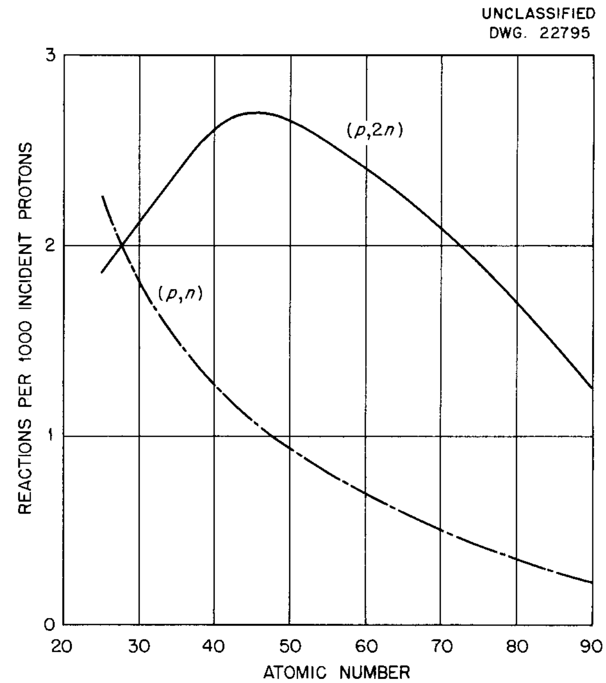


Fig. 2. Estimated Thick-Target Yields for 22-Mev Protons.

[1] J. M. Blatt and V. F. Weisskopf, *Theoretical Nuclear Physics*, Wiley, New York, 1952.

[2] S. N. Ghoshal, *Phys. Rev.* 80, 939 (1950).

[3] *Electromag. Res. Semiann. Prog. Rep. March 20, 1953*, ORNL-1531, p. 8.

annulus limits the energy loss to about 7 Mev.

A target of this type was tested to destruction; a beam current of 260 μa was required to melt a small hole in the outer tube. Materials thus far bombarded in this target at a current of 200 μa are strontium fluoride, strontium oxide, magnesium oxide, magnesium chloride, lanthanum oxide, and germanium metal.

A new method has been used to apply metal coatings to the surface of grazing-incidence targets. A metallizing gun was used successfully in appling nickel and zinc coatings to aluminum target bases. The targets produced in this manner were tested in the cyclotron and operate equally as well as targets with electroplated coatings of the same metals.

Isotope Production

Two lithium-coated targets were bombarded for the production of Be^7 by the (p,n) reaction with Li^7. The data for these runs are given in Table 1.

Operation on these two targets was substantially improved over the first run (October 1952) during which an average current of 420 μa was obtained.

Gallium-67 production was continued at a somewhat reduced scale during the past period; approximately 2.1 curies was produced as compared with 8.5 curies for the previous period. The reduction is a result of programmatic changes at the ORINS Medical Division which is at present the sole user of the Ga^{67} produced by the 86-in. cyclotron.

TABLE 1. PRODUCTION OF Be^7 BY (p,n) REACTION ON Li^7

	TARGET NO.	
	S-7	S-15
Run length, hr	5.2	5.1
Integrated beam, μah	3150	3040
Average beam current, μa	606	596
Maximum beam current, μa	700	700
Estimated yield,* mc	535	517
Actual yield, mc	390**	***

*Estimated yield based on the 170 mc/mah obtained for the first lithium bombardment (October 1952).

**20% of the activity on this target lost through a chemical processing accident; thus the actual yield is not known.

***Target S-15 presently being processed.

Some other runs of short duration were made to determine the yield of various isotopes. Strontium oxide was bombarded for the production of Y^{88}; magnesium chloride for A^{37}; germanium for As^{73} and As^{74}; and nickel for Co^{57}. A small quantity of highly purified (cerium-free) lanthanum oxide was bombarded to produce a carrier-free sample of Ce^{139} for the ORNL Chemistry Division. In another bombardment done for the ORNL Chemistry Division, 10 mg of 2.6-y Pm^{147}, a fission product, was bombarded in a search for Sm^{146}.

BEAM DEFLECTOR DEVELOPMENT

A beam-deflection system is being developed to deflect the proton beam from the lower edge of the dees in a horizontal direction into a reaction room to the south of the cyclotron pit. In designing the deflector, advantage is taken of the relativistic phase lag; when the dee-to-dee potential is at its maximum, the bunched protons are about 70 deg from the dee-to-dee gap. The deflector will consist of a grounded plate covering about 60 deg of the north dee, placed about 1 in. from the periphery. When the protons are about midway along this deflector channel, the potential gradient between the ground plate and the dee will be approximately 200 kv/inch. This deflector will produce a maximum orbit separation of 4 in. at the bottom of the dees.

At the dee-to-dee gaps, the dees were both cut back at an angle of 20 deg to compensate for the added dee-to-ground capacity of the deflector. This increases the gap from 4 in. to 24 in. at the periphery. The electric model of the cyclotron was modified similarly, and the calculated resonance frequency was verified.

Deflection of the beam to 4 in. beyond its normal orbit is not sufficient to bring the beam out of the magnetic field in the desired direction. Since the reaction room is at the same floor level as the cyclotron, it is necessary to bring the beam out in a horizontal direction. This will require an extreme weakening of the magnetic field at the bottom of the cyclotron.

Tests were made to determine the field weakening that can be obtained with iron bars in a magnetic field of 9000 oersteds. Field reductions of 30% were measured 1 in. from iron bars. Field changes extend inward, however, and disturb inner orbits of the beam. Some means of compensating for the iron bars must be developed to prevent undue disturbances in the normal beam orbits.

A deflector septum has been designed which consists of a grid of water-cooled tubes spaced $\frac{1}{4}$ in. apart and aligned parallel to the magnetic field. Aluminum alloy 52S tubes 0.050 in. OD and 0.046 in. ID have been obtained for this purpose. The stainless steel tubes previously tested were unsatisfactory because of the extreme radioactivity induced. Preliminary erosion tests indicate that if the ordinary cyclotron-cooling water is used the tubes will fail after 250 to 750 hr at a water velocity of 85 fps. This water has a conductivity of about 40 μmho/cc and contains what appears to be suspended rust particles. Other tests being made with distilled water indicate an improvement in tube life by a factor of at least 3. When full power dissipation in the septum is not required, however, the water velocity can be reduced to further extend the life of the tubes.

A set of dees from which the periphery had been removed was installed in the cyclotron for tests pertaining to beam deflection. U-shaped straps extending 3 in. outside the dee were placed between the dee sides to maintain mechanical stability. By using the "half-coils" described in a previous report[4] to obtain a magnetic-field gradient across the pole face, the beam could be moved to a position outside the dees. Beam currents in excess of 100 μa at 16 to 18 Mev were obtained at a point 2 in. beyond the dees (37-in. radius), and a 23-Mev beam of 300 to 400 μa was obtained at a point 1 in. outside the dees. During this series of tests, a 26-Mev beam was measured at a radius of 34 inches. The "half-coils" will be incorporated in the deflector system to provide for shifting the effective beam center to the optimum position.

Engineering drawings have been made for a completely new dee assembly including the water header, support frame, shorting spider, dee stem clamps, and septum. Parts for some of these items have been fabricated. A contract for building the dees and stems in an outside shop is being negotiated.

CYCLOTRON OPERATION

Performance of the cyclotron was very satisfactory, but the innage time was somewhat low because of the short runs and relatively long interrun periods of the experimental programs. During a two-week period in April, the dees were removed and the older set of dees, with modifications, was installed for use in tests by the Deflector Development Group. A ten-day shutdown was required in July when the field of the motor of the main motor-generator set became grounded and repairs were necessary.

Present Cyclotron Program

The present work schedule is two shifts a day, five days a week. The time is divided among three general programs: nuclear-physics experiments, isotope-production experiments, and cyclotron development, including experiments for beam deflection.

The radiation-damage program was discontinued because of a curtailment of funds; only five runs were made during the period.

Cyclotron Performance

The average innage, exclusive of the above-mentioned breakdown and exclusive of the time the machine was shut down for deflector experiments, was 40%, or 32.5 hr per 80-hr week. The time summary for a typical week is shown below:

	Hours	Per Cent
Attempted innage and baking-out time	5.9	7.4
Innage (beam on target)	32.7	40.9
Source – routine change of filament and adjustment	2.2	2.7
Targets – routine change and inspection	19.3	24.1
Experimental tests and measurements	4.7	5.9
Equipment failure and troubles	6.8	8.5
Standby (no target available)	4.6	5.8
Weekly startup and shutdown	3.8	4.7

During the past period, the following bombardments were made on the 86-in. cyclotron:

Nuclear physics	287
Radiation damage	5
Isotope production	30
Biology	22 (~310 exposures)
Experimental	81
Operational	19
Total	444

[4] *Electromag. Res. Semiann. Prog. Rep. March 20, 1953*, ORNL-1531, p. 9.

The Biology Division made exposures of both plants and animals (mice, rats, and guinea pigs). They also made calibration checks on chambers to be used in the Nevada bomb tests. In the animal exposures, 2 to 24 animals, depending on their size, were exposed at one time.

Modifications

The installation of air conditioning in the pit and in the contaminated work area greatly improved working conditions in those areas. A large amount of heat is given off by the magnet coils and vacuum pumps and, with protective clothing, the working conditions were unsatisfactory.

At the request of the Biology Division, a lead box was placed outside the vacuum tank as close to the target as possible for the neutron-irradiation of organisms. The box has 1-in.-thick walls, internal dimensions of 18 × 16 × 8 in., and the same external dimensions as those of the older box with 4-in.-thick walls that it replaces. The new box provides a better ratio of neutrons to gamma radiation and accommodates more test specimens.

In order to permit the detection of neutron-induced activities of short half life, a 1-in. copper tube was passed through a hole in the top of the shielding and extended to a point as near to the target as possible. Samples are exposed to neutron irradiation and are then blown up the tube and into counting apparatus by compressed air.

THE 63-INCH CYCLOTRON

The previously reported nuclear physics experiments with the 63-in. cyclotron were performed with an internal beam of N^{+++} ions. In attempting to obtain a deflected beam, it was found that reasonably large ion currents were circulating at the smaller radii but that practically all of the beam was lost to the dee walls at approximately the 24.2-in. radius. Not more than 1 μa arrived at the deflector septum, radius 25.3 in., and this was insufficient for deflection purposes. Consequently, the experimental program was interrupted to permit tests and modifications necessary for increasing the deflected beam.

The magnetic field was reshimmed, and particular attention was paid to the location of the median plane. It has become apparent that the median plane of the magnetic field of the cyclotron is an extremely important and critical parameter. A deviation from the geometric median of only $\frac{3}{8}$ in. over 1 in. of radius deflects the beam into one side of the dees. By repeated shimming of the pole pieces, the median plane was aligned to within $\frac{1}{4}$ in. of the geometric median. As a result of this shimming operation, the circulating beam intensity was increased from 1 μa to 40 μa.

Even with this larger beam, there still seem to be two difficulties associated with the machine. A large percentage of the beam hits the west wall of the dees at the 21-in. radius, and probably not more than 1 μa arrives at the septum at the proper angle. Efforts are being made to correct both these difficulties. Eliminating the loss at the 21-in. radius should increase the beam at $24\frac{1}{4}$ in. to the order of several hundred microamperes. The second difficulty is probably associated with the septum geometry and might be eliminated by shifting the position of the dees.

In the meantime, a small deflected beam, about 0.02 μa, has been measured at the exit port at the top of the cyclotron. (Note: The deflected beam has since been increased to over 1 μa.) The emerging beam was first detected with a zinc sulfide screen and later measured with a Faraday cup. The fact that this is indeed a high-energy nitrogen beam was substantiated by activation experiments at the exit port. From the known reaction cross sections, the deflected beam current was calculated to be 0.02 μa. Further efforts will be made to increase the beam.

Small beams of triply charged carbon ions, produced from the graphite of the ion-source structure, were accelerated in the 63-in. cyclotron by lowering the magnetic field. Since lowering the field altered the focusing characteristics of the magnetic shims, the C^{+++} current thus obtained was too small for conventional nuclear physics experiments. Sufficient carbon ions were obtained, however, to bombard nuclear emulsions. In a manner described previously,[1] the range energy

[1] *Electromag. Res. Quar. Prog. Rep. Sept. 30, 1952*, ORNL-1383, p. 16.

relation for carbon ions in emulsion was measured. The results agree well with conclusions drawn from the previous measurement of the range of nitrogen ions in emulsion.

Chemical separation of activities induced in sulfur targets bombarded with 25-Mev nitrogen ions confirmed the presence of Sc^{44}. Ion exchange and paper chromatography were used for the separation of target elements and the identification of scandium.

THE 44-INCH CYCLOTRON

The 44-in. test cyclotron is being modified to permit operation with higher beam currents and higher proton energy. The design and construction of a more powerful oscillator is approximately 90% complete. Design work for modification of the dee system and the vacuum tank is 85% complete, and 40% of the components have been fabricated.

All components of the r-f system have been designed except for the filament-coupling circuit. Since this circuit depends upon the electrical characteristics of the resonant dee system, it cannot be designed until these characteristics are determined. All other major components of the r-f system have been installed in the oscillator housing and plate coupling shield. The principal difficulty encountered was in the fabrication of several large water-cooled r-f coils. Electrical wiring of the oscillator cabinet is under way.

The new dees have a radius of 22 in. and are 7½ in. thick. They are mounted in a vertical plane on horizontal dee stems, 7 in. in diameter. The dee stems are supported within a vacuum housing on a plate at the ground-plane position. The whole dee system is insulated from ground so that a bias potential may be applied to control ion loading.

In order to accommodate the new dee system, it was necessary to make several modifications in the vacuum tank and manifold. The removal of the flat shims from the tank increased the magnet gap to 13½ in. and provides sufficient clearance to permit operation of the dees at a potential of 100 kv. The vacuum manifold is being modified to provide for the insertion of the ion source and beam probe through the back of the tank.

In the past, it was not possible to move a high-current-type target into the space between the dees to measure the circulating current at various radii. A new design will permit the use of a high-current target at the edge of the dee for both the 11-in. radius (1.5-Mev protons) and the 20-in. radius (4.9-Mev protons). This is achieved by means of a removable 14-in. extension or spacer between the vacuum tank and the faceplate upon which the dee system is mounted; a choice of radius, 11 in. or 20 in., is thus obtained by shifting the position of the dees and target. In either case the ion source position remains unchanged and the beam orbits remain centered with respect to the magnetic field.

The approximate specifications for the revised 44-in. cyclotron are summarized below:

Beam radius, in.	11		20
Proton energy, Mev	1.5		4.9
Magnetic field, oersteds		6400	
Magnet gap, in.		13.5	
Dee diameter, in.		44	
Maximum dee-to-dee potential, kv		100	
Frequency, megacycles/sec		9.7	
Oscillator tube		F 134	
Oscillator output, kw		~200	

VARIABLE-ENERGY HEAVY-PARTICLE CYCLOTRON

A preliminary study is being made of the feasibility of constructing a variable-energy cyclotron for the acceleration of heavy particles, carbon through neon, to energies above 100 Mev.

The two major problems involved in the design of an r-f system for a variable-energy cyclotron are the development of an oscillator which will operate relatively efficiently and stably over the desired frequency range and the construction of a dee system which can be tuned for the various frequencies. These two problems were considered separately in this experiment. Satisfactory solution of the separate problems does not, however, ensure a workable composite system, since the two circuits are interrelated.

Several tests were made on oscillator circuits which are applicable to a variable-energy cyclotron. The circuit which proved to be most satisfactory is a self-excited, push-pull type directly connected to the dee stems. This oscillator displayed the following desirable characteristics: only two controls are required for changing the frequency; the driving voltage can be accurately and simply controlled; and the oscillator is insensitive, frequency-wise, to variation in the driving voltage.

The push-pull circuit for this test was constructed by using an 8-ft section of the electrical model of the 63-in. cyclotron dee stems as the resonant system. Dees were simulated by a capacitor connected from the end of each dee stem to ground, and tuning was accomplished by varying the value of this capacitance. Other circuit components were selected to have approximately the same values as those in a full-scale operation. The driving voltage was controlled by varying the length of a balanced, shorted transmission line connected between the grids of the two oscillator tubes.

The operation of the push-pull oscillator was, in general, very satisfactory. Tuning was accomplished with a minimum number of controls, and the driving voltage could be adjusted to the optimum value without appreciably affecting the frequency.

Although the resonant dee system can be tuned by the use of variable capacitors connected from dee stem to ground, this was not considered to be an entirely satisfactory solution to the second problem, and further experimentation has been undertaken to develop a more practical method.

One method of transmission-line tuning which was tested involves the use of a secondary circuit magnetically coupled to the dee-stem system. This circuit consists of a coil and variable capacitor connected in series, plus the inherent resistance of both elements. The magnetic coupling between the dee stems and secondary circuit results in an impedance being reflected into the dee stems from the secondary. This reflected impedance may be varied, thereby changing the resonant frequency of the dee stems, by adjusting the variable capacitor in the secondary circuit. A resonant frequency varying from 6 megacycles to 12 megacycles was achieved with the particular circuit tested.

Although the desired frequency range can be obtained with the aforementioned circuit, it has one undesirable characteristic in that the resonant impedance of the dee stems varies markedly with the frequency due to the comparatively low "Q" of the secondary circuit. Therefore further work on this method of transmission-line tuning is considered necessary before a definite conclusion can be reached regarding its adaptability to the variable-energy cyclotron.

Part II

[redacted] WORK

ABSTRACT

Preliminary tests in preparation for the separation of gram quantities of enriched plutonium isotopes were completed; the efficiency and yields obtained in the calutron are much less for plutonium than for uranium. A preliminary design study for a 10-megawatt pressurized-water package reactor power plant for operating in remote areas was completed; a plant producing 1000 kw of electricity and 3500 kw for heating would cost approximately $\$1.7 \times 10^6$, exclusive of fuel, installed locally; the kwhr cost for producing electricity and steam at 70% load is 5.52 and 1.37 cents, respectively. A total ion (lithium) current in excess of 6 amp was obtained in the apotron with only three arcs in operation.

SPECIAL SEPARATIONS

The program for the separation of gram quantities of plutonium, enriched in its higher isotopes, by the electromagnetic process is at present in the production phase. Evaluation of the final experimental run indicated that a process efficiency of 4% and a tenfold enhancement can be expected. The efficiency of the ion source for plutonium is found to be less by a factor of 4 than that for uranium. With respect to its behavior in the arc, plutonium bears a closer resemblance to the rare earths. The experimental runs yielded plutonium that was 99.3% Pu^{239} and 0.7% Pu^{240}. Processing of the collector is expected to yield 1 g of Pu^{239} depleted in Pu^{240} and a fraction of a gram of Pu^{240} assaying 10%. Further plutonium separations are to start with highly irradiated material containing from 5 to 12% Pu^{240}.

SPECIAL-SEPARATIONS LABORATORY

Experience in the processing of ionium and plutonium indicates that the present facilities and transfer methods are adequate for the safe handling of large quantities of alpha-active materials on an experimental basis. No spread of contamination outside controlled areas was detected, and an extensive health-physics monitoring program inside the areas showed that air levels and surface contamination were consistently low except during the transfer of calutrons highly contaminated with plutonium. During these transfers, airborne activity levels in some cases exceeded laboratory tolerance (without respiratory protection) but were not considered as excessive for the type of operation involved. There was evidence that small amounts of plutonium migrated through the double-clamp arrangement on gloved-box ports during glove changes, but it is felt that this can be adequately controlled by good housekeeping procedures. Some components of the laboratory have had only limited use and cannot yet be considered to be adequately tested.

Several minor alterations and additions were made to the facilities to improve safety and convenience in operations. A storage facility was provided for contaminated materials, chiefly for the storage of contaminated calutrons but also for the storage of other equipment and salvage materials. The room is maintained at a slight negative pressure, with the exhaust air passing through a CWS filter before being released to the outside. Air samples and surface-contamination measurements are taken on a routine basis.

Permanent air samplers were installed in the calutron wash facility for routine monitoring of the general area. This made the portable air samplers available for monitoring specific operations and should result in better contamination control. An innovation in the air-monitoring procedure during transfers provides for an immediate count of air samples without waiting for the decay of radon products. While this method is not precise, it gives immediately an upper limit for airborne activity and is considered to be useful.

At the end of a plutonium isotope separation run, chlorine gas is admitted to the calutron vacuum tank in order to minimize formation of insoluble plutonium oxides. Alterations were made in the mechanical pumping system which permit chlorine to be admitted to and evacuated from the tank without damage to the vacuum pumps. Additional pumping capacity was also provided.

Natural-rubber gloves which were used with University of California type of glove ports proved to be quite unsatisfactory owing to rapid deterioration. They disintegrated after a few weeks of exposure to the atmosphere under apparently noncorrosive conditions, and were replaced with Neoprene gloves of the same design which are giving satisfactory service.

SHIPMENTS OF ENRICHED, CLASSIFIED ISOTOPES

The distribution of electromagnetically enriched isotopes of heavy elements to various laboratories since March 1953 is given in Table 2.

TABLE 2. DISTRIBUTION OF ISOTOPES

TO	ISOTOPE	AMOUNT (mg)	PURITY (%)
Oak Ridge National Laboratory	U^{235}	105	99.94
University of Arkansas	U^{235}	804	99.86
Massochusetts Institute of Technology	U^{235}	929	99.81
General Electric Research Laboratory	U^{235}	999	99.50
Oak Ridge National Laboratory	U^{236}	51	94.90
University of California Radiation Laboratory	U^{238}	47	99.99992
General Electric Research Laboratory	U^{238}	931	99.9993
Oak Ridge National Laboratory	U^{238}	203	99.999
Brookhaven National Laboratory	U^{238}	2,001	99.9988
University of Rochester	U^{238}	19,429	99.9988
Du Pont, Savannah River	U^{238}	3,002	99.9956
Oak Ridge National Laboratory	U^{238}	15,000	99.994
General Electric Research Laboratory	U^{238}	1,000	99.992
Westinghouse Electric Corporation	U^{238}	28,877	99.992
Naval Research Laboratory	U^{238}	20	99.45
University of California Radiation Laboratory	Th^{230}	109	87.65

A PROPOSED PACKAGE REACTOR[1]

The preliminary design of a 10-megawatt pressurized-water package reactor power plant has been completed, and a preliminary report will be issued in the near future. The reactor was designed to supply both heat and electric loads for a military application such as an AC and W station (a radar station for aircraft control and warning). This reactor will not compete with conventional small plants in the United States, but as a power producer for a remote location it may become competitive because of the logistic effort required to supply a conventional station. Estimates for construction and operation of the plant at a location similar to Oak Ridge have been prepared; an independent organization will estimate the cost of such a plant at a remote location. The results of this study are expected to indicate the economic feasibility of the plant as a power producer in isolated areas.

This package reactor is only one of several which have been studied at this laboratory and by private organizations. An analysis of the various reactor types indicated that the type chosen for study would require a minimum of developmental effort before a reliable plant could be constructed. It is anticipated that the first pilot plant could be in operation within 18 to 24 months, depending on the urgency attached to the project.

[1]Personnel from the following divisions of ORNL participated in the design: the Electronuclear Division, the Reactor Experimental Engineering Division and the Research Director's Division. Personnel from the following outside organizations also were part of the design group: the American Machine and Foundry Company, the Bendix Aviation Corporation, and the Corps of Engineers, U.S.A.

ABRIDGED SUMMARY OF DESIGN SPECIFICATIONS

Over-all Plant Performance

Thermal power developed in reactor, kw	10,000
Electric power generated, kw	1,300
Net electric power delivered, kw	1,000
Steam heat load delivered, kw	3,535
Btu/hr	12,065,000
Over-all thermal efficiency, %	45.4
Thermal efficiency of net electric power generation, %	15.5
Power density of reactor core, kw/liter	57.2
Core life before refueling, megawatt-years	30

Core

Average diameter, in.	22.0
Height, in.	22.0
Uranium content of new core, kg (93.5% U^{235})	37.4
Reactivity (new, cold, clean core), %	7
Maximum reactivity during operating period (hot), %	8.4
(cold), %	15.2
Neutron flux (average, thermal), $cm^{-2} \cdot sec^{-1}$	5×10^{12}
Reflector thickness (water), in.	7

Fuel Plates

Type of plates: rectangular, flat UO_2-Fe-B_4C core clad in type 304L stainless steel

Geometry of plates	Fuel Section	Over-all
Thickness, in.	0.020	0.030
Width, in.	2.500	2.760
Length, in.	22.00	23.0

Stainless steel cladding	
Thickness, in.	0.005
Spacing between plates, in.	0.134
Composition of fuel section of plates	
UO_2, wt %	34.221
Fe, wt %	65.302
B_4C, wt %	0.477
Fuel plates per subassembly	18
Number of subassemblies	40
Number of control rod subassemblies	5
Total number of fuel plates	800

PLANT OPERATION

The way in which nuclear heat is transformed into steam and electric power in this reactor power plant will be best understood by referring to the flow diagram (Fig. 3). The plant is composed essentially of two main cycles: the primary-coolant cycle (Fig. 4) which consists of the reactor core, heat exchanger, and main coolant pumps and the steam cycle (Fig. 5) in which the heat exchanger, steam turbine, and feed water pumps are located. Auxiliary circuits consist of the primary-coolant purification system, the evaporator system, the turbine-condenser cooling system, and the pressurizer system.

The Primary-Coolant System

The primary coolant (H_2O) leaves the reactor vessel (Fig. 6) at the rate of 4000 gpm at 450°F and passes through the tube side of the heat exchanger. The coolant is then returned to the reactor vessel at a temperature of 432°F. The coolant system is pressurized to 1200 psia to prevent boiling in the reactor core and yet to permit a temperature high enough to generate 200-psia steam in the secondary system. Pressurizing is accomplished by electric heaters in the pressurizer tank. Make-up water for the primary system is supplied from the steam cycle, passes through a demineralizer and filter, and is then stored in a tank. The make-up is then injected into the system through the control-rod seals by means of high-pressure pumps. Appropriate instrumentation for the monitoring and control of the system is as shown on the flow diagram.

The Steam System

Steam is generated in the secondary side of the heat exchanger at 200 psia under full-load conditions. It passes through a regulating valve to the turbine and is then condensed in the turbine condenser. The condensate is returned through pumps to the deaerating, feed-water heater. Make-up water from the evaporator enters the cycle through the deaerator. The condensate is then returned to the heat exchanger by the feed-water pumps. The turbine condenser is cooled by water circulating through air coolers in a closed system.

The steam for the heating load is extracted in parallel with the turbine load and passes through a pressure-reducing valve to the unit heaters for the building. The condensate is then returned to the steam cycle through a storage tank and pumps.

THE CONTROL SYSTEM

The control circuit is designed to match the power level of the reactor to the demand level of the load and to maintain that level. This is accomplished by maintaining the temperature of the primary cooling water flowing from the pressure vessel at an approximately constant value of 450°F. The value of 450°F for the hot-leg temperature of the primary-coolant water at a pressure of 1200 psia was determined as a maximum safe temperature; this allows for a 20°F rise in temperature before boiling could occur at hot-spot regions in the core. The maintenance of the primary-coolant temperature at 450°F may be considered as the basic function of the automatic control system.

The control system (Fig. 7) functions as follows: An increase in load demand results in more steam flow and in a lower steam temperature; this tends to lower the primary-coolant temperature and results in a demand for an increase in reactor power. The lower hot-leg temperature as indicated on the recorder effects a rotation of the motor-driven demand-level potentiometer, which results in a

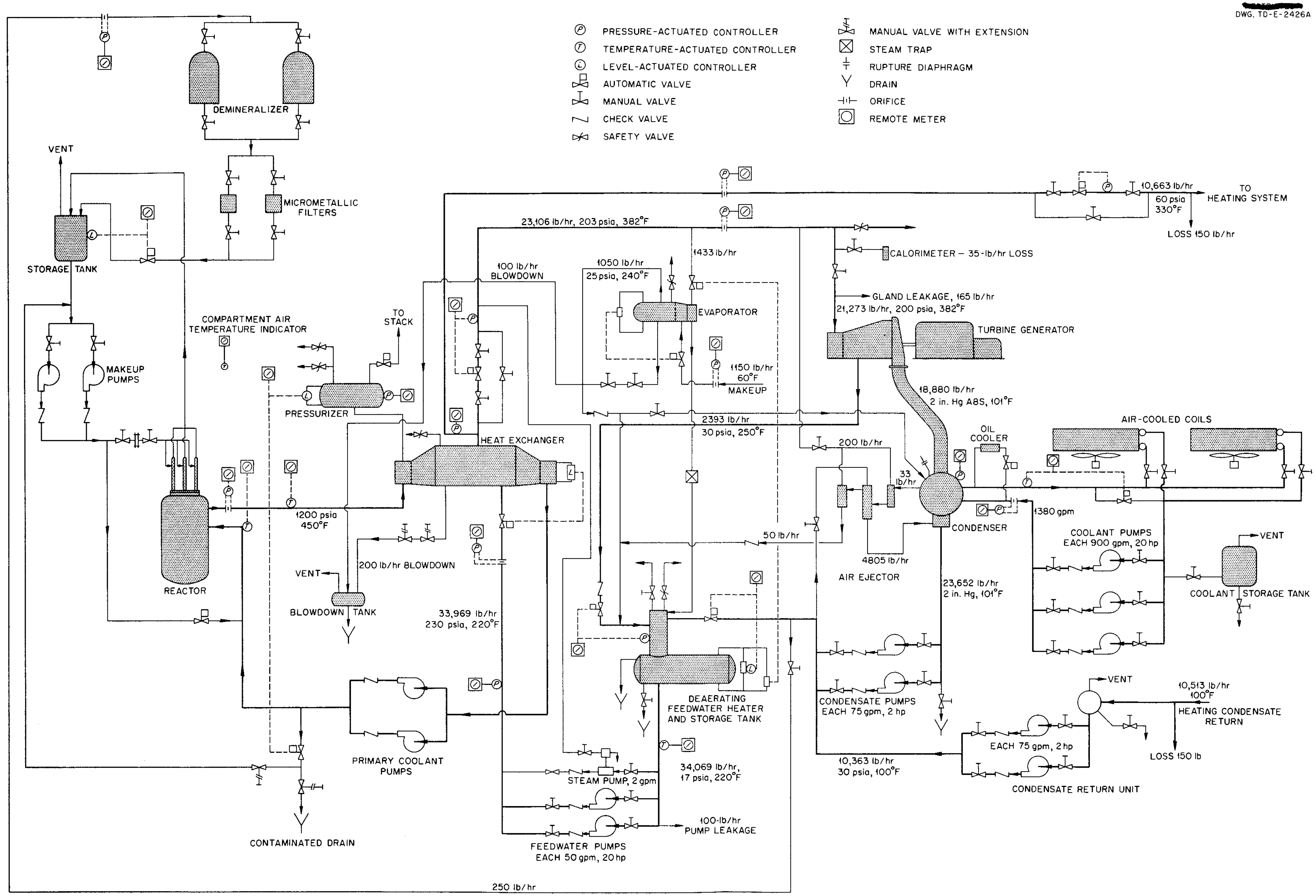


Fig. 3. Flow Diagram.

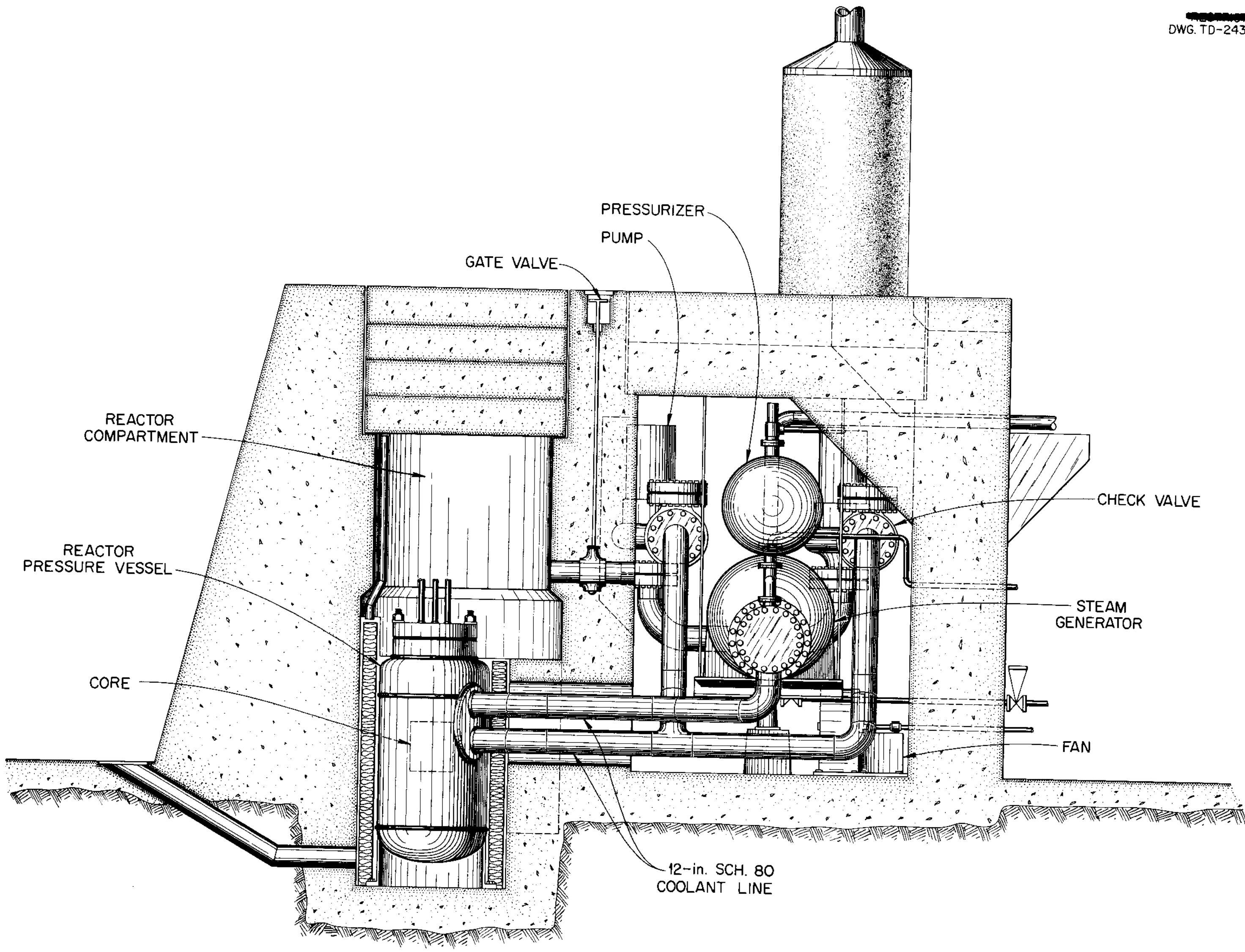


Fig. 4. Primary-Coolant System, Equipment Layout, Vertical Section.

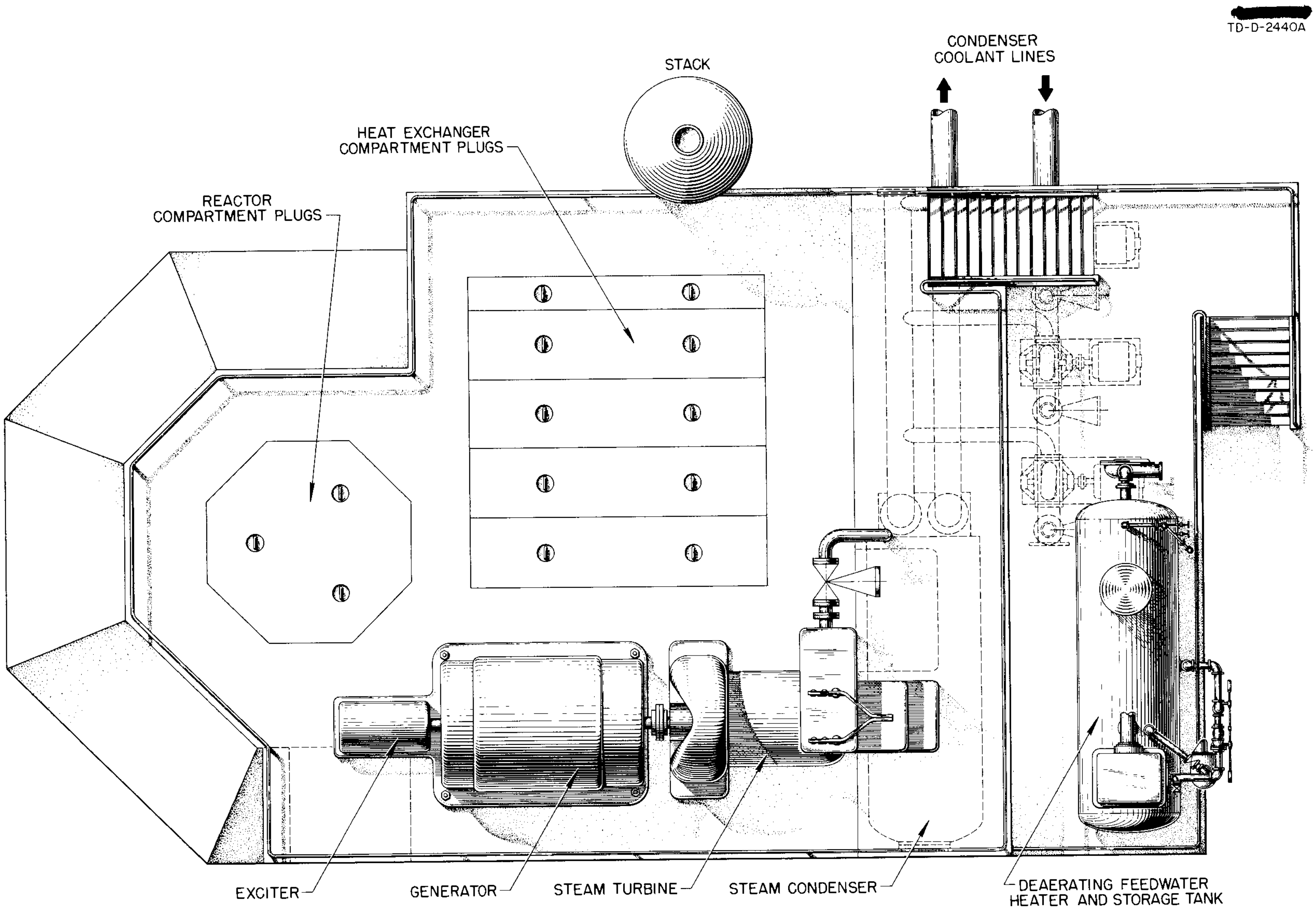


Fig. 5. Steam and Auxiliary Equipment, Plan View.

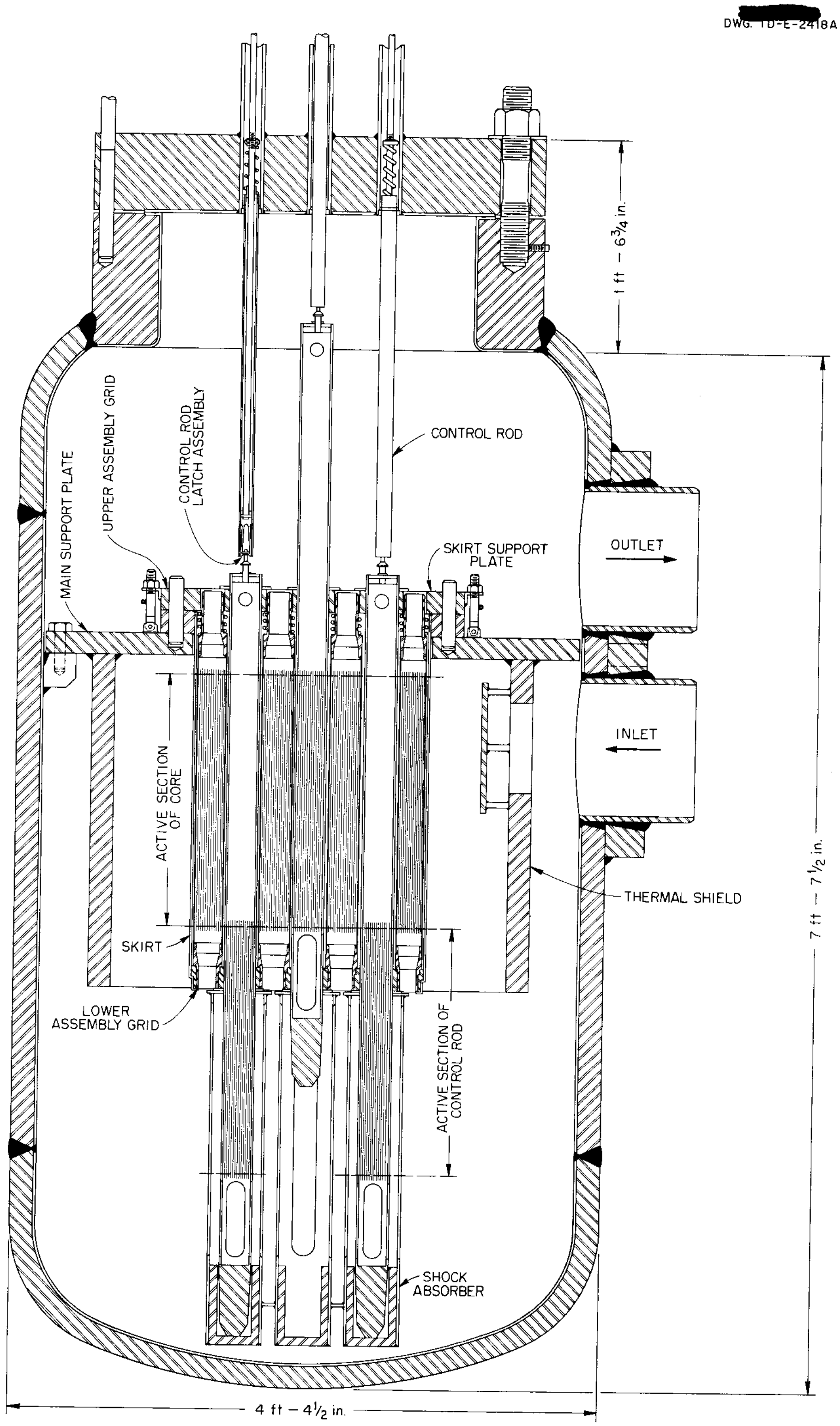


Fig. 6. Pressure Vessel and Reactor Assembly.

signal to the servo-system for withdrawal of the regulating rod; this increases the reactor power level until equilibrium is again established at a primary-coolant temperature of 450°F. A lower load demand would, of course, cause insertion of the regulating rod and would lower the reactor power level to match the new load conditions. A small range of temperature-level settings is provided by a potentiometer network in the temperature recorder. The demand-level network can be set to any predetermined maximum-power level.

A signal that is proportional to neutron flux in the reactor, as measured by an ionization chamber (PCP), is also fed into the demand-level network. If the reactor power level represented by the neutron-flux level exceeds the maximum setting of the network, the servo-system inserts the regulating rod and lowers the power level. The temperature is, therefore, the main controlling element until the maximum power setting is reached, at which time the neutron-flux level becomes the controlling factor and overrides the temperature signal. Such a system will prevent the occurrence of high power excursions of the reactor when the power level is being changed.

Reactor control simulator tests are now in progress; the result of the tests will determine the stability of the reactor and will indicate which additional control features are necessary, if any.

CONSTRUCTION AND OPERATING COSTS

All major components were engineered sufficiently to enable several reliable manufacturers to quote construction costs. The costs shown are believed to be realistic for construction at a developed site similar to Oak Ridge. An additional research and development fee of roughly one-half million dollars would probably be required for the first reactor plant. The major component costs including installation are listed below:

Reactor	$ 148,000
Primary coolant system	357,000
Steam system	171,000
Main condenser cooling system	61,500
Evaporator system	22,000
Primary coolant purification system	32,000
Pressurizer system	40,500
Instrumentation and controls	120,500
Electrical systems	82,000
Building	260,000
Shielding	70,500
Miscellaneous equipment	42,000
Contingencies, 10%	140,700
Engineering, 10%	155,300
Total cost	$1,703,000

A summary of estimated costs follows:

Plant construction costs	$1,703,000
Installed plant cost, per kilowatt	
Electric	$936
Steam	$216
Operating costs, per kilowatt-hour (70% average load)	
Electric	5.52 cents
Steam	1.37 cents
Operating costs, per kilowatt-hour (100% average load)	
Electric	4.21 cents
Steam	0.94 cent

DEVELOPMENT PROBLEMS

This study was undertaken for evaluating the cost and feasibility of designing and constructing a small power plant which would afford the greatest immediate chance for success and a minimum developmental effort. The design has been sufficiently detailed to give a reasonable, reliable cost estimate. The developmental effort required would primarily consist of the following items:

Corrosion Problem. More information is needed concerning the magnetic iron oxide deposits that were found on fuel plates in the stainless steel system of the STR. The present effort being devoted by other laboratories to this problem should supply the necessary information.

Critical Experiments. Additional information is needed on the fuel loading and the effectiveness of the shim-safety system. The flux distribution should be known more accurately, since it directly affects fuel-element hot spots which produce boiling of the coolant.

Fuel Assemblies. Work is now under way on techniques for fabricating the fuel elements. A fuel assembly should be tested in a reactor loop.

Control-Rod Mechanisms. Additional studies should be made on the kinetics on the reactor-control loop. Simulator studies are now under way.

The investigation of the above problems would undoubtedly result in some design changes; however, it is not considered likely that the feasibility or cost of the plant would be affected appreciably.

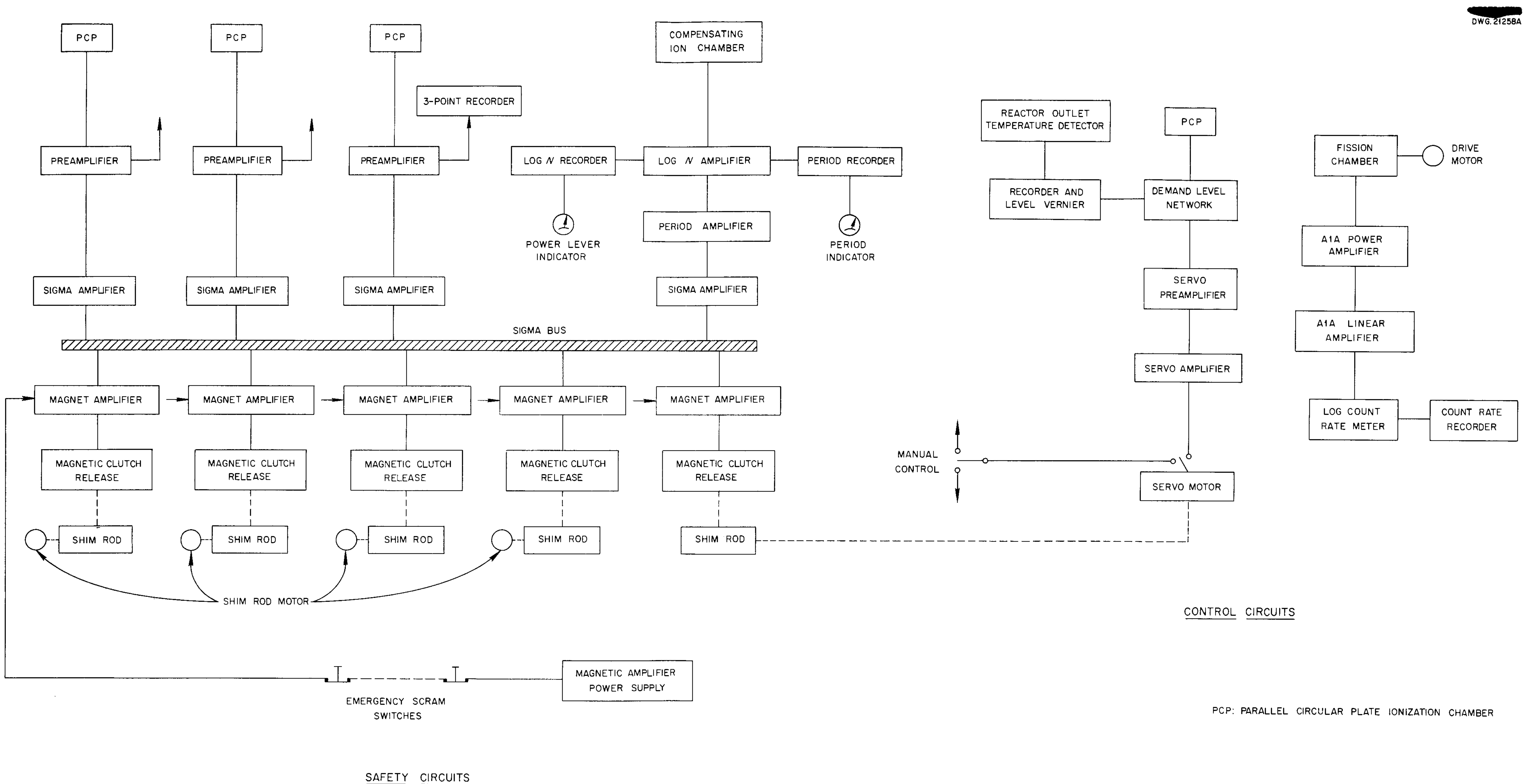


Fig. 7. Package Reactor Control System.

[redacted]

THE APOTRON

A total ion (lithium) current in excess of 6 amp was obtained in an apotron with only three arcs in operation. It was found that the number of arcs that can be operated successfully at one time is affected by the Cl^+ beams. When this beam strikes on or near an adjacent unit, local high-pressure and unstable conditions result which make high-output operation of the six-unit apotron impossible. Three units were operated successfully and it appears that, with proper spacing, four or five units could be operated.

Progress has been made toward simplification and stabilization of operation. A new rigid system of mounting the units has eliminated the need for accelerating-slit adjustments. Electrons were injected into the beam plasma from a barium oxide coating on the baffles which define the beam. A high rate of water flow through the collectors, 200 gpm at 90 psi, makes it possible to dissipate as much as 60 kw over long periods of time with no evidence of wear.

OPERATION SUMMARY

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

Special separations	64
Electromagnetic fundamentals	146
Electronuclear machines	21
The 86-in. cyclotron	444
The 63-in. cyclotron	141
The apotron	50

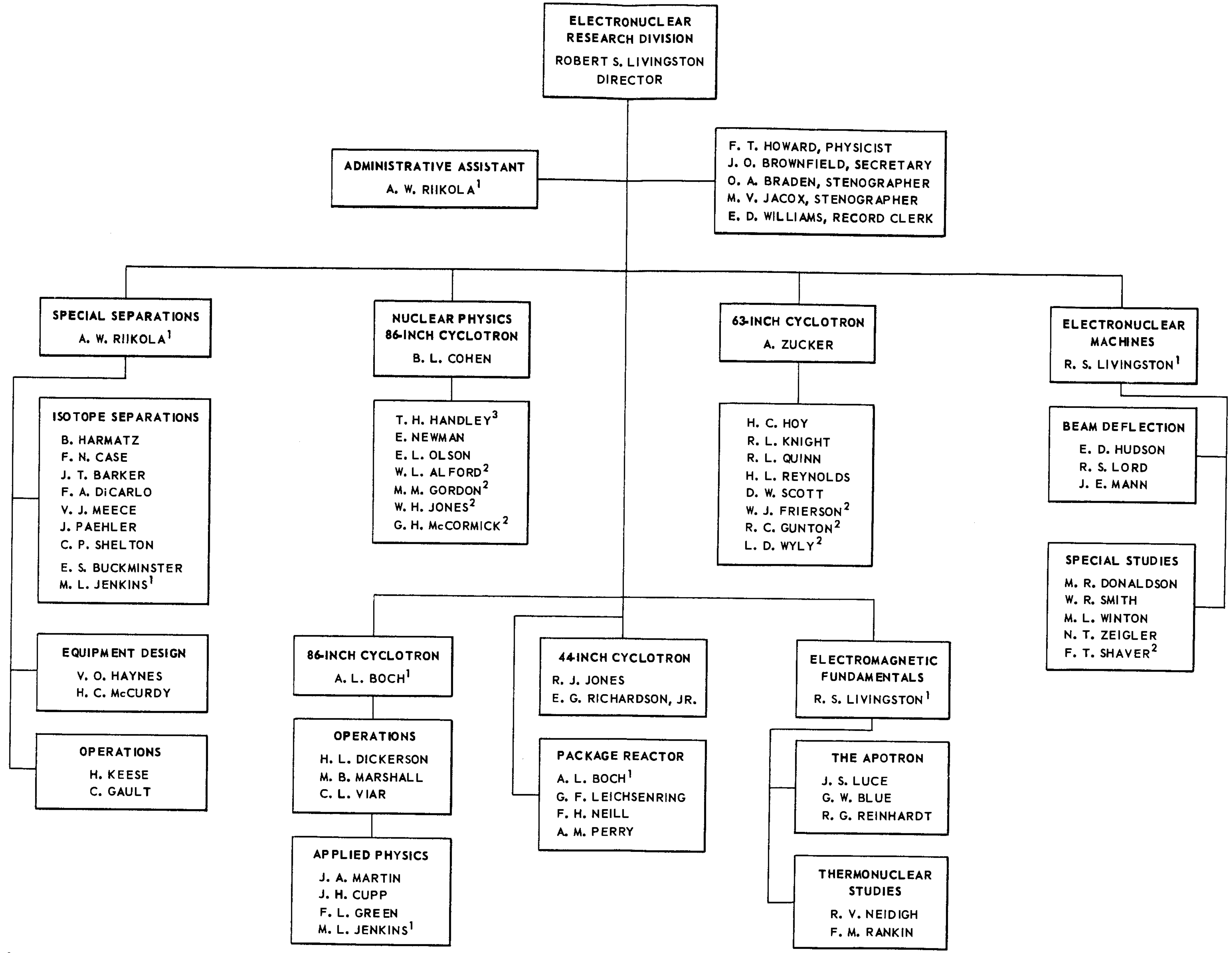
The distribution of shop time charged to each of the various projects is given in Table 3.

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

TABLE 3. TIME DISTRIBUTION – MECHANICAL SERVICE AND MACHINE SHOPS, MARCH 20 THROUGH SEPTEMBER 20, 1953

ACCOUNT NUMBER AND PROJECT	MECHANICAL SERVICE		MACHINE SHOP			
			Carbon		Metal	
	Hours	Per Cent of Total Time	Hours	Per Cent of Total Time	Hours	Per Cent of Total Time
33 Special separations	1,617.8	10.5	1079.5	55.4	253.0	7.6
34 86-in. cyclotron applied physics	926.8	6.0			48.0	1.5
35 86-in. cyclotron operations	3,464.0	22.4	36.0	1.9	259.0	7.8
36 Fundamental electronuclear research	3,764.0	24.3	575.0	29.5	986.0	29.8
37 Electronuclear machines	1,553.3	10.0	32.0	1.6	321.0	9.7
39 86-in. cyclotron nuclear physics	248.0	1.6			137.0	4.1
40 63-in. cyclotron physics	1,064.7	6.9	124.0	6.4	396.0	12.0
41 63-in. cyclotron operations	982.5	6.4	26.0	1.3	404.0	12.2
42 Apotron development	1,274.5	8.2	71.0	3.7	124.0	3.8
43 Package reactor	16.0	0.1				
44 44-in. cyclotron	498.7	3.2	4.0	0.2	381.0	11.5
1 Building maintenance	62.0	0.4				
Total	15,472.3	100.0	1947.5	100.0	3309.0	100.0

[redacted]



[1]Dual capacity
[2]Research participant
[3]On loan from Analytical Chemistry Division

Personnel: Monthly 41
Weekly 11
52