

EUGENE WIGNER, NUCLEAR ENGINEER

Wigner led the design of the Hanford nuclear reactors
and founded a school to teach reactor physics to people working in industry.

Alvin M. Weinberg

In addition to being a theoretical physicist of the first rank, Eugene Wigner (1902–95) was the founder of nuclear engineering. He led the group that designed the first very high-powered nuclear reactors, which were built at Hanford, Washington, for the production of the isotope plutonium-239.

I first met Wigner (see portrait, figure 1) in the winter of 1942. At the time of our first meeting, he was commuting between his home in Princeton, New Jersey, and the University of Chicago, where the plutonium part of the Manhattan Project was being centralized. I have since been very closely associated with him, and he and I collaborated on *The Physical Theory of Neutron Chain Reactors* (U. of Chicago Press, 1958).

A mind completely prepared

When fission was discovered late in 1938, Wigner was the completely prepared mind. After all, in 1936 he had codiscovered the Breit–Wigner formula for the shape of neutron resonances in nuclei. And, through his friendship with Leo Szilard, he had been thinking since 1934 about the possibility of releasing nuclear energy. Szilard had postulated that a chain reaction based on neutrons would be possible, and he took out a British admiralty patent on the concept.

Wigner was impressed with Szilard's general idea. He says in his memoirs that he thought long and hard to see whether some kind of law of nature—somewhat like the law of conservation of energy—would preclude the possibility of a nuclear chain reaction.¹ He decided as early as 1936 that no such law existed, and in his unpublished speech that year to the Gamma Alpha Society at the University of Wisconsin, he said that within five years scientists would figure out how to release nuclear energy. He later wrote that he had no reason for specifying five years, but he was confident that the nuclear community would discover a neutron-initiated nuclear reaction that would produce both energy and neutrons.²

Once Otto Hahn and Fritz Strassman discovered fission in 1938, Wigner and fellow Hungarians Szilard, Edward Teller, and John von Neumann realized that nuclear bombs were possible. Wigner and Szilard, whose European–Hungarian background taught them what happens

when a country is run by dictators such as Adolf Hitler, became obsessed in their desire to push forward the development of the atomic bomb.

By early 1939, war in Europe was imminent. Wigner realized that humanity was in a struggle with the forces of evil, and that whoever made the bomb first would rule the world. Therefore, he, along with Szilard and Teller, decided that they would have to enlist the US government in the project to develop the atomic bomb. Wigner suggested that he and Szilard persuade Albert Einstein to write a letter apprising President Franklin Roosevelt of the grim possibility that was opened up by the discovery of fission. Once the letter was written in August 1939, they enlisted an economist from New York City, Alexander Sachs, to convey it to Roosevelt.

Most historians say that because of bureaucratic bumbling, the Einstein letter actually slowed the pace of the bomb project.³ But one outcome of that letter was that the US government granted \$6000 to Enrico Fermi at Columbia University to expand his work on a neutron chain reaction in a mixture of natural uranium and pure graphite. In addition, the letter spawned a committee, chaired by the director of the National Bureau of Standards, Lyman Briggs, to track the progress of uranium research. Dealing with the committee, according to Wigner, was like “swimming in syrup.”

At about the time the Briggs committee was formed, Wigner began working out the theory of the neutron chain reaction. In this, he paralleled much of the work being done by Fermi at Columbia; Carl Eckart at the University of Chicago; Jim Fisk and Bill Shockley of Bell Telephone Laboratories; and Werner Heisenberg, Carl Friedrich von Weizsäcker, and others overseas. Much of the theory was developed very early, probably in 1940 or 1941. Thus, by 1942, many physicists, including Wigner, had a good idea of what should be theoretically possible with respect to a nuclear-energy producing reactor and had derived all of the important formulas for the physics of the nuclear reactor.

A water-cooled machine

Beginning in 1942, all the work on nuclear reactors in the US was consolidated at the University of Chicago under Arthur Compton. Wigner spent three years there, from 1942 to 1945, during which he supervised the theoretical-physics and reactor-engineering work of the Metallurgical Laboratory.

Wigner was well qualified for that task because he had

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FIGURE 1. EUGENE WIGNER, photographed by Howard Schrader. (Used with permission of the Princeton University physics department.)

received a doctorate in chemical engineering from the Berlin Technical University. After earning his degree, he served as a chemical engineer for two years in his father's leather factory. That comes as a surprise to many people who think of Wigner as a theoretical physicist; Wigner, though, often told me that he never had a formal college-level course in physics. But, in fact, he was also a skilled engineer who enjoyed designing the first large-scale Hanford reactors.

The Metallurgical Laboratory brought together all of the groups that were working in the US on uranium reactors and uranium bombs. Leading the reactor effort was Fermi. He and Szilard had suggested as early as 1940—if not in 1939—that the moderator should be graphite. It was clear then that one should be able to make a chain reaction work with a graphite moderator; at issue was whether one could *engineer* a large-scale chain reaction that would produce enough plutonium to affect the outcome of the war. When the Metallurgical Laboratory was organized early in 1942, it was not clear whether the multiplication factor was large enough to make a chain reaction of practical size. Thus, helium, which absorbs no neutrons, appeared to be the best material for a reactor coolant. A good deal of nuclear engineering was applied to a large helium-cooled nuclear reactor moderated with graphite and fueled

with natural uranium.

Wigner, with his chemical engineering background, objected very strongly to helium cooling. He argued that if helium were the coolant, then the reactor would have to run at a very high temperature, perhaps 400–500°C. That would mean immense materials problems. It was not that Wigner thought the problems were insoluble, but rather that solving them for such a hot reactor would take a very long time. He proposed cooling the reactor with ordinary water instead of using helium at a relatively high temperature. Now, making that proposal was a very brave thing for him to do because, at that early time, it had not yet been experimentally demonstrated that any chain reaction was possible. But Wigner had so much confidence in the accuracy of his calculations (backed, of course, by Fermi's experiments) that he insisted that, though the presence of water in the reactor would reduce the multiplication factor by perhaps 3%, enough reactivity would be left to make a reactor of modest size. Moreover, Wigner emphasized that a water-cooled machine could be built much more quickly than a helium-cooled reactor.

Compton found Wigner's ideas attractive. He instructed Wigner to design a 500 000-kW water-cooled reactor that would produce 500 g of plutonium per day but would use only 200 tons of uranium, which was very scarce at the time. The restriction on the uranium mass placed certain constraints on the reactor design. Wigner and his small group proceeded to design what became the Hanford reactors.^{4,5} Figure 2 shows a face of one of the three reactors.

When E. I. du Pont de Nemours and Co entered the reactor project around September 1942, it came to the same conclusion as Wigner: Water, not helium, should be the coolant. DuPont adopted what was, in essence, Wigner's design and built the three Hanford reactors, each producing 250 000 kW (rather than the original design goal of 500 000 kW).

Friction developed between Wigner and DuPont as to who was in charge. DuPont officials apparently perceived that the company had oversight responsibility, and they may have doubted that Wigner had the proper engineering credentials. I don't think the DuPont people fully appreciated that Wigner was a PhD chemical engineer who had spent two years in his father's tanning factory plying his trade. But perhaps more fundamentally, DuPont viewed the reactor as a huge, permanent device that required many more resources than the Metallurgical Laboratory possessed, whereas Wigner conceived his water-cooled reactor as a simple and temporary device that could be thrown together rapidly by the original design group. The group's design report, presented in January 1943, does a

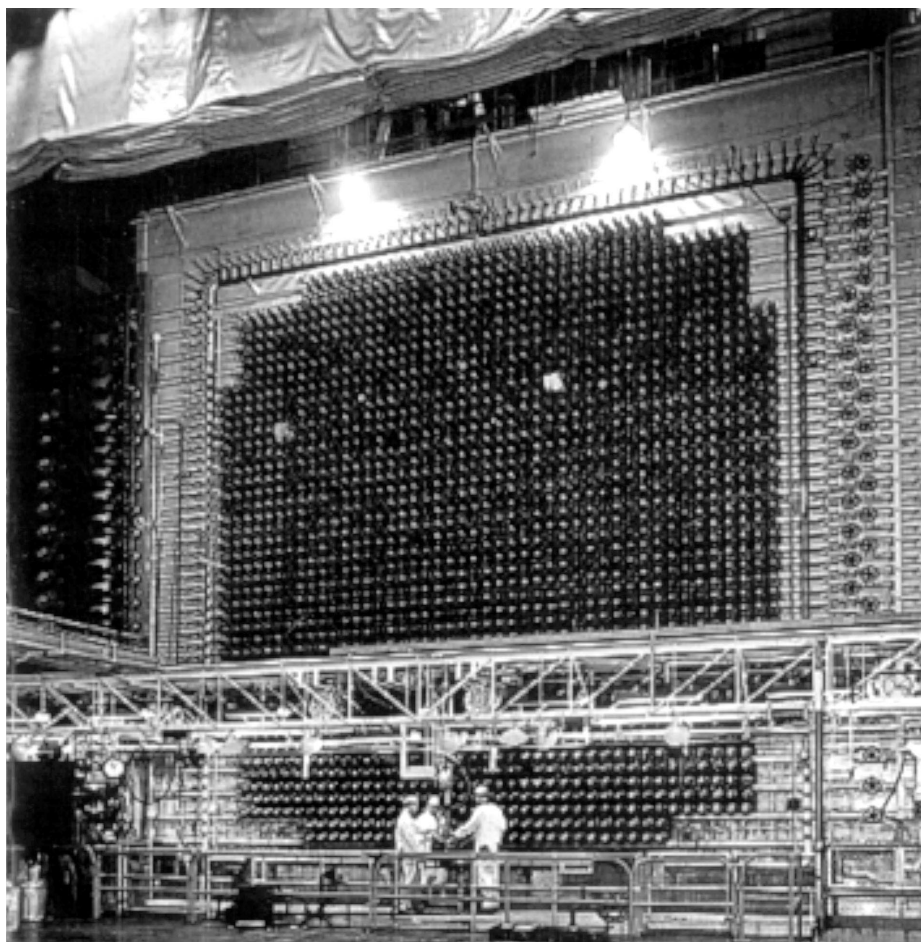


FIGURE 2. HANFORD REACTOR face, showing 2004 water cooling tubes surrounded by masonite shielding. The uranium core inside the reactor is not visible in the photograph. The standing workers give a sense of the scale of the three equal-sized Hanford reactors. (Photo courtesy of Pacific Northwest National Laboratory.)

good job of capturing the atmosphere of the Metallurgical Laboratory during the previous year. The report notes, “A water-cooled plant is described with a rating of 500 000 kW from 200 tons of metal, and a potential output somewhat higher . . . and provides a thickness of material at corrosion points which should be easily ample for a lifetime of 100 days.”⁴ One hundred days of operation was the goal in the original design plan: The 50 kg of ²³⁹Pu that could be produced in that time was considered enough to end the war. DuPont, by contrast, expected Hanford to keep producing plutonium long after the 100 days were over.

Xenon poisoning

The story of what happened at Hanford when the first reactor was turned on in 1944 is well known. The reactor started up and it reached thousands of kilowatts with ease. But once that power was reached, the chain reaction slowly decayed to zero. For a while, the whole Hanford project hung in the balance; something was going on that had not been expected. It turns out that one of the fission products, xenon-135, has the enormous absorption cross section of 3.5×10^6 barns—by far the largest absorption cross section of any nuclide. When the reactor was run at high enough power to produce a large amount of ¹³⁵Xe, the ¹³⁵Xe would poison the reactor. Fortunately, ¹³⁵Xe has a half-life of about 9 hours and, therefore, if one waited until the ¹³⁵Xe decayed, the reactor would recover. It is to the everlasting credit of John Wheeler, Fermi, and Dale Babcock that they were able to identify ¹³⁵Xe as the culprit by analyzing the curves of the rise and fall of the reactor power. Once the culprit was identified, the DuPont engineers suggested loading 504 additional tubes with ura-

nium in the empty corners of Wigner’s design. (Volney C. Wilson, then head of control design for Hanford, has told me it was actually Fermi who made the suggestion.) The additional tubes were enough to overcome the xenon poisoning.

An argument that has lasted for 50 years is whether Wigner’s original design would have counteracted the poisoning. Wigner’s reactor was a cylindrical block of graphite with 1695 process tubes and Compton’s mandated 200 tons of uranium. Wigner had suggested less aluminum on the fuel elements than DuPont; had Wigner’s thinner aluminum coating been built, the xenon poisoning could have been somewhat alleviated even in the 200-ton reactor.

That Compton directed Wigner to design the reactor with 200 tons of uranium is not generally known, even by people on the project. I happen to have been the only person present when Compton gave that directive. DuPont recommended that the reactor contain about 250 tons of uranium; Wigner acceded to this recommendation. DuPont’s conservativeness paid off and enabled Hanford to operate at its design power of 250 000 kW.

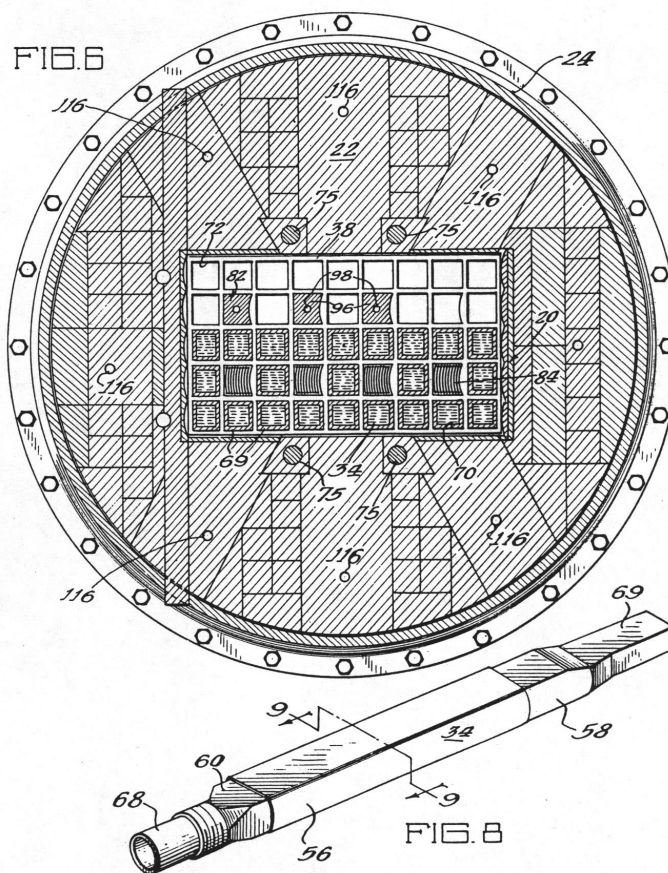
Wigner was responsible for reviewing every blueprint that DuPont drew up for Hanford. This was a tedious job that Wigner and his group took most seriously. Hanford, as built, was based on blueprints approved by Wigner.

After Hanford

Once the Hanford reactors were operating, there wasn’t much left for Wigner’s group to contribute to the project, so the group examined other possibilities. Indeed, Wigner obtained 37 engineering patents⁶ on various kinds of reactors: reactors moderated with heavy water, homogeneous reactors, fast reactors, air-cooled research reactors, and water-cooled compact reactors enriched with uranium-235. In all those instances, Wigner served as the spark behind the designs.

In 1945, Wigner had the idea of developing the Clinton Laboratories in Tennessee into a major reactor facility, and he drew up a tentative organization chart of a greatly expanded laboratory. (Clinton became the Oak Ridge National Laboratory in 1948.) In 1947, Wigner served as research director of Clinton. During that year, he established the Oak Ridge School of Reactor Technology, directed by his former student Fred Seitz. Its purpose was to convey the knowledge of reactors developed at the Metallurgical Laboratory

FIGURE 3. THE REACTOR TANK of the materials testing reactor is illustrated in cross section in the 6th of 14 drawings accompanying Eugene Wigner's 1952 patent application. The numbers on the drawing indicate reactor components described in the text of the application. For example, the object labeled 82 is a control element containing a neutron-reflecting material. Elements labeled 34 are fuel assemblies, one of which is shown in detail in Wigner's figure 8. The active part of reactor core, which comprises the three rows containing fuel elements, has dimensions of about 22 cm $\times$ 71 cm $\times$ 66 cm. (Reprinted from *The Collected Works of Eugene Paul Wigner*, ref. 2, p. 797.)



INVENTOR.
Eugene P. Wigner
BY *Richard A. Anderson*
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to industrial people. The most prominent alumnus of the school was Hyman Rickover. He was a captain at the time, terribly rude, but nevertheless extraordinarily effective in getting the Nuclear Navy going.

While he was research director, Wigner laid down the design precepts for what became the materials testing reactor (see figure 3). The MTR was the first high-powered, enriched-uranium reactor cooled and moderated with water (although Hans von Halban had independently taken out a French patent on the idea). The fuel was ^{235}U borne in thin, curved plates. The curved plate was an invention of Wigner's: Such a plate would be less inclined to buckle than would a flat plate. The water-cooled MTR eventually operated at 40 000 kW. In a way, it was a prototype for the reactor in the *USS Nautilus*, which likewise was a water-cooled, water-moderated reactor with plate fuel elements that burned ^{235}U . The main difference between the MTR and the *Nautilus* reactor was that the MTR operated at room temperature and low pressure, whereas the *Nautilus* reactor operated at a high temperature and high pressure. Although Wigner was not actively involved with the design of the nuclear-powered submarines developed by the navy after the war, he was a consultant to Argonne National Laboratory, where the *Nautilus* reactor was designed.

Wigner was also a consultant to DuPont for its Savannah River heavy-water reactors, which were used to produce tritium at the time of the hydrogen-bomb effort. That arrangement, I assume, signified that, despite the wartime disagreements between Wigner and DuPont, the company, in the final analysis, appreciated Wigner's genius both as a physicist and as an engineer. In his memoir, Wigner offered what he called a silent apology to DuPont for having misunderstood the company's motives.⁷ Wigner was somehow misled into thinking that DuPont was purposely pushing him out of the Hanford design because it saw dollars in the postwar world for those who had an inside track on nuclear energy.

Wigner did a fair amount of thinking about what he called the long-range view of nuclear energy. In several papers, which were published in semiscientific journals, he argued that the future of nuclear energy would be determined, as much as anything, by how much uranium would be found in the dilute ores in rocks.⁸ Already, in 1944, Philip Morrison had estimated that only a pitifully small amount of uranium could be economically extracted—something like a few thousand tons in the entire US. If

that were the case, uranium power would be a flash in the pan: There simply would not be enough uranium to support an expanding enterprise.

It was on this account that many of us took up the breeder reactor, in which neutrons from fissioning ^{239}Pu are captured by ^{238}U , ultimately to yield more ^{239}Pu . The idea was variously attributed to Fermi, Szilard, Wigner, and von Halban. Wigner and Harry Soodak were the first to design, in some detail, a fast-neutron, sodium-cooled reactor that would breed. The two received the original patent on the liquid-metal breeder.⁹ Wigner, though, pointed out that if one could find more (presumably low-grade) uranium ore and then could find a way of extracting the uranium economically, that would undercut the requirement for the breeder. Richard Garwin and Georges Charpak have recently come to essentially the same conclusion: If the billions of tons of uranium in the sea can be mined at an acceptable price, the breeder can be postponed for a long time.¹⁰ I believe that the public will hear much debate over the next 50 years between those who want to go ahead with the breeder because, they say, uranium from seawater is too expensive, and those who argue that the breeder can be put off for a long time because scientists will learn how to extract the low-grade ores at an acceptable cost.

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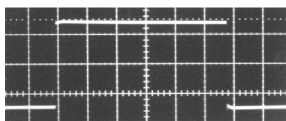
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A person who cares

"One must understand that the uranium problem mobilized the best scientific brains of the time." So begins a passage that I wrote with help from Wheeler, in which I assessed Wigner as a nuclear engineer.¹¹ The unique constellation of physicists working to build a nuclear reactor included Szilard, the brilliant visionary; Fermi, the all-powerful experimental and theoretical genius, who actually achieved the first chain reaction; and Wigner. Still, one must recognize that the chain reaction was easy to achieve: Lesser people than those who gathered at Chicago and Los Alamos could have succeeded. But could they have succeeded in only two years, the time from the first exponential experiment that showed the multiplication factor exceeds unity to the time of the Hanford reactors?

I believe not. Although the underlying ideas are straightforward, only scientists and engineers of genius could have pushed the Hanford project through in such an incredibly short time. And of all the able people assembled, Wigner was unique in possessing a complete command of nuclear physics, immense mathematical power, an aptitude and liking for detail engineering, a powerful grasp of chemistry, and, perhaps most important of all, an unmatched zeal and sense of responsibility. Wigner knew from firsthand contact with Nazi Germany that the project had to succeed no matter what administrative obstacles or criticism he might encounter.

Wigner committed himself absolutely and completely. He was, as Wheeler said, a person who cares. I saw this in innumerable ways, but perhaps most strikingly when Wigner, the same person who had published the monumental mathematical paper "On Unitary Representations of the Inhomogeneous Lorentz Group,"¹² would pore over the detailed blueprints of the Hanford reactor, sufficiently confident in his judgment to insist on changes when he spotted a deficiency.

I hope this account of Wigner's contribution to nuclear energy will serve to remind the present generation of nuclear scientists and engineers that Wigner is one of those on whose shoulders they stand. He demonstrated how nuclear engineering and nuclear science at the highest level can be done. We who follow Wigner must rededicate ourselves to a strict adherence to his standards of excellence and responsibility.

This article is based on a paper I presented on 21 April 2002 at the American Physical Society Meeting in Albuquerque, New Mexico.

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