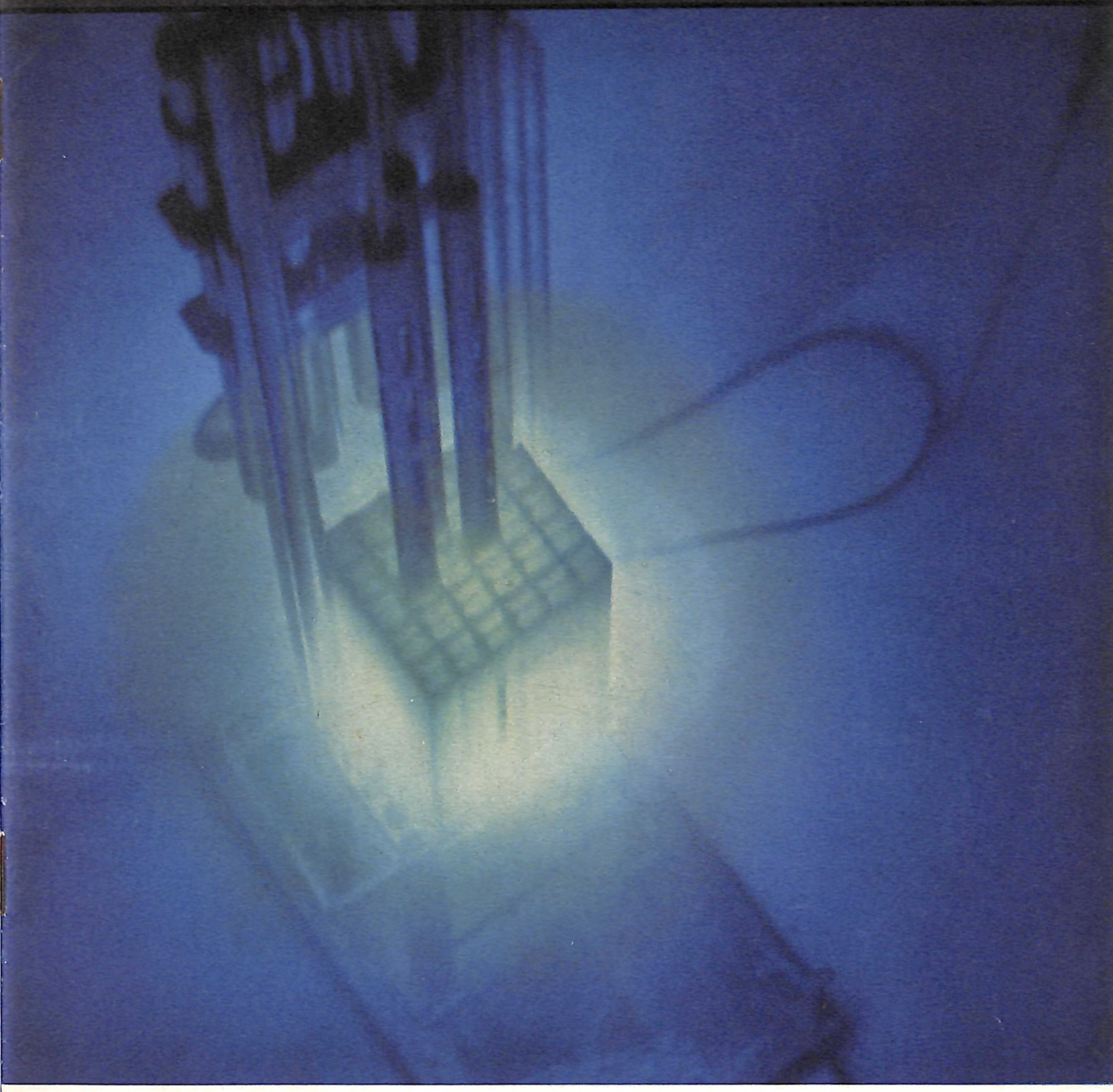
United States Research Reactor



ATOMS FOR PEACE

UNITED STATES OF AMERICA

INTERNATIONAL CONFERENCE ON THE PEACEFUL USES OF ATOMIC ENERGY

PALAIS DES NATIONS GENEVA AUGUST 8 TO 20, 1955

Foreword

The U. S. Research Reactor exhibited in operation at the International Conference on the Peaceful Uses of Atomic Energy in Geneva is one of several types of compact, versatile and relatively inexpensive reactors that can be constructed and operated for research, educational and engineering test purposes.

This booklet describes briefly the reactor and the exhibit panels displayed in the same building. More detailed information is available in the U. S. Technical Library, near Salle XV in the Library wing of the Palais des Nations.

The U. S. Research Reactor was constructed beginning in March, 1955, at Oak Ridge National Laboratory, and assembled for testing late in May. Meanwhile, work had been started on the special building in Geneva, and by June 17 it was completed. The reactor was flown from the United States and installed in July. A period of testing preceded the official opening August 8.

The active core of the reactor is composed of uranium, enriched to 20 per cent in uranium-235, and enclosed in aluminum "sandwiches." The fuel lattice is immersed in a pool of water, giving rise to the colloquial expression "pool-type reactor." The water acts as a coolant, a moderator, and a radiation shield, and permits complete visibility of the reactor core and of experiments in progress.

The reactor operates at a power level of 10 kw. nominal and 100 kw. maximum, and contains 3.6 kg. of U^{235}.

The uranium, 20 per cent enriched, which is used in this reactor, is the same type that has been offered by the President of the United States to other nations for the construction of research reactors, in furtherance of the policy to promote worldwide peaceful uses of atomic energy. Two hundred kilograms of the material have been set aside by the President for this purpose.

President Eisenhower has also announced that the United States Government is prepared to help provide research reactors for other free nations and to contribute half of the cost, as well as to furnish the nuclear fuel required.

ABOUT THE REACTOR

The core of the reactor consists of 23 fuel elements compactly arranged and mounted on an aluminum grid plate supported from the bottom of the tank. Three of the fuel elements contain holes that are designed for insertion of control and safety rods; one special piece is designed to hold a neutron source to facilitate control of the reactor during starting operations.

The blue glow associated with the operating reactor is known as the Cerenkov effect, caused by the slowing down of high-energy radiation in the water with the release of part of the energy as visible light.*

The total loading of the reactor is approximately 18 kg. of uranium of which 20 per cent, or 3.6 kg., is U^{235}.

The pool of water in which the reactor is immersed is contained in a steel tank 10 feet in diameter and 22 feet deep, the lower 18 feet buried in the ground. The tank contains approximately 13,000 gallons of ordinary water, which has been demineralized by passing through a mixed-bed ion exchange unit that produces water of a quality approximating that of distilled water. The depth of water above the reactor core is 16.5 feet, which at the reactor operating power of 10 kw. provides sufficient shielding to reduce the radiation level at the water surface to about 0.5 mr/hour, or about one fourth of the intensity of radiation given off by the surface of a radium-dial wrist watch. The amount of radioactivity induced in the water is quite low and any traces are continuously removed by recirculating the pool water through another ion exchange unit. (See Panel 14.)

Three movable rods containing boron carbide are used to control the reactor. Electromagnets attached to each of the electric-motor-driven rod mechanisms provide a means of coupling the drive units to the control rods.

The panel behind the glass doors to the right is used to control the reactor. This assembly is more extensive than that normally employed with a reactor of this power. The nuclear instrumentation provided is adequate for high-power, short-period reactors. In addition, a completely automatic start-up has been provided, as well as a simple servomechanism to maintain constant power.

Electrical devices are used to indicate the position of the three control rods. Switches are used to limit the travel of the rods. The speeds at which the control rods may be withdrawn and, therefore, the rate of reactivity addition is limited, permitting a total

*More fully described in an article by W. H. Jordan in *The Scientific American*, a reprint of which is available in the U. S. Technical Library adjacent to Salle XV.

start-up time of about seven minutes.

The reactor control and safety system consists of three neutron-level safety channels, two counting-rate channels, one period channel, and one linear channel connected into a servo-control mechanism.

On many reactors only two safety circuits are used; on this reactor an extra circuit is provided as an additional safety measure. The radiation level is constantly measured at three locations—the control room, the water demineralization room, and the area around the reactor pool. If the radiation level should become too high at any of these points (or if the instruments themselves become inoperative), an alarm is sounded and the motors on the control rods will reverse, driving the rods into the reactor core and immediately stopping the chain reaction. In addition to these safety devices, another instrument constantly samples the air in the room, measures the amount of radioactivity (if any), and sounds an alarm if the air should become contaminated.

Complete data on the nuclear characteristics will be found on Panel No. 6, to the left of the reactor pool. Technical personnel in attendance will be happy to answer questions concerning the design and operation of the reactor.

EXHIBIT PANELS

PANEL NO. 1

Fuel Elements

The reactor is operated with uranium containing 20 per cent U^{235} incorporated into aluminum, curved-plate-type fuel assemblies, which were designed specifically for service in low-temperature, high-neutron-flux research reactors.

The fuel plates consist of enriched UO_2 particles uniformly dispersed and imbedded in a matrix of aluminum powder, which is clad on all sides with high-purity aluminum sheets. The core, or fuel-bearing, section of the composite plate is composed of 54 per cent (by weight) UO_2 and 46 per cent aluminum powder. Pressed powder cores are jacketed by the so-called "picture-frame" technique, which hermetically seals the uranium dioxide from exposure to the cooling water. The hot-rolling operation employed in fabrication results in a sound metallurgical bond between the cladding layers and core matrix. The core of the composite

fuel plate is 0.025-inch thick and the cladding on each side is 0.0175-inch thick.

Eighteen of these composite plates are assembled into a single unit, which is designated as a fuel element or assembly. The fuel plates are spaced 0.117-inch apart and brazed into a pair of aluminum spacer plates. This type of construction is employed to yield a high surface-to-volume ratio, permitting a rapid transfer of heat to the water used as a coolant.

An aluminum end-box casting is welded onto the lower end of the fuel assembly and positions the fuel element in the supporting grid. Each standard (18-plate) fuel unit contains 967 G of UO_2 or 170 G of U^{235}.

PANEL NO. 2

Reactor Section

This panel shows the mechanical arrangements of the control rod in the reactor lattice, with its associated drive mechanism. Starting with the components at the bottom of the display, the first item is the grid plate, which supports the fuel elements. Hollow cylindrical adapters on each fuel element fit in the holes in the grid and permit water to rise convectively up through the grid and the fuel plates as the neutron flux heats the fuel plates. Sections of the adapters are mounted in the grid plate.

Cutaway sections of dummy fuel elements mounted in the grid plate show the difference in construction between the regular fuel element and the control rod fuel element. The control element has the nine center plates removed to permit the insertion of the boron carbide neutron absorber rod, which controls the neutron flux level of the reactor.

The reactor is brought to power by withdrawing the boron carbide rods from the reactor lattice. This action is only possible when the control rod is supported by the electromagnet. The electromagnet moves inside a guide tube to maintain proper alignment between the electromagnet and the boron carbide rod and connects to the rack of the drive unit through a universal joint. The clutch switch is a device that indicates whether or not the electromagnet is supporting the control rod.

A quick shutdown of the reactor is obtained by cutting off the current to the electromagnet. This drops the boron carbide rods into the lattice, thereby rapidly reducing the neutron multiplication. Each rod is equipped with a piston-type shock absorber to protect it and to prevent recoil of the rod.

PANEL NO. 3

Uses of the Enriched U^{235} Reactor

The various principal uses of an enriched U^{235} pool reactor in the fields of education in nuclear science, nuclear physics research, reactor design, radioisotope production, activation analysis,

study of radiation effects, and biomedical research are described briefly. Further details are given in subsequent panels.

(Near Panel 4)

Nuclear Reactor Simulator and Model Reactor

The neutron flux in a nuclear reactor increases when a neutron-absorbing control rod is moved out of the fuel element lattice. An electronic reactor simulator was developed at Oak Ridge National Laboratory to demonstrate the way in which the neutron flux can be made to vary in a reactor. This device has been used primarily to check the action of automatic control circuits of the reactor. In this Nuclear Reactor Simulator display, the simulator has been built into a panel to demonstrate the control of a nuclear reactor. This simulator can be operated by visitors to this building.

The instrumentation for the simulator panel includes the nuclear reactor simulator, the simulator power supply and a Log-N amplifier. The Log-N circuit amplifies the voltage from the simulator, which represents power level, and extracts period* information. The signals for the power level and the period are fed into two recorders on the panel.

The flux recorder indicates the power level of the reactor and has an automatic "scram" or shutdown if the indicated power level exceeds a predetermined level. The period recorder indicates the rate at which the power level is changing. The automatic shutdown on this recorder is activated if the period is shorter than five seconds.

The rod control and rod position indicators are used in conjunction with the model reactor, which is a full-scale plastic facsimile of the core of the operating U. S. Research Reactor. This model can be used with the nuclear reactor simulator control panel to demonstrate the action of introducing excess reactivity (Δk) into a reactor. The control rods can be withdrawn by means of the rod control switch on the simulator panel. Changing the rod positions will also change the voltage in the simulator circuits, a larger amount causing the reactor flux level indicator to increase more rapidly, as indicated on the period recorder. As the power level indicator changes, the voltage applied to lights in the model reactor will change in the same manner; thus the model resembles a working reactor. The simulator controls can be set so $k = 1$ at a selected flux level, and the model will operate like a manually controlled reactor. A magnetic clutch arrangement allows the control rods to be dropped by a scram, thereby shutting down the reactor. The scram can be initiated manually by a scram switch, or by simulated safety circuits in the two recorders.

*The "period" is the time required for the power to change by a factor equal to e (2.7183).

PANEL NO. 4

Radiation Detection and Protection of Personnel

Special instruments for the detection of radiation are shown. There are two main types of hazard—exposure to external radiation, which penetrates the body, or actually swallowing or breathing small amounts of radioactive material. The basic concepts of protection against radiation—time, distance, shielding, and protective clothing—are demonstrated, together with practical methods for decontamination.

PANEL NO. 5

Neutron Therapy

This panel shows how a beam of neutrons from a reactor, such as the pool reactor, is used directly for killing tumor tissue in the brain, with the help of boron. It has been found that, if sodium borate is injected intravenously, the boron is taken up preferentially by the tumor tissue, absorbing three times as much as the surrounding normal brain tissue. When thermal neutrons react with boron-10, a neutron is captured and an alpha particle is ejected. Because the alpha particle is very energetic and has a short range, it produces intense ionization within the tissue. Because the range of the alpha particle in tissue is only 36 microns (or about the diameter of a single cell) the intense alpha radiation is restricted to the tissue containing boron. Boron has a particularly great affinity or "cross section" for neutrons, roughly 700 times as great as other elements in tissue.

PANEL NO. 6

Specifications of the Reactor Core

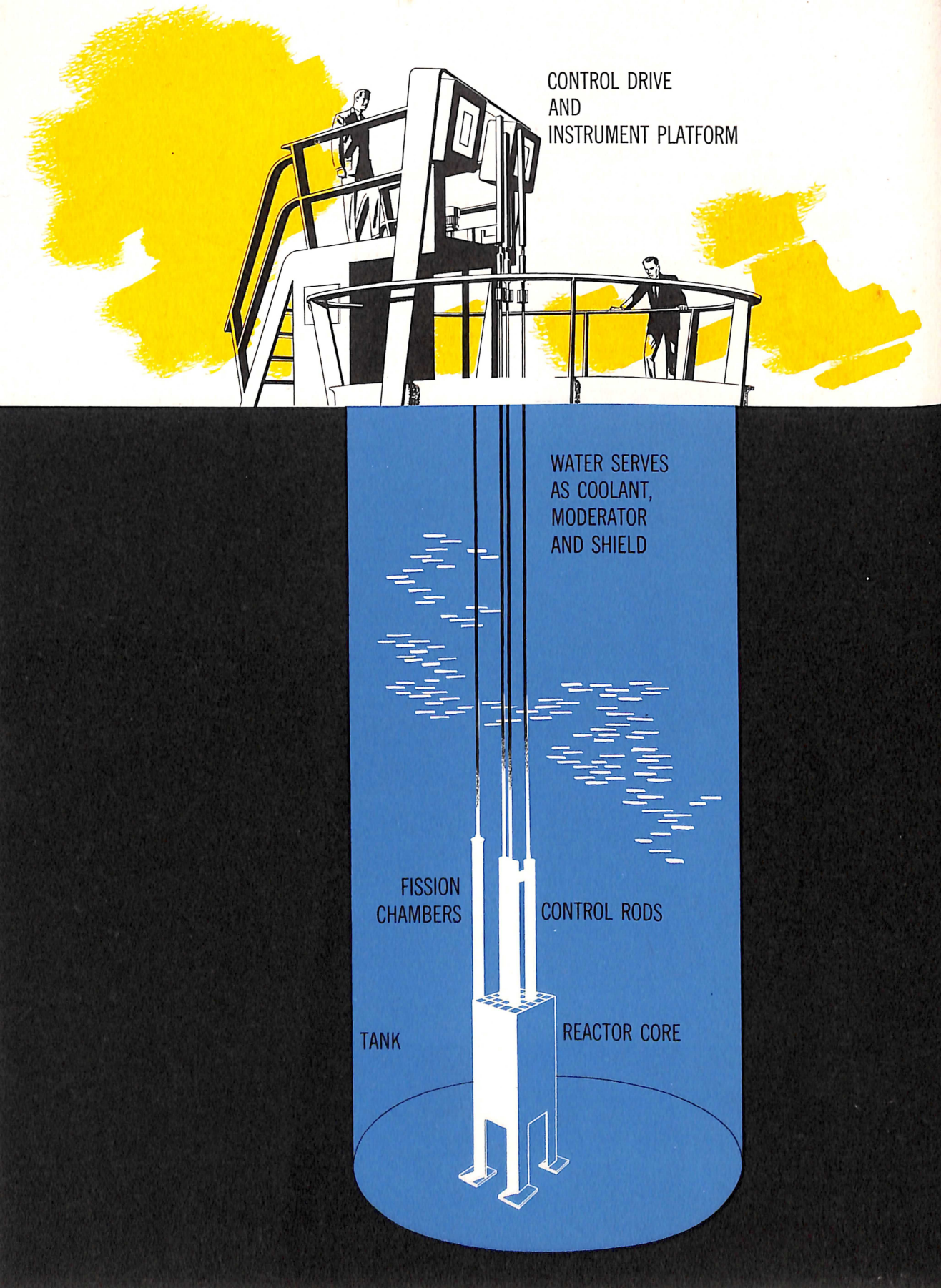
Various data concerning the amounts and kinds of materials used in the reactor core and the nuclear constants are tabulated in this panel.

PANEL NO. 7

Reactor Design and Nuclear Research

This panel describes the use of a small reactor for research in connection with reactor design or nuclear physics.

(a) In the upper left, is an illustration of the effect of replacing part of the water reflector around an operating reactor with a void. The introduction of the void increases the neutron leakage from the reactor and hence reduces reactivity. If, then, a neutron-absorbing control rod is withdrawn an appropriate distance, the reactivity loss can be compensated for and the


CONTROL DRIVE
AND
INSTRUMENT PLATFORM
WATER SERVES
AS COOLANT,
MODERATOR
AND SHIELD
FISSION
CHAMBERS
CONTROL RODS
TANK
REACTOR CORE

reactor made chain reacting once again. The distance the rod is removed is a quantitative indication of the effect of the void on reactor criticality.

(b) In the upper right, is an illustration of the measurement of the energy released per U^{235} fission. One element of the reactor is isolated so that the temperature rise and flow of the cooling water can be carefully measured. The rate of fission within the fuel element is determined by observing the radioactivity of small U^{235} samples, which are separately inserted into the fuel element. The quotient of these two observations gives directly the energy released per fission.

(c) On the lower left, a shielding experiment is illustrated. In this example, a large block of shielding material is placed next to the reactor. The radiation intensity of the neutrons and gamma rays that penetrate the shield is measured with suitable instruments.

(d) At the lower right, the use of the reactor in conjunction with a thermal column is illustrated. In this example, a large block of graphite is used to slow down the fast neutrons to thermal energies. These thermal neutrons can then be used for any of a number of experiments. In the example illustrated, the thermal neutrons are used to cause fission, and the fast neutrons from the fission are measured in a spectrometer to obtain the energy spectrum of the fission neutrons. The prompt gamma rays accompanying fission can be measured in another spectrometer.

PANEL NO. 8

Research in Nuclear Engineering

One of the principal advantages of a pool-type research reactor is that it can be readily adapted to a wide variety of nuclear research. Coupled with the ease of obtaining relatively high neutron fluxes and high radiation intensities, this reactor is well adapted for performing engineering-type experiments necessary for the development of nuclear power reactors.

The experiments listed in Panel 8 comprise those which deal with the behavior of the reactor from the standpoint of heat removal, gas production, and stability, in addition to the utilization of the reactor as a neutron and gamma-ray source. In this latter regard, one important problem concerns the effect of radiation on various fluids that might be used in a nuclear power reactor of advanced design. The experimental assembly shown toward the bottom of the panel is a duplicate of the actual equipment used to irradiate an aqueous solution of a uranium salt at temperatures up to 300°C and pressures up to 2,000 pounds per square inch. In this experiment, the uranium solution is circulated by a completely sealed rotor pump of 20-liters-per-minute capacity through the cylindrical stainless steel bomb, where it is exposed to radiation. Metal samples can be placed within the bomb to test the effect of radiation on their corrosion by the solution. The remaining components of the assembly are for controlling the temperature and pressure

inside the loop and taking samples of the solution.

The in-pile loop assembly can also be used to test the radiation stability of coolants and other reactor fluids.

PANEL NO. 9

Chemical Effects of High-Energy Radiation

The effects of radiation on organic materials used in the plastic industry are shown. In general, two types of effects are observed: (1) building up, or cross-linking of simple molecules to form larger ones; (2) breakdown, or chain cleavage of complex molecules to produce smaller ones.

(a) The first effect is illustrated by the polymerization of acrylonitrile, which is the monomeric parent of one of the synthetic materials used for textile fibers. The tubes all originally contained a seven per cent solution of acrylonitrile in water, as shown in the first tube on the left. When the solution is irradiated, very active chemical groups are formed, which initiate the polymerization reaction. As the reaction proceeds, the acrylonitrile is transformed from a water-soluble monomer to a water-insoluble polymer after approximately 30,000 roentgens of radiation, as illustrated by the turbidity in the second tube. The reaction accelerates rapidly until finally the monomer is all converted and the solution has set into a stable gel in the last tube.

(b) Physical changes are produced in irradiated plastics and elastomers, as shown in the sets of various samples shown in the lower half of the panel. Both cross-linking and cleavage reactions proceed at varying rates, and the result depends on which reaction predominates, as shown in the following table:

Physical Property	Cross-Linking Predominant	Cleavage Predominant
Tensile Strength	Increased	Decreased
Hardness	Increased	Decreased
Young's Modulus	Increased	Decreased
Elongation	Decreased	Increased
Impact Strength	Decreased	....
Melting Point	Increased	Decreased
Solubility	Decreased	Increased
Density	Increased	....

(c) Although the useful properties of all plastics and elastomers are ultimately destroyed by radiation, smaller doses of radiation can occasionally be used to improve a property of some plastics. For example, the melting

point of polyethylene can be raised by irradiation so that it can undergo heat sterilization without physical distortion.

PANEL NO. 10

The Reactor for Education in Nuclear Science

Students attending a reactor school may represent many different professions, among which may be mechanical, chemical and electrical engineers; physicists and chemists; mathematicians; marine architects; and many others. Actual experimental work with a reactor is one of the best teaching methods.

For some experiments, the reactor is used only as a source of neutrons. A neutron beam is useful for many experiments, such as measurement of the fission cross section of uranium and the number of neutrons emitted per fission.

For experiments with the reactor itself, the students operate the controls. In one experiment, the students insert the fuel elements one by one and, with a neutron source and a fission counter, study the approach to the "critical" loading. In another experiment, the reactor is shut down by use of the control rods. The reactor is allowed to cool off, as judged by the temperature of the uranium. It is then restarted and the negative temperature coefficient of reactivity is measured experimentally. During all these operations the students acquire knowledge regarding the critical mass and geometry of the reactor, the speed with which control rods can be inserted or withdrawn, the positions at which neutron flux measurements are made, the time of response for changes in reactor operations, and the precautions necessary for personal safety.

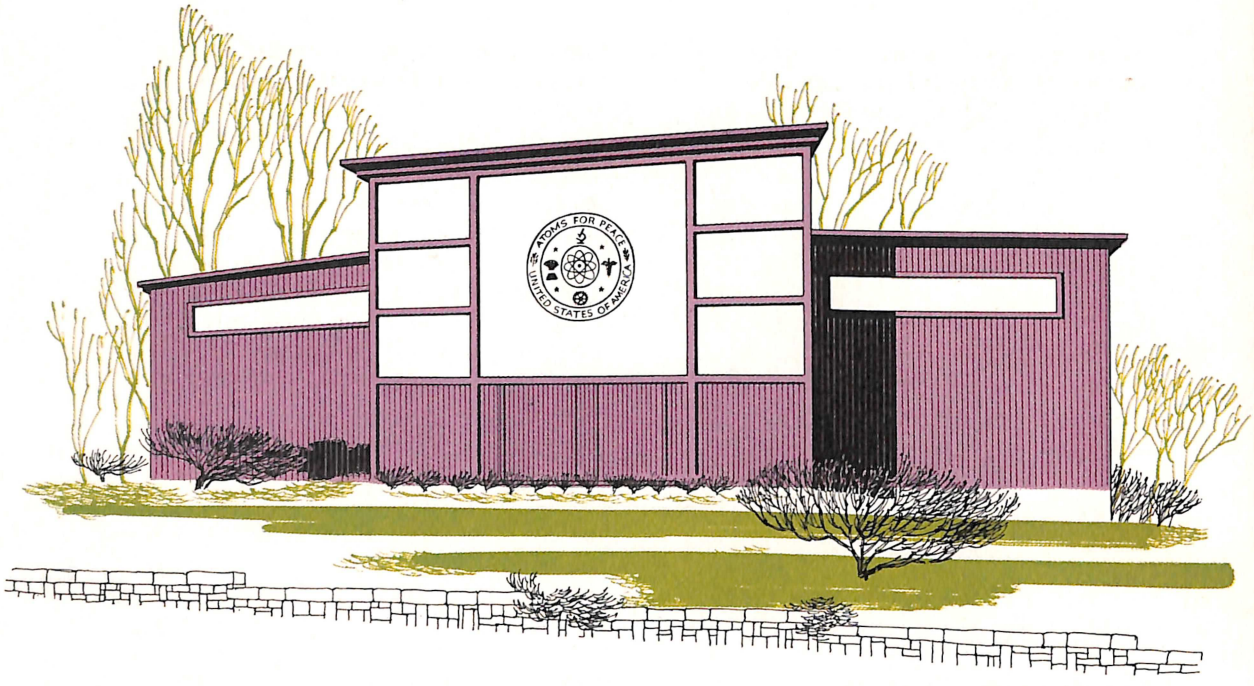
PANEL NO. 11

Production of Radioisotopes

The pool reactor is well suited for the production of millicurie quantities of most radioisotopes. Because the core is easily accessible, capsules containing materials to be irradiated can be placed adjacent to the reactor in a simple holder, and the sample later removed with long tongs. Pneumatic tubes containing light aluminum capsules can also be used to position materials outside the core for thermal neutron irradiation, or inside the core for fast neutron irradiation. The capsules are blown through the tubes with compressed air.

Short-lived radioisotopes may be produced quite conveniently, and by a system of pneumatic tubes the radioisotopes produced can be delivered to nearby laboratories in a few seconds.

With the reactor operating at 100 kw., the neutron flux approximates 5×10^{11} neutrons/cm^2/sec; useful amounts of many radioisotopes can therefore be prepared with adequate specific activity for most applications, as shown in the following table:



Nuclide	Half Life	Specific Activity (mc/g element)
Na^{24}	14.9 h	210
K^{42}	12.4 h	14
Br^{82}	35.5 h	180
Au^{198}	2.7 d	3,300
Cu^{64}	12.9 h	340
Sb^{122}	2.8 d	210
As^{76}	26.8 h	440
Cd^{115}	43.0 d	20
Ga^{72}	14.2 h	150
La^{140}	40.0 h	460
Hg^{197}	2.7 d	150
Os^{191}	15.0 d	65
Pd^{109}	13.1 h	220
Pr^{142}	18.9 h	630
Rb^{86}	19.5 d	31
W^{187}	24.1 h	420
Y^{90}	2.5 d	93

PANEL NO. 12

Neutron Activation Analysis

Neutron activation analysis involves the irradiation of a sample in the reactor (or other source of neutrons) and the subsequent identification of the radioisotopes produced by their specific radiation characteristics. The method of analysis can be made either qualitative or quantitative. For quantitative analysis, standard samples containing known concentrations of the suspected elements are irradiated at the same time as the unknown sample.

This type of analysis has proved particularly useful where the concen-

tration of the unknown element is too low to be identified by conventional methods of analysis, or where conventional methods are rendered invalid by interfering contaminants. The method is unique in that after a microquantity of element has been made radioactive, it may be diluted with amounts of the same (non-radioactive) element large enough to enable one to use ordinary chemical separation procedures while the original microquantity retains its identity.

Neutron activation analysis has been used successfully in analyzing for almost every type of substance.

PANEL NO. 13

Changes in Crystal Structure Due to Radiation

Crystals are made up of the simple orderly array of atoms, which form solids. When such an orderly atomic arrangement is exposed to bombardment with energetic neutrons, this stable array may be partially or completely destroyed by the atomic displacement.

Large changes in the physical properties of such solids may be detected by X-ray diffraction, as shown by the diffraction photographs of irradiated quartz crystals in the exhibit.

(a) Increasing amounts of neutron irradiation causes quartz crystals to expand anisotropically (unequally in different directions), eventually increasing the crystal volume by 14.7 per cent. The orderly atomic array of the crystalline lattice becomes increasingly distorted until coherent X-ray diffraction patterns can no longer be observed and the crystal becomes essentially amorphous (random atomic arrangement). Oddly enough, no flaws in the crystal can be observed by the naked eye despite these large volume changes.

The Brazilian quartz crystal shown under the magnifying glass was exposed to 7.6×10^{19} neutrons/cm^2 and subsequently annealed at 950°C for 30 minutes. Parallel to the C-axis, and in the twin bands, two rows of holes were formed. These are nearly regularly spaced, about 0.3 mm. apart, and are about 0.05 mm. in diameter extending entirely through the 5-mm.-thick crystal. The formation of these holes is probably related to the C-axis twin bands, interstitial channels and the anisotropic expansion of quartz upon neutron bombardment. A possible explanation of this hole formation is that an A-axis strain is set up in the crystal because of the crowding of oxygen atoms into interstitial channels; the subsequent thermal diffusion of these trapped atoms out of the channels results in a strain release over some very small distance perpendicular to the C-axis. This strain relaxation may result in the generation of macroscopic holes parallel to the C-axis.

(b) The copper single-crystal tuning forks demonstrate an effect of neutron irradiation upon the damping capacity, or internal friction, of copper single crystals and, quite probably, of metal crystals in general. An irradiated specimen tuning fork "rings" while an unirradiated one does not. This is because the neutron irradiation has lessened the internal friction so that energy, which is dissipated internally in the unirradiated tuning

fork, remains as vibrational energy to be dissipated as sound in the irradiated one.

It is interesting to note that only a relatively small number of neutrons are required to produce the ringing. The ringing has been obtained with irradiations in the range of 1.5×10^{14} to 1.5×10^{18} total neutrons/cm^2. If it is assumed that one incident-fast neutron can produce 100 interstitial-vacancy pairs, and the average scattering cross section of copper is 6 barns, this corresponds to the production of only 0.000009 to 0.09 per cent of the possible interstitial-vacancy pairs.

(c) When electrons in insulators such as glasses or alkali halides are displaced from their normal energy levels, they may become trapped in less stable configurations. In these new configurations, the electrons are more easily excited to higher energy levels, and this may result in absorption of visible light.

The colors shown in the exhibit in KCl and KBr result from F-centers, which are electrons trapped at negative-ion vacancies. The NaCl had an amber color immediately after irradiation, but subsequent bleaching of F-centers by light, accompanied by formation of other color centers, resulted in change of color. The yellow color of LiF is thought to be due to M-centers, which consist of an electron trapped in a configuration of one positive and two negative-ion vacancies.

Colors in vitreous silica are probably due to electrons trapped at impurities in the silica. The exact nature of the color centers in glasses is not known.

PANEL NO. 14

Water Demineralization

It is desirable to remove mineral salts from the reactor cooling water to prevent the activation of various impurities, particularly sodium, and to inhibit corrosion of the reactor metal.

This exhibit is a schematic representation of the demineralization process, which produces water of about the same quality as distilled water (resistivity, approximately 500,000 ohm/cm). Ion-exchange resins (synthetic organic materials) are used to remove both the dissolved cations (e.g., Ca^{++}, Mg^{++}) and anions (HCO_3^-, $SO_4^=$). Initially, the active groups of the cation-exchange resin are saturated with hydrogen ions (H^+); these are exchanged for the mineral cations, Ca^{++}, Mg^{++}, etc. The anion resin is initally saturated with hydroxyl ions (OH^-), which are exchanged for Cl^-, HCO_3^-, $SO_4^=$, etc. The hydrogen and hydroxyl ions when released combine to form pure water; the net result is that the mineral salts are taken out and replaced with pure water.

The ion-exchange resins may be regenerated by treating the cation resin with acid (to supply H^+) and the anion resin with alkali (to supply OH^-).

The reactor cooling water absorbs some impurities from the tank wall and reactor parts, particularly extremely minute amounts of short-lived radioactive Al^{28}, Mg^{27}, and Na^{24}, which "recoil" from the reactor aluminum parts when struck by energetic neutrons in the reactor core. These impurities are also removed by recirculating the reactor water through an ion-exchange unit.

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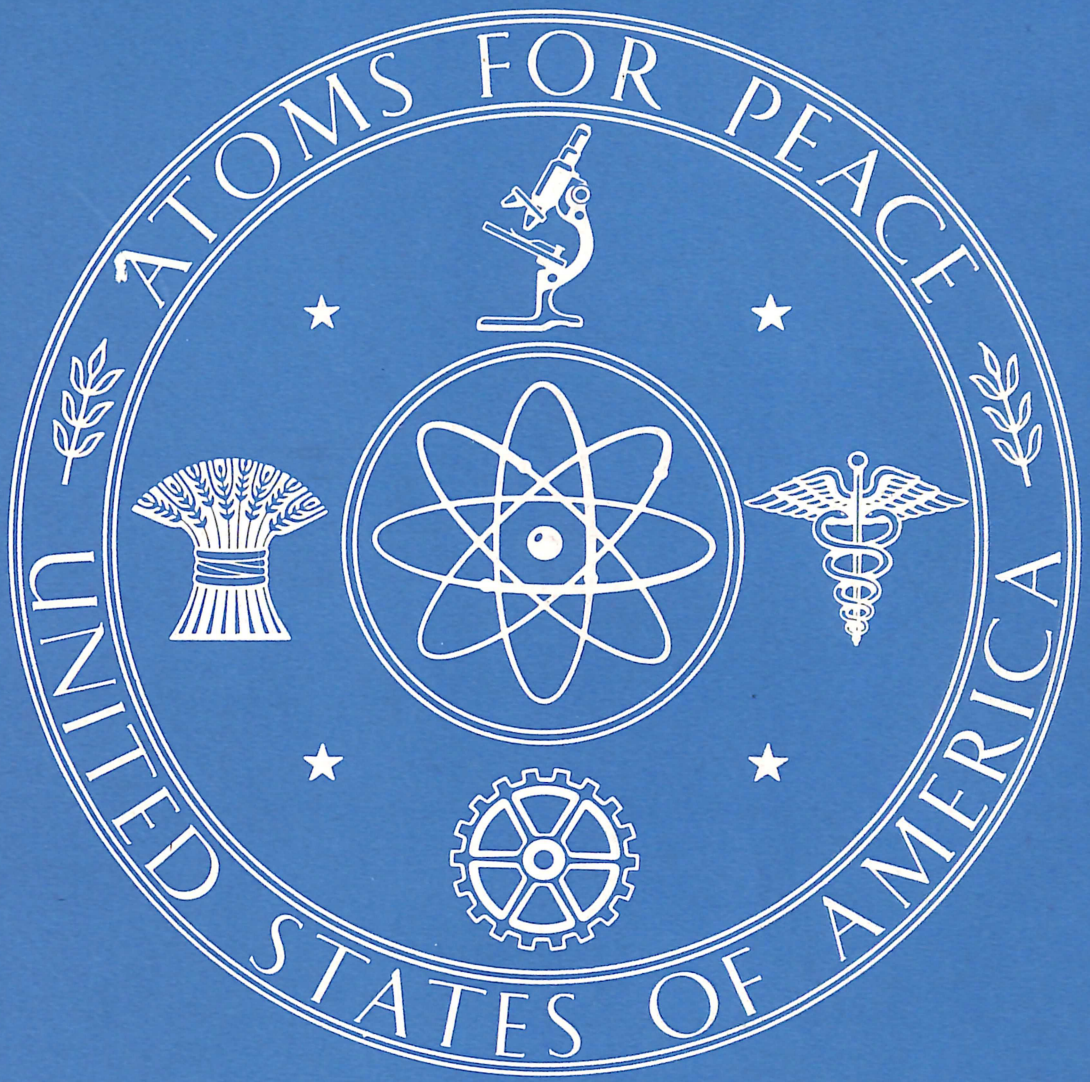

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by the

UNION CARBIDE AND CARBON CORPORATION