CHAPTER EIGHT

THE REACTOR ZOO GOES CRITICAL

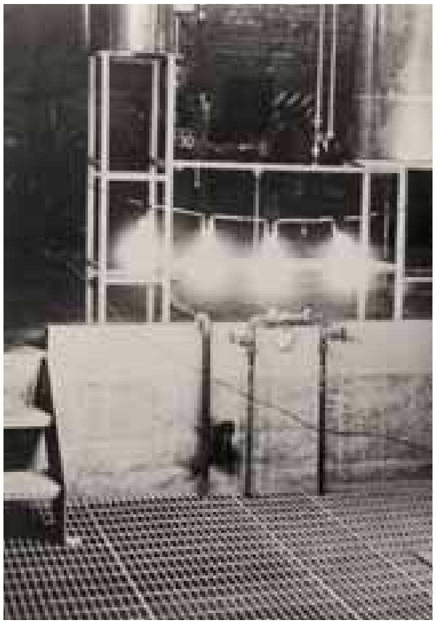
Then gradually construction workers were replaced by operations people.

—Idaho Department of Labor, 1951—

Walter Zinn's estimate was too low. He thought the breeder reactor was ready for action in late May 1951. He had ordered forty kilograms of enriched uranium packed into 179 fuel rods and some extras as a margin for error. His crew placed them into the core one after the other, measuring reactivity effects each time. As the supply of rods dwindled, dignified guests and visitors waited expectantly in the control room, watching needles trace ink on scrolls of data paper. The extra rods went into the reactor. With the last one inserted, the reactor remained calm.

Any reactor has several milestone moments in its early life. The first is the day and the hour it attains criticality for the first time. After that, the operators pass mini-milestones as they gradually step up the power levels, calibrate instruments, and run safety tests. A final moment of truth arrives when it runs under perfect control at its maximum-rated power level.

Going critical for the first time is significant because it shows that the physicists have loaded the reactor with enough fuel and arranged it suitably. The first criticality runs at a "zero power" state, meaning that the reaction produces just enough neutrons to keep the chain reaction alive. This generates very little heat. In the early 1950s, when every reactor—along with its fuel—was a first of its kind, reactor designers could only estimate how much uranium would form a critical mass.



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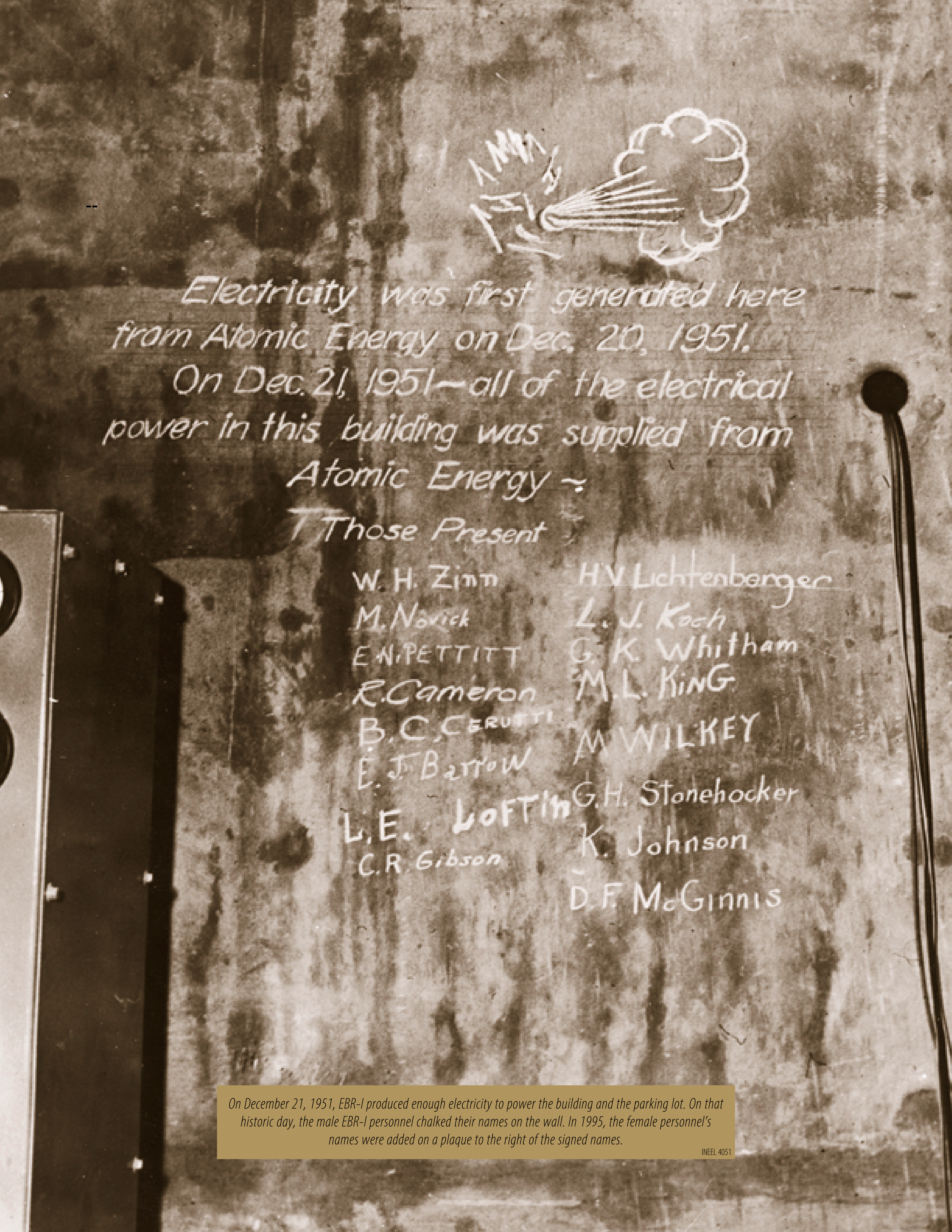
The four famous lightbulbs at EBR-I were strung up between the generator (out of picture) and the handrail.

Zinn figured he needed seven and a half more kilograms of enriched uranium and asked the AEC to release it from military supplies. The material went to the Argonne Laboratory in Chicago where the engineers fabricated more fuel rods. These procedures cost him three months.[1]

The deed was done. Finally, on August 24, 1951, the EBR went into history as the first reactor to go critical at the NRTS, the first to use U-235 fuel, and the first to use a liquid-metal coolant. The physics measurements indicated that the arrangement and shape of the fuel rods needed improvement before the reactor could be connected to an electrical generator. Two-thirds of the fuel rods were shipped back to Chicago where the fuel was removed from its stainless-steel cladding, placed in a hydraulic press and die, and made slightly shorter and fatter. Returned to Idaho, the rods were arranged in a belt around the original rods. The new massing of uranium allowed the reactor to produce the core temperatures required to power the generator.[2]

On December 20 the reactor was connected *via* the generator to a string of four lightbulbs. At 1:23 p.m. the bulbs glowed brightly, and Zinn wrote in the



Electricity was first generated here
from Atomic Energy on Dec. 20, 1951.
On Dec. 21, 1951—all of the electrical
power in this building was supplied from
Atomic Energy ~

Those Present

W. H. Zinn
M. Novick
E. N. PETTITT
R. Cameron
B. C. CERUTTI
E. J. Barrow
L. E. LOFTIN
C. R. Gibson

H.V. Lichtenberger
L. J. Koch
G. K. Whitham
M. L. KING
M WILKEY
G.H. Stonehocker
K. Johnson
D. F. McGinnis

On December 21, 1951, EBR-I produced enough electricity to power the building and the parking lot. On that historic day, the male EBR-I personnel chalked their names on the wall. In 1995, the female personnel's names were added on a plaque to the right of the signed names.

INEEL 4051

log book, "Electricity flows from atomic energy. Rough estimate indicates 45 kw." After a second experiment the next day, Zinn took up a piece of chalk and wrote his name on the concrete wall of the reactor building and invited the crew present to follow, one by one.[3]

Atomic power was a reality. The NRTS had its first stunning success. The first nuclear reactor in the world to generate a useable amount of electrical power would forever be linked to Idaho and the NRTS. A few days later, the excitement over, the reactor began producing the electricity needed for routine operation of the EBR complex.

The MTR went critical for the first time on March 31, 1952, the first of many milestones. Visitors from Oak Ridge and Argonne, who had cooperatively built the project, along with Bill Johnston, Richard Doan, Bion Philipson, and others crowded together to listen to the clicking of an instrument counting the fissions taking place inside the core. Physicist Fred McMillan operated the reactor's control rods. This time, the reactor didn't disappoint. Johnston said, "Well, we got us a reactor." And that was that—no chalk, no champagne. The newspaper reporter was more effusive, recognizing the "new atomic egg they were hatching" as a historic event: mankind's first materials testing reactor. The weary team that had been working nineteen-hour days after months of preparation simply went home to their beds.[4]

But they were back soon. Doan demanded that the stepped-up progress to full-power operation must also prove that the people working near the reactor would be safe from radiation. This work was the province of five HPs. Doan had them report directly to his office and not to the reactor manager. Their sole mission was to prevent all workers, including absent-minded scientists whom the HPs sometimes referred to as "squirrels," from suffering the potentially harmful effects of radiation. For this, they had the power to evacuate work areas and scram (shut down instantly) the reactor if they thought it necessary.[5]

One of many safety tasks was to test the shielding around the MTR. This assignment fell to HP John Byrom, a new Phillips employee in 1952. He had trained in radiological physics in a special class of twelve people at Oak Ridge and then moved to Idaho Falls with his family. Like most other NRTS employees, he began the daily habit of traveling to work on a Site bus.

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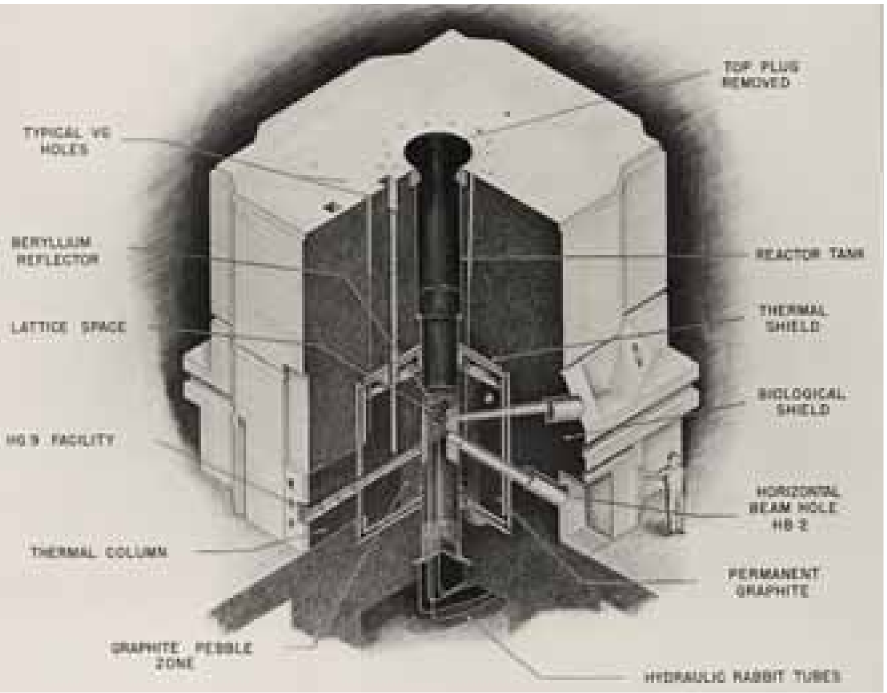
Above. MTR control room as reactor goes critical on March 31, 1952. Below. The top of the MTR, as seen from catwalk above it. A crane (unseen) lowers the top plug over the reactor core. Taken on March 31, 1952, engineers were making a final check of the control rod drive. Apparatus above round plate is the control rod mechanism that ensures the control rods are attached to the drive mechanism.

Getting to the MTR operating floor required passing several safety and security barriers. The MTR complex was enclosed behind a chain-link fence studded with night lights and further defended by a ten-foot-wide patrol road. The bus dropped him at the MTR gatehouse, where a guard checked his security badge each day. If anyone cared to notice, they could see that the 250-foot MTR exhaust stack stood on the downwind side of the complex and, for security reasons, showed no aircraft warning lights. To get to the reactor, Byrom passed into the "exclusion" area that contained the MTR building with its laboratory wing and fuel storage "canal," along with other special labs and storage buildings. The building was about 130-feet square and made of prefabricated concrete slabs.[6]



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Above. The thickest wrapping around the MTR is the biological shield. Right. The MTR hot cells. Behind viewing windows three feet thick, operators examine test samples. Note shield plugs above and below windows for electrical leads, instrument air, oxygen, or other requirements.

INEEL 61-4707

Inside, the enriched uranium core of the reactor was like a small jewel wrapped in successively thicker layers of wrapping. Surrounding the fuel was a steel tank thirty-feet deep and six feet in diameter. A steel lid fit over the top. Pumps forced cooling water through the tank under pressure to keep it from boiling. Two types of reflectors surrounded the tank to bounce neutrons back toward the core. The closest to the fuel was made of beryllium metal. Just beyond was an outer zone of graphite, cooled by forced air. Then came ten feet of dense concrete and gravel—the main biological shield. A casing of steel enclosed the whole contraption, which looked like an oversized cube thirty-two feet to the side.[7]

It was the one hundred holes piercing the reactor that were Byrom's special concern. A complicated plug stoppered each hole, made up of the same sequence of materials as those adjacent to it in the reactor cabinet. While the reactor was shut down, operators removed a plug and inserted a test sample toward the core. Overhead, a thirty-ton crane helped maneuver the heavy plugs into and out of shielded containers called "coffins." The plugs were supposed to prevent neutrons from straying to the outer edge of the plug openings. But would they?

Byrom used X-ray film to check for leaks, the same 14x17 inch size that physicians used for chest X-rays. He ordered dozens of boxes. In the MTR's photographic darkroom, one of several labs in the MTR laboratory wing, he loaded each sheet into a light-tight holder containing a thin lead foil backing. He matched the film to grid marks on the cabinet and numbered each grid cell. When the reactor operators started "noodling" the control rods, moving them up and down to get familiar with the MTR as they advanced toward full power, Byrom was ready.

We had already surveyed to see if we had any heavy leaks. For that we used several kinds of meters—GM meters, cutie pies, and something we called a rudolf. The barytes concrete in the shield, which had been packed in there pretty well to eliminate bubbles, did a pretty good job. Still, neutrons can squirt around corners and come out the holes, so we had to check those very carefully.

I plastered that reactor. We marked it off and pasted these films all over the reactor—holes, every place that was designed to give access into the reactor core. We used a lot of duct tape.

Then we ran the reactor at low power with the reactor holes closed up tight. Any radiation coming through the openings would produce an image on the film, black rings or dots, or whatever the shape of the leak. It took months of the physicists playing around with the reactor to give all of the film an equal amount of time. They were making their own tests of reactor fluxes in the different parts of the reactor, so on any given day, one side of the reactor might get more neutron flux than the others.

We found many places where the design was a little bit inadequate. I turned over this data to the engineers, and they designed better, more efficient plugs. But we still had to add extra shielding against some of the bigger openings. We stacked boxes of paraffin and sheets of cadmium, which absorb neutrons, and then blocks of lead and concrete in front of that. That was a lot of weight, and it had to be moved away whenever it was time to load or unload the experiments.[8]

Paraffin itself was a hazard. Someone occasionally left a box near a hot water pipe, where it would get too warm and combust. Word of one too many paraf-

INEEL 13405

Radiochemist loads an irradiated MTR flux wire into a scanner. The machine will "count" how many of the wire's atoms absorbed neutrons while in the reactor.

Reactor Power!

Power is the time rate at which energy is converted from one form to another; it is commonly measured in "watts." Reactor power is the rate at which work can be done by the heat that the reactor generates. It is measured in "thermal" watts. If the reactor produces steam to drive generators, the output is measured in "electric" watts.

A related concept is the "reactor period," once called the "doubling period." This is the amount of time it takes for the neutron flux to double (approximately). The art of reactor start-up and control is to keep the chain reaction from doubling at too rapid a rate. The operator adroitly moves regulating (control) rods in and out of the core to maintain a constant power level. If the neutrons multiply too fast, they will outpace the ability of the coolant to carry away heat. Therefore, it is not desirable to allow the neutrons to multiply at an ever-smaller doubling time.

A reactor operator is concerned with three basic measurements of neutron flux: the doubling period, the water temperature, and the water flow. The reactor is set to shut itself down automatically if any of these reaches certain previously established values.

Someone coined the dainty term "excursion" to describe a sudden and unplanned rapid rise in the power level. Many experiments at the Site involved deliberately planned excursions, one purpose of which was to learn the safe operating limits of nuclear reactors.

fin fires reached the ears of Dr. Doan, who reportedly issued a terse memorandum stating, “There will be no more paraffin box fires.” And apparently, there were none.[9]

Another aspect of safety was for reactor operators to understand exactly how neutrons moved about inside the reactor. The one hundred openings led to different positions near the core or in the graphite around it. Flux differed at every spot, which was desirable because not all experiments would need the same exposure. The scientists could tailor an experiment to the most appropriate flow of neutrons. The reactor designers at Oak Ridge had predicted where the flux would be weak or intense. Now their work had to be tested.

Technicians placed tiny strands of cobalt wire in hundreds of locations in the graphite and inside the core, gaining access *via* small holes in the beryllium reflector. The reactor was made to go critical for a few minutes to irradiate the cobalt. The cobalt wires were withdrawn and sent to a laboratory down the hall for counting. Measuring instruments could detect how many atoms in each wire had absorbed neutrons. After months of doing this, the physicists plotted a map of the MTR’s neutron flux. It pleased the Oak Ridge designers to learn that their predictions had been reliable.[10]

Handling spent fuel also required safety procedures. When the reactor was fully in business, the operators shut down to replace the fuel about every seventeen days. Using remotely controlled equipment, operators opened the lid of the reactor and transferred the hot fuel into lead-lined containers. These were lowered into a water-filled trough, called a canal, where the containers ejected their fuel elements under cover of sixteen feet of water. Workers, shielded by the water, leaned over the canal with long-handled tools and moved the fuel to its resting place. The fuel, referred to as “green” because it was fresh from the reactor, emitted gamma radiation and lit up the water with the soft glow of Cerenkov radiation.

After about three months in the canal, the fission products with short half lives lost their radioactivity, leaving the fuel safer to handle. Workers loaded the fuel into a special cask and trundled it over to the Chem Plant, which recovered its unused U-235.

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Phillips took the MTR up to its full power of 30 megawatts on May 22, 1952, another landmark day at the NRTS. The MTR was ready in August for its mission to assist other reactor designers by testing the materials of which their reactors would be composed.

The first reactor the MTR assisted was the Rickover reactor five miles up the road, the S1W (S for submarine, 1 for first prototype, W for Westinghouse). Westinghouse physicists had determined that the predominant source of

NRTS News, August 1968

Two versions of the MTR canal. Above, as depicted in Site newspaper; left, a technician poses with “cutie pie,” a beta and gamma radiation detector. His colleague withdraws capsule of cobalt-60. Lights and tools dangle down side of canal.

gamma radiation from the reactor was nitrogen-16, which was generated in the reactor cooling water when a stray neutron struck an atom of oxygen-16. What they didn't know was how likely it was for any given number of nitrogen atoms to capture neutrons and therefore how big a problem nitrogen-16 would be. Dr. John Taylor, responsible for the *Nautilus* shielding studies, recalled:

> *Because the half-life of nitrogen-16 is only 7.35 seconds, the capture cross-section [probability of capture] could not be measured by the normal accelerator methods. Without that information there was no way to design the major components of the shielding for the submarine. Thus, a closed loop was installed in the MTR to circulate water through the MTR neutron flux so as to be able to measure the nitrogen-16 activity generated in the water. The inferred cross section was used to design the shielding. The facilities at the NRTS were essential to solving this key question bearing on the radiation safety of the Navy crew.*[11]

Another issue for the Navy was the long life of the reactor and its fuel. Changing fuel in the cramped spaces of a submarine was extremely inconvenient, not to mention hazardous. Replacing the entire core was worse. The boat had be dry docked while welders cut open the skin of the boat and removed the reactor the same way a surgeon might remove a bad appendix. The procedure would tie up the boat for up to two years, hardly the place for a weapon system during war or an international crisis.

The Navy's Westinghouse team sent sample capsules to the MTR for irradiation for the requisite number of weeks or months, whatever would duplicate the capsules' lifetime radiation in a ship. The team sent fuel alloys, control rod materials, and structural metals. The work was highly classified; MTR workers sometimes did not know what was inside the test capsules.

Westinghouse scientists took the capsules back to their own labs, dismantled them, and studied them in minute detail—weigh, X-ray, measure, count. Little by little, they learned which materials would hold up and which would not. The scientific habits of making predictions, observing closely, and keeping detailed records were the same as those so recently practiced by the Bureau of Ordnance. Every experiment at the MTR—and everywhere else at the NRTS—began with the sponsor's prediction and ended with some increment to the world's store of knowledge, however large or small.


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Above. A straddle carrier transported spent fuel elements from the MTR to the Chem Plant. Left. Fuel elements cool in the MTR canal. As a side experiment, a can of food rotates in a special rig so that contents get equal exposure to gamma radiation.

The Navy experiments were costly because the conditions in the capsule duplicated the effect of pressurized water on the sample. One of the Navy's useful early findings was to discover that radiation affected stainless-steel welds by making them stronger, but also made the metal more brittle.[12]

The S1W had gone through the same kinds of start-up and safety procedures as the EBR and the MTR. It was scheduled to go critical on March 29, 1953, but Rickover's approach to milestone moments was rather more calculating than either Phillips' or Argonne's. He felt the occasion to be of extreme importance. Certain people who should have been there were not. Some of those who were present should not have been. So he postponed the procedure for a day and adjusted the mix of people in the control room. The reactor first went critical shortly before midnight on March 30, 1953.[13]

Two months later it was time to prove that the high-temperature reactor could produce enough power to turn a propeller shaft. Rickover was again in the control room, along with AEC commissioner Thomas Murray. At the epochal moment, Rickover instructed Murray to open a certain valve. John Simpson later wrote:

> *The commissioner was thrilled at the chance to play an active role in making history. Murray stepped forward, grasped the valve handle, and slowly turned it. In the adjoining area, inside the hull of this submarine-on-land, steam hissed against the turbine blades. A propeller shaft began to turn.*[14]

The heat of the reactor was doing muscle work. A hasty champagne made of alcohol from the chemistry lab and soda water from a soft drink dispenser was mixed for a toast.[15]

When Westinghouse was ready in June to take the reactor to its next milestone, full operating power, it began a 24-hour endurance run. Again Rickover intervened. He was anxious to convince skeptics that nuclear-powered propulsion was truly reliable—that a boat could remain submerged for a protracted run and the crew come safely home. He decided suddenly to extend the run and simulate a crossing of the Atlantic Ocean. This would take nearly a hundred hours at full power.[16]

INEEL 6477

Above. The S1W building, camera facing southwest. Note MTR area in background. Below. Inside the S1W hull during construction.

Naval Reactor Facilities

Charts went up on the wall of the reactor control room for plotting a 2,500-mile route from Nova Scotia to Ireland, and the Navy men who happened to be there for training began four-hour watches. For sixty hours, the run went well. Then a condenser tube began to leak, and radiation was soon detected near it. Next a steam generator sprung a few small leaks. The Westinghouse people argued among themselves: should they shut down the reactor? Given the location of the leaks, neither public nor personnel safety was at stake. The run continued.[17]

Department of the Navy, Submarine Force Museum

Naval Reactor Facilities

Then the control for one of the steam generators failed, causing the water level to drop and the reactor power level to become erratic. Debate about shut-down became more heated. The crew reduced the power level to half and restored the water level. In the end, the reactor "crossed the Atlantic" in ninety-six hours, but not entirely at full power. The crew had resourcefully fixed emerging problems and kept the reactor running. Had there been an accident, the nuclear navy might have become a political impossibility.[18]

But there was no accident, and there would be none. Rickover was well aware of the engineering work yet to be done. "We are having trouble with valves and with controls," he wrote soon after the run, "but we are solving every one of them, and as fast as we learn anything that needs modification, we are incorporating it into the *Nautilus*."[19]

The success of the S1W led to the launch of *USS Nautilus* on January 21, 1954, five years after design had started. The Navy was proud of its innovation, and the public eagerly consumed news of its many "firsts." One of them occurred in 1958 when the submarine became the first to travel beneath the ice at the North Pole. After the ship's celebrated return, skipper William Anderson sent a telegram to Idaho, paying tribute to those who had engineered the S1W prototype.

> *... during* Nautilus*' North Pole submerged transit from Pacific to Atlantic the performance of our engineering plant exceeded all expectations. To the first manufacturer of naval nuclear propulsion our sincere thanks for providing the plant that made possible this first transpolar crossing.*[20]

In the roster of reactor concepts "proved" for the first time at the NRTS, the S1W was the first to use water under high pressure as a coolant. Because it succeeded so well, Rickover and the AEC chose the same technology to demonstrate that the concept could support a civilian power industry. In December 1957, the Shippingport Atomic Power Station went critical in Pennsylvania, operated by the Duquesne Light Company. Rickover invested in it the same attention to detail he had with the submarine. He obliged the company to allow his own representative access to the control room at any time with full authority to

Above. The launching of USS Nautilus, *January 1954.*
Left. USS Nautilus *at sea and at speed.*

shut down the plant if he thought it was not operating safely. Rickover explained himself clearly: the "whole reactor game hangs on a much more slender thread than most people are aware. There are a lot of things that can go wrong and it requires eternal vigilance."[21]

In 1956 Congress proceeded with the construction in Idaho of the prototype reactor for the aircraft carrier *USS Enterprise*. Thereafter, an entire nuclear-powered fleet slid down the shipyard ways into the sea.[22]

Cerenkov Radiation

In 1934, a Russian physicist named P.A. Cerenkov placed some radium in a flask of water. He saw a bluish-white glow in the water.

Cerenkov learned that this glow was caused when the gamma rays hit electrons in the water. The energy of the gamma rays was so great that the electrons moved through the water faster than light moves through water.

This beautiful blue light was a common sight around the NRTS. Whenever an irradiated fuel slug was removed from a reactor and placed into a water-filled storage canal, the diffuse blue glow surrounded the slug. Cobalt-60, which also emits gamma rays, also produces the light when it is stored in water. The most brilliant display of "Cerenkov radiation" appeared when a reactor operated within a tank of water. NRTS photographers prized certain photographs of this effect and used them frequently in pamphlets and public information brochures.

Humorous road sign, erected by an Idaho business owner on Highway 20 near the Site, entertained tourists and Site workers alike.

Argonne National Laboratory-West 9112