ORNL
Central Files Number
53-12-126

Obsolete, replaced by enclosed Brochure available from Mr. Cowens office
8-12-57

THE OAK RIDGE NATIONAL LABORATORY

GRAPHITE REACTOR

Brochure entitled Graphite Reactor

OAK RIDGE NATIONAL LABORATORY • U.S. ATOMIC ENERGY COMMISSION

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

UCC

POST OFFICE BOX P
OAK RIDGE, TENNESSEE

ORNL
Central Files Number
53-12-126

THE OAK RIDGE NATIONAL LABORATORY

GRAPHITE REACTOR

1-200. D. D. Cowen

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

THE ORNL GRAPHITE REACTOR

C. D. Cagle

The Oak Ridge National Laboratory's graphite-moderated, natural-uranium reactor is perhaps the most publicized of all those operated by the United States Atomic Energy Commission with respect to both research and the production of radioisotopes. At different phases of its career, it has gone by various names: the X-Pile, the Clinton Pile, and the ORNL Graphite Reactor--even by such affectionate nicknames as "The Old Lady" and "Grandma." During the past decade it has been the nucleus for much of the research and production work at Oak Ridge National Laboratory, which now employs about 3000 people.

Few tools of science have ever lent themselves to such a variety of interests and done so with such consistency and dependability for so long a time. The oldest continuously operating reactor in the world, and the second oldest in mankind's history, the ORNL "pile" is generally always quietly operating while many research personnel carry on a constant buzz of activity around it, using its neutrons and gamma radiation in every conceivable manner. Its exterior bristles with experimental equipment constantly gathering data, and its interior contains still more equipment carrying out the same work, as well as hundreds of target materials being made radioactive for uses in other locations.

This reactor has far exceeded any of the original expectations of its usefulness in the over-all development of the atomic energy program.

HISTORY

It was early in 1939 that Hahn and Straussman in Germany announced the discovery of uranium fission by neutron bombardment. By 1942 this phenomenon had been proved by many scientists in this country, and its importance was recognized by our government to the extent that the great atomic energy development centers, of which Oak Ridge is one, were being planned as rapidly as possible. The plans included the great plutonium-producing reactors at Hanford, Washington, following the discovery that plutonium-239 was also fissionable.

It was on December 2, 1942, that the first controlled nuclear chain reaction took place in the 200-watt pile assembled under the West Stands at the University of Chicago by Dr. Enrico Fermi and other distinguished scientists. In this reactor, the uranium was in the form of metal and oxides located as discrete lumps within a graphite moderator. This method did not lend itself to being cooled or to easy removal of fuel for the purpose of extracting plutonium. At that time, only a few micrograms of plutonium-239, produced by proton bombardment of uranium-238 in a cyclotron, were available for studying the chemistry of this new element. Much of the separation techniques used at the Hanford Engineering Works were developed with this tiny amount, using tracer methods, but gram quantities were necessary for both proving and improving these procedures. The West Stands pile could not supply this material because of the lack of recharging facilities and the 200-watt limit on the power, which made the production rate impossibly slow.

It was the necessary conclusion, then, that a pilot-plant reactor must be built that could perform this supply function, as well as adapt itself to other usages, such as personnel training, furnishing operational data, instrument development, neutron-cross-section studies, radiation-damage studies, and biological radiation-effect studies.

Plans for such a reactor were hurriedly drawn up, and construction of the X-Pile was started early in 1943 by the du Pont de Nemours Company under the guidance of the University of Chicago. This reactor type was not the most efficient from a fuel-spacing standpoint, but it was air-cooled, allowing continuous operation at a 1000-kilowatt power level. Another important feature was the inclusion of many openings into the moderator to permit the carrying out of many kinds of research work.

The whole reactor was surrounded with thick concrete shielding for the protection of personnel. Fortunately, because of lack of detailed knowledge, most of the components were well overdesigned; it is this overdesigning which made possible the continued life and use of the reactor long after it had served its initial purpose.

On November 3, 1943, critical loading of the completed reactor was achieved, and plutonium production started according to plan. After the first few days of operation, the overdesign was easily recognized, and steps were taken to take full advantage of it. These included a change in the loading pattern, better cladding for the fuel, some rerouting of the cooling air, and larger cooling fans. When all these features were incorporated, the power was raised to about 3600 kilowatts in 1944, and the continued use of the reactor as a valuable research tool was fairly well assured. The concrete shielding was still more than adequate, the lattice was not overloaded with fuel, and control was easy and dependable.

It might be added here that the X-Pile, or ORNL Graphite Reactor, as it is now called, fulfilled its original purposes more than adequately except in one respect: that of being the pilot plant for the Hanford Engineering Works. This inadequacy was no fault of the reactor itself, but was the result of a change of plans in the type of cooling for HEW reactors. At first, a closed helium-cooling system had been planned. For this, an air-cooled reactor would have served well as a pilot plant, but when the design was changed to water cooling, the air-cooled model was somewhat deficient but not entirely inadequate. By inserting a few water-cooled fuel tubes of the Hanford type into some of the experiment holes, most of the individual tube studies were completed.

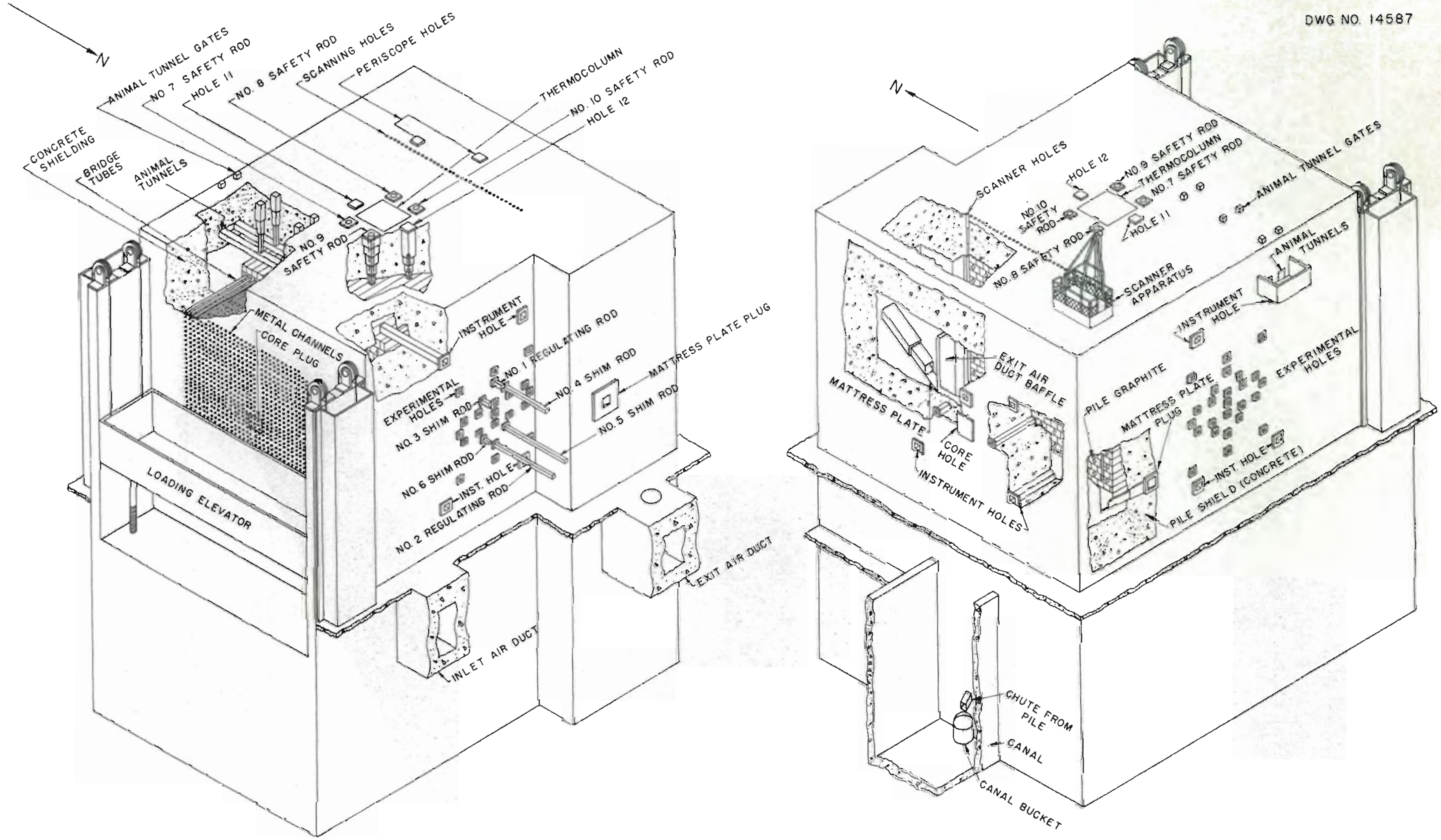
STRUCTURE AND FUEL

The accompanying isometric drawing of the ORNL Graphite Reactor will clarify much of the following explanation. The drawing shows only the parts of the reactor itself -- the four stories of floor levels that provide working access to the experimental facilities are not shown.

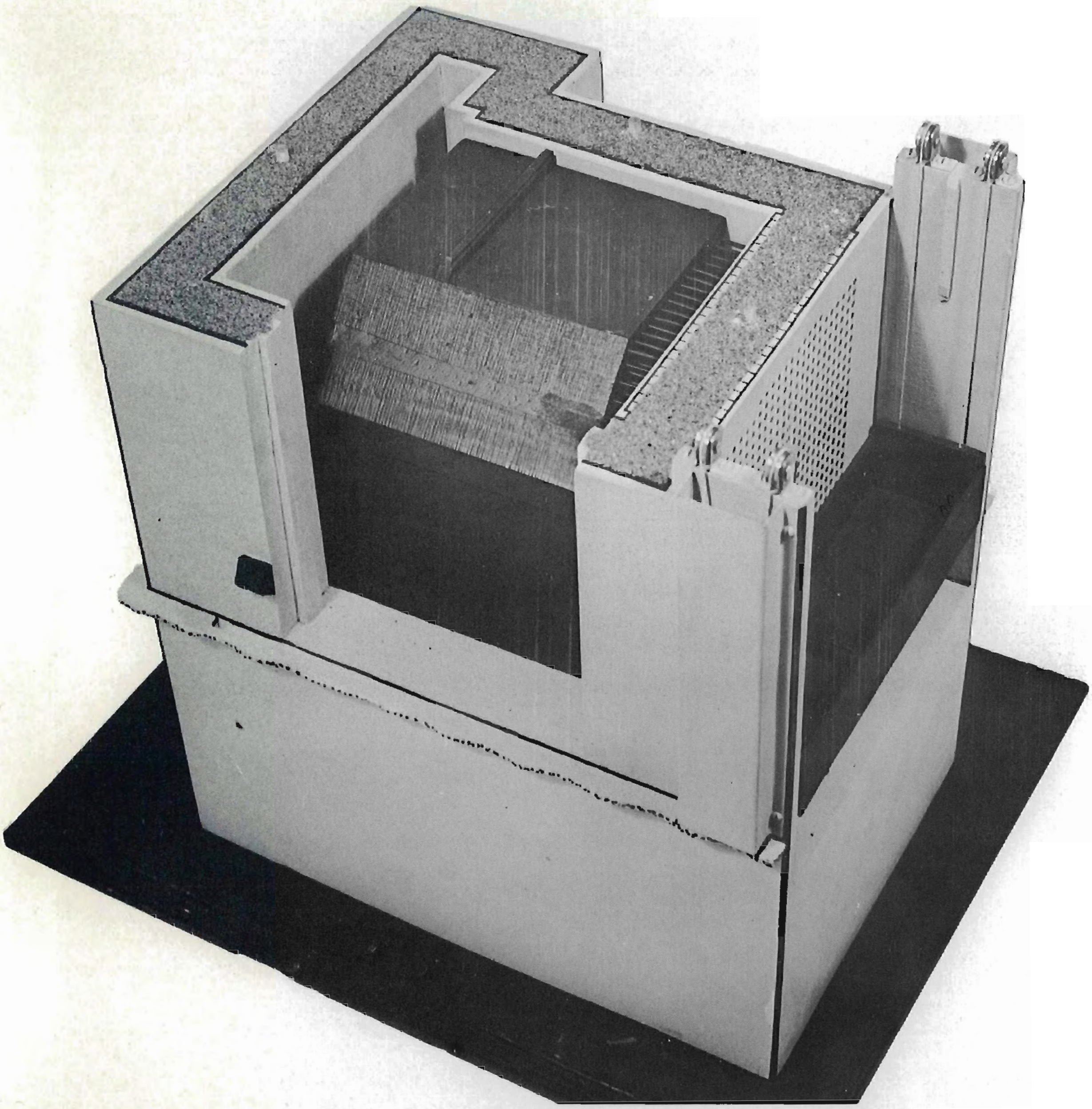
The external dimension of the reactor structure in the north-to-south direction is 38 feet; from east to west, it is 47 feet; the height from ground level is about 35 feet. It rests upon a concrete pad that goes down to bed rock.

Nothing of the internal part of the reactor is visible; even at the Laboratory, it is necessary to use a model to demonstrate its general construction and various parts. The accompanying photograph shows this model with the top and side removed to show how the reactor looks under its concrete shield.

The black block is the moderator -- a 24-foot cube of graphite blocks, 4 inches by 4 inches and up to 50 inches in length. These blocks are stacked in layers and keyed together at the edges. Layers that run in the east-west direction have V-cuts in the blocks that, when assembled, form diamond-shaped holes running all the way through the moderator. There are 1248 of these holes,



Isometric drawing of the ORNL Graphite Reactor.



Model of the ORNL Graphite Reactor with top and side removed.

spaced with the centers 8 inches apart. These are the fuel channels of the reactor.

The graphite layers between those containing the fuel channels are made up of solid 4-by-4 blocks. Strings of these solid blocks have been omitted at intervals, providing small tunnels through the moderator, between and perpendicular to the fuel channels. These tunnels are the experiment holes that have made the reactor of such great value as a research tool.

The graphite used in the reactor is as pure as could be obtained at the time. The absorption cross section of pure carbon is only 4.5 millibarns per atom, so it makes a good, relatively cheap moderator and has enough structural strength to make a fairly strong matrix. There are no liners in the fuel channels or experiment holes, so that movement of fuel and experimental equipment always causes some abrasion of the graphite; however, after ten years of operation, no appreciable damage has been caused any channel through normal wear and tear.

The moderator is entirely surrounded by a concrete shield 7 feet thick. This shield has proved to be more than adequate, and is one of the components that was overdesigned.

Steel-lined openings through the shield give access to the experiment holes and to the fuel channels. These openings are stepped in size to accommodate shield plugs of successively larger size, going from the moderator to the outer face of the shield -- the easiest and most straightforward method of stopping the streaming of neutrons and gamma radiation along the sides of the shield plugs normally kept in the openings through the shield.

Between the shield and the moderator on the east and west sides are air gaps; the east gap is three feet wide and the west gap is six feet. These are the inlet and exit cooling-air manifolds. (The cooling air is drawn through the reactor rather than blown through, so that it is under negative pressure while operating; thus it is not necessary to make the openings airtight because all leakage is inward.) The three-foot inlet manifold is spanned by $1\frac{1}{4}$-inch standard steel pipes that serve as bridge tubes through which the fuel is pushed into the matrix from the east face. The air enters the inlet manifold from a duct that runs below floor level from a bank of filters at the north side of the reactor building where atmospheric air is drawn into the system. It then passes down the length of the fuel channels over the fuel and into the 6-foot exit manifold. The air enters the channels at the corners around the bridge tubes, since they are round pipes stuck into square holes, and also through slots cut into the tubes themselves. From the 6-foot manifold, the air is led by a duct under the ground floor and up a hill north of the reactor building, where it passes through banks of pocket-type glass fiber filters that remove more than 99 per cent of all particles above one micron (approximately 1/25,000 of an inch) in diameter. From the filter house, the air enters two 900-horsepower centrifugal blowers that force it up a 200-foot concrete stack from which it discharges into the atmosphere. The flow through the system is slightly above 100,000 cubic feet, or 7300 pounds, per minute, and the negative pressure in the exit manifold is normally maintained at about 29 inches of water, as compared with normal atmospheric pressure of 408 inches of water.

When the reactor was built, a 10-inch air gap was left between the graphite and the concrete shield on top to prevent heat damage to the concrete, and the underside of the concrete was further protected by a layer of insulating material. After the reactor was put into operation, it was found that the great quantity of air flowing through this gap was unnecessary, so to increase the flow through the fuel channels in order that the power could be raised above the 1000-kilowatt level, this air flow was stopped by pushing a lead-covered steel H-beam into the gap through an ionization chamber hole that opened into the gap. This change, together with stopping the flow through unused fuel channels and procuring better cooling fans, provided sufficient air flow across the fuel to allow the power to be raised to about four times the design level.

During a 24-hour operating day, approximately 500 curies of radioactive argon are discharged from the stack. This is produced from the 9/10 of 1 per cent of argon present in the atmosphere, and is the major reason for the height of the stack, which must release the air at a level high enough to prevent its return to ground level before its radioactivity has either decayed or been diluted. The half-life of the radioargon is 110 minutes.

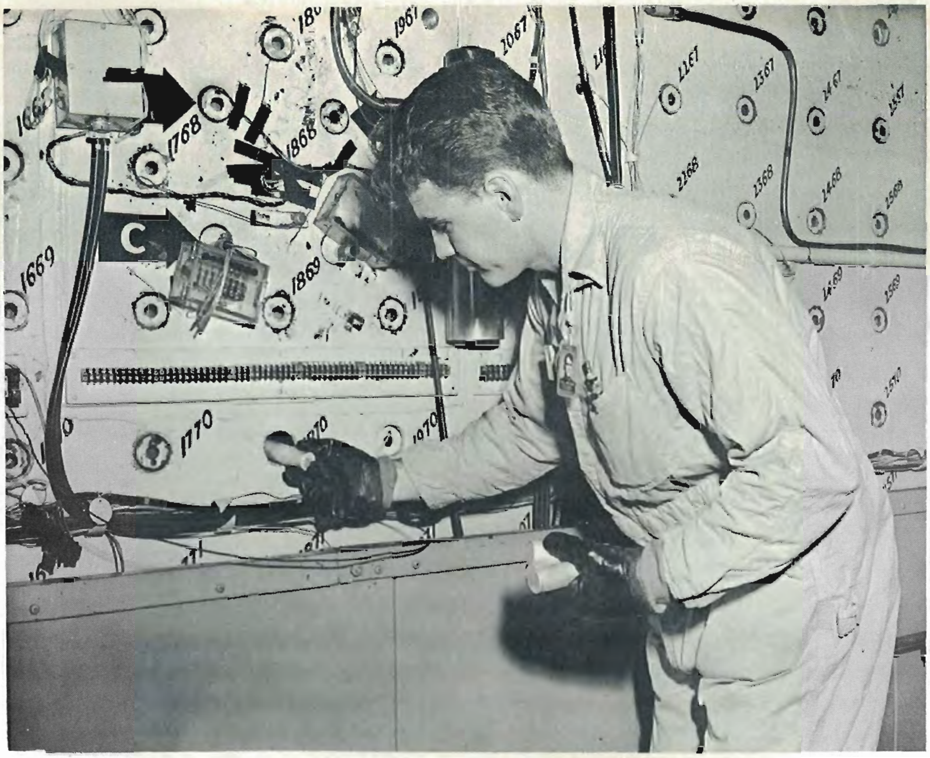
The particles deposited on the exit filters are also radioactive, as any material passing through the neutron cloud in the reactor becomes radioactive to some extent. Practically all of the materials deposited there are particles dislodged from inside the reactor, such as graphite, concrete, aluminum, uranium oxide from faulty fuel.

Because the reactor began operation in 1943, it was necessary to use normal uranium as fuel. Normal uranium contains only 7/10 of 1 per cent of the fissionable U-235 isotope, plus a trace of the U-234 isotope; the remainder is U-238. This low concentration of the U-235 isotope is what makes the 8-inch spacing of the fuel channels necessary. Eight inches of graphite will slow the ordinary fast neutrons from neighboring fuel elements to the thermal range where they can be captured by the U-235 and thus produce fission. It is only in a field of thermal neutrons that the abundance of the U-238 isotope is overcome by the much greater affinity of the U-235 atoms for these thermal neutrons.

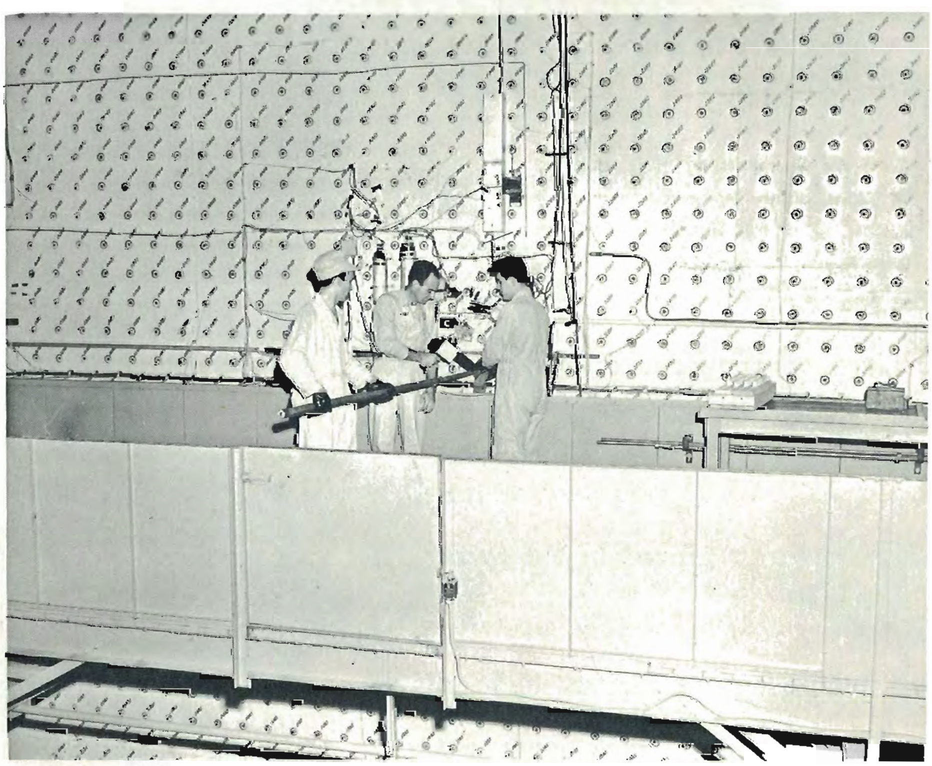
The ORNL graphite reactor is called heterogeneous because the fuel is located as rods in a pure moderator. If the graphite and normal uranium were homogeneously mixed, a chain reaction would be impossible because too many of the neutrons would be captured by the U-238 at the resonance-capture energies that are above thermal energy. This hindrance could be overcome, of course, by increasing the percentage of U-235 in the fuel -- a very expensive undertaking.

The fuel, as used in the graphite reactor, is in the form of $2\frac{1}{2}$-pound metallic uranium slugs 4 inches long and slightly over 1 inch in diameter. They are clad in aluminum jackets approximately 35/1000 of an inch in thickness. The purpose of the aluminum cladding is to protect the metal from oxidation. At the 536-degree-Fahrenheit maximum temperature normal to operation, unclad uranium oxidizes fairly rapidly, and the oxide would flake off and be carried away by the air stream. This oxide would be contaminated with radioactive fission products. These slugs are loaded into the reactor, end-to-end, to simulate rods. The purpose of the short length of the slugs is for ease in handling, both in the charging and discharging processes.

The slugs are loaded into the reactor manually and positioned with measured steel rods to center them in the moderator. Discharging is accomplished by pushing the slugs into the exit air manifold with steel rods. This can be done, of course, only when the reactor is shut down and the shield plugs are removed from the fuel-channel openings. Upon being pushed into the exit air manifold, the slugs fall upon slanted, neoprene-covered, cadmium-plated stainless steel plates that funnel them into a 20-foot-deep water pit below the ground-floor level. In the days when plutonium extraction was carried out



Operator is shown here inserting aluminum-clad uranium slugs into one of the 1,248 fuel channels in the loading face of the reactor.



Operators are shown inserting uranium slugs into the center of the reactor with special connected lengths of steel rod. Operator in center is monitoring radiation from the fuel channel to be certain radiation does not exceed tolerance level for personnel.

at ORNL, these discharged slugs were transported under water by way of a 9-foot-deep canal to the plutonium-processing cells in an adjacent building. The 9 feet of water is roughly equivalent to 9 inches of lead for shielding from gamma rays, so ponderous lead shields were not necessary. However, shielding of some sort is necessary as, after exposure to neutrons in the reactor, the slugs are dangerously radioactive because of the presence of fission products. At present, plutonium processing is not being carried out, so no slugs are pushed except those from which fission products are separated for the radioisotope-distribution program, for special research purposes, or because of failure of the aluminum cladding. The depletion rate of the fuel is less than 1 per cent a year; therefore, refueling for renewal purpose has thus far been unnecessary.

When an amount of uranium sufficient for operation is in the reactor, the start of the chain reaction is spontaneous. For this reason, the reactor must have enough neutron absorber in its safety and control system to absorb neutrons much faster than they can be produced by the reactor. The safety system consists of three rods of cadmium encased in steel and two steel rods containing $1\frac{1}{2}$ per cent boron. The three 8-foot-long cadmium rods are suspended in shafts in the top shielding, and drop by gravity through their shafts into the central part of the reactor in the event of emergency or normal shutdown. These three rods are attached to cables that, in operating position, are wound up on the drums of electric-driven windlasses and held up by electric brakes. If an electric power failure should occur, the rods automatically fall into the reactor when the power to the brakes goes off. For normal shutdowns, the power to the brakes is turned off by a switch at the control console, causing the rods to be released. There were originally four of these rods but one has been removed to allow its shaft to be used for experiment insertions.

Two hydraulically driven horizontal rods, called shim rods, enter the reactor from the north side and go into holes similar to the experiment holes. These rods were designed to be partly inserted during operation to limit the amount of excess reactivity -- therefore the name, "shim rods." Originally there were four of these rods, but two have been removed to release their holes for experimental purposes. These rods are normally driven by hydraulic motors, but in the event of emergency or normal shutdown, 900 pounds per square inch of pressure is released to pistons connected to their drive and the rods are rapidly thrust into the reactor for their full travel. This 900-psi oil pressure is maintained by an "accumulator" system consisting of two large sand-filled tanks resting upon pistons and automatically kept raised. The pressure is withheld from the drive system by a solenoid valve that opens when the electric power to it is cut off; therefore, shutdown by this system is as automatic as the gravity-dropped rods on the top of the reactor. These shim rods are 1-3/4-inch-square steel rods that have a full travel of approximately 17 feet into the reactor; their absorbing material is $1\frac{1}{2}$ per cen boron.

These five rods comprise the normal safety system. Power regulation is accomplished with two other rods. These are exactly the same as the shim rods as far as size and travel distance are concerned, but their speeds are slower. They are electrically driven and do not go into the reactor automatically in the event of a shutdown. During operation these rods are constantly adjusted by the operator to maintain the reactor at an equilibrium. Indicators at the control console keep the operator informed as to the positions of the rods, and these are checked each quarter-hour and the positions plotted on a graph in the daily records. Originally, it was planned to have one of these rods operated by an automatic control to keep the power constant, but since fluctuations were so small and gradual, the automatic-control idea was abandoned.

There are two main types of instrumentation associated with the reactor, for maintaining power equilibrium and safety. The first type is neutron-level instrumentation, the second, heat-output instrumentation.

The neutron level is determined in two ways, both making use of the affinity of boron for neutrons. One of these is the measure of gas ionization between boron-coated electrodes in cyclindrical chambers located in holes in the concrete shield that "see" a low neutron flux from the reactor matrix. The maximum thermal neutron flux at the reactor center is slightly over 1,000,000,000,000 neutrons per square centimer per second, but the chambers are in a flux of about 100,000,000 neutrons per square centimer per second. These chambers are of two types: those that are automatically compensated for ionization due to gamma radiation, and those that read the total ionization. Gamma compensation is accomplished by having actually two chambers located together; one is boron coated, the other is not. The two signals are bucked against each other, so that the net reading is produced by neutron action only. The boron-chamber technique is extremely efficient for neutron detection because boron-10, upon absorbing a neutron, breaks down to a lithium particle, plus an alpha particle that is highly ionizing to a gas.

The current leakage due to neutrons, as measured by a galvanometer connected to a compensated chamber, is used by the operator to show instantaneous changes in neutron level. The galvanometer is calibrated against the heat power of the reactor and reads directly in kilowatts. By means of a sensitivity shunt, the one galvanometer scale can be used to read the power with about 1 per cent accuracy over the whole range of the reactor -- that is, from zero to over 4000 kilowatts.

Three of the uncompensated type of boron-coated chambers are connected into the safety circuits to shut the reactor down automatically if the power level should inadvertently be allowed to get too high. These need not be compensated, as their utilization is only in the range where the neutron flux is so high that the ionization caused by gamma rays is negligible.

The other mehod of neutron detection is the use of special thermopiles made with each couple opposed by another so that general temperature effects are cancelled. Half of the couples are then coated with boron. Such a thermopile, in a neutron field, will have an output proportional to the neutron flux and will not be changed by a general rise in the temperature. The output is due to the heat energy liberated when the boron captures neutrons and splits into lithium and alpha particles. The response of a boron-coated thermopile to changes in neutron level is slower than that of the ionization chambers, so they are used only in the safety circuit to back up the ionization chambers.

The ionization chambers and the thermopiles, of course, measure the neutron flux only where they are located, but since the power is directly proportional to the neutron flux, their outputs can be calibrated in terms of power. The true power output of the reactor is measured by the conventional method of monitoring the flow and temperature rise of the cooling air. A calculation of the heat power is made each hour and plotted on a graph together with the power as shown by the galvanometer. As often as necessary -- about once or twice a month -- the neutron chambers and the boron thermopiles are adjusted so that they show the true power output of the reactor. Instantaneous measurement of the heat output is almost meaningless because of the heat capacity of the reactor, which loses more heat to the cool night air than it does to the warmer air of daytime. An average of several days' operational data is always used in calibrating the ionization chambers.

In addition to the neutron level and power output, another important item requiring carefully monitoring is the temperature of the slug jackets. This temperature is the real criterion in setting the highest permissible operating power level. To measure this temperature, about 40 thermocouples are welded to slug jackets in the reactor and their temperatures constantly recorded. Experience has shown the points in the reactor most likely to be at the highest temperatures and thermocouples are kept in these locations. The highest point is kept at or below 536 degrees Fahrenheit, the power level being adjusted as necessary to maintain this condition. The maximum permissible power level, therefore, varies from about 3600 kilowatts in summer to about 4100 kilowatts in winter, depending, of course, upon the inlet temperature of the cooling air.

Instruments also monitor the radioactivity of the cooling air, the negative pressure within the shield, the graphite temperature, and the radioactivity level in the building.

OPERATION

To keep the ORNL general purpose reactors and their components operating 24 hours a day and to maintain a number of other associated services requires the full attention of five technical and 20 nontechnical men. By other services is meant aiding research personnel in charging, discharging, and subsequent handling of experiment equipment; preparing radioisotopes; keeping the building decontaminated and otherwise safe; and operating a water-demineralization plant and a hydrogen liquefier. Operation of the reactor itself is fairly simple, while it is in operation, and normally involves only juggling the regulating rods to keep the power level constant and taking a few meter readings every hour. On shutdown days, however, (each Monday), all the regular maintenance work is carried out in addition to the shuffling of experimental equipment and radioisotopes into and out of the reactor and inspection of each of the fuel channels to be certain there is no failure of an aluminum fuel jacket.

The cooling-air suction fans behave very well and require little attention. The filter houses require only the changing of the filter media about once a year.

In addition to the regular operating force, it is necessary to call upon the plant maintenance crews for everything from new paint to new tools -- in fact, the only thing that is not always being improved or changed is the interior of the reactor itself. Since the shield was completed and operation started over ten years ago, induced radioactivity has prevented any change in that quarter.

EXPERIMENTAL FACILITIES AND THEIR USES

The 4-inch by 4-inch tunnels built into the moderator are what make the ORNL graphite reactor so valuable as a research tool. From these, experimenters can take collimated beams of neutrons for work outside the reactor, or they can be used as exposure chambers into which apparatuses can be inserted and studies made while specimens are being subjected to neutron bombardment. The total facilities provide for the carrying out of more than 36 experiments and the exposure of more than 1000 target materials all at the same time.

As examples of work being carried out at the Laboratory with neutron beams, there are at present three neutron spectroscopes in operation to study the properties of crystals. These spectroscopes are operated much the same as those using x-rays, but they have the unique feature of dealing with the nuclei of a crystal's atoms rather than with the electron shells. For this reason, studies of crystals containing hydrogen are carried out. In order to select a monoenergetic beam of neutrons from the reactor's spectrum, a crystal -- usually sodium chloride, lead, or copper -- is set in the primary beam where it acts as a neutron prism, scattering neutrons of different energies at different angles. By shielding out all except a very narrow angle of these scattered neutrons, a very nearly monoenergetic beam is obtained. The neutrons have a wave form and obey the Bragg diffraction law, so, from this point on, the procedure is standard. Boron-coated counter chambers are used as detectors for the neutrons.

A similar technique is used to determine the total cross sections of elements for neutrons of different energies.

Another important program using a neutron beam has been the determination of the half-life of the neutrons themselves. It is known that a neutron decays to a proton by emitting a beta ray, but the determination of the half-life is quite different from that of any other substance, because neutrons are always in rapid motion; the so-called "slow" neutrons in the beam are traveling at a velocity between 2000 and 3000 meters per second, or 4470 to 6706 miles per hour, so that measuring their decay as they pass by is a considerable feat, especially as they are accompanied by beta rays and some protons. The best figure so far determined for the half-life is about 13 minutes.

Most of the work involving measurements of specimens inside the reactor deals with materials of construction, moderators, and fuel for future reactors or for equipment to be associated with new reactors. Among the items so tested have been metal alloys, lubricant oils, fuel solutions for homogeneous reactors, fuel plates for new-type heterogeneous reactors, and shield materials such as concrete.

Metals exhibit changes in thermal and electrical conductivity, even in strength, after exposure to radiation. These changes are of great importance when the metals are used for uranium jackets or for coolant conductors from a heat-transfer standpoint. Properties relating to strength, such as creep, shear, tensile strength, and the like, are important from the structural angle, and these too are changed by fast-neutron bombardment. Since the fast-neutron flux in the graphite reactor is considerably lower than that in the new reactors being planned, the samples are generally inserted into hollow cylinders of uranium to "soup up" the fast-neutron flux. Such a cylinder allows most of the fast neutrons to pass through its walls, but the slow neutrons are absorbed to cause fissions and produce more fast neutrons which reach the specimen without passing through any moderating material.

Hydrogenous compounds such as lubricant oils and greases, and insulating and gasketing materials like rubber and polymers, suffer rapid and severe damage from both neutron and gamma bombardment. The radiation literally tears the molecules to pieces, and these pieces either recombine to form compounds entirely different from the original or the lighter components from the molecules are given off as a gas and, in an enclosed space, can build up tremendous pressures.

After radiation, some of the oils changed to tar and some to brittle solids -- all were damaged. It was found, however, that certain oxidation inhibitors retarded the damage. Rubber and plastics become brittle and exhibit symptoms similar to heat charring when irradiated, and some turn into a sort of solid froth as the result of bubbles of hydrogen and light hydrocarbons forming within the plastic.

Fuel solutions for homogeneous reactors are under study in small electric furnaces located in experimental tunnels, with solvent dissociation and recombination being of major importance. Associated with this work and using the same equipment is the determination of corrosion rates of the fuel containers.

There are two large openings through the reactor shielding from which neutron beams of large cross-sectional area can be taken. Both of these are at present being used as shield-testing facilities. One of these opens horizontally out of the side opposite the charging face of the reactor into the 6-foot exit air manifold. The minimum cross section is about $2\frac{1}{2}$-feet square. A large tank of water outside of the opening serves as a neutron and gamma shield for personnel safety and provides a medium into which shielding materials can be inserted to have their neutron- and gamma-stopping powers measured. These measurements are generally made with underwater neutron-sensitive ionization chambers. The primary neutron beam from the reactor is augmented by the converter tenchique of placing a slab of uranium in the beam which, in effect, converts the slow neutrons to fast ones by absorbing them, producing fission. Data for shielding materials and for specific shield mock-ups are being taken 16 hours a day at this facility.

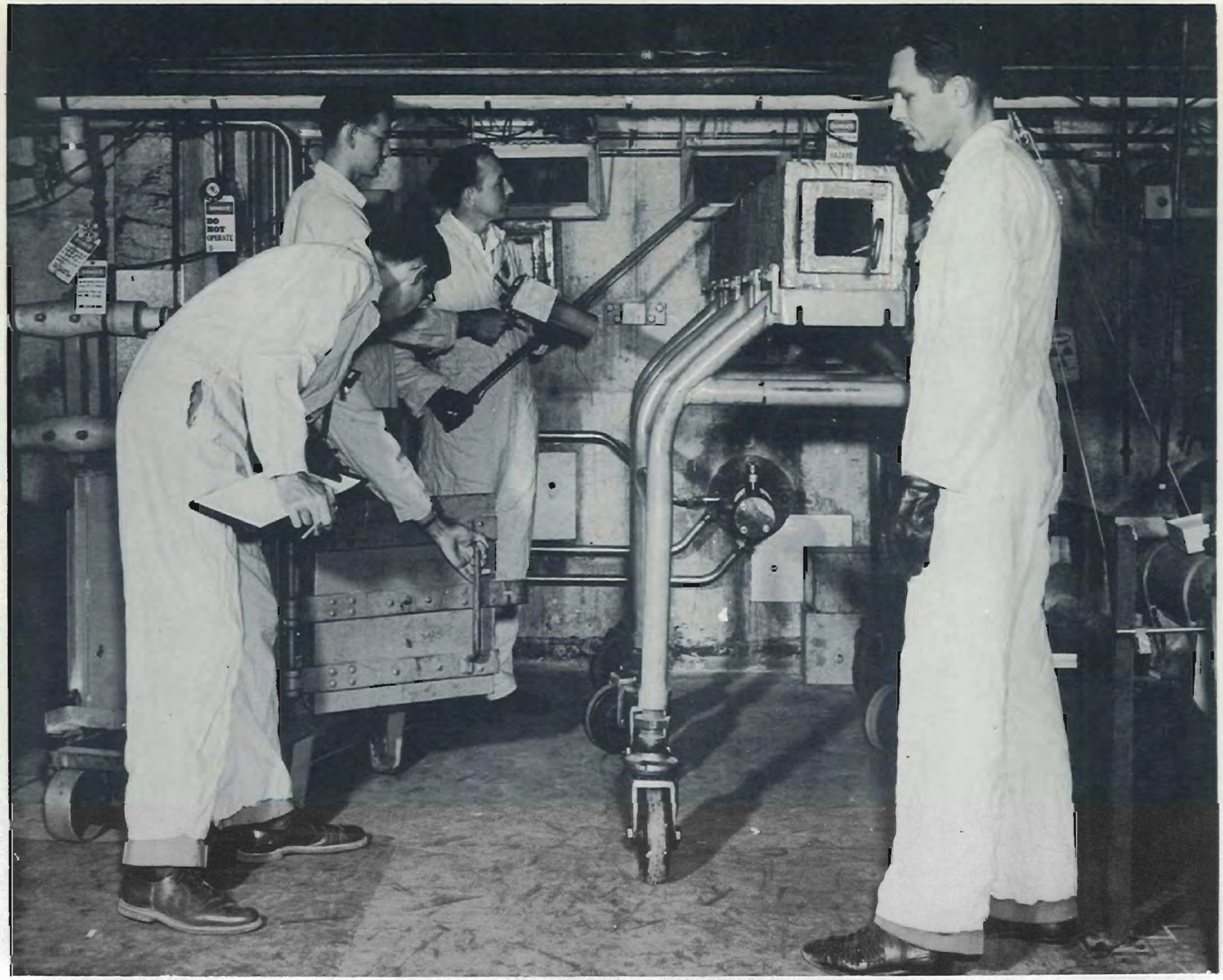
The other large opening is on top of the reactor, directly over the top of the moderator. To provide a nearly pure thermal beam of neutrons, the hole through the shielding is filled with graphite. A water-filled tank rests upon the graphite column as a personnel shield. The shielding work carried out here has delt primarily with the determination of the best shapes for coolant and air ducts to be used through reactor shields.

Two 14-inch-square tunnels built into the reactor shielding so that their bottoms open on the top of the moderator through the 10-inch air gap provide space for the irradiation of small animals and other biological specimens. The ORNL Biology Division has exposed hundreds of mice and rats here, and is raising several generations of their progeny to study mutations caused by radiation. Such things as soy beans and popcorn seed are also irradiated here for the use of agricultural schools making the same type of mutation studies. To protect personnel, these tunnels open into a concrete barricade, and each has three thick lead gates that can be opened only one at a time.

For fast or fairly short exposures of target materials in small amounts, two penumatic tubes have been built into one of the 4-inch-by-4-inch experiment holes. They are used principally by the ORNL Chemistry Division for making radioactive tracers and for other radiochemistry projects. These tubes are similar to the money tubes used in some department stores, and the speed of the capsules that pass through the tubes has caused them to be generally known as "rabbits." This term has occasionally caused a good deal of confusion for new employees; one man, hearing of "rabbit samples," formed the idea that research workers tied target materials to live rabbits and let them run through the tunnels to expose the materials to neutrons.

One of the most widely publicized programs associated with this reactor is that of radioisotope distribution to practically the whole world. These radioisotopes include those of every element that has a radioactive isotope of sufficiently long half-life to permit it to arrive at its destination and still be a radioisotope. Four radioisotopes used principally in the fields of medical and biological research make up the bulk of the shipments from ORNL. They are radioiodine, radiophosphorus, radiocarbon, and radiocobalt.

Radioisotopes produced in the reactor in any appreciable quantity are generally the result of three types of nuclear reactions, all caused by neutrons. The most common of these is the neutron-gamma ray reaction, expressed as (n,γ), in which a neutron is absorbed and a gamma ray emitted -- the most probable



Irradiated elements being removed from isotope-loading face of the reactor. Graphite stringers are withdrawn into lead casket at right, and samples withdrawn from the caskets are placed in lead-shielded safe for transportation to the processing and packing areas.

interaction between a slow neutron and all but a very few isotopes. Radiocobalt is produced by this (n, γ) reaction; the target is cobalt-59 (a pure isotope) which absorbs a neutron and becomes the radioactive isotope, cobalt-60.

Fast neutrons frequently enter nuclei and cause protons to be ejected. Such a reaction immediately changes the identity of the nucleus to that of another element. By putting a nitrogenous compound in the reactor, we get radiocarbon-14 formed from nitrogen-14, and from sulfur-32 we get radiophosphorus-32. Since the element itself has been changed, it can be separated from its parent element by chemical means so that nearly pure samples can be obtained.

Then, of course, there are the radioisotopes produced by the fission of uranium. The radioiodine-131 now being distributed is one of these. All the elements in the middle of the periodic table, from zinc to europium, have representative radioisotopes from this source. Many of them when first produced are so unstable that they decay through several steps before becoming stable nuclei, and change to a different element with each successive emission of a beta particle. One example is xenon-145, that goes by a series of beta decays to cesium, barium, lanthanum, cerium, praseodymium, and finally to stable neodymium-145.

In addition to the normal procedure of taking a compound or a pure element and making it radioactive for tracer or biological work, the Laboratory has irradiated such items as piston rings, cylinder liners, and other parts of engines and machinery for wear tests. The tiniest amount of abrasion can be determined by testing the lubricating oils from the parts for radioactivity after the machine has been run for a short time. Also, the transfer of tiny amounts of material from one surface to another can be measured with a Geiger counter or x-ray film even though the amount is too small to be seen or detected by chemical analysis.

Neutron sources are one of the latest additions to the radioisotope distribution program. To produce these, a piece of antimony metal is first enclosed in a beryllium metal sheath, and then both are clad with aluminum. When this assembly is placed in the neutron field of the reactor, the neutrons pass through the aluminum and beryllium and are absorbed by the antimony, which becomes extremely radioactive. When it is removed from the reactor, the radioactive antimony in decaying emits 1,720,000-volt gamma rays that are energetic enough to knock neutrons out of the beryllium. Of course, all of this radiation does not produce neutrons; some of it escapes to make the source dangerous from a gamma-radiation standpoint.

PERSONNEL TRAINING

Among the important uses of the ORNL graphite reactor is that of training personnel. The Oak Ridge School of Reactor Technology uses the reactor to familiarize its students with the effects of radiation, reactor-operation techniques, and radiation hazards. Some of the enrollees in this school represent industrial companies all over the United States that wish to have personnel in their employ who are familiar with reactors when they become available for use in industry. Operators for newer reactors such as those at Brookhaven National Laboratory, New York, and the National Reactor Testing Station at Arco, Idaho, were trained at Oak Ridge National Laboratory.

TROUBLES AND FIASCOS

Although the reactor has operated rather smoothly since 1943, ORNL personnel using it have occasionally run into adverse conditions that they lump into two categories: troubles and fiascos. Troubles include normal equipment failures; fiascos cover poorly designed experimental equipment that fails. Representative of equipment failure is the instance when one of the large cooling fans failed and tore itself and its immediate surroundings to pieces, Fortunately, no one was near it at the time. The cause of its breakdown was never determined; however, it did not cause any harm to the reactor, as the fans are located in a separate building.

The fiascos have been more frequent than equipment failures, but none of them have been really serious. Most have involved radioactivity, but no one has experienced any detectable harm in any instance. The tolerance levels or permissible exposure quantities at ORNL are so low that the safety factor is more than 100.

On two occasions the reactor building has had to be evacuated because of the release of radioactive noble gases into the atmosphere by faulty experimental equipment. On one occasion, a supervisor walked into the locker room and found a staff member clad only in a red necktie -- the one item of apparel he had not contaminated while performing some work without proper protective clothing. All his personal clothing, except the tie, had been confiscated by the Health Physics monitor, and he had to wear a pair of work coveralls home. A similar incident involved another member of a research group. He, too, lost all his clothing and even had to decontaminate his pipe before he could smoke.

Much speculation has been given to what would happen if, for some reason, the reactor should go out of control. No one knows exactly what would happen, but experience with the reactor's operating characteristics indicate what will not happen and the worst things that could happen.

First, there could not be an atomic explosion. The worst occurence would be a fast rise in temperature that would, in all probability, melt the aluminum jackets off the fuel slugs, and uranium oxide would be released into the cooling air to be caught by the filters. But this same rise in temperature would, after only a brief instant, cause the power level to drop again to a low value.

Such an occurrence would have to be deliberate. It would necessitate the removal of the control rods and much experimental equipment simultaneously, and would require the combined and well-timed efforts of many people. Consequently, Laboratory staff members are fairly certain that the matter of what might happen to the reactor under such circumstances can safely be left in the field of idle speculation.