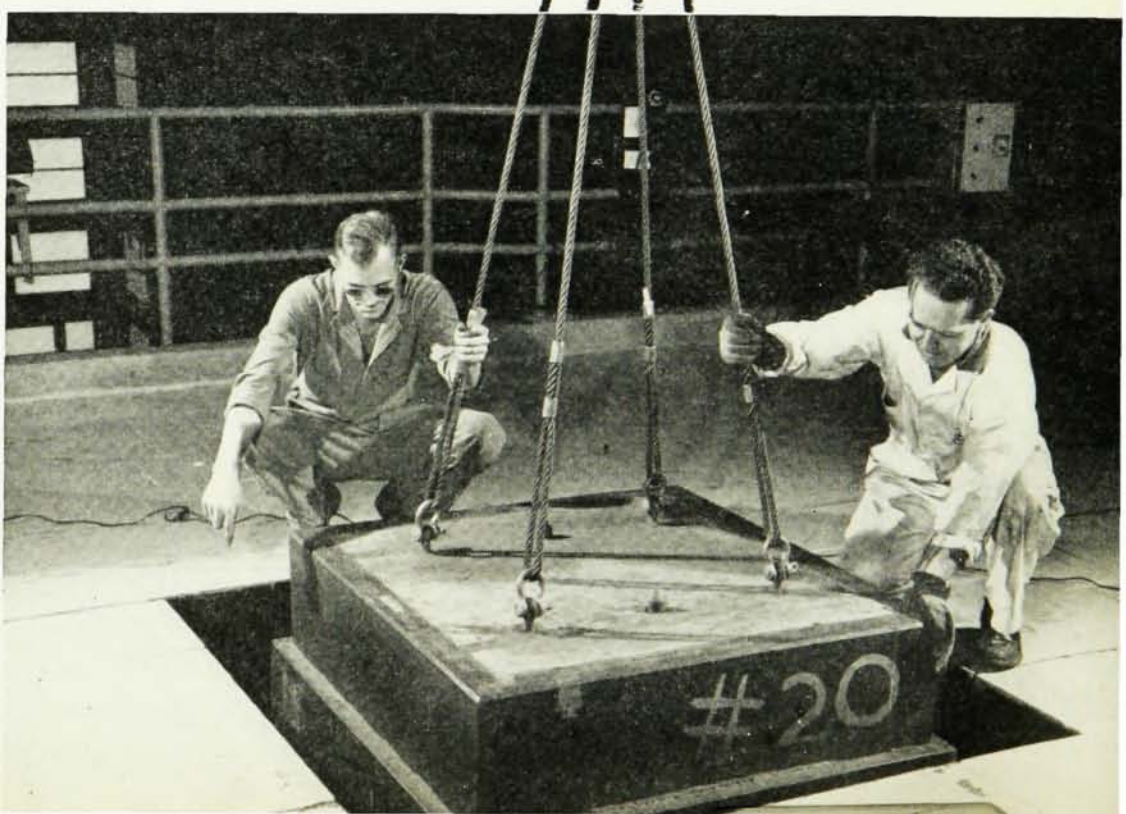
The Brookhaven Nuclear Reactor

By Lyle B. Borst

The building of the AEC's newest graphite-uranium pile was first proposed in 1946 and one year later construction was begun at Brookhaven National Laboratory on Long Island. The present article, written by the chairman of Brookhaven's department of reactor science and engineering, reviews the reactor research program of the laboratory.



Lowering section of top shield into place. Removable section of top shield permits placing large equipment on top of graphite structure.

On August 22, 1950 the Brookhaven reactor became critical. The work of scientists is notable for its lack of drama. It is usually difficult to say when a piece of apparatus starts to work, and it is even more difficult to decide when an experiment is complete. The uranium chain reaction is outstanding, therefore, since the change from an inert subcritical assembly of fissionable material to a supercritical chain reactor is sudden and, to all intents and purposes, discontinuous.

A small lump of uranium undergoes spontaneous fission of U^{238} with a half-life at least a million times that for alpha decay. The rate is so slow as to render measurement difficult. By assembling quantities of uranium in a moderator such as heavy water or graphite, the rate of fission is found to vary with the amounts of material used. Upon adding additional materials, the neutron level at a given position and, of course, the fission rate (partly now in U^{235}) increase rapidly at first, then slowly, approaching a new constant level. The steady level may be two, ten, or a million times that to be expected from the spontaneous fission rate.

As the size of the reacting system increases, the time to reach a steady state increases until finally, in the ideal case (never well established experimentally), the system does not become saturated but increases indefinitely at the rate spontaneous neutrons are added. Experimentally, because the spontaneous neutrons are few in number, the neutron level remains constant at whatever level has been established. This is called the critical size of a reactor. If the reacting system exceeds the critical size, the neutron level increases, mathematically without bound. After passing through a transient, the neutron level increases as an exponential function. The greater the excess size, the shorter the period of the exponent.

After the suspense of loading the reactor the work of the next months is prosaic, for during this period extensive measurements are made to evaluate the nuclear and engineering characteristics of the reactor. The nuclear studies are carried out at a nominal power level of 50 to 100 watts, to avoid activating the structure. It is still necessary for people to make measurements inside the reactor shield adjacent to the uranium-containing graphite structure. Everything within the reactor shield becomes radioactive, but by minimizing the operating level and the operating time it is possible to avoid rendering the structure uninhabitable. After operation at the design power level, even for a few seconds, the structure will be so active as to prevent entering and working within the shield.

Nuclear measurements during this initial period of low level operation are directed toward a more precise evaluation of the constants of uranium and of the reactive medium than has been obtained heretofore.

In addition to fundamental data, the reactor itself must be calibrated before being carried to operating levels. Ionization and radiation sensing instruments must be calibrated for use in determining the power output of the reactor. The control rods must be evaluated since most reactivity measurements are made in terms of control rod position. Barometric and temperature changes affect the chain reaction, and these must be carefully measured.

At the conclusion of the nuclear measurements, studies of the air cooling system were made to determine conditions of optimum operation. These studies conclude the work at low power.

The power level of the reactor was raised to a megawatt (1000 KW) or a neutron flux of nearly 10^{12} neutrons per cm^2 sec. At this stage the reactor becomes a useful research tool.

Exponential behavior is usually considered a characteristic of a supercritical reactor. When the power level becomes sufficiently high to change the temperature of the system, there will be deviations. In the case of the Brookhaven reactor, the reactivity diminishes with increased temperature (the critical size increases). The reactor will therefore approach a limiting temperature level, and will operate at such a power as to maintain this temperature. In steady state operation therefore the reactor will always be an exactly critical system.

A reactor such as Brookhaven's is exceedingly stable for it will automatically compensate for changes in environmental conditions. Changing the coolant temperature will cause the reactor to establish a new equilibrium condition. Changes in coolant flow will cause transients both in power and temperature. Changes in control rod position will result in new operating powers and temperatures.

The approach to the long term operating level will take several months since the reactor will be held at each power level until enough is learned of its operating performance to justify proceeding to the next level. Just as an airplane of new design must be test-flown for long periods before it is declared ready for normal operating service, so the reactor must be tested and analyzed as it approaches high level operation. A period of several months

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may be required to achieve the design power of 28,000 KW associated with a central flux of 4×10^{12} neutrons per cm^2 sec. However, as soon as the reactor starts temperature operation, the flux available to experimenters will approximate that available at other US experimental reactors. The reactor, on November 15, reached a power level of 4 MW, or a flux of 10^{12} neutrons per cm^2 sec.

General Description

The Brookhaven reactor consists of a cube of high quality graphite which acts as a neutron moderator penetrated by a rectangular array of parallel holes carrying the uranium metal rods. These rods are encased in aluminum to protect them from oxidation. Cooling air is pulled through the holes to remove the heat generated in the metal by the fission of uranium.

The graphite is surrounded by a thick concrete shield to prevent the escape of nuclear radiations. All large openings must be plugged to prevent the escape of radiation. Exceptions are the air ducts which carry the cooling air and experimental ports from which neutron beams emerge. The air ducts have carefully designed labyrinths to prevent the escape of excessive amounts of radiation, whereas the experimental ports must be very carefully limited in size to prevent raising the radiation level in the experimental area.

Control of the reactor is achieved by a number of long rods containing the element boron. When such a rod is inserted into a reactor at constant power, neutrons are captured by the boron, disturbing the equilibrium of the nuclear reaction. The number absorbed by uranium is now less than that required to sustain the chain reaction so the neutron density diminishes with time. When a rod is removed from the reactor at constant power, the number of neutrons absorbed by uranium is more than enough to sustain a steady state, and the neutron density (and, with it, the power level) increases.

Nuclear reactions can operate at an almost unlimited power level, the limiting case being an atomic bomb. The greatest power and neutron flux of a reactor are determined ordinarily only by the ability of the cooling system to remove the heat generated, and to maintain safe temperatures of the structural elements. Air cooling was chosen for the Brookhaven reactor because of its simplicity, reliability, and stability. The system used is of the induced draft variety so that all parts of the reactor are at less than atmospheric pressure. Heavy duty centrifugal compressors eject the heated air at the rate of several tons a minute from a stack. The inlet air is filtered to remove dust which might become active while passing through the reactor, or might lodge within the graphite structure. The heated air is again filtered on leaving the reactor to remove activated particles originating within the reactor structure. The velocity of the cooling air reaches approximately half of sonic velocity. Such velocities permit relatively effective heat transfer from the uranium.

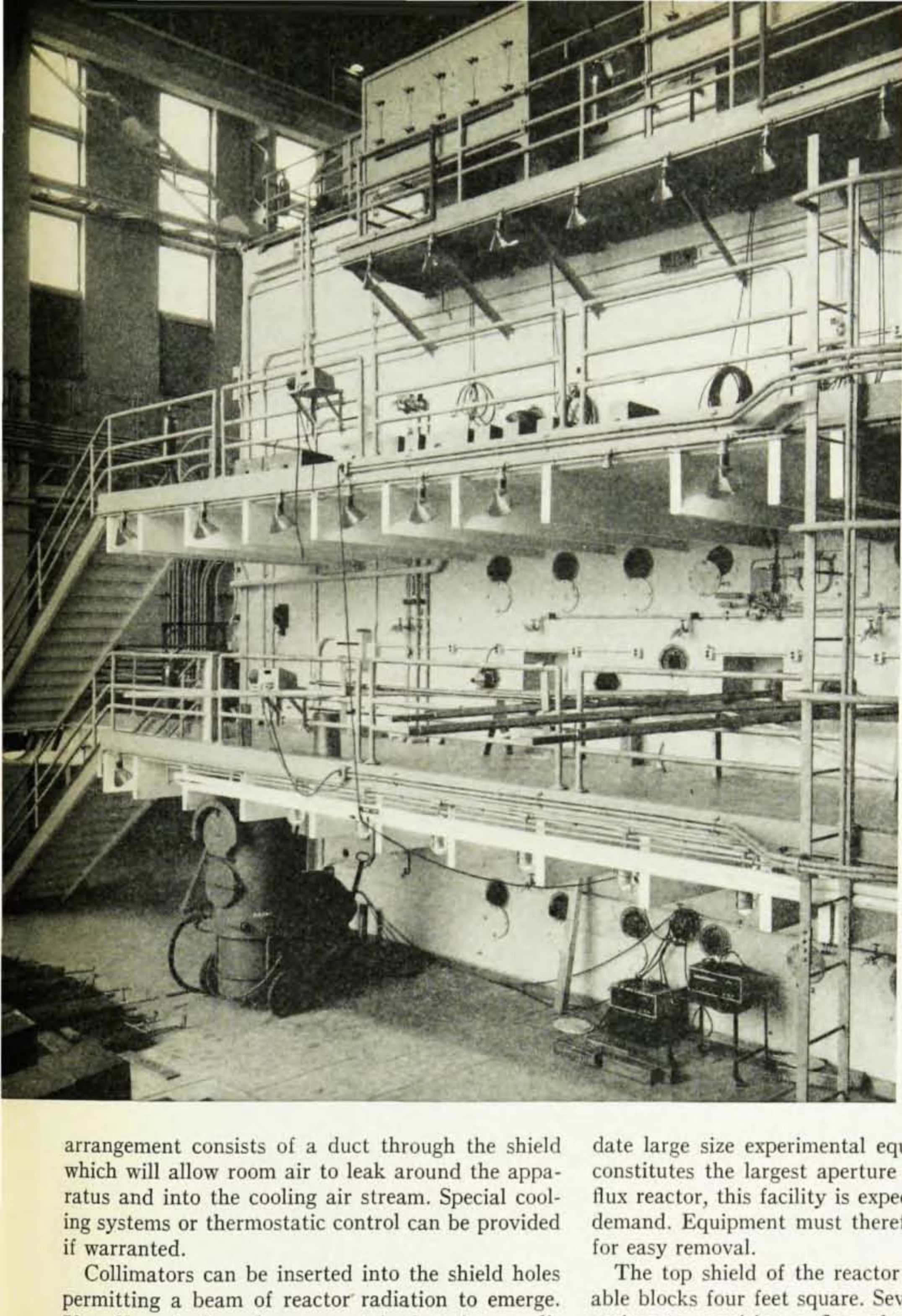
Argon is the principal constituent of the atmosphere to absorb neutrons and become seriously radioactive. A^{41} is characterized by a half-life of nearly two hours and a beta ray of 1.5 MV as well as by a gamma ray of 1.4 MV. The heated air from the reactor is therefore released 350 feet above the surrounding country. By maintaining a meteorology station, and a number of radiation monitoring stations, it will be possible to insure that areas surrounding the laboratory will be exposed, on the average, to only a small fraction of the intensity they receive from cosmic radiation. Weather and background observations have been recorded for more than a year, and from these data it is possible to predict that reactor operation will be curtailed only at relatively rare intervals.

Experimental Facilities

Brookhaven's reactor was designed to support a substantial and diversified research program. Ample facilities are provided for many simultaneous studies.

Most experiments will be conducted at a number of four-inch square experimental holes extending horizontally through the graphite structure and both shields. These are located at table height above the working balconies to permit convenient handling of research equipment. The neutron flux available at each hole will depend largely upon its position with respect to the center of the reactor. One row of these holes will extend through a region of graphite without uranium. The neutron flux in this internal thermal column will be particularly rich in thermal neutrons and relatively depleted of fast fission neutrons.

These experimental ports may be used for the insertion of equipment into the shield, or into the graphite structure. In these experiments fluxes up to 4×10^{12} neutrons per cm^2 sec. can be obtained. Under normal circumstances the equipment would reach the ambient temperature of the graphite. For experiments requiring temperature control, heating or cooling can be introduced. The simplest cooling



Experimental face of reactor. Photograph, taken before criticality, shows pattern of horizontal experimental holes used for most experiments.

arrangement consists of a duct through the shield which will allow room air to leak around the apparatus and into the cooling air stream. Special cooling systems or thermostatic control can be provided if warranted.

Collimators can be inserted into the shield holes permitting a beam of reactor radiation to emerge. If unfiltered, these beams contain fast, intermediate, and slow neutrons, and also gamma and beta rays. Filters can be devised to enrich the beam with regard to any of these constituents. Beams can be run to a distance of 40 feet within the building, and to much greater distances outside the building.

A single twelve-inch square hole will accommodate large size experimental equipment. Since this constitutes the largest aperture penetrating a high flux reactor, this facility is expected to be in heavy demand. Equipment must therefore be constructed for easy removal.

The top shield of the reactor consists of removable blocks four feet square. Several large scale experiments requiring a flux of approximately 10^{11} neutrons per cm^2 sec. can be conducted simultaneously. As semipermanent installations, there will be a vertical thermal column and a source of nearly pure fission neutrons.

Beneath the reactor are two experimental tunnels, one and two feet square. Carts will convey experimental equipment through radiation locks, and under the reactor to a radiation window. The neutron flux at this location is uncertain but probably in excess of 10^{10} neutrons per cm^2 sec.

The foregoing facilities will be used for irradiating equipment both internal and external to the reactor. Additional facilities are available for irradiating large numbers of small samples of chemicals and specimens for examination and study after removal from the reactor.

Short exposures of from a few seconds to a few hours can be made in the reactor by means of a number of pneumatic conveyors. A sample of 1.25 inches maximum diameter and less than 4 inches long can be enclosed in a fibre cartridge and propelled into the reactor by pneumatic pressure. After irradiation it is removed by pneumatic pressure and may be accepted either at the reactor face or may be sent on to a laboratory.

Exposures from a day to a few weeks can be made if the sample does not exceed ¾ of an inch in diameter and 2 inches in length. No cooling is provided for these samples so they must be capable of withstanding sustained temperatures of 150°C.

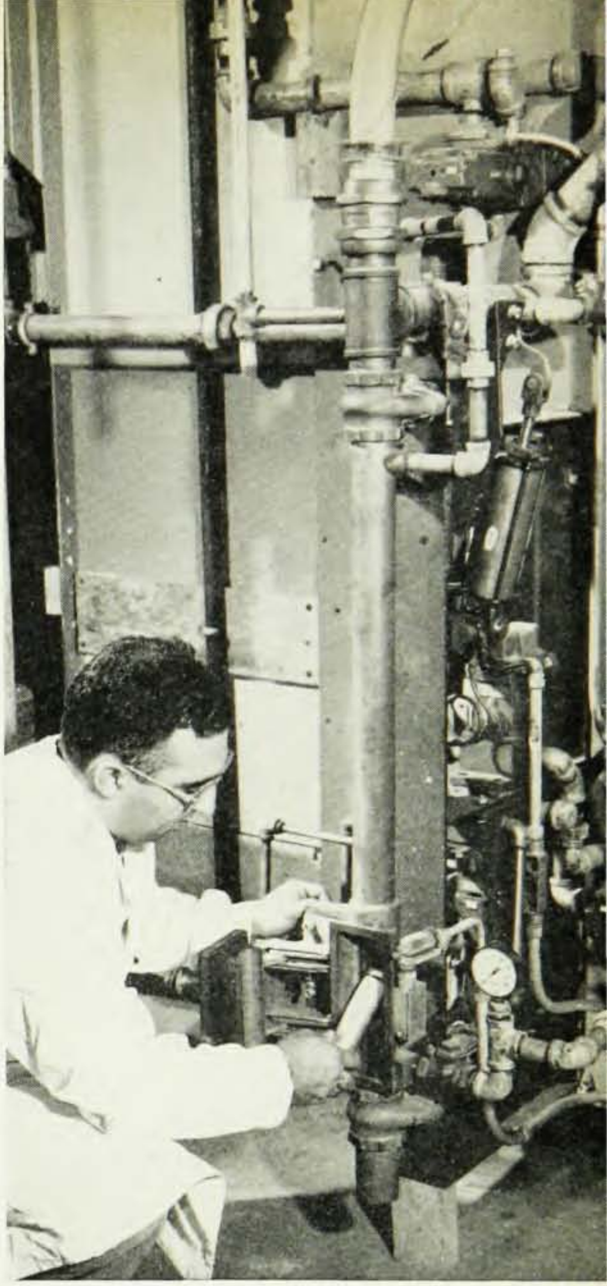
Long exposures of months or years are best made by charging the samples into the uranium-bearing channels of the reactor.

Laboratory Facilities

Adjacent to the reactor is a laboratory building. Shielded counter rooms provide low background space for sensitive measurements. Twenty large sized laboratory rooms are available for assignment to scientists working at the reactor. These rooms are carefully designed to minimize the danger of accidents with radioactive materials. While not intended for the handling of large quantities of active substances, samples of significant size (0.5 curie of powdered solids or 0.05 curie of liquids) may be handled with safety.

Accessibility

While many parts of the reactor, such as the control system and uranium-handling facilities, will be accessible only to scientists who have received full AEC clearance, it will be possible for visiting scientists, by arrangement, to carry out unclassified studies at one face of the reactor without gaining access to "restricted data". This term has been defined in Section 10 of the Atomic Energy Act of 1946, which regards as restricted all data concerning the manufacture or utilization of atomic weapons, the production of fissionable material, or the use of fissionable materials in the production of power.



Inserting capsule into pneumatic conveyor used for rapid inse and removal of samples, and for delivery to laboratories and laboratory.

Partitions are being erected to segregate one vertical face of the reactor from the rest of the reactor structure. At this face it will be possible to use neutron beams and to insert equipment through the reactor shield into the graphite structure. Experimental tunnels will be accessible and activated samples can be delivered to the laboratories associated with these facilities.

Hot Laboratory

The reactor can be the source of thousands of curies of radioactive substances. In operation it generates large quantities of fission products and its neutron atmosphere may be used to activate nearly all the elements. Large quantities of activity cannot properly be handled in conventional laboratory facilities. Work must be done by remote control, proper provisions must be made for the disposal of radioactive wastes, and extensive precautions must be taken to safeguard laboratory workers.

The hot laboratory is an auxiliary to the reactor which will permit the preparation and study of highly active samples. Cells of advanced design will permit the chemical processing of 50 curies of 2 MV gamma emitter and increasing amounts of materials giving softer radiations. In these cells the apparatus is completely surrounded by a thick radiation shield and complete remote control is used. Several semihot cells are provided to permit semi-remote handling of samples of 1 millicurie to 1 curie of 2 MV gamma emitter. The work in this case is performed in a well ventilated hood behind a portable wall of shielding. Tongs and special manipulators are used in conjunction with a system of mirrors.

A large open space will be available for the construction of specialized equipment for specific studies. Pilot plants may be built for the evaluation and development of industrial processes.

Research Program

The research program to be carried out at the reactor, and with reactor materials, will be highly diversified. The reactor itself will be studied as a nuclear and engineering mechanism.

The physics program at the reactor will include studies of the characteristics of the neutron as a particle, as well as its interactions with matter. Studies will be made with polarized neutrons obtained by total reflection from magnetized metallic mirrors and by passing through an inhomogeneous magnetic field. The depolarization of such neutrons may be used to study the force fields around nuclei.

Crystal diffraction of neutrons will be used to produce monochromatic neutrons. In a time of flight spectrometer a rotating shutter will produce neutron bursts which are detected by delayed counting circuits. Nuclear levels will be studied by each method.

Neutrons will be used for the study of crystal structure by means of a second crystal spectrometer.

The nuclear scattering of neutrons will be used both to study the nucleus and to gain information on the magnetic characteristics of crystals and alloys.

The effect of gross reactor radiation on chemical and metallurgical systems will be studied under a variety of experimental conditions.

The reactor will be a prolific source of radioactive elements which may be studied at the reactor, throughout the laboratory or in academic or industrial institutions.

Nuclear disintegration schemes will be studied for isotopes having half-lives as short as a microsecond, or as long as billions of years. Many varieties of instruments will be used to characterize the nuclear radiation; for example, beta and gamma spectrometers, cloud chambers, various specialized counters and pulse chambers. Chemical techniques will be used to identify the chemical specie responsible for a given radiation.

Radioisotopes will be prepared, purified, and used for tracer studies at Brookhaven and elsewhere. Short lived materials must be prepared and used with a minimum of chemical purification. Longer lived species can be carefully purified in quantity in the hot laboratory. Such production will be limited initially to a very few varieties and will be aimed at supplementing the isotopes already available at Oak Ridge. Each element will represent a development problem since the intent will be to produce purified radioisotopes on a relatively routine basis. Various processes of an industrial nature and of particular interest to the Atomic Energy Program will be studied at the reactor and in the hot laboratory.

Biological studies will be conducted to determine particularly the effect of neutrons on living systems. Genetic studies are already under way with x-rays. These will be extended to neutrons in the near future. Studies of radiation effects on the whole organism and upon individual parts will be conducted with various components of pile radiation. Biological use of small tracers of rare elements is receiving increased attention. Radioisotopes may be used for tracers or samples can be analyzed by subjecting them to bombardment and by identifying the induced activities. Medical diagnosis and therapy using radioiodine are among the lines of effort. Preparation of short lived iodine in the hot laboratory will assist this program.

Conclusion

The Brookhaven reactor will make available to scientists comprehensive facilities for scientific and engineering studies of the uranium chain reaction and its neutron and radioactive products.