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UNIVERSITY OF CALIFORNIA
RADIATION LABORATORY

Progress Report for 1947
Contract No. W-7405-Eng-48

November 28, 1947

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SURVEY OF ACHIEVEMENTS IN 1947

by D. M. Wilkes

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Introduction

The year 1947 has witnessed the dawn of a new era of atomic science, a flowering of fundamental knowledge of the nature of matter which appears to be unsurpassed even by that period of the 1930's which led to the age of plutonium.

A great new cyclotron, an atom-smasher ten times more powerful than the one which brought plutonium into the world, has carried mankind over a new horizon of sub-atomic space. It has brought scientists at last to grips with the infinitely small and rapid forces, until now beyond reach, which operate within the incredibly tiny distances of nuclear space.

On the new energy frontier created by the giant machine, new laws govern nuclear reactions. Methods are at hand, heretofore unavailable, which permit the measurement and determination of the nature of sub-atomic forces. Under ultra-high energy bombardment, the nucleus presents a different appearance from the nucleus of Bohr and Rutherford, the nucleus of atomic energy fission.

The new exploration of the atom has been sponsored by the Atomic Energy Commission with the giant, new 4000-ton cyclotron in the Radiation Laboratory of the University of California. This is the third major machine built by the Director of the Laboratory and inventor of the cyclotron, Professor Ernest O. Lawrence.

Whether the new knowledge will be of immediate practical consequence cannot now be predicted. Nor could Professor Lawrence predict, when in 1934 he established a new atomic energy range for that day with his first cyclotron, that the fundamental knowledge he pursued would be climaxed with the discovery of plutonium. What can be predicted is this: without the new basic knowledge, practical atomic developments of the future would be limited to the applicability of the fundamental information which made possible the initial release of atomic energy. In short, the nation's atomic potential has been greatly expanded.

These investigations of the nature of the atom by no means tell the whole story of the broad research program which the Commission sponsored during the past year at the Radiation Laboratory. The discovery of 100 or more artificially radioactive elements has been brought within reach. The synthetic element 96, curium, has been isolated for the first time. Fission in five elements below the radioactive series has been achieved. A method has been devised for decontaminating the "hot ships" made radioactive at Bikini Lagoon. In biological research, the metabolic studies fundamental to any eventual practical method of treating or mitigating the effects of radiation poisoning have been done,

and a foundation has been laid in devising tests for the early detection of radiation damage and for the eventual restoration of damaged tissue. The year has brought greater understanding, through the use of radioactive carbon, of photosynthesis, the process whereby plants produce the world's food. The synthesis with radioactive carbon of 50 organic compounds, invaluable in spying out new information about disease, in solving innumerable agricultural and other scientific problems, has been accomplished. And these are only a few of the high spots.

Possibly of even greater importance than any of these achievements has been the training of young scientists. The nation has a great deficit in atomic manpower. The University of California is making up its share of this deficit in no small measure through the research facilities and grants made available to it by the Atomic Energy Commission. Training in every phase of atomic science -- physics, chemistry, the biological sciences -- is being stimulated under the Commission's program.

The following is a brief summary of research progress under the Atomic Energy Commission program in 1947 at the University of California:

The Giant Cyclotron

This 4000-ton machine, constructed from an original grant of the Rockefeller Foundation, is the most powerful atom-smasher in the world. Its magnet was completed in 1942, and was immediately devoted to the development of the process of electro-magnetic separation of U-235, adopted on a large scale at Oak Ridge. Toward the end of the war its reconversion to its original purpose as a cyclotron was started, with the assistance of the Manhattan District. Completed late in 1946, it has been operating for the past year under the auspices of the Atomic Energy Commission.

Particles Accelerated to New High Energies

The great cyclotron accelerated four kinds of atomic projectiles, each of which makes it possible to learn something different about the atom. The four types of particles and the energies to which they are accelerated are:

Deuterons, the nuclei of heavy hydrogen atoms, of 200 million electron volts. (An atom of lead traveling 2000 miles per hour has the energy of one electron volt.)

Neutrons, which trigger the atomic bomb and are a basic nuclear particle, of 100 million electron volts.

Protons, the nuclei of ordinary hydrogen atoms and a basic nuclear particle, of 100 million electron volts.

Alpha particles, the nuclei of helium atoms, of 400 million electron volts.

In each instance, the energies achieved are about 10 times or more energetic than the particles accelerated in the previous most powerful cyclotron, the 225-ton machine at the University of California.

What is the object of accelerating these nuclear particles to such huge energies? It is simply that the harder nuclear particles can be knocked together, the more can be learned about atomic processes. The atoms themselves cannot be seen, of course. But the effect of knocking particles together can be recorded both photographically and by a large number of delicate instruments. From these observed effects, scientists deduce the nature of unbelievably transitory events occurring within the infinitely small spaces (a nucleus is about 10 trillionths of a centimeter in diameter) of the sub-atomic world.

Determination of the Nature of Nuclear Forces

For example, the great cyclotron demonstrated for the first time that, in addition to ordinary mechanical forces of motion, there is another force operating between the particles of the atomic nucleus which is unlike any

other known on earth. This is called an "exchange force", and it demonstrates that the electrical charge is constantly tossed back and forth among the particles in a nucleus, thus setting up a balance which enables these particles to be held together in the tight, hard nuclear core.

The Nucleus Becomes Transparent

Other experiments have permitted the Berkeley scientists to draw a picture of the atom under high energy bombardment radically different from the atom known to scientists when they first achieved fission. The "new" nucleus appears to be "soft" and to have space between the nuclear particles, particularly at the edges, which was not found in lower energy bombardments. Thus the laws which governed the nucleus of Rutherford and Bohr do not work in the energy range created by the giant cyclotron.

Laboratory Cosmic Rays

Another result of the operation of this atom-smasher has been the duplication for the first time in the laboratory of lower energy cosmic ray phenomena. These phenomena for years have been photographed in cloud chambers by scientists who often take their equipment to mountain tops, frequently taking thousands of photographs in order to obtain one of any value. No machine can yet create high energy cosmic rays, in the billion volt energy range. But the giant cyclotron, at the very bottom of the range of these high energy particles, is like a cosmic ray hose when its beam is aimed at a cloud chamber. "Stars", the flying apart of atomic nuclei in high energy disintegrations characteristic of cosmic rays, and other cosmic ray phenomena have thus been created at will by this cyclotron beam. These studies are of critical importance in finding new information in the high energy range.

Massive Disintegrations Achieved

A new chapter in the transmutation of elements is being written in the bombardments with the high energy beams of deuterons, neutrons and alpha-particles. Pre-war cyclotrons usually were able to knock two or three particles out of the nucleus, transmuting elements one or two steps up or down the periodic table. The great cyclotron is able to knock as many as 30 particles out of a nucleus, transmuting an element as much as 16 steps down the periodic table. As many as 30 different radioactive elements may be produced as the result of a single bombardment. A hundred or more new radioelements, many of which should be useful for "tracer" studies in biology, medicine, and chemistry, will result from these massive disintegrations, for which a new word, "spallation", has been invented.

Fission Produced in Five more Elements

The ultra high energy particles from the big atom-smasher have produced fission, the reaction which in plutonium and uranium creates the atomic bomb explosion, in five lighter elements; tantalum (element 73); bismuth (element 83); lead (element 82); thallium (element 81) and platinum, (element 78).

Fission of the explosive type, however, cannot be created in these elements, the research had demonstrated, because the chain reaction cannot be sustained. This research has demonstrated that the lighter elements cannot be used in atomic bombs, at least not in any way now known. Only a machine of this great power could create fission in the lighter elements.

The 225-ton Cyclotron

The 225-ton cyclotron in the Radiation Laboratory, with which neptunium, plutonium, americium, and curium have been discovered, has been operated during the past year on a 24-hour day, seven day week basis. Ninety percent of this time has been devoted to bombardments for the Commission's projects at Berkeley and Oak Ridge. This workhorse of the atomic research program, second most powerful cyclotron in the world, has been producing in the past year radioactive isotopes which cannot be made in the atomic piles.

Isolation of Curium

One of the chief chemical achievements has been the isolation for the first time in pure form of the new synthetic element 96, curium. Curium, the heaviest substance known to man, is one of the four transuranic elements discovered with the University's 225-ton cyclotron. The isolation of curium was even more difficult than the isolation of plutonium, accomplished also in the Berkeley laboratory, because of its higher radioactivity and the smaller quantity in which it could be obtained. The curium isolated, smaller than a grain of sand, is being used for studies of its chemical structure and characteristics.

Medicine, Biology and Health Physics

Research by several groups of scientists at the University of California in the fields of biology, medicine, and health physics has been directed toward obtaining precise knowledge about the biological effects on man of the radiations unleashed by the atomic age. The elimination of guesswork in this field is of critical importance for two reasons: 1) scientists and workers must be protected against the new radiations with which they must work, both in atomic production and in pure research; 2) every effort must be made to devise means of defense against and mitigation of biological effects of radiation in case of atomic conflict.

Noteworthy progress has been made in some of the problems in this field, which is possibly the most difficult in atomic science. Only a beginning has been made in other instances.

Decontamination of Naval Vessels

An outstanding accomplishment during the year 1947 was the development by University of California scientists of a satisfactory and practical method of decontaminating Naval vessels made uninhabitable by their accumulation of radioactivity in the underwater Bikini atomic bomb explosion. The chief problem here has been to eliminate the radioactivity

imbedded in the rust and barnacles in the ships' salt water lines. In brief, the solution involved flushing of the salt water lines in the vessels with a mixture of hydrochloric and citric acids. These acids dissolve out the rust and the barnacles, containing plutonium and the fission products. Nearly all Bikini vessels are decontaminated and inhabitable as a result.

Metabolism and Fission.

During 1947, a group of biological researchers continued their studies of the metabolism in the body of the fissionable elements and the fission products which result from atomic explosion. Many of these substances, when they get into the body through the mouth, lungs or scratches on the body surface, are extremely dangerous and carry the possibility of fatal consequences. Their action is similar to that of radium, and the deaths from radium poisoning early in the century are well known. No satisfactory method has ever been devised to treat radium poisoning, the only defense being to prevent its entrance into the body. But this is not enough in the atomic age, for the dangers are many fold greater. About one kilogram of radium, which has about 1000 curies of radioactivity, has been isolated in the last 50 years. In contrast, kilogram quantities of plutonium are manufactured in the Hanford piles alone; and comparable masses of fission products are also produced. The radioactivity produced, in complicated processes in which thousands of workers are involved, is in the range of millions of curies. The possible uses of these materials in a sort of atomic biological warfare have been widely discussed.

In 1947, a group of University of California scientists determined the biological action in animals of the fission products, astatine, element 61, silver, cadmium, indium and antimony; and of the fissionable elements, actinium, americium and curium. This work was a continuation of earlier studies of plutonium and a large number of fission products.

The most significant finding of the researchers was that many of the highly radioactive group of elements studied are deposited in a thin layer of tissue, called the osteoid matrix, adjacent to the bone marrow cavity, where red blood cells are manufactured. The body has no means of ridding itself of these elements, once they are deposited in the bone. Plutonium, americium and curium and many of the fission products are included among those elements deposited in the osteoid matrix where their radiations, inhibiting the formation of red blood cells, presumably would cause death.

Attempts to Treat Radiation Poisoning

With this basic knowledge of the metabolic characteristics of the fissionable elements and the fission products, a group of University of California scientists have set to work to devise artificial means of eliminating these substances from the body. Attempts to remove them by the use of BAL (British Anti-Lewisite), cystein, a sulfur containing amino acid, and zirconium citrate, have not met with significant success. However, these studies have demonstrated some fundamental differences between ordinary mineral metabolism and the metabolism of these elements in the bone structure.

This information will be of inestimable value in continuing the search for methods of treating radiation poisoning.

Detection of Radiation Damage

Another biological problem has been the study of possible methods for the early detection of radiation damage to tissue. Radiation causes changes in the blood, and a good start has been made in determining whether these changes have occurred, both by electrical tests of blood and by examination of blood cells under the microscope.

Restoration of Damaged Tissue

The possibility of restoring bone marrow which has been damaged by radiation is also being studied. At present the only way of combating the anemias suffered in this condition is by the indefinite continuation of blood transfusions. This is not a satisfactory method. A group of University of California researchers have started experiments toward the end that the body may once again be able to produce its own blood cells. They have concentrated on the experimental transplantation of marrow in animals. Successful transplants have been made into rat livers, where transplants grew freely, protected by a layer of bone forming around them. This encouraging research will be continued.

Fission in Tissue.

In another series of experiments, mice with uranium injected into them have been placed near the Oak Ridge piles by a group of University of California scientists to determine the biological effect of fission in tissue.

Radiations from the Giant Cyclotron.

Still another area of research has involved experiments on the biological effect of the enormous energies of the particles accelerated in the giant cyclotron. These researches are designed to determine what, if any, differences there are in the biological effect of these radiations from lower energy radiations. Protection of the staff at Berkeley and at other laboratories where such high energy particles will be accelerated in the future is the primary object of these experiments.

Synthesis of Organic Compounds.

Everyone knows that the radiations emitted by the artificially radioactive elements make these substances useful as "tracers" in seeking out hidden processes in experiments in biology, chemistry, medicine, agricultural science, and other fields of research. In this regard artificially radioactive substances, which are manufactured in the atomic piles and in cyclotrons, have been likened to the microscope. This quality of radioactivity has greatly expanded the possibilities of scientific research.

But before these substances can be used in such research, they must be built into ordinary organic compounds which are used by the body or by plants or animals. The synthesis of such compounds has been one of the tasks of a group of scientists in the University's Radiation Laboratory.

During 1947 this group synthesized 12 major compounds, including the amino acids, glycine, tryptophane, and tyrosine, and related substances. These substances have been put to use in cancer research.

Tracer studies with another major substance synthesized, dibenzanthracene, a cancer-causing compound found in coal-tar, yielded new information about the metabolism of this substance in the body.

Another compound synthesized at Berkeley with radioactive atoms, methanol, a basic substance for producing other compounds, is now being produced by the Berkeley method on a commercial scale by both the Eastman Company and Atomic Energy Commission at Oak Ridge.

Photosynthesis.

An understanding of photosynthesis, the process whereby green plants manufacture sugar, starches and all of the other energy food of the earth, would be an inestimable boon to mankind. Such an understanding might enable scientists to increase the efficiency of the photosynthetic process by from 10 to 20 percent, thereby increasing the world's food supply by the same percentage.

Man has a clearer insight into the photosynthetic process as a result of research done with carbon 14 at the University of California Radiation Laboratory during the past year. The starches and other energy foods are manufactured by plants from sunlight, water and carbon dioxide.

In the Berkeley experiments, plants were allowed to carry on photosynthesis in the presence of radioactive carbon dioxide. At different time intervals, plants were analyzed to determine what had happened to the "tagged" carbon dioxide. The carbon was found in a number of organic substances, intermediate compounds between the raw materials of photosynthesis and the finished product -- the starches and carbohydrates. These intermediates include amino, succinic, fumaric and malic acids and other basic organic substances. Scientists had predicted that some of these substances should be formed, but had no way of telling definitely until carbon 14 became available. Further, the scientists at Berkeley were able to draw a step-by-step route by which these intermediates were transformed into sugars and starches. There are still some gaps, but our area of knowledge has been greatly enlarged by these researches of the past year.

This research, incidentally, resulted in the first synthesis of radioactive sugar, which is expected to be invaluable in seeking out metabolic processes of the body, such as those found in diabetes.

Construction

Major construction at the University of California during 1947 has centered about two new types of atom-smashers, the synchrotron and the linear accelerator, both of which were started under the sponsorship of the Manhattan District. These machines were designed to do atom-smashing jobs different from those accomplished by the giant cyclotron.

Linear Accelerator.

The linear accelerator is a cannon-like atom-smasher, 40 feet long, which was constructed as an experimental machine to explore the possibility of building an instrument of this type to accelerate protons in the billion volt energy range. This machine was recently completed, producing protons of 32 million electron volts, the energy for which it was designed. The machine does not yet operate efficiently at this energy, though it is expected that further work will increase its efficiency. Since construction was started on this machine two years ago, an easier and less expensive atom-smasher known as the Bevatron has been designed to accelerate protons to the multi-billion volt range. The present linear accelerator is expected to be an efficient and useful tool for atomic research in the energy range for which it was designed, though plans for a larger machine have been dropped.

Synchrotron.

The synchrotron is an atom-smashing machine based on an idea developed at the end of the war simultaneously by an American scientist, Professor Edwin M. McMillan, of the University of California, and a Russian physicist. It may be described as the "scalpel" of atom-smashing. The Berkeley synchrotron will accelerate electrons to energies of 300 million electron volts, the most potent particles of this type ever produced by man. The electron is about two thousand times lighter than the lightest particle accelerated in the giant cyclotron. The synchrotron will provide information different from that obtained by the giant cyclotron. It will produce a different type of cosmic ray than does the great cyclotron. The possible fruits of research with this machine are rich and varied. For example, if it is possible to split the particles of the nucleus now considered to be indivisible - - the neutron and the proton - - the light, ultra-high energy particles of the synchrotron should do it. Design and construction of the synchrotron was started nearly two years ago. Because of the difficulties in obtaining the materials for this machine, construction has lagged behind schedule. However, it is about 80 percent complete, and should be in operation by May, 1948.

The Future

The Production of Mesotrons.

While the great cyclotron has crossed into a new domain of the atom, and insured the continuation of American leadership in atomic research for the time being, new horizons of the nucleus still loom ahead.

Within almost immediate reach is the creation in the laboratory of mesotrons, the ephemeral, elusive atomic particles which are one of the types of cosmic rays. Mesotrons, which possess greater energy than any other piece of matter yet observed by man and have a lifespan of about a millionth of a second, are intimately tied up with the force which holds the atomic nucleus together. Wherever scientists have been able to observe the violent disintegration of nuclei, they have found mesotrons emerging from the break-up. Their production would mean the unleashing in the laboratory of that ultimate, sub-atomic binding force which holds the nucleus together and which is being probed by indirect means with the giant cyclotron. This force could be studied and measured, with what implications no man can now say.

Toward the end that mesotrons may be created, research has been conducted during the past year which will make possible the modification of the giant 4000-ton cyclotron so that it will produce protons of 350 million electron volts. Physicists calculate that protons of this energy will produce mesotrons. Remodeling of the giant cyclotron has already started, and it will begin accelerating the ultra-high energy protons early in 1948.

A Billion Volt Machine.

That America may continue in the vanguard of atomic research, the experienced scientists and engineers who have already constructed three great cyclotrons at the University of California have solved the theoretical problems of, and designed, a massive atom-smasher, called the "bevatron." This huge machine would accelerate protons to the almost unbelievable energy of six billion electron volts, far into the domain of Nature's cosmic rays. What may be found there is at present impossible to predict. A possibility is the creation of matter out of energy -- a reversal of the atomic energy process of obtaining energy from matter. That the fruit of such a venture will be rich and well worth the effort, no one can deny.

PHYSICS

I. 184-inch Cyclotron Construction, Operation and Development

W. M. Brobeck

A. Previous History

The cyclotron project started in 1940 with funds obtained principally from the University and the Rockefeller Foundation. At the beginning of the war the cyclotron building was completed and the magnet core requiring approximately 4,000 tons of steel had been assembled. The magnet coils still had to be wound. During the Spring of 1942 the magnet coils were wound in the shortest possible time with 24-hour shifts and after their completion in May 1942 the magnet was used almost continuously for work on the Manhattan Project.

At the end of the war, the equipment then being tested was removed and work started on restoring the magnet as required for completion of the cyclotron. This involved removing certain magnet pole plates and placing them in a different position and removing the magnet coil tanks and inspecting the coils. As a result of the hurried work at the beginning of the war certain conditions existed which were obviously undesirable but could not be corrected because of the large amount of effort that would be required. Fortunately these conditions did not seriously interfere with the operation, although they have caused some inconvenience.

The cyclotron completion went ahead at first on the basis of constant oscillator frequency which would require the use of dee voltages on the order of a million volts and oscillator power inputs of a thousand kilowatts to obtain 60-100 Mev deuterium ions. In February of 1946, as a result of the success of the synchrotron principle as tested in the 37-inch cyclotron the design was changed to incorporate frequency modulation to obtain 200 Mev deuterons with the reduction in the oscillator power below 50 kilowatts. Additional apparatus in the form of a rotating variable condenser to produce the frequency modulation was required.

The cyclotron project profited greatly by experience gained during the war years on the Manhattan Project as well as from the increased facilities of the Laboratory. Construction proceeded smoothly with concentration on only the necessary equipment to obtain the high energy beam, and on November 1, 1946, the desired 200 Mev deuteron beam was obtained after less than a week's experimentation. At the end of the year, the cyclotron was being used for many experiments in the activation of target materials with the high energy deuterons and in the study of the emerging neutron beam produced when the deuterons strike the internal target. Operation at full output was limited to approximately five minutes per shift to avoid overexposure of the operators since the shielding was then inadequate and since there were many

minor parts of the machine which were not in a completed condition. A number of temporary changes have been made to overcome difficulties which showed up on the first operation.

B. Construction during 1947.

First in importance in construction work during the year has been protection of personnel. The principal item in this work was the provision of concrete shielding surrounding the cyclotron. A wall consisting of about 80 thirty-ton concrete blocks has been built providing five-foot thickness in a horizontal line and a roof of similar construction two-feet thick. Installation of this shielding required removing the six-inch concrete slab over a large part of the floor area and replacing it with an eighteen-inch reinforced concrete floor. Construction of columns and beams was required to support the shielding wall where it passed over the pit surrounding the magnet and to support the roof. The shielding included railings, ventilation equipment, and sufficient supports to insure against earthquake failure. Two forty-ton concrete doors operated by electric motors providing 6 x 8 feet openings with provision for manual operation in case of power failure were included in the shielding installation. The installation described was completed in March and reduced the radiation intensity outside the shield to a level at which exposure of personnel was negligible. However, the intensity remaining was sufficiently high to interfere the operation of measuring equipment, and since an increase in the cyclotron output was expected and acceleration of higher energy protons was contemplated, construction of a second five-foot thickness of wall and two-foot roof was started. At present about one-third of this second wall and none of the roof has been installed. However, authorization has been obtained for the continuation of this work, and delivery of the remaining blocks is expected to be complete in two or three months.

A second protection program has centered around the handling of the probe targets. Besides the usual long handling hooks and storage receptacles, a probe has been put into service in which the target is blown by compressed air under remote control from its position in the cyclotron tank to a carrying receptacle. A second handling system adaptable to larger targets provides for removing the internal target and depositing it in a truck surrounded by three inches of lead. This equipment can be operated from a distance of about fifteen feet. A large number of target holders of different types have been built for the needs of the experimental program.

The third part of the protection program has been electrical interlocking to prevent any possibility of accidental exposure of personnel to radiation. This takes the form of door switches, warning lights and bells, safety switches that can be operated from inside the shield and automatic shutoff in case the radiation rises beyond the expected level. All equipment is duplicated so that failure of a single part will not interfere with the operation of the protection functions.

A principal line of development which will greatly improve the usefulness of the cyclotron is the deflection of the high energy beam to a point outside

the vacuum chamber. Because of the high beam energy, conventional methods of deflection used on smaller cyclotrons are not applicable and the problem had to be considered on a fundamental basis. The system which evolved during the year consists of an electrostatic deflector designed so that the circulating beam can enter the region between the electrodes before the deflecting field is applied. A power source is used that is capable of supplying a single pulse of 200 kilovolts, balanced with respect to ground, at each frequency modulation cycle. In addition to the electrostatic deflector there is used a magnetic deflecting channel between two iron bars shaped to shield the deflected beam from the main magnetic field. Correcting plates are provided by which the disturbance to the circulating beam produced by the deflecting bars is eliminated. The part of this program requiring the greatest effort was that of producing the rapid high voltage pulse. After many methods were tried a pulse transformer, with a battery of hydrogen thyratrons for control and a low inductance condenser, has been developed which is expected to give satisfactory performance. During the last few months the problem has been one of providing capacity for continuous operation under the high voltage stresses involved. The beam emerges through a port in the cyclotron tank which is covered by an aluminum plate one-eighth inch thick. A focusing magnet weighing about six tons is being installed at the present time to turn the beam through a slight angle and focus it at a point outside of the shielding wall where it will be used for experimental work. The electrostatic section of the deflector occupies 120° of the circumference of the magnet pole and is provided with externally operated mechanical radius adjustments at three points. The magnetic deflector is approximately six feet long and is provided with two externally operated radius adjustments which have sufficient stroke to move the deflector completely clear of the neutron beam leaving the target. These adjustments are not yet provided with controls operable from the cyclotron room. Part of the deflector power supply is the device for controlling the time in the frequency modulation cycle at which the deflector voltage pulse occurs.

A large part of the experimental work with the cyclotron has been done with the beam of high energy neutrons proceeding from the target. In order to collimate this beam, a series of tubes have been built to go between the cyclotron tank wall and the point beyond the concrete shield at which the beam is studied. By the use of this collimating system a beam about two inches in diameter is obtained; the radiation intensity outside of the beam being reduced by the factor of over a thousand from the maximum at the center line. In order to avoid absorption of the beam in measurements in which the angular spread is studied, a window of aluminum one-eighth inch thick and two and one-half feet in diameter has been installed in the wall of the vacuum tank, and for use outside the shielding wall equipment of the optical bench type has been built to study scattering and absorption. A considerable number of counting channels and detecting instruments have been built for use in this work which are described elsewhere.

A number of rather extensive jobs for completion of the cyclotron have also been done. The gas supply and control system providing hydrogen, deuterium or helium to the ion source with flow control from the cyclotron control room has been completed during the year to take the place of the

temporary equipment first installed. This includes an electrolyzer with which deuterium can be generated from heavy water reducing the cost and inconvenience involved in the use of tank deuterium gas. Lighting has been installed inside the shielding at all necessary points. The communication system has been improved and platforms covering most of the work area inside the shielding have been completed. Removal of the XA and XC magnets from the cyclotron building has considerably increased the available floor space.

In addition to the work on the cyclotron itself, the project for conversion of the machine to the acceleration of protons has been actively pursued during the year. When this installation is made, the energy will be increased to 350 Mev. All of this energy will be carried by a single nucleon rather than by the two nucleons as in the deuterium ion which share the present 200 Mev. To accelerate protons a considerably greater change of frequency is required than is the case with deuterons so that the rotary condenser and resonance system in use at present are no longer applicable. First plans were based on the use of rotating condenser plates in the main magnetic field. However, in July a different system of operation was devised which permitted the use of a single rotating condenser outside the magnetic field which avoided the problem of eddy currents in the rotating disks and synchronization of several rotors. Tests of a half-scale radio-frequency model have proceeded for the last four months with very satisfactory results. Mechanical design is well advanced and bids are now being requested for the principal vacuum tank parts required. It is expected that this equipment will be ready for installation early in the summer of 1948.

C. Operation

The cyclotron has been operating from eight A. M. until midnight almost constantly during the year. About sixty percent of this time was spent on useful beam production for experimental work and the set-ups required for the experiments. Twenty percent was spent on the installation of new equipment, completion of the original construction and adjusting and ten percent in repair and trouble shooting. The operating staff consists of a crew of nine operators with a supervisor, assistant and secretary. In addition an average of three electronics technicians, three mechanical technicians and operating engineers are required to work on the machine. In addition about fifteen percent of the laboratory shop and twenty-five percent of the engineering time has been used on the cyclotron during the year.

The output of the cyclotron is monitored by neutron sensitive ionization chambers at an angle of thirty degrees from the line of the main neutron beam. At this point, the radiation runs about 10 r per hour and this figure has been approximately constant during the year. The radiation in the center of the neutron beam is approximately 80 r and the circulating beam approximately one microampere of time average current. The deflected beam measured outside the tank is approximately 2×10^{-9} amperes at the present time. These intensities are more than adequate for the work in progress and no concerted effort has been made to increase the output.

Some experimental work has been done during the year in studying the performance of the cyclotron to obtain data useful in the design of similar machines and to point the way to improvements in performance. It was found that the cyclotron beam can not be accelerated beyond the eighty-two inch radius point due to coupling between vertical and axial oscillations of the orbit which causes the beam to expand vertically and strike the dee. This information has been of great value to other laboratories designing large cyclotrons. Observation of the time structure of the pulse of current reaching the target has shown that a precession of the orbit with an amplitude of one to two inches occurs. This fact is basic to the design of the electrostatic deflector. Measurements of the shape of the magnetic field and the performance characteristic as a function of the various operating parameters have been correlated with the theory of the machine as covered by reports issued and papers prepared by the theoretical group at the Laboratory. These results have had as wide a circulation as possible among the designers of similar machines.

The important scientific results obtained with the cyclotron are not included in this section as they will be discussed elsewhere.

II. 60-Inch Cyclotron

The 60-inch cyclotron has operated quite satisfactorily during most of this year. However, some difficulty was experienced with sparking in the deflector. This was caused by marked erosion of the molybdenum liners that lie within the house enclosing the deflector. To remedy this problem, a set of inserts was designed to be placed in the house in such a way that its disassembly is not required. Thus the sparking trouble was cleared up without the possibility of exposure of the crew to dangerous amounts of induced radioactivity in the deflector. Two shutdowns for major overhauls were necessary. During the second, more adequate cooling was installed on the dee stems and no further trouble has been experienced with them.

High operating efficiencies with alpha-particles have been achieved. Steady currents of eight to ten microamperes are not uncommon and the average is of the order of 5 microamperes per hour.

Several sources for the production of stripped carbon and oxygen atoms have been developed and one source, a double negative P.I.G. (oscillating electron) source, promises gratifying results. Heavy discharges of several kilowatts are produced as compared to arc discharges of 5 to 25 watts. P.I.G. sources have also been used to produce alpha-particle currents at the target, of 2 to 3 microamperes.

Some work has been done on the acceleration of beryllium and boron ions and it is planned to continue it in the near future.

The 60-inch cyclotron has been used for bombardments of a wide variety of elements for other laboratories and for chemists and physicists here.

III Synchrotron Construction Progress Since January 1947

M. Martin

Early in January of this year, work was commenced on the installation of the vacuum header diffusion pumps, mechanical pumps, vacuum valves, and the water and electrical services to them. (Fig. 1) This work was completed and the parts vacuum tested early in 1947. Temporary power was run to the building for this purpose. The wiring of the pumps, their control panels, and circuit breakers, however, was permanent. Other services to the building have been added during the year, including treated water (low conductivity and mineral free), compressed air, gas, and telephones.

The steel base for supporting the 135 ton magnet was installed on its vibration absorbing mounts, and the necessary alignments made. (Fig. 2) The first magnet slabs arrived in May and assembly of the magnet was commenced at that time. The lower yoke has been completely assembled including the lower magnetizing coil, compensating coils, flux bar ties, spacers, and the lower pole base ring. The upright portion at one end of the magnet has been assembled complete with compensating coils. (Figs. 3, 4, 5, 6) The other upright is now in the process of assembly, the parts having arrived recently from the factory. Most of the parts for the upper yoke are on hand, but assembly will not start until they all have been received.

The 40,000 KVA capacitor bank has been completely installed with fuses on each individual capacitor. (Figs 7, 8) The feeders and overhead bus system have been completed and run through the overhead tunnel into the magnet room. (Fig. 9) The electronic contactor and ignitrons have been installed, and the connecting of the control equipment and cooling system is nearly complete. The control desk, cross connect panels, and the racks for miscellaneous control equipment have been installed; and the majority of the switches and instruments inserted and connected. (Figs. 10, 11 and 11a).

The 48 megacycle oscillator was re-designed after tests were completed on the experimental model. The parts for the new oscillator were completed by the shop, and the assembly of the oscillator proper is complete up to the point of connecting it to the resonant system. (Fig. 12) The oscillator power supply has been completed in the shop and is now being installed in the building. (Fig. 13)

The transformer yard, which will supply permanent power to the building, is about 85% complete (Fig. 14); and it is expected that the temporary power service can be removed and the building switched over to the permanent power source on about the first of the year.

Eighty-five pole tip wedges have been completed in the shop, machined, etched, vacuum impregnated and baked, and tested. (Fig. 15) The gaskets have been cemented to the sides of these wedges and ground to provide

the flat surfaces necessary for assembly.

The plastic vacuum chamber walls, pump manifolds, and port covers (Fig.16) were received from the manufacturer and it was found necessary to subject them to further impregnation in order to make them satisfactorily vacuum tight. An impregnation tank was built in our own shop, and the necessary pumps, valves, and heaters were assembled (Fig.17) and an oven rented to permit baking of the large parts. It was found necessary to repeat the vacuum impregnation process several times on the majority of the parts in order to completely eliminate the porosity which existed. At present all parts are tight except the 90 inch diameter outer ring. This part, which was the most difficult to construct, had numerous internal voids which did not communicate with the surface and were, therefore, not filled during the impregnation process. Since many of them were opened during the baking cycle and as a result of the attachment of other equipment, it has been found necessary to develop means of filling the voids individually. This process is not yet perfected and is currently the subject of considerable effort on the part of the technical staff.

A concrete shielding wall (Fig. 18,19), to protect operating personnel from radiation, consisting of a stack of concrete blocks 4 feet thick and 10 feet high has been completed. This wall was constructed of high density concrete blocks (230 pounds per cubic foot) and is adequate to protect personnel during the earlier phases of operation. After radiation measurements are made, additional shielding will be added as required.

Considerable work has been done on injector development. Injectors and power supplies have been built and tested and measurements made of pulse rise time, maximum permissible voltage, and beam divergence. Equipment has been built to outgas injector assemblies by induction heating and to store them in vacuum. A satisfactory pulse transformer (Fig.20) has been designed and built which places a 70 KV pulse in the injector (Fig. 21) with a rise time of less than one microsecond. Injector and target actuating mechanisms consisting of hydraulic cylinders have been designed and built. (Fig. 22) Experimental work has continued on testing the methods to be used in making the necessary measurements and adjustments to produce the required shape of magnetic field in the gap. Tests have been run on the performance of flux bars in a model magnet pulsed by an electronic switch similar to that to be on the synchrotron.

A mechanism for locating and moving search coils and peaking strips in the gap has been built. This equipment will be used to survey the field strength in the useable portion of the gap in order to permit the necessary adjustments to be made.

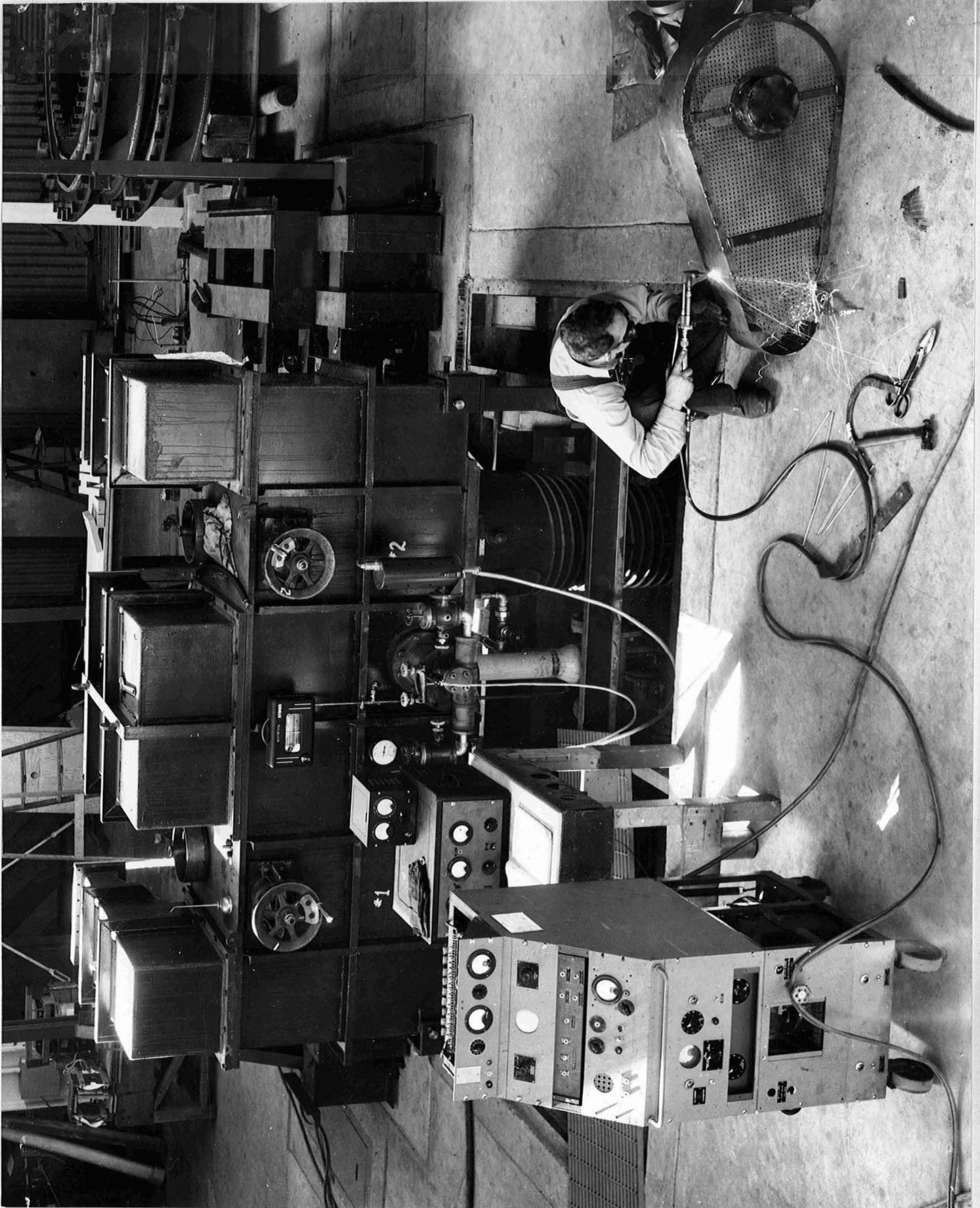


Figure 1 - Vacuum header, diffusion pumps and valves.

SYNC-189

2-26-47

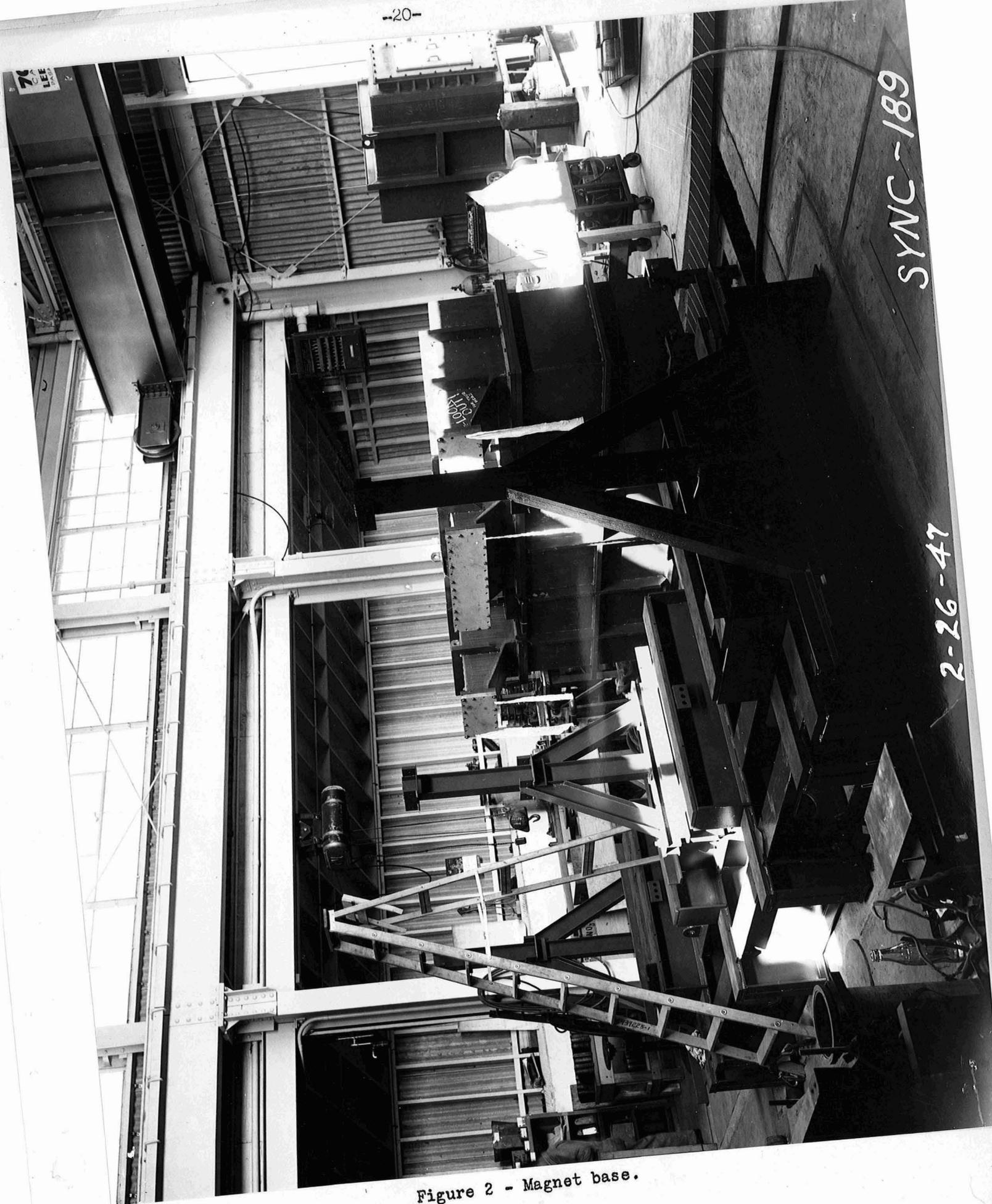
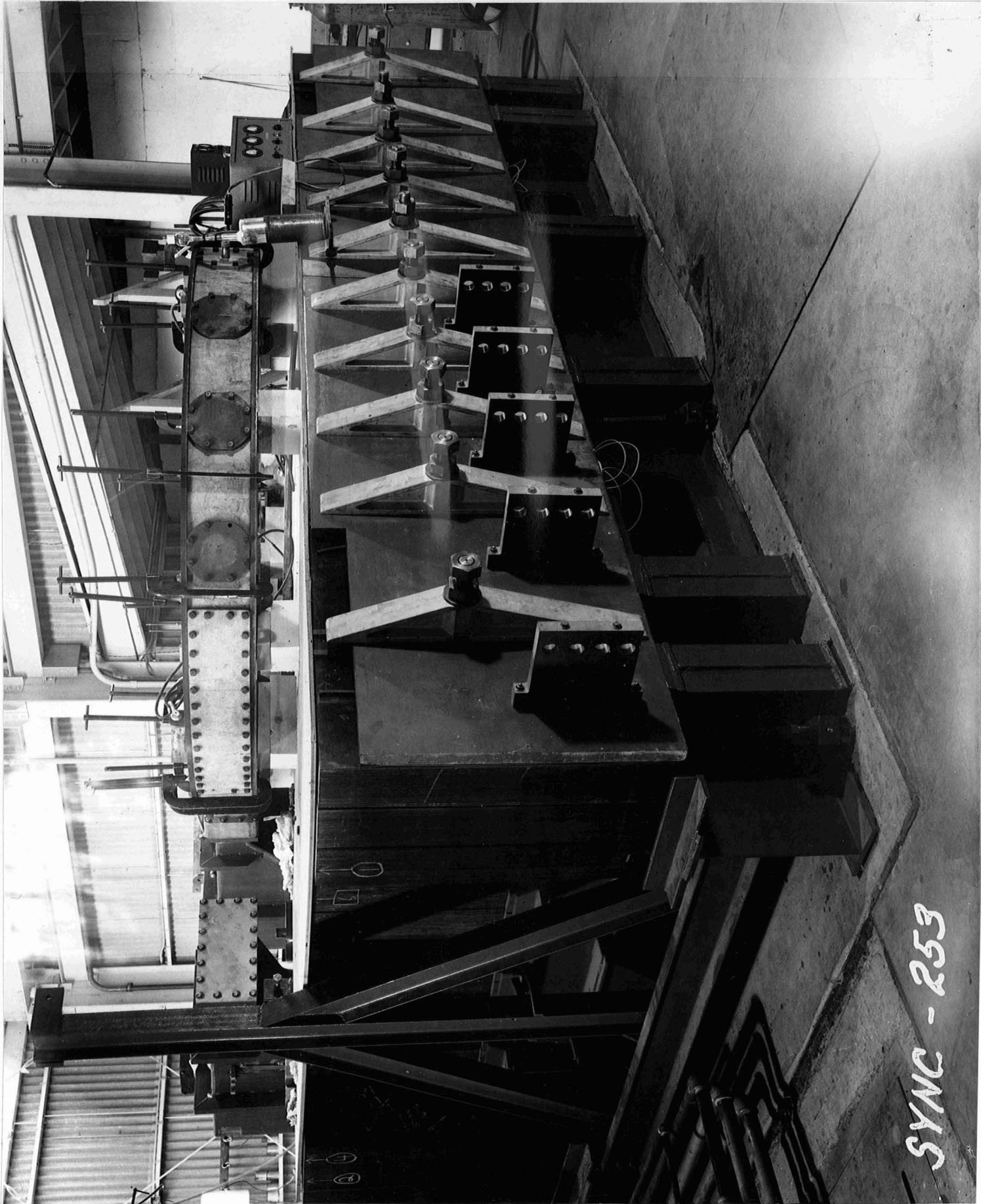


Figure 2 - Magnet base.



Figure 3 - Assembly of lower yoke.



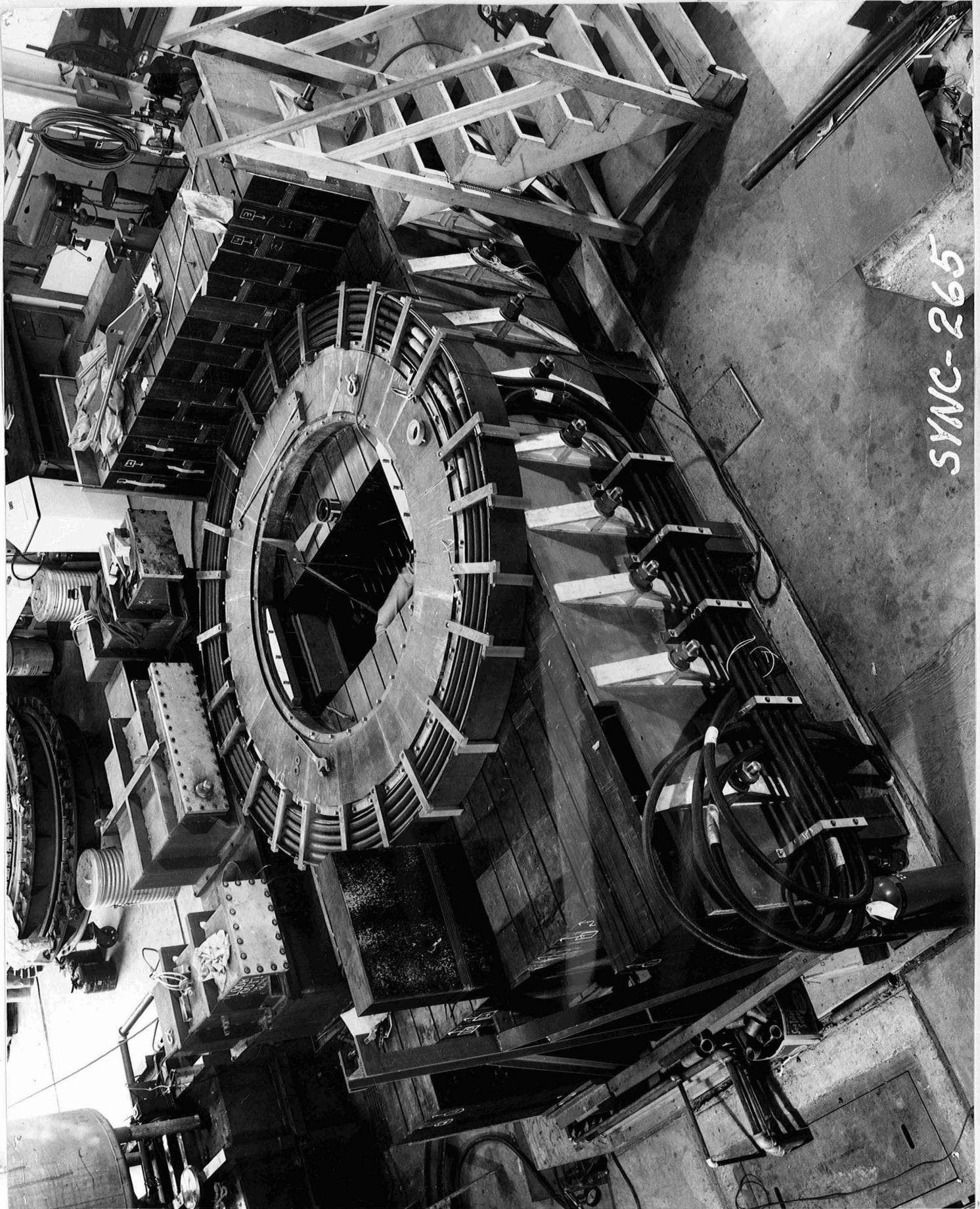
SYNC - 253

Figure 4 - Lower yoke and vacuum chamber.



SYMC-254

Figure 5 - Pole base ring assembly.



SYNC-265

Figure 6 - Lower yoke complete with coils.

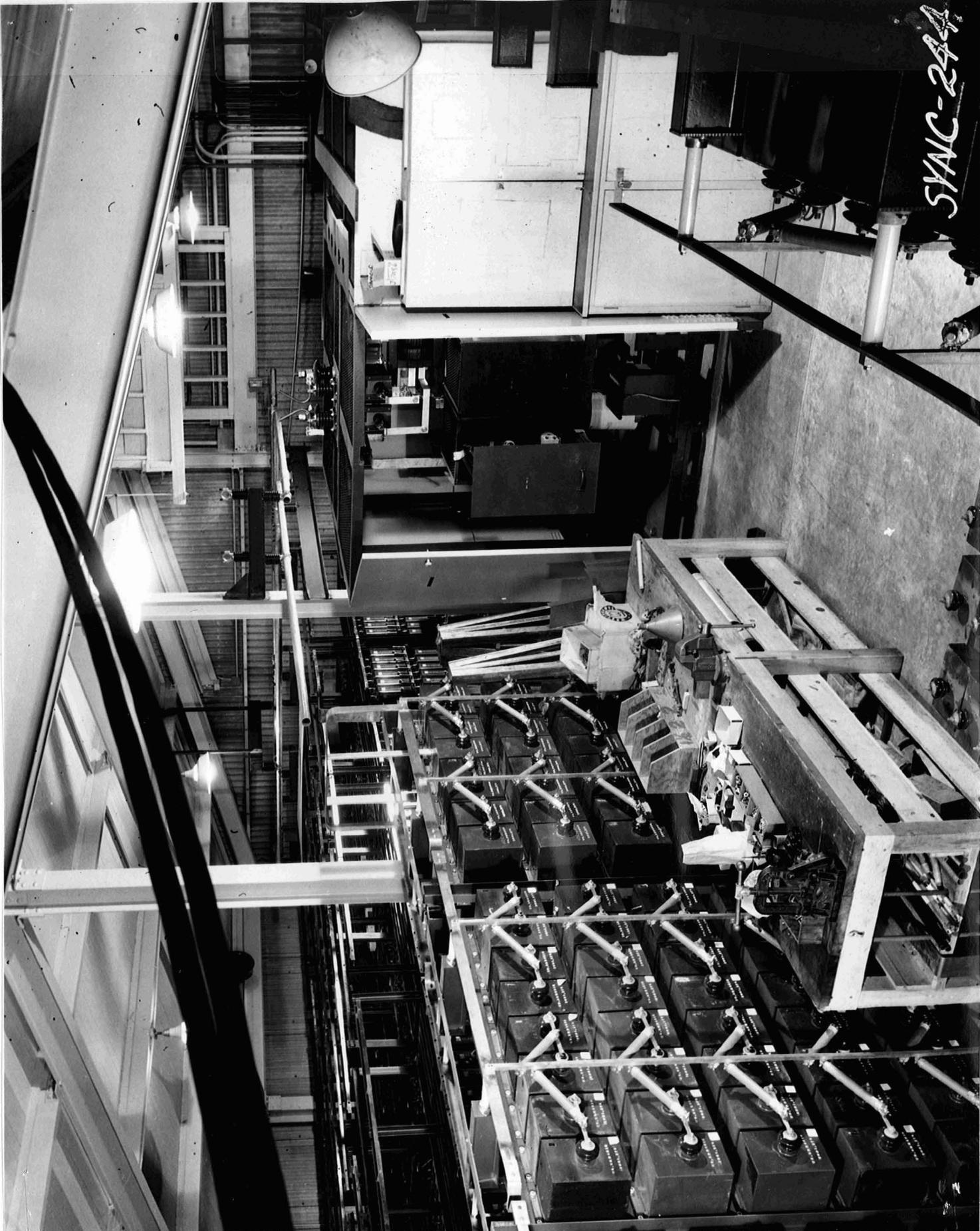


Figure 7 - Capacitor bank assembly and electronic contactor.



Figure 8 - Feeders and capacitor fuses.

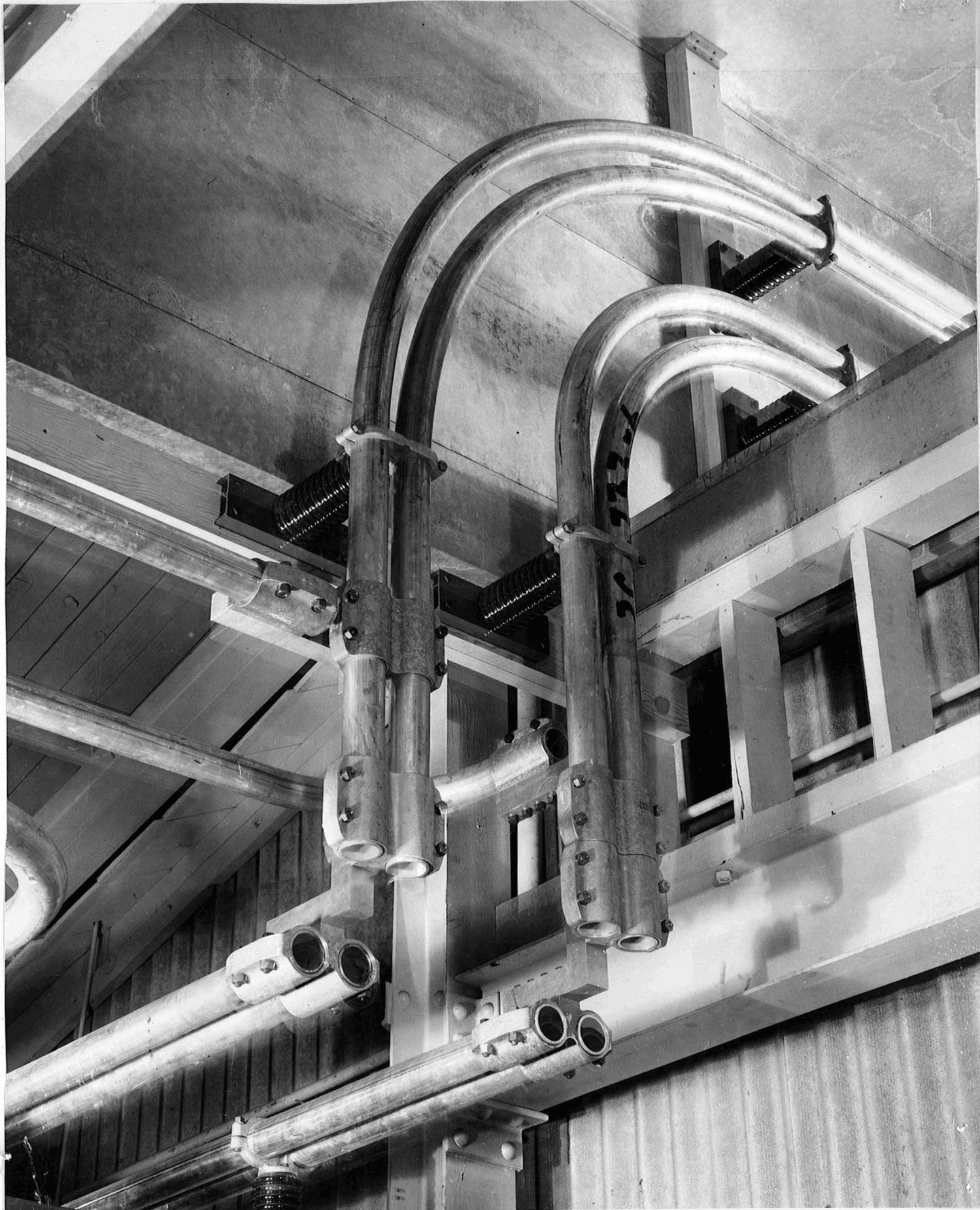


Figure 9 - Overhead tunnel and bus system.



SYNC-307

Figure 10 - Control desk.

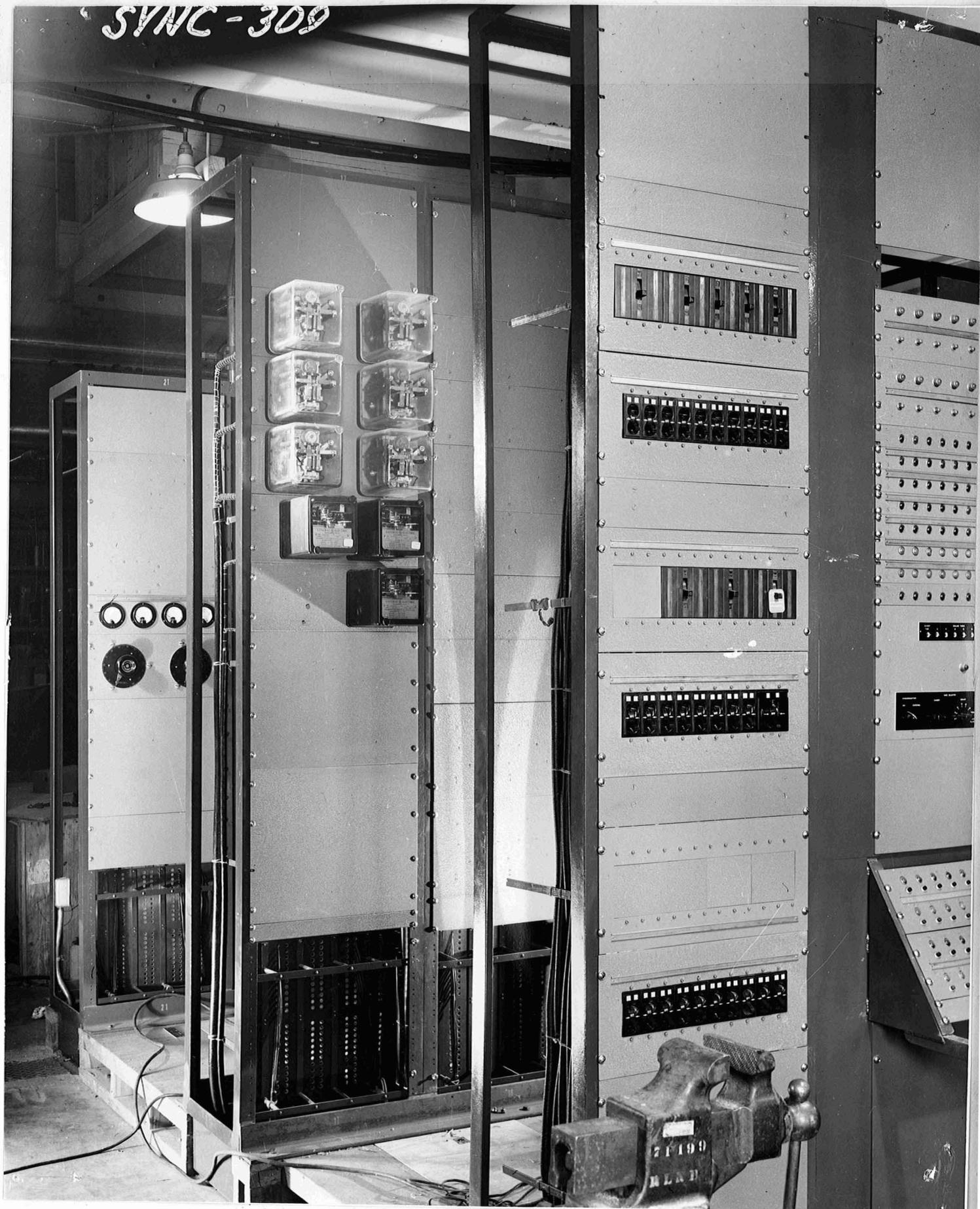


Figure 11. - Cross connect racks.

SYNC-310



Figure 11a - Cross connect racks.

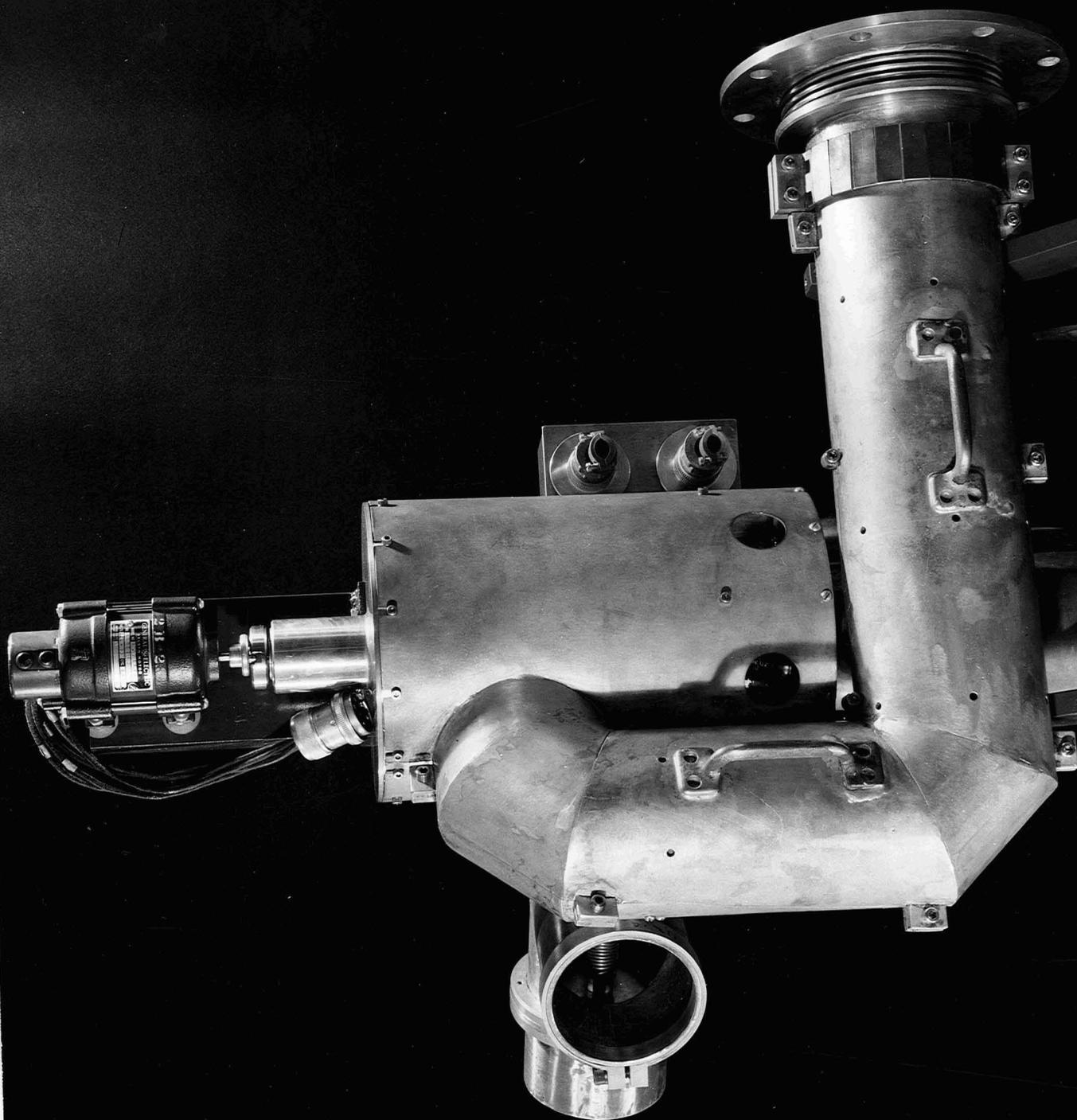


Figure 12 - R.F. oscillator.

SYNC - 228

SYNC-308

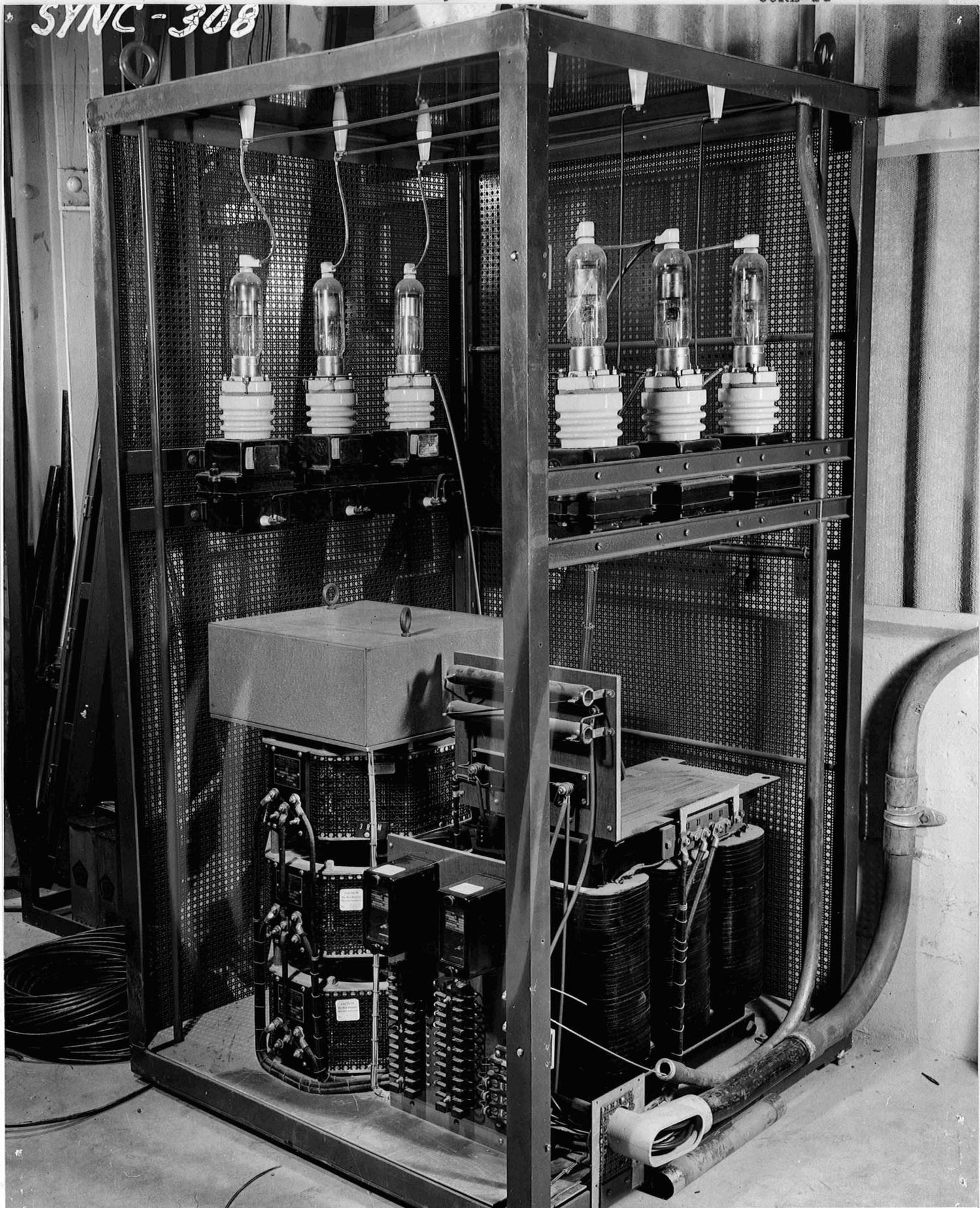


Figure 13 - Oscillator D.C. power supply.

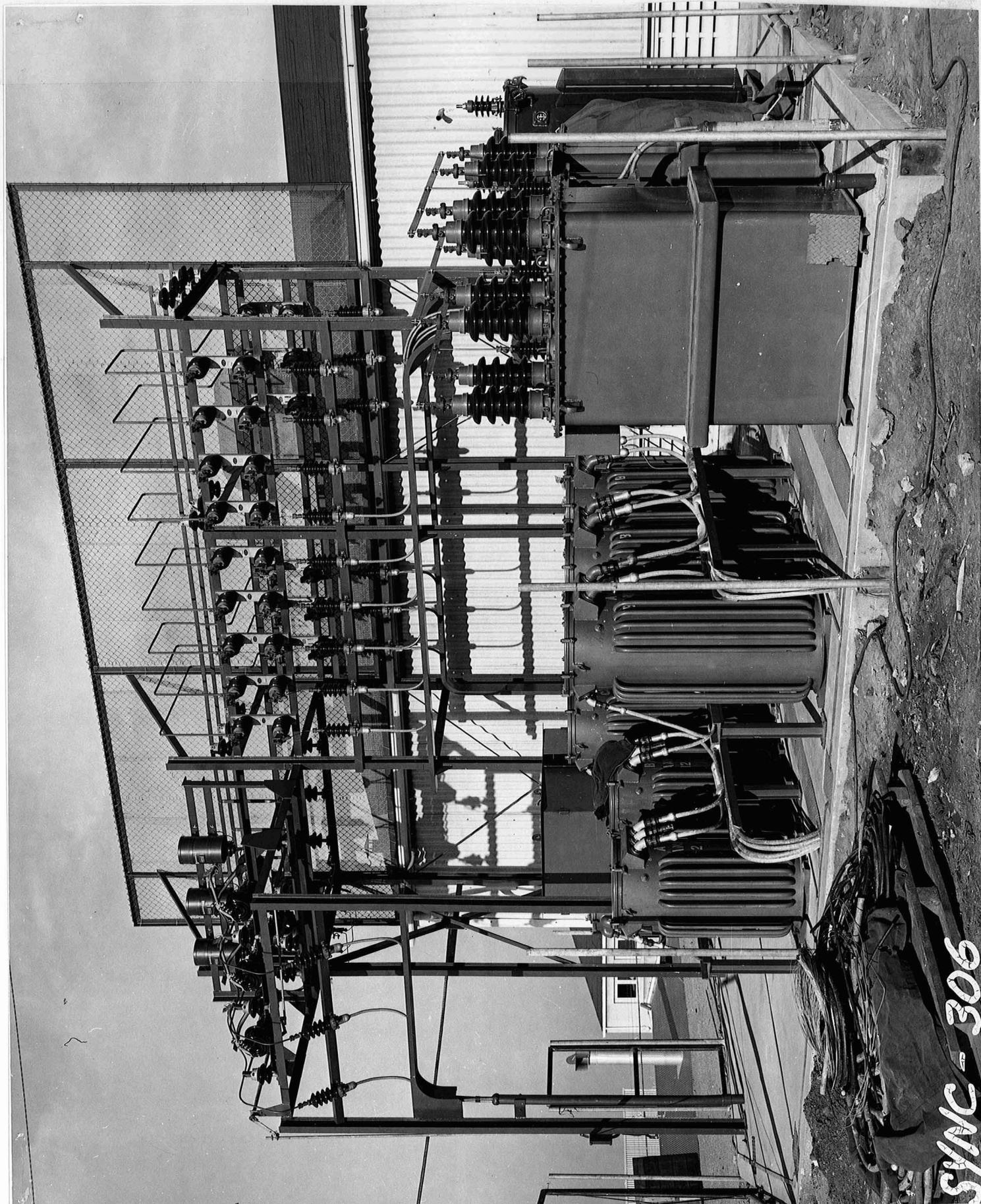
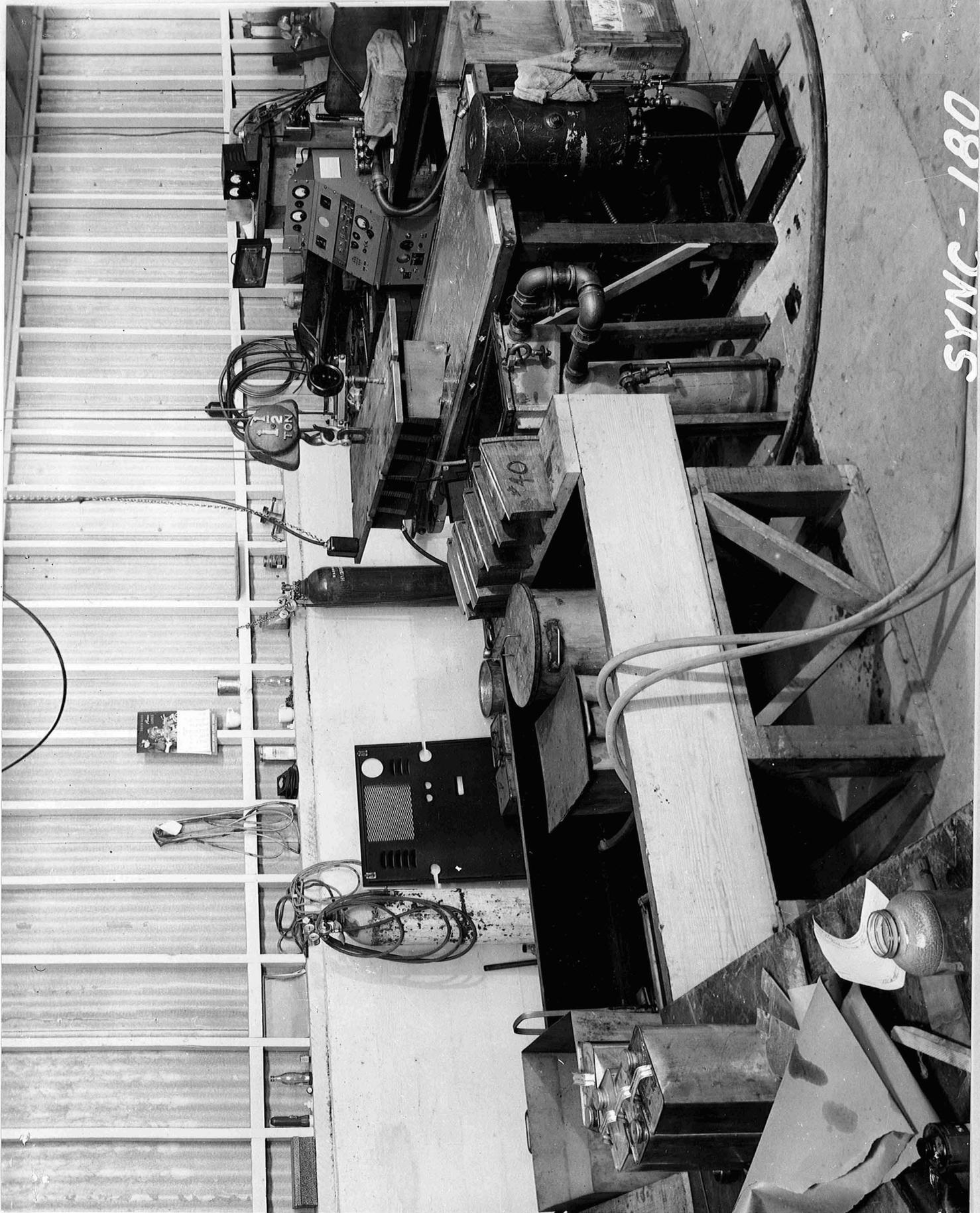


Figure 14 - Transformer yard.



SYNC-180

Figure 15 - Pole tip wedge etching, impregnating and testing station.

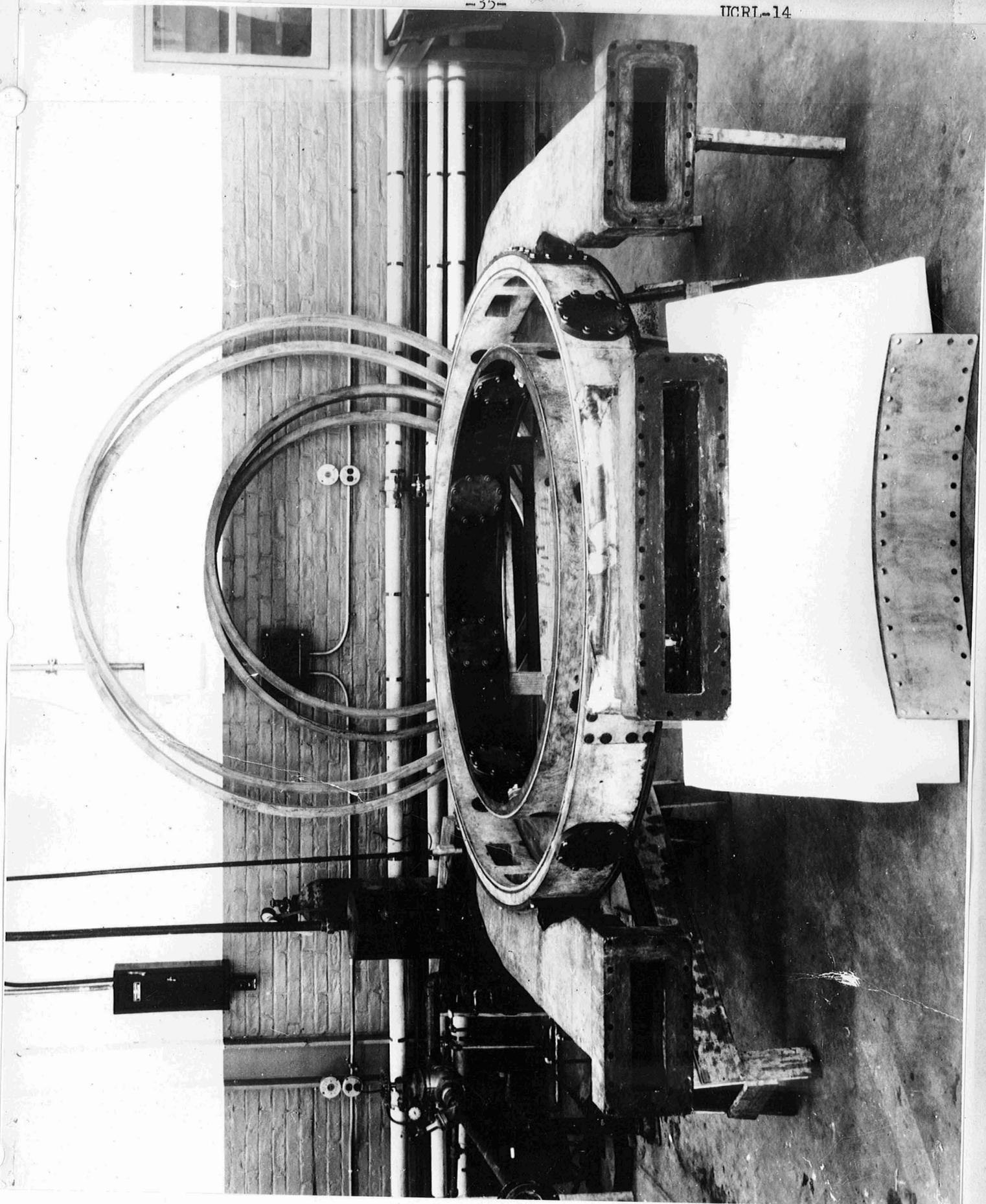


Figure 16 - Plastic vacuum chamber parts.

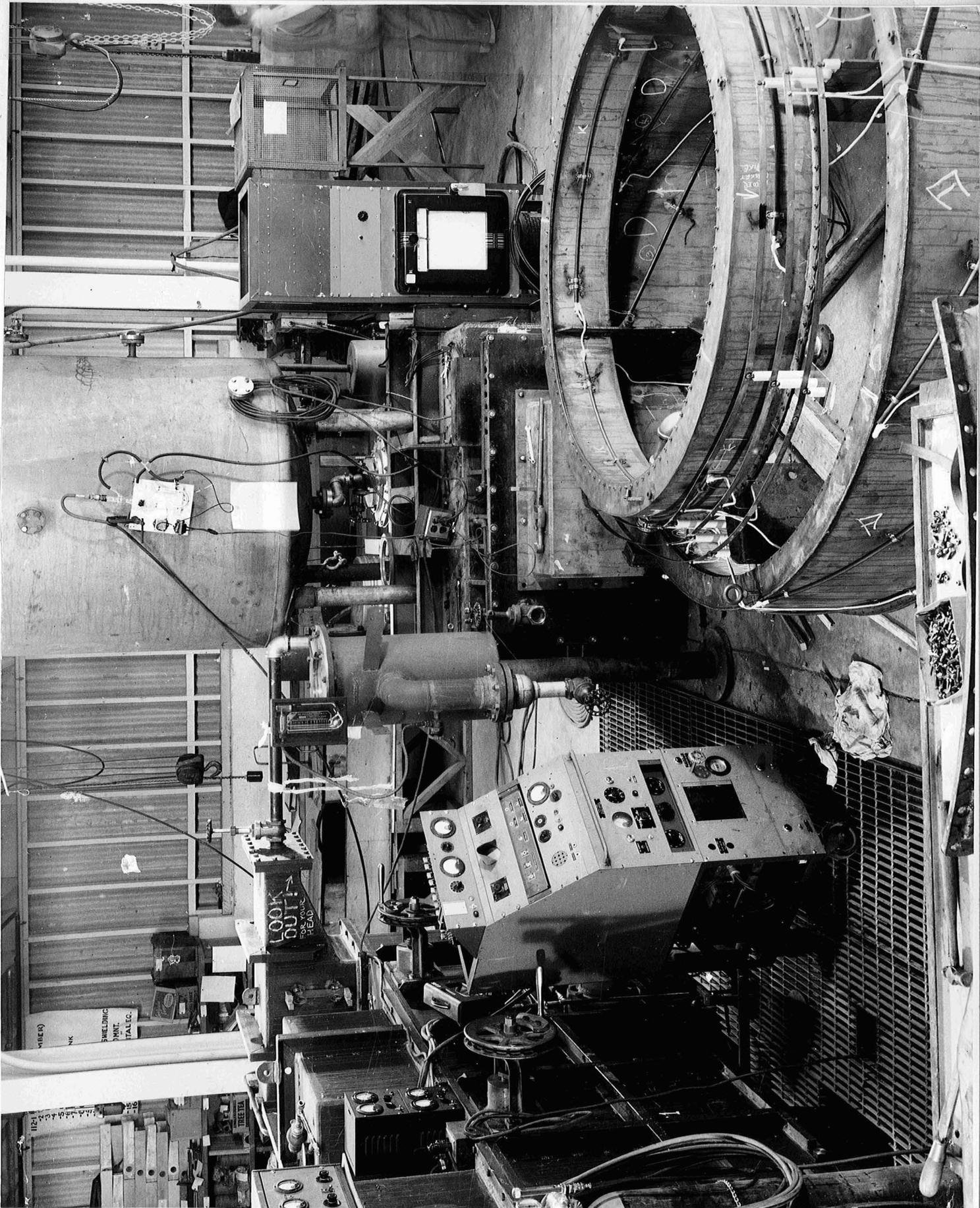
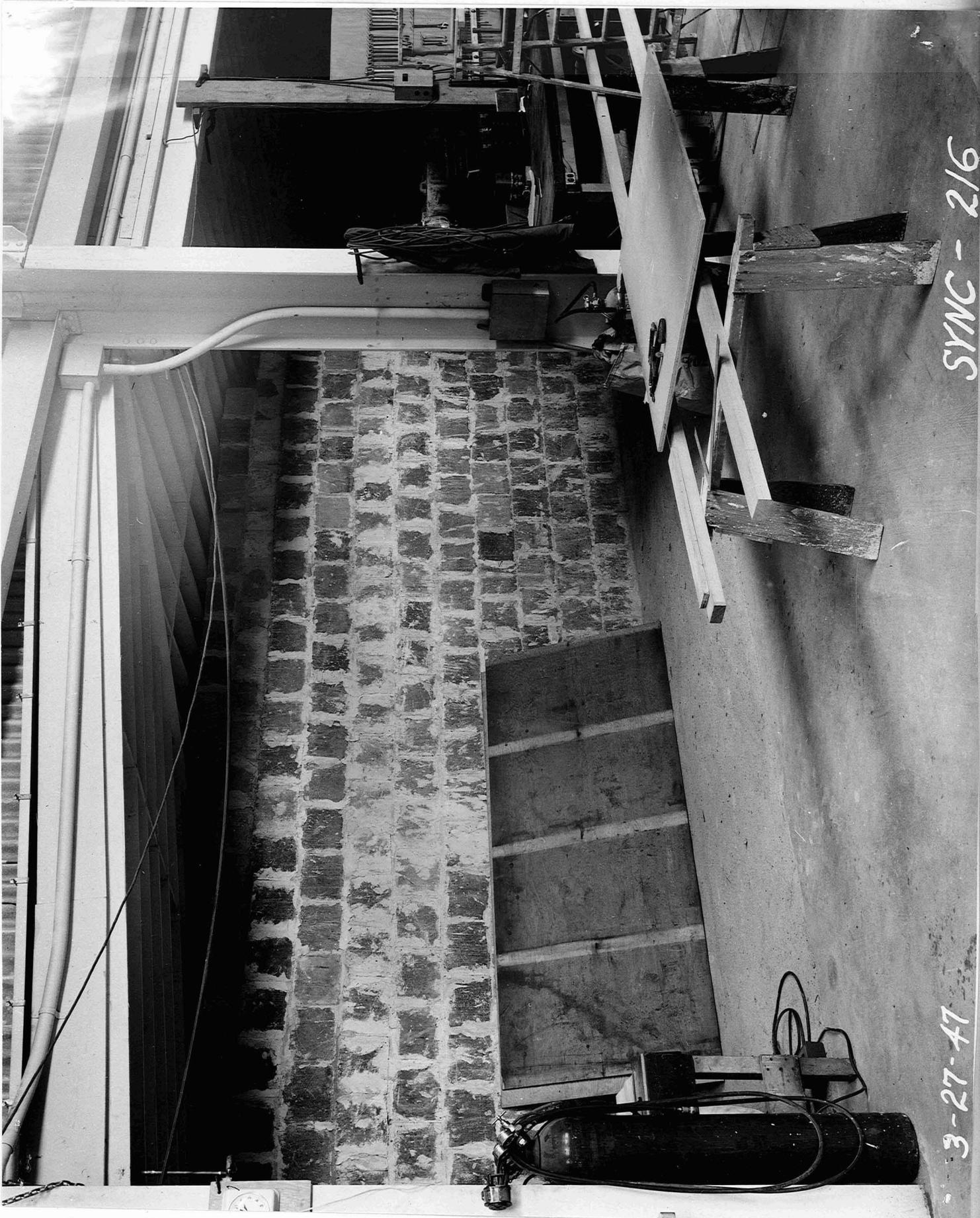


Figure 17 - Vacuum impregnation equipment for plastic parts.



SYNC - 2/6

3-27-47

Figure 18 - Concrete radiation shield.

SYNC-217



Figure 19 - Concrete radiation shield.

SYNC - 160

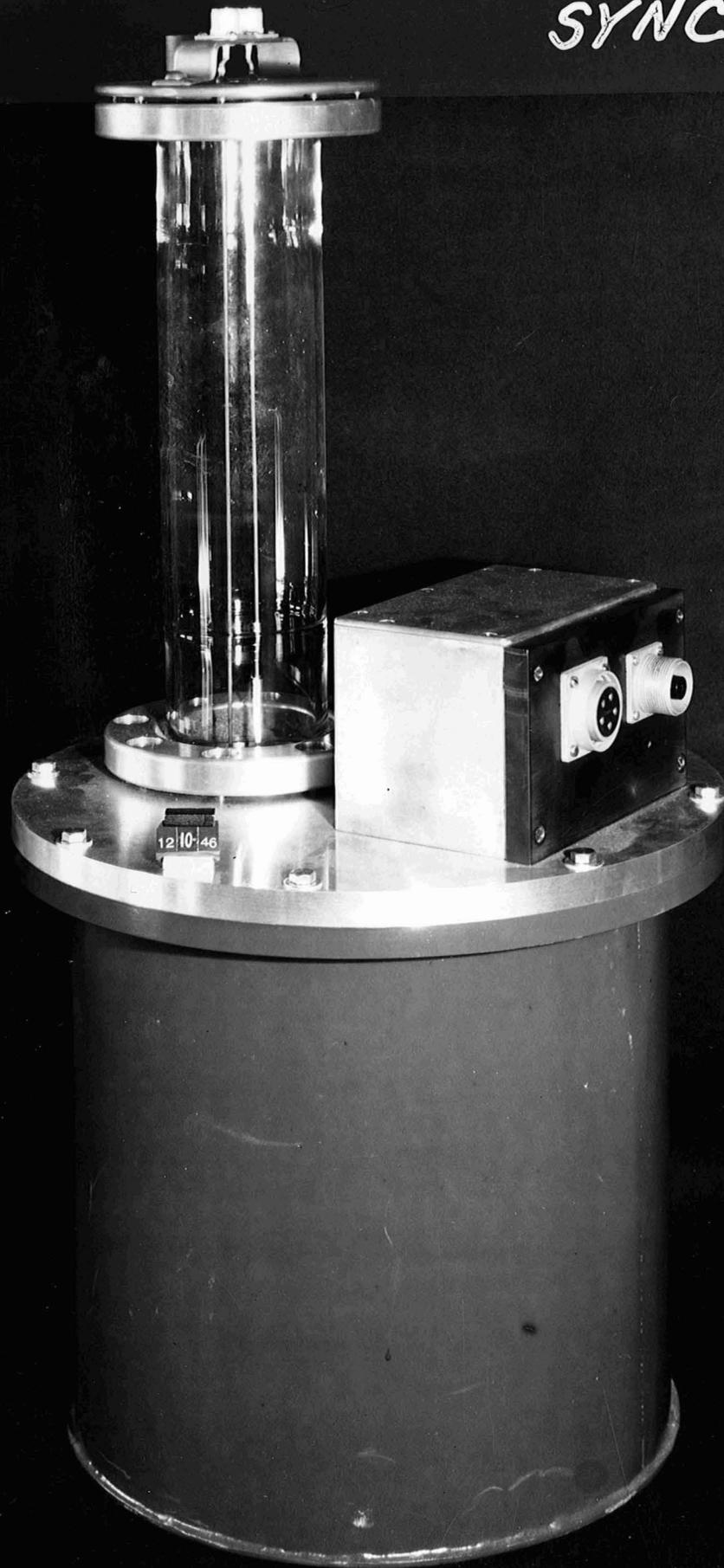


Figure 20 - Injector pulse transformer.

SYNC - 204



Figure 21 - Injector.



Figure 22 - Injector positioning cylinder.

SYNC - 191

IV. Linear Accelerator

Luis W. Alvarez

A. Introduction

Just before the end of the war, many of the men who had been engaged in war research started to think again on the problems of high energy nuclear physics. The high energy limits of the cyclotron and the betatron were understood to be in the neighborhood of approximately 100 Mev and 300 Mev respectively. It was obvious that improved methods of accelerating particles beyond these limits would have to be developed if cosmic ray phenomena, particularly mesotron production, were to be reproducible in the laboratory. McMillan and Veksler independently proposed the synchrotron, which immediately raised the betatron limit to greater than 1 Bev. Some months after the end of the war it was demonstrated at Berkeley that the synchrotron principle could also be used to circumvent the cyclotron's "upper limit." But it seemed at that time, and for approximately a year later, that the cost of building super energy synchro-cyclotrons would be so high that the theoretical possibilities of the machines might never be realized in practice. However, recent developments in synchro-cyclotron design show quite conclusively that by using a ring type magnet it is possible to reduce the building cost of such a machine to quite reasonable values, even in the 10 billion volt range.

The work on the Berkeley proton linear accelerator was started late in 1945, since it seemed at that time that such a device might be considerably less expensive, even though somewhat more complicated than a large synchro-cyclotron. Plans were therefore made to build a pilot model producing protons in the 30-40 million volt range. The proposal was to investigate the properties of a proton linear accelerator, and on the basis of its performance, to decide later whether or not to embark on the rather formidable task of building a very long machine to reach the billion volt range. It now appears quite certain that no matter how well the pilot plant might work, that it is not competitive with the large synchro-cyclotron - or bevatron, as it is known at this laboratory - either from the point of view of complexity or cost. The 40-foot section, however, which has just recently operated for the first time, will be a useful scientific tool in its own right, and several important experiments are to be performed with it before it is eventually dismantled. It is presently producing protons of 32 Mev, which are available externally without the complicating effects of the magnetic field. Incidentally, the highest energy protons previously produced by direct acceleration were of 15 Mev. This is, in a way, fortuitous, since it has been possible for a long time to accelerate protons to a greater energy. The cyclotron produces protons with energies between 60 and 140 Mev as a result of a simple nuclear process involving high energy deuterons. Therefore, for most experiments involving high energy protons, the cyclotron is a superior source. However, for the very important experiments on proton-proton scattering, it appears for the moment that the linear accelerator can yield more accurate data, since it has available an external collimated beam in a field-free region.

This introduction is in the nature of an explanation of the reasons for which the pilot model was built. History has apparently repeated itself, since in the early days of design of accelerators, particularly at the University of California, a large number of different types of machines were investigated on the pilot model scale, and all but the cyclotron were eventually dropped, since the latter appeared to have the most desirable characteristics. One could not tell in advance the relative values of the various machines, but instead had to build models of each to see how they compared in actual operation.

B. Progress Report of the Linear Accelerator.

By the end of 1946 most of the design features of the linear accelerator had been settled upon by a long series of theoretical and experimental investigations. Almost all of the large mechanical equipment had been designed and ordered and much of it was set up in the laboratory. Since that time, a great deal of detailed work has had to be done to check the electrical performance of the equipment on full scale, rather than on the model scale which had been used in the early tests. The radar oscillators which were received from the Signal Corps have undergone two modifications and now give approximately four times the output power, even though they use the original tubes. The problem of phasing large numbers of self-excited oscillators into a single resonant load has been solved successfully on this project for perhaps the first time. The linear accelerator vacuum tank has about 34 million volts from one end to the other, which is by far the largest potential ever produced with any comparable equipment. Problems involving discharges under these high electric field conditions have accounted for many difficulties, but they now seem to be solved, so that the machine runs quite steadily at 34 million volts. Under these conditions, protons gain 28 Mev of energy, so they emerge with 32 Mev; their injection energy is 4 Mev.

To insure that the protons remain near the axis of the machine while being accelerated, and also that they maintain proper phase relationship with the r.f. fields, it is necessary to place conductors across the entrance end of each accelerating electrode. It had been intended for some time to use thin beryllium foils for this purpose, but it soon became apparent when the foils were tried in the 40-foot tank, that they could not stand up under the discharge conditions. Previous tests under nearly the same electrical fields had indicated that they would be satisfactory, so plans for "focusing" the beam had to be changed a few months ago. Metallic grids made of tungsten sheets are now being used and they appear to work satisfactorily. It would, of course, be preferable to have the grids as nearly transparent as possible, but under these conditions the electric fields at the edges of the sheets are above the field emission point. A compromise has therefore to be made, and present grids are approximately 95 percent transparent so that about 10 percent of the proton beam which enters the accelerator during the proper phase for acceleration arrives at the target with 32 Mev.

The Van de Graaff generator, which is used as a source of protons, is now working in a very satisfactory manner, but it presented a large number of problems which had to be solved one by one. It now produces very high currents of 4 Mev protons and there is good reason to believe that at the moment it is the most satisfactory electro-static generator in operation. The rather high injection energy was chosen since it was planned to use foils for focussing, and the scattering from the foils decreases rapidly as the injection voltage is raised. If the linear accelerator were to be re-designed today, the injection voltage would be dropped to perhaps two million volts, where the engineering problems would be very much less severe. However, it is probably fortunate that the higher energy was chosen since it appears that a 4 million volt Van de Graaff generator could be useful as an injector for the bevatron, whereas a 2 million volt machine would not be at all satisfactory. There are, of course, a large number of problems in the field of nuclear physics for which the Van de Graaff generator by itself is unsurpassed, but most of these problems are not of the type in which the University of California Radiation Laboratory has been primarily interested in the past.

Two major technical improvements have been made in the generator to make it more suitable for use as an injector into either a linear accelerator or bevatron. One is the installation of high vacuum pumps in the high potential electrode, and the other is the provision for pulsing of the ion source. Both of these allow to be accelerated much larger ion currents than are usually available in such machines. The use of the pump permits a larger exit hole from the ion source into the accelerating tube, and the pulsing permits the ion source to be over-voltaged momentarily so that its output is much greater than could be obtained under steady operating conditions.

C. Initial Performance of the Linear Accelerator

The first time the accelerator produced a beam of 32 Mev protons, the ion current was quite low - of the order of 10^{-15} amperes average. Since that time the injected current from the electrostatic generator has been raised from approximately 1/10 microampere to approximately 100 microamperes, and its focus has been improved considerably so that the increase in effective injected current should be larger than that indicated by the two numbers above. In addition, the transparency of the grids has been increased by a factor of more than 10 and the over-all operation of both machines has been made much more reliable. It is therefore anticipated that when the two machines are run together again, within the next few days, that currents in excess of 10^{-11} amperes will be observed. It is possible to do a satisfactory experiment on the proton-proton trans- action with currents of approximately 10^{-12} amperes, so optimism is warranted at the moment about the possibility of doing such experiments.

V. Experimental Physics

A. Experimental Work with the 184-inch Cyclotron During its First Year of Operation

E. M. McMillan

1. Introduction. Particles Available from the Cyclotron. In November of 1946 the 184-inch synchro-cyclotron of this laboratory first operated; now, a year later, the scientific results obtained with this machine can be surveyed and evaluated in terms of the conclusions that can be drawn from them. The order followed will be more or less that of increasing complexity of nuclear phenomena, since this will show the logical connections of various parts of the work better than a division by methods of investigations; detailed discussions of the work of special groups are given in other parts of this report.

First, then, is the subject of the actual performance of the cyclotron as an accelerator; A considerable body of "operational data" has been gathered, which is of importance not only to the operators but also because of its bearing on the detailed theory of the machine. Here it will suffice to say that the cyclotron operates just about as predicted, even to fine details such as the occurrence of radial, axial and phase oscillations of the ion orbit. One feature, the loss of the beam at a certain limiting radius, was not predicted but could have been if the full implication of the theory had been appreciated before the observation was made. The most important facts are that the cyclotron gives on a target at the maximum radius of 81 inches a beam current of about one micro-ampere of deuterons having a mean energy of 190 Mev, or if helium is fed into the ion source instead of deuterium, it gives a somewhat smaller current of 380 Mev helium ions. (These beams contain a small spread of energies, with upper limits of 195 and 390 Mev respectively.)

Targets can be bombarded directly in the circulating beam, which is quite adequate for many purposes, but for some experiments it is desirable to use a deflected beam. Therefore an electrostatic deflector was built and installed, and works very successfully. The principle is to apply a very sharply rising high voltage pulse to a set of deflecting electrodes after the beam has entered into the range of their electrostatic influence; the deflection produced by a passage of the ion through this region is great enough to displace the orbit by about 2 inches toward the target. This allows enough clearance to put in special targets. For example, the ranges of the fast particles in various substances were measured by passing the deflected beam through wedges backed by photographic plates; the thickness of the wedge at the boundary between black and clear on the plate gives the range directly. These measurements furnished a valuable check on the high energy range curves contributed by the theoretical group. A further extension of the deflected beam to points outside the cyclotron tank by means of additional magnetic deflection is being developed and has successfully passed its first tests.

Free neutrons and protons are made available for research by a remarkable but simple nuclear process known as "stripping" that was observed very soon after the cyclotron started and has been studied extensively. The idea is that a fast deuteron, striking any nucleus, may collide in such a way that only one component particle hits the nucleus, while the other (either neutron or proton) misses and goes on its way as a free particle. This would at first sight lead to neutrons and protons having exactly half the energy of the deuterons, but when the internal velocity distribution associated with the binding energy of the deuteron is included, a certain spread in both energy and angle is introduced. Experimental studies of the angular distribution of the neutrons and the energy distribution of the proton indicate by their agreement with the theory that this picture is essentially correct. Thus by letting the circulating deuteron beam pass through a "thin" target (usually 1/2 inch of Be, representing a reasonable compromise between yield and energy loss which vary in opposite ways with the thickness), one gets both neutrons and protons in ample numbers.

The neutrons come out in a beam about 10° wide, and can be used for experiments either inside or outside the concrete shield; a 2-1/2 inch hole in the shield forms a narrow sharp beam which has been found extremely useful. The neutron flux at a point 52 feet from the target is about 10^6 neutrons per square cm. per second. The neutron energy distribution has a peak at about 90 Mev with a width at half maximum of about 27 Mev; these theoretical figures have been roughly confirmed by measurements of the energies of recoil protons from hydrogen. The orbits of protons from the target are curled up by the magnetic field into the center of the cyclotron, where the particles are used by putting experimental equipment there. The field sorts them out by energy, so that any desired energy up to about 140 Mev can be picked out. The current density in the center of the cyclotron at the peak of the energy distribution is about 4×10^{-12} amperes per square centimeter.

Thus there are available from the cyclotron deuterons, helium ions, neutrons, and protons, whose energies can be stated in a compact form by saying that they all have in round numbers 100 Mev per nucleon, and all of these have been used in the experiments to be described below.

2. Neutron-Proton Scattering. The simplest nuclear interaction is that between just two nucleons, and this has a special importance because its very simplicity makes an interpretation of the results in terms of the forces acting between particles relatively easy. A considerable amount of work has been done on the scattering of neutrons by protons, using the 90 Mev neutrons in the narrow beam outside the shield, and making the observations by counting the numbers of protons recoiling out of hydrogen at various angles. Three experimental groups using two methods (coincidence counters and a cloud chamber) are now working on this problem, and results have already been obtained showing a reasonable degree of agreement with each other and allowing certain definite conclusions to be drawn. There is positive evidence for the existence of both exchange and ordinary forces, apparently in about equal amounts. This is the first direct demonstration of the existence of the long-discussed exchange forces.

Also the results show that the frequently used "square well" potential to describe the forces, which is adequate for describing low energy phenomena, cannot be correct, and that something like the Yukawa potential is probably closer to the truth. These experiments when brought to greater precision will allow a rather detailed determination of the shape of the neutron-proton potential, and it is planned in the future to do the same for proton-proton forces by scattering protons from hydrogen.

Work on the scattering of 90 Mev neutrons from heavier nuclei has been done using as a detector for the scattered neutrons, blocks of carbon in which activity is induced by the reaction $C^{12}(n, 2n)C^{11}$. The observations so far on scattering from Pb, Cu and Al indicate that the main effect producing fast scattered neutrons is the diffraction of the "neutron waves" by the nucleus, in the same way that light waves are diffracted by a spherical obstacle. The results agree with this interpretation in both magnitude and angular distribution of the scattered neutrons.

3. Total Neutron Cross Sections. Another simple experiment is the measurement of the total cross sections of nuclei for neutrons. This is done simply by observing the reduction in intensity of a neutron beam when blocks of matter are put in its way. The cross section is the apparent area per nucleus which is active in stopping or deflecting a neutron. Early measurements by the Health Physics group using very large blocks of matter gave data useful in designing the cyclotron shield, but are not simply interpretable in terms of cross sections. Later measurements using small blocks ("good geometry") and carbon detectors furnish accurate determinations of the cross sections for 90 Mev neutrons of the nuclei of H, D, Li, B, C, N, O, Mg, Al, Cl, Cu, Zn, Sn, Pb, and U. The interpretation of these results is very interesting. The actual sizes of nuclei were already pretty well known from earlier cross section measurements at lower energy. The 90 Mev cross sections were found to be about the same for heavy nuclei, but to be considerably smaller for light nuclei, the difference becoming more and more pronounced as one goes down the periodic table. The only reasonable interpretation is that the smaller nuclei are partially transparent, allowing some of the neutrons to pass right through without any effect. This idea can be developed still farther; one can think of nuclear matter as a gas through which fast nucleons can move with a certain mean free path, of the order of the diameter of light nuclei. This mean free path can be computed from the measured proton and neutron cross sections. The latter is given roughly by the difference between the measured deuteron and proton cross sections and is roughly one third the proton cross section. When this is done it is found to be consistent with the degree of transparency observed for all the nuclei examined. Thus we have a transparent or gaseous model instead of a liquid drop model. This result, while not entirely surprising in view of earlier ideas on nuclear forces, is completely new as far as experimental confirmation is concerned. Further cross section measurements are now being done using the high energy part of the neutron distribution picked out by a bismuth fission chamber used as a neutron detector. These experiments are not complete but preliminary results seem to indicate a still greater transparency at high energy.

4. Detailed Study of Reactions in the Light Elements. The ideas discussed above furnish a model from which certain features of nuclear

reactions can be predicted; comparison of these predictions with experimental results then gives a further check on the correctness of the model. According to the older "liquid drop" model, when a particle strikes a nucleus it is stopped and gives up its whole energy. The nucleus is then "hot" or highly excited and evaporates nucleons until it has cooled down. The number of particles evaporated is roughly proportional to the energy of the incident particle. Therefore the yield of any particular product should first increase with bombarding energy, then decrease at still higher energy, because of the evaporation of still more particles. This behavior is well known in the region of a few million volts bombarding energy. The "gaseous" model however leads to different results at high energies, where the mean free path of nucleons in nuclear matter becomes comparable to the diameters of nuclei. Then the bombarding particle may go through with no effect, or it may make a single collision giving up part of its energy, or it may make two or more collisions, the relative chances of these events being governed by simple probability laws. After a collision the nucleus may have different degrees of excitation. If the excitation is small, one or two particles evaporate giving a single reaction; if it is high, many particles evaporate giving a many-particle reaction (what is called a "star" when seen in a cloud chamber or photographic emulsion). The yield of a given product should, according to this picture, first increase with bombarding energy, then remain roughly constant. This type of behavior has been observed in several reactions, such as the formation of radioactive C^{11} from stable C^{12} by proton, deuteron, and helium ion bombardment. In some other cases, such as in the formation of Na^{24} from Al^{27} by deuteron bombardment, the other type of reaction requiring complete stopping of the incident particle is sufficiently important that there appears in the curve of yield versus energy a peak in addition to the flat plateau. The basic theory of these effects has been given by the theoretical group.

The experimental studies are made in several ways. When the product is radioactive the activity can be measured after bombardment. By varying the energy, the "excitation curve" is obtained; by bombarding different substances in the same beam, relative cross sections for activation are found; finally, if the beam strength is measured, absolute cross sections are obtained. Excitation curves for the formation of C^{11} from C^{12} by protons and deuterons and helium ions have been done. Also the reactions of deuterons and helium ions on Al^{27} giving Na^{24} and Na^{22} have been examined in this way, and still other reactions are at present being studied. The theory of the carbon reaction with protons has been worked out in some detail.

Relative cross sections for a number of reactions produced by 90 Mev neutrons in the elements C, N, O, and F have been measured, and it is found that all possible radioactive products (at least all those having half-lives in the region investigated) are produced in each case, with definite relative yields which can be compared with the theory.

Some data on relative cross sections for proton - induced reactions have been obtained. Absolute yields have been measured for production of C^{11} from C^{12} by proton and neutron bombardment. The values obtained check those

computed roughly, probably within the accuracy of the theory, which requires certain approximations. The ratio of these two cross sections is less sensitive to the approximations, and the fact that it is about three times as big for protons as for neutrons can be taken as further significant evidence for the existence of exchange forces.

Many - particle reactions are observed most easily as "stars" in cloud chambers and photographic emulsions. An extensive statistical study of stars made by deuterons and alpha-particles in photographic plates has been compared with the theoretical predictions and shows good general agreement. Many very fine pictures of stars in cloud chamber have been obtained.

5. Detailed Study of Reactions in Heavy Elements. When large nuclei are bombarded, the chance for many collisions occurring in the nucleus is great, and processes involving high excitation are relatively more abundant, although single reactions are still not completely excluded. Thus a very great variety of products involving the ejection of various numbers of nucleons is to be expected and has been found in all the elements tried. The problem of sorting out the various active products involves chemical separations as well as physical measurements, and therefore this work has been done mostly by the chemical group. Since their part of the report will describe it in detail, nothing need be said here beyond the fact that reactions of great complexity involving the ejection of many neutrons and protons have been identified. In fact, it is probably not wrong to say that any nucleus bombarded with the high energy deuterons or helium ions from the 184-inch cyclotron gives to some extent every possible product that can be made by ejecting particles from it.

Another important observation is that high energy bombardment gives rise to fission in elements where it has not been seen before. The word "fission" implies a reaction in which the nucleus breaks into large pieces, usually into two roughly equal parts. The other kind of reaction where small parts or individual particles evaporate off is sometimes called "spallation" to distinguish it from fission. The chemistry group have established the occurrence of fission in elements as far down as tantalum when bombarded by the high energy helium ions. The fission products occur mixed up with all the many spallation products in the same target, so it is clear that highly developed chemical methods have had to be used for sorting them out. One interesting fact that has emerged is that the distribution in sizes of the fission fragments in these cases is quite different from what it is when the fission is produced by slow neutrons in uranium or plutonium. Therefore the detailed mechanism of the fission reaction must be quite different at high energy.

Direct observation of fission by physical methods can be made by observing the large pulses of ionization given by the passage of the fragments through an ionization chamber. This has been done, using the fast neutrons as bombarding particles. Fission was found in Pt, Au, Hg, Tl, Bi and some separated lead isotopes, and the relative yields from these substances and the variation of yield with neutron energy were measured. The theoretical interpretation of the results is complicated but when made

should yield some information on the mechanism of the process at these energies.

6. Conclusion. All the results given above can be tied together in terms of elementary forces between nucleons, and allow a much closer specification of these forces than was possible before. However there are other types of processes that one might hope to observe at high energy. These are processes in which neutrons and protons themselves are altered, created, or destroyed, or in which certain peculiar particles called "mesotrons" are produced. When these processes are seen and studied, a much more intimate understanding of the nature of nuclear matter will be possible. One can say that all the phenomena seen so far in the laboratory can be understood in terms of mere rearrangements of fundamental particles, while there is reason to believe from cosmic ray data and from theoretical speculations that at high enough energy the fundamental particles themselves can be broken up. Searches have already been made in this laboratory for negative protons and for mesotrons produced by high energy bombardment. None have been found, but the search has not been abandoned and the hope of finding such things when the cyclotron has been modified to give 350 Mev protons is much better. It is also hoped that the synchrotron may be able to make mesotrons when it is completed, and if these fail to do so there is still the possibility of building a bevatron to make particles of still higher energy.

B. Cloud Chamber Program.

Wilson Powell

1. Survey of Development. General procedure has been to make as many useful observations as development of techniques and apparatus would permit. The type of observations, their limitations and value are described.

The 184-inch cyclotron produced a beam for the first time near midnight on November 1, 1946. About two months before, one man had been assigned to cloud chamber work. A cloud chamber lent by Wilson M. Powell to the laboratory was adapted for cyclotron use and prepared in time to make observations. During the first half hour of operation of the cyclotron a photograph was obtained of a nuclear disintegration. This observation confirmed the presence of high energy neutrons in the cyclotron beam.

Earlier in the fall of 1946 Professor R. B. Brode directed the construction of a cloud chamber and part of the electrical control circuits. At the same time designs were made by W. M. Powell of a large solenoid magnet for the cloud chamber. This magnet was designed to give a field of 10,000 gauss over a circle 18 inches in diameter.

During construction of the magnet, work was done with the original small chamber. A field of 10,000 gauss on this chamber permitted exploratory work to go on although none of this work had the accuracy needed for measuring the high energy particles appearing in the neutron beam from the cyclotron. Also the lack of shielding around the cyclotron made study of events of interest very difficult. However, much valuable experience in operation with the cyclotron was obtained, and qualitative results on energies and types of events and particles appearing in the neutron beam appeared.

The larger chamber, which will be called the 16-inch chamber hereafter, was used without magnetic field and attempts were made to measure high energies by placing lead plates across the chamber. This attempt did not meet with success because of the confusion arising from lack of shielding. Some evidence appeared for the existence of protons with energies above 100 Mev but this was not capable of proof until the large magnet could be used.

In March 1947 the large magnet was completed and energized by a substitute generator so that a field of 9500 gauss was obtained. Almost immediately it was possible to show that a few protons in the neutron beam had energies as high as 195 Mev. This unexpectedly high energy was subsequently explained by Professor R. Serber who predicted the distribution with energy of the neutrons in the beam. Thus far we have not found any significant variation from the predicted energy distribution though no special effort has been expended on this problem. These high energy tracks were described in a report at the meeting of the American Physical Society at Stanford.

Attempts were made to confirm the existence of these high energy particles by passing them through lead plates in the chamber, but again lack of adequate shielding made this sufficiently difficult so that only a few confirming tracks were obtained.

The problem of the scattering of protons by neutrons in the neutron beam is the most fundamental one within the grasp of present techniques. Every effort was directed towards obtaining data which would determine the facts. Paraffin and carbon plates were placed side by side in a chamber and the energy and angular distribution of the protons from each plate determined. This experiment was difficult and was obscured by excessive background. Turbulence in the chamber near the plates made curvature measurements inaccurate, and it was difficult to determine (though not impossible) which tracks went through the plates and which started in the plates.

As soon as the shielding around the cyclotron was completed the cloud chamber was moved outside and the beam was carefully collimated so as to go through the center of the chamber. The reduction in background improved the observations tremendously and a few runs were made with oxygen in the chamber. The abundance of oxygen stars (complete nuclear explosions of oxygen atoms) make it possible to obtain enough data in a few hours running of the cyclotron to keep a group of technicians working for several months on the interpretation.

Oxygen has been broken up into as many as six fragments visible in the cloud chamber and preliminary work has been done to determine what these fragments are and how much energy they have.

After many experimental runs with different types of shielding it at last became possible to make accurate measurements of the scattering of protons by the neutron beam. An intense pulse of neutrons from the cyclotron is sent through the center of the cloud chamber. In September the first of these pictures was obtained showing protons knocked out of the hydrogen gas in the cloud chamber. The new mine sweeper generator for the cloud chamber gave a magnetic field of 14,000 gauss instead of the 10,000 gauss expected. By skillful design and careful assembly of the electrical parts it was possible with the experience obtained in using the apparatus to more than double the power obtained from the mine sweeper generator. Our cloud chamber magnet has been turned on and off nearly 10,000 times and although the forces in the magnet amount to many tons it has shown no signs of wear at all.

Since September all efforts have been directed towards obtaining accurate results on neutron-proton scattering. More than 3000 individual cloud chamber photographs have been examined and from these accurate measurements have been made on over 600 protons scattered by the neutrons. The fact that everything that a proton does in a cloud chamber leaves a visible record makes this work of great importance because errors due to incorrect interpretation are likely to be small. The measuring equipment

and techniques have been very accurately worked out. The photographs are reprojected in three dimensions by means of a double projector imitating in detail the optics of the special double camera used to take the photographs.

2. Calculations. Careful calculations and estimates of the ranges of particles which might appear in the chamber have been made. Special formulas have been developed by Professor R. Serber's group for calculating errors due to scattering of protons in the gas in the chamber. All these calculations assure the accuracy of our measurements and, most important of all, allow us to recognize at once any new discoveries which might appear in the cloud chamber.

3. New Cloud Chamber Magnet. In the next two weeks a new magnet using iron to increase the magnetic field will be tried out. Our earlier results showed the necessity for a stronger magnet because many of the nuclear explosions send out large fragments which can be identified only with a very powerful magnet. The new magnet uses coils identical with the original one in every respect.

On October 24th, helium gas was put in the cloud chamber and the helium atom was broken up for the first time. Calculations show that a neutron capable of breaking up the helium atom must have an energy of at least 47 Mev. This makes it the hardest atom of all. The cloud chamber showed more than ten cases of this break-up in a run four hours long.

C. Photographic Film Program. E. Gardner

1. Introduction. One method that has been used to detect the high energy particles from the 184-inch Berkeley cyclotron is by means of photographic plates. Photographic plates made especially for detecting charged particles are available commercially, and it has been found that these standard plates are well suited to the needs. The results are similar to those obtained with the cloud chamber, but the information is not as complete. Since the tracks recorded by the photographic plates are seldom more than a few millimeters in length, it is not possible to observe bending in a magnetic field. Also, the identification of particles by grain count in photographic plates is not as good as identification by droplet count in the cloud chamber. On the other hand, some types of data can be collected very rapidly by means of photographic plates. If the plates are exposed in such a way that there is one event per field of view under the microscope, or even one event per ten fields of view, there will be thousands of events on each plate. Another factor which makes the photographic plate technique valuable is that the plates can often be placed in positions which are inaccessible to other types of detectors.

The use of photographic plates in connection with the 184-inch Berkeley cyclotron may be grouped as follows: (a) to count numbers of particles, (b) to study stars in photographic emulsions, and (c) instrumentation, e.g. to study tracks of known particles for the purpose of describing characteristics of the plates.

2. Photographic Plates Used to Count Numbers of Particles. One application of photographic plates is in finding the number of charged particles striking a given area. A problem of this type which has been worked on is the study of protons from the target of the 184-inch cyclotron. This study is described in a paper "Energy Distribution of Protons from a Target Bombarded by 190 Mev Deuterons" by Chupp, Gardner, and Taylor.

A program has been started in which it is planned to detect scattered particles by means of photographic plates. If the method works well, it is planned to study scattering of deuterons and protons on various materials.

3. Study of Stars in Photographic Emulsions. Photographic plates mounted on a probe have been exposed to the circulating beam in the 184-inch cyclotron in such a manner that the beam strikes the edge of the emulsion. When the plates are developed and examined under the microscope they are found to contain stars of a number of types. In the case of 190 Mev deuterons, the plates are not sensitive enough to record the tracks of the incoming particles. For stars of this type it is not ordinarily possible to find out what type of nucleus is responsible for the disintegration. Furthermore, it is not known how many neutrons are given off or in which directions, so it is not possible to make a momentum or an energy balance. Thus it appeared that a detailed study of individual stars would not yield results which could be interpreted very easily. One can, however, tabulate average properties of the stars such as the number

of prongs (i.e., the number of tracks making up the star). The experimental observation of these quantities can then be compared with theoretical predictions.

A group of about 1200 stars initiated by deuterons was observed and average properties were tabulated. The group included about 300 stars at each of four deuteron energies.

A study is now being made to find the average properties of stars initiated by alpha-particles. For stars initiated by alpha-particles it is possible to see the track of the initiating particle. Thus, in addition to information about numbers of prongs, it is also possible to find the cross section for formation of stars. This is now being done by counting sections of tracks made by alpha-particles and the stars originating on these tracks.

4. Instrumentation. A study has been made of alpha-particle and deuteron tracks in photographic plates in order to contribute to the usefulness of the plates as tools of research. It is found that, with some types of emulsions, it is possible to distinguish between alpha-particle tracks and deuteron tracks.

D. Other Experimental Studies.

E. Segrè

1. Astatine Studies. An extensive study of astatine (element 85) has been undertaken. This element is the heaviest of the halogens and can be only produced artificially. The first isotope, of mass 211, was discovered at the Radiation Laboratory in 1940 by bombarding Bi with alpha particles of the 60-inch cyclotron. The war prevented a thorough investigation of this substance and in 1946 the work was renewed. The isotope of mass 211 has a half-life of 7.5h and it would be highly desirable to find one with a longer life in order to be able to work more leisurely and ultimately to accumulate a weighable amount of the new element. For this reason an attempt was made to form some new isotopes of astatine. At²¹² with a half-life of only 0.4s and At²¹⁰ with a half-life of 8.3h were successfully prepared, but because of their short half-lives do not represent an improvement with respect to At²¹¹. However, At²¹⁰ emits gamma radiation of about 1 Mev whereas At²¹¹ emits only alpha-particles and this fact is of considerable advantage for some types of investigations. Other isotopes of At can not be expected to be formed with the 60-inch cyclotron, but with the 184-inch it should be possible to discover several more.

Chemical investigations on the tracer scale have been performed with At²¹¹ and At²¹⁰.

2. Excitation Functions. Another problem on which work was done is the one of determining excitation functions i.e. the cross section of certain nuclei for special nuclear reactions as a function of the energy of the bombarding particle. It is especially important, at the present state of our knowledge of the subject, to make absolute measurements, and for this reason bombardments that lead to alpha emitters were started for which absolute measurements are relatively easy. The $\alpha_n, \alpha_{2n}, \alpha_{3n}$ reactions on Bi were investigated with the 60-inch cyclotron. The type of curves obtained are shown in Fig. 1. Also the dp, dn, d_{2n}, d_{3n} on Bi the (d, α, p, n) on Al to give Na²⁴. Some of these excitation curves at lower energies and not on an absolute scale had already been measured in this and other laboratories, but the higher energy and yield of the 60-inch cyclotron has permitted substantial improvements and extensions of these measurements. In this connection some measurements have been made of the stopping power of various substances for alpha-particles up to 40 Mev, which will be of general usefulness to workers in this field. Except for oral presentations at meetings of the American Physical Society (July 12, 1947, Stanford) this work is not yet published, but the experimental part, at least for Bi, is practically complete.

It is planned to extend the measurements to other substances in order to obtain a survey over several elements.

3. Variation of Half-life with Chemical Combination. In orbital electron capture the probability of capture is proportional to the probability of finding the electron to be captured at the nucleus. For a very light

element like Be^7 it seems possible to change the $|x(0)|^2$ enough by passing from one chemical compound to another, to affect in an observable way the half-life of the substance. With the invaluable co-operation of the Ames group which has performed the difficult metallurgical reductions involved in the preparation of the samples, the half-life of Be^7 metal has been compared with the half-life of Be^7 oxide. The relative variation of the decay constant observed is $\frac{\Delta\lambda}{\lambda} = 3 \times 10^{-4} \pm 2 \times 10^{-4}$. The reason for the smallness of the effect is not known. It is possible that the $x(0)$ in the two substances is very much the same, although this is slightly surprising because, although real calculations are extremely difficult, estimates led one to expect a $\frac{\Delta\lambda}{\lambda}$ between 10^{-2} and 10^{-3} . It has not yet been decided whether or not to repeat the experiment with other Be compounds. For this experiment a system of differential ionization chambers was built which is very sensitive and with moderately strong sources (0.1 mgn Ra eg.) allows the determination of the half-life of a substance in times of the order of 1% of the half-life with a precision of few percent. This work has been presented orally at a meeting of the American Physical Society (Stanford, July 12, 1947 MDDC 1098).

4. Fission. As soon as the 184-inch cyclotron started working, many new scientific problems became accessible to experiment, and new detecting techniques to take advantage of the new machine had to be developed. In particular it was desirable to have detectors sensitive only to very high energy neutrons and a fission chamber containing bismuth as the fissionable material was made to this effect. The fission of Bi, Pt, Tl, Hg, Au, Pb nuclei was investigated. This study, however, was superficial because other pressing problems had to be attacked and it was hoped to renew the study of fission under high energy bombardments later. The results of this investigation are reported in BP-112.

5. Neutron - Proton Collision. One of the most important problems in nuclear physics is the law of interaction of elementary particles, especially between the neutron and proton. All the information that can be collected at low energy has been accumulated and interpreted in the last fifteen years. At present, progress can be obtained only by using high energy particles. This situation is well known among physicists and one of the first tasks set for the 184-inch cyclotron was the investigation of the n - p collision. In view of the great importance of the problem, various groups tried this experiment by different techniques. In this experiment telescopes of coincident proton counters and neutron detectors of various kinds were used. The qualitative results of these investigations, by other groups and by ourselves, point to a large fraction of exchange forces between neutrons and protons, but a quantitative result has not been obtained and most of the effort is concentrated at present on this subject.

An oral presentation of the results obtained so far will be given at the Los Angeles meeting of the American Physical Society. The work mentioned above has been done by full or part time employees of the Atomic Energy Commission. In addition to this, several graduate students of the University, not on the payroll of the Atomic Energy Commission, have been working on excitation functions using the 60-inch cyclotron. Their work is not reported here although it is in close relation to the work reported under 2.

E. Instrument Development and Construction.

R.L. Thornton

The main direction of wartime research at the Radiation Laboratory did not lead, in contrast to other installations, to the development of a larger instrument section and the availability of considerable quantities of radiation detection and counting equipment. In addition, the pulsed character of the beam from present day accelerators, particularly the synchro-cyclotron, imposes very stringent demands upon counting equipment. Accordingly, much effort has been devoted to the construction of such equipment for research and health physics purposes and to the development of apparatus to meet our special needs. The laboratory is now quite well equipped with the essential equipment although much further work is required before all needs are adequately met.

Conventional high speed proportional counters have been successfully applied to counting problems associated with the cyclotron (e.g. neutron-proton scattering) when used in multiple coincidence circuits. While this involves the use of a considerable amount of equipment, it provides a satisfactory solution to the problems raised by the high instantaneous counting rates resulting from the pulsing character of the cyclotron beam. Considerable work has been done on the development of crystal counters (silver chloride crystals have been most extensively used) and associated electron equipment. In this connection it appears that considerable improvement in the band width of amplifiers can be obtained through pulsed operation of the amplifiers in synchronism with the cyclotron beam. It is hoped that by these techniques, and others such as spark counters which are also under development, it may be possible to so increase the speed of counters as to significantly alleviate this problem.

Development of methods for the measurement of fast neutrons has received considerable attention. In addition to ionization chambers and threshold detectors (such as $C^{12}(n,2n)C^{11}$), a satisfactory bismuth fission chamber has been constructed and used for certain experiments.

Measurement of the radioactive carbon content of various substances is of great importance in biological and other applications of the tracer technique using C^{14} . Satisfactory measurement techniques have been worked out and set up to handle this on a routine basis.

VI Theoretical Physics

R. Serber

Introduction. The work of the Theoretical Group during the past year can be grouped under three main headings: the theoretical aspects of the construction, operation, and use of accelerators, and the instrumentation of various experiments; the scattering experiments (neutron-proton, neutron-neutron, and proton-proton scattering) which give direct information on the nature of nuclear forces; and the mechanism of high energy nuclear reactions. In addition, it is felt that the theoretical group is performing a useful function in training a dozen graduate students as theoretical physicists.

A. The Theoretical Aspects of the Construction, Operation, and Use of Accelerators, and the Instrumentation of Various Experiments. The theoretical work on the dynamics of particles in the accelerators was begun late in 1945; the first detailed paper, "The Theory of the Synchrotron", appeared last year. A second paper, "The Theory of the Synchro-Cyclotron" was written during the Spring, and has since been published. The actual operation of the 184-inch cyclotron agreed quite well with the expectations developed in these papers; the only significant effect which had been overlooked was the effect of resonance between vertical and horizontal beam oscillations in slightly reducing attainable energy. The theory of this resonance effect has been worked out, and a paper is now in preparation by Henrich and Sewell explaining it, giving a detailed description and analysis of the operation of the machine. The beam dynamics in the linear accelerator had also been worked out last year, and the theory was applied as problems arose. A brief account of this work will be given at the Los Angeles meeting of the American Physical Society on January 2, 1948. Work is also in progress on questions arising in the design of the bevatron.

Numerous calculations have been made for the experimental groups, e.g., calculations concerning the cyclotron deflector system and estimates of requirements and performance for various proposed experimental set ups. A good deal of work has also been done on range energy relations of high energy particles. The calculated ranges of 190 Mev deuterons in various materials are in satisfactory agreement with measurements made by Stephan and Thornton.

Under the heading "Use of the Cyclotron" we may include the theory of deuteron stripping. This mechanism for the production of high energy neutron and proton beams was first investigated in the Summer of 1946. The reality of the effect was confirmed as soon as the cyclotron went into operation, and detailed studies of the neutron angular distributions for targets of the full range of atomic numbers were made by Helmholtz, McMillan and Sewell. The calculated distributions agree quite well with these observations. The observed energy distribution of the stripped protons also agrees well with that predicted, as does the total yield. The mechanism of this convenient effect is thus felt to be well understood.

B. The Scattering Experiments. A good part of the effort of the theoretical group has gone into developing methods of treating scattering problems at high energy, since it was felt that the most important information which could be obtained with the high energy particles now available would be more precise knowledge of the forces which act between nuclear particles. The experiments on $n - p$ scattering being carried out by York and by Powell and his group show clearly that both exchange and non-exchange forces act, and indicate that the two kinds of force are present in about equal amounts. A force of this kind, half exchange and half ordinary, can be explained in a simple way by saying that in the course of the interaction a neutron or proton completely forgets which kind of particle it was to begin with. However it is a quite different type of force than any in current fashion. Calculations by Finkelstein show that it is possible to get a fairly good fit to the observed angular distribution, and to the total cross section measured by Cook, McMillan, Sewell and Peterson, by using a force with this exchange character and a reasonable dependence on radius (e.g., a Yukawa well). Their calculations were based on the Born approximation, which may be off by as much as 20 percent. We have developed an improved method of calculating cross sections, based on a variation principle due to Schwinger, which gives much more reliable results than the Born approximation and is much simpler than other existing methods. Calculations using this method are now in progress. It will be applied to $n - n$ and $p - p$ scattering also. To complete the story, a study is being made of the relativistic effects which may be expected at these velocities.

C. Mechanism of High Energy Nuclear Reactions. Our third group of problems has to do with forming a picture of what nuclear reactions are like at high energy, and developing and elaborating the model of comparison with the experimental findings. The general ideas of what would occur were first formulated during a series of lectures at the Radiation Laboratory in the Spring of 1946. When the cyclotron got into operation, the general feature of the nuclear events as they were observed were in very good qualitative agreement with what had been expected. Since then we have been making more detailed and quantitative comparisons between the experiments and our model.

The model is based on the idea that for high energy of the bombarding particle, its collision time with nuclear particles is so short that one can treat the collisions as taking place between the incident particle and individual particles in the nucleus. **Secondly**, at high energy the cross section for such a collision between two particles gets so small that the nucleus begins to become transparent to the bombarding particle. It will frequently pass through the nucleus and emerge having lost only a fraction of its energy.

The transparency of the nucleus to high energy neutrons has been shown by the measurements of cross sections for 90 Mev neutrons carried out by Cook, McMillan, Sewell and Peterson. The fact that the incident

particle may lose only a fraction of its energy in traversing the nucleus explains the results of the experiments by Seaborg, Perlman and their group which show that a wide range of radioactive end products results from energy bombardment of a nucleus, since a wide range of end products shows a wide range of energy transfers to the nucleus. The same point is illustrated by the measurements of cross sections for a number of reactions as a function of energy. The general behavior of these excitation curves is in agreement with theoretical expectations and detailed calculations carried out by Heckrotte and Wolfe for the reactions $C^{12}(p,pn)C^{11}$, and $C^{12}(n,2n)C^{11}$ agree quite nicely with the observed facts. Satisfactory agreement has also been found between calculations of star sizes and angular distributions as calculated by Horning, and the observations of stars in photographic plates made by Gardner.

In addition to the effects produced by the neutron striking the nucleus, it was predicted that the shadow cast by the nucleus would give rise to diffraction scattering at small angles. Striking experiments by Hildebrand have fully confirmed the description of this effect.

Further attempts to give detailed explanations of experiments on high energy reactions are in progress.

VII. Isotope Research Program

B. J. Moyer

A. XC Calutron. The entire period has been given to the program of relocating the XC facilities. Since January 1, 1947, the following operations have been accomplished.

1. The magnet was placed on a new foundation.
2. The coils and vacuum tank were installed.
3. Engineering and plans were completed for the new building and facilities.
4. The building was completed except for installation of plumbing, wiring, etc.
5. A new vacuum manifold was installed on the tank.
6. Liquid N₂ evaporation system was built for the dry N₂ supply.
7. A heat exchanger was procured for the magnet cooling.
8. A 350 KW, d.c. power line, for supplying the magnet current from Building #6, is planned but not yet installed.

B. JA Calutron

1. Development of a Small Calutron Unit. For certain specific purposes a small calutron unit, approximately 1/2 B size, with single arc, high-potential source, and grounded collector has been constructed and utilized in the JA magnet. The specific purposes were:

- a. To handle small amounts of materials
- b. To permit rapid processing of materials so that mass separations on radio-activities with short half-lives could be accomplished.
- c. To allow high recovery efficiency.

For this program the magnetic gap in JA was altered, a new vacuum tank constructed, shims installed, two recovery liners built, and two source and collector units constructed.

The source units allow gas feed for supporting the arc while running on small quantities of vapor of the processed material. They also allow insertion of the charge into the charge bottle region through a vacuum lock so as to avoid outgassing delays. A separate report on design and operation of this source unit is in preparation. It has been extensively used in the experimental program in isotope work.

2. Experimental Program on JA

- a. Production of ion beams of various elements. Four different methods have been successfully employed in separation and analysis problems.

B. JA Calutron (con't)

2. Experimental Program

a. Production of ion beams of various elements.

- (1) The heating of a volatile compound of the element desired in the charge chamber (or the admission of a vapor of the compound volatile at room temperature)
- (2) Bleeding Cl_2 gas over heated metal in the charge chamber.
- (3) Suspending a metallic sample in arc chamber while operating the arc on a supporting gas (usually Cl_2)
- (4) "Charge bottle reactions", such as the reduction of BeO under vacuum conditions in the charge chamber. This was accomplished by passing Cl_2 over an intimate mixture of BeO and carbon at elevated temperature. The gas flow led directly into the arc and provided a satisfactory Be^+ beam.

Variations on these methods will yield at least small beams of anything tried thus far including: Li, Be, C, Na, Mg, Si, Cr, Fe, Co, Ni, Cu, Mo, Ag, Cd, In, Sn, Sb, Te, Rare earths, Tl, Pb. Beams large enough for quantity separation were not always produced, but beams satisfactory for collection of amounts needed in the experiments involved were obtained.

b. Identifications of radio-activities. Identification of the following activities were made.

- | | | |
|-----|-----------|----------------------------------|
| (1) | 24.5 min. | Cu^{60} |
| (2) | 2.7 hr. | In^{111} |
| (3) | 6 day | Te^{118} |
| (4) | 1.8 hr. | Co^{61} |
| (5) | 9.4 hr. | Co^{62} |
| (6) | Long life | Be^{10} (See section C) |

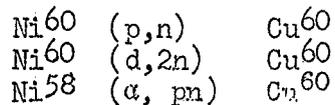
In these identification experiments the processing time could be made short enough to deal with activities with half-lives measured in minutes. For instance, with the 24.5 min. Cu^{60} enough sample was collected at mass 60 to allow study through six half-lives, with absorption measurements and particle identification. Methods were developed for rapidly transforming the metal collector pocket into a counting plate for measurement in a Geiger-Mueller counter.

- c. Methods have been developed for depositing a highly enriched sample of C^{14} by the calutron, with the end in view of studying hyperfine structure and B-ray spectrum.

B. JA Calutron (con't)3. Radio-activity Studies. New activities produced and studied in the isotope program in this period were:

- a. Cu^{60} , 24.5 min. β^+ 1.8 and 3.3 Mev, gamma 1.5 Mev.

The activity was induced in isotopically enriched samples of Ni as follows:

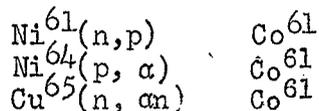


Identification was made chemically, and mass assignment by the calutron.

Energies were estimated by absorption in Pb and Al.

- b. Co^{61} , 1.75 hr., β^- 1.3 Mev, no gamma.

The activity was induced in enriched Ni isotopes, and in Cu, by the reactions



Assignment by chemistry and calutron. Beta end point by absorption in Al.

- c. Co^{62} , 14 min., β^- 2.5 Mev, gamma in 1.3 Mev.

The activity was induced by the reaction $\text{Ni}^{62}(\text{n,p}) \text{Co}^{62}$. It did not arise from neutrons bombarding any other Ni sample.

Assignment by chemistry to Co. Energies by absorption in Pb and Al.

Coincidence counting showed the β^- and α to be in coincidence.

- d. Co^{62} , 9-10 hr, β^- 2.8 Mev.

Activity induced by $\text{Ni}^{62}(\text{n,p}) \text{Co}^{62}$, and more prominently by $\text{Cu}^{65}(\text{n}, \alpha) \text{Co}^{62}$ and $\text{Cu}^{65}(\text{d}, \alpha\text{p}) \text{Co}^{62}$.

Assignment by chemistry and calutron; energy by absorption in Al. This nucleus is evidently isomeric with that mentioned in 3.

B. JA Calutron (con't)

3. Radio-activity Studies (con't)
 - e. Radio-activity of Be^{10}

From a Be target long used in the Washington University cyclotron, samples of Be^{10} were prepared. The formation of the basic acetate by dissolving BeOH in glacial acetic acid was employed in the chemical purification of the Be. Measurement of the isotopic abundance ratio $\text{Be}^{10}/\text{Be}^9$ with a mass spectrometer, combined with measurement of the specific activity, permitted an evaluation of the half-life to be $(2.5 \pm 0.5) \times 10^6$ years.

Absorption measurements in aluminum gave a beta-particle maximum energy of 560 ± 10 Kev.

An approximate excitation curve was calculated from simple theoretical considerations, with the aid of data on activity vs. depth of Be in the target. The latter data was obtained by preparing samples successively milled from the face of the target. Theoretical predictions of yield were in satisfactory agreement with the observed yield of .0039 active atoms per deuteron at 16 Mev.

C. Mass Spectrometer

1. Analyses were made of C^{14} samples in support of work by chemists.
2. Analyses were made on Ni samples previously enriched by the calutron.
3. The spectrometer installation was moved to the new XC building, where it has been installed with re-designed mounting (greater accessibility) and modified electronic circuits including a recording system.

CHEMISTRY

I. Nuclear Chemistry Program

By I. Perlman

Introduction

The work of the nuclear chemistry group falls into several broad categories, some of which are characterized as pure nuclear research while others are recognizably pertinent to the atomic energy developments of the immediate future. Graduate students receive training through participation in all parts of the program.

One phase of the work has to do with the nuclear properties of the heavy elements, in particular, the transuranium elements. These studies afford a preview of isotopes that will appear in high energy piles of the future and allow determination of their fissionability and decay properties. The regularities of properties that appear allow a further extrapolation into the future. Along with the nuclear properties of the heavy elements, studies of their chemical properties are being carried out. The information obtained can be of importance for chemical processes for separating plutonium from other transuranium elements. The basic chemical studies also show up correlations which permit predictions in general of chemical properties of the heavy elements.

The 184-inch cyclotron allows the study of nuclear transformations with high energy particles. A part of the group's efforts is concerned with the identification of the transformation products. This consists of chemical identification followed by determination of the radioactive decay properties. Among these problems are the determination of nuclear reactions in which scores of particles are ejected from nuclei and the fission of elements induced by high energy particles.

A. Nuclear Properties of Heavy Isotopes

1. Spontaneous Fission of Curium. A program has been initiated to determine spontaneous fission rates among newly available heavy isotopes. These measurements are of great interest because it is probable that spontaneous fission will become more prevalent as atomic number increases but the exact atomic number and nuclear type at which the effect becomes prominent are not readily predictable.

Isotopes of curium, atomic number 96, can be made by irradiating americium, atomic number 95, with neutrons in the pile. The principal isotope formed is Cm^{242} , but small amounts of higher isotopes are also produced when the neutron flux is sufficiently high.

Samples of curium were tested for spontaneous fission and a surprisingly high rate was encountered. The rate can be expressed in terms of a half-life if the responsible isotope is known. There is experimental evidence for assigning the fissionability to Cm^{242} . If this is done the "half-life" is only a few million years, corresponding to a rate many times higher than any known up to this time.

2. Slow Neutron Fission. A number of further measurements have been made to determine the nuclear types that undergo fission with slow neutrons.

By careful measurements with the Argonne pile it is possible to measure appreciable cross sections for fission with micro-microgram amounts of material.

Two isotopes have been found which have cross sections for fission of the order of magnitude of, or higher than, that of U^{235} . These are Np^{238} and Pa^{232} , both of which significantly have an odd number of neutrons. On the other hand Cm^{242} and Pu^{238} have small but measurable cross sections.

3. New Isotopes of Americium. The previously known isotopes of americium are Am^{241} and Am^{242} , the first being an alpha-emitter of 500-years' half-life and the second a beta-emitter of 18-hours' half-life. This group has been extended by three new members. Two of these have been assigned to Am^{238} and Am^{239} produced by the cyclotron bombardment of neptunium and plutonium. The third constitutes a very interesting nuclear phenomenon since it is an isomer of the 18-hour Am^{242} . This new isomer probably has a half-life of several hundred years and decays by both beta- and alpha-emission. This is the first case of nuclear isomerism found among the heavy elements besides the pair which is found among the natural radioactivities, namely, UX_2 and UZ . It is interesting to note that the two pairs of isomers are of the same nuclear type, that is, both have an odd number of neutrons and an odd number of protons.

4. Properties of Curium Isotopes. The trends in nuclear properties of curium isotopes are of importance, among other reasons, since it is through curium that elements 97 and 98 might be reached. By carefully examining the properties of the currently accessible curium isotopes one might be able to predict which curium isotope might be expected to beta-decay into element 97.

The isotope Cm^{242} (150-days' half-life) apparently is beta-stable. However, examination of 27-day Cm^{240} shows that it decays mainly by orbital electron capture. Both isotopes were prepared by cyclotron bombardment of plutonium. Another activity is showing up, with 45-50 days' half-life which is also unstable with respect to orbital electron capture and may be Cm^{241} . With these facts it seems almost certain that Cm^{243} , Cm^{244} , and Cm^{246} are beta-stable and probably Cm^{245} is also. Therefore Cm^{247} is probably the first isotope that can be surely expected to decay into element 97.

B. Chemistry of the Heavy Elements

1. Production and Properties of Metals. This is a continuation of the program that resulted in the production of plutonium metal on the sub-milligram scale and the determination of its metallurgical, chemical and physical properties. An attempt is being made to fill in the gaps: protactinium (91), neptunium (93), americium (95), and possibly curium (96). The difficulties are those of working with the extremely small amounts of starting materials available, the chemical nature of the metals which makes reduction possible only by drastic means, and the intense alpha-radioactivity of these elements. The importance of the problem is the basic knowledge of chemical properties obtainable from the metals and the practical knowledge of preparing the metals for special uses.

Protactinium metal (element 91) has probably been prepared by the

reduction of the potassium fluoride with metallic barium, although insufficient protactinium can be obtained to check the results properly. The preparation had a very high melting point ($\approx 2200^{\circ}\text{C}$) which would make it more like tantalum than a rare earth. This comparison is made in order to shed some light on the similarity of individual heavy elements with other elements in the periodic table. The preparation showed no hydride formation, unlike its neighbors, thorium and uranium. The x-ray diffraction pattern was taken which allowed the calculation of the density as about 12.

Neptunium metal has been prepared using the long-lived isotope Np^{237} obtained as a by-product of Hanford pile operations. A special device was made to overcome normal difficulties in obtaining melting points of sub-milligram pellets of metals and this was successfully used to obtain a melting point of 639°C for neptunium metal. This conforms with the low melting points of neighboring heavy elements and of the rare earths and is quite unlike rhenium, at one time thought to be the lower homologue of neptunium in the periodic system. With these preparations of neptunium metal high density values of 19.7 have been obtained. Using a specially constructed micro-calorimeter it has been possible to obtain accurate thermal data on neptunium metal and its compounds such as the heat of solution of the metal.

After laboriously working up large volumes of certain plutonium wastes it has been possible to obtain a number of milligrams of americium (element 95) in the form of the 500-year alpha-emitter Am^{241} . This has been the source of americium for a large number of experiments of which metal production was one. One point of great interest was the finding that the density of the metal is probably in the range 10-12, unlike its neighbor plutonium. This phenomenon is encountered in the rare earth elements with europium and gives added proof for the actinide hypothesis for the structure of the heavy elements since americium falls in the same position with respect to actinium as europium does with lanthanum, its prototype in the rare earth series. The melting point of americium metal is relatively low, that is, around 850°C which again is very unlike iridium, a possible homologue on another hypothesis.

2. Chemistry of Americium. This element has been shown to have the chemistry predominantly of a trivalent ion in solution. However, it has been possible under powerful oxidizing conditions to oxidize it to what is apparently the pentavalent state in mildly alkaline solution (carbonate solution). The compound formed has similar properties to pentavalent plutonium, that is, it has a very low solubility in carbonate solution. The compound can be dissolved in dilute acid solution where it is reduced by the water at a measurable rate. As a result its absorption spectrum has been taken and found to be distinctly different from that known for the trivalent state.

The conditions for preparing a lower oxidation state analogous to the divalent state of europium are being worked out but no unambiguous results have been obtained.

Two methods for performing the difficult separation of americium from rare earths and from curium have been worked out which do not involve alteration of oxidation states. One of these involves complex ion formation (chelation) with fluorinated diketones. In this case the americium

is more readily complexed and extracted into benzene than is lanthanum, a rare earth, but the separation from curium is not very effective. The procedure is of some importance in that lanthanum is present in the only present sources of americium. The second method consists of column adsorption on synthetic resins and selective elution according to procedures suggested by similar work at Clinton Laboratories. This method has been developed to give very fine separations and has allowed the quantitative removal of curium from americium and both from rare earth elements.

Other comparisons between the heaviest elements and the rare earths have been made with americium. These include relative affinities for fluoride ion, which information is valuable in precipitation processes involving fluorides. It has been found that rare earth ions form fluoride complexes and then precipitate more readily than does americium.

In non-aqueous systems AmF_3 has been prepared and its crystal structure determined by x-ray diffraction methods. Oxides of americium are also under investigation.

3. Chemistry of Neptunium. A program is under way to study selected phases of neptunium chemistry because of its importance as an element formed in piles and because it affords the best example of an element in which the pentavalent state is prominent. Among the results obtained so far are the preparation of compounds of neptunium(V), the finding that the neptunium(V) nitrate is not extracted into solvents that extract uranium(VI) and plutonium(VI), and the finding that insoluble fluorides will carry from solution appreciable quantities of neptunium(V). Other studies involve the preparation and determination of the crystal structure of oxides and halides of all oxidation states of neptunium.

4. Isolation and Chemical Properties of Curium. A small amount of americium was irradiated for many months in one of the Hanford piles, as a result of which a number of micrograms was transmuted to the 150-day Cm^{242} . By column adsorption methods the extremely small amount of curium was separated from americium, concentrated, and finally isolated as a relatively pure compound. This is the last of the known transuranium elements to be isolated. The availability of visible amounts of curium allows some measurements that cannot be made at tracer concentrations.

Spectrographic analysis was made of the preparation and it was found to be pure although limits of detection of impurities are of the order of several per cent with samples of the size used. In the measurement several dozens of curium emission lines were catalogued giving independent confirmation of the presence of a new element. Using micro-adaptors the absorption spectrum in solution was measured in a spectrophotometer. There was no detectable absorption in the visible spectrum but heavy absorption in the ultraviolet. These properties are what would be expected according to the actinide hypothesis for heavy element structure since curium falls in this series in the same position as gadolinium in the rare earth series, and gadolinium does not absorb light in the visible region.

The trivalent nature of curium deduced previously from tracer experiments has been confirmed from the properties of curium at high concentrations.

C. Nuclear Transformations with High Energy Particles

1. Spallation Reactions. "Spallation" is a new term to indicate nuclear processes in which a high energy particle gives energy to a nucleus which ejects many particles in dissipating the energy. The determination of spallation products gives information on the behavior of highly excited nuclei and results in the discovery of many new radioactive species not obtainable at lower energies. The work has taken the form of examining the reactions from bombardment of representative elements in different parts of the periodic table. These elements which are being bombarded along with their atomic numbers are uranium (92), bismuth (83), tantalum (73), antimony (51), arsenic (33), and copper (29). Most of the work to date has been done with uranium, antimony, arsenic and copper. Because of the extreme complexity of the processes resulting from irradiation with particles of hundreds of millions of electron volts energy, the generalizations that will become possible cannot yet be made.

Uranium-238 when irradiated with 200-Mev deuterons shows a long range of reaction products. Typical of these are ${}_{92}\text{U}^{230}$, ${}_{89}\text{Ac}^{225}$, ${}_{86}\text{Ra}^{223}$ (AcX), ${}_{85}\text{At}^{211}$, ${}_{79}\text{Au}^{196}$, ${}_{76}\text{Os}^{191}$, ${}_{75}\text{Re}^{186}$. It is apparent that some new phenomena are involved since over 50 units of mass have been removed which would be energetically impossible if they should come out instantaneously as neutrons and protons. Besides these spallation reactions, fission is also observed.

Reactions with bismuth and high energy deuterons have produced spallation reactions whose distribution is being followed. Also radioactive isotopes of bismuth of low mass are produced which emit alpha-particles. These are the lowest mass alpha-emitters known above lead and are therefore of interest in nuclear theory. Bombardment of bismuth with deuterons has produced another new type of nuclear process in which an element two higher in atomic number is produced, in this case ${}_{85}\text{At}^{211}$. The mechanism has not yet been proved but it is believed that high energy deuterons can eject alpha-particles from the bismuth, which themselves are of sufficiently high energy to react with other bismuth nuclei giving an element two greater in atomic number than bismuth.

Spallation reactions with antimony, arsenic and copper have shown that isotopes well below the target element and as far as some forty mass units lower can be produced. Also, for a particular product element, isotopes are formed that are both heavier and lighter than stable isotopes for that element. This means that competing reactions take place in which predominantly neutrons are ejected on the one hand and predominantly charged particles on the other. The sorting out of the yields of the many competing reactions will help in the understanding of nuclear reactions in general. In these studies a number of new isotopes have been produced as well as previously known isotopes by new mechanisms. Some of these new isotopes and others that will be found may prove to be valuable tracers.

2. Fission of Uranium and Thorium. The characteristics of heavy element fission were studied at medium energies (40-Mev alpha-particles) and at high energies (200-Mev deuterons and 400-Mev alpha-particles). One of the differences from slow neutron fission is the diminution of the valley between the peaks for the heavy and light fragments characteristic of asymmetric fission. With high energy induced fission a wide range of fission

products is obtained but the symmetrical cleavage seems to be nearly as probable as the asymmetric process.

3. Fission of Light Elements. It has been possible to produce the fission reaction in such elements as bismuth (element 83), lead (82), thallium (81), platinum (78), and tantalum (73), with high energy particles. Fission has been observed in one or more of the cases cited with alpha-particles, deuterons and neutrons. In the case of bismuth it is found that particles of about 50-Mev energy are required to produce fission in measurable yield. In general the probability of fission goes down with decrease in energy and with decrease in atomic number.

Most interesting is the apparent mechanism for the fission of these light elements. By measuring the distribution of fission products, it is found that the mass sum of the two fragments is smaller than the mass of the starting nucleus. Also neutron deficient fission products are noted, which is quite unlike the slow neutron fission of uranium. The mechanism proposed is that the fission process is preceded by the ejection of 10-15 neutrons from the highly excited compound nucleus. Theoretically a neutron deficient heavy isotope should undergo fission more readily and the experimental results would be explained.

II. Chemistry of Astatine

E. Segrè and R. Leininger

A. Introduction

Astatine 211 was used exclusively for the chemical studies. Carrier free samples were easily prepared by distillation of the astatine from the bismuth at 300-350°C and collection of the astatine in a U-tube at liquid nitrogen temperature. Solutions were prepared by dissolving the material in the U-tube in the appropriate solvent---nitric acid, water, or carbon tetrachloride. Yields as high as 90% have been attained for the entire process.

Since astatine 211 emits both α -particles and x-rays, the material may be easily detected. Unfortunately, astatine 211 has a short-half life (7.5h,) so that all work must be done on a tracer scale where results are often of difficult interpretation.

Since astatine is the heaviest member of the halogen family, it could be expected to have the general properties of a halogen and to resemble iodine more closely than the other halogens (bromine, chlorine, and fluorine). However in the last row of the periodic system, adjacent elements more often resemble each other than their lower homologs. In the case of astatine, the lower homolog is iodine and the adjacent elements polonium and radon.

The chemical properties of astatine and iodine differ markedly and a preliminary investigation of astatine chemistry by Corson, MacKenzie and Segrè in 1940 brought out mostly the metallic properties of astatine in preference to the characters common to the halogens. In the studies performed after the war, conditions have been found under which astatine behaves like a halogen and its analogy with iodine has now been investigated.

The investigation will be discussed under different headings. (B) Electrochemistry; aimed at a rough determination of the oxidation potentials and the charge of the ions in solution. (C) Volatility; a basic physical property essential to chemical studies. (D) Solvent extraction; a powerful tool for the investigation of halogen chemistry and (E) Chemical carrying experiments; useful when carefully applied in determining the actual ions present in solution. At the present time, we recognize the existence of four oxidation states of astatine.

The minus one state (astatide) has been produced by strong reduction and carries with silver iodide. It is a negative ion as indicated by migration experiments. It must be a negative oxidation state, since it may be produced from the zero state by reduction (see solvent extraction). Electrolytic experiments are contemplated for the future.

The zero state is soluble in water and organic solvents (see section on solvent extraction). The extraction coefficient for carbon tetrachloride is greater than 90 and for benzene is greater than 105. In basic solution the zero state disproportionates into At^- and some positive oxidation state

(possibly AtO_3^-). The oxidation potential of astatine zero to astatine +5 (astatate) is approximately -1.22 volts (see electro-chemistry).

The +5 oxidation state has been assigned after much hesitation. It is formed by dissolving astatine zero in concentrated nitric acid. If the formula of the acid were HAtO , from a knowledge of halogen chemistry we would predict that it would be very unstable and be a very weak acid $K_a < 10^{-12}$. On the contrary, it is very stable in solution and exists as a negative ion at all acidities (see electro-chemistry). Therefore, it is a strong acid. The iodine compound HIO_3 is very stable and a strong acid. The +5 state in acid solution is reduced at the cathode in electrolysis at -1.22v and oxidized at the anode -1.452. It carries under certain conditions with AgIO_3 .

The ion formed when the + 5 state is strongly oxidized is probably perastatate (AtO_4^-). It is carried more consistently by AgIO_3 than is astatate (AtO_3^-). The true nature of this fourth state is as yet uncertain. A fourth state, however, is necessary to explain the experiments with electrolysis (deposition at the anode.) A more detailed and technical description of the experiments follows. It must be borne in mind that all these experiments were performed on the tracer scale, a fact that adds considerably to the difficulty of interpretation.

B. Electro-Chemistry

The electro-chemistry of astatine has been studied in acid solution using the method of von Hevesy and Paneth (1) with the experimental refine-

(1) von Hevesy and Paneth, Wein. Ber. 123 1619 (1914)

ments of Joliot (2). The electrolysis was performed in a glass cell in the

(2) F. Joliot J. Ch. Phys. 27 1 (1930)

form of an inverted tee. The ends of the tee were fitted with thin gold windows which could be penetrated by the astatine deposited on the surface producing ions in the air beyond. These ions were collected by an electric field and the resulting current measured with a FP 54 electrometer. Using this apparatus the course of the electrolysis could be followed without disturbing the electrodes or solution. The initial deposition potentials for astatine in acid solutions have been determined for anodic and cathodic deposition.

Table I

Critical Deposition Potential of Astatine
at the Cathode from Various Solutions

Solution	Concentration of Astatine	Critical Deposition Potential
	Moles / liter	/ normal H ₂ Electrode
0.066 M HNO ₃	2 x 10 ⁻¹²	1.22 ± .005 v
1.0 M HNO ₃	5 x 10 ⁻¹³	1.245 ± .005 v
0.75 M H ₂ SO ₄	6 x 10 ⁻¹²	1.20 ± 0.02 v

The critical deposition potential is measured by determining the rate of deposition at various potentials and extrapolating to zero rate.

Table II

Critical Deposition Potential of Astatine
at the Anode in 0.066 M HNO₃

Astatine Concentration in	Critical Deposition Potential
Moles / liter	/ normal H ₂ Electrode
2.2 x 10 ⁻¹² M	1.44 ± 0.02
5.3 x 10 ⁻¹² M	1.45 ± 0.01

From these potentials we would expect astatine to dissolve in concentrated nitric acid to form an ionic compound but not in water or sulfuric acid. However astatine as the element is soluble in water and sulfuric acid (similar to I₂).

Migration experiments were attempted to determine the sign of the charged ions in solution, if any. The astatine compound was placed in the bottom of a U-tube made of 1 mm glass tubing with stop cocks at each end. The side arms of the U-tube were made of 10 mm glass tubing and were filled with an inactive solution identical in composition to the solution in the bottom of the U except for the astatine. The whole apparatus was placed in a thermostat and carefully leveled. A potential difference of 110v d.c. was applied across the migration cell between platinum electrodes for 1 hour. At the end of that time the solutions in the side arms were analyzed to determine the direction of migration. In all experiments the astatine migrated as a negative ion. Experiments were made in the following solutions. In all cases the astatine was initially dissolved in nitric acid.

5 M HNO₃
 .5 M HNO₃
 .1 M phosphate buffer pH 3
 .1 M phosphate buffer pH 7
 .1 M sodium hydroxide
 .1 M sodium hydroxide + 0.05M sodium sulfite
 .5 M HNO₃ + .1 M potassium persulfate

C. Volatility

Distillation experiments were run to determine the volatility of astatine and its compounds under various conditions. The various starting mixtures are listed in Table III.

Table III

Distillation of Astatine

Starting Material 10 ml Volume	Percent of Astatine in Distillate	Percent of Solution in Distillate
16 M HNO ₃	1.2	85
12 M HCl	17 a	60
60% HClO ₄	1.3	60
1:1 H ₂ SO ₄	1.7	75
1:1 H ₂ SO ₄ containing		
0.001 Ag ⁺ and 0.2 M K ₂ S ₂ O ₈	<0.1 b	83
5 M HNO ₃ +3 mg I ⁻	<2.0	c
0.5 M H ₂ SO ₄ and 0.05 M. FeSO ₄	70.	20
CCl ₄	<5.0 a	60

- a. Showed a progressive increase in the amount of astatine carried over into distillate.
 b. The persulfate was decomposing during this distillation. Boiling was very smooth with no bumping. Results up to 2% could easily be due to entrainment.
 c. A very small fraction of the total solution was distilled, however all of the iodine was in the distillate.

The volatility of drying and dried astatine samples was also investigated, since this was very important for our experimental techniques. A sample of astatine in nitric acid was placed on a platinum plate close to a γ -counter. The change in activity as the sample dried was noted. In

two experiments 26% and 28% of the activity disappeared as the samples dried. Subsequent experiments have shown that the nitric acid solution is a mixture of At° and At as a compound. The activity loss is no doubt due to the evaporation of At° .

Further volatility experiments have shown that samples of the astatine salt in nitrate solution dried on glass slowly lose activity due to evaporation, and that there is little or no loss of activity from this compound on Au or Pt.

Samples of At° prepared on glass show a rapid loss of activity, gold a smaller loss and Ag and Pt zero loss. Since these experiments indicated a varying affinity of astatine for various surfaces; the following experiment was run to check it. Six different common metals were cleaned and placed in a glass tube with a bombarded bismuth sample and the tube evacuated and sealed. The tube was heated for 1/2 hr at 325°C and cooled. The tube was then broken and the metal foils counted. The results are summarized below. Similar experiments were done with carrier free I_2 from Oak Ridge

Table IV

Relative Surface Affinities of Various Metals for At_0 and I_2 Vapors.

Metal	Percent of I_2 on Metal		Percent of Astatine on the Metal
	(1)	(2)	
Aluminum	0	0.3	0.17
Gold	0	0.9	0.12
Nickel	0	1.3	0.64
Copper	50	37%	0.57
Platinum	0.9	3%	33.6
Silver	49	57%	65.0

The affinities may be due to surface forces acting on the halogen atoms and holding them, or it may be due to compound formation. Distillation techniques allow the separation of extremely pure At from the bombarded Bi . In particular, by operating under controlled conditions, the Po can be separated out by a factor of better than 10^6 in relative alpha activity.

D. Solvent Extraction

Extraction experiments have been tried on astatine in carbon tetrachloride and benzene. The largest extraction coefficients found so far were obtained by repeated extraction of carbon tetrachloride or benzene solutions of astatine by 0.01 Molar nitric acid. These results are shown on following page.

Table V
Solvent Extraction Experiments

	Benzene / 0.01 M HNO ₃	CCl ₄ / 0.01 M HNO ₃
First Extraction	40	58
Second Extraction	83	86
Third Extraction	112	91
Fourth Extraction	106	
Fifth Extraction	89	

In addition, extraction of the carbon tetrachloride layer from the third extraction with 0.1 M NaOH yielded a coefficient of 0.85. When the basic water layer was acidified (0.1 M HNO₃) and the layers recombined and re-extracted the coefficient was 25.

Experiments as yet incomplete are attempting to determine how powerful a reducing agent is necessary to remove astatine from the carbon tetrachloride layer by the formation of an astatide (homolog of iodide). At the present writing Fe⁺⁺ is insufficient (benzene coefficient of 89) but acid SO₂ partially removes it (carbon tetrachloride coefficient of ~0.6).

E. Chemical Carrying Experiments

The At⁻ state has been produced in acid and basic solution. SO₂ or Na₂SO₃ are sufficient to reduce astatine so that it carries on AgI 90-100%. The regular nitric acid solution carries less than 2% on AgI. Under certain conditions both the nitric acid solution and the nitric acid solution strongly oxidized (HClO, K₂S₂O₈, O₃) carry on AgIO₃. In addition, all of the experiments described in the paper of 1940 have been verified, and the present experiments indicate that astatine has the metallic properties ascribed to it at that time.

III. Bio-Organic Chemistry

M. Calvin and B. Tolbert

A. Introduction.

The Bio-Organic Group of the Radiation Laboratory was organized primarily for the development of fields of research involving the long-lived radioactive isotope of carbon, namely carbon fourteen. It began activities early in 1946, and at that time most of its effort was expended toward the development of methods of preparing and isolating the radioactive isotope itself. These purposes having been accomplished, its present activities consist largely in the extension and development of fields of usefulness of the isotope.

The work of the laboratory can be roughly divided into three areas:

1. Synthetic and Experimental Chemistry. The synthesis of compounds containing the labeled atom in a known position - this is a preliminary step to practically all work involving the use of radioactive carbon. In the course of this work, it is often necessary to examine the mechanism of a variety of organic reactions and thus also to extend our fundamental knowledge of the chemical behavior of organic compounds.

The other two fields could be called:

2. Studies in Animal Biochemistry. Studies have been made in animal biochemistry particularly with reference to neoplastic diseases and the effects of radiation on metabolic processes.

3. Plant Biochemistry. Plant Biochemistry is the third subject which deals particularly with the problem of photosynthesis, for which the carbon isotope is the tool par excellence.

This last problem, namely, the mechanism of the conversion of electromagnetic energy into chemical energy by green plants, is not only of fundamental scientific interest but of great practical importance as well. A more detailed account of each of these three fields follows.

B. Experimental Data.

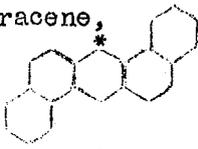
1. Synthetic and Experimental Chemistry.

(a) Synthesis of Organic Compounds. This preparation of labeled organic compounds has been investigated. This work is of considerable importance; before the carbon fourteen now available from Oak Ridge can be used, techniques must be developed for the conversion of the carbon to organic compounds that are of use to the chemical, biochemical, agricultural and medical research worker. Special procedures and synthetic methods have been developed to permit high yield synthesis, on a small scale, of many highly radioactive materials from carbon fourteen.

The following labeled organic compounds have been synthesized:

(1) Methanol and methyl iodide, CH_3OH and CH_3I , - intermediates for use in synthetic chemistry.

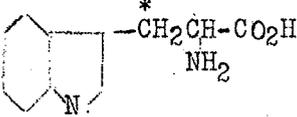
(2) Glycine, $\text{H}_2\text{NCH}_2\text{CO}_2\text{H}$ and $\text{H}_2\text{NCH}_2\text{CO}_2\text{H}$, - an amino acid and a metabolic intermediate in plants and animals.

(3) Dibenzanthracene,  - a carcinogen (that is, a cancer producing compound).

(4) Acetic Acid, $\text{CH}_3\text{CO}_2\text{H}$ and $\text{CH}_3\text{CO}_2\text{H}$, - metabolic intermediate, synthetic intermediate, and useful organic compound.

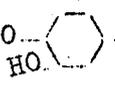
(5) Pyruvic acid, $\text{CH}_3\text{C}(=\text{O})\text{CO}_2\text{H}$, - metabolic and synthetic intermediate and useful in chemical studies.

(6) Formaldehyde, HCHO , - synthetic intermediate and useful in chemical studies.

(7) Tryptophane,  an essential amino acid.

(8) Toluene,  - chemical intermediate, used in chemical studies.

(9) Propyl alcohol, propyl bromide and propylene, $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$, $\text{CH}_3\text{CH}_2\text{CH}_2\text{BR}$, $\text{CH}_3\text{CH}=\text{CH}_2$, - chemical intermediates and used in chemical studies.

(10) Dihydroxyphenylalanine (Dopa),  - an amino acid like precursor of melanin, one of the major constituents of certain types of tumors.

(11) Tyrosine, CH_3O -  - an amino acid.

(12) Indol-3-acetic acid,  - a plant growth hormone.

(13) Lactic acid, $\text{CH}_3\text{CH}_2\text{OHC}_2\text{H}_4\text{CO}_2\text{H}$, - a metabolic intermediate.

In addition to these compounds listed, some 50 or 60 other labeled compounds have been prepared, mostly for use as synthetic intermediates.

A book is being written by five members of the synthetic group on the techniques of isotopic carbon work. The book is to be published by John Wiley and Sons and will appear sometime in 1948. The book, designed as an advanced laboratory manual on isotopic carbon, deals with this subject in

all of its practical phases from a review of the experimental applications to a detailed discussion of the measurement of isotopic concentrations, published syntheses of labeled organic compounds (both biological and chemical), and degradation methods.

(b) Carbon Fourteen Recovery. A study has been made to determine possible methods for recovery of carbon fourteen from beryllium nitride which has been radiated with slow neutrons. This compound is one of the best for the production of carbon fourteen in piles because of its excellent nuclear properties, as well as its physical and chemical properties. It has been found that it is possible to recover the carbon fourteen from beryllium nitride with at least 95% overall yield. The procedure developed involved dissolution of the beryllium nitride in acid solution and oxidation of the organic compounds to carbon dioxide with chromic oxide. Volatile compounds were oxidized in a hot furnace with copper oxide. This procedure was done on a large laboratory scale and the conditions for plant operation outlined. A patent has been applied for on this work by the Atomic Energy Commission.

(c) Propylene Isomers. A study has been made of the isomerizations that occur in the synthesis of propylene. This work is of interest to practical as well as theoretical chemists for isomerization reactions are extensively used in industrial chemistry. Three methods have been studied:

- (1) Dehydration of propyl alcohol with metaphosphoric acid.
- (2) Dehydration of propyl alcohol over heated alumina at 400° C.
- (3) Pyrolysis of n-propyl trimethyl ammonium hydroxide.

The dehydration experiments both showed extensive rearrangement. In the use of metaphosphoric acid, an equilibrium mixture of the two isomers, $\text{CH}_3\text{CH}=\text{CH}_2$ and $\text{CH}_2\text{CH}=\text{CH}_2$, was obtained, while the alumina gave a product that showed over 50% rearrangement. The pyrolysis of the quaternary ammonium hydroxide gave practically pure 1-labeled propylene.

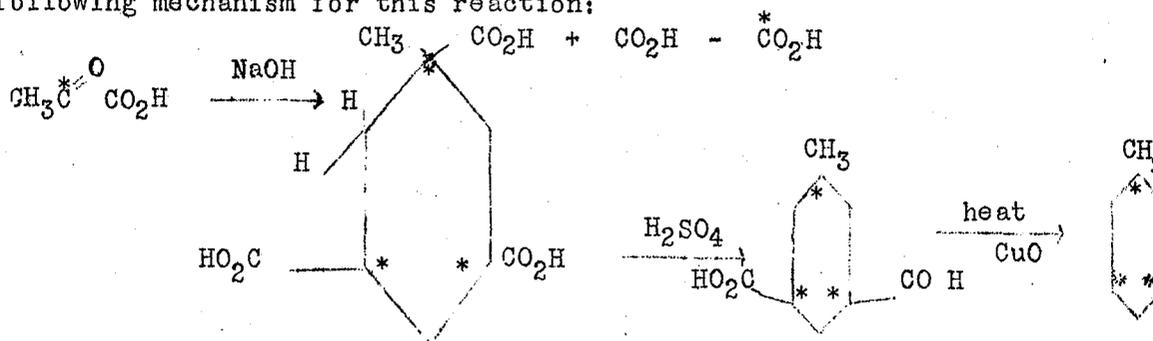
In conjunction with this work, the mechanism of the oxidation of propylene with KMnO_4 was studied. It was found that at 25° C and pH 4 some 70-80% of the propylene is split at the double bond giving acetic acid and carbon dioxide, while the rest of the propylene seems to be split at the single bond, giving carbon dioxide and oxalic acid.

(d) Carbon Fourteen Beta Emission. Isotopic tracer work using carbon fourteen is often hindered because the beta particles which carbon fourteen emits are so weak that a large fraction of them are absorbed in the material of the sample. A study has been made of a general method whereby accurate corrections can be made for this 'self-absorption'. This work has been applied to barium carbonate and a study by this method showed that the calculated and observed absorption of such samples can be correlated

within the counting error, which for the experiments mentioned was less than 0.5%. A study was also made of geometric efficiency of counters.

(e) Carbon Fourteen Production. In the neutron irradiation of beryllium nitride, the carbon fourteen produced is found in a number of different chemical forms. The nature of these radioactive forms has been investigated and the approximate yields determined. Irradiations of Be_3N_2 powder at a Hanford pile for several months gave, on acid solution of the powder, the following carbon-containing compounds: methane, carbon monoxide, carbon dioxide, hydrogen cyanide, methanol and formic acid. Formaldehyde was not found. The distribution of the activity was not affected by the acidity of the solvent.

(f) Toluene Preparation. The preparation of ring labeled toluene from pyruvic acid has been studied. Earlier workers have proposed the following mechanism for this reaction:



The activities of the radioactive intermediate compounds and of the products isolated in the synthesis were found to agree with the activities that would be calculated if one assumes the above mechanism.

(g) Decarboxylation of Ethyl Pyruvate. The decarboxylation of α -keto esters has importance in synthetic chemistry and related reactions are widely postulated in biochemical mechanisms. The thermal decarboxylation of carbon fourteen carbonyl-labeled ethyl pyruvate has been studied. It was shown that the evolved carbon monoxide came from the carboxyl group of the α -keto ester.

2. Biological Chemistry. Biochemical studies have been made in three fields; (a) the metabolism of carcinogens and the mechanism of induction of cancers (b) the metabolism of amino acids and compounds that could localize in some types of cancerous tissues (c) the rate of oxidation to carbon dioxide of simple amino acids and biological intermediates.

(a) Carcinogen Studies. The study of the mechanism of production of cancers may lead to some information on how to cure and prevent them. The use of carcinogens, chemical cancer producing compounds, is particularly useful in this work; thus, 1,2,5,6-dibenzanthracene, a carcinogen, was prepared labeled with carbon fourteen in the 9 position. The biological distribution of the radioactivity found in the mouse, after

administration of this compound, was studied and the effect of different modes of administration observed. Intravenous, subcutaneous, stomach tube and intraperitoneal injections were made with a total of 15 mice and the total dose accounted for in the mouse and excreta. It was found that little material is absorbed in the tissues and that most of the compound is rapidly excreted; however, tumors produced by the dibenzanthracene had appreciable amounts of radioactivity six months after subcutaneous injection. In intravenous injections, the elimination is entirely through the bile. There is a very rapid metabolic degradation of the dibenzanthracene to water soluble substances by the body.

(b) Selective Localization Experiments. Work has been carried out to investigate the possibility of finding a compound which will localize in cancerous tissue. If much localization could be brought about, it might be possible to kill the tumor by administrations of a suitable compound containing radioactive carbon atoms in its molecule. The compound would enter the tumor and the radiations from the carbon would cause recession of the tumor. Because of the heavy formation of pigment in melanomas (black cancer), compounds from which it is thought that pigment is formed in the tissue have been synthesized using carbon fourteen and fed to mice bearing these growths. Three of these compounds, tyrosine, dihydroxyphenylalanine and tryptophane, have been synthesized containing radioactive carbon.

It has been found that tyrosine does form the pigment in the tumor. Unfortunately, it enters other tissues than the tumor. Consequently, its use as a drug against melanoma is not practical since it would destroy healthy tissue as well as the tumor. Contrary to expectations, dihydroxyphenylalanine does not form pigment when injected into experimental animals. The investigation with tryptophane has not yet reached the point where any definite conclusions can be drawn.

(c) Elimination Studies. A study was made of the rate of elimination of radioactivity in the carbon dioxide in respiration of mice given small amounts of carboxyl-labeled acetic acid, methyl-labeled acetic acid, carboxyl-labeled glycine, and plant-synthesized glucose. Studies were made with both normal and tumor bearing mice. Present data indicate the elimination is made up of two processes - one fast and one slow. Thus for carboxyl-labeled acetic acid, the half time for the slow elimination is about 180 minutes and that for the fast elimination about 10 minutes. About 80% of the activity is eliminated by the fast process and 20% by the slow process. The other compounds are eliminated more slowly than acetic acid. There seems to be some difference in this elimination rate between normal and cancer bearing mice. If this can be confirmed and extended, it would provide not only a very valuable diagnostic method, but also a deeper insight into the biochemical behavior of neoplastic tissue.

3. Photosynthetic Chemistry. Photosynthesis is the process, or processes, by which plants convert carbon dioxide from the air in the presence of sunlight into organic plant material. The chemistry of this fundamental phenomenon has been studied for a long time, but it is not yet fully understood. The application of tracer chemistry to the problem has opened new lines of attack and new and startling results have been discovered. The procedure generally used is to feed the plants radioactive carbon dioxide or other synthetic intermediates and then isolate from the plant the compounds that contain radioactivity. By this process, the actual compounds synthesized from the carbon dioxide of the air can be isolated and distinguished. Eventually, all or most of the fundamental processes of photosynthesis can be detailed.

(a) Isolation of Intermediates. One of the primary problems of this work, then, is to isolate the active photosynthetic intermediates that are produced on feeding active carbon dioxide. Procedures have been developed here for the isolation of three types of important radioactive compounds: sugars, amino acids, and organic plant acids.

The radioactive sugar thus isolated has been used by other workers for the study of metabolism in normal, cancerous, and diabetic animals. A method has been developed for the determination of the distribution of carbon fourteen fixed in the six carbon atoms of the sugar molecule. This distribution is indicative of the method of synthesis of the sugar by the plant in photosynthesis. The results show that sugar is formed by the union of two 3-carbon intermediates and that the intermediates are formed by successive addition of $C^{14}O_2$ to the precursors. The study of the nature of these precursors will be mentioned shortly.

By use of the new ion exchange resins, the types of amino acids formed in photosynthesis have been isolated. The major amino acid formed in the dark is alanine. This compound has been degraded chemically and has been found to have the same distribution of radiocarbon as is in the sugar synthesized by the plant. This indicates that another compound, pyruvic acid, is in equilibrium with the alanine and that pyruvic acid is an intermediate in photosynthesis. Organic acids have been isolated by use of a silica gel adsorption column. The method has been developed to extend the number of known intermediates of photosynthesis which are plant acids.

(b) Effects of Light. As has already been mentioned in this review, certain precursors are synthesized by the plant in the presence of light which can pick up carbon dioxide in the first step of photosynthesis. By studying the absorption of carbon dioxide by plants in the dark, it has been possible to establish a tentative mechanism of this heretofore obscure process.

By use of this technique, the relationship of the dark fixation of carbon dioxide to photosynthesis has been studied and one of the major radioactive constituents synthesized by plants in the dark has been isolated. This was done by following the compound in question, by virtue of its radioactivity, until it was obtained in the pure state and identified

as succinic acid. A chemical degradation of radioactive succinic acid has been developed to determine the location of the labeled carbon atoms. Succinic acid formed in the dark normally is labeled only in the end carbon atoms - the carboxyl groups.

An investigation of the effect of pre-illumination, without carbon dioxide, upon the ability of plants to fix carbon dioxide in the dark has been made. This work is of interest, not only to aid in the isolation of the maximum yield of photosynthetic intermediates, but also in the nature of the photosynthetic process in general. This work has shown that plants are able to store reducing power, which can convert carbon dioxide to sugar, for a considerable length of time and that the absorption of light is not directly connected with the reduction of carbon dioxide. By strongly illuminating plants previous to administration of radioactive carbon dioxide in the dark, it has been shown that 10 to 16 times as much carbon dioxide can be reduced and at least fifty times as much radioactive sugar is formed in the dark as in plants not pre-illuminated.

The rate of growth of this reducing power upon illumination and the rate of decay upon cessation of illumination has been determined. At the period of maximum stored reducing power, the rate of carbon dioxide uptake is very nearly that of photosynthesis under optimal conditions. This is additional evidence that there is a dark phase of the photosynthetic process. Intermediates formed in the dark after strong pre-illumination, have been found to differ greatly from those formed without pre-illumination. Succinic acid isolated has been found to contain radioactivity in the methylene carbon atoms in addition to the carboxyl carbons. Alanine isolated also has been degraded and found to contain 10% of its radioactivity in the alpha carbon atom and 90% of its activity in the carboxyl carbon atom.

Degradation of sugar formed in the dark under these conditions indicates that 90% of the activity is in the carbons 3 and 4 and 10% is in the carbons 2 and 5 of the glucose molecule. This sugar is the first isolated sugar that has been synthesized by plants in the dark. The distribution of radiocarbon in these photosynthetic intermediates is indicative of the mechanism of photosynthesis. A tentative mechanism has been worked out and experiments planned to confirm or disprove the mechanism.

(c) Phosphorous. The role of phosphorus in photosynthesis has been studied using radiophosphorus as a primary tool. It has been shown that phosphorylation, an essential process in metabolism, is not directly involved in photosynthesis. Methods have been developed for studying the rate of exchange of radioactive phosphate ions with the organic phosphate cell constituents of the working plant. No difference in rate was found upon illumination of the plant.

(d) Chlorophyll. The role of chlorophyll in photosynthesis has been studied using heavy water which contains marked hydrogen atoms. Using heavy water, it has been shown that chlorophyll has hydrogen atoms which are replaceable by deuterium during periods of photosynthesis. This may indicate the chlorophyll is engaged as a chemical as well as a physical agent in photosynthesis.

The phosphorescence of both chlorophylls a and b have been studied to determine the nature of the excited state of this molecule and its possible relation to photosynthesis. Only chlorophyll b has been found to have a measurable lifetime, about 0.03 seconds. A theory as to the nature of this excited state has been proposed, namely a triplet state.

IV. Thermodynamic and Basic Chemistry.

W.M. Latimer

A. High Temperature Thermodynamics and Metal Studies.

The most important accomplishment in this work has been the systematic investigation and tabulation of the properties of uranium and the trans-uranic elements and their compounds at high temperatures. This includes vapor pressures, decomposition pressures and important equilibria which would permit the calculation of the stable molecular species under widely varying experimental conditions up to 2000°K.

Another phase of the work has been the evaluation of thermodynamic data which may have direct application to high temperature pile operation. Examples of these are the determination of the vapor pressure and heat of sublimation of graphite, the determination of heat transfer coefficients in film boiling, and the evaluation of the Free Energy function for many elements and compounds up to 5000°K.

Definite advances have been made in the production of refractories, particularly sulfides, oxysulfides and carbides.

Progress has also been made in the study of low melting uranium alloys which may be useful in homogeneous liquid piles.

Various problems under investigation for which published reports have not been written are summarized below.

1. Heat of Formation of CN and Absorption Coefficients of CN and C₂. The heat of formation of CN gas from the elements is being determined by a spectroscopic method similar to that used for C₂. Also the relative emission probabilities of CN and C₂ are being determined to obtain their relative absorption coefficients. This work is almost completed.

2. Heats of Formation of Gaseous Species by Spectroscopic Method. Preliminary work has been done to test the application of the spectroscopic method used for C₂ and CN to the following gaseous species: CH, CF, CCl, CS, MoO, MoCl, SiO, AlO, TiO. The preliminary work has indicated that modifications of the method will be required for every one of these species and modification of the method and materials of construction are under way to allow such molecules to be studied.

3. Study of Gaseous Hydroxides. Preliminary work has been done to examine the possibility of studying gaseous hydroxides at high temperatures. A number of obstacles, namely lack of materials of construction, have been found. Work is in progress to remove these obstacles and to construct apparatus for such studies.

4. Oxide Phase Diagram Studies. The following oxide systems have been studied by x-ray methods: Mo-O, W-O, Zr-O, Ta-O, Al-O, and Si-O. It has been demonstrated that no x-ray patterns can be found for oxide phases below the tetravalent oxide in the Mo, W, Zr, and Ta systems. Work on the Al and Si systems is still in progress. No stable lower oxides have been found in the solid phase. It is being attempted to prepare AlO and SiO solids in a metastable form by condensation from the gas. A study of HfO₂ was made and it was shown that the stable form at room temperature is the monoclinic form rather than the cubic form usually given.

5. Sulfides and Oxide-Sulfides. HfS₂ and HfOS have been prepared and their x-ray structures determined. Also, some CeS crucibles have been prepared.

6. UCl₄ - UBr₄ Phase Diagram. An apparatus was set up to study the UCl₄ - UBr₄ phase diagram to determine if distinct mixed halides exist. No satisfactory results have been obtained yet. Work is suspended now until the apparatus can be modified.

7. Thermal Conductivities. An apparatus was constructed to determine thermal conductivities and the conductivities of CeS, UC, and UN determined.

8. Fission Product Studies. Calculations were made on the effect of fission products on metal, carbide, nitride, and oxide systems with respect to change in melting point and volatility. Experiments were run with mixtures of UO₂ and fission products which indicated that the melting point of UO₂ is not appreciably lowered by the presence of fission products until the uranium is largely converted to fission products. A new value for the melting point of UO₂ has been obtained.

9. Heats of Formation of Metal Compounds. The high temperature calorimeter is being used to determine the heats of formation of NaSn and similar compounds.

10. Low Melting Uranium Alloys. The ternary phase diagrams of the Na-U-Sn and Na-U-Bi systems are being studied. X-ray studies have been made to determine the various phases of importance. New dry box techniques have been worked out to handle these systems. Analytical methods have been worked out. Cooling curves are in progress.

11. Production of Refractory Carbides. Fabrication methods for TiC, ZrC, CbC, and TaC are being developed. The reaction of graphite with TaCl₅ and hydrogen as well as the reaction of tantalum with hydrocarbons are being used.

12. Diffusion Studies. A study has been made of the various diffusion errors involved in high temperature gaseous equilibrium measurements, and methods of minimizing these errors have been devised. Experiments are being considered to determine the effect of thermal diffusion on distribution of materials in solids.

13. Induction Heating Theory. Further studies have been made of induction heating under various conditions and the theory further developed.

14. Testing of Optical Pyrometers. The theory of the application of optical pyrometers to temperature measurements has been studied and experiments devised to test the accuracy of measurements at high temperatures. Various sources of error have been found, and further experiments are in progress in an attempt to eliminate them.

15. Cuprous Halide Gaseous Species. The species existing in cuprous chloride vapor have been shown to be CuCl and Cu₃Cl₃. The vapor pressure of cuprous chloride and the thermodynamic properties of the various species have been determined. It has been shown that cuprous bromide vapor behaves in a manner similar to that of cuprous chloride. The work is expected to be completed shortly with a check of the equilibria involved by a spectroscopic method.

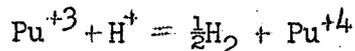
B. Basic Chemistry Including Solvent Extraction by Chelate Formation.

The solvent extraction and decontamination of plutonium from Hanford uranium slugs has been carried through a semi-works program using one liter quantities. Employing the TTA chelate in benzene, 98.7 per cent recovery was obtained with a beta decontamination factor >10⁷. Fundamental studies have been completed on the chemistry of the process including the nature of the chelate formed with important fission products.

Various studies have been completed on the thermodynamics of uranium and plutonium in aqueous solutions. The data obtained permit an accurate calculation of the equilibria involving the oxidation states and are important from the standpoint of analytical and process chemistry.

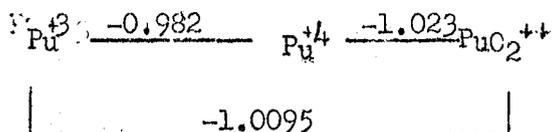
Other research programs completed or partially completed but not published follow.

1. The Pu(III) - Pu(IV) Potential. The e.m.f. for the Pu(III) - Pu(IV) couple in perchloric acid was redetermined and the previously reported value was shown to be in error. The potential of the reaction



in 1M HClO₄ at 25°C was measured to be -0.982 ± 0.001 volts. The new value removes the apparent anomaly that Pu⁺⁴ was being complexed more by ClO₄⁻ than by Cl⁻.

Combining the above value with equilibrium measurements the following potential scheme was obtained where all values refer to the potential of the indicated couple versus the H₂ - H⁺ couple at 25°C in 1M HClO₄ solution.



A value of -46.1 entropy units for the difference in entropy of Pu^{+4} and Pu^{+3} in 1M HClO_4 was obtained by studying the potential of the above reaction as a function of temperature.

2. Solvent Extraction. The extraction properties of Zr(IV), La(III), and U(VI) in the benzene - TTA system have been determined.

Attempts have been made to determine the species of U(VI) nitrate which extracts into ether. The compound was shown to be non-ionized in the system and probably contains H_2O .

3. Rate of Exchange of Iodine Between I_2 and IO_3^- . The rate of this reaction was found to depend on the 0.6 power of the I_2 concentration and the 0.8 power of the IO_3^- concentration. The dependence on hydrogen ion concentration is being investigated but is complicated by the weakness of HIO_3 .

4. Activity Coefficients of Pu^{+4} Salts. The activity coefficient of $\text{Pu}(\text{ClO}_4)_4$ in various perchloric acid solutions has been determined by studying the distribution of Pu^{+4} between an aqueous perchloric acid phase and a benzene phase containing TTA. The activity coefficient passes through a minimum at ca. 0.5M HClO_4 . At 9M HClO_4 the γ^\pm for $\text{Pu}(\text{ClO}_4)_4$ is ca. 800 times the minimum value.

5. Zirconium Species in Aqueous Solution. The degree of hydrolysis of Zr^{+4} in aqueous perchloric acid solutions has been studied by measuring the extraction of Zr(IV) into benzene solutions containing TTA. Preliminary results indicate that at approximately 1M HClO_4 there are between one and zero hydroxide groups on the Zr^{+4} .

6. U(VI) Species in Aqueous Solution. The work of King on the U(VI) species in aqueous solution is being checked to try to explain certain anomalies in his results. The method used is to measure the extraction coefficient of U(VI) into benzene containing TTA and determine the H^+ dependence. King's values did not correspond exactly to whole numbers but agreed fairly well with the formula UO_2^{++} up to 1.5M H^+ . The measurements will be extended to lower acidities. A new species present in the benzene phase has been identified as the uranyl chelate with an additional TTA attached.

7. Graduate Training. This research has been carried out almost entirely by graduate students under staff direction and this constitutes a training program for project men. We regard this as one of the most important contributions.

I. Biological Program for Project 48-A-1 and the
60-inch Cyclotron of Crocker Laboratory

Joseph G. Hamilton, M. D.

Introduction.

The biological research program of Project 48-A-1 is concerned primarily with the study of the metabolism of the fission products and of the fissionable elements extending from actinium to curium. During the current year, a detailed study has been made of the metabolic characteristics of seven of the fission products and three of the fissionable elements. In addition to the direct tracer studies, a great deal of work has been done in the field of radioautography for the purpose of investigating the relationship between the microscopic anatomy of certain tissues, notably bone, and the deposition of those fission products which accumulate in these structures. There has also been an extensive study of ways and means of combating possible poisoning, both from the long-lived fission products and plutonium. This work has taken two different channels of approach, one, research for agents which may either increase the rate of elimination of these substances or decrease their absorption should they gain entry into the body by inhalation or through cuts or abrasions. The other phase of this work has been the successful development of dietary regimes which made possible the covering up of a considerable fraction of plutonium by new bone formation. This procedure should reduce the radio-toxicity of this element to some degree because of the short range of the alpha-particles emitted by it. Over and above the regular biological program, a significant fraction of total effort of the group on Project 48-A-1 was devoted to the development of successful methods of the decontamination of the Navy Task Force vessels which had become contaminated with radioactivity as the result of the Bikini tests. During the present year, six regular officers, four from the Navy and two from the Army, have received extensive training in the field of radioactivity, radio-chemistry, and the general biological and medical aspects of nuclear energy.

A. Metabolic and Radioautographic Studies

The metabolic studies, which are quite detailed in character, include a careful survey of the absorption, distribution, retention and excretion of the following radio-elements: arsenic, silver, cadmium, indium, tin, antimony, element 61, actinium, americium, and curium. Rats were the experimental animals usually employed and they received the individual radio-elements in the carrier-free state by both intramuscular and oral administration. The animals were sacrificed in groups of three at 1, 4, 16, 64, and 256 days after receiving the different radioactive materials. Throughout the various time intervals, daily collections of the urine and feces were made. Fifteen to twenty of the different organs and tissues, as well as the excreta, were individually assayed for their content of the administered radioactive element. In addition to these tracer studies, radioautographic studies were made in considerable detail to study the distribution of these administered agents in those tissues where a high

degree of selective accumulation took place.

1. Metabolism of Element 61. The metabolism of element 61, as might be expected from its close chemical relationship to other members of the lanthanide rare earths, was almost indistinguishable from the behavior in the rat of lanthanum, cerium, and praseodymium. The most significant metabolic property of element 61 was its high degree of deposition in the liver and in the skeleton following intramuscular administration. The fraction of element 61 accumulated by the liver, which was initially 75 percent of its amount in the body, was released at a relatively rapid rate. The approximate half-time of its retention in this organ was of the order of ten days. The fraction of this element deposited in the skeleton was approximately 20 percent of the total amount absorbed following intramuscular injection, but unlike the liver, no appreciable release of this element from the skeleton was noted over varying intervals of time, which now extend to more than two months. The radioautographic studies of the bone from animals which had received element 61 reveal that most of the material was deposited in the region of the osteoid matrix adjoining the bone marrow and, in addition, there was a significant fraction present in the region of the small blood vessels of the dense cortical bone. The presence of significant amounts of element 61 in the region of the small blood vessels has also been noted with cerium and presumably would be observed with lanthanum and praseodymium were their half-lives of sufficient lengths to permit the preparation of satisfactory radioautographs. This same effect of localization about the small blood vessels has been noted with americium and curium. It was of considerable interest to note that the relative uptake of americium and curium in the liver and skeleton, as well as the curious radioautographic pattern in the bone, was indistinguishable from the behavior of the four lanthanide rare earths which have been studied to date. In other words, in the body there is no perceptible difference between the metabolism of americium and curium and the lanthanide rare earths, thus they are all highly dangerous materials once they gain entry into the body. These observations are notable in the view of the close resemblance in chemical properties which americium and curium bear to the rare earths. As might be expected from the earlier experiences with lanthanum, praseodymium, and cerium, element 61 as well as americium and curium are not absorbed in any appreciable amounts from the digestive tract.

2. Metabolism of Radioarsenic. The metabolism of carrier-free radioarsenic in the rat has shown that this substance shows a very high degree of concentration in the hemoglobin fraction of the red cells and is retained there for a period of many weeks. This property has been noted to a less striking degree in some work done before the war in which carrier-free material was not employed. Excretion took place primarily by way of the digestive tract and no very striking degree of selective localization took place in any of the tissues except in the red cells. In an attempt to evaluate the possibility of species difference, less detailed but comparable studies were made with chicks, guinea pigs, rabbits, cats, and dogs. The highest level of concentration

in the blood noted with these animals was of the order of 2 percent of the administered dose in the cat, as contrasted to nearly 50 percent in the rat in a comparable time interval.

3. Metabolism of Carrier-free Silver. The metabolism of carrier-free silver reveals that this element, following intramuscular administration, is excreted with extreme rapidity and the digestive tract acts as the chief channel of elimination. Nearly 95 percent is excreted within 24 hours after administration. No significant degree of selective localization took place in any of the other structures in the bone, including the skin under the conditions of these experiments. Less than 1 percent was found to be absorbed from the digestive tract following administration by stomach tube. In view of the very rapid excretion of material from the digestive tract, it was thought possible that carrier-free silver was excreted by way of the bile. In order to evaluate this point, rats, which had previously been subjected to bile duct ligation, were given radio-silver by intramuscular injection. Within 48 hours, approximately 60 percent of the administered silver was found to be present in the liver, which indicated that when the bile duct was blocked the silver accumulated in the liver. Appreciable amounts were present in both the digestive tract and the feces, which suggested some excretion apparently took place by other routes, possibly by way of the pancreas.

4. Metabolism of Radio-cadmium. The parenteral administration of carrier-free radiocadmium is followed by a striking degree of localization in the liver, kidney, thyroid, pancreas, and adrenals. Excretion is apparently slow and occurs by way of the intestinal tract. It is quite unlikely that the high uptake of radiocadmium by the liver is due to the entrapment of this material by the reticulo-endothelial system inasmuch as the content in the spleen was found to be negligible. The concentration in bone was found to be roughly one-hundredth that of the liver on a per gram basis.

5. Metabolism of Carrier-free Indium. The intramuscular administration of carrier-free indium reveals that in the earlier time intervals up to 16 days, that the highest concentration takes place in the liver, spleen, and kidneys, and excretion is fairly rapid, taking place primarily by way of the digestive tract. At the later time intervals, the organ showing the highest degree of accumulation, both on a per organ and per gram basis, is the skin. A rather significant fraction of indium is accumulated in the skeleton and its per gram uptake is of the order of one-third of the concentration in the liver, kidney, and spleen.

6. Metabolism of Carrier-free Tin. The tracer studies with carrier-free tin are of such an incomplete nature at the present time that about all that can be said at the moment is that this element distributes itself rather uniformly throughout most of the tissues and the skeleton.

7. Metabolism of Radioantimony. Carrier-free radioantimony is excreted with a surprising degree of rapidity following intramuscular administration, approximately 95 percent being eliminated in the rat within the first 24 hours, with the kidneys acting as the principal channel of elimination. It is of

interest to note that the organ showing the highest degree of initial concentration, as well as the most marked degree of retention, is the blood. While the various observations for the earlier time intervals are of the order of one-twentieth that noted with carrier-free radioarsenic, it is of interest to note a qualitative similarity between these two elements that belong in the main series of Group 5 in the periodic table.

8. Metabolism of Actinium. The tracer studies with actinium are very incomplete at this moment due to the fact that several months must elapse to permit the attainment of the radioactive equilibrium of its radioactive descendants, notably thorium 227 (half-life, 18.9 days), and radium 223 (half-life, 11.2 days). Preliminary results, however, suggest that the distribution of actinium in the body will follow very closely that of the lanthanide rare earths in that most of the activity is present in the liver and bone.

Many of the tracer studies described above are investigations in progress and do not represent completed studies. Thus, there may be certain quantitative reservations to be applied to the statements presented, but the qualitative picture of their metabolic characteristics are felt to be quite firmly established.

9. Radioautographic Studies. The most significant of the radioautographic studies made during the past year has been the demonstration of the almost identical microscopic distribution in the bone of curium, element 61, americium, and cerium. These differ remarkably from the pattern noted with plutonium in that a significant fraction of the four elements noted above is deposited in the region of the small blood vessels of the mineralized structure of the bone. This behavior is in sharp contrast to the localization of plutonium in the bone where almost all of the activity is confined to the region of the membrane which covers the inner and outer surfaces of the bone. Radioautographic experiments with thorium, done during this interval, show that this radioelement, thorium 228 being used for the studies, is laid down in the bone in such a manner as to form a pattern which is indistinguishable from that of plutonium. The fact that plutonium shows a relatively small uptake in the liver and has a radioautographic pattern of distribution almost identical to that of thorium, makes it appear highly probable that plutonium exists in the animal body in a valence of plus 4, regardless of the valence state of its administered compounds.

10. Development of Radiochemical Techniques. One of the most time consuming and difficult obstacles that had to be met in this program for the current year was the development of satisfactory radiochemical techniques to make possible isolation of radiochemically pure and carrier-free radioactive isotopes of silver, cadmium, indium, tin, and antimony. These five elements were made by the transmutation of adjoining stable elements by deuteron and alpha-particle bombardment using the 60-inch cyclotron at Crocker Laboratory. A successful procedure for the isolation of technecium from the deuteron transmutation of molybdenum was developed. Work is still in progress to develop a quantitatively accurate and

reproducible procedure for the isolation of this quite volatile element from biological materials.

11. Effect of Metabolic States on Deposition and Retention. The investigation of the effect of normal and various pathological metabolic states upon the deposition and retention of representative members of the long-lived fission product group and the actinide elements has been in progress. Rickets will reduce the deposition of radiostrontium in the skeleton by a factor of almost ten-fold, whereas the corresponding alternation of deposition and retention of plutonium, radiothorium, zirconium, and cerium is so small as to fall within the limits of experimental error. This is another link in the chain of evidence to support the contention that the mechanism whereby the rare earths, zirconium, and the actinide rare earths are deposited in the skeleton is totally different from the biochemical phenomena responsible for the mineralization of bone by the alkaline earth group elements, notably, calcium, strontium, barium, and radium. It has been shown in these studies that the deposition of barium and radium follow very closely the distribution noted in the accumulation of strontium in the skeleton following pathological metabolic disturbances noted in rickets and profound phosphorus deficiencies; as well as the normal variant of age. It is of interest to note in passing, in the study of the kinetics of the deposition of strontium in the skeleton, that this process proceeds with extreme rapidity and at an apparent exponential rate of a half-time of 30 minutes following the intravenous administration of this fission product.

12. Metabolism of Plutonium. Attempts to influence both the total accumulation in the skeleton and the excretion of plutonium have met with rather poor success. No significant action was noted following the administration of large doses of BAL (British anti-*lewisite*) and cysteine. If the skeletons of rats which had previously been given plutonium are depleted of calcium and phosphorus by a phosphorus deficient diet, no significant increase of plutonium excretion is noted. However, if the animals are then given a normal diet containing adequate amounts of phosphorus and calcium, the new bone that is laid down will cover up a considerable fraction of the plutonium. This overlaying effect should serve to prevent to an appreciable degree the irradiation of radiosensitive bone marrow by the plutonium alpha-particles since their range of penetration is very small. This is the only procedure to date which shows any possibility of therapeutic application.

It should be pointed out that our status of knowledge concerning the metabolism of plutonium is still essentially empirical in character. We know that it is laid down in the skeleton by a series of mechanisms very different from those responsible for the accumulation of calcium, as well as the other alkaline earth elements. It seems probable that it is fixed in a protein rather than being directly incorporated into the mineral structure of the skeleton. Much fundamental knowledge must be obtained concerning this unique behavior, not only of plutonium but other members of the actinide elements, as well as the lanthanide series of rare earths, zirconium, and yttrium.

B. Decontamination Studies.

The major part of the work concerned with the development of methods for the decontamination of Naval Task Force vessels which became radioactive after Test Baker, Bikini, was accomplished prior to January 1, 1947. However, during the interval from January to June 30 of this year, the results of the experimental work done earlier were drawn together and turned over to the Navy in such form as to make possible the successful application of these procedures to most of the contaminated Task Force ships. In addition to this, a large number of animal studies were made of the plutonium and fission product ratios in a variety of samples from Bikini and contaminated areas of the Task Force vessels. This was done partly to secure additional information for the purpose of evaluating health hazards and also as a security measure to avoid the possibility that the procurement of active materials from these vessels by unauthorized persons might permit the calculation of bomb efficiency. It was found that a value very close to the true efficiency could be established from core samples taken from the lagoon at Bikini and those contaminated vessels which had not been properly treated to remove the activity which is primarily laid down in the pipes of the salt water system. This entire phase of our activity, aside from consultation and advice to the Navy, was completed June 30, 1947.

In addition to the various research activities of Project 48-A-1, six officers, two from the Army and four from the Navy, received detailed training in the field of radioactivity, radio-chemistry, and the metabolic and biological problems relating to the release of nuclear energy. These officers included: Lt.(jg) M. Morton, USNR; Lt. George Morrison, USN; Lt. Commander Robert Conard, USN; Lt. Victor Bond, USNR; Lt. Colonel A. Hirsch, USA; Major Roy Maxwell, USA. Most of these men, notably, Lt. Morton, Lt. Morrison, Lt. Colonel Hirsch, and Major Maxwell, have spent a large share of their time actually working in Crocker Laboratory with our staff, in addition to taking a number of scheduled courses at the University dealing primarily in the fields of physics, chemistry, and the biological sciences.

C. The 60-inch Cyclotron.

The 60-inch Medical Cyclotron is operated for twenty-four hours a day, seven days a week. Its primary function has been to prepare those radioactive isotopes that cannot be produced by the chain reacting pile. Over 90 percent of the operating time has been devoted to bombardments for the project at Berkeley and the Clinton Laboratories at Oak Ridge. The primary role of the operating staff is, of course, to run the cyclotron as an instrument of production. The 60-inch is employed for the production of 10 million volt protons, 20 million volt deuterons, and 40 million volt alpha particles. Thus far, during the year 1947, there have been made approximately 500 different bombardments, some of a very prolonged character as well as a great many very short irradiations. In addition to the rather exacting demands of maintaining the instrument in a reasonable degree of operating efficiency, it has been possible to apply some time and effort

to the development of changes and improvements to enhance the efficiency and effectiveness of the instrument as a tool of research. These have included the revision of existing equipment in such a manner as to promote more satisfactory running, the development of measures to reduce the risk and amount of radiation exposure to the operating staff and those who come to the laboratory to do actual experiments with the instrument, and last, attempts to produce and accelerate stripped ions of beryllium, boron, carbon, nitrogen, and oxygen.

A considerable share of the bombardments for the Berkeley project have included the deuteron and alpha particle bombardment of most of the actinide elements, notably Th^{232} , Th^{230} , Pa^{231} , U^{238} , U^{235} , Np^{237} , Pu^{239} , and Am^{240} . These bombardments resulted in the production of more than twelve isotopes of this series of fissionable elements which cannot be produced in a chain reacting pile. In some instances, it has been possible to prepare isotopes by these transmutations in sufficient quantities to permit determination of their fission cross-section by subsequent slow neutron irradiation in the pile. A number of new radioisotopes of lead and bismuth have been isolated and identified by the bombardment of the separated isotopes of lead and the bombardment of thallium. An extensive study has been made of the transmutation of bismuth by alpha particle bombardment to form astatine. Two new isotopes of this interesting element have been identified as a result of this work and much information obtained concerning the excitation function of the formation of these three astatine isotopes. A number of bombardments of the separate isotopes, nickel, copper, and cadmium have been made for the purpose of the identification and mass assignment of the radioisotopes of adjoining elements. The work done by the 60-inch cyclotron for the Clinton Laboratories at Oak Ridge has included a series of bombardments of lithium with protons to produce radioactive beryllium for certain experiments there that relate to the development of the beryllium moderated pile. Other bombardments for the Clinton Laboratories included the deuteron bombardment of the separated isotopes of molybdenum for the identification and mass assignment of the various isotopes of technetium and the deuteron bombardments of thulium and europium for study of the radioisotopes of ytterbium and gadolinium respectively. In addition to the bombardments made for the physics and chemistry groups at Berkeley, there have been a large number of shorter bombardments for the production of many of the carrier-free fission products described in the section devoted to the biological program, which include technetium, silver, cadmium, indium, tin, and antimony.

II. Biological Effects of Radiation
and Work with the 184-inch
Cyclotron

John Lawrence, R. L. Dobson,
Hardin Jones and Cornelius Tobias

The research program of the Medical Section of the Health Physics Group has been carried out in conjunction with the research program of 48A, Division II. Its special interests have been the biological effects of radiation and work with the 184" cyclotron. Both programs are outlined together below.

We have undertaken the investigation of various biological effects of radiations and the mechanisms producing these effects. During 1947 main emphasis was laid on the following lines of study:

- A. Study of Biological Effects due to Nuclear Fission.
- B. Detection and Prevention of Radiation Damage.
- C. Metabolism and Determination of Certain Trace Elements.
- D. Adaptation of the 184" Cyclotron to the Study of Radiation Effects.
- E. Localization of Radioactive Substances at Specific Points of the Body. (Partial support of the Atomic Energy Commission).

Within these broad fields, the following specific results were achieved:

- A. Study of Biological Effects due to Nuclear Fission.

Colloidal suspensions of ThO_2 and UO_2 were obtained, consisting of relatively uniform particles the size of which could be varied between .2 and .02 microns mean particle diameter. The distribution of these colloids in the body (after I.V. injection) is a function of particle size (as found previously with other colloids by Jones and Gofman). With larger sizes the bulk of the uranium was found in the spleen and liver, with smaller sizes, more in the bone marrow.

Alpha ray auto-radiography established the presence of colloidal aggregates of uranium in the reticuloendothelial system. Acute toxicity of these colloids was only 1/40 or less of that of soluble compounds of uranium.

After injection of colloids of uranium enriched in the 235 isotope a large number of mice were exposed to slow neutrons. 100% of these mice had succumbed 3 weeks after this exposure. Adequate control experiments on mice who received uranium but no neutrons, neutrons but no uranium, or uranium and x-rays of a proper dose established that ionization of fission fragments

and of fission products had a decisive role in the lethal effects. Only a negligible fraction of control animals died. As corollaries to these observations, blood counts, weights, and histological changes were studied, revealing severe damage to tissues that contained the enriched uranium.

It was found that in order to produce biological effects of equal severity, the radiation dose delivered by P^{32} measured in energy units had to be about 27 times that of the dose by fission.

At the present time further comparative studies of beta and fission recoil effects are being made with isotopes UX_1 , U^{234} , U^{235} .

B. Detection and Prevention of Radiation Damage

One of the results of exposure to radiation is the development of hypoplastic and aplastic anemias. Bone marrow severely damaged by radiation may not recover sufficiently to maintain the organism. At the present time continuous transfusions are necessary to keep persons with aplastic anemia alive. Experiments were begun to study the transplantability of healthy bone marrow in animals. It is hoped that transplanted bone marrow can be made to take over the production of blood cells. Successful transplants of marrow were made into rat livers where they grew freely protected by a layer of bone forming around them. Such animals were under observation for more than a month.

In an effort to find suitable tests for early radiation effects, blood clotting time is being studied by the method of electrical resistance measurements of whole blood in conjunction with blood counts, prothrombin time determinations and several other hematological tests. Likewise the evaluation of the neutral red staining cytoplasmic granules of lymphocytes described by investigators at the Los Alamos project as a clinical measure of small amounts of radiation damage is being carried out on groups of laboratory personnel with adequate control groups being studied at the same time.

A group of about 100 patients who have or had severe cases of leukemia or polycythemia vera, were under observation for the tenth year. These patients have received radioactive phosphorus in therapeutic doses and they constitute the oldest group in the United States treated at repeated intervals with known doses of a radioactive isotope. So far no carcinogenic effect of beta radiation have been noted in this group.

The carcinogenic effects of phosphorus beta irradiation for induction of bone and skin tumors is being tested in a moderately large group of animals.

C. Metabolism and Determination of Certain Trace Elements.

A technique is being developed to extend the biological uses of radioactivity. By this method one is able to determine the submicroscopic amount of certain elements present in a sample of tissue or tissue ash. One irradiates the sample with a suitable particle beam, for example slow neutrons.

By doing the radioactive chemical separation and measurement of the radioactivity of the isotopes desired it is possible to calculate the amount of the element originally present in the sample. The sensitivity of this method for the detection of some of the elements is very high. Using the Hanford pile as little as 10^{-12} grams of gold and 10^{-10} grams of cobalt or zinc may be measured with this technique. In view of the numerous trace elements that have important biological function it is expected that the method will find wide application.

The metabolism of cobalt is being studied by means of the five year isotope, Co^{60} . This element is of interest because of its action in inducing polycythemia.

Radioactive Fe^{59} is being used to study distribution of iron in leukemic mice and to tag the red cells in an effort to study radiation effects on parabiotic rats. In a number of pairs of rats the red cells were found to equilibrate within three hours between pairs. This method will be utilized to study toxic substances produced in the blood by irradiation in one animal and their effect on the other member of the pair.

Radiation effects are studied on radio-resistant and radio-susceptible strains of the bacterium E. coli. An effort is being made to understand the reasons for the differences of radio-sensitivity between these two strains of the same organisms. Already it is found that radio-sensitive bacteria are more susceptible to heavy metal poisoning by gold than the radio-resistant ones. The uptake of gold on the surface of these bacteria was measured by means of tracer techniques and it is found that the ratio of the density of the gold in the bacteria to that in the suspension is 20 to 1.

New techniques have been developed for assay of radioactive isotopes of materials in a tissue or tissue ash. An improved electroplating system is used. Methods have been perfected for uranium, gold, cobalt, and iron.

A standardization of the measurement of the absolute disintegration rates of radioactive samples has been undertaken. Three independent methods are being compared.

D. Adaptation of the 184" Cyclotron to the Study of Radiation Effects

The LD50 dose of 90,000,000 volt neutrons on white mice has been measured. The results were compared to the LD50 dose from a 180 kilowatt x-ray machine. The mice exposed to the high energy neutron beam were enclosed by three inch slabs of paraffin, hence the radiation which was responsible for the biological effects was made up in large part of secondary protons. This was done to simulate the conditions which would prevail if a man were exposed to the beam. When the dosage rates were the same, the LD50 dose of neutrons (and protons) was the same as for x-rays. However, a marked dose intensity factor was found--as the dosage rate is decreased the animals tolerate very much larger amounts of radiation.

A study of the biological effects of the neutron beam is being rapidly expanded to many different animal species. This is of considerable interest to the health protection program.

E. Localization of Radioactive Substances at Specific Points of the Body.
(Partial support of the Atomic Energy Commission).

The problem of finding radioactive substances which can be made to localize in specific tissues or at specific sites in the body is important. Such methods are a necessary starting place for a general program to ascertain the response of tissues to irradiation. Since there is a very complex relationship between any one tissue or organ and the rest of the body, only selective tissue irradiation can give clues as to whether effects of irradiation are confined to the tissue irradiated or whether there are effects upon the non-irradiated tissues. Such differentiation of effects is a necessary part of a study of biological effects of radiation.

Work on this project (partially or entirely supported by Atomic Energy funds) has produced the following substances which can be used for specific tissue irradiation:

1. Yttrium, lanthanum, zirconium, and uranium colloids which can be used to irradiate liver and spleen selectively. The uranium colloid has been a particular feature of this work because it permits the study of the biological effects of fission energy.

2. Radioactive yttrium colloids have been prepared which concentrate selectively in the red marrow. Other radioactive compounds (strontium salts, radium salts, and a fission products form of yttrium) have been found by other investigators to concentrate in the bone substance, but this is the first radioactive compound which has been found which concentrates in the red marrow itself. It may have particle usefulness as a method of effecting irradiation of the marrow in the treatment of leukemia and polycythemia vera.

3. A large amount of research has been done on methods of effecting specific localization in other tissues but no useful methods have yet been developed which are of medical use. This work includes work with radioactive tyrosine (C^{14} labeled) which as a precursor of melanin was apparent as a possible method of concentrating radioactive carbon in the cells of the malignant cancer, melanocarcinoma. High concentrations of radiocarbon have been effected by tyrosine administration to melanomatous animals, but at the same time the adrenals and thyroid tissue have equal or higher concentrations. Other substances which are related to melanin formation are being investigated. Perhaps one of them, tryptophane or dopa, will be concentrated highly only in this cancerous tissue. This work at the same time has added valuable information on the biochemistry of melanin formation.

It has been found in a study of desoxyribose nucleic acid metabolism that irradiation of the liver selectively produces profound changes in the desoxyribose nucleic acid formation of other non-irradiated tissues in the same animal, particularly in tumor tissue. Desoxyribose nucleic acid is an important factor for cell division and tissue growth. Experimentally, cancer

growth can be prevented for a few weeks by this type of liver irradiation. It is important to identify the indicated biochemical substances which are presumably formed or inhibited by this liver irradiation. The part of this work and the radioactive materials used to effect liver irradiation were supported by Atomic Energy funds.

The specifically irradiated thyroid has been studied. This study of effects of radioactive iodine upon the metabolism of iodine in the thyroid gland has been completed. The dosages necessary to inhibit various steps in the formation and release of thyroxine have been determined and the following facts established:

1. Thyroid colloid is very sensitive to irradiation from radioactive iodine.
2. Thyroxine is released from the irradiated thyroid before there is any apparent decrease in the capacity of the gland to synthesize thyroxin.
3. Cellular damage (as manifested by subsequent disappearance of thyroid cells) is much more sensitive to the level of thyroid irradiation than immediate biochemical changes in the capacity of the irradiated cells to form and release thyroxine. Although immediate biochemical changes may not be marked with certain dose levels of radiation, the cells eventually die from the effect of this irradiation.

III. Effects of Body Irradiations from Internal
and External Sources

Robert S. Stone, M. D.*

This project was originally set up at the University of California Hospital and Medical School with the object of observing over long periods of time the blood picture of patients being treated by total body x-rays. The treatments were given for therapeutic purposes. It was started in 1942 using x-ray machines as the source of radiations. In 1946 it was extended to include the effects on the blood of general body radiations coming from intravenously administered radiophosphorus, P³². In the same year studies of the distribution of radio-iodine in the human body and of the effects of the radiations from this localizing element were commenced.

In all instances the radiations or radioactive materials are given to the patients with a reasonable expectation that there will be direct benefit to the patient, either from therapeutic effects or from the information obtained relative to possible therapeutic procedures.

The project is divided into three parts, the first two of which are closely related.

- A. Hematological Effects of Total Body Irradiation from External Sources. B.V.A. Low-Beer, M. D., in charge.
- B. Hematological Effects of General Body Irradiation from Internal Sources. B.V.A. Low-Beer, M. D., in charge.
- C. Metabolism and Effects of Radio-Iodine. Earl R. Miller, M. D., in charge.

A. Hematological Effects of Total Body Irradiation from External Sources.

1. Apparatus and Method of Irradiation. The apparatus used consisted of three x-ray machines producing x-rays of 100,200 and 1000 kilovolts maximum.

The patients were placed about 3 meters from the x-ray tube targets in such a way that the entire body was irradiated at one time, and all parts of the surface facing the target were exposed to about the same intensity. Anterior and posterior surfaces were alternated daily.

The daily exposures were mainly 10, 15, or 20 roentgens, but some 5 and some 50 roentgen exposures were given. The exposures were measured on the surface of the body.

* Work performed at the University of California Medical School in San Francisco.

The rate of exposure was about 3 r per minute.

The total exposures varied from 100 to 300 roentgens, the majority being 300, given in 15 to 30 days.

2. Experimental Subjects. The patients selected for this study were those for whom total body irradiation was indicated, but who had relatively normal blood pictures at the start. Most of them had arthritis of the spine.

During 1947 no new cases were given such irradiation, but observations were continued on 9 of those who had been treated in previous years. Three have been followed for about 3.8 years, 3 for about 2.5 years and 3 for about 1 year since the onset of exposure.

3. Laboratory Procedures. The following laboratory procedures were done at varying intervals. The aim was to do items (a) and (g) at least once per month. During 1947, 345 individual procedures were performed.

- (a) Total red blood cell counts.
- (b) Hemoglobin per 100 cc.
- (c) Total white blood cell counts.
- (d) Differential and absolute white blood cell element counts.
- (e) Lobation studies on the polymorphonuclear cells.
- (f) Red blood cell size determination.
- (g) Platelet counts.
- (h) Prothrombin concentration determination.
- (i) Sedimentation rate measurement.
- (j) Icteric index measurement.
- (k) Hematocrit measurement.
- (l) Blood cholesterol measurement.

4. Observations. The immediate responses to the irradiation are in the reports for previous years. During 1947 the following findings were observed.

(a) The red blood cell counts which had tended to be low 200 days after treatment in some patients appeared to fluctuate within the normal limits at these later intervals.

(b) The hemoglobin concentration which tended to increase between 100 and 300 days after irradiation was found to be above normal in 4 of the 9 patients.

(c) The total white blood counts having decreased immediately following the irradiation were relatively normal during 1947.

(d) The number of lymphocytes had returned to normal.

(e) The lobation indices in all cases had returned to normal.

(f) All the other studies showed normal findings.

(g) The irradiation appeared not to have affected the general health of the patients.

5. General Conclusions.

(a) A decrease in the number of polymorphonuclears and in the number of lobes of the nuclei follows soon after irradiation of these quantities and qualities given, but these changes do not persist.

(b) The total number of lymphocytes decreases very soon after starting the irradiation, but returns to normal in a few months.

(c) The monocytes show the greatest variation in numbers, a relatively great increase occurring during the treatment period in many patients.

(d) A macrocytic anemia of mild degree develops a few months after the irradiation with x-rays, but it disappears later.

B. Hematological Effects of Total Body Irradiation from Internal Sources.

1. Procedure. Radiophosphorus in a solution of disodium hydrogen phosphate was given intravenously at an average rate of 2 mc per week. The total doses varied from 3.5 to 8 millicuries. Two patients were given 2 doses; 2, 3 doses; 12, 4 doses; and 1, 5 doses.

2. Experimental Subjects. The patients were selected in the same way as for the irradiation with x-rays. There were 17 patients treated from January to October 1947. They made a total of 255 visits to the laboratory.

3. Laboratory Procedures. The same laboratory procedures were performed on these patients as described under A above. A total of 2013 such tests were run.

4. Observations. It is to be noted that these patients are now being observed for their early responses, the largest period of observation being 322 days, while the x-ray treated patients are being followed now for late changes. Only the positive findings are recorded here.

(a) The total red blood cell counts, total white blood cell counts and the hemoglobin concentrations show some transitory fluctuations beyond the physiological limits.

(b) The platelet counts frequently dropped below the normal limits, but in every instance returned to normal. This finding was striking and much more marked than in the patients treated with x-rays.

(c) The prothrombin values decreased considerably in several cases. Such changes were not observed after irradiation with x-rays.

(d) All the other tests showed no change beyond the physiological limits.

C. Metabolism and Effects of Radio-Iodine.

The primary purpose of this part of the program is to determine the distribution, excretion, and radiation effects of radio-iodine in humans and animals. The thyroid is known to have a great affinity for iodine. The studies so far have been directed toward the thyroid. All I^{131} has been administered by mouth.

1. Apparatus.

- (a) Shielded Geiger-Muller counters for gamma ray measurement.
- (b) Unshielded Geiger-Muller counters for beta ray measurement.
- (c) Lauritsen electroscope.

2. Method of Procedure. The radio-iodine, I^{131} , was administered orally and the following procedures carried out.

(a) Determination of the amount of I^{131} in the thyroid as a function of time over a 2 to 7 day period by the use of gamma counters and electroscopes. Measurements are made over the thigh to determine the background in a tissue about the same size as the neck but containing no thyroid. The excess radiation measured from the neck is assumed to come from the thyroid gland. The radiation from the thyroid is calibrated by means of measuring the radiation from known amount of the stock solution of I^{131} placed in bottles nearly the size and shape of the thyroid and measured under the same conditions as the measurements of patients are made.

(b) Determination of the amount of I^{131} excretion in the urine as a function of time usually over a 48 hour period. The urine is bottled in containers the same size and shape as known amounts of the stock solution and by direct comparison the amount of iodine in them can be determined.

(c) Determination of the distribution of the I^{131} in the thyroid by radio-autographs of excised specimens.

The following additional studies have been made.

(d) Comparison of the results of measurements in vivo and in vitro on excised specimens, in order to check the method.

(e) Study of the effect of shielding, distance, thyroid size (by using bottles of different sizes).

(f) Study of efficiency and accuracy of counter versus electroscope methods of determining uptake and excretion of I^{131} .

3. Experimental Subjects. Patients have been studied who had the following conditions of their thyroid glands.

Normal thyroid function	11
Hyperthyroid	50
Hypothyroid	4
Thyroiditis	7
Neoplasms (malignant)	22
	<u>94</u>

4. Clinical Studies. The following preliminary clinical studies were carried out on these patients by the medical staff of the hospital.

- (a) History, physical examination, routine laboratory work.
- (b) Careful estimation of thyroid size.
- (c) Basal metabolic rates.
- (d) Cholesterol and protein-bound iodine content of the blood.

Follow-up studies usually at monthly intervals are carried out. These include the repetition of the preliminary studies.

5. Typical Dosage and Procedure Schedule.

(a) For tracer study: 100 - 250 microcuries I¹³¹ administered in the morning. Thyroid uptake studies twice the first day, three times the second day, and once the third day. Where possible, once more at the end of a week. Urinary excretion levels determined in four 12 hour samples or in all individual voidings.

(b) For therapy study (in cases having hyperthyroidism): 1 - 4 mc I¹³¹ administered in the morning. The rest of the schedule exactly as above.

(c) For study of cases to be operated upon; These are as above with the addition of determination of the amount of iodine in the removed specimen and estimation of the weight of the gland remaining. This is followed by radio-autography.

(d) For study of cases with malignant tumors of the thyroid: usually 2 mc are given by mouth. The procedure is as for other tracer studies. Clinical and radiographic search for metastases is made. Local counter measurements are made over any area suspected of being involved in metastatic tumor. A biopsy or more radical removal of some of the tumor is carried out and this is handled as in (c) above.

6. Results.

(a) A method of determining thyroid uptake and urinary excretion of orally administered I^{131} has been worked out.

(b) The percentage uptake of iodine in the gland is independent of the size of the dose.

(c) When the metabolism of a patient is high due to hyperthyroidism, then almost all of the administered iodine can be accounted for by measuring thyroid uptake and urinary excretion. When the metabolism is normal then a variable amount of the administered iodine can not be accounted for by carrying out these two measurements.

(d) Rough, direct correlations between clinical evidence of activity of the thyroid and of the percent uptake of the administered iodine have been observed. Attempts at detailed correlation between percent uptake of the iodine with 1) clinical, chemical, and histological evidence of normalcy or disease and 2) gland size has lead to no useful result to date.

(e) Hyperthyroid patients have tolerated single doses of 2 mc and total doses up to 12 mc.

(f) In patients with asmuch as 1 mc of I^{131} in the thyroid, tenderness of the gland, elevation of the sedimentation rate, and increase in the protein-bound iodine in the blood is observed.

(g) Preliminary animal experiments with high doses of radioiodine (up to 4 mc I^{131} per pound of rabbit) have shown histological evidence of tracheal kidney and liver damage.

(h) Inhomogeneity of the distribution of the iodine in the thyroid and the inability to accurately determine thyroid size in vivo continue to be stumbling blocks in determining exactly how much radiation the thyroid receives even though the amount of radio-iodine in the gland is accurately known.

(i) Two carcinomata of the thyroid in our series have taken up sufficient iodine so that treatment of the disease is contemplated by administration of large doses of radio-iodine. Most carcinomata of the thyroid do not take up sufficient iodine to make this approach reasonable.

(j) Moderate Graves' disease is satisfactorily controllable by the administration of a proper dose of I^{131} . Prediction of the required dose is not yet possible from our data.

(k) Thyroids showing evidence of thyroiditis have uniformly taken up practically no I^{131} .

IV. Personnel Protection

A. Chemistry Section

N. B. Garden

Four important advances have been made in the chemical section of personnel protection during the year.

1. Adoption of a No-Contamination Policy. The adoption of a no contamination policy was the result of the success attained in confining work with radiobactive material to closed spaces. Starting with the difficult problems presented in the close handling of activities up to one curie, certain techniques developed which showed promise of enabling chemists to carry out any chemical process in a closed space.

This might appear an extreme measure in cases where the work involves only tracer amounts of activity. Although there may be considered no health hazard present, contamination would definitely reduce the accuracy of the results, if not completely eliminate the value of the experiment.

Although it will be some time before equipment and techniques are available to make this policy very extensive, progress has been made during the last year, and ultimately it is hoped that all active material will be handled in closed containers and spaces with "no contamination".

2. Successful Development of Lead Cave and Gloved Boxes and of Accompanying Remote Control Devices. Among the equipment developed along the lines just discussed, a "cave" with a minimum of six-inch lead shielding was built. This cave was provided with a horizontal viewing device, which proved much more satisfactory to the workers than the overhead mirror or periscope systems used previously. The equipment is set up in individual laboratories and moved into the shielded cave where the active material is added. Thus, the cave is in use only during the actual time required for the experiment.

The gloved boxes have gone through a testing period and can now be furnished for almost any chemical process such as those requiring a centrifuge, columns, induction heating and micro-manipulation with microscope.

A psychological problem exists with chemists who have long pursued their problems from minute to minute developing equipment as required. It has been difficult to show them that an over-all planning before starting the process increases efficiency and safety and will prove more satisfactory in the end. Planning has proved to be successful, however, especially with those chemists under Dr. Seaborg, who have done extensive work with radioactivity.

3. Satisfactory Technique for Active Waste Disposal. Active waste disposal has been a problem in many communities, but at the Radiation Laboratory the solution has proven fairly simple and certainly seems to

provide a safe disposition. Active waste material is mixed with cement so that a large part is bonded to the cement particles. The cement-filled drums and individual cement blocks, where such are necessary, are dumped miles out at sea. It is difficult to imagine a process whereby the slow disintegration of the cement can release enough activity over any decade to increase the radioactive background in the sea or in living organisms to a troublesome, much less a dangerous, level. Should the blocks sink into the silt and be covered further, it is probable that the activity will never be released. This disposal system may well be the answer to the problem in other localities since the concrete blocks can be transported by truck or rail with safety.

4. Clarification of Responsibilities in the Over-All Health Program.

It is felt that considerable progress has been made in the past year in clarifying the responsibilities in the Health Program. Although the specifications for tolerances in activity hazards could be specified by the Medical Laboratories, once these are set the design and maintenance of these standards is a technical problem to be solved by architects, engineers, physicists and chemists. The medical approach to the health problem seems fairly well defined as to the problem of shielding accelerating machines. This latter group is properly a physics problem with its peculiar radiation hazards, which cease when the machine is turned off. There may remain, however, activity from some chemical substances such as the target or some part of the machine which then becomes a Health Chemistry problem. A division of these responsibilities has been made during the last year and the indications are that it has resulted in greater success in dealing with the problems. The Health Chemistry group, whose activities are covered in this report, now have the following functions to perform, in every case acting as a service group to the Project:

- a. Maintain complete pertinent records concerning active isotopes.
- b. Monitor hands, feet, and air in special cases.
- c. Monitor personnel and laboratories with instruments, badges, and other detecting devices.
- d. Maintain protective equipment and clothing to be issued.
- e. Decontaminate equipment and areas.
- f. Launder active clothing, removing contamination before going to regular laundry.
- g. Receive, transport, store, or dispose of active material as required.
- h. Conduct research and develop chemical equipment and processes to enable carrying out the desired chemical work in safety.

B. Physics Section

R. J. Moyer

1. Personnel Monitoring Program. During this period the facilities and staff for operating the film badge and pocket dosimeter program have been developed. At the present time there are in service 450 film badges which are measured and renewed weekly. This number does not cover the office workers and shop men who are remote from radiating machines. Coverage is to be extended to include all hill workers as soon as badges in sufficient quantity arrive. Also in regular service are 50 gamma-ray pocket chambers (dosimeters) which are worn by cyclotron crew members, experimenters and certain other persons whose regular duties bring them in the vicinity of radiating machines.

Between 90 and 100 quartz-fiber pocket electroscopes are available for use by the same group mentioned in the preceding paragraph. These provide them with a running account of dosage and a check against the film badge and pocket chamber.

For slow neutron exposure records 68 boron lined pocket chambers have been calibrated and are about to be placed in service on the crew members of the 184-inch and 60-inch cyclotrons.

Radiation field monitoring is performed whenever a new condition of operation or shielding occurs in order to evaluate any hazards and to provide information to guide steps taken to eliminate them. In particular the radiation fields of the cyclotron during the progress of its shielding construction have been closely followed. The x-ray field from the linear accelerator has been studied currently as the machine has been brought into operation. Necessary lead shielding to permit safe operation has been installed by the linear accelerator staff.

2. Studies of Energy Absorption from the Neutron Beam of the 184-inch Cyclotron. (Work to be published by R. Loevinger). In an effort to measure the radiation dosage received by animal tissue in the very high energy neutron beam, experiments were performed leading to the evaluation of coefficients X_H , X_C , and X_O which describe the contributions per atom of hydrogen, carbon, and oxygen, respectively, in the absorption of energy from the beam. It was assumed that energy absorbed could be measured by ionization produced, hence the experiments employed the Bragg-Gray cavity principle at depths in organic materials where equilibrium between primary and secondary radiation obtained. In order to be sure of satisfying the conditions for validity of the cavity principle, observations were made with an extrapolation chamber imbedded in a plastic medium. These observations indicated the size of cavity which allowed the cavity principle to apply. The physical radiation dosage (rep) for an arbitrary compound of H, C, and O can be estimated from knowledge of the coefficients if the intensity of the neutron beam is known. With neutron beams currently in use this dosage is of the order of 70 rep/hr at a distance of 50 feet from a Be target when the D^2 beam current is about 0.5 microampere. The fast neutron flux density at this level is about $10^6 \text{ cm}^{-2} \text{ sec}^{-1}$.

3. Studies of Shielding against Fast Neutrons. Measurements of absorption coefficients for various materials used as slabs in a broad fast neutron beam have been made, using ionization chambers as detectors. Studies of this type with concrete absorbers have contributed to understanding and planning the final shielding to be provided for the cyclotron.

Absorption curves for various materials studied, showing transition effects followed by exponential attenuation, have been described by Moyer, Hildebrand, et al.

The absorption of the primary fast neutron radiation in concrete shows a half-value thickness of 9 1/2 inches.

Measurements of slow neutron flux density in the five-foot concrete shielding as a function of depth, in regions not irradiated by the primary neutron beam from the target, have given absorption curves displaying a hardening action upon the neutron flux penetrating the walls. The slow neutron flux density within the concrete falls from about $2 \times 10^6 \text{ cm}^{-2} \text{ sec}^{-1}$ to $5 \times 10^3 \text{ cm}^{-2} \text{ sec}^{-1}$ in the portions of shielding investigated. This pertains to a D^2 beam of about 1 microampere at the target.

4. Animal Studies. Studies of the lethal action of the fast neutron beam upon rats and mice have begun during this year. Statistics are not yet conclusive enough to justify reporting results.