The Ford Nuclear Reactor and Phoenix Memorial Laboratory

RUSSELL B. MESLER, WILLIAM K. LUCKOW, AND HENRY J. GOMBERG

The University of Michigan has established the Michigan-Memorial-Phoenix Project to pursue the peacetime applications of atomic energy. As a part of this project the $1,000,000 Ford nuclear reactor and the $1,500,00 Phoenix Memorial Laboratory have been planned and built. This article describes the experimental facilities of these two installations.

In 1948 the University of Michigan created the Michigan Memorial-Phoenix Projects as a "War Memorial Center to explore the ways and means by which the potentialities of atomic energy may become of beneficent influence in the life of man." As a part of this program the $1,500,000 Phoenix Memorial Laboratory has been erected and the $1,000,000 Ford Nuclear Reactor is nearing completion. The two facilities are located in adjacent buildings on the newly created North Campus of the University of Michigan.

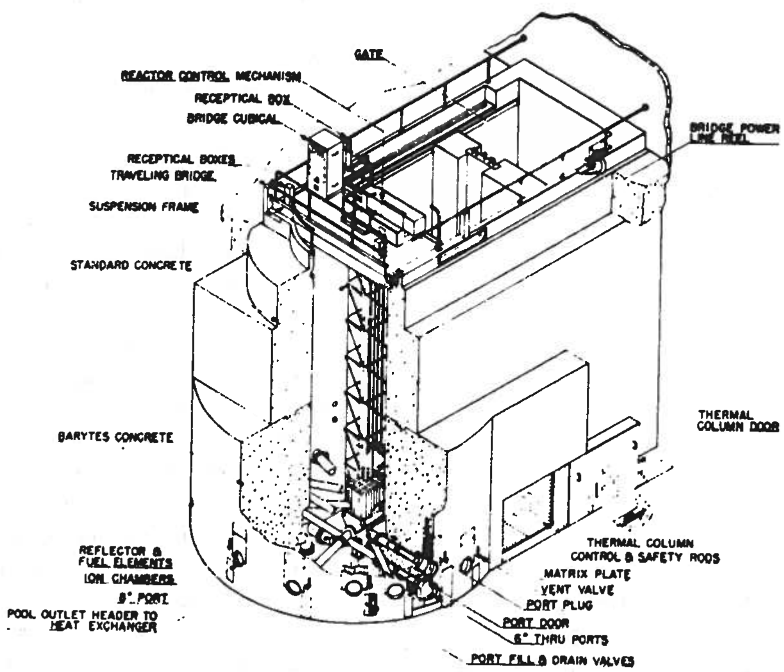

Fig. 1. Isometric view of the Ford Nuclear Reactor.

The purposes of the reactor are (1) to provide an intense source of neutron and gamma radiation for research, (2) to supply radioactive isotopes, primarily those with short half-lives, and (3) to aid in training scientists and engineers in reactor technology. The Phoenix Memorial Laboratory is designed to provide the special laboratory facilities necessary to experiment with radioactive materials such as will be produced in the reactor.

Michigan-Memorial Phoenix Project, University of Michigan, Ann Arbor, Michigan

REACTOR

The Ford Nuclear Reactor is a swimming-pool reactor designed to operate at power levels up to 1 Mw. It is water cooled and moderated. The sides of the reactor are graphite reflected.

The fuel for the reactor is 90% enriched U^{235} contained in eighteen-plate MTR-type fuel elements. The fuel elements sit in a grid plate eight elements wide and ten elements long. The graphite is contained in similarly shaped elements and is placed around the central fuel positions.

The reactor is suspended from a movable bridge, which also accommodates the safety and control-rod drives and other auxiliary equipment, and is operated from a control room overlooking the bridge. The reactor is shielded on the top by 20 ft. of water and on additional stations. Four terminals are located in hoods in the Phoenix Laboratory. The fifth terminal is in Laboratory *B* of the Reactor Building. The five terminals (eventually seven) are connected by means of 1½-in. tubing to four reactor irradiation stations through a switching device. The switch permits manual interconnections by the choice of the appropriate connector tube of any of the five laboratory terminals to any of the four reactor stations. The tubes enter the reactor pool through a special opening in the pool floor and fan out along the one side of the reactor at the beam-hole position. The portion of the pneumatic system which is in the pool is removable without draining the pool.

Carriers operate under vacuum both to and from the reactor to prevent the escape of activated air and dust into the building atmosphere. Motivation sufficient for the simultaneous use of two tubes is supplied by two 5-hp. blowers each developing 230 cu. ft./min. at a 40-oz. vacuum. Inlet air to the system is filtered through a Fiberglas prefilter and a Cambridge absolute filter to reduce dust intake. Air is exhausted to special ventilation systems for radioactive gases.

The blower power is under the control of the reactor operator for safety purposes. Control of carrier movement is exercised by the individual experimenter from control panels at each terminal. The solenoid-operated wind gates which divert the air are activated manually or by an automatic timer operating in the range of 2 sec. to 20 min.

The system will handle loaded carriers weighing up to 4 oz. Maximum carrier length is 3 in. The system is designed for a minimum transit and irradiation time of 2 sec. Signal lights at each terminal and in the control room indicate the presence of a carrier at a given reactor irradiation station.

THERMAL COLUMN

The thermal column is a 6- by 6- by 8-ft. stack containing 12½ tons of graphite. The thermal column will be used for dry irradiations requiring well-thermalized fluxes over a large volume. Also the thermal column furnishes a source of thermal-neutron beams and a medium in which age, diffusion, and similar "stack" experiments may be perfomed. The graphite can be removed and the space used for dry large-component irradiations.

The graphite is in the form of 4-in.-square stringers of various lengths. These are cross stacked to give a voidless interlocked parallelepiped. Fifteen of the stringers running the length of the stack are removable to permit the insertion of foils and experiments or the extraction of beams.

The shell of the thermal column is 1¼-in. carbon steel lined with ¼-in. boral or ¹⁄₁₆-in. cadmium and with an innermost layer of lead. The boral or cadmium prevents activation of the steel shell by thermal neutrons and the lead reduces the radiation intensity inside the opening due to activation of the steel by fast neutrons. Therefore, the thermal column will be accessible after prolonged operation.

The outside face of the thermal column is covered by a 1-ft.-thick carbon steel and lead door which rolls away to yield free access to the face of the graphite stack. The door is penetrated by eight plugged access openings in line with the removable stringers in the graphite stack. At the reactor end of the column a 4-in. lead curtain attenuates reactor gammas and a stiffened aluminum cover plate seals the end of the column.

REACTOR BUILDING

Because of the high power and the absence of a fenced-off exclusion area around the reactor building, the building is specifically designed as a reasonably gas-tight structure. There are no windows and the walls are all reinforced concrete. The doors and the building dampers are all fitted with special gaskets to provide a tight seal when closed.

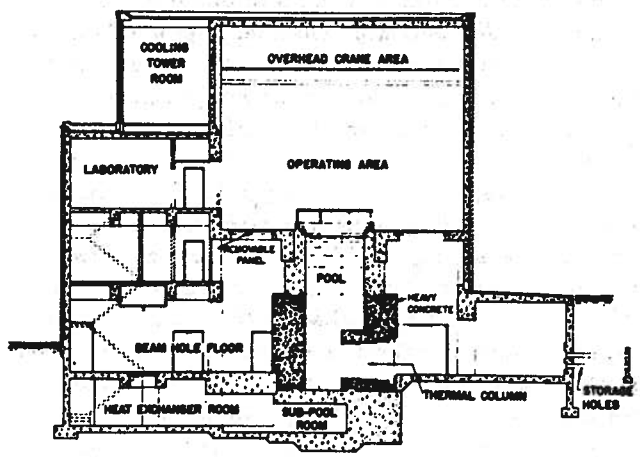

Fig. 3. Cross-sectional view of the reactor building.

Although a part of the Phoenix Memorial Laboratory, the reactor building is a completely separate structure designed around the 26-ft.-high reactor pool. The building is four stories high with the bottom of the pool just below the first floor and the top of the pool just below the third floor. The first floor is wider than the floors above to give a 30-ft. minimum distance between the outside building wall and the outside face of the shield. This was done to give adequate working space at the beam holes.

A partial basement with a ceiling up to 3½ ft. thick provides shielded space for the heat exchangers, the circulating pumps, and the demineralizers. The first floor is devoted entirely to experimental space for work at the beam holes and thermal column. The second floor contains mechanical equipment, offices, and

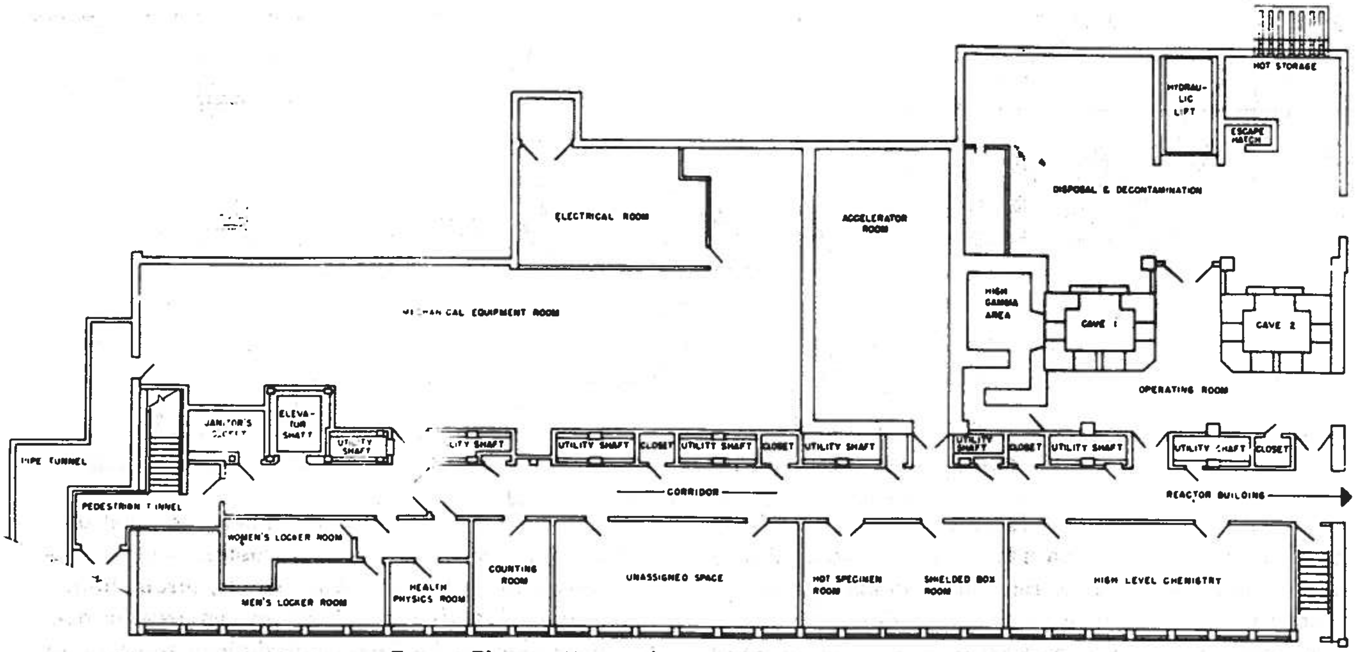

Fig. 4. Phoenix Memorial Laboratory—first-floor plan.

steel doors 14 in. thick and weighing 9 tons each close the back of each cell.

These cells, together with the manipulators, cost $270,000.

Adjacent to the hot cells is a room equipped to irradiate specimens in an intense field of gamma radiation. The source of the gamma rays is an assembly of forty-two reactor-irradiated aluminum-clad cobalt rods. Together the rods contain approximately 4 kcurie. of Co^{60}. Close to the source the dose rate is in excess of 200,000 reps/hr. Safe access to the room is obtained by lowering the source in a 16-ft. well of water. A labyrinth leads into the room to provide the shielding at the entryway when the source is up. A small passage connects the adjacent hot cell and the well. This furnishes the means by which the source may be unloaded from its shipping container and loaded into the well.

On the other side of the hot cells is the reactor pool. One hot cell, directly back of the pool, is provided with a pass through to the pool. Samples up to 4 ft. in length and 12 in. in diameter may be passed through an air lock directly from the pool into the cell. The pool-side inlet to the lock is under 13 ft. of water.

Across from the hot cells are located laboratories where lesser amounts of radioactivity may be handled. These are equipped with all the normal services and in addition special ventilating and drain services for radioactive materials. There are nine hoods, provi-

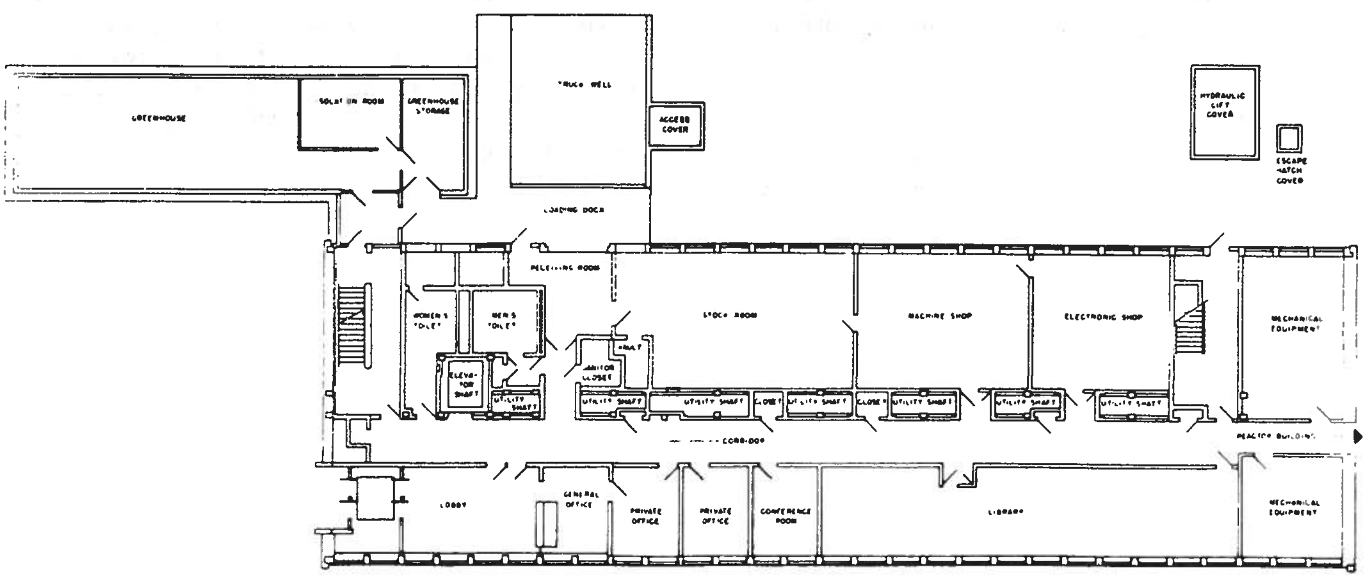

Fig. 5. Phoenix Memorial Laboratory—second-floor plan.

NRL #129
Proposal for NRL Res. Reactor

The "Swimming Pool"
—A Low Cost Research Reactor

Slightly over $200,000 would be needed to construct and house this particularly safe reactor that provides wide flexibility for research. Reactor and its controls cost $61,000 when prototype was built in 1950

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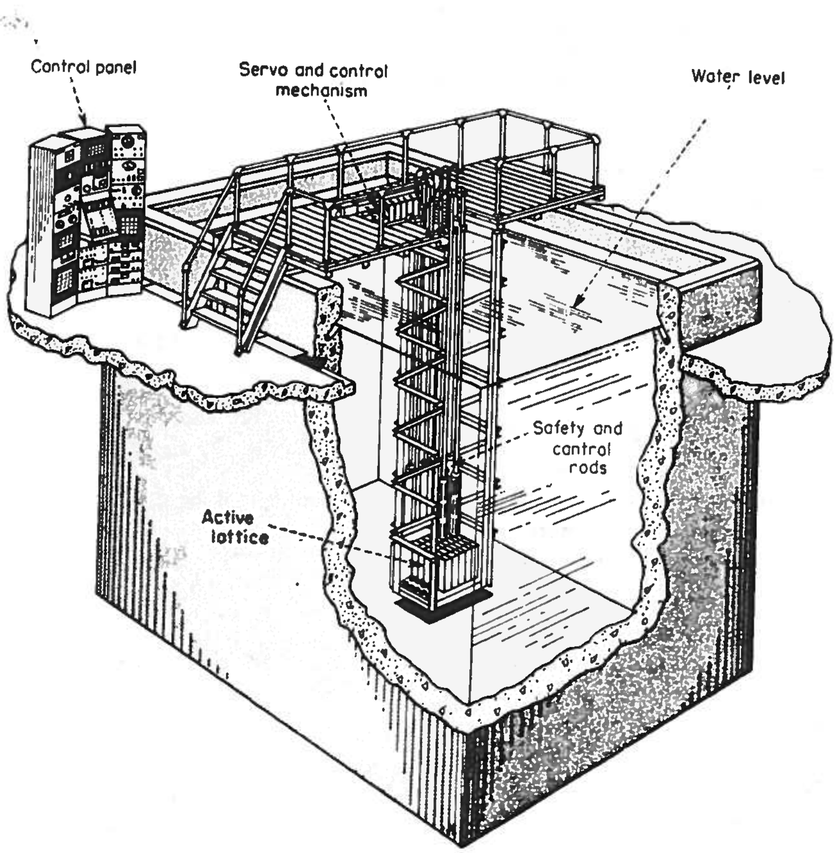

FIG. 1. Three-dimensional view of low cost reactor

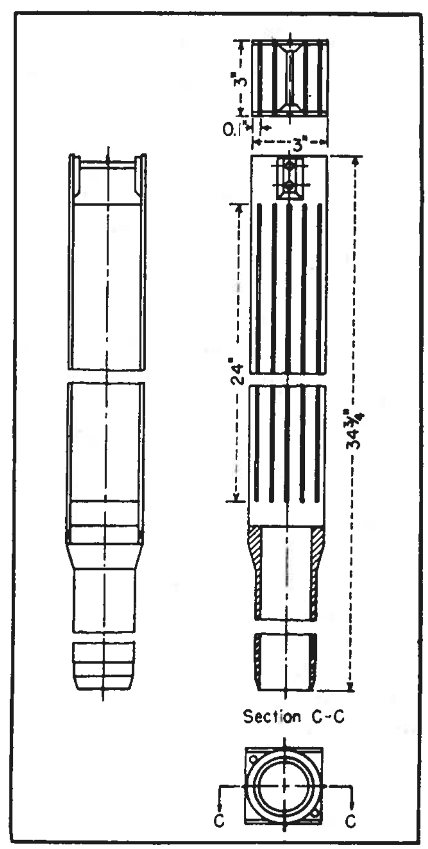

FIG. 2. Fuel element for low cost reactor

USES OF A RESEARCH REACTOR

Beck (*3*) has previously discussed possible research programs for a low-cost research reactor. It seems worthwhile, however, to point out several studies which the "swimming pool" reactor could be used for.

NEUTRON DIFFRACTION. Collimation of the neutron beam is accomplished with an empty pipe leading through the water to the surface. This beam can be used with velocity selectors to obtain monoenergetic neutrons.

ANALYSIS BY RADIOACTIVATION. Ample flux is present for satisfactory bombardment of samples for chemical analysis.

RADIATION DAMAGE. Relatively few systematic studies have been made, and much remains to be done. Biological studies are also possible.

RADIOISOTOPE PRODUCTION. Fairly intense specific activities can be produced. Investigation of short-life beta and gamma activities resulting from slow-neutron bombardment is of considerable interest at present.

TRACER STUDIES. As an aid in tracer studies, materials can be made radioactive. An example is the study of gear wear (*5*).

FISSION PRODUCTS. Exposing a uranium salt to neutron bombardment makes it possible to obtain fission products for studies of their uses. The AEC is vitally interested in this work (*6*).

retain all of the fission products produced during the life of the element.

These fuel elements can be made at ORNL at a cost of about $120 each, (not including enriched uranium). They should be reprocessed after about 10% burn-up, which corresponds to a total reactor energy output of about two-thirds of a megawatt-year.

The AEC possesses facilities for recovering the fuel from the spent elements, and reprocessing should present no problem to the institution owning the reactor. Also, in case of national emergency, the fuel can be restored to regular production channels in a relatively short time.

Active Lattice

Twelve to sixteen of the elements are placed on end in an aluminum grid to form the active lattice of the reactor. A conical end box is welded to the bottom of each fuel element used in the assembly. These end boxes fit into holes in the aluminum grid. Figure 3 shows the bottom grid and a partial assembly of the core, with guides for the control rods in place above the fuel elements and aluminum cans containing ionization chambers in the background.

The grid contains 54 holes, which are more than are required to support fuel sufficient to make the reactor critical. The extra holes can be used to hold dummy elements containing beryllium oxide reflector or specimens to be irradiated, or to vary the loading pattern.

The design of the fuel elements is based on the requirement that the active lattice dissipates some 100 kw by convection cooling, with a reasonable margin of safety. This and nuclear considerations dictate five plates per element and result in an aluminum-to-water ratio of about 0.3. This is the ratio of the volume of aluminum in the fuel elements including side plates to the volume of water enclosed in the active lattice. The amount of fuel required decreases with the aluminum-to-water ratio, although not in direct proportion.

Reflector

A good reflector placed around the active lattice will reduce the fuel required and improve the flux distribution in the core. It also reduces the available neutron flux external to the reactor.

One method of installing the reflector is to provide a number of aluminum cans of the same outline as a fuel element but filled with cold-pressed beryllium oxide bricks. These can be placed on end in the grid around the active lattice. With 3 in. of beryllium oxide on the four sides of the reactor, the critical mass is reduced by about ¾ kg. Figure 4 is a photograph of the reactor completely loaded, including BeO reflector units.

Advantages of Pool

Submerging the reactor in a pool of water provides a number of advantages. Besides cooling and moderating the reactor, the water supplies a foolproof shield for the operating personnel. Furthermore, should this shield (the water) accidently become contaminated, it can be drained and refilled. With 16½ ft of water above the active lattice, gamma rays are attenuated sufficiently so that a person standing next to the pool will receive considerably less than 50 mr in 8 hours.

The neutron flux is attenuated much more rapidly than the gamma flux in the water. A depth of 3½ ft of water between the reactor and the pool floor and walls will keep the concrete from becoming seriously activated. Thus, if the fuel elements and control rods are removed and the pool drained, personnel can work on the reactor structure after a waiting period of a few hours. This is a feature unique to this particular facility.

Aluminum has a half-life of 2.4 minutes, and, since the reactor structure is made of commercially pure aluminum, the radioactivity decays to a safe level in a relatively short time.

Unless care is taken, the life of the fuel elements may be determined by corrosion. At ORNL it has been found that addition of 50 parts per million by weight of sodium chromate to the ordinary process water used in the pool inhibits corrosion. Other water supplies may require different treatment. If a very low background is necessary, demineralized water must be used, unless the work can be completed in a few hours after a fresh refilling of the pool.

Infinite beam hole. The design of most reactors used for experimental

COST OF REACTOR AND CONTROLS

Exact costs as of the summer of 1950 were determined from ORNL records. The costs pertinent to the reactor can be broken down as follows.

Fuel elements: 20 at $120 each, exclusive of cost of enriched uranium	$2,400
Reactor assembly: Labor, overhead and materials (motors, magnets, grid, superstructure, etc.)	28,000
Electronic circuits: Labor, overhead and materials (chambers, circuits, recording instruments, etc.)*	28,000
Servo automatic control	2,600
Total: Reactor and Controls	$61,000
In addition, the following equipment is very desirable:	
BeO reflector (30 elements)	17,000
Spares (chambers and electronic equipment)	9,000
Health physics instruments	7,500
Total	$33,500
Grand Total	$94,500

* This complete equipment is now available commercially at approximately this cost. However, the cost will be greater if switchboard mounting, console operation, etc., are desired.

current to the electromagnets which support the safety rods. An increase in chamber current results in a decrease in magnet current, and the amplifiers can be adjusted to drop the magnets at any predetermined flux level within the range of the chambers. Two complete electronic circuits, two chambers, and two rods are supplied. Each rod is worth 5 to 6% in reactivity, depending on the loading.

Safety

This is really a very safe reactor. It has a slight negative temperature coefficient of approximately 0.0075%/° F. This is small, and while it will serve to stabilize the reactor partially, it will take care of less than ½% in reactivity. Safety comes from the fact, which has been demonstrated experimentally, that if the power level rises to more than a few hundred kw, the reactor will boil, and steam will displace sufficient moderator to inhibit runaway. Thus it is not possible to operate the reactor at too high a power level.

Costs

A summary of the costs of this reactor, taken from ORNL records, is tabulated above. The cost of the building and pool will depend on the design, materials, difficulty of excavating, etc. One interesting design involves the location of the facility on the side of a hill. In this way, horizontal beam holes from the reactor can be installed on one side, while the hill forms the shielding on the other three sides of the pool.

Our estimate, based on the cost of a similar structure here, for a pool 14 ft by 18 ft by 22 ft deep, a bay 28 ft by 30 ft high containing the pool and reactor, and 2,500 ft² of laboratory space is $125,000. This makes the bare minimum cost of the reactor, pool, and building a little over $200,000. To these costs must be added the expenses of additional facilities for whatever experimental program is desired.

Higher Power Operation

This reactor can be modified to operate at somewhat higher power levels, but costs will be greater. Among other things, additional shielding and forced-circulation cooling must be supplied.

The bottom of the reactor can be boxed-in and water drawn through the fuel elements by an external pump. Flow through the fuel elements with a Reynolds number sufficient to insure turbulent flow (about 5,000) will provide cooling for 750 kw, with a 15° F rise in the coolant. There is no point in having a much smaller flow than this since laminar conditions will prevail, with a resulting sharp decrease in the heat removal and possible local boiling.

At these high powers and forced circulations, the pump and the line must be shielded because of activity in the water. Radioactive nitrogen, with a half-life of 7 seconds, is formed by the reaction $O^{16}(n,p)N^{16}$. In addition, there is the activity of minerals dissolved in the water. If the pool walls are given a nonsoluble coating and the pool filled with demineralized water, then a flow of cooling water through the reactor of 400 gal/min (possibly with a purge of perhaps 30 gal/min) should afford satisfactory operation at 750 kw. This problem does not arise in the case of convection cooling at lower power because activation is less and the water does not diffuse to the surface rapidly enough.

We do not recommend that this design be operated at power levels of more than a megawatt.

NOTE ADDED IN PROOF: The writer has just learned that the General Electric Co. has been operating a thermal, heterogeneous, oil or water cooled, graphite-moderated research reactor for the past year at power levels up to 100 watts. They consider this model suitable for use in industry, research organizations, and universities for nuclear investigations using thermal neutrons.

* * *

A large number of people from the ORNL staff contributed to the design and construction of the present facility upon which this design is based. The original design was investigated by E. P. Wigner, A. M. Weinberg, M. C. Leverett, H. Soodak, E. Greuling, and others. Critical experiments to confirm the design were carried out by M. M. Mann. The control and safety circuits were proposed by H. W. Newson and P. R. Bell, and designed and built by W. H. Jordan, T. E. Cole, J. E. Owens, E. P. Epler, and others. The design upon which this report is largely based was developed by W. R. Gall, who was aided by operational investigations made by S. E. Beall. ORNL is operated for AEC by Union Carbide and Carbon Corp.

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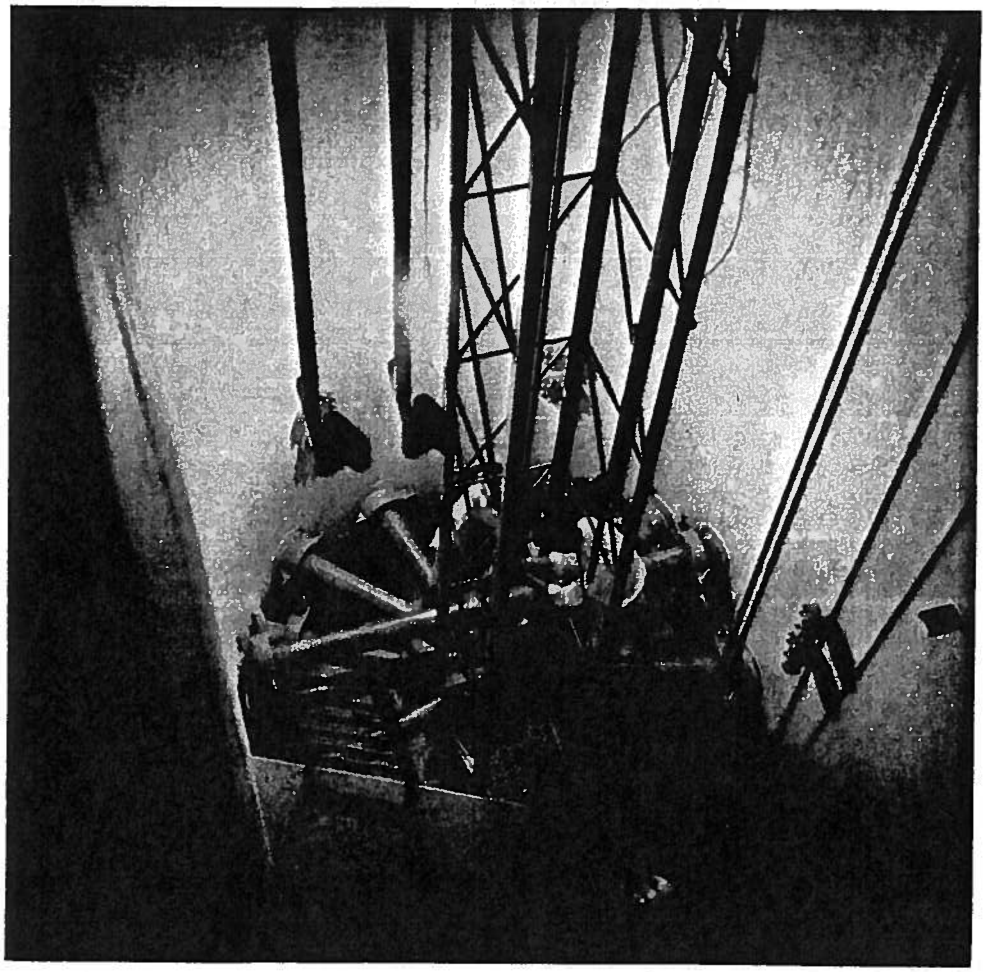
THE FORD NUCLEAR REACTOR



OF THE MICHIGAN MEMORIAL PHOENIX PROJECT

THE UNIVERSITY OF MICHIGAN FORD NUCLEAR REACTOR

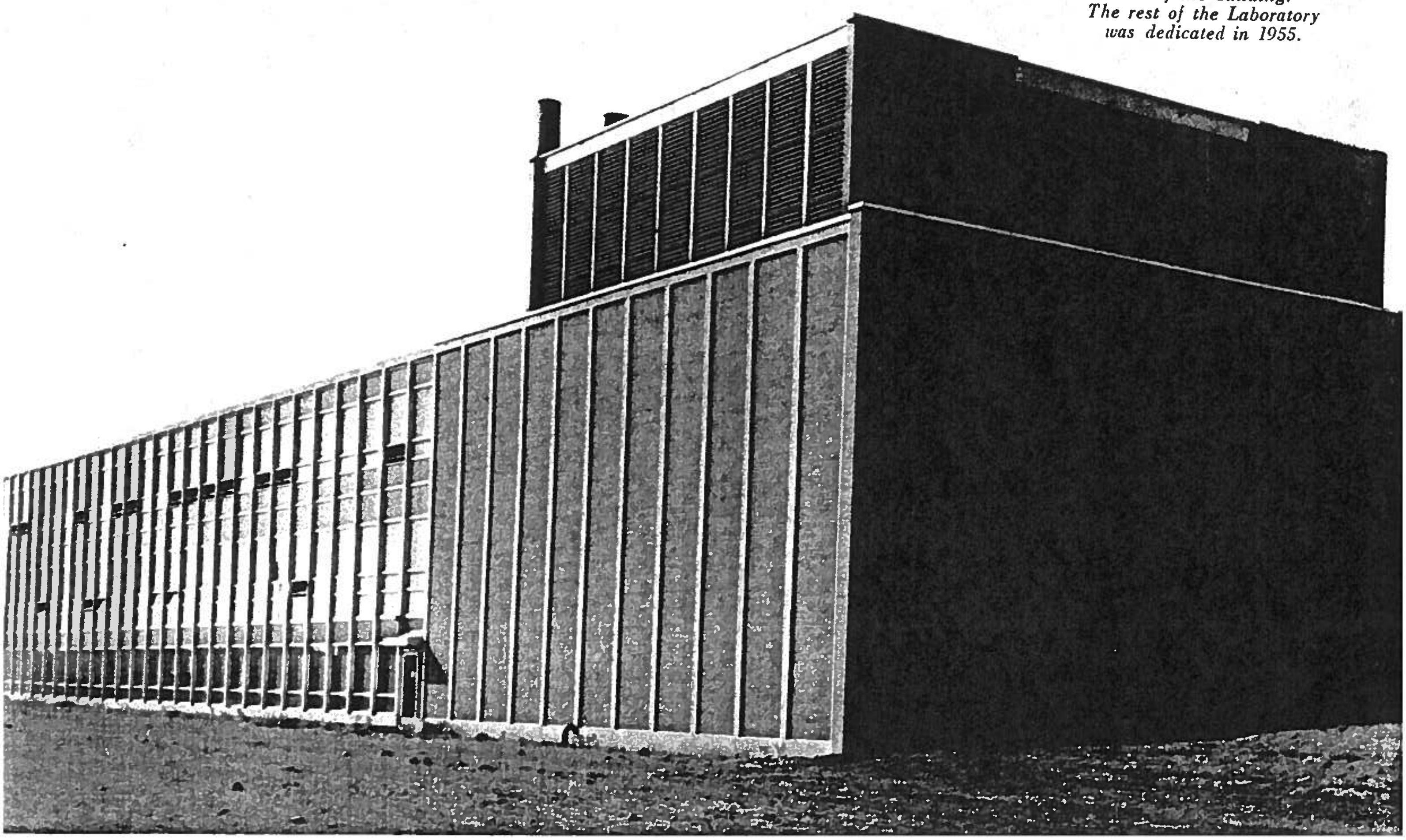
November 16, 1956

"Dedicated to the study of the peacetime implications and applications of atomic energy"

Early in 1955 ground was broken by Jeffress-Dyer Inc. for the 3-story building which houses the reactor. The reactor proper was built by the Atomic Energy Division of the Babcock & Wilcox Co., and installed after the central tank was in place. Leeds & Northrup Co. then installed the control equipment needed for operating the reactor. This 2-year building program brought to a close the planning of years on the part of faculty members and experts in nuclear facility design and construction.

The reactor will serve as a part of the physical plant of the Michigan Memorial-Phoenix Project—a $7,600,000 project dedicated to the memory of the University dead of World War II for research in the peaceful uses of atomic energy. The reactor represents an expenditure of $1,000,000 of this total, and was made possible by a gift of the Ford Motor Co. Fund. The reactor fuel is provided without charge by the United States Atomic Energy Commission under the Atomic Energy Act of 1954.

The Ford Nuclear Reactor completes the Michigan Memorial-Phoenix Laboratory. The Reactor is housed in the block-like structure at the end of the building. The rest of the Laboratory was dedicated in 1955.



THE PROGRAM

9:00 to 12:00

Registration—Lobby, Rackham Building

10:00 to 12:00

Morning Technical Session

Lecture Hall, Rackham Building

presiding: HENRY J. GOMBERG

Phoenix Research Highlights

In the Field of Bacteriology . . . . . LLOYD L. KEMPE

In the Field of Physics . . . . . DONALD A. GLASER

In the Field of Law . . . . . SAMUEL D. ESTEP

In the Field of Medicine . . . . . PAUL H. DEVRIES

12:30 to 2:15

Luncheon, Michigan League Ballroom

presiding: . . . . . . HARVEY M. MERKER

speaker: . . . . WALTER H. ZINN

3:30 to 4:30

Dedication of the Ford Nuclear Reactor at the Reactor

presiding: . . . . RALPH A. SAWYER

remarks: . . . . W. KENNETH DAVIS

remarks: . . . . ALFRED B. IDDLES

address and presentation: . ERNEST R. BREECH

acceptance: . . . . . HARLAN HATCHER

DIRECTORY

ERNEST R. BREECH
Chairman of the Board, Ford Motor Co.

W. KENNETH DAVIS
Director, Division of Reactor Development, United States Atomic Energy Commission

PAUL H. DEVRIES
Senior Clinical Instructor in Surgery, University of Michigan

SAMUEL D. ESTEP
Professor of Law; Director of Legislative Research Center, University of Michigan

DONALD A. GLASER
Associate Professor of Physics, University of Michigan

HENRY J. GOMBERG
Professor of Nuclear and Electrical Engineering; Assistant Director, Phoenix Project, University of Michigan

HARLAN HATCHER
President, University of Michigan

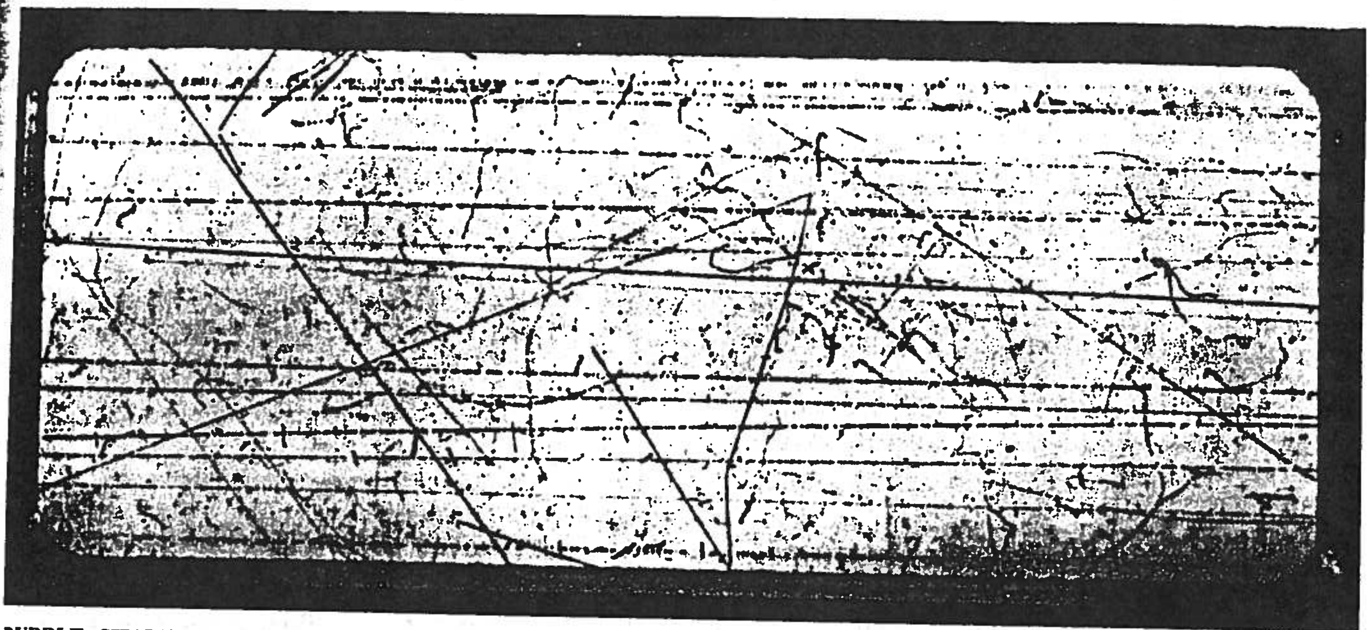
ALFRED B. IDDLES
President, Babcock and Wilcox Company; President Atomic Industrial Forum

LLOYD L. KEMPE
Associate Professor of Chemical & Metallurgical Engineering; Associate Professor of Bacteriology, University of Michigan

HARVEY M. MERKER
Chairman, Phoenix Alumni Advisory Committee

RALPH A. SAWYER
Dean, Horace H. Rackham School of Graduate Studies; Director, Phoenix Project, University of Michigan

WALTER H. ZINN
President, General Nuclear Engineering Corporation



BUBBLE CHAMBER enables physicists to study tracks of bubbles left by atomic particles shot from atom smashers.

A Nobel Prize For Michigan Research

THE Pretzel Bell tavern, six blocks from the University campus, has become something of a latterday landmark to numberless students who have attended Michigan since 1934.

Over its stained tables, students have held many an earnest conversation and enjoyed good fellowship in a relaxed atmosphere.

Few persons would attempt to study amid the noise and bustle of the Bell. And few places could be more implausible as the birthplace of a breathtaking scientific concept.

Yet, one of the world's most prestigious honors — the Nobel Prize for physics — was awarded last month to a man whose big idea came as a sudden flash of genius while he was relaxing with friends in the Bell nine years ago.

The man was Donald A. Glaser, then a 25-year-old University instructor armed with a spanking-new Ph.D. earned the year before at Caltech. His idea, inspired by watching bubbles rise in a glass of beer, led to development of a "bubble chamber" that today enables nuclear physicists to view the arcane world of subatomic particles.

"I had been looking for something better than the Wilson cloud chamber to track high-energy particles," he recalls. "It occurred to me that bubbles in a liquid might perform like water droplets in a cloud chamber."

The next day Glaser started to work on his concept. He bombarded a glass of beer with high-energy particles "just to see what would happen." Nothing did, but Glaser didn't stop there.

For years, physicists had been tracking movements of high-energy particles through the trails of water droplets they left behind in the supersaturated atmosphere of a Wilson cloud chamber. However, in the comparatively wide-open spaces of the gas in the chamber, head-on collisions between particles and nuclei were too rare. The constant compression and decompression needed to produce a supersaturated atmosphere caused eddy currents that distorted the tiny vapor trails left by the particles. And when collisions and disintegrations did occur in the chamber, the resulting fragments disappeared from the chamber before observers could see what happened when they decayed.

Glaser's concept solved all three problems. He knew that a pure liquid in a clean, smooth-sided vessel could be heated above its usual boiling point without disturbing its equilibrium. He also knew that even a small particle introduced into the superheated liquid could make it boil violently.

Glaser constructed a thimble-sized Pyrex chamber filled with ordinary medicinal ether. He heated it under several atmospheres of pressure until the ether was above its normal boiling point, then suddenly released the pressure. The ether remained in its superheated state for as long as three minutes without boiling. Then he brought a cobalt 60 source near the superheated ether. As the invisible high-energy particles showered down, the ether erupted.

Next, Glaser placed the cobalt source 30 feet away and shielded it with lead before superheating