A diamond in Dogpatch: The 75th anniversary of the Graphite Reactor

Part 2: The Postwar Years

Following World War II, the Graphite Reactor was the foundation upon which Oak Ridge National Laboratory was built, and it gave birth to many of the technologies we take for granted in the 21st century.

By Sherrell R. Greene

Part 1 of this article described a series of unlikely events that resulted in the construction of the Graphite Reactor in the hills of East Tennessee in a location so remote that the Met Lab scientists and others in the Manhattan Project dubbed it "Dogpatch." Indeed, almost everything about the Graphite Reactor story could be characterized as "unlikely"—its location, the partnership between the scientists at the Chicago Met Lab and DuPont that produced a remarkably simple but capable machine, the incredibly short construction schedule, its trouble-free startup and operation, and its contributions to the success of the Manhattan Project. Part 2 of the story focuses on the Graphite Reactor's unlikely post–World War II roles in the birth of Oak Ridge National Laboratory (ORNL), the advent of "Big Science," and the evolution of nuclear technology as one of the key enablers of modern life.

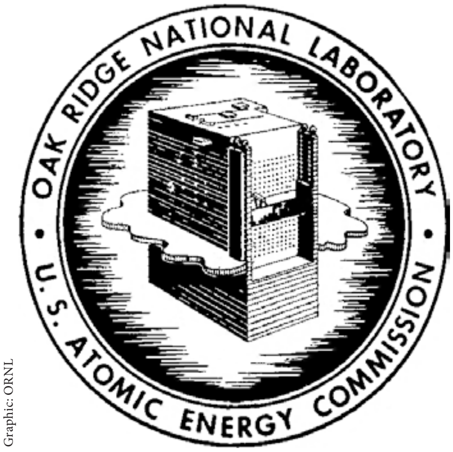
Anchoring ORNL's birth

The end of World War II left both the Met Lab in Chicago and Clinton Laboratories at Oak Ridge in the classic "hammer-in-search-of-a-nail" dilemma. Hanford's plutonium production mission would continue. Los Alamos's mission would continue. With their original missions accomplished, however, the futures of the Met Lab and Clinton Labs were in doubt. Clinton had an ace in the hole—the Graphite Reactor—a tool that had already shown itself to be a remarkably versatile vessel for probing the New World. The wizards at Clinton would waste no time in finding additional uses for it.

During the later months of 1944 through the summer of 1945, scientists at Clinton converged on a strategy for the lab's postwar role in the New World. Their strategy was built around two central themes: (1) exploitation of the Graphite Reactor and the scientists' radiochemical separations expertise; and (2) the development of new "piles" with different fuel cycles and expanded capabilities for research and for the production of electricity and process heat for civilian applications.

The Graphite Reactor would anchor a multifaceted program of radioisotope production, together with basic and applied research in the biological, medical, and health physics arenas; materials science; chemistry and radiochemistry; neutron science; and physics. This strategy would be the polestar of ORNL's mission until the mid-1970s. The role of the Graphite Reactor in ORNL's birth and postwar success was reflected in the fact that an artist's rendering of the Graphite Reactor served as ORNL's official logo until 1974, over a decade after the reactor had shut down. It is almost certainly the case that ORNL would not exist today as one of the world's premier scientific research laboratories had it not been for the Graphite Reactor.

President Harry Truman signed the Atomic Energy Act on August 1, 1946, and the newly established Atomic Energy Commission (AEC) assumed control of the Manhattan Project facilities and programs on January 1, 1947. One of the AEC's first acts was to dedicate the laboratories in Chicago, Clinton, and Los Alamos, as well as the (newly created) Brookhaven Laboratory, as "national laboratories." Clinton Laboratories was designated by the AEC as Oak Ridge National Laboratory on March 1, 1948, as operating responsibility for the lab transitioned from Monsanto (which had assumed responsibility for the operation of Clinton Labs in July 1945) to Carbide and Carbon Chemicals Company (later Union Carbide). It was time to leave the beaches and move inland to explore the interior of the New World.



Graphic: ORNL

The original Oak Ridge National Laboratory logo, 1948–1974.

Beyond the bomb

The scope of the Graphite Reactor's contributions to the modern age extends far beyond its direct roles in the Manhattan Project. The reactor's contributions directly or indirectly touch many aspects of life in the 21st century. The range of activities undertaken there from 1946 to 1963 is breathtaking, even by modern standards. If something could be probed or produced with neutrons and radiation, it was. A few of the reactor's many contributions and "firsts" are briefly noted here.

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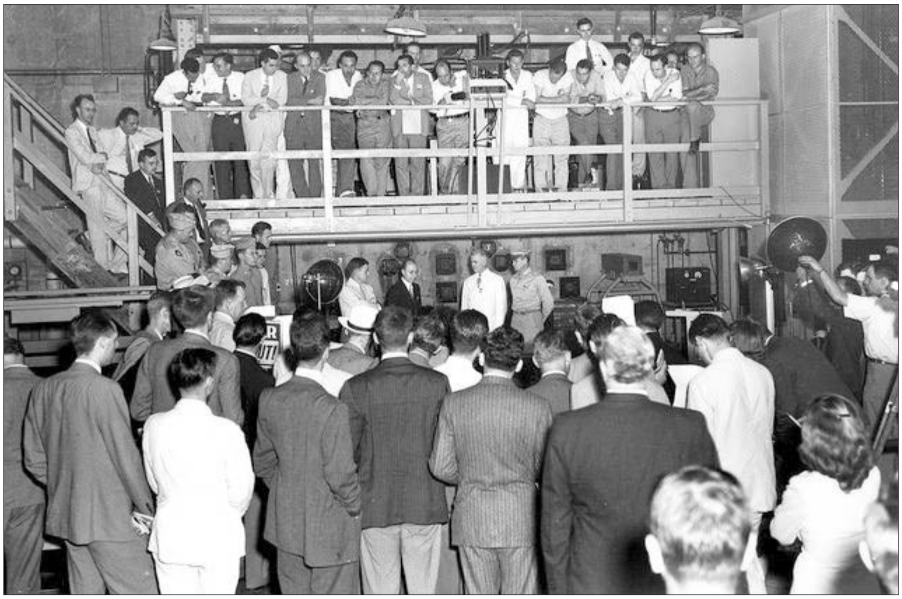

Photo: DOE/Ed Wescott

The first delivery of the medical radioisotope carbon-14 to the Barnard Free Skin and Cancer Hospital in St. Louis, Mo., on August 2, 1946.

Alvin Weinberg famously stated, "If at some time a heavenly angel should ask what the laboratory in the hills of East Tennessee did to enlarge man's life and make it better, I daresay the production of radioisotopes for scientific research and medical treatment will surely rate as a candidate for first place."

In June 1946, ORNL (still Clinton Labs at the time) published a notice in *Science* magazine announcing that some 20 fission product isotopes and 60 nonfission product isotopes would be available to researchers and the medical community. The first commercial shipment of radioisotopes—1 millicurie of carbon-14 to the Barnard Free Skin and Cancer Hospital in St. Louis, Mo.—occurred on August 2, 1946.

In its first year of production, the Graphite Reactor produced material for over a thousand shipments of radioisotopes. Demand was particularly high for carbon-14, iodine-131, and phosphorus-32, which would become a workhorse radioisotope for mapping metabolic pathways and labeling DNA. By the end of 1951, the lab had made nearly 30,000 shipments of radioisotopes. By the time the Graphite Reactor shut down in 1963, over 27 kg of technetium (Tc-99m is the most frequently used radionuclide in nuclear medicine) had been shipped from the lab. Over the course of its lifetime, the Graphite Reactor and its associated radiochemical processing facilities served as an "atomic apothecary," producing over 200 different radioisotopes (many synthesized for the first time at Oak Ridge) for medical treatments, industrial applications, and scientific research.

It was also in the Graphite Reactor that the experiments were done that demonstrated the major role boron content played in determining the biological (cytogenetic/chromosomal mutation) effects of slow neutrons and from which modern-day boron neutron capture therapy was developed. If you or someone you know has undergone a nuclear medicine procedure, it's quite likely that the radioisotopes and technologies employed trace their history to the Graphite Reactor.

Plans for the use of the Graphite Reactor to explore the effects of radioactivity on organisms were in place at the Clinton Pile by April 1943. Those plans included both the impact of radiation from external sources, from inhaled and ingested radioactive species, and studies of how radioactive species are metabolized in mammals (specifically mice and rabbits). Many of the studies involved the irradiation of mice in the "animal tunnels" at the top of the reactor (*NN,* Nov. 2018, p. 40) and sought to distinguish between the effects of fast neutrons, slow neutrons, and gamma radiation. It was from this work that the original "LD 50" guidelines for lethal radiation dose in humans were developed.

The Graphite Reactor's contributions to reactor technology include the first use of two-group neutron transport (diffusion theory) to design a reactor lattice; the first operation of a nuclear reactor at temperatures sufficiently high to "see" the reactivity temperature feedback effect; the first fabrication and use of sealed nuclear fuel elements; the first natural uranium–water lattice experiments (which provided the basis for early light-water reactor designs); the first demonstration of water tank shields (which provided the motivation for the ubiquitous pool-type research reactors constructed around the world in the 1950s and 1960s and information used in the design of early naval reactor shields); the first use of experimental reactivity oscillator devices; and the discovery of the low-capture cross section of zirconium (which became the standard fuel cladding for the world's commercial nuclear power fleet).

Fuels for homogeneous and molten-salt reactors were first tested in the Graphite Reactor. The use of pneumatic tubes, or "rabbits" (a now-common design feature of research reactors worldwide), for the insertion and retrieval of material samples while the reactor was operating was perfected at the Graphite Reactor.

One would be remiss to overlook the world's first production of electricity from nuclear energy, which occurred at the Graphite Reactor in September 1948, when researchers connected a tabletop Jensen #50 steam engine/generator to a simple steam generator driven by 10 fuel slugs in the pile. The electricity powered a small flashlight bulb. Although appar-

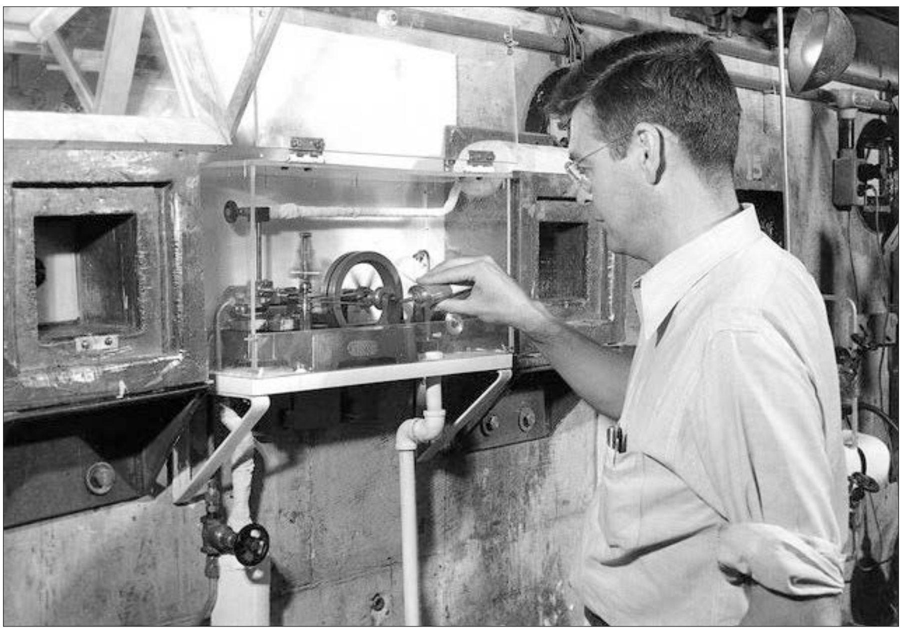

Photo: DOE/Ed Wescott

The first electricity is generated from nuclear power, September 1948.

ently done more for entertainment value than anything else, the stunt was the first conversion of nuclear energy to electrical energy. (The steam engine used in the “experiment” is on display in the viewing gallery of the Graphite Reactor today.)

Finally, it is no stretch to claim that the modern disciplines of nuclear engineering (reactor and radiochemical engineering) were birthed in the effort to design, build, and operate the Oak Ridge Pilot Plant (the Graphite Reactor and its companion radiochemical separations facility).

The Graphite Reactor functioned as a transformational analytical instrument almost from the moment of its initial criticality. It was the first reactor used for neutron activation analysis—a powerful analytical tool for discerning the elemental composition of unknown materials. The reactor was being employed before the end of 1943 to scan for potential neutron activation problems that might be presented by the materials (including water) to be used in the construction and operation of the Hanford reactors. It was at the Graphite Reactor that Ernest Wollan and Clifford Shull conducted their pioneering neutron scattering/neutron diffraction studies beginning in 1944, work recognized with the Nobel Prize in Physics in 1994.

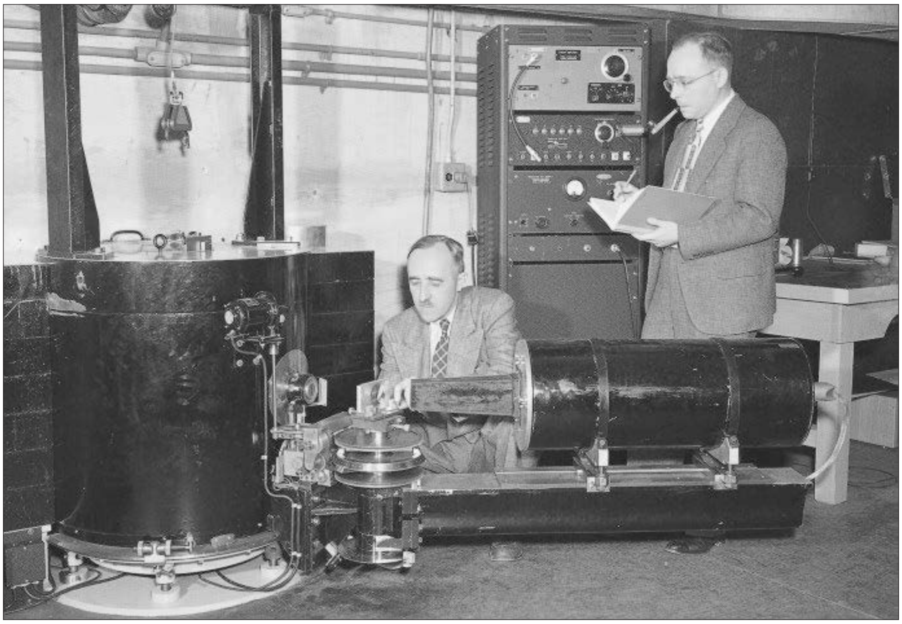

Photo: DOE/Ed Wescott

Ernest Wollan and Clifford Shull with their double-crystal neutron spectrometer at the face of the Graphite Reactor in 1949.

The Graphite Reactor was employed during its lifetime for thousands of “solid-state” irradiation experiments aimed at understanding the effects of radiation on nonbiological matter. Pioneering studies were conducted there on the effect of irradiation on semiconductors, work that enabled early spacecraft and satellite systems.

In addition to the early neutron activation analyses noted above, the reactor was pressed into service in 1943–1944 to provide understanding of the impact of neutron irradiation on the physical properties (for example, strength, hardness, and elasticity) of structural materials used in reactor construction. In 1956, researchers installed a helium-cooled cryostat in hole No. 12 of the Graphite Reactor, the first irradiation facility at an operating reactor that allowed neutron bombardments of material samples at liquid hydrogen temperatures. This work produced the first data on fast and slow neutron radiation damage mechanisms in metals and other materials irradiated at temperatures below 20 K. The refrigeration system for the cryostat was a pathfinder for today’s cold neutron source systems in neutron scattering research at reactors around the world. (In a nod to the then popular and now immortal movie starring Humphrey Bogart and Katherine Hepburn, the refrigeration system was promptly dubbed the “African Queen” due to the similarity of the sound it emitted during operation to that of the little steam boat piloted by Bogart’s character, Charlie, in the 1951 movie.)

Photo: ORNL

At the Graphite Reactor shutdown ceremony, from left, Richard Doan, Alvin Weinberg, and Glenn Seaborg, November 4, 1963.

Mission accomplished

The Graphite Reactor was permanently shut down on November 4, 1963, 20 years to the day after it first came to life. With a push of a button, Richard L. Doan, the first research director of ORNL, gave the command for the control rods to drive


Photo: ORNL

The Graphite Reactor building as it appears today.

into the old graphite core for the very last time. Glenn Seaborg, Eugene Wigner, Alvin Weinberg, and a host of other dignitaries shared the speaker's platform in front of the reactor that afternoon. As reported in ORNL's employee newspaper, *The News*, "The crowd . . . filled the old pile building to overflowing. People lined the stairs, the hallways, even the top of the reactor itself to watch the ceremonies." Visitors to ORNL that day were treated to speeches by the dignitaries and tours of the Gas Cooled Reactor, the Health Physics Reactor, the Molten Salt Reactor, the Tower Shielding Facility, the Oak Ridge Research Reactor, and the High Flux Isotope Reactor (then under construction), each of which could in some way trace its lineage to the Graphite Reactor. The following morning, Wigner received the news that he would share that year's Nobel Prize in Physics for "his contributions to the theory of the atomic nucleus and elementary particles." It was somehow all fitting and proper.

The scene of November 4, 1963, was largely repeated three years later, on September 13, 1966, when the ORNL Graphite Reactor was designated a National Historic Landmark in a ceremony headed by Seaborg, then chairman of the AEC, and Wigner, a former research director at ORNL, along with Weinberg, director of ORNL, and a host of other notables. Weinberg, the man Wigner credited with having single-handedly created the nuclear design of the Graphite Reactor, opened the ceremonies. Speaking affectionately of the reactor, Weinberg referred to it as "an old Oak Ridge friend" and "a beloved reactor." He recounted many of its exploits and emphasized its role for more than 20 years as "an early symbol of Big Science," saying, "This lady needs nothing more to establish her immortality."

Seaborg, in accepting the National Historic Landmark plaque from Elbert Cox, regional director for the National Park Service, recounted the reactor's Manhattan Project contributions and emphasized its postwar role as a source of radioisotopes for a multitude of applications, adding, "As a training instrument for reactor operators and technicians, the reactor lays claim to worldwide alumni, and the number of experiments and irradiations hosted over the years within its core are legion. . . . More efficient reactor systems . . . were the direct outgrowth of technology developed by this now-famous reactor. Even the modern nuclear power plants of today have an ancestry traceable to the X-10 pile."

Speaking last, Wigner noted the unique role the reactor played as the first catalyst for collaboration between nuclear scientists and engineers and emphasized the reactor's role as a "cohesive force for a large laboratory in which a great variety of talents and human strengths and weaknesses work side by side." He added that this latter role "may have been fully as important as its other functions."

The most poignant comments that day were offered by Seaborg, who ended his speech with the following words, which perhaps best summarize the legacy of the Oak Ridge Graphite Reactor: "From its secret birth to its reluctant retirement, the Graphite Reactor contributed immeasurably to the defense of this nation's liberty, and to the betterment of man's everyday life. Most assuredly, the X-10 Reactor occupies a unique niche in the annals of American history."

The knowledge and technologies that emerged from the Graphite Reactor between November 1943 and November 1963 touch our lives today in a multitude of ways. Beyond its role in the Manhattan Project, the Graphite Reactor's contributions in such diverse fields as reactor engineering and technology, physics, chemistry and radiochemistry, biology, health physics, nuclear medicine, and materials science firmly establish it as one of the transformational scientific and technical tools of the 20th century. It was the foundation upon which one of the world's great scientific laboratories was built. It was arguably the first "Big Instrument" of "Big Science." Seventy-five years after it began operation and 55 years after its shutdown, no other nuclear reactor in the world can boast an equally impressive list of accomplishments.

Indeed, the Oak Ridge Graphite Reactor was an incubator of the nuclear age.

Visiting the Graphite Reactor

The Oak Ridge Graphite Reactor is one of eight Signature Facilities of the Manhattan Project National Historical Park. It is open for public bus tours from March through November. Those wishing to visit the reactor must register in advance at <https://amse.org/2018/02/09/2018-doe-public-bus-tour/>.

Author's postscript

It is impossible to do justice to the history of the Graphite Reactor in this two-part article, much less to pay due respect to the hundreds of distinguished Graphite Reactor "alumni." The list of individuals who were involved in some manner with the Graphite Reactor and the Pilot Plant is a virtual "Who's Who" in the annals of 20th century nuclear science and engineering. It includes Arthur Compton, Crawford Greenwalt, Ernest Hollander, Miles Leverett, Karl Morgan, Hyman Rickover, Theodore Rockwell, Glenn Seaborg, Frederick Seitz, Clifford Shull, Louis Slotin, Katherine Way, Alvin Weinberg, Martin Whitaker, Eugene Wigner, Ernest Wollan, Gale Young, and a host of others. Some helped birth the reactor and the Pilot Plant. Some harnessed its amazing capabilities. Some spent days at the Graphite Reactor; others spent decades there. It is to that generation of giants, who harnessed the invisible to accomplish the unimaginable, this article is dedicated. NN