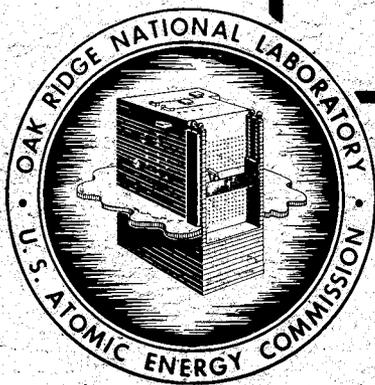


ORNL  
CENTRAL FILES NUMBER  
52-1-212

OAK RIDGE NATIONAL LABORATORY  
RESEARCH AND RADIOISOTOPE PRODUCTION



OAK RIDGE NATIONAL LABORATORY  
OPERATED BY  
CARBIDE AND CARBON CHEMICALS COMPANY  
A DIVISION OF UNION CARBIDE AND CARBON CORPORATION



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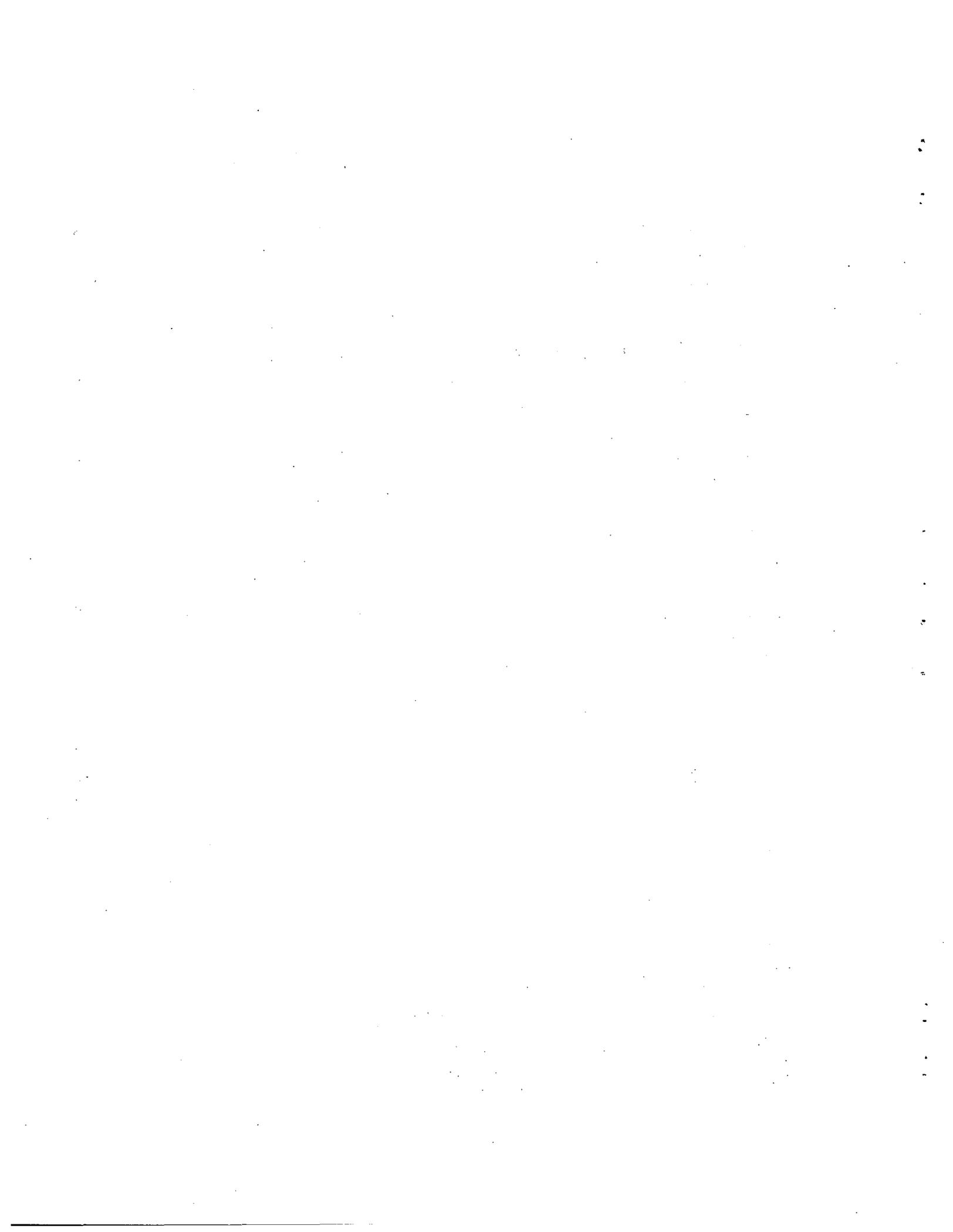
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RESEARCH AND RADIOISOTOPE PRODUCTION

W. E. Thompson

January 1952

OAK RIDGE NATIONAL LABORATORY  
Operated by  
CARBIDE AND CARBON CHEMICALS COMPANY  
A Division of Union Carbide and Carbon Corporation  
Post Office Box P  
Oak Ridge, Tennessee



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## THE OAK RIDGE NATIONAL LABORATORY

The Oak Ridge National Laboratory, originally known as the Clinton Laboratories and now including the research facilities of the electromagnetic plant (Y-12), is operated for the AEC by Carbide and Carbon Chemicals Company, a Division of Union Carbide and Carbon Corporation. The original installations were constructed during the war as parts of the Manhattan District's Clinton Engineer Works, the establishment of which stemmed directly from three events that occurred in 1941 and 1942.

First, scientists at the University of California, using the cyclotron, discovered the new element, plutonium, and found that the plutonium<sup>239</sup> isotope, when bombarded with slow neutrons, would undergo fission in the same manner as the already well-known uranium<sup>235</sup>. In 1941, theoretical considerations indicated that plutonium<sup>239</sup> could be produced in quantity by neutron bombardment of the nonfissionable uranium<sup>238</sup> isotope, which is 140 times as plentiful in uranium ores as the fissionable U<sup>235</sup> isotope.

Then, in December 1942, at the University of Chicago Metallurgical Project, a self-sustaining uranium chain reaction was demonstrated in the first nuclear reactor (pile). Since a chain reaction was found to supply tremendous numbers of neutrons, and since natural uranium used in the chain reaction is over 99 per cent uranium<sup>238</sup>, it was clear to the scientists that plutonium<sup>239</sup> is constantly being produced in a natural uranium reactor. Thus, by the end of 1942, it became apparent that a plutonium-production program was feasible and that the project should be undertaken on a large scale. Up to this time, however, plutonium had been produced only in microscopic amounts, and very little was known about its chemical behavior, so one immediate problem was to determine how to separate plutonium from the uranium in which it was produced and from the highly radioactive fission products formed by the splitting of uranium atoms. Larger amounts of plutonium for experimental

purposes were needed.

With the prospect of exploiting atomic energy for wartime purposes, an area known officially as the Clinton Engineer Works was acquired by the Army for the Manhattan District Program. The location in the Tennessee Valley was chosen because of its relative isolation in the foothills between the Great Smoky and Cumberland Mountains, and because of the availability of TVA hydroelectric power and a plentiful water supply. Within this area were located the plants for the concentration of uranium<sup>235</sup> and the pilot plant for the production of plutonium.

### THE WARTIME PERIOD

As in most wartime projects, temporary construction was used where possible, and the research and development activities were limited to those with the greatest promise of immediate returns.

#### *Clinton Laboratories, the Plutonium Pilot Plant (X-10)*

The pilot plant (Clinton Laboratories) was organized under the University of Chicago Metallurgical Project to produce gram amounts of plutonium and to develop a chemical process for separating and purifying the plutonium. It was also charged with evaluating the health hazards associated with processing and handling large amounts of highly radioactive materials from a uranium reactor and with training personnel to operate the full-scale plutonium production plant to be built at Hanford, Washington.

*Construction of Facilities.* - Construction of the pilot plant was started by E. I. du Pont de Nemours and Company, Inc., on February 1, 1943, and proceeded on a rush schedule which enabled the pile (the first uranium reactor with an appreciable potential for producing plutonium) to be placed in operation on November 4, 1943. Even though it was the largest reactor built up to that

time--indeed, only one other had been built before--and was the first cooled reactor, it operated with better than the expected performance.

A second major facility constructed at Clinton Laboratories was the chemical pilot plant where the process for separating and purifying plutonium was to be developed. Because chemical operations involving radioactive materials had never before been attempted on anything even approaching the scale planned in the pilot plant, the design and construction of these facilities was an engineering achievement of the first magnitude.

All equipment for the operations was enclosed in "hot cells" surrounded by 5 feet of concrete. Remote control was required for even the simplest operations, which were accomplished by workers who could not even see the operation they were performing. At one stage of the process, a television set was used to allow observation of a critical operation. For the most part, the performance of equipment was determined by the readings on a bank of instruments which covered the walls of the "operating gallery".

Other facilities constructed at the same time included laboratories for chemistry, physics, and medical (health physics) research; machine shops; instrument shops; and several administration buildings and warehouses. One hundred and fifty buildings, large and small, were constructed at a cost of about \$13,000,000. More than 3,000 construction workers were on the job during the peak construction period.

*Accomplishment of the Objectives.* - Construction of the chemical pilot plant was completed in November 1943, about the same time that the reactor was ready to operate, and processing operations were started at once. For the first trial runs of plutonium separation, uranium irradiated in the Washington University (St. Louis) cyclotron was used because it contained smaller amounts of

the highly radioactive fission products, and therefore would leave the equipment less seriously contaminated in case operational difficulties were encountered and repairs or alterations became necessary.

From these first runs, a few milligrams of purified plutonium were prepared and shipped to the Metallurgical Project in Chicago for research uses. This first shipment was made on December 30, 1943. Following this, uranium irradiated at low power in the Clinton Laboratories reactor was used, and shortly thereafter, processing of uranium irradiated at full power in the Clinton reactor was started and plutonium shipments became correspondingly larger.

When the reactor at Clinton Laboratories was put into operation, very little was known about the hazards which could be expected. Reflecting upon the number of known injuries which had resulted from a single type of radiation, X-ray, and from one radioactive element, radium, the health physicists knew that there might be serious hazards associated with an operation involving hundreds of radioactive isotopes as well as several different kinds of radiation. Although tolerance levels for radiation exposure had been established and the maximum allowable levels of radium in the body and in the air were well known, there was little else to serve as a guide in determining human tolerances for the plutonium and radioactive fission products which were being produced in large quantities.

The program in health physics during the war was concerned primarily with monitoring (that is, measuring radiation levels to assure that they were kept satisfactorily low), determining the adequacy of shielding around the reactor and "hot labs", and maintaining a surveying program to assure that radioactive materials were confined to the proper locations and that the air, water, or environment did not become contaminated as a result of leakage of radioactive materials. By developing suitable radiation-detection and measuring instruments,

and by working closely with the biologists who were studying the effects of various radioactive substances on animals, the health physicists were able to determine radiation levels and to set tolerance values. The success of this program is attested by the fact that, since the start of operations, there have been no known cases of injury to an individual resulting from exposure to radiation at the Oak Ridge National Laboratory.

The fourth objective of the original Clinton Laboratories was accomplished by an on-the-job training program which gave trainees actual operating experience. This included not only people to operate the reactors and chemical plants, but also health physicists and other du Pont employees who were to be associated with the Hanford plant.

*Wartime Research.* - Physics research during the war was concerned primarily with the immediate and urgent problems of the military application of atomic energy. First, the physicists were charged with responsibility for getting the reactor into operation, determining its operating characteristics, and insuring that it would operate with maximum safety. Tests made by physicists using the reactor determined the adequacy of the Hanford reactor shielding. Other projects, both fundamental and applied, were performed in close cooperation with the Physics Division of the University of Chicago Metallurgical Project. Most of this work, because of its relation to military uses of atomic energy, was in the "secret" category.

Research in chemistry was primarily concerned with the development and improvement of the plutonium-separation and purification processes. Equally important was the development of analytical procedures for determining the elements and compounds involved in these processes. Study of the basic chemistry of heavy elements, particularly the new elements neptunium and plutonium, was also an important project for the chemists.

In addition to plutonium, the uranium reactor produces fission products. These are radioactive isotopes of over thirty of the elements of medium atomic weight ranging from zinc to gadolinium. The chemical research program covered the chemical separation of fission products from uranium and from each other, the determination of the characteristics of each radioactive species, development of radiochemical analyses, and studies of fission-product yields.

In the investigation of chemical-separation processes, a method of separation by ion-exchange was developed. This process enabled the laboratory to prepare for the first time relatively large amounts of the individual rare earth elements. These elements are so nearly alike in their chemical properties that they were almost unknown previously in their pure form. While working on this project, scientists at the laboratory discovered a new element in the rare earth group, element number 61, promethium. They were also able, by their new processes, to produce the element technetium and the tritium isotope of hydrogen in much larger quantities than the microscopic amounts which had been produced prior to that time. Enough tritium was produced to allow some of its nuclear properties to be studied for the first time.

One very important question which arose with the processing of large amounts of highly radioactive materials was, "What effect will the radiation from these materials have upon the various substances exposed to it?" That radiation would have some effect was well known from experience with X-ray and other radiations, but the extent of radiation damage for various materials was a critical question. Fundamental research on radiation damage was necessary to evaluate various materials for use in reactors, in "hot labs," and in other locations where they would be exposed to intense radiation.

During this period, the first radioisotopes produced by the laboratory were used by the Manhattan Project biologists in their

studies of radiation hazards. Research on radioisotope production processes was so successful that, by the end of the war, some radioisotopes were in routine production.

#### *The Electromagnetic Plant (Y-12)*

Due to the urgent demand for uranium<sup>235</sup> in the early days of the Manhattan District, the calutron, a development of the mass spectrograph, was perfected at the University of California Radiation Laboratory. A production plant utilizing the calutron for separating U<sup>235</sup> by the electromagnetic process was constructed without the usual intermediate pilot-plant stage. Stone and Webster Engineering Corporation was chosen to build the electromagnetic plant, and Tennessee Eastman Corporation was selected to operate the equipment and to develop the chemical processes.

*Production Plant.* - The single aim which motivated the construction and operation of this \$400,000,000 electromagnetic plant was to achieve maximum production of highly concentrated uranium<sup>235</sup> in the least possible amount of time. Construction began in 1943. Successful operation early in 1944 resulted in an enlargement of the plant, which was completed in 1945. The achievement of the production goal is now history.

*Process Improvement.* - Conversion of the mass spectrograph from a small-scale instrument, suitable for use in a university laboratory, to the calutron, a piece of large-scale plant equipment capable of the quantity production of U<sup>235</sup>, presented a multiplicity of problems. These problems were not confined solely to the physical separation of the isotopes, but extended to the chemical processes necessary for the preparation of feed materials, maximum recovery of products and by-products, final purification of the desired isotope, highly important factors of health and safety, and methods of control, both quantitative and qualitative.

In the absence of a pilot plant, it was

necessary to investigate these problems under actual production conditions. Development groups organized under the direction of both Tennessee Eastman Corporation and the University of California were directly responsible for improving all phases of the process. An additional responsibility of these groups was the training of sufficient personnel to operate the plant. There was very little opportunity for long-term research.

#### POSTWAR DEVELOPMENTS AT CLINTON LABORATORIES

On July 1, 1945, a contract for the operation of the Laboratory was negotiated with the Monsanto Chemical Company by the Manhattan Engineer District.

Because of the unique facilities for pilot-plant and research work at Clinton Laboratories, the successful accomplishment of the four primary objectives did not mark the end of operations as originally expected. Instead, the laboratory embarked on a new course of fundamental research and engineering development concerned primarily with reactor design.

The new program of research and development undertaken after the end of the war led to the organization in 1946 of several new research and development divisions within the laboratory. Experience during the war had shown that continuous monitoring and surveying of the work areas was necessary to assure adequate protection of personnel from radiation hazards. The Health Physics Division was created to perform these services and to carry out fundamental and applied research directed toward improving radiation-protection practices. The Biology Division, which has been concerned primarily with establishing tolerance levels for radioactive materials, was enlarged at the same time to perform broad fundamental studies of the biological effects of radiation. A Metallurgy Division was organized in 1946 to carry out applied research primarily related to the reactor program.

During this early postwar period, the Manhattan Engineer District initiated a radioisotope distribution program under which radioisotopes produced at the laboratory were made available to users outside of the atomic energy project. The first shipment under this program was made on August 2, 1946. The laboratory became, and remains, the world's principal source of radioisotopes.

One of the most interesting activities at the laboratory during this period was the Clinton Laboratories Training School, established as the first nuclear-technology school for scientists interested in entering the new field of atomic energy. The original training school operated for only one year; nevertheless, it numbers among its alumni, as does the laboratory, several of the best-known figures in the American atomic energy effort. In 1950, the present Oak Ridge School of Reactor Technology was established at the laboratory. In this school, some sixty-five future nuclear engineers from industry and university staffs are trained each year.

#### DEVELOPMENTS AT THE ELECTROMAGNETIC PLANT

Operation of the electromagnetic plant continued under Tennessee Eastman Corporation until early 1947. Emphasis on U<sup>235</sup> production decreased, however, as the gaseous-diffusion plant assumed the major responsibility for the production of U<sup>235</sup>. As a consequence, facilities and experienced scientific personnel became available in the electromagnetic plant for the research and development program.

Late in 1945, the adaptation of calutron equipment to the separation of isotopes of elements other than uranium was undertaken. With the successful separation of various stable isotopes and with the increasing importance of these purified isotopes as tools of research, this program was expanded, the goal being the separation of the isotopes of all the elements. Progress to-

wards this goal has required extensive modification and development of electromagnetic equipment, and research in the obscure chemistry of many of the less common elements. Associated with the production of stable isotopes have been problems of spectroscopic analysis, leading to fundamental investigations of nuclear properties, and development of new methods for using these isotopes as research tools.

Calutron development continued, with emphasis on its potentialities with respect to U<sup>235</sup> production and the production of very highly purified isotopes. Investigations of the fundamental principles involved in the formation and transport of ions in electric and magnetic fields were undertaken. New methods of utilizing electromagnetic equipment for isotope separation were examined. Experience with ion sources has been extended to studies of other particle accelerators, with the objective of neutron sources other than reactors and designing improvements for the cyclotron.

The development of uranium chemical processes made great demands upon chemical technology. Plant experience in this respect was readily applied to uranium-ore studies, problems of assay and analysis, the purification of other elements, and to the investigation of physicochemical processes for isotope separation. It has frequently been necessary to solve special chemical problems of importance to various aspects of atomic research.

These phases of research and development continued to expand after responsibility for the electromagnetic plant was assumed in May 1947 by Carbide and Carbon Chemicals Company. As results of research became known, additional problems were referred by the AEC to the groups concerned with this phase of the program. In 1949, the following three research divisions were established in the electromagnetic plant: Isotope Chemistry and Production, Electromagnetic Research, and Materials Chemistry.

## ORGANIZATION OF THE OAK RIDGE NATIONAL LABORATORY

On January 1, 1947, the newly-formed AEC, created by the Atomic Energy Act of 1946, took responsibility for the atomic-energy program. Clinton Laboratories continued to be operated by Monsanto Chemical Company until March 1, 1948, at which time the name of the installation was changed by the AEC to Oak Ridge National Laboratory. Carbide and Carbon Chemicals Company then assumed the operating responsibility. Carbide was at that time, and still is, the major production contractor for the AEC. The company operates the gaseous-diffusion plant for production of U<sup>235</sup>, and the Y-12 or electromagnetic plant, and was recently chosen to operate the new gaseous-diffusion plant in Paducah, Kentucky. Carbide is the only industrial contractor operating a major research facility for the AEC.

During 1947 and 1948, as Carbide accepted increasing responsibilities for carrying out various phases of the AEC research program, it became apparent that the wartime facilities of the laboratory, originally intended to last only about two years, were inadequate for an expanding program. Consequently, in 1949, a \$20,000,000 program of permanent construction and improvement was undertaken. Among the first of the new facilities to be completed was a radioisotope-processing area, consisting of ten buildings especially designed for the chemical processing, storage, packing, and shipping of radioisotopes, and an additional pilot plant facility for chemical-process development.

### CONSOLIDATION OF RESEARCH IN THE Y-12 AREA WITH ORNL

Following the termination of uranium<sup>235</sup> production activities in the Y-12 electromagnetic plant, many large permanent buildings became available at that location for use in other programs. Since both areas were operated by Carbide, two large buildings in the Y-12 area were remodeled for the Biology Division of Oak Ridge National Laboratory,

providing 75,000 square feet of floor space for modern and well-equipped laboratories. These included chemical laboratories for preparing carbon<sup>14</sup>-labeled compounds for biological tracer experiments and for distribution to other users. Still other buildings afforded space for development and testing laboratories as well as offices for the Reactor Experimental Engineering and Aircraft Nuclear Propulsion Divisions.

With this growing association between ORNL and the electromagnetic plant, which are only six miles apart, the research programs of the two installations became more closely integrated. As the natural outcome of this increased cooperation, on February 1, 1950, the research activities of the Y-12 electromagnetic plant were made a part of the program of Oak Ridge National Laboratory.

With the expansion of facilities and the increase in scope of the laboratory's program, the number of employees by July 1951 was nearly double the wartime peak. The scientific and technical staff numbers about 1,500 out of a total of over 3,000 employees. As a result of merging the Y-12 research group with the laboratory and realigning the functions of some of the research groups, the laboratory now has twelve major research units: Analytical Chemistry Division, ANP Division, Biology Division, Chemistry Division, Materials Chemistry Division, Chemical Technology Division, Electromagnetic Research Division, Health Physics Division, Isotope Research and Production Division, Metallurgy Division, Physics Division, and the Reactor Experimental Engineering Division. All of these have outstanding scientists as consultants.

In addition to the research divisions, the laboratory has six service and operating divisions which carry out vital functions in support of the research and development programs. These are the Engineering and Maintenance, General Office, Health, Industrial Relations, Laboratory Protection, and Operations Divisions.

## THE LABORATORY'S PROGRAM

As an outgrowth of its own original interests and problems, and in line with the Atomic Energy Commission's broad objectives, the Oak Ridge National Laboratory under Carbide's operation has developed a wide program of research and development. Projects range from basic studies in physics, chemistry, and biology to reactor technology, metallurgy, particle accelerators, isotope production, isotope properties, health protection, and education. In determining the actual scope of its activities, the laboratory has been guided by several basic considerations:

*First*, as part of the Commission's urgent program of reactor development, the laboratory is devoting intensive effort to three reactor projects: the Materials Testing Reactor, the Aircraft Nuclear Propulsion Program, and the Homogeneous Reactor.

*Second*, the laboratory performs fundamental research that can be accomplished only with the facilities and equipment available at a large laboratory such as ORNL. Certain projects require a large supply of neutrons that only a nuclear reactor can produce. Others involve the electromagnetic separation units or special-purpose laboratories. Universities and other private research institutions do not, and cannot, at least at present, afford such facilities. In addition, the Atomic Energy Act of 1946 restricts ownership of many types of facilities to the Atomic Energy Commission.

*Third*, fundamental research in support of applied technology is strongly emphasized at ORNL. Obviously, processes and techniques which become a part of technology must first be explored and developed through basic studies. Only in this way can technology be expanded. Hence, the laboratory has strong basic research programs in biology, chemistry, physics, metallurgy, and health physics.

*Fourth*, the laboratory seeks to perform a

broad educational function. To this end, working relationships with southern universities have been established through the Oak Ridge Institute of Nuclear Studies to allow faculty members and graduate students to take advantage of the laboratory's facilities for work on research problems of mutual interests. Both the laboratory and the visiting research workers benefit from these research contacts. The laboratory also serves as a training center for representatives from other AEC agencies. A training program in health physics has been established, and a program of training in reactor technology is being expanded.

*Fifth*, the ever-growing demand for stable and radioactive isotopes stimulates research and development in isotope production and utilization. The laboratory is continuously seeking improved or new physical and physicochemical methods of isolating these isotopes, and is carrying out a vigorous program of basic studies to determine their properties and applications.

### *Cooperative Projects*

It should be emphasized that research projects, for the most part, are not aligned entirely on a divisional basis. For example, in fulfilling its responsibilities in reactor technology, the Oak Ridge National Laboratory has set up projects which include physicists, chemists, metallurgists, and engineering designers in nine of the twelve major research divisions. The coordinated activity of these groups, operating in their respective divisions, results in an integrated program of reactor technology which approaches reactor problems through both fundamental and applied research.

The integration of the laboratory's research and development programs with those of other agencies and of other AEC installations has resulted in the establishment of several cooperative projects: (a) joint responsibility with Argonne National Laboratory for the Materials Testing Reactor, coordinated by a three-man steering committee;

(b) cooperation with southern universities through the Oak Ridge Institute of Nuclear Studies; and (c) joint work with the General Electric Company and the National Advisory Committee for Aeronautics on the Aircraft Nuclear Propulsion Project.

## RESEARCH PROGRESS AT ORNL

Some of the research projects at ORNL have been outstandingly successful and have received with scientific acclaim. The following highlights of research progress at the laboratory is concerned with unclassified discussion of the work, since about half of the laboratory's program remains in the secret category and cannot be described here.

### *Physical Research*

*Neutron Studies.* - Neutrons which are so essential to the operation of a uranium reactor are the subject of investigations in strong programs of basic research at ORNL.

*Neutron Half-Life.* - From theoretical considerations, it has been predicted that a neutron emitted by some nuclear process, such as fission, should be radioactive, and decay by the emission of an electron to form a proton. At ORNL, evidence of neutron decay is now being sought in a complex experiment designed to detect both the emitted electron and the resultant proton. It has been definitely established that the neutron does decay in the manner described, and current effort is directed toward determining the half-life associated with this radioactivity. Early results indicate that the half-life is about 15 minutes.

*Neutron Absorption.* - A program for the systematic measurements of neutron absorption by all elements and isotopes has been essentially completed. In this program, samples of all available elements and isotopes were exposed to neutron beams and the amount of neutron absorption in the sample was measured, yielding fundamental information of great value in nuclear physics and reactor technology.

*Neutron Diffraction.* - The neutron-diffraction studies of crystal structure have become an exceedingly powerful tool for determining how atoms are arranged in crystals. This technique overcomes the limitations of X-ray and electron-diffraction studies; it permits the structural analysis of components which cannot be studied satisfactorily by any other method.

### *Instrument Development*

The development of suitable instruments for detecting and measuring all types of radiation is a vital part of the Health Physics Division program. A recently developed instrument for which there has been a great need is the neutron survey meter, a portable instrument which may be used to measure neutron radiation.

Another instrument of great scientific interest has been developed at ORNL in the Physics Division. It is the scintillation spectrometer, which measures the number and intensity of light flashes emitted from an anthracene crystal when radiation strikes it. Not only can this instrument measure the amount of radiation, but also the energy. This is a good example of the fruitfulness of pure fundamental research, such as that which led to the discovery that anthracene crystals give a flash of light when a beam of radiation strikes them, and that the brightness of the flash is proportional to the energy of the radiation.

### *Spectroscopy Research*

As an outgrowth of the wartime need for precision quantitative and qualitative process control in the electromagnetic plant, and present similar demands of the plutonium research program and the isotope-production and research program, a very well-equipped spectroscopy laboratory has been established. In this laboratory, investigations of fundamental properties of isotopes are carried out by X-ray, optical, infrared, microwave, nuclear-induction, and mass-spectrometer techniques.

### *Particle Accelerators*

Both the electromagnetic equipment and experience in the development of ion sources are now being utilized in the construction and operation of particle accelerators. The availability of these accelerators is essential to a nuclear-research program. Such instruments are used in the study of nuclear forces and nuclear reactions, and in the production of certain isotopes obtainable in no other way.

A small, 2-million-volt cyclotron and a 2-million-volt Van de Graaff accelerator have been in operation for several years. A larger, 86-inch cyclotron recently placed in operation is the only such instrument in the southeast. A 5-million-volt Van de Graaff accelerator has also been placed in operation recently.

The use of a low-voltage ion source for the deuteron-deuteron reaction now makes it possible to produce neutrons without the expenditure of fissionable materials.

### **CHEMICAL RESEARCH**

The elements technetium and promethium were first isolated and purified in measurable quantities at the Oak Ridge National Laboratory by means of a new chemical process. Scientists at the laboratory were credited with discovery of the element promethium.

Production of pure compounds of these elements is now on a more-or-less routine basis at the laboratory.

#### *Purification Methods*

Promethium, a member of the rare-earth group of elements, was first isolated by means of a process developed at the laboratory for the separation of the rare earths.

This process has enabled the routine preparation of exceedingly pure (99.9 per cent or better) rare-earth elements for the first time.

### *Synthesis of Carbon<sup>14</sup>-Labeled Compounds*

The usefulness of carbon<sup>14</sup> as a tracer in biological studies was recognized in the early days of radiochemistry. Consequently, an effort to synthesize carbon<sup>14</sup>-labeled compounds was started at the laboratory several years ago. Since that time, scientists at ORNL have successfully produced more than 50 different carbon<sup>14</sup>-labeled organic compounds ranging from the simplest organic acid, known as formic acid, to such complex chemical compounds as synthetic vitamin K. Many of these compounds are distributed through the AEC Isotopes Division for scientific investigations impossible by any other means.

#### *Studies in Basic Chemistry*

Since the ORNL reactor was the first capable of producing large amounts of fission products and plutonium, chemical studies of these new substances occupied the attention of many chemists from the earliest days of the laboratory.

The characteristics of fission products, their radiations, half-lives, abundance, and radioactive decay schemes were for the most part unknown. Methods of radiochemical analysis were needed in the study of the fission products. Research and development work along these lines, started during the war, have been very successful, supplying information which enables the rate of formation of most fission products in the reactor to be predicted and their characteristics to be determined.

The chemical behavior of the new elements neptunium and plutonium and the other heavy elements is now better known as a result of this research.

#### *Raw Materials*

From the point of view of the long-range atomic-energy program, the self-sufficiency of this nation with regard to uranium sources may be realized only by exploitation

of the enormous deposits of extremely low-grade materials. With this regard, the staff of the Oak Ridge National Laboratory has been actively cooperating with other installations in the development of methods for purifying uranium from these low-grade materials.

### *Chemical Technology*

In any reactor, the fission products ultimately build up to such a high concentration that they interfere with the operation of the reactor, and it becomes necessary to take the uranium from the reactor and remove the contaminants. In reactors where the production of plutonium or new fission material is an objective, chemical processes for the separation and purification of these products as well as the uranium are required. ORNL, with its pilot-plant facilities, has been outstandingly successful in the development of chemical processes for carrying out these operations.

### REACTOR DEVELOPMENT

The design and development of a new reactor or a new type of reactor cannot be hurried or haphazard. It is a process which takes years of painstaking effort—checking, testing, altering, and improving—until the final design represents the best and most up-to-date reactor of its type that scientists and engineers know how to build.

### *Materials Testing Reactor*

Oak Ridge National Laboratory's staff has long been interested in the design and construction of a reactor which would produce a high concentration of neutrons—the type known as a high-neutron-flux reactor. In 1947, a feasibility report written by ORNL scientists indicated that the design and construction of such a reactor was quite possible. Although the particular design which they suggested was not used, it has served as a guide for a Materials Testing Reactor presently being constructed. In carrying out its responsibilities in the de-

sign of the MTR, the laboratory has constructed a full-scale model of the reactor to test certain phases of the design. This experimental work has verified some aspects of design and indicated changes in others.

### *Homogeneous Reactor*

One of the earliest types of reactors investigated was the homogeneous reactor, given a great deal of attention in the early war years. Fundamental difficulties caused this work to be discontinued in favor of other projects.

Recently, interest in the homogeneous reactor, in which the fuel, moderator, and possibly other elements are mixed intimately together, has been revived. This type of reactor makes it possible to incorporate into the system a chemical reprocessing plant for treating the nuclear fuel so that production of fissionable material, for example, can be carried out in continuous instead of "batch" operations. In April 1950, the Oak Ridge National Laboratory was authorized to construct a pilot model reactor of the homogeneous type.

### *Reactor Materials*

In the construction of reactors certain metals, desirable from the nuclear standpoint, are put to uses in which they have never been tried, and frequently subjected to unusual conditions when the reactor is in operation. For example, in reactors for producing power, materials must not only withstand the damaging effects of radiation, but must also have strength and corrosion resistance at the high temperatures at which these reactors must operate. To insure that suitable metals and alloys can be made for these conditions, a strong program of metallurgical and chemical research is carried on at the laboratory.

The effect of radiation upon materials used inside reactors is not well understood. As reactors are built to operate at higher power levels, this problem becomes more se-

vere. Radiation-damage studies at ORNL have successfully explained the effects of radiation on certain types of materials. A Physics of Solids Institute has been established and housed in a new building which contains elaborate "hot laboratory" facilities. This special laboratory will give impetus to the rapidly expanding program.

## RADIATION PROTECTION

Perhaps the most prevalent characteristic of the work of the nuclear scientist is his dependence upon nuclear radiations. Not only does he generally depend upon one or another of these radiations to produce and control the nuclear changes in which he is interested, but it is by means of radiations originating in, or altered by the nuclei of, atoms that he is most frequently informed of nuclear changes. His work frequently is made much more difficult by the fact that the same radiations which are indispensable tools of his trade could, if allowed to penetrate the tissues of his body, produce harmful or even lethal biological effects that are dependent upon the extent and period of exposure.

### *Radiation Effects on Living Cells*

Although the damaging effect of radiation on living cells has long been known, there are very few factual data on how the damage is caused, or why certain tissues are more sensitive to radiation than others, or why hereditary abnormalities are caused in some cases but not in others. These and other fundamental problems concerning the nature of radiation effects must be studied to make possible more effective diagnosis and treatment of abnormalities caused by radiation. Research programs at ORNL have been particularly successful in improving the understanding of radiation effects on living cells and tissues.

### *Shielding Against Radiation*

The problem of protecting workers from radiation arises in any project dealing with

radioactive materials. With the advent of large-scale operations using radioactive materials, it has been necessary to develop more efficient shields.

In any mobile reactor, such as might be used in an airplane or naval vessel, shielding becomes critical. ORNL is conducting an extensive investigation of the theoretical aspects of shielding. Accompanying this is an applied research program for the development of more efficient shields and shielding materials. These two programs have already shed new light on shielding phenomena and, on the immediate practical side, have resulted in new and more effective shielding materials.

### *Control of Radioactive Wastes*

ORNL was the first atomic-energy installation to encounter the problem of controlling radioactive wastes on a large scale. This problem has been solved by the laboratory with varying degrees of success.

Radioactive wastes are chiefly airborne and waterborne. An extensive program of research and development has demonstrated methods of controlling both types. Airborne wastes are removed in two ways: mechanically, by filtering; and chemically, by passing air through a chemical "scrubber" which literally washes it. Liquid wastes, due to their excessive volume and radioactivity, present a problem of storage. Radioactive materials presently are concentrated into small volumes by precipitating the radioactive materials as solids and by evaporating the pure water from the waste solution.

Active research programs are now developing newer and still better methods and equipment for the control of all types of radioactive wastes.

## ISOTOPE PRODUCTION

As the center of production and distribution for both radioactive and stable isotopes in the United States, the Oak Ridge

National Laboratory has continued to develop methods for the production and chemical processing of these isotopes. The number of stable isotopes available for distribution has increased from less than ten when the program was started to about 200 which are currently available. When the radioisotope-distribution program started, three major radioisotopes were available in purified form; this number has been expanded to about forty purified radioisotopes which are in routine production. In addition to increasing the variety of isotopes available, the laboratory has also greatly increased its production capacity.

By the end of 1951, the isotope production program had resulted in nearly 30,000 shipments of radioactive isotopes and 1,400 stable isotope shipments. The average rate of production of radioisotopes is now greater than twice the rate in 1948, and production of stable isotopes has increased over 300 per cent in the same period.

#### *Stable Isotopes*

Electromagnetically enriched isotopes of about forty elements have been supplied for research purposes to AEC contractors since January 1946, and to numerous university and industrial laboratories since January 1948. Some of these have been used for the determination of their various physical and chemical properties; others have been converted by the users into radioisotopes for study of their properties. Many research projects throughout the nation have been made possible by these isotopes, and increasing numbers of scientific papers are being published as a result of such research.

The electromagnetic process for separation of isotopes has been developed to the point that, potentially, any desired concentration of an isotope can be obtained; many isotopes have been purified to better than 99 per cent and one ( $U^{238}$ ) to over 99.999 per cent. High enrichments obtained for several rare isotopes, such as beryllium<sup>10</sup> (artificially produced), iron<sup>58</sup>, and potassium<sup>40</sup>, have

been essential to the completion of fundamental nuclear-research projects. The determination of the isotopic composition of enriched isotopes has been accompanied by precise measurements of natural isotopic abundances which have been accepted as standard values.

#### *Radioactive Isotopes*

The rapid increase in the demand for radioisotopes made it essential for ORNL to expand its production facilities. A new radioisotope-processing area was designed to meet the special requirements arising from the handling and processing of radioactive materials. This specialized chemical plant for radioisotope production embodies all the most recent equipment and facilities which have been developed as a result of eight years' experience in working with radioactive materials.

Because it is unique, most of the equipment used in this area could not be purchased from manufacturers and had to be designed and constructed by the laboratory. The successful operation of this equipment has placed the production of radioisotopes on an "assembly-line" basis. The "assembly line," it should be pointed out, must be operated by remote control because of radiation hazards. The production of radioisotopes will be described in detail in the following sections of this book.

#### HISTORY OF RADIOISOTOPE PRODUCTION AT ORNL

Although primarily a research organization, ORNL is the center of radioisotope production for the Atomic Energy Commission. It should be pointed out, however, the relationship to the overall laboratory program, that actually less than 15 per cent of the scientific staff of the laboratory—about 5 per cent of the total laboratory personnel—are concerned with radioisotope production.

#### *Wartime Developments*

As a part of the original research program

in 1943 for the development of new processes, radioisotopes were produced from the earliest days of the reactor's operation.

Since the Oak Ridge reactor could produce radioactive materials in much larger quantities than any other facility then available, it became necessary to develop a completely new sort of chemical technology—the handling of large amounts of radioactive materials. It is difficult now to realize the magnitude and multiplicity of problems which presented themselves in 1943 and 1944. No one had experience in handling large quantities of radioactive materials and there was little earlier experience with remote-control operation; indeed, many radioisotopes common today were then completely unknown. Much research was done to develop ways and means of performing tasks never before attempted.

Out of this program came the experience, the new techniques, and the discoveries which made possible the successful accomplishment of the initial four objectives. So unique were the facilities designed and built and so unusual the techniques developed in the field of radiochemistry and nuclear physics that, upon the accomplishment of the original objectives, they were immediately put to use in an expanding program of research and development.

Many radioisotopes were produced in wartime for Manhattan Project installations over the country; in these early days many of the basic processes for radioisotope production were developed. During the same period, many new radioisotopes were discovered and new techniques found for separating and purifying them. Perhaps the most outstanding of these was the ion-exchange process for separation and purification of various elements from gross mixtures of fission products. The ion-exchange process had long been known—it is used in tank-type household water softeners—but the application of this process to the separation and purification of elements was completely new.

### *Postwar Developments*

As research workers developed processes for the separation and purification of an increasing number of radioisotopes, the laboratory was able to supply a wider variety for use by installations within the Atomic Energy Commission. Radioisotope production techniques and equipment design were steadily improved to give increased production, greater safety, and higher quality.

Although there could be no single routine process for producing all radioisotopes, a general scheme of operations applied to all.

From the preparation of the target material for neutron bombardment in the reactor to the final shipment of the product, the production of radioisotopes demands skilled personnel and special equipment. When the reactor is shut down for the removal of irradiated samples, each member of the team of workers must know his assignment precisely and carry it out quickly and without error. Geiger counters and other radiation-detection equipment must be used constantly to check radiation. In subsequent chemical treatment of materials, special remotely controlled equipment located inside "hot cells" must be operated by a skilled operator who, in many cases, can see what he is doing only by looking in a mirror, through a periscope, or through a transparent shield. Each radioisotope, moreover, is a separate production problem, involving its own combination of requirements—for target material, irradiation time, chemical treatment, safety precautions, and the rigid time limits associated with its inflexible half-life.

### *An Industry is Born*

At the war's end, Oak Ridge National Laboratory was actually producing some radioisotopes routinely. So when the decision was reached in June 1946, to make radioisotopes available to off-project scientists and research workers all over the country, Oak Ridge National Laboratory immediately became the center of radioisotope production—first

for the Manhattan Project, then for the Atomic Energy Commission.

The first radioisotope shipment to general users made under the new Radioisotope Distribution Program was on August 2, 1946, to the Barnard Free Skin and Cancer Hospital in St. Louis, Missouri. The shipment was one millicurie of carbon<sup>14</sup>.

At first, radioisotopes were allotted only for research and medical use. Although the reactor had sufficient capacity to produce isotopes for all purposes, time was needed to develop still more new processes, skills, and apparatus required for production. By late 1947, the increased supply of radioisotopes permitted liberal allocations for research in all fields. The demand seemed always to keep just a little ahead of production capacity, and by early 1948 it was apparent that production facilities would soon be strained to their limit.

When radioisotopes production was first undertaken on a large scale, processing facilities were installed in existing "hot labs" and cells which could be changed over from their previous uses. As the variety and quantity of radioisotopes being produced increased, additional space was utilized. This resulted in a series of production facilities so scattered in odd nooks and corners that efficient, integrated operations were virtually impossible. The need for expanded facilities increased, and by midyear 1948 a decision had been made to construct a new radioisotope-processing area.

In the five years between the startup of the uranium chain-reactor in November, 1943, and the start of design work on the radioisotope-processing area in the latter part of 1948, ORNL personnel had gained a vast amount of experience. The benefit of this experience, plus the experiences of other AEC installations, was to allow a group of buildings to be designed and built for the express purpose of processing radioisotopes. These buildings represent the most advanced design which could be attained, and

incorporate every reasonable safety feature, such as the remote-control equipment of intricate design which puts radioisotope processing, packing, and shipment on an assembly-line basis.

Because this unique remote-control equipment for radioisotope handling and packing could not be obtained from commercial forms, design of all equipment in the new processing area had to be done by the Operations and Engineering Divisions of the laboratory; the equipment was fabricated in the research and central shops of the laboratory.

The modern remote-control equipment cuts down to a great extent the time-consuming method of handling radioisotopes by hand and enables more shipments to be sent out in a shorter time and with greater safety. From this "Atomic Apothecary" go the thousands of shipments to various users in the United States and abroad.

## A NEW RADIOISOTOPE-PROCESSING PLANT

### *General Area Layout*

The Isotope-Processing Area consists of a group of buildings containing about 20,000 square feet of floor space, designed especially to be used for the processing, handling, and shipping of radioisotopes. The facilities are divided into several subareas.

The Office Building contains Operations Division offices, in particular those dealing with radioisotope work, on the second floor, and lockers, area stores, and the building utility room on the first floor.

The work of analyzing, storing, packing, and shipping of radioisotope preparations through use of intricate remote-control equipment is housed in an Analytical Building. Six small buildings are used for various types of radioisotope production and development. Another similar building, the Service Building, is used as supply and control point for the various specialized services for the area. Another large building

with garage-type doors, big enough to accommodate the largest trailer trucks, is provided for washing and decontamination of heavy equipment.

A brick stack 250 feet high is provided, together with associated fans, blowers, jets, filter, precipitators, and ductwork, to decontaminate and discharge the ventilating air and exhaust gases from the Isotope Area, as well as that from other chemical operations close by.

The use of separated small process buildings to minimize the effects of fire, explosion, and poisonous gases resulting from chemical processing is not new in industry; various forms of this basic pattern have been used for many years in processing explosives, organic chemicals, and toxic biological preparations. While situations arising from fire, explosion, or contamination with pathogenic bacteria are quite different from radioactivity hazards, they are comparable in some respects. Experience gained in processing large and small amounts of radiochemicals indicates that the new laboratory area possesses the following advantages:

1. Isolation of work helps prevent cross-contamination by use of unclean equipment from neighboring processes. In some cases, such as the production of phosphorus<sup>32</sup> and carbon<sup>14</sup>, the volume of production is large enough to justify a separate building for each.

2. Separation of work at various radiation levels is advantageous; it is well known that radiochemical work at various levels of radiation intensity should not be mixed together. Small, specialized process buildings provide an effective way of separating processes involving only beta radiation, low-level gamma radiation, intermediate-level beta-gamma, and high-level gamma work.

3. Maintenance work is easier, faster, and safer. Equipment may be torn down and worked on with any possible contamination

confined to a small, controlled area. Workers on other processes in other buildings are not subjected to radiation and airborne contamination which often accompanies such operations.

4. Control of ventilating air is simplified. In a simple one-room structure, it is easy to be sure which way the air is moving at all times. Interconnected rooms in a single building require a complex balancing of air flows and pressures.

5. It is easier to avoid contamination of air over a large area. If a "spill" occurs in one building, which grossly contaminates the air, the building can be evacuated and the trouble localized. Work can continue without interruption in the other buildings.

6. Isolation in case of fire, explosion, or similar disaster minimizes these hazards. The buildings are located far enough apart so that even serious fires and damage from explosions could be easily confined. It is extremely important to localize radioactive contamination in case of such disasters.

7. Use of distance instead of heavy shields for the reduction of radiation intensity lessens construction costs. Barricades, hot hoods, and cells located against the side walls have no rooms on the other side and consequently require no heavy shielding on that side to prevent exposure to penetrating gamma radiation.

8. Dispersal of contaminated floor wash water and tracking by shoes is minimized. A great deal of scrubbing, hosing, steaming, etc., is required after spills. It is difficult to keep wash water confined to a small area in a large building with many rooms; the contamination is carried about on shoes of persons in the building and is often tracked around a big building in a short time.

9. It is easier to control unauthorized

congregation of personnel. Any persons in a process building must have a legitimate reason for being there. Since only the minimum required personnel are allowed in each process building, fewer persons would be exposed to radioactivity hazards in case of accident.

## RADIOISOTOPES

### *What is an Isotope?*

The identity and chemical characteristics of an atom are determined by the number of protons in its nucleus. An atom having one proton in its nucleus is called hydrogen; all atoms having only one proton in the nucleus are hydrogen atoms. There are 92 elements from hydrogen to uranium, and each successive element has one more proton in its nucleus than the one preceding it; uranium has 92 protons.

Thus, the number of protons in the nucleus of an atom determines what element it is. But atomic nuclei contain neutrons as well as protons, and although the number of neutrons in a nucleus has no effect upon the identity of the atom, it does effect the weight. Hydrogen with one proton in its nucleus has a mass number of 1 to indicate its atomic weight; however, an atom with one proton and one neutron in its nucleus is also hydrogen—its mass number is 2. Similarly an atom with one proton and two neutrons in the nucleus is hydrogen with mass number 3, called hydrogen<sup>3</sup>, or tritium.

The name hydrogen applies to all atoms having one proton in the nucleus, regardless of the number of neutrons. The different hydrogen atoms are called isotopes (Greek: *iso*-same; *tope*-place) to indicate that while they are atoms of the same element, their nuclei are different. An isotope is one of two or more kinds of atoms which are of the same element but have different weights, and a particular isotope is identified by giving the name of the element and its weight. Thus the hydrogen isotopes are called hydrogen<sup>1</sup>, hydrogen<sup>2</sup>, and hydrogen<sup>3</sup>.

A *radioisotope* is any isotope which is radioactive. All elements have one or more isotopes which can be made radioactive.

Radioisotopes have been called "the most useful research tool since the invention of the microscope"; in 1948, the Atomic Energy Commission's Advisory Committee on Biology and Medicine stated that "the availability of radioisotopes is contributing more than any other factor today to the advancement of medicine and biology." The story of how radioisotopes are made available to doctors and scientists centers on a new industry which today takes its place on the American scene; the completion of a highly specialized radioisotope-processing plant marks radioisotope production as a permanent new industry—an industry which even now is growing at a rapid rate.

### *A New Industry*

Radioisotope production is not only a new industry but a completely new type of industry. Imagine a manufacturer whose total production for 1950 weighs less than one-tenth of an ounce, an industry which makes approximately 9,000 product shipments a year with the net weight of product in each shipment being less than the weight of pencil lead used in writing your name. But these small weights are deceiving; in the amount of radiation given off, a year's production of radioisotopes is the equivalent of about 5 pounds of radium.

This radiation is, of course, the source of the usefulness of radioisotopes. The shielding required to keep radiation from penetrating the sides of the shipping container must be reasonably thick and heavy, consequently, an average shipping container weighs about *one billion* times as much as the radioactive material it contains.

### *Usefulness of Radiation*

Many isotopes are not radioactive, and a large number of these are separated in pure form at the Oak Ridge National Laboratory

facilities in the electromagnetic plant area.

Since the radiation emitted by radioisotopes makes them useful, it is reasonable that they be sold to consumers on the basis of the amount of radiation they give off rather than on the basis of weight commonly used in chemical industry elsewhere.

The units of radioactivity used in computing radioisotope costs were originally based on the radioactivity of radium. It has been found that in one gram of radium about 37 billion atoms disintegrate every second, and in honor of the discoverer of radium this amount of radioactivity, 37 billion disintegrations per second, is called one *curie*. Originally, one curie was defined as the amount of radioactive material needed to give the same number of disintegrations per second as one gram of radium; however, the recent trend is to define one curie as that amount of material in which there are 37 billion disintegrations per second, without reference to radium.

A curie is quite a large unit, being equivalent to one gram of radium, so the unit most commonly used in radioisotope production is the *millicurie*, one-thousandth of a curie, or 37 million disintegrations per second. Since each atom, as it disintegrates, gives off one or more rays which are somewhat similar to X-rays, one millicurie of any radioisotope gives off at least 37 million rays per second. Radioisotope costs are given in terms of dollars per millicurie rather than dollars per unit of weight. No customer is much concerned with the weight of his shipment of radioisotopes; in fact, net weight is not even determined for the shipments. What he is interested in is how many disintegrations per second—how many rays of atomic energy—it will supply.

#### *Kinds of Radiation*

Each radioisotope has a certain definite energy associated with the rays it emits. These rays range in energy from very weak (low energy) to very strong, and fall into

three categories. These three kinds of radiation are called alpha, beta, and gamma.

An alpha ray is a nuclear bullet composed of two protons and two neutrons shot from the nucleus of a radioactive atom. Although it may have a very high energy, an alpha particle (or ray), because of its relatively large size, will not penetrate solid materials very far. Most alpha particles can be stopped by a few sheets of paper or just the human skin. Because of their low penetrating power, alpha particles require very little shielding and present no radiation hazard unless they come from a source inside the body. When alpha particles are emitted inside the body, even though they are not capable of traveling very far through tissue, they may damage a vital organ simply because they come from radioactive material which has been absorbed in the organ itself. Thus, the major precaution to be taken with alpha-emitting radioisotopes is to keep them out of the body.

A beta ray is a much smaller bullet (an electron) shot from the nucleus of a radioactive atom. Because they are much smaller than alpha particles—about 7,000 electrons weigh as much as an alpha particle—their penetration through matter is somewhat greater, although still not very great. Most beta radiation can be stopped by a fairly thin sheet of metal; at ORNL sheets of transparent plastic are frequently used to shield beta radiation. Most radioisotopes are beta emitters and many of them emit gamma rays as well.

Gamma radiation is not associated with a particle; there is no gamma "bullet" as such. Gamma rays are similar to light rays in that there is no particle involved, simply a beam of radiation. Gamma rays, essentially identical with X-rays, are the most penetrating of the three forms of radiation. They require thick, heavy shielding. Gamma radiation requires that "hot" cells and other equipment used in radioisotope production have several feet of concrete or several inches of lead around them.

## *The Handling of Radioactive Materials—Shielding*

Since most radioisotopes emit beta and gamma radiation, any process involving relatively large amounts of radioisotopes must be shielded in order to protect the workers. A shield is nothing more than a physical barrier between the worker and the source of radiation, but it imposes severe limitations upon the number of operations the worker can perform. The presence of a shield requires that all operations be performed by remote-control devices and in many cases requires the worker to look through a periscope, mirror arrangement, or transparent shielding, to see what he is doing. Remote-handling devices have been developed for performing practically all operations which can be performed manually.

## *Waste-Disposal and Contamination Problems*

The rate at which radiation is emitted by a radioisotope depends upon its half-life, and nothing can change this half-life by even the smallest amount. Consequently, once an isotope is made radioactive it continues to emit radiation until finally all of its atoms have disintegrated. Nothing can stop this radiation-decay process, neutralize it, or even delay it. While this is of prime interest to the scientists using radioisotopes for research, it poses two problems in the production phase.

Ordinary industrial wastes can be neutralized by various procedures and then disposed of in the usual ways—but not radioactive wastes. Because there is no possible way of neutralizing, stopping, or delaying the radiation from radioactive materials, there is only one way to handle large-scale radioactive wastes, and that is to isolate and store them until the radioactivity decays naturally. About the only processing that can be done is to reduce the waste volume to simplify the storage problem. This is done by means of various processes designed to separate the radioactive constituents of the wastes from the water,

chemicals, and other nonradioactive materials with which they are mixed. The most common procedure used at ORNL involves the concentration of radioactive wastes by evaporating the water from them. This has proved helpful in alleviating the storage problem.

Nevertheless, the storage capacity of the ORNL tank farm, which contains eleven underground storage tanks having a total capacity of a little over a million gallons, is usually in use to the fullest extent, despite the fact that a steady stream of water, stripped of most of its radioactivity by evaporation or precipitation processes, is being pumped out of the tanks. In an average week, about 50,000 gallons of highly radioactive wastes are concentrated to the smallest possible volume and stored in these tanks. This is called the "hot" waste system.

A "warm" waste system is used to handle wastes containing only small amounts of radioactive materials. This system handles the water from the "hot" waste system, the water used in washing floors and water from the plant laundry and similar sources where the level of radioactive materials is quite low. A large portion of the water going through this system is water used in cooling tanks and various equipment for radioisotopes work at the plant.

Cooling water normally contains no radioactive material, but is run through the "warm" system just in case a tank that is being cooled might develop a leak and allow some radioactive material to leak into the cooling water. All this water runs into a 1,600,000-gallon "settling basin," whose purpose is twofold: first it allows solids to settle out, carrying some of the radioactive material with them, and second, it delays or holds up the water until a large part of the radioactivity has decayed away.

The settling basin is ingeniously arranged with baffles so that the flow of water takes as long as possible and has essentially no

turbulence to interfere with the settling process. The outlets are so arranged that only water from within 1 inch of the top of the 6-foot-deep settling basin can drain out into the small natural stream running nearby. About a mile and a half further down, this little stream has been dammed to form a 50-acre lake which serves as additional holdup to allow further decay of any radioactive materials remaining. This system, which handles about 7,000,000 gallons of water per week, is so effective that the level of radioactivity in the waters of the Clinch River, into which the system ultimately drains, is lower than that of many natural mineral waters.

A second problem arising from the handling of radioactive materials is surface contamination. This results from the fact that, after all radioactive material has been removed from equipment, some radioactive atoms still cling to the walls. Before maintenance work can be done on this equipment, it must be decontaminated. Only in rare cases is washing with soap and water sufficient. After that has been tried, more drastic chemical treatments are supplied until contamination is reduced to the desired level. Unfortunately, even with the most modern equipment and highly skilled operators, spills of radioactive materials do occur. And when a spill occurs, quite a large area is apt to become contaminated through splashing or tracking of the material. This requires extensive cleanup work which often takes days when the spill is serious.

Every reasonable precaution is taken to avoid leakage or spills of radioactive materials; but, realizing that accidents may happen, the engineers try to design work areas that can be easily cleaned. This means avoiding porous surfaces which absorb radioactive materials, avoiding cracks and inaccessible spots where they might accumulate, and using chemical-resistant materials which will stand up under chemicals used for decontamination.

### *Radioisotope Decay*

Because their atoms are constantly disintegrating, most radioisotopes last only a relatively short time. The rate at which the atoms of a radioisotope disintegrate is determined by a physical constant, the half-life, which is characteristic of that particular radioisotope. Radioactive iodine<sup>131</sup>, one of the major radioisotopes produced by Carbide at Oak Ridge National Laboratory, has a half-life of eight days. This means that, in eight days, half of the radioactive atoms will disintegrate; in the following eight days, half of those remaining will disintegrate, leaving one-fourth the original number of atoms; and so the process goes on—every eight days the number of iodine<sup>131</sup> atoms remaining will decrease by one-half, leaving one-eighth, then one-sixteenth, and so on.

### *Need for Speed in Processing and Shipping*

The fact that the number of radioactive atoms of any radioisotope decreases by half with every half-life that elapses means that radioisotopes with short half-lives cannot be stock-piled. They must be produced currently as orders come in. For example, in the case of iodine<sup>131</sup> (eight-day half-life), if chemical processing time is five days and shipping time is three days, one half-life will have elapsed by the time the shipment reaches its ultimate user. This means that if the consumer is to receive one millicurie, *two millicuries—twice the amount sold*—must be produced to fill the order, because half this amount will disintegrate in the first eight-day period during processing and shipping. Thus, for iodine<sup>131</sup>, phosphorus<sup>32</sup>, and other short-lived radioisotopes, chemical processing time and shipping time must be held to a minimum.

### *High Purity and Quality Essential*

Radioisotopes are used in exact scientific investigations and in medical therapy where the presence of impurities is highly undesirable. Therefore, all radioisotopes must

meet rigid specifications as to purity and quality before they can be shipped.

Iodine<sup>131</sup>, for example, is produced from uranium which has been bombarded with neutrons in the ORNL reactor, and is always associated with about a hundred radioactive fission products plus large amounts of uranium. Among the fission products are several, such as tellurium (the radioactive parent which decays to form iodine<sup>131</sup>), which are toxic and cannot be tolerated in solutions of radioactive iodine which are often used in medical therapy. And, of course, the final product shipment cannot contain any uranium because, besides being toxic in itself, uranium is an alpha emitter. It has already been pointed out that alpha radiation is dangerous when it comes from a source inside the body. So, iodine<sup>131</sup> must be highly purified before it can be sent to a consumer. High purity and quality are essential for all radioisotopes.

Although every effort is made to assure a high degree of purity, radioisotopes shipped from Oak Ridge National Laboratory cannot be guaranteed to meet pharmaceutical standards. The final responsibility for assuring their purity and strength must rest with the doctor or scientist who uses them.

#### THE PRODUCTION AND PROCESSING OF RADIOISOTOPES

The artificial production of radioisotopes for scientific use dates back only about seventeen years. However, the radioactive elements that occur in nature were used as sources of radiation and even as tracers (to "trace," by their radioactivity, materials which could not be detected in any other way), virtually from the time of their discovery during the early years of the century. In fact, Hevesy, the Danish investigator who demonstrated that radium-D was chemically the same as lead (thus helping to prove that isotopes exist), used the radiations of the radium-D lead isotope to learn about the chemical behavior of lead. This was the first tracer experiment; the

year, 1912.

The modern era of the utilization of radioisotopes as scientific tools began about seventeen years ago. In 1934, the Joliot-Curies in France discovered that radioactive isotopes of naturally stable elements could be produced by nuclear bombardment. Within a few years, cyclotrons and other particle accelerators had produced radioisotopes of all of the eighty-three stable elements. By 1940, some 370 varieties were known.

The cost and scarcity of cyclotron-produced radioisotopes, however, would long have prevented their use in most laboratories had it not been for the wartime development of the nuclear reactor—the uranium pile. These reactors can manufacture radioisotopes in hitherto undreamed-of quantities.

#### *Pile Production of Radioisotopes*

In a normal manufacturing process, for example, the manufacturing of furniture, the producer starts with his raw material—in this case, we might say mahogany lumber—and through a series of processing steps manufactures a mahogany table. Note that he started with mahogany lumber and finished with a mahogany table. To continue the analogy, we might say that a radioisotope producer starts with pine lumber and manufactures a mahogany table.

The point is: Normal manufacturing processes involve changing the physical form and shape, perhaps even the chemical composition of the raw materials; but radioisotope manufacture involves more than that, it incorporates a change in the basic *nature* of the raw material. This is what is meant when it is said that the radioisotope manufacturer produces a mahogany table from pine lumber—he changes the very nature of the pine so that it not only resembles mahogany, it is mahogany.

Radioisotope production will never reach the stage where mahogany can be made from

pine, but the transmutations which take place in many of the radioisotope-production processes are perhaps even more startling than that. Under neutron bombardment, sulfur, for example, forms phosphorus, metallic tellurium becomes iodine, nitrogen forms carbon, and in all of these cases the end product has a completely different nature; in no way does it resemble the raw material.

Broadly speaking, there are three ways in which neutrons in the pile produce radioisotopes: (1) by splitting atoms of fissionable uranium into new atoms of entirely different elements, called the fission products, which are radioactive themselves; (2) by being captured in the nuclei of atoms of special "target material" inserted into the pile, turning them into heavier isotopes of the same element; (3) by altering the electrical charge of the nuclei of the target material, thereby transmuting them into isotopes of a different element.

Uranium fission products removed from the pile contain a great variety of radioactive materials, which were produced by method (1) above, and which can be extracted and purified by chemical means. However, the radioisotopes obtained in this way are all those of elements near the center of the atomic scale between zinc (number 30) and gadolinium (number 64).

With the exception of iodine<sup>131</sup> and strontium<sup>90</sup>, these do not enter significantly into many medical, biological, or agricultural uses at present. Therefore, most of the radioisotopes supplied by Oak Ridge National Laboratory must be prepared by methods (2) and (3). These require the preparation and pile irradiation of special target materials. Phosphorus<sup>32</sup>, one of the most widely used radioisotopes, can be produced by both methods and may be used to illustrate the production processes.

#### *Typical Process-Phosphorus<sup>32</sup>*

In the production of phosphorus<sup>32</sup> by

neutron capture (method (2)), phosphorus<sup>31</sup>, contained in chemically pure phosphate, is put into aluminum cans which are set in holes in a graphite block and pushed into the pile. Each atom of the stable element, phosphorus<sup>31</sup>, that captures a neutron becomes radioactive phosphorus<sup>32</sup>. But the neutrons present in the Oak Ridge pile are insufficient to convert more than a small proportion of the phosphorus atoms to the radioactive state. Hence, the phosphorus<sup>32</sup> is still very much diluted with phosphorus<sup>31</sup>, with which it is chemically identical, and the treated phosphate is not highly radioactive. Nor can the phosphorus<sup>32</sup> be separated by chemical means from its nonradioactive brother, phosphorus<sup>31</sup>. Phosphorus<sup>32</sup> produced in this way is said to have a low specific activity; that is, the ratio of radioactive phosphorus atoms to the total number of phosphorus atoms is small, the average being about seventeen millionths of 1 per cent.

#### *Phosphorus is Produced from Sulfur*

In practice, therefore, phosphorus<sup>32</sup> is usually produced by method (3), the transmutation of sulfur. In this process, sulfur, which has sixteen protons and sixteen neutrons in its nucleus, absorbs a neutron and ejects a proton, giving an atom which has seventeen neutrons and only fifteen protons in the nucleus. This atom cannot be sulfur, because sulfur, element number 16, must have sixteen protons in its nucleus; since this atom has fifteen protons in its nucleus, it is element number 15, phosphorus. Neutrons and protons each contribute one mass unit to the weight of the atom, so the mass number is 15 (protons) plus 17 (neutrons)-32; the new atom is called phosphorus<sup>32</sup> to distinguish it from phosphorus<sup>31</sup>, which has fifteen protons but only sixteen neutrons in its nucleus.

The process begins with the preparation of the target material, which, in this case, is sulfur. Highly purified sulfur is melted in an oven and poured into an aluminum can, which is then sealed with an airtight cap.

These cans are inserted into the pile for neutron bombardment. The length of time the target material must be exposed to neutron bombardment depends upon the half-life of the radioisotope being formed.

At first, the phosphorus<sup>32</sup> content of each can of sulfur builds up rather rapidly, but after a fairly large number of radioactive atoms have been formed, the number which decays becomes quite significant. Ultimately the stage is reached where the radioisotope is decaying as fast as it is being formed and further neutron bombardment will not increase the amount of the radioisotope. It turns out that after a period of time equal to three half-lives, almost 90 per cent of the maximum possible number of radioactive atoms has been formed; in a period of five half-lives 97 per cent of the maximum possible amount has been formed. So it is customary to expose target materials to neutron bombardment usually for a period of time equal to about three half-lives.

In the case of phosphorus<sup>32</sup>, which has a 14-day half-life, the cans of sulfur are usually bombarded in the pile for about 30 days. In this length of time, over 75 per cent of the maximum possible amount of phosphorus<sup>32</sup> will be produced. The maximum possible production of phosphorus<sup>32</sup> is small, however, and each can containing 5 pounds of sulfur will yield only about one ten-millionth of an ounce of phosphorus<sup>32</sup>. The process of recovering this small amount of phosphorus from 5 pounds of sulfur requires special apparatus and careful operating techniques.

While the sulfur is being bombarded, the aluminum can in which it is contained becomes extremely radioactive. Fortunately, the radiation from aluminum has a very short life, so after eight hours' cooling outside the pile, this radiation has virtually completely disappeared and only that from the phosphorus remains. But this radiation from aluminum does create problems; because it is most intense when the can is being removed from the pile, the workers who per-

form this operation must be shielded from the radiation. This is done by using a long rod to catch the can and pull it from the pile into a portable lead tunnel which acts as a shield. The aluminum can is left in this lead tunnel, which is moved to the storage area for the eight-hour cooling period.

Phosphorus<sup>32</sup> emits only beta radiation, and because of this has fairly low penetrating power. After the radiation from the aluminum has died out, a worker can safely carry the can by holding it at the end of an 8-foot carrying rod. The 8-foot distance between the worker and the can allows sufficient reduction in intensity of the radiation so that the amount reaching the man is not dangerous. This carrying rod is used in taking the irradiated sulfur from the pile building to the chemical processing area.

#### *Chemical Processing—Separation of Phosphorus*

The chemical processing of phosphorus is performed by remote control behind suitable shielding in the "low-level-beta" processing building. In this building, the can is opened and placed in an oven where chemical processing begins with the melting out of the sulfur. Phosphorus is extracted from the molten sulfur into a weakly acidic solution, which is separated by letting the sulfur solidify and then draining off the solution.

The phosphorus-containing solution is given a series of chemical treatments to remove all impurities. Following the purification steps, the solution is evaporated to the proper concentration, sampled for radiochemical analysis and drawn off into a glass bottle for temporary storage while the analysis is being performed. The final volume of concentrated solution resulting from the processing of 20 pounds of sulfur (four cans) is about 1 pint, which contains approximately 4 ten-millionths of an ounce of phosphorus<sup>32</sup>.

The only phosphorus present in this solution is the radioactive phosphorus formed

from neutron bombardment of sulfur, so the specific activity is 100 per cent; this actually is higher than is necessary or desirable for most uses, so in routine production a small amount of stable phosphorus<sup>31</sup> is added as a "carrier" to simplify the processing. However, "carrier-free" phosphorus<sup>32</sup>, to which no stable phosphorus has been added, is available upon request.

The storage bottle containing the phosphorus<sup>32</sup> solution is placed into a lightly shielded wooden carrying case (light shielding is all that is necessary for the beta radiation from radioactive phosphorus) and taken to the storage barricade in the packing and shipping room. When the bottle is placed in the storage racks behind the barricade, the code number of its position is recorded in a log book so the bottle can be located easily when it is needed for filling orders.

The bottle remains in storage until a complete chemical analysis of its contents has been performed and it has been determined that the product satisfactorily meets rigid specifications.

#### *Packing and Shipping-Beta Emitters*

The packing and shipping process takes place in a well-ventilated hood, so arranged that air always moves from the room into the hood, never from the hood into the room. The storage bottle is placed in this hood, where it is opened by remote control, using an ingenious bottle-cap remover which unscrews the cap and lifts it off. Two sheets of transparent plastic shielding enable the operator to see what he is doing, but require that he perform all operations by remote control.

After the storage bottle is opened, the amount of solution needed to fill an order is drawn up into a pipette. The pipette is lifted from the storage bottle, after which the bottle carriage moves the shipping bottle under the pipette to receive the solution. The shipping bottle is sealed

with a plastic screw-cap and moved over to an instrument which measures the radiation from the radiophosphorus inside the bottle. The shipping bottle is then placed into a concrete cylinder which serves as a shield inside the shipping container. This concrete cylinder is placed inside an ordinary tin can which is sealed to avoid any possibility of leakage in case the bottle breaks during shipping. The tin can, packed in absorbent paper to cushion shocks and also to give added insurance against leakage, is then sealed into a heavy cardboard shipping box.

Health physicists survey the box to insure that the shielding is adequate and there is no possibility of radiation overexposure for express handlers during shipping or even for photographic film which may be stored close by. The shipping box is labeled as to contents and instructions for handling.

Experience has shown that when more than 375 millicuries of phosphorus<sup>32</sup> are shipped in one container, heavier shielding than that described above is required. Consequently, shipments containing more than this amount are routinely packed in a different way. The glass bottle is placed into a stainless steel cup, which is sealed to prevent leakage in case the bottle breaks. The stainless steel cup is placed inside a 1/8-inch lead shield, which is bolted in place inside a wooden shipping box. This wooden box is then surveyed and prepared for shipping in the same way as the cardboard boxes.

#### *Packing and Shipping-Gamma Emitters*

The packing and shipping procedure for iodine<sup>131</sup>, cobalt<sup>60</sup>, and other gamma emitters differs somewhat. Most of the gamma emitters stored behind the barricade in the shipping room are too radioactive to permit handling, even with long tongs, unless some shielding can be kept between the worker and the radioactive material. For this reason, iodine<sup>131</sup>, cobalt<sup>60</sup>, and the others are not carried to separate locations, but are

packed for shipping behind the same barricade which shields the storage area.

This barricade has rails along its top to allow the remote-control storage tongs to be moved into position for picking up any bottle in the storage area. The tongs consist of a set of clamps operated by a mechanical gear arrangement which can be manipulated with sufficient flexibility to allow a bottle to be picked up or deposited anywhere in the storage area. The tongs are rolled along the rails to a point in line with the sample to be picked up. They can also be moved back and forth across the entire width of the barricade. After reaching their position over the correct row of bottles, the tongs move across the width of the barricade to a point over the exact bottle and adjust to the proper height to grasp the bottle. The jaws of the tongs, previously opened, can now be closed around the bottle to grip it securely. Thus the bottle can be lifted out of its place in the rack and moved to any desired location.

For packing and shipping purposes, the tongs carry the bottle out past the end of the storage area and place it in a circular, aluminum storage-transfer table, adapted for holding bottles. This table can be rotated around its center or swung in an arc around the corner of the L-shaped barricade from the storage area to the packing and shipping area. The bottle is placed in this table on the storage side. Then it is rolled along the rail around the corner to the shipping side. At the end of the rail the table engages a set of gears which allow it to be turned on its axis.

The transfer table is rotated until the bottle is in position under the "decapper" which is used to remove the bottle cap and lift it out of the way. Then the table is rotated, moving the open bottle to a position under the remote-control pipette which is used to measure and deliver the correct amount of the radioisotope solution needed to fill the order. After this amount of solution has been drawn up into the pipette,

the pipetting assembly can be moved to a new position over the shipping bottle into which the solution is drained. Another bottle capper is used to place the cap on the shipping bottle and tighten it.

Here the packing tongs, also remotely controlled, are put to use. This device again is a set of tongs essentially similar to the others in purpose but more flexible. In addition to moving to the left and right, forward and backward, and up and down, these tongs also swing about in an arc from any position. They are used to pick up the filled shipping bottle and carry it to a position in front of a radiation-detection instrument where the unshielded radiation coming through the bottle is measured.

At the end of the shipping area, there is a hydraulically operated lead door in the barricade. By opening this door, an operator can roll the heavy shipping boxes (which often weigh several hundred pounds, including shielding) on rollers to a position inside the barricade. With the shipping box in position, the worker, after taking the radiation measurement of the shipment, uses the tongs to place the bottle into a stainless steel cup inside the shipping box. The cup, resting inside a lead shield, is sealed with a screw cap and then the heavy lead top is placed on the shield—all by remote control. After this is done, the radiation is shielded and the container rolled out from behind the barricade to allow the lead top to be bolted in place and the wooden shipping box to be sealed by hand.

After sealing, the box moves along on rollers, now out in the open, to a point in front of a radiation detection instrument which is used to check the radiation on all sides of the box. Also, a "smear test" is performed to determine whether the outside of the box has become contaminated during the packing process. If the shipment passes its radiation and smear tests, it rolls on the scales for weighing. After weighing, the box is reinforced by binding it with steel tape, and it is then labeled with the

shipping label, handling instructions, and caution signs. The box now moves to the end of the "assembly line" where a power-driven belt carrier takes it up to the bed of a waiting truck. The shipment now is on its way to the customer.

#### *Packing and Shipping-Solid Materials*

At present, carbon<sup>14</sup> is the only separated radioisotope which is customarily shipped in solid form. The carbon<sup>14</sup> is shipped either as barium carbonate powder or in the form of a carbon<sup>14</sup>-labeled compound. However, it is anticipated that several others can also be made available in solid form soon. For the packing of carbon<sup>14</sup>, there is a "dry-box" serving two major purposes: (1) it eliminates any possibility that radioactive dust will escape into the atmosphere of the room; and (2) it supplies shielding and remote-control packing devices.

The "dry-box" is ventilated in such a way that the movement of air is always from the room through the box into the exhaust system so there is no possibility that radioactive material from inside the box will escape into the room. To allow the operator to reach inside the box and manipulate the equipment without leaving a hole through which material might escape into the room, the wrist bands of two sets of rubber gloves have been sealed to the edges of holes in the front of the "dry-box."

These gloves are arranged so that the operator simply slips his hands through the holes and into the gloves. Then, with his hands in the gloves, the operator is able to work inside the dry-box without actually coming in contact with the air or any of the material. The equipment inside the box consists of tongs for handling bottles and other objects, various small tools used in measuring and transferring the material, and a remote-control balance which weighs accurately to 1 three hundred-thousandth of an ounce. Barium carbonate (carbon<sup>14</sup>) or other solids can be measured out accurately, placed in the shipping container, and sealed,

all inside the dry-box. The processing of the shipping container is the same as for other isotopes already described.

"Irradiation units," materials contained in aluminum capsules which are exposed to neutron bombardment but are not given any chemical processing, form another type of product handled in the packing and shipping room. When the aluminum cans are removed from the pile, they are placed in a lead "casket" which gives adequate shielding and can accommodate twenty-eight cans in individual holes. This casket, upon its arrival in the packing and shipping area, is carried in by the electric hoist and placed behind the packing barricade. Here, the packing tongs are used to lift the aluminum can out of the "coffin" and place it into the leadshielding of the shipping container. The top to the lead shield is put in place and bolted down by the same method described earlier. The completion of the packing and shipping operation is the same.

#### *Research Pays Off*

The processes and facilities described could not have come into being without the fundamental studies—the basic foundation—supplied by scientists in their research laboratories. In 1943, when the Oak Ridge National Laboratory came into being as a wartime project, many radioisotopes now routinely produced were unknown; the techniques of handling large amounts of radioactive materials had not been developed and much of the remote-control equipment now commonly used had not even been dreamed of, much less designed.

In eight years, radioisotope production has grown from a scientific experiment for determining the effect of neutron bombardment into the nation's newest industry. The fruition of this research is in the expanded program of radioisotope production which makes available to science "the most useful research tool since the invention of the microscope," and in the new radioisotope-processing plant which embodies the most

effective improvements and designs.

As scientists report the results of experimental work made possible by the availability of radioisotopes in increasing amounts, the value of research becomes increasingly apparent.

## USES OF RADIOISOTOPES

The uranium chain-reactor operated by Carbide at Oak Ridge National Laboratory is the source of most of the radioactive elements (radioisotopes) which are being made available for medical, biological, industrial, and agricultural research, and for treatment of certain diseases in the United States and over two score foreign countries. Among the elements which are made radioactive and shipped to various users are iodine, carbon, sulfur, phosphorus, sodium, calcium, chlorine, copper, cobalt, gold, iron, mercury, silver, tin, and zinc.

Since August 2, 1946, nearly 30,000 shipments of radioisotopes have gone out from the laboratory. Orders for radioisotopes are processed by the Isotopes Division, Atomic Energy Commission, Oak Ridge.

In the past year, the number of groups using radioisotopes in this country has increased over 35 per cent. Actually, the number of individual projects in which radioisotopes are used has increased more than this, since many groups have simultaneous projects.

Uses of radioisotopes to date have been based upon two basic phenomena: (1) their radiation enables radioactive atoms to be detected and "counted" in the presence of other atoms of any variety in locations where they could not be detected with comparable accuracy by other means; (2) radiation has a pronounced effect upon many types of matter. These are the two phenomena which make possible the numerous "tracer" experiments and therapeutic applications, respectively.

## *Biology and Medicine*

Perhaps the most widely publicized uses of radioisotopes have been those in the fields of biology and medicine. Almost half of the technical reports published describing work with radioisotopes have been concerned with activities in these fields.

As "tracer" atoms, radioisotopes are being used to tag a large number of body constituents and other related substances in a variety of research investigations. They also are being used to develop an entirely new technique for studying body metabolism and for studying the synthesis, transport, utilization, and breakdown of various body components.

To date, only a few applications have been found for radioisotopes as tools of diagnosis and therapy. An increase may be expected as results of investigations now under way become firmly established, and as a greater variety of isotope-labeled compounds becomes available. Table 1 (page 27) lists some of the better known diagnostic and therapeutic applications which have been made to date.

## *Plant Physiology and Animal Husbandry*

Applications of radioisotopes made thus far in the field of plant physiology fall primarily into two categories: studies of photosynthesis and studies of fertilizer utilization. Most of these investigations employ radiocarbon or radiophosphorus.

The most fundamental plant studies are those designed to learn the mechanism of photosynthesis by which green plants, with the aid of sunlight, convert water and carbon dioxide into complex sugars and other organic compounds. Investigators hope to learn the details of the mechanism of photosynthesis by identifying the intermediate compounds formed prior to the formation of sugars. It is generally agreed that photosynthesis proceeds in steps; several compounds are formed during the conversion of

Table 1

Isotope	Type of Application	Use
Sodium <sup>24</sup>	Diagnosis	Correlation of sodium turnover with congestive heart failure.
Sodium <sup>24</sup>	Diagnosis	Differentiation of normal and restricted blood flow.
Sodium <sup>24</sup>	Diagnosis	Radiocardiography (determining pumping qualities of the heart).
Phosphorus <sup>32</sup>	Diagnosis	Determination of the extent of tumor mass in brain-tumor surgery.
Iodine <sup>131</sup> (diiodo-fluorescein)	Diagnosis	Location of certain brain tumors.
Iodine <sup>131</sup>	Diagnosis	Detection of hyperthyroidism and location of thyroid-cancer offshoots or metastases.
Phosphorus <sup>32</sup>	Treatment	Treatment of polycythemia vera and chronic leukemia.
Cobalt <sup>60</sup>	Treatment	Interstitial sources for treating accessible tumors and teletherapy units for deepseated tumors.
Strontium <sup>89,90</sup>	Treatment	Beta-ray source for treating surface lesions.
Iodine <sup>131</sup>	Treatment	Treatment of hyperthyroidism thyroid cancer and metastases.
Gold <sup>198</sup> (colloidal)	Treatment	Treatment of subsurface tumors of the lymphoid system and chronic leukemia.

simple carbon dioxide to a complex sugar. Finding out what these compounds are and how rapidly they are formed may give a clue as to how and why they are formed.

In these studies, simple plants, such as algae, are grown in an atmosphere containing tracer amounts of radioactive carbon dioxide. After the process has been under way for certain lengths of time, investigators search for radioactive carbon-labeled compounds produced in the plants. Five com-

pounds have been identified as having been formed within 5 seconds. Within 90 seconds, at least fifteen labeled compounds are produced, including simple sugars containing 6 carbon atoms.

Although present investigations are primarily of academic interest, they are potentially of immeasurable economic significance. Not only does photosynthesis account for the production of plant nourishment, but also, indirectly, for the produc-

tion of all food. If nature's method of food production can be fully revealed, the possibility arises that the process may be duplicated, at least to some extent, in the laboratory.

Field studies using phosphate fertilizers labeled with radioactive phosphorus are being carried out in about fifteen states on such crops as corn, potatoes, tobacco, sugar beets, alfalfa, oats, clover, rye, grass, cotton, and peanuts. By tracing the radio-phosphorus, scientists can correlate plant growth with quantity and placement of fertilizer under varying conditions of climate and soil. Scientists are learning not only when is the best time to apply fertilizer but also where is the best place to apply it on the surface of the ground, plowed in near the roots, away from the roots, and so on. Variations in these factors have already been found for several types of crops.

Most radioisotope applications in the field of animal husbandry have been concerned with metabolism studies in poultry, cattle, and sheep. Radioisotopes have proved extremely useful in studying mineral metabolism because of the trace quantities of the elements involved. For example, it had been observed, prior to the use of isotopes, that cattle and sheep require between 0.04 and 0.07 parts per million of cobalt in their diet, whereas simple-stomached animals such as horses, rats, and rabbits do not require cobalt. Chemical studies of such low concentrations are extremely difficult. On the other hand, this problem easily lends itself to the "tracer" technique, which also permits the investigator to follow the metabolic path of the element.

Findings obtained to date with radiocobalt indicate that when cattle acquire cobalt from pasture feeding, an extremely small amount of it is absorbed from the intestines for use within the body. The same results are found in animals having only one stomach, such as horses and rabbits.

From these experiments and other considerations, it seems that the cobalt is needed in the rumen, or first stomach, of cattle. It was also found with radiocobalt that, when cobalt is injected by vein into cattle, little of it reaches the first stomach, and deficiency symptoms are not relieved. This also supports the belief that cobalt is needed in the first of vitamin B-12 complex, which has been shown to be important in preventing and curing certain types of anemia.

#### *Chemistry and Physics*

Radioisotopes have given the chemist a tool which goes far beyond the sensitivity of other analytical techniques previously at disposal. When an isotope such as radioactive sodium is used, for example, its short half-life and high-energy radiation enable instruments to detect amounts as small as 10,000 atoms, a quantity which would weigh less than 1 million millionth of a gram. Even for a radioisotope like carbon<sup>14</sup>, which has a 5,100-year half-life and emits very weak radiation, the sensitivity of detection is over a million times that of chemical methods.

The ability to detect minute amounts of radioisotopes helps greatly in understanding the mechanisms of chemical reactions and in learning about such phenomena as diffusion, crystallization, solubility, and catalysis.

A radioisotope, gold<sup>198</sup>, has been prepared in rather large quantities for the National Bureau of Standards. Gold<sup>198</sup> forms mercury<sup>198</sup> as a result of its radioactive decay and this pure mercury—pure in the sense that being made from gold, it contains no trace of other mercury isotopes—when placed in a mercury-vapor light bulb, emits a very sharp and clear green light whose wavelength can be measured very accurately. It has been suggested that this wavelength of the green light from mercury<sup>198</sup> be adopted as a new standard of length because it can be measured very accurately, because it does not change with temperature (as the length

of a ruler does), and because it can be made available anywhere. (The present standard of length, one meter, marked off on a platinum bar, is located in Paris.)

#### *Industrial Uses*

Industry has already found several ways to use the radiation from radioisotopes. These include unique devices for gauging liquid levels and for determining thicknesses of sheets of material, and techniques for making radiographic inspections, all of which are generally adaptable for plant-scale use. In these uses, the radioisotope is not incorporated into process material, and there is no possibility of its remaining in the final market product. Furthermore, after their installation has been completed, these devices can usually be operated by people of limited training.

One research group has investigated engine wear with piston rings made radioactive in a nuclear reactor. It has been possible to test engine wear with great accuracy and in a short period of time while the engine is running continuously. Radioactive particles worn off the rings drop into the lubricating oil which can be sampled and measured for radioactivity content. This method of testing engine wear is quicker and more accurate than any other, and the technique does not require repeated disassembly of the engine.

Although radioactive thickness gauges were developed shortly after the isotope-distribution program began, these gauges have been routinely employed by industry only during the last year. Two firms are now offering the gauges commercially for use in measuring the thickness of paper, rubber, and steel sheets.

One company is using a radioactive height gauge to measure the amount of liquid steel in a furnace or "cupola." The gauge is particularly well suited for this purpose, because it can be operated from outside the cupola and not be affected by the surrounding heat.

Certain man-made radioactive materials such as radiocobalt can be used like radium in making radiographic tests of welds and castings. Radiocobalt is more versatile in its use than radium because it can be machined to any desired shape before being made radioactive.

These are only a few of the uses of radioisotopes. A bibliography of over 1,850 published papers on experimental work using radioisotopes is published in the booklet, "Isotopes . . . A Three-Year Summary of U. S. Distribution."

Table 2, "Radioisotope Distribution," is given on the following page.

Table 2

## RADIOISOTOPE DISTRIBUTION

Period	Number of Shipments (from ORNL)	Monthly Average	Increase Over Previous Period (per cent)
August through December 1946	270	23	
1947	1,945	162	620
1948	3,540	295	80
1949	5,597	466	58
1950	8,075	673	44
1951	<u>9,491</u>	791	18
Grand Total	28,918		

RADIOISOTOPENUMBER OF SHIPMENTS

Iodine <sup>131</sup>	8,039
Phosphorus <sup>32</sup>	5,717
Carbon <sup>14</sup>	848
Sodium <sup>24</sup>	922
Sulfur <sup>35</sup>	494
Gold <sup>198, 199</sup>	675
Calcium <sup>45</sup>	308
Iron <sup>55, 59</sup>	290
Cobalt <sup>60</sup>	278
Potassium <sup>42</sup>	376
Strontium <sup>89, 90</sup>	390
Others	<u>10,581</u>
Total August 1946 through December 1951	28,918