The First Pile

Workers assembling CP-1 (Photo: Argonne National Laboratory)

BY CORBIN ALLARDICE AND EDWARD R. TRAPNELL

Fermi closed his slide rule—"The reaction is self-sustaining," he announced quietly, happily. "The curve is exponential."

ON DECEMBER 2, 1942, man first initiated a self-sustaining nuclear chain reaction, and controlled it.

Beneath the West Stands of Stagg Field—the University of Chicago's athletic stadium, in Chicago—late in the afternoon of that day, a small group of scientists witnessed the advent of a new era in science. History was made in what had been a squash-rackets court.

Precisely at 3:25 p.m. [3:36 is now the accepted official time], Chicago time, scientist George L. Weil withdrew the cadmium-plated control rod, and by his action, man unleashed and controlled the energy of the atom.

As those who witnessed the experiment became aware of what had happened, smiles spread over their faces and a quiet ripple of applause could be heard. It was a tribute to Enrico Fermi, Nobel Prize winner, to whom, more than to any other person, the success of the experiment was due.

Fermi, born in Rome, Italy, on September 29, 1901, had been working with uranium for many years. In 1934 he bombarded uranium with neutrons and produced what appeared to be element 93 (uranium is element 92) and element 94. However, after closer examination, it seemed as if nature had gone wild; several other elements were present, but none could be fitted into the periodic table near uranium— where Fermi knew they should have fitted if they had been the transuranic elements 93 and 94. It was not until five years later that anyone, Fermi included, realized he had actually caused fission of the uranium and that these unexplained elements belonged back in the middle part of the periodic table.

Fermi was awarded the Nobel Prize in 1938 for his work on transuranic elements. He and his family went to Sweden to receive the prize. The Italian Fascist press severely criticized him for not wearing a Fascist uniform and failing to give the Fascist salute when he received the award. The Fermis never returned to Italy.

From Sweden, having taken most of his personal possessions with him, Fermi proceeded to London and thence to America, where he has remained ever since [Fermi died in 1954—*Ed.*].

The modern Italian explorer of the unknown was in Chicago that cold December day in 1942. An outsider looking into the squash court where Fermi was working would have been greeted by a strange sight. In the center of the 30- by 60-ft room, shroud-

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This article is an edited and adapted version of the original essay, "The First Pile," written in fall 1946 because nowhere in the extensive records of the Manhattan Project was there a narrative history of the first self-sustaining nuclear chain reaction. Prepared for a press release by the Manhattan Engineer District, the report included background material that was part of the final report on a significant experiment.

The original authors of "The First Pile" were Corbin Allardice and Edward R. Trapnell, two public information officers for the Atomic Energy Commission, the agency that succeeded the Manhattan Project on January 1, 1947. Allardice later served in various public information posts for the Atomic Energy Commission and Trapnell became Special Assistant to the AEC General Manager, with responsibilities for congressional relations. Trapnell and Allardice felt that the story of the experiment that was successfully completed on December 2, 1942, was of such significance that it should be written down while still relatively fresh in the minds of those who took part. Their essay is based on postwar interviews with more than a dozen of the 50 scientists present at the Stagg Field on that December 2nd. Another valuable source was the tape on which was traced the neutron intensity within the first pile.

The fourth anniversary reunion of the CP-1 scientists on the steps of Eckhart Hall at the University of Chicago, on December 2, 1946. Back row (left to right): Norman Hilberry, Samuel Allison, Thomas Brill, Robert Nobles, Warren Nyer, and Marvin Wilkening. Middle row: Harold Agnew, William Sturm, Harold Lichtenberger, Leona W. Marshall, and Leo Szilard. Front row: Enrico Fermi, Walter Zinn, Albert Wattenberg, and Herbert Anderson. (Photo: ANL)

ed on all but one side by a gray balloon cloth envelope, was a pile of black bricks and wooden timbers, square at the bottom and a flattened sphere on top. Up to half of its height, its sides were straight. The top half was domed, like a beehive. During the construction of this crude appearing but complex pile (the name that was applied to all such devices for the first few years of the atomic age, but which gradually gave way to "reactor") the standing joke among the scientists working on it was: "If people could see what we're doing with a million-and-a-half of their dollars, they'd think we are crazy. If they knew why we are doing it, they'd know we are."

In relation to the fabulous atomic bomb program, of which the Chicago Pile experiment was a key part, the successful result reported on December 2nd formed one more piece for the jigsaw puzzle that was atomic energy. Confirmation of the chain reactor studies was an inspiration to the leaders of the bomb project, and reassuring at the same time, because the Army's Manhattan Engineer District had moved ahead on many fronts. Contract negotiations were under way to build production-scale nuclear chain reactors, land had been acquired at Oak Ridge, Tenn., and millions of dollars had been obligated.

Three years before the December 2nd experiment, it had been discovered that when an atom of uranium was bombarded by neutrons, the uranium atom sometimes was split, or fissioned. Later, it had been found that when an atom of uranium fissioned, additional neutrons were emitted and became available for further reaction with other uranium atoms. These facts implied the possibility of a chain reaction. . . . The facts further indicated that if a sufficient quantity of uranium could be brought together under the proper conditions, a self-sustaining chain reaction would result. This quantity of uranium necessary for a chain reaction under given conditions is known as the critical mass, or more commonly, the "critical size" of the particular pile.

For three years, the problem of a self-sustaining chain reaction had been assiduously studied. Nearly a year after Pearl Harbor, a pile of critical size was finally constructed. It worked. A self-sustaining nuclear chain reaction was a reality.

Construction of the pile

Construction of the main pile at Chicago started in November. The project gained momentum, with machining of the graphite blocks, pressing of the uranium oxide pellets, and the design of instruments. Fermi's two "construction" crews, one under Walter H. Zinn and the other under Herbert L. Anderson, worked almost around the clock. Volney C. (Bill) Wilson headed up the instrument work.

Original estimates as to the critical size of the pile were pessimistic. As a further precaution, it was decided to enclose the pile in a balloon-cloth bag that could be evacuated to remove the neutron-capturing air.

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This balloon cloth bag was constructed by Goodyear Tire and Rubber Company. Specialists in designing gasbags for lighter-than-air craft, the company's engineers were a bit puzzled about the aerodynamics of a square balloon. Security regulations forbade informing Goodyear of the purpose of the envelope, and so the Army's new square balloon was the butt of much joking.

The bag was hung with one side left open; in the center of the floor a circular layer of graphic bricks was placed. This and each succeeding layer of the pile was braced by a wooden frame. Alternate layers contained the uranium. By this layer-on-layer construction a roughly spherical pile of uranium and graphite was formed.

Facilities for the machining of graphite bricks were installed in the West Stands. Week after week this shop turned out graphite bricks. This work was done under the direction of Zinn's group, by skilled mechanics led by millwright August C. Knuth. In October, Anderson and his associates joined Zinn's men.

Describing this phase of the work, Albert Wattenberg, one of Zinn's group, said: "We found out how coal miners feel. After eight hours of machining graphite, we looked as if we were made up for a minstrel. One shower would remove only the surface graphite dust. About a half-hour after the first shower the dust in the pores of your skin would start oozing. Walking around the room where we cut graphite was like walking on a dance floor. Graphite is a dry lubricant, you know, and the cement floor covered with graphite dust was slippery."

Before the structure was half complete, measurements indicated that the critical size at which the pile would become self-sustaining was somewhat less than had been anticipated in the design.

Photo of CP-1 during construction, before layer 19 was complete. Pure graphite layers like 19 alternated with layers of uranium dioxide "pseudospheres" embedded in graphite, such as can be seen on the exposed edges of layer 18. Parts of the wooden scaffolding and surrounding balloon cloth also are visible. (Photo: ANL)

Computations forecast success

Day after day the pile grew toward its final shape. And as the size of the pile increased, so did the nervous tension of the men working on it. Logically and scientifically they knew this pile would become self-sustaining. It had to. All the measurements indicated that it would. But still the demonstration had to be made. As the eagerly awaited moment drew nearer, the scientists gave greater and greater attention to details, the accuracy of measurements, and exactness of their construction work.

Guiding the entire pile construction and design was the nimble-brained Fermi, whose associates described him as "completely self-confident but wholly without conceit."

So exact were Fermi's calculations, based on the measurements taken from the partially finished pile, that days before its completion and demonstration on December 2nd, he was able to predict almost to the exact brick the point at which the reactor would become self-sustaining.

But with all their care and confidence, few in the group knew the extent of the heavy bets being placed on their success. In Washington, the Manhattan District had proceeded with negotiations with E. I. duPont de Nemours and Company to design, build, and operate a plant based on the principles of the then unproved Chicago pile. The $350 000 000 Hanford Engineer Works at Pasco, Wash., was to be the result.

At Chicago during the early afternoon of December 1st, tests indicated that critical size was rapidly being approached. At 4:00 p.m., Zinn's group was relieved by the men working under Anderson. Shortly afterwards, the last layer of graphite and uranium bricks was placed on the pile. Zinn, who remained, and Anderson made several measurements of the activity within the pile. They were certain that when the control rods were withdrawn, the pile would become self-sustaining. Both had agreed, however, that should measurements indicate the reaction would become self-sustaining when the rods were withdrawn, they would not start the pile operating until Fermi and the rest of the group could be present. Consequently, the control rods were locked and further work was postponed until the following day.

That night the word was passed to the men who had worked on the pile that the trial run was due the next morning.

Assembly for the test

About 8:30 on the morning of Wednesday, December 2nd, the group began to assemble in the squash court.

At the north end of the squash court was a balcony about 10 feet above the floor of the court. Fermi, Zinn, Anderson, and Arthur H. Compton were grouped around instruments at the east end of the balcony. The remainder of the observers crowded the little balcony. Robert G. Nobles, one of the young scientists who worked on the pile, put it this way: "The control cabinet was surrounded by the 'big wheels'; the 'little wheels' had to stand back."

On the floor of the squash court, just beneath the balcony, stood George L. Weil, whose duty it was to handle the final control rods. In the pile were three sets of control rods. One set was automatic and could be controlled from the balcony. Another was an emergency safety rod. Attached to one end of this rod was a rope running through the pile and weighted heavily on the opposite end. The rod was withdrawn from the pile and tied by another rope to the balcony. Norman Hilberry was ready to cut this rope with an axe should something unexpected happen, or in case the automatic safety rods failed. The third rod, operated by Weil, was the one that actually held the reaction in check until withdrawn the proper distance.

Since this demonstration was new and different from anything ever done before, complete reliance was not placed on mechanically operated control rods. Therefore, a "liquid-control squad"—composed of Harold V. Lichtenberger, Warren E. Nyer, and Alvin C. Graves—stood on a platform above the pile. They were prepared to flood the pile with cadmium-salt solution in case of mechanical failure of the control rods.

Each group rehearsed its part of the experiment.

At 9:45 Fermi ordered the electrically operated control rods withdrawn. The man at the controls threw the switch to withdraw them. A small motor whined. All eyes watched the lights which indicated the rod's position.

But quickly, the balcony group turned to watch the counters, whose clicking stepped up after the rods were out. The indicators of these counters resembled the face of a clock, with "hands" to indicate neutron count. Nearby was a recorder, whose quivering pen traced the neutron activity within the pile.

Shortly after ten o'clock, Fermi ordered the emergency rod, called "Zip," pulled out and tied.

"Zip out," said Fermi. Zinn withdrew "Zip" by hand and tied it to the balcony rail. Weil stood ready by the "vernier" control rod which was marked to show the number of feet and inches that remained within the pile.

At 10:37 Fermi, without taking his eyes off the instruments, said quietly: "Pull it to 13 feet, George." The counters clicked faster. The graph pen moved up. All the instruments were studied, and computations were made.

"This is not it," said Fermi. "The trace will go to this point and level off." He indicated a spot on the graph. In a few minutes the pen came to the indicated point and did not go above that point. Seven minutes later Fermi ordered the rod out another foot.

Again the counters stepped up their clicking, the graph pen edged upwards. But the clicking was irregular. Soon it leveled off, as did the thin line of the pen. The pile was not self-sustaining—yet.

At eleven o'clock, the rod came out another six inches; the result was the same: an increase in rate, followed by the leveling off.

Fifteen minutes later, the rod was further withdrawn and at 11:25 was moved again. Each time the counters speeded up, the pen climbed a few points. Fermi predicted correctly every movement of the indicators. He knew the time was near. He wanted to check everything again. The automatic control rod was reinserted without waiting for its automatic feature to operate. The graph line took a drop, the counters slowed abruptly.

At 11:35, the automatic safety rod was withdrawn and set. The control rod was adjusted and "Zip" was withdrawn. Up went the counters, clicking, clicking, faster and faster. It was the clickety-click of a fast train over the rails. The graph pen started to climb. Tensely, the little group watched, and waited, entranced by the climbing needle.

Whrrrump! As if by a thunder clap, the spell was broken. Every man froze—then breathed a sigh of relief when he realized the automatic rod had slammed home. The safety point at which the rod operated automatically had been set too low.

"I'm hungry," said Fermi. "Let's go to lunch."

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Time out for lunch

Perhaps, like a great coach, Fermi knew when his men needed a "break."

It was a strange "between halves" respite. They got no pep talk. They talked about everything else but the "game." The redoubtable Fermi, who never says much, had even less to say. But he appeared supremely confident. His "team" was back on the squash court at 2:00 p.m. Twenty minutes later, the automatic rod was reset and Weil stood ready at the control rod.

"All right, George," called Fermi, and Weil moved the rod to a predetermined point. The spectators resumed their watching and waiting, watching the counters spin, watching the graph, waiting for the settling down and computing the rate of rise of reaction from the indicators.

At 2:50 the control rod came out another foot. The counters nearly jammed, the pen headed off the graph paper. But this was not it. Counting ratios and the graph scale had to be changed.

"Move it six inches," said Fermi at 3:20. Again the change—but again the leveling off. Five minutes later, Fermi called: "Pull it out another foot."

Weil withdrew the rod.

"This is going to do it," Fermi said to Compton, standing at his side. "Now it will become self-sustaining. The trace will climb and continue to climb. It will not level off."

Fermi computed the rate of rise of the neutron counts over a minute period. He silently, grim-faced, ran through some calculations on his slide rule.

In about a minute he again computed the rate of rise. If the rate was constant and remained so, he would know the reaction was self-sustaining. His fingers operated the slide rule with lightning speed. Characteristically, he turned the rule over and jotted down some figures on its ivory back.

Three minutes later he again computed the rate of rise in neutron count. The group on the balcony had by now crowded in to get an eye on the instruments, those behind craning their necks to be sure they would know the very instant history was made. In the background could be heard Wilcox P. Overbeck calling out the neutron count over an annunciator system. Leona W. Marshall (the only woman present), Anderson, and William J. Sturm were recording the readings from the instruments. By this time the click of the counters was too fast for the human ear. The clickety-click was now a steady brrrr. Fermi, unmoved, unruffled, continued his computations.

The curve is exponential

"I couldn't see the instruments," said Weil. "I had to watch Fermi every second, waiting for orders. His face was motionless. His eyes darted from one dial to another. His expression was so calm it was hard. But suddenly, his whole face broke into a broad smile."

Fermi closed his slide rule—"The reaction is self-sustaining," he announced quietly, happily. "The curve is exponential."

The group tensely watched for 28 minutes while the world's first nuclear chain reactor operated.

The upward movement of the pen was leaving a straight line. There was no change to indicate a leveling off. This was it.

"O.K., 'Zip' in," called Fermi to Zinn who controlled that rod. The time was 3:53 p.m. Abruptly, the counters slowed down, the pen slid down across the paper. It was all over.

Man had initiated a self-sustaining nuclear reaction—and then stopped it. He had released the energy of the atom's nucleus and controlled that energy.

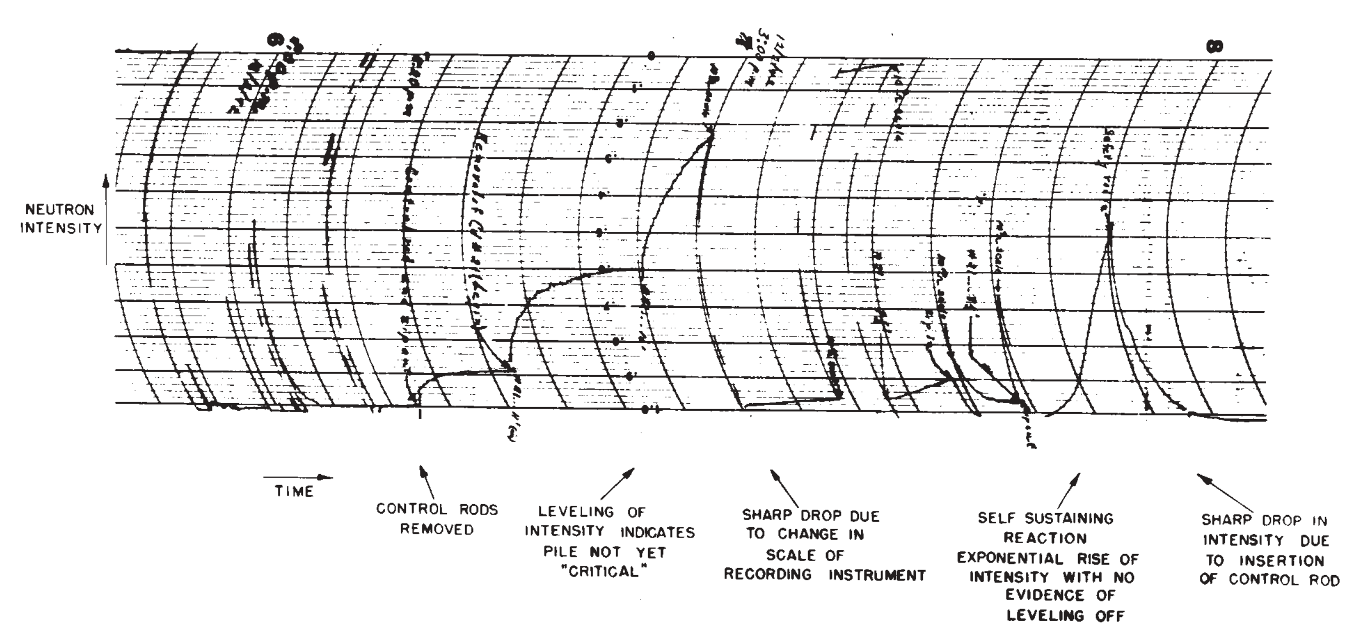
Right after Fermi ordered the reaction stopped, the Hungarian-born theoretical physicist Eugene P. Wigner presented him with a bottle of Chianti wine. All through the experiment Wigner had kept this wine hidden behind his back.

Fermi uncorked the wine bottle and sent out for paper cups so all could drink. He poured a little wine in all the cups, and silently, solemnly, without toasts, the sci-

The 50 CP-1 Pioneers: A List of Those Present at the Chicago Pile 1 Experiment, on December 2, 1942*

- Harold M. Agnew (retired, living in California)
- Samuel K. Allison (died in 1965)
- Herbert L. Anderson (died in 1988)
- Wayne Arnold (deceased)
- Hugh M. Barton (living in Oklahoma)
- Thomas Brill (died in 1998)
- Robert F. Christy (on faculty of the California Institute of Technology)
- Arthur H. Compton (died in 1962)
- Enrico Fermi (died in 1954)
- Richard J. Fox (died in 1996)
- Stewart Fox (living in the Bahamas)
- Carl C. Gamertsfelder (died in 2000)
- Alvin C. Graves (died in 1965)
- Crawford H. Greenewalt (died in 1993)
- Norman Hilberry (died in 1986)
- David L. Hill (living in Connecticut)
- William H. Hinch (living in Colorado)
- Robert E. Johnson (living in Illinois)
- W. R. Kanne (died in 1985)
- August C. Knuth (living in Illinois)
- P. G. Koontz (died in 1991)
- Herbert E. Kubitschek (deceased)
- Harold V. Lichtenberger (died in 1993)
- George M. Maronde (died in 1966)
- Leona Woods Marshall (died in 1986)
- Anthony J. Matz
- George Miller
- George D. Monk
- Henry Newson (died in 1978)
- Robert G. Nobles (retired from ANL; living in Idaho)
- Warren E. Nyer (living in Idaho)
- Wilcox P. Overbeck (died in 1981)
- Howard Parsons (living apparently in California, as of 2000)
- G. S. Pawlicki (living in Illinois)
- Theodore Petry (living in Illinois)
- David Rudolph (living in West Virginia)
- Leon Sayvetz (living in Washington state and New York)
- Leo Seren (died in 2002)
- Louis Slotin (died in 1946)
- Frank H. Spedding (died in 1984)
- William J. Sturm (died in 1999)
- Leo Szilard (died in 1964)
- Albert Wattenberg (living in Illinois)
- Richard J. Watts (living in New Mexico)
- George L. Weil (died in 1995)
- Eugene P. Wigner (died in 1995)
- Marvin Wilkening (living in New Mexico)
- Volney C. (Bill) Wilson (living in Colorado)
- E. O. Wollan (died in 1984)
- Walter H. Zinn (ANL's first director; died in 2000)

*The current status of each individual, if known, is indicated in parentheses following the name; last updated on July 23, 2002. According to Argonne National Laboratory's Office of Public Affairs, "To the best of our knowledge, no CP-1 pioneer has yet died of leukemia," which is "the type of cancer typically associated with [the] type of external radiation exposure" related to the CP-1 experiment on December 2, 1942. (Source: ANL—adapted, revised, and edited)



Neutron intensity during startup of the first self-sustaining chain reaction, on December 2, 1942, as recorded by a galvanometer (Source: ANL)

entists raised the cups to their lips—the Canadian Zinn, the Hungarians Leo Szilard and Wigner, the Italian Fermi, the Americans Compton, Anderson, Hilberry, and a score of others. They drank to success—and to the hope they were the first to succeed.

A small crew was left to straighten up, lock controls, and check all apparatus. As the group filed from the West Stands, one of the guards asked Zinn:

"What's going on, Doctor, something happen in there?"

The guard did not hear the message Arthur Compton was giving James B. Conant at Harvard, by long-distance telephone. Their code was not prearranged.

"The Italian navigator has landed in the New World," said Compton. "How were the natives?" asked Conant. "Very friendly."

Epilogue

The 1942 CP-1 chain reaction experiment marked the culmination of a process of European scientific discovery and American technical development in nuclear physics research that dated back to 1934, when Enrico Fermi split the atom without realizing it.

In this sense, the final success of the Metallurgical Laboratory was almost anticlimactic. The legendary bottle of Chianti produced by Eugene Wigner and signed by all the participants was actually purchased a year before the successful experiment was completed.

Nor was the success of CP-1 especially decisive in pushing the Manhattan Project forward. A visiting committee of scientists and engineers had already recommended continuing the pile project before they arrived in Chicago on December 2, and a day earlier, Gen. Leslie Groves, director of the Army project, had written the du Pont Company a letter authorizing design and construction of the massive Hanford, Wash., plant to produce plutonium, using the pile project as a prototype.

In this context, the famous telephone call from Compton to Conant takes on a different meaning. Conant, an enthusiast of Ernest Lawrence's project to separate electromagnetically U-235 from U-238 as the quickest route to the bomb, remained skeptical of the pile approach, and criticized the visiting Lewis committee report for pushing the pile project toward a full-scale plant. In telephoning Conant, Compton was not only conveying a secret message, but advocating a particular route to the new weapon.

On December 28, 1942, President Roosevelt approved the report from Vannevar Bush, of the Office of Scientific Research and Development, calling for an all-out effort to build an atomic bomb with private industry working under Army supervision. In this crucial decision, CP-1 had played an important part, for it had transformed scientific theory into technological reality, and demonstrated that an awesome new form of energy had been harnessed to man's purposes.

In early 1943, following the success of CP-1, work on the production piles shifted to new plants springing up at Oak Ridge, Tenn., and Hanford, Wash. The scientists of Chicago gave way to the engineers of du Pont, and the major work of the Manhattan Project moved away from that city.

In February 1943, Groves ordered Fermi's pile moved from Stagg Field to Site A, a 20-acre area of the Argonne Forest Preserve south of Chicago, where it was reassembled as CP-2. CP-2 was considerably larger than CP-1, and had a 5-foot concrete shield built around it to avoid radiation exposure to staff.

CP-2 was followed in 1943 by CP-3, a heavy-water reactor designed by Eugene Wigner and built by Walter Zinn.

In 1944, the modest collection of cinderblock and corrugated iron buildings at Argonne became the Argonne Laboratory, directed by Fermi. Its function now became basic research on nuclear fission, rather than weapons development, with consequent shortages of both funding and personnel until after 1945.

In January 1947, the Atomic Energy Commission purchased a new site near Lemont, Ill., southwest of Chicago, for the Argonne National Laboratory. At the new laboratory, the wartime reactors became peacetime centers of research into neutron diffraction, the effects of radiation, and applied mathematics. The pile of graphite and uranium known as CP-1 thus spawned a full-scale nuclear research laboratory. Its work no longer was used to study plutonium production, but the broader ramifications of nuclear fission—biological and medical research, basic physics, reactor analysis, and nuclear power.

In the end, the various offspring of CP-1, the first reactor, continued its original mission: to push back and explore the frontiers of science in the never-ending quest for knowledge of the universe in which we live. NN

This is an edited and adapted reprint of the Epilogue from the December 1982 pamphlet, "The First Reactor" (DOE/NE—0046), published by the Department of Energy to commemorate the 40th anniversary of the CP-1 experiment on December 2, 1942. For "The First Reactor" (which, incidentally, itself reprinted "The First Pile" essay), historical revisions and updates were provided by Prof. Robert C. Williams, of Washington University in St. Louis, and by History Associates Inc.