

The Italian Navigator Lands in the New World

Two German radiochemists, Otto Hahn and Fritz Strausmann, discovered nuclear fission just at Christmastime 1938—nine months before the beginning of the Second World War in Europe. When news of the fateful discovery reached the United States at the end of January 1939, the first question the émigré Hungarian physicist Leo Szilard wanted to answer was, would uranium chain-react? That is, would more than one of the two or three neutrons that burst from a uranium atom when it split encounter other uranium atoms nearby, fission them in turn, releasing yet more neutrons which would encounter yet more uranium atoms and fission them, in an exponential cascade. If so, then in about 80 generations—a few thousandths of a second—the heating, expanding, chain-reacting mass would blow itself apart in

a burst of shock and fire which would be the equivalent of thousands and tens of thousands of tons of high explosives.

Or, alternatively, if a large number of slugs of natural uranium could be arranged in a three-dimensional lattice in a matrix of light material such as water or graphite which would slow down the neutrons released in fission, with control rods to absorb some of them to prevent the chain reaction from running away, could the energy from fission be harnessed for power? Could a “nuclear reactor” be added to the sources of energy available to humankind, the first potentially major source of energy not dependent directly or indirectly upon sunlight?

Or, alternatively, since many of the neutrons bombarding natural uranium would convert one of its forms—one of its “isotopes”—to a new, manmade element, plutonium, would that element prove to be even more fissile than uranium?

Leo Szilard and his Italian colleague Enrico Fermi, working at Columbia University, didn't conceive all these possibilities immediately: plutonium wasn't created and identified until December 1940. But the possibilities of uranium at least were evident from the beginning. In spring 1939, the two physicists set out to determine if uranium chain-reacts.

Szilard, a resourceful maverick of a physicist, borrowed hundreds of pounds of black, greasy uranium-oxide powder from two acquaintances who owned a Canadian uranium mine. Fermi and a crew of his students at Columbia packed the powder into pipe-like tin cans and arranged them equally spaced within a large tank of water-mixed-with-powdered-manganese. At the center of the arrangement they placed a neutron source. Neutrons from the source, slowed down by the water, would penetrate the uranium atoms in the cans and induce fissions. If the fissioning atoms released more neutrons,

those “secondary” neutrons would irradiate the manganese. Measuring the radioactivity induced in the manganese would tell Fermi and Szilard if the fissions were multiplying. If so, then a chain-reaction might be possible.

They were. And it was.

But not with water. Ordinary water absorbed too many neutrons to allow a natural-uranium chain reaction to become self-sustaining. Szilard immediately began investigating an alternative moderator: graphite, pure carbon.

1939 was the summer when Szilard, Edward Teller and their Hungarian colleague Eugene Wigner sought out Albert Einstein to carry a message to President Franklin D. Roosevelt: the message that Germany might be working on an atomic bomb. So began the courting dance between nuclear physicists and the U. S. government.

It was not immediately propitious. Imagine three young, heavily-accented Hungarians presenting themselves, as they did in spring 1940, to a U.S. army ordnance officer in Washington, and explaining to him that under the right circumstances a small volume of an exotic metal—a sphere the size of a softball—could be made to explode with the force of twenty thousand tons of TNT. “In Aberdeen,” the skeptical officer told them, meaning at the army’s Aberdeen Proving Ground in Maryland, “in Aberdeen we have a goat tethered to a stick with a ten-foot rope, and we’ve promised a big prize to anyone who can kill the goat with a death ray. Nobody has claimed the prize yet.” After further discussion, and grudgingly, the officer offered support to the extent of \$6,000 (the equivalent of about one hundred thousand dollars today) for further research on uranium.

That first funding was enough to begin measuring physical constants and investigating reactor materials.

More funding followed across the next 18 months as the scientific community and its representatives in government worked their way through the radically unfamiliar and unlikely concept of a nuclear explosive. By autumn 1941, Fermi and his crew were preparing to assemble a series of subcritical reactors made of blocks of graphite and eight-inch soldered iron cans of uranium oxide powder that weighed 60 pounds each. They needed muscle, Fermi recalled. “We were reasonably strong,” he said later, “but we were, after all, thinkers. So Dean Pegram looked around and said, That seems to be a job a little bit beyond your feeble strength, but there is a football squad at Columbia that contains a dozen or so of very husky boys who take jobs by the hour just to carry them through college. Why don’t you hire them.” (Imagine that: university football players doing odd jobs!) “And it was a marvelous idea,” Fermi concludes; “it was really a pleasure...to direct the work of these husky boys, canning

uranium—just shoving it in—handling packs of 50 or 100 pounds with the same ease as another person would have handled three or four pounds.”

Fermi called his subcritical reactor a “pile.” As his colleague and fellow countryman Emilio Segré explained to me, “I thought for awhile that this term was used to refer to a source of nuclear energy in analogy with Volta’s use of the Italian term *pila* to denote his own great invention of a source of electric energy”—that is, the Voltaic battery. “I was disillusioned,” Segré said, “by Fermi himself, who told me that he simply used the common English word *pile* as synonymous with *heap*.”

In the meantime the British had been exploring building a bomb as well, and had progressed farther than we had. They had shared their discoveries and plans with their American counterparts, with the result that on Saturday, December 6, 1941, the U. S government committed to a full-scale industrial program to pursue an

atomic bomb. The next morning, December 7, 1941, the Japanese bombed Hawaii's Pearl Harbor, destroying most of America's Pacific fleet docked there conveniently side by side, and the United States entered the war.

By the following October 1942, Fermi and his pile materials had been moved here to the University of Chicago, where the so-called Metallurgical Laboratory, the scientific center of what was now called the Manhattan Project, had been located. Leo Szilard had produced and was continuing to produce uranium and graphite of high purity.

"Szilard at that time," Fermi recalled, "took extremely decisive and strong steps to try to organize the early phases of production of pure materials....He did a marvelous job which later on was taken over by a more powerful organization than was Szilard himself. Although to match Szilard," Fermi quipped in conclusion, "it takes a few able-bodied customers."

Building a series of subcritical piles of increasing scale, first in New York and then in Chicago, Fermi had methodically calculated the perimeters of a self-sustaining, chain-reacting uranium and graphite pile. And here, that winter, he and his team prepared to build one.

There was a convenient space available, out of the public eye. Robert Maynard Hutchins, this university's fifth president, who took office in 1929 at the young age of 30, was no fan of football. "Football," he wrote once, "has the same relation to education that bullfighting has to agriculture." In 1939 the university dropped varsity football from its program. That left its football stadium largely abandoned. The Met Lab took over a warren of disused rooms under the West Stands. Among those spaces was a double squash court, sixty feet long, thirty feet wide, twenty-six feet high and sunk half below street level. That was where Fermi would construct his historic nuclear reactor, now designated Chicago Pile No. 1: CP-1.

With the help of a half-dozen graduate students and 30-odd high-school students waiting to be drafted. The pile would be the size of a two-car garage, stacked of some 45,000 graphite bricks, each 4 and a quarter by 4 and a quarter inches square and 16 and a half inches long. They weighed 19 pounds each, for a total of about 360 tons, which were lifted with a materials elevator but then had to be muscled into place by hand. A quarter of them had to be drilled with two 3-and-a-quarter-inch blind holes each to accommodate comparably-sized pseudospheres of uranium oxide, another 45 tons, or uranium metal slugs, another six tons. Some of the graphite blocks had to be slotted to make channels for ten control rods, neutron-absorbing strips of cadmium nailed to flat strips of wood. I'm sure you've seen a photograph of the pile's layers: a layer of plain graphite, then two layers of graphite plugged with uranium, then another layer of graphite, two more graphite and uranium layers, and so on. For stability

the lower half of the structure would be encased in a solid frame of raw four-by-six pine boards.

It would not be shielded. Despite its formidable size, its power output would only be half a watt, hardly enough to light a flashlight bulb. On the other hand, no one had taken a uranium assembly to critical mass before. What if it ran away and melted down? Arthur Compton, the Nobel laureate physicist who was head of the Met Lab, consulted with Fermi and concluded they had adequate controls to prevent such a disaster. He chose not to discuss the question with President Hutchins, however. As he explained later:

“As a responsible officer of the University of Chicago, according to every rule of organizational protocol, I should have taken the matter to my superior. But this would have been unfair. President Hutchins was in no position to make an independent judgment of the

hazards involved. Based on considerations of the University's welfare, the only answer he could have given would have been—no. And this answer would have been wrong. So I assumed responsibility myself.”

Walter Zinn and his day crew began stacking blocks in the squash court on the morning of 16 November 1942. Thereafter the two crews, Zinn’s and Anderson’s, each worked twelve-hour shifts, twenty-four hours a day. As the pile rose from the floor in its wooden framing Fermi checked its increasing reactivity: he had calculated a reciprocal so that the approach to criticality was a countdown to zero.

As winter locked down, the unheated west stands turned bitterly cold. Graphite dust blackened walls, floors, hallways, lab coats, faces, hands. A black haze dispersed light in the floodlit air. White teeth shown. Every surface

was slippery, hands and feet routine casualties of dropped blocks.

Fermi had designed a 76-layer spherical pile, but purer graphite and the six tons of high-purity uranium metal slugs made it possible to reduce the volume of the pile, which became doorknob-shaped, a flattened rotational ellipsoid 25 feet wide at the equator and 20 feet high from pole to pole. It cost about one million dollars to produce and build—about 15 million dollars today.

Herb Anderson's crew assembled CP-1's final configuration on the night of December 1st, seventy-five years ago today. "I resisted great temptation," Anderson recalled, "to pull the final cadmium strip and be the first to make a pile chain-react." Instead he inserted all the control rods, locked them in place and went home to bed.

The morning of December 2nd, 1942, dawned clear and cold, "terribly cold," Fermi's protégé Leona Woods remembered, "below zero. Fermi and I crunched over to

the stands in creaking, blue-shadowed snow and repeated Herb's...measurements." They discussed the day's schedule, then hiked to Woods's nearby apartment and had pancakes. It was the second day of gasoline rationing; Chicago commuters jammed streetcars and the L, leaving half their cars at home.

"Back we mushed through the cold, creaking snow," Woods continues. "Fifty-seventh Street was strangely empty. Inside the west stands it was as cold as outside. We put on the usual gray (now black with graphite) laboratory coats and entered the doubles squash court containing the looming pile....The balcony was...filled with control equipment and read-out circuits glowing and winking and radiating some gratefully-received heat."

Fermi began the crucial experiment about mid-morning. First he ordered all but the last cadmium rod removed and checked to see if the neutron intensity matched the previous night's measurement. It did. George

Weil then moved the final control rod about halfway out and Fermi checked the count against his calculations. Another six inches, another increase in counter clicks before they leveled off.

The slow, careful checking continued through the morning. A crowd began to gather on the balcony. Leo Szilard arrived, Eugene Wigner, 25 or 30 people in all, most of them the young physicists and students who had done the work. Fermi was calm. The pile rising before them, faced with raw pine timbers up to its equator, domed bare graphite above, looked like an ominous black beehive in a bright box. Neutrons were its bees, dancing and hot.

Another observer recalled a startling moment that must have stopped a few hearts: "Suddenly there was a loud **crash!** The safety rod, which was called ZIP, had been automatically released. ZIP's relay had been activated because the intensity exceeded its arbitrary setting. It was

11:30 a.m. Fermi said, 'I'm hungry. Let's go to lunch.'" The Italian navigator was a man of habits. He may have decided as well to give everyone time to calm down.

At two that afternoon they prepared to complete the experiment. Compton joined them. Forty-two people now occupied the squash court, most of them crowded onto the balcony.

Fermi ordered all but one of the cadmium rods again unlocked and removed. He asked Weil to set the last rod at one of the earlier morning settings and compared pile intensity to the earlier reading. When the measurements checked he directed Weil to remove the rod to the last setting before lunch, about seven feet out. The pile was nearly critical. He ordered ZIP inserted. That adjustment brought down the neutron count. "This time," he told Weil, "take the control rod out twelve inches." Then he ordered ZIP winched out as well. "This is going to do it," he told Compton. "Now it will become self-sustaining. The

recorder trace will climb and continue to climb; it won't level off."

Anderson remembered the moment:

"At first you could hear the sound of the neutron counter, clickety-clack, clickety-clack. Then the clicks came more and more rapidly, and after awhile they began to merge into a roar; the counter couldn't follow anymore. That was the moment to switch to the chart recorder. But when the switch was made, everyone watched in the sudden silence the mounting deflection of the recorder's pen. It was an awesome silence. Everyone realized the significance of that switch; we were in the high-intensity regime and the counters were unable to cope with the situation anymore. Again and again, the scale of the recorder had to be changed to accommodate the neutron intensity, which was increasing more and

more rapidly. Suddenly Fermi raised his hand. 'The pile has gone critical,' he announced. No one present had any doubt about it."

CP-1 achieved criticality at 3:25 p.m. on December 2nd, 1942. It ran for about four-and-a-half minutes at half a watt before Fermi shut it down.

Eugene Wigner recalled the awe he and the others felt that afternoon:

"Nothing very spectacular had happened [Wigner said]. Nothing had moved and the pile itself had given no sound. Nevertheless, when the rods were pushed back in and the clicking died down, we suddenly experienced a let-down feeling, for all of us understood the language of the counter. Even though we had anticipated the success of the experiment, its accomplishment had a deep impact on us. For some

time we had known that we were about to unlock a giant; still, we could not escape an eerie feeling when we knew we had actually done it. We felt as, I presume, everyone feels who has done something that he knows will have very far-reaching consequences which he cannot foresee.”

It was Wigner who produced the famous *fiasco* of Chianti with which they toasted the event from paper cups. Compton called Conant in Washington to announce, “The Italian navigator has just landed in the new world.” Szilard shook hands with Fermi and told him he thought that day would go down as a black day in the history of mankind.

But CP-1 was a first iteration of a cornucopia. Out of its bounty came weapons of mass destruction, which paradoxically have contributed to the prevention of world-scale war. Out of its bounty came, as well, a new source of

energy, carbon-free and inexhaustible. Today 31 countries operate 451 nuclear power reactors for electricity generation, without contributing to global warming. In 15 countries, 60 new nuclear plants are under construction. Nuclear generates 11 percent of world electricity.

You started something here at the University of Chicago on a cold December day seventy-five years ago. And with uranium now extractable economically from sea water, there's no end to it in sight.

Thank you.