Shippingport Atomic Power Station
Shippingport
25 miles northwest of Pittsburgh
Beaver County
Pennsylvania

HAER No. PA-81

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PHOTOGRAPHS

WRITTEN HISTORICAL AND DESCRIPTIVE DATA

HISTORIC AMERICAN ENGINEERING RECORD
MID-ATLANTIC REGION NATIONAL PARK SERVICE
DEPARTMENT OF THE INTERIOR
PHILADELPHIA, PENNSYLVANIA 19106

HISTORIC AMERICAN ENGINEERING RECORD

SHIPPINGPORT ATOMIC POWER STATION

HAER No. PA-81

Location:	Shippingport, Pennsylvania, 25 miles northwest of Pittsburgh, Beaver County, Pennsylvania, on the Ohio River. UTM Coordinates: Zone 17, Northern Half, 477966 meters (to nearest 100 m)
Present Owner:	Site and electrical generating portion of the plant is owned by the Duquesne Light Company; Nuclear heat generation portion of the plant is owned by the U.S. Department of Energy (DOE).
Present Occupant:	Site is currently leased by DOE.
Present Use:	No longer used as a nuclear test or electrical generator facility as of October 1982; preparation ongoing for the decontamination and decommissioning of the site.
Significance:	Operational in December, 1957, Shippingport Atomic Power Station was the first large-scale central station nuclear power plant in the United States and the first plant of such size in the world operated solely to produce electric power; it was the first to have training classes for operators and supervisors; it was the first to use a water-cooled breeder core for a power plant.
Project Information:	The plant which had been run for 25 years by the DOE Naval Reactors program has been shut down and responsibility transferred to DOE's Office of Terminal Waste Disposal and Remedial Action. It is the objective of this Office to decontaminate and decommission the site, making it safe from a radiation standpoint for unrestricted return to the owner. An auxiliary objective of the project is to serve as a decommissioning demonstration to the nuclear industry by providing useful information and data for future decommissioning projects.
	This material is based on the Department of Energy booklet: "Shippingport: The Nation's First Atomic Power Station," (1983) prepared by Francis Duncan and Jack M. Holl, History Division, U.S. Department of Energy, and submitted in lieu of HAER written data.

INTRODUCTION

At 4:30 a.m. on December 2, 1957, the Shippingport Atomic Power Station reached criticality, becoming the Nation's first large-scale central station nuclear power plant to attain a chain reaction. In Chicago, fifteen years earlier to the day, the Italian-born Nobel laureate Enrico Fermi had achieved the world's first self-sustained chain reaction, an event which is often accepted as the beginning of the nuclear age. Fermi and his associates had reached their goal by using a simple assembly of graphite, uranium metal, uranium oxide, and wood. The Chicago Pile was an experiment designed to prove the correctness of theoretical physics. Fermi and his team knew it would produce no useful power.

In contrast, the Shippingport reactor was a complicated piece of machinery, generating large amounts of heat, requiring an elaborate cooling system, depending upon materials which only fifteen years earlier had been laboratory curiosities, and relying upon sophisticated components and instruments which did not exist when Fermi conducted his experiment. The purpose of this plant was to demonstrate the feasibility of producing useful energy from the atom for civilian application and to advance civilian power reactor technology.

From conception through almost all of its operating life, Shippingport was the responsibility of Admiral H. G. Rickover. The Bettis Atomic Power Laboratory, often supported by the Knolls Atomic Power Laboratory, made technical recommendations but he and his organization made the key decisions. He carried his responsibilities, however, far beyond the realm of technology. To him the purpose of Shippingport was much more than the demonstration of the engineering feasibility of using atomic power for commercial application: the station was to establish standards for training personnel and to apply procedures for safe operation. These were to set an example for industry.

ACHIEVEMENTS

The Shippingport Atomic Power Station reactor was of the pressurized water type. In this approach uranium was the fuel and water, kept under pressure to prevent boiling, removed heat from the core and moderated--or slowed down--the neutrons to the energies at which the fission process could continue. Movable hafnium control rods absorbed excess neutrons. Because water passing through the core became radioactive, two separate systems converted the reactor's heat to steam to produce electricity. In the first or primary system, water flowed from the core through a heat exchanger called a steam generator and back again. In the steam generator, heat from the primary system passed through tubes to water in a secondary system. In the secondary system water flashed to steam to drive the turbine and electric generator, condensed, and returned to the steam generator.

Shippingport has often been referred to by the initials "PWR", but the designation subsequently has been applied to pressurized water reactors as a type. By 1982, 101 of the nuclear power plants planned, under construction, or in operation in the United States were the pressurized water type. The total capacity of those in operation was 50,266 megawatts.

Shippingport proved that an atomic power station could function on a utility network as a base load plant--meeting the demand for power which is constant--or as a swing load plant--meeting the demand for power which increases and decreases during a given period. Shippingport provided development and dissemination of civilian power reactor technology and demonstrated the first inplace decontamination of an entire nuclear power plant. Furthermore, the first school for training civilian reactor operators and supervisors, foreign as well as domestic, was at the station.

The success of Shippingport was of particular concern to the Eisenhower administration. At the United Nations Second International Conference on the Peaceful Uses of Atomic Energy, held in Geneva, Switzerland from September 1-13, 1958, a cutaway model of the Shippingport pressure vessel and core easily dominated the American exhibit. A collection of technical papers on the atomic power station made up one of the thirteen presentation volumes describing the American atomic energy program. The station even became a piece in the game of international politics, for it was a prominent feature on the itineraries of many foreign dignitaries as evidence of American leadership in peaceful application of the atom. Frol Kozlov, Deputy Premier of the Soviet Union, toured Shippingport and other American atomic energy facilities before Vice President Richard Nixon went to Russia in 1959, an exchange of visits which was part of a major effort by President Dwight D. Eisenhower and Premier Nikita Khrushchev to ease tension between the two countries.

Most of Shippingport's contributions were highly technical. Some of the reactor components--main coolant pumps, valves, piping, and steam generators--were the first to be designed, developed, and fabricated for civilian nuclear power application. Shippingport was the first to have reactor containment, a structure which housed in a series of large, interconnected, vapor-tight vessels all parts of the plant containing the reactor and primary system. The development of uranium dioxide fuel contained in zircaloy tubing proved outstandingly successful and has been widely adopted in the industry.

In 1977 Shippingport began operating on a thorium-uranium 233 core to demonstrate the feasibility of breeding in a water-cooled reactor; that is, producing more reactor fuel than was consumed. The project was called the "LWBR" or the "Light Water Breeder Reactor." Whether the fuel actually bred will not be accurately determined until tests and analyses are carried out after the fuel is removed following reactor shutdown. However, in the final stages of the breeder core's operation every indication of breeding continued to be favorable. The light water breeder core was designed so that the concept could be widely adopted by other pressurized water reactor power plants--by those plants which already existed and for which the technology was best known. There were no known reasons why the light water breeder concept could not also be applied to a boiling water reactor plant, another type built here and abroad, but no specific work has been done on the subject.

Because it was a government-owned reactor, Shippingport was not subject to many regulatory requirements. However, so that commercial application could be fully demonstrated, Admiral Rickover determined from the beginning that Shippingport was to adhere to the regulations which would govern commercial ventures to the fullest extent possible for design, construction, and operation. Thus the Reactor Safeguard Committee (predecessor of the Advisory Committee on Reactor Safeguards) reviewed the original site selection. For the same reason, Admiral Rickover applied industry standards, such as the ASME (American Society of Mechanical Engineers) Boiler and Pressure Vessel Code, which included a special state permit, as the basis to develop nuclear standards; and environmental standards, which included obtaining a special state permit for release of processed, purified, radioactive waste water. The design, technology and standards were to be unclassified. An independent regulatory group within the Atomic Energy Commission responsible for licensing commercial reactors reviewed a safety analysis reports at each partial and complete refueling of the reactor. Modifications to the reactor plant were made periodically to upgrade the reactor and reactor operations to reflect lessons learned at Shippingport and at other licensed commercial reactors.

From the beginning of operations, a government representative was stationed in the control room at the Shippingport station. His responsibility was to ensure that the plant was run safely, and he had the authority to shut down the plant if he believed it necessary.

ORIGINS

The Atomic Energy Act of 1946 placed control of the new source of energy in the hands of a civilian Atomic Energy Commission. Subject to the needs of national defense, the Commission was to direct the development and utilization of atomic energy as far as practicable toward improving public welfare, increasing the standard of living, strengthening free competition in private enterprise, and promoting world peace. Some gains had been made, especially in science and medicine. Thus when President Harry S Truman laid the keel of the nuclear submarine NAUTILUS at Groton, Connecticut on June 14, 1952, he spoke of the ship as the forerunner of "atomic powerplants producing electricity for factories, farms, and homes."

For several reasons progress toward an atomic power plant after World War II had been slow. Uranium was in short supply. Furthermore, the cold war led the United States to accelerate its weapons programs, a priority which left little surplus for non-military purposes. In addition, the technology of reactors for producing fissionable material for weapons overlapped the technology of power reactors; therefore much of the information was secret and not readily available to industry. Finally, the role of the government in developing atomic power fell into the political dispute of whether the public or private sector should lead in the technology's development.

Moreover, the technology itself was complex. A power reactor had to be safe, reliable, and able to produce usable amounts of power economically. But several types were possible--one individual counted 80 or more--and although this was an extreme number, no one could decide which among them were most suitable to generate power for civilian use. An extensive research and development effort had to be carried out to determine the best type of fuel, a safe means of reactor control, the most suitable coolant, and the means for circulating the coolant. Much work was needed to investigate the behavior of materials exposed for long periods to high temperatures and intense radiation. Valves, pumps, heat exchangers, and piping had to be designed, tested, and fabricated to new standards--and often the standards themselves were not known. Because the new standards would be more stringent, more exacting manufacturing and quality control would be required.

A CIVILIAN POWER PROJECT

By 1953 many of these constraints were lessening. A vigorous exploration program had eased the shortage of uranium and, since the Chicago Pile, thirteen testing, research, and experimental reactors had contributed to nuclear theory and reactor technology.

Of the technical achievements, the successful operation of the land-based reactor prototype for the submarine NAUTILUS was easily the most outstanding feat of 1953. Located at the National Reactor Testing Station in Idaho, the facility was part of the joint effort of the Atomic Energy Commission and the Navy, and had been designed, developed, and constructed under the direction of Admiral (then Captain) Rickover.

Admiral Rickover had been part of the atomic energy program since 1946. Before the Commission was established, the Navy had sent him, along with a few officers and civilians, to Oak Ridge, Tennessee, one of the major atomic energy installations. Their assignment was to investigate the use of atomic energy for ship propulsion. Out of this effort had come the NAUTILUS prototype in Idaho. Reaching criticality on March 30, 1953, the prototype generated several thousand kilowatts of thermal power on May 31. Several days later the prototype made a simulated non-stop run across the Atlantic. At the same time the NAUTILUS was well under construction at Groton, Connecticut.

The inauguration of President Dwight D. Eisenhower and the return of a Republican majority to both houses of Congress brought a shift in policy toward nuclear power. The President was dedicated to finding peaceful applications of nuclear energy. The powerful Joint Committee on Atomic Energy (composed of nine senators and nine representatives) strongly favored using nuclear energy for power generation. Both the President and the Congress saw the need to amend the Atomic Energy Act. As the new administration launched its first tentative investigation into the feasibility of developing a civilian nuclear power program with industrial participation, the government also explored ways to fulfill the President's pledge to cut Federal spending. Lewis L. Strauss, a former commissioner and now President Eisenhower's special advisor on atomic energy, evaluated the Commission's budget, including the reactor development program. To save money, Mr. Strauss proposed to the

National Security Council on March 31, 1953, eliminating plans for a land-based prototype propulsion reactor for an aircraft carrier. The prototype was to drive a single shaft and, after serving its immediate purpose, produce power and also plutonium for weapons. The President approved the recommendation on April 22.

The Commission appealed the decision. On April 29, Henry D. Smyth, acting on behalf of his fellow commissioners, asked the President to redirect the aircraft carrier project toward civilian power. Pointing out that the Council itself had declared that the early development of nuclear power by the United States was a prerequisite for maintaining leadership in atomic energy, Smyth noted that the aircraft carrier prototype offered a promising approach to civilian power. "If the pressurized light water reactor is not continued, this country will be in the position of having a policy for the speedy development of civilian atomic power without a reactor in prospect for attaining that goal." Gordon Dean, Chairman of the Commission, convinced President Eisenhower on May 4 to endorse the recommendation, pending the availability of private financing.

The Commission had two alternatives. One, proposed by Admiral Rickover, entailed strong centralized governmental control. In this way the government could assure itself of the specific direction of the effort, fulfill its responsibility for strict control over the expenditure of funds, and avoid protracted studies. To save time he would utilize as much as possible of the work done on the aircraft carrier prototype. The chief of the production reactor branch, that part of the Commission's organization responsible for reactors producing fissionable material for military purposes, offered a second approach. He would assess several possible pressurized water reactor designs, for one might produce more power than the modified aircraft carrier reactor. Only by generating a significant amount of power could an atomic power plant begin to compete economically with a conventional power plant. In addition, he proposed to allow industry and the Commission's several laboratories a large degree of participation.

On Thursday, July 9, the Commissioners decided: the civilian power project would be based on the aircraft carrier reactor--stripped of its military features--and assigned to Admiral Rickover. Congress on July 27, 1953, specifically authorized funds for research, development, and construction of a large-scale central station nuclear power plant.

Although the Commission had a civilian power project, it did not yet have an industrial partner. At a meeting of utility executives in Chicago, Commissioner Thomas E. Murray, on October 22, 1953, invited the participation of a power company to finance, build, and operate the electrical generating portion of the plant. The initial response was slow; a month later the Commission renewed its invitation and set a deadline of February 15, 1954, for the proposals.

Even though the project had hardly begun, President Eisenhower seized upon the first atomic power plant as evidence of American purpose and commitment to the development of the peaceful uses of atomic energy. Before the United Nations General Assembly on December 8, 1953, he declared: "The United States knows that peaceful power from the atomic energy is no dream of the future. That capability, already proved, is here--now--today."

SPECIFICATIONS

In July 1953 the Commission established the general specifications calling for a reactor plant which would generate at least 60 megawatts of useful electricity. The fuel was to be slightly enriched uranium and the coolant demineralized ordinary water. The life of the fuel elements was to be as long as possible and refueling was to take place with a minimum shutdown period.

For a brief time, Admiral Rickover and his engineers considered a higher capacity but decided against it. The technical uncertanties were too great: 60 megawatts was a reasonable extrapolation of existing technology. Going higher would mean larger components, higher costs, and would provide little additional data than provided by a 60 megawatt plant.

DESIGN PHILOSOPHY

Admiral Rickover and his team recognized that the project had two purposes: to show that a central station nuclear power plant could function on a utility network, and to provide technical information to advance civilian power reactor technology. Deeply conscious that he was setting precedents for a new industry, he deliberately chose a conservative design philosophy. First among the requirements he established was safety. He and his organization paid a great deal of attention to the water which became radioactive when transferring heat from the core. The reactor coolant had to be contained in a sealed system and the material in contact with the coolant had to be corrosion resistant. The most serious potential accident was a loss of coolant such as might result from a leak. If the core became uncovered, it could reach the melting point and release fission products to the plant container. To prevent a loss-of-coolant accident, all pipe lines leading to the reactor vessel were equipped with either automatically or remotely operated isolation valves. The decision to have four main coolant loops from the reactor core to the steam generators was another example of conservative design philosophy. Because only three loops were needed for full power operation, one could serve as a spare. By incorporating in the plan proper shielding, it would be possible to isolate one loop for maintenance without having to close down the station.

This conservative design philosophy also was applied to the reactor core and pressure vessel. The core was to be thoroughly instrumented. Comparing actual data from an operating reactor on such matters as fuel temperatures, coolant temperatures, and coolant flow rates at various stages of life with data derived from theory would be most valuable in developing technology. The reactor pressure vessel, which would contain the core, was recognized as one of the factors limiting the capacity of pressurized water plants and was to be designed to make the greatest possible contribution to the fabrication of larger vessels.

As for the fuel, the plant had to be able to operate even if a few elements did not maintain clad integrity; indeed the reactor was to be capable of operating for months, if necessary, until a convenient time was reached for removing those elements. Furthermore, difficulties with an element were not to induce problems with its neighbors, nor to cause the radioactivity in the reactor coolant system to rise to an unacceptable level. Because so much had to be learned about reactor fuel, the design was to permit the shifting of an element from one part of the core to another, and to allow the replacement of an individual assembly. The design was also, of course, to permit the replacement of the entire core in a minimum amount of time.

ORGANIZATION

By choosing Admiral Rickover and Naval Reactors (called the Nuclear Propulsion Directorate in the Navy and Naval Reactors in the Department of Energy), the Commission was also obtaining a laboratory and a contractor. The Bettis Atomic Power Laboratory, owned by the Commission and operated by the Westinghouse Electric Corporation, was located on the site of a former airfield about thirteen miles southeast of downtown Pittsburgh, Pennsylvania. Bettis was a single purpose laboratory; its sole mission was to develop naval propulsion reactors. Under Admiral Rickover's direction, the laboratory had designed the NAUTILUS prototype and was at work on other pressurized water reactors for naval propulsion. The Commission contracted on October 9, 1953, with Westinghouse to design, fabricate, assemble, and test the new civilian reactor and the primary heat transfer system.

At the time of the signing, neither a site nor a utility had been selected. By the deadline of February 15, 1954, the Commission had received nine proposals from industry. Of these, the one by the Duquesne Light Company of Pittsburgh was determined to be clearly superior. Under Philip A. Fleger, Chairman of the Board of Directors, the company offered a site it owned at Shippingport, a small town on the Ohio River about twenty-five miles northwest of Pittsburgh. Duquesne Light proposed to build the turbine generator part of the station, and operate and maintain the entire facility. The financial terms were good. The company offered the site at no cost to the government, would contribute $5 million to the reactor portion of the station, and would purchase the steam at the equivalent of 8 mills per kilowatt-hour, a comparatively good price from the government's standpoint. The combination of Duquesne Light, the Shippingport site, Westinghouse, and Bettis--all in the Pittsburgh area--was an additional attraction.

With this major decision made, the Commission turned to selecting its other contractors. In April 1954, the General Manager approved the selection of Stone & Webster Engineering Corporation of Boston for architect-engineer services associated with the design of the reactor plant portion of the project. In 1955 a Commission contractor selection board chose the Dravo

Corporation of Pittsburgh to install piping and other equipment for the reactor plant. Duquesne Light took responsibility for building the non-nuclear portion of the plant.

Nothing, however, altered the fact that the Commission was looking to Admiral Rickover to assume the Commission's responsibility for the project. That meant that Naval Reactors, acting upon the technical recommendations of Bettis, had to approve all aspects of the nuclear plant design, including performance requirements and details of design development.

SEED-BLANKET CORE

Early reactor specifications called for a uranium core slightly enriched in the uranium 235 isotope. Natural uranium was composed largely of two isotopes, 238 and 235. It was the latter, amounting to 0.7 percent of natural uranium, that was the only naturally occurring fissionable material. A natural uranium reactor such as those built to produce plutonium for weapons was possible but it would be huge. By enriching natural uranium with the 235 isotope the reactor could be made smaller. The one for the Nautilus prototype was fueled with a highly enriched core which was small enough to fit into a submarine. On the other hand, highly enriched fuel was expensive and civilian electric power plants did not need small reactors. Slightly enriched fuel was therefore an attractive possibility. However, slightly enriched cores had never been built and the technical uncertainties were great.

In September 1953, Alvin Radkowsky, Chief Physicist of Naval Reactors, proposed a design called the "seed-blanket core." In brief, highly enriched elements--the seed--were surrounded by natural uranium elements--the blanket. The seed alone made the fission process possible. Neutrons from the fissioning uranium 235 not only fissioned more uranium 235 but also converted the natural uranium 238 in the blanket to plutonium 239, itself a fissionable material. The seed-blanket concept had several attractions. The highly enriched seed could be based on the technology already developed for the naval nuclear propulsion program. Because the seed was the driving force, it seemed to hold the key to a simplified reactor control system. Moreover, the blanket would remain in the reactor for the life of more than one seed, perhaps producing about half the total power. That meant the reactor would not need as much uranium 235--a valuable natural resource.

DECISION ON THE FUEL

The technology for the highly enriched cores developed for ship propulsion gave fair assurance that the seed could meet the specifications, but the same confidence did not exist for the blanket. These assemblies had to maintain their integrity over a long period of intense radiation if the blanket was to make its planned contribution to the generation of power. Bettis undertook a massive research program of various alloys that would resist corrosion in high temperature water. Although the uranium-molybdenum alloy looked most promising, samples exposed in the Materials Testing Reactor were producing troubling results in the summer of 1954. Extrapolating the data to the conditions expected in the power reactor revealed a major corrosion problem. Fuel seriously attacked by corrosion would release fission products to the coolant and, if the contamination was severe enough, the reactor would have to be shut down. Possibly further research was the answer, but this course meant testing the alloys under conditions expected in actual reactor operation: no one had designed, built, or operated such test equipment. As the problem with the uranium-molybdenum alloy mounted, the laboratory began working on uranium dioxide for the blanket fuel. Although the initial results looked promising, data were far from complete.

A decision had to be made in the spring of 1955, for the schedule called for the manufacture of the fuel in July. On April 26 Admiral Rickover at Bettis assessed the evidence. He strongly favored alloys: for one thing Naval Reactors had acquired a great deal of experience with them. Although uranium dioxide looked good, research was still in an early stage, and no one could state with confidence that no insurmountable barrier to its use existed. Further more, choosing uranium dioxide meant a major shift in the research and development effort. Nonetheless Admiral Rickover decided that uranium dioxide would be the blanket fuel.

He did so because hot water corroded and oxidized-rusted-the alloy. That was a fact of nature from which there was no escape. But, uranium dioxide was already oxidized: in so far as contact with hot water was concerned, it should be able to maintain its dimensional stability.

It was a tough decision. Bettis had a great deal to do to make certain of such physical characteristics as thermal conductivity and chemical properties, and had to explore the techniques to sinter and fabricate the uranium dioxide powder into pellets of the required density and uniformity. As it turned out, the choice of uranium dioxide and zircaloy tubing was crucial in the history of civilian power reactors. The materials proved so successful that they were widely adopted in the civilian power industry: they are two of the major technical contributions of Shippingport.

CONSTRUCTION

Ground breaking took place on Labor Day, September 6, 1954. To mark the occasion President Eisenhower at Denver, Colorado, spoke of his confidence that "the atom will not be devote exclusively to the destruction of man, but will be his mighty servant and tireless benefactor." At the end of his address he passed a neutron wand over a neutron counter. It flashed an electronic signal 1,200 miles to the site at Shippingport, starting up a bulldozer. However, because of the severe Pennsylvania winter, heavy construction did not begin until May 1955. The intervening months were spent in organization and preparation.

To coordinate the activities of all the contractors, Admiral Rickover set up on February 7, 1955 a carefully chosen PWR Integrated Schedule Committee, later named the PWR Coordinating Committee. He persuaded Westinghouse to appoint as its representative John W. Simpson, who had supervised the completion of the Nautilus prototype. He convinced Duquesne Light to select John E. Gray, an engineer who had spent more than a year working under Admiral Rickover in Naval Reactors. For his own project officer, Admiral Rickover turned to Captain Joseph H. Barker, Jr., whom he had known before World War II and who was working at the Pittsburgh Naval Reactors Office, which represented the Commission at Bettis. As his own representative at the construction site Admiral Rickover chose Lieutenant Commander Donald G. Iselin of the Navy's civil engineer corps. These men were to review the progress in the design, installation, and construction of the facilities, keep track of deadlines, uncover problems, and propose solutions. Issues they could not handle they were to refer upward. Finally, they were to coordinate those activities requiring the cooperation of more than two organizations. Membership in the committee varied as the nature of the work changed. But through telephone calls--often several a day--frequent visits, and by detailed written reports, Admiral Rickover remained in constant contact with the project.

On March 15, 1955 Admiral Rickover approved a schedule calling for the completion of construction by mid-March 1957. When he did so, by far the greater part of the design had yet to be completed and heavy construction at the site had yet to begin.

The philosophy of safety called for a number of barriers separating radioactivity in the fuel from the environment. First was the cladding encapsulating the fuel; second was the pressure containing walls of the primary reactor coolant system; third was a series of interconnected containers to surround the reactor and the primary reactor coolant system. When Admiral Rickover inspected the site at Shippingport he added a fourth: he would place the reactor container system in an underground concrete structure. The latter feature was to be unique to Shippingport.

The final design called for the container to consist of four interconnected units: a sphere for the reactor, two cylinders, each for two steam loops, and a third cylinder for the auxiliary equipment. The volume of the container was to be sufficient to hold the vapor resulting from a complete release of all the reactor coolant and all the secondary water from one steam generator. The reactor sphere was to be placed on a lower elevation than the rest of the containment so that in the unlikely event of an accident the water would run into the sphere and keep the core immersed, thus preventing serious damage to the fuel elements. The concrete structure surrounding the container consisted of slabs, five feet thick under the cylinders, and walls five feet thick, rising to a height of fifty-five feet.

Progress on the reactor container set the pace for much of the work at the site. Erection began in November 1955, but steel shortages, bad weather, and design changes delayed completion and testing from April 15 to September 1, 1956. At its finish about 10,000 cubic yards of concrete slabs had been poured, more than 2,200 tons of steel put in place, and over 13,000 feet of one and one-quarter inch thick field welding had to pass x-ray inspection.

The reactor pressure vessel was made of manganese-molybdenum carbon steel plates and forgings and clad with one-quarter inch stainless steel on its inner surface. In shape the vessel was cylindrical; in dimensions the walls were about eight inches thick, the internal diameter 109 inches and the internal height 375 inches. Water entered by four nozzles at the bottom and after picking up heat by passing through the core, left by four nozzles near the middle of the vessel.

To the men waiting at the foot of the railway spur at the construction site on October 6, 1956, a different set of measurements mattered. The vessel, manufactured by Combustion Engineering, Incorporated, was about 25 feet long, 10 feet in diameter, and weighed about 153 tons. Working it off the oversized flat car and into an upright position, moving it 100 feet, and lowering it 55 feet into the reactor chamber required unique rigging. Even then the vessel was not in place, for it was suspended from a frame over the chamber so that thermal insulation and stainless steel cladding could be applied. In February 1957 the vessel was gently jacked down into position.

Many of the other components were already in place. As the various systems were completed, their responsibility passed from the construction force to a test and operations group. The change was reflected on May 2, 1957 with the demise of the Coordinating Committee and the establishment, under the chairmanship of Captain Barker, of the PWR Operations Committee. October 6, 1957 saw the installation of the core. For eight hours the core, weighing 58 tons, was gently lowered into the pressure vessel.

Industry was following the progress of Shippingport. Before the fourth annual meeting of the Atomic Industrial Forum in New York City on October 30, 1957, W. Kenneth Davis, Director of the Commission's Division of Reactor Development, spoke of the government program and plans. Of all the various types, the water reactors, in which he included the pressurized water type, had the best hope of being first to be competitive in the United States.

The construction cost of the reactor plant had gone up over the original estimate of nearly $38 million. Overtime and more realistic technical data raised the cost to $45 million in the summer of 1956. In the early months of the next year the construction cost rose to $55 million.

TRAINING AND ORGANIZATION

The Commission and Bettis began to train Duquesne Light engineers at the laboratory in April 1954. Practical training at Commission facilities was an integral part of the preparation of plant personnel. The Nautilus prototype trained the largest percentage of personnel because the program, already established for the Navy, met so many of Shippingport's requirements. Over periods ranging from two to eleven months, forty-eight station personnel gained experience at the prototype in reactor plant chemistry, health physics, maintenance, operations, instrumentation and control, and testing. Some men obtained training in health physics and chemistry for several weeks at the Materials Testing Reactor in Idaho, while a few nuclear instrument and control engineers worked at the production reactor site at Savannah River, near Aiken, South Carolina. In addition, Bettis gave some practical training and some formal classroom work. Occasionally, outside instructors from local institutions lectured on special technical matters.

As 1957 drew to its close and start up was imminent, the number of Duquesne Light personnel assigned to the station steadily increased. A conventional steam plant would ordinarily require 66 employees; in contrast, the roster for Shippingport totaled 132, and of these 37 were technically trained. As the first plant of a new and complex technology, Shippingport needed the larger number. Moreover the plant had special needs, such as health physicists and testing personnel for technology and development, that a conventional plant did not require. Finally, the company in its personnel planning had to take into account normal turnover.

A thoroughly and intensively trained group of supervisors and men filled the plant organization chart. A superintendent, responsible for operation, maintenance, and safety, headed the station. To assist him he had five groups: security and clerical, reactor technical, operation and maintenance, testing and industrial hygiene.

START UP

The next few days after reaching criticality on December 2, 1957 saw various tests of the reactor plant and the steps to synchronize the turbine with the Duquesne Light power system. As these activities were successfully completed the schedule called for the plant to generate power for the Duquesne Light network on December 17, 1957. Up to this point, Westinghouse, as designer and developer of the reactor, had been in charge. With the flow of power over the transmission lines, Duquesne Light was to assume the responsibility.

As the testing was being completed, Admiral Rickover was concerned that he did not have adequate control over plant operations. The Commission was responsible for the safe operation of the plant and that body was depending upon him. He did not see how he could meet his obligations unless he had his personal representative in the control room at all times. That man had to have the absolute authority to shut down the plant when he thought it was warranted. In addition, his representative was to report directly to him--not through Duquesne Light.

Mr. Fleger was opposed. To him the contract called for Duquesne to operate the plant; the company's men had been trained for that purpose. A government representative with that power was contrary to the spirit of the entire project. As Admiral Rickover was adamant, Mr. Fleger relented.

By 7:00 a.m. on December 18, twelve megawatts of electricity were flowing through the transmission lines. On December 23 Shippingport reached its capacity of 60 megawatts and five days later completed a 100 hour run at that level before shutting down for further testing. From July 9, 1953--the date the Commission assigned the project--until December 23, 1957 was 1,629 days. Shippingport was not the first nuclear plant to generate power for civilian use: in October 1956 the Calder Hall Station in England won that place in history. The British gas-cooled reactor, however, was dual purpose, for it generated power and produced plutonium for the British weapon program. But Shippingport was the first, large-scale, central station nuclear power plant in the United States and the first plant of such size in the world operated solely to produce electric power.

DISSEMINATION OF INFORMATION

A stream of technical documents, some single subject, others issued periodically, flowed from the plant to the engineering and scientific community as well as the public. Through June 1982 the number of technical documents was almost 2,300. The reports provided a permanent documentation of the technology, allowed the widest dissemination of the information, and were listed and abstracted in Nuclear Science Abstracts and successor abstracts.

In addition to the reports, Duquesne Light, under contract to the Commission, offered a course to employees of other organizations, including those abroad, to obtain information on reactor plant operation and maintenance. The course began in February 1959 with 20 students from a dozen utilities. At the request of the Commission, the course was soon shortened from six to four months to minimize the impact on plant operations. The work was divided into three sections: general classroom training in which the students studied pressurized water reactor technology; special classroom training in specific areas, such as operating chemistry, health physics, instrumentation and maintenance, and test and analyses; and finally, ten weeks of practical experience. Because of training subsequently offered by other facilities in the United States and in foreign countries, the Commission discontinued the program in 1965. Looking back, and judging by later standards, the duration was too short for the thorough training required; nonetheless the effort served as a beginning.

OPERATIONS AND INFLUENCE

Shippingport more than met its objectives. It operated with the continuity and reliability needed to meet the demands of a base load plant, and it also showed the flexibility needed to meet the demands of a swing load plant. Shut down and start up under normal conditions took less time than any plant on the Duquesne Light system in 1957. Procedures to safeguard personnel and protect the environment proved successful and no problems posing serious operating hazards occurred. Although training of operating and maintenance personnel was greater than that required for conventional plants, and procedures were more elaborate, Shippingport showed that the requirements could be met. Of course there were equipment problems: in the first four years three coolant pumps failed and some steam generators had to be modified, but the reactor behaved well.

OPERATION OF THE SEED-BLANKET CORE

Performance of the seed-blanket core exceeded expectations. During its six-year life, core 1 utilized four seeds. The life of each seed was longer than the design called for, and by February 9, 1964, when the plant was shut down for final testing of core 1, more than half the total gross generation of 1,799,000,000 kilowatt hours came from the blanket. Average load factor--the percentage of time operated at full capacity--was astonishingly high for a new plant. Exclusive of testing, the average load factor for seed 1 was 75 percent, but for the other three seeds it was 97 percent.

DECONTAMINATION

Shippingport operated for 67 months on core 1. During this time period, radiation surveys of the primary system, the reactor vessel area, and other areas within the reactor plant containers, showed an increase in the average radiation level. The increase came from activated corrosion products--minute particles in the primary coolant which became radioactive in passing through the reactor and which were deposited upon the interior surface of the main coolant system. The deposited corrosion products did not increase the level of radioactivity in the primary coolant itself; that level had not changed significantly during the operation of core 1.

Bettis had already begun to develop a second seed-blanket core with a far greater capacity. Although the new core was to be designed so it could be installed in the same pressure vessel, the increase in capacity required other plant modifications, including new main coolant pumps and heat exchangers. Decontaminating the plant to reduce radiation levels would simplify the task of making the modifications as well as facilitate subsequent plant testing and operation.

Duquesne Light began the task on February 29, 1964, following the decontamination process, system, and overall procedures prepared by Bettis. Chemical solutions removed the radioactive particles to a decontamination facility on site for storage and processing. Encountering no major obstacles, Duquesne Light completed the job on March 14, 1964. Surveys taken before and after decontamination showed that the effort was successful. It was the first in-place decontamination of an entire nuclear power plant.

OPERATION ON CORE 2

By means of larger fuel assemblies of improved design, the capacity of core 2 was to be 150 electrical megawatts gross, more than double that of core 1. For core 2 operation, the turbine-generator was uprated to provide 108 electrical megawatts output. Also, a supplemental heat sink was installed to dissipate enough additional power to permit periodic operation of the new core at its full capacity. Shippingport reached criticality on February 3, 1965 on core 2 seed 1. Power operation and testing without the heat sink began on April 30, 1965. On September 25 the reactor reached full power of 150 megawatts.

THE CHANGING BACK-GROUND

The civilian power program had made some progress since the Commission assigned Shippingport to Admiral Rickover. To hasten the growth of the industry Congress passed the Atomic Energy Act of 1954. The law now allowed the private ownership of facilities to use nuclear materials, made the use of these materials (but not their ownership) possible, made access to information on reactor technology easier, liberalized the patent policy, and permitted the Commission to offer certain materials and services to industry.

Even with the liberalized provisions, industry remained hesitant, seeing the technical and economic uncertainties too great. To give industry some assurance and experience and to advance reactor technology, the Commission on January 10, 1955 announced a power reactor demonstration program. Over the years parts of the program changed but its fundamental assumption remained the same: Commission-industry cooperative reactor projects were to be a major step in shifting the burden of civilian nuclear power from the government to industry. Although a number of nuclear power plants were built under the program, industry was still reluctant to substantially increase the number of plants.

In the early 1960's the Kennedy Administration, the Joint Committee on Atomic Energy, and the Commission reviewed the progress of the civilian nuclear power program. Each proposed a different direction for continued government involvement in civilian nuclear power. On March 15, 1962 Congressman Chet Holifield of the Joint Committee called for a new and vigorous effort in which the Committee and the Commission staff would frame a new program which would have as its goal a number of large-size demonstration projects, among them a seed-blanket power plant. President Kennedy on March 17 asked the Commission to undertake a wide-ranging study on the place of atomic energy in meeting the Nation's future energy needs. For its part, the Commission was preparing invitations for a new cooperative project with industry.

Before the committee on May 18, 1962, Admiral Rickover described the approach he would follow for a 500 megawatt seed-blanket plant. In an engineering study he would examine various concepts and undertake an intensive development program in all phases of reactor technology: physics, heat transfer, hydraulics and mechanical design. He did not promise economical power from the initial plant, but he believed that the plant would be an important stride in that direction.

In August 1962 the Commission invited industry to take part in a new cooperative project: a power reactor of 300 to 500 megawatt capacity. In a few years a plant of this size, according to Commission estimates, could generate power economically in those parts of the country where fossil fuel costs were high. The Commission offered design, technical, and financial assistance, but the utility was to provide the site, pay construction costs, and operate the plant for at least five years. The Commission made one further stipulation: the reactor was to be of proven technology. That provision effectively limited the type to pressurized or boiling water.

On November 20, 1962 the Commission sent its report to the President. It foresaw an inexorable growth of energy requirements and an inevitable depletion of fossil fuels. Nuclear energy could and should make an important and even vital contribution to meeting the long term requirements. Because reactor technology development was costly, the Federal Government should continue its near term role to stimulate industrial participation. Because pressurized and boiling water reactors were nearest to achieving economy and because their technology was becoming developed, the Commission could taper off its support of these types. In addition, it should begin focusing on further development by the government toward their ultimate goal: the development of breeder reactors for commercial use, which would not only generate power, but also produce more nuclear fuel than it consumed.

The report discussed two approaches to breeding, placing the greatest emphasis on uranium 238 and plutonium 239. By absorbing an unmoderated or fast neutron from the fissioning uranium 235, uranium 238 became plutonium 239. The latter element was fissionable by fast neutrons and gave off energy and neutrons to create more plutonium 239 from uranium 238. The second approach was based on thorium, an element more plentiful in the earth's crust than uranium. By capturing a moderated or slow neutron, thorium became uranium 233--a fissionable material which gave off enough neutrons to create more uranium 233 from thorium.

The two concepts differed in important ways. The plutonium 239 approach required the development of a very advanced and sophisticated reactor and plant. It would, however, produce enough plutonium 239 to refuel itself and another reactor. The approach had another advantage. To develop a plutonium weapon during World War II, the Manhattan Engineer District had constructed industrial facilities for processing the material. Consequently the "fast breeder" approach had the elements necessary for an industrial base. Because the uranium 233 approach depended upon thermal or slow neutrons this concept could possibly use the proven water reactor plant technology. However, a reactor fueled with uranium 233 would only give off enough neutrons to produce fuel to replenish itself. In that sense the uranium 233 breeder was, as one individual called it, "A hold your own reactor."

The report to the President was clear: breeder reactors--or those representing a significant advance toward that goal--were most likely to receive Commission support. That conclusion cast doubt upon the future of the large seed-blanket reactor.

THE POSSIBILITY OF THORIUM

Bettis, while placing its main effort on the large uranium seed-blanket reactor, was investigating the potential of thorium and uranium 233. On November 19, 1962 George W. Hardigg, the Bettis project manager, reported that breeding might be within reach. On March 19, 1963 Philip N. Ross, General Manager of Bettis, forwarded to Washington an interim report on a 500-megawatt seed-blanket reactor for a large central station power plant.

The laboratory summarized four designs: two based on uranium and two based on thorium. In one of the thorium designs a seed of uranium 235 was surrounded by a thorium blanket and optimized for maximum formation of uranium 233. Calculations showed that after three years the blanket assemblies could be reprocessed and the uranium 233 extracted. If fuel reprocessing losses could be kept low, it might be possible to reach a self-sustaining cycle.

> ...that is to say, using the thorium-uranium-233 cycle, <u>it may be feasible to breed in a light water cooled and moderated seed blanket core.</u>

Not everyone liked the idea of the large seed-blanket reactor, breeder or not. The General Advisory Committee, a prestigious group of scientists with the task of assessing the Commission's programs and advising upon them, was opposed. Admitting thorium-uranium 233 utilization and breeding were important objectives, the committee thought their development, as far as the seed-blanket approach was concerned, should be left to industry. Other reactor types were more deserving of Commission support because they would better serve to advance reactor technology.

The committee's reference to the seed-blanket core and industry was significant. Shippingport had contributed immensely to the development of nuclear power plant components, to fuel element design and analysis, and to procedures for operating, adopted the seed-blanket core. They preferred the slightly enriched core because the fuel elements were less costly to fabricate and the power density of the core was more uniform.

To Admiral Rickover and Naval Reactors, a large seed-blanket reactor had much to offer. High on the list was the development of long-lived fuel elements; if successful, these would increase significantly the time between refuelings. In addition, the project would pioneer the design, development, and fabrication of large components. Finally, he wanted to use the project to establish the specifications, procedures, and standards for industry to follow in constructing and operating large central station nuclear power plants. He and his engineers saw the large seed-blanket reactor almost as another Shippingport.

However, the situation was vastly different from the time when Shippingport first began operating. By the end of 1963, civilian nuclear power seemed well established. The net installed electrical generating capacity in nuclear plants in the United States had reached more than a thousand megawatts, although a small portion of this figure was in experimental plants. In overall terms, about 0.48 percent of the generating capacity of the country was provided by nuclear energy. Of eight central station nuclear power plants, three, including Shippingport, were pressurized water. More revealing were the near term estimates. Seven plants had been announced for construction. Of these, three were pressurized water, three were boiling water, and one was nuclear superheat. The largest of the pressurized water reactor plants planned was 463 megawatts, a far cry from Shippingport.

Statistics showed a growing market for nuclear power. The State of California, in looking for a source of power for a huge irrigation system, considered the large seed-blanket reactor. Design for the seed elements called for a life of far greater duration than elements for commercial plants. In addition, the core would have a central portion to investigate the feasibility of breeding using thorium. On January 1, 1965 the Commission and California signed an agreement outlining the responsibility each would assume in the design of a large power plant. Almost at the same time, data from irradiation tests for the non-breeding portion of the core showed disturbing anomalies. Because the project was an integral part of California's irrigation plan, Admiral Rickover in April 1965 warned the State and the Commission he could not meet the schedule. As research during the remainder of the year only confirmed the uncertainties, on December 20, 1965 he recommended that the Commission drop the project. In its place he proposed research and development of the thorium breeder technology at Shippingport. The Commission authorized the water breeder reactor project in December 1965.

BREEDING

In its assessment of the large seed-blanket reactor and breeding, the General Advisory Committee suggested using Shippingport to explore the technology. Admiral Rickover, his headquarters, and Bettis had considered the proposal earlier and had decided against it because of the properties of thorium and uranium 233. The small number of neutrons generated per neutron absorbed in uranium 233 was the main reason. In any reactor some neutrons escape or are absorbed by reactor materials. Losses could be minimized in a core which had sufficient volume so that the elements could be arranged to reflect the neutrons back toward the center of the core. Placing the breeding section in the center of the large seed-blanket core planned for California would have lessened the number of neutrons that escaped. But the reactor vessel volume available at Shippingport had appeared too small. Subsequent detail design work resolved how to use the volume available.

THE TECHNICAL CHALLENGE

The technical challenge of demonstrating the feasibility of breeding at Shippingport was immense. Bettis had to clarify the nuclear characteristics and properties of thorium and uranium 233 as well as the physical properties of the thorium oxide and uranium oxide fuel. The light water breeder core demanded meticulous design and engineering. In addition to acquiring basic nuclear and physical data, the program included the design and test of mechanical components, material tests, thermal and hydraulic studies of reactor fuel design, nuclear design critical experiments, and fuel material irradiation. The Knolls Atomic Power Laboratory at Schenectady, New York, a facility which, like Bettis, had as its sole purpose the design and development of naval propulsion reactors, checked and advised on the work. At Naval Reactors many people, including Philip R. Clark, David T. Leighton, John E. Mealia, Harry F. Raab, Jr., Charles R. Thomas, and James W. Vaughan, would become deeply involved in the core design, fabrication, and operation of the breeder project throughout its years from its inception in 1965 to power operation in 1977.

Roughly speaking and with great oversimplification, the research and development effort fell into four areas: the reactor coolant and moderator, fuel, fuel cladding, and reactor control. The reactor coolant and moderator offered a series of complicated technical problems. Water slowed down the neutrons to thermal energies at which the fission process in pressurized and boiling water reactors took place. However, water also absorbed some neutrons. It was possible to lessen the number neutrons captured by reducing the amount of water in the core--"by squeezing out some of the water." Decreasing the amount of water meant less moderation and therefore an increase in neutron energies to the intermediate range. The change was serious. At thermal energies, uranium 233 gave off an average of 2.3 neutrons per neutron absorbed, although not all reactions took place at these energies. At intermediate energies that number appeared to decrease to 2.07, an almost impossibly slim margin for breeding. Through different experimental and analytical techniques, Bettis and Knolls determined that the actual value for intermediate energies was 2.13. Additional work revealed another favorable factor. At high energy ranges additional neutrons were produced by fast fission in thorium and by a reaction in which a neutron captured by thorium caused the emission of two neutrons. The overall effect was that the number of neutrons produced for each neutron absorbed was 2.26. And, with more reactions occurring, and at intermediate energy ranges, the neutrons were less apt to be captured by the coolant.

The reactor fuel was thorium and uranium 233 in oxide form. Tests showed that the oxides behaved similarly to the uranium oxides in the first two seed-blanket cores, but had a higher melting temperature, greater dimensional stability at high temperature, and better corrosion resistance. The oxides were shaped into pellets--four types in the final design. Fabricating the oxide powder into pellets of proper density and uniformity required pressing and high sintering temperatures, very near the melting point. The Oak Ridge National Laboratory produced the uranium 233 oxide. Bettis planned for a contractor to fabricate the pellets but this proved to be impractical since continuing development work on pellet fabrication had to be quickly factored into production, with very demanding specifications. Having no alternative, Bettis equipped a building on the laboratory site to do the work.

Cladding was zircaloy-4, an alloy of zirconium developed in the naval nuclear propulsion program. Plans called for zircaloy tubes to contain the pellets. To minimize neutron loss and maximize heat transfer, the tubing was kept thin. The Wolverine Tube Division of Union Oil Products manufactured the tubes: meeting the specifications at first proved difficult, but tightening quality control procedures was the answer. The fuel rods were about ten feet long and spaced closed together than in other pressurized water reactors. Although held in position at the top or bottom, some additional support was necessary to prevent them from bowing, touching each other, and blocking the flow of water. Commercially available grids to hold fuel rods in position could not meet the specifications; high strength, thin metals with low neutron absorption were needed. Because no vendor would offer fixed price bids, the Bettis laboratory had to make them. As finally designed and developed, each grid was composed of several hundred stamped components of AM-350, a type of stainless steel. Wire pins, passing through a hinged joint, held the components together. The hinged joints were brazed with a filler metal to make the grid rigid and dimensionally stable.

In other reactor types, control was achieved by a material which absorbed neutrons. In the case of the first two cores of Shippingport, the material was hafnium, a corrosion resistant element with a strong affinity for neutrons. With the necessity of conserving neutrons in the light water breeder core, neutron-absorbing control rods were most undesirable. The answer was in poaitioning the seed modules. Moving the seed modules vertically changed their, position relative to the fixed blanket position modules, thereby attaining the desired neutron balance by altering the core geometry.

To the men in Washington, Bettis, and Knolls, veterans with years of experience in designing and developing naval propulsion reactors, the light water breeder posed severe technical challenges. Preventing the loss of the wayward and elusive neutron was basic: its escape could vitiate the entire effort. All involved were caught up in the excitement of the challenge. In so many technical ventures, initial ideas look good, only to collapse beneath the weight of stubborn and disappointing data. But with the light water breeder it was different. Hard won data eroded uncertainty and confusion, and in their place erected exhilaration and certainty.

TURBINE TROUBLE

While Bettis was designing and developing the light water breeder core, the Shippingport station continued to operate well on the second seed of core 2. On February 4, 1974 the operators felt extensive turbine vibration. Despite prompt shutdown, investigation revealed severe damage to the turbine. As repairs were necessary, this unexpected downtime was used to upgrade components and make preparations for installing the new breeder core.

In the last half of the 1960's, a growing segment of public opinion was determined to protect the environment against what it saw as needless and destructive exploitation by industry. Although the issue was far broader than atomic power stations, these received their share of both thoughtful and emotional criticism. Atomic power plants were new, their technology still unfamiliar to the public, and the wide ranging and long-lasting consequences of a potentially serious accident were recognized.

In 1970 the National Environmental Policy Act went into effect. It required federal agencies to prepare statements on major actions affecting the environment. For the Commission, the environmental statement had to cover several areas, among them site and reactor characteristics; power needs in the area; environmental impact, including radiological and non-radiological aspects; provisions for enhancing the quality of the environment; unavoidable adverse environment effects; and any irreversible and irretrievable commitment of resources. A 1973 court decision expanded the scope of the environmental report to take into account not only a specific nuclear power plant but also those facilities required by a power industry based on new technology.

Shippingport came under scrutiny on environmental matters in the 1970s. Allegations in 1973 of adverse effects on the environment were reviewed and refuted by the independent Environmental Protection Agency, the Commonwealth of Pennsylvania, and by three independent groups within the Commission. Operation of Shippingport with the light water breeder reactor core represented a new technology. Accordingly, Shippingport received the full range of environmental review for a new station in the mid-1970s, including a Draft Environmental Statement, government and private reviews and comments, public hearings, and a final statement documenting the reviews. This final statement, published in 1976, concluded that there was no reason to defer or change the schedule for the operation of the light water breeder reactor core in the Shippingport station.

The LWBR environmental impact statement was required by law: licensing Shippingport was not, because the reactor was government-owned. Such was not to say that its operation had not been scrutinized. During the period of its construction the Reactor Safeguard Committee, a group of reactor experts and specialists in other fields appointed by the Atomic Energy Commission, considered the plant, the location, and its design. On November 4, 1957, just before start up, the Committee stated that Shippingport could by operated at design power with an acceptable low risk to the health and safety of the public. Renamed the Advisory Committee on Reactor Safeguards, it considered the plant again in 1960 and 1964. The meetings were important, for the committee's members had the technical background to question those individuals responsible for design and operation.

The Commission also had its responsibilities for safe operation of power reactors. In the Atomic Energy Act of 1954, Congress had assigned the Commission the responsibility for licensing certain activities making use of nuclear material. For nuclear power plants, a utility had to apply for a construction permit and, when the plant was nearing completion, for an operating license. Before the license could be granted, the Commission was to hold a hearing upon the request of any individual who believed his interest might be affected. Further, any final order was subject to judicial review.

By the end of 1965, when the Commission approved the light water breeder program, the regulatory staff and the advisory committee were heavily overworked because of the growing number, size, and complexity of commercial power reactors. At that time, fourteen reactor plants were in operation, seven were under construction, and applications for construction permits for four others were under review. One of the four was a pressurized reactor of 873 electrical megawatts. The capacity of all four was about 2,600 megawatts, almost double the installed capacity of all licensed power reactors. Moreover, the trend over the next few years showed a sharp increase in the number of reactors under review, under construction, and in operation.

Hearings on applications grew ever more lengthy and the Commission fell under attack for having conflicting interests--its responsibility for promoting civilian nuclear power and its responsibility for licensing reactors for safe operation. In 1974, as part of a much larger reorganization of energy-related government agencies, the Atomic Energy Commission was abolished and most of its functions were absorbed into the Energy Research and Development Administration. In 1977 that organization became a part of the Department of Energy. The civilian regulatory functions of the Atomic Energy Commission, however, were no part of the duties of either successor agency. They became the responsibility of the Nuclear Regulatory Commission. It was to this Commission that the Advisory Committee on Reactor Safeguards now reported.

To support the planned operation of Shippingport with its breeder core, Naval Reactors and Bettis worked closely together in preparing the Safety Analysis Report for the Commission. Their product was a ten volume heavily technical document, touching all aspects of the core design and station operation. Admiral Rickover sent the volumes to the Nuclear Regulatory Commission on June 30, 1975. The Commission began its evaluation and sent copies to the Advisory Committee on Reactor Safeguards.

The Commission and the Committee took over a year to analyze the report. On July 22, 1976 the Commission concluded that Shippingport, with its light water breeder core, could be operated without undue risk to the health and safety of the public, subject to a few technical modifications, to the continued rigid control by Naval Reactors over the design, construction, operator training and qualification, and reactor operation, and completion of their review of a few technical points. A supplementary report of December 8, 1976 covered these matters and reaffirmed the earlier position. Earlier, the Advisory Committee at its meeting of August 12-14, 1976 concluded that the station could be operated as planned.

THE STATE OF PENNSYLVANIA

Pennsylvania was also paying close attention to Shippingport. The interest was not new: in July of 1954 the Atomic Energy Commission had informed the

State of plans to build the atomic power station. In subsequent years the Commission and its successor agencies continued to keep State officials informed. To monitor atomic energy activities within its boundaries, Pennsylvania had an Advisory Committee on Atomic Energy Development and Radiation Control. Its members had studied the LWBR Safety Analysis Report, visited the station, and attended a meeting of the Advisory Committee on Reactor Safeguards. On December 23, 1976 the State's Department of Environmental Resources raised a number of technical points on the Safety Analysis Report. In brief, the State officials believed that the Nuclear Regulatory Commission and the Advisory Committee had focused too much on the reactor and the light water breeder core, and not enough on the rest of the station.

Admiral Rickover replied on March 23, 1977. As background he indicated that he had taken an extremely conservative approach to every question of safety from the very first. He had maintained that philosophy, insuring that the plant had been upgraded where necessary to assure safe operation and to conform with the standards of the Nuclear Regulatory Commission, the Advisory Committee on Reactor Safeguards, and industry. The remainder of his letter he devoted to the specific issues the State had raised.

Pennsylvania turned to the Nuclear Regulatory Commission and the Advisory Committee on Reactor Safeguards. The Commission stated that Admiral Rickover's reply of March 23 dealt adequately with the issues. The Advisory Committee reviewed the State's position on June 9-10 and found no reason to change its findings. On August 12, 1977 Pennsylvania declared that it had no further comments.

THE LWBR CORE

The first fuel module assembly arrived at Shippingport in January 1976; the final module assembly in March 1977.

The nuclear core which had evolved from a dozen years of hard work consisted of three types of fuel modules. The three central modules were hexagonal, identical, symmetrical, and were made up of two types of fuel rods. The assemblies in the center of each of these three modules were the movable seed and contained a mixture of uranium 233 and thorium dioxide. The rods in the outer assembly of the module were the blanket and contained a mixture of the same elements except for different proportions--the blanket rods having less uranium 233. These three modules were designed as if they were intended for --and they could have been used in--a large central station.

The purpose of the other two types of modules was to simulate for the three central modules the environment of a core for a large central station. As part of this effort, the design provided nine hexagonal modules each with seed and blanket assemblies to surround the central modules and to flatten the power distribution within the core. The proportion of uranium 233 in the power flattening blanket was somewhat greater than in the blanket for the central modules. The third type of module was a reflector blanket and consisted of rods containing only thorium. They captured neutrons which might otherwise have escaped from the core. Use of the power flattening and reflector blankets permitted a breeder demonstration in the volume available in the Shippingport reactor plant. By the end of August the time for criticality was near.

The approach to criticality was made by lifting twelve seed assemblies and moving them together as a bank into their blanket assemblies. As the bank entered the core, the neutron flux increased and, at some point, the reactor would achieve criticality. A graph recorded the count rate ratio against the bank height.

About 12:30 on the morning of August 26, 1977 the Duquesne Light operators began raising the bank, lifting it for seven seconds and waiting for 23 seconds. To the men watching the instruments the question was how close actual criticality would come to that predicted by theory and experiment. First readings were slightly erratic, although the general trend was becoming clear. At 4:38 a.m. the Light Water Breeder Reactor reached criticality: the bank was only 0.55 inch higher than calculated, an amazingly close correspondence.

The 60 net megawatt station spent the next two months undergoing tests at different power levels. On December 2, 1977, thirty-five years to the day after the first chain reaction in Chicago, Admiral Rickover, with James R. Schlesinger, Secretary of the Department of Energy, met at the White House with President Jimmy Carter, a proud alumnus of the naval nuclear propulsion program. With Admiral Rickover were William Wegner, Deputy Director, and David T. Leighton, Program Manager, both of Naval Reactors. On a blackboard the President wrote: "Increase the light water breeder reactor power to 100%. Jimmy Carter." Pausing for a moment, the President underlined the word "breeder."

The blackboard was connected electronically with a screen set up in the Shippingport control room. As the President wrote, his words flashed upon the screen. Under the direction of Thomas D. Jones II, the Duquesne Light Station Superintendent; and in the presence of John M. Arthur, Chairman of the Board of Duquesne Light; Robert E. Kirby, Chairman of the Board of Westinghouse; and William H. Hamilton, General Manager of Bettis; the reactor reached full power at 10:48 a.m.

Shippingport operated very well on its new core. Near the end of the original planned operation of 18,000 effective full power hours, the Advisory Committee on Reactor Safeguards on May 6, 1980 agreed with Naval Reactors' conclusion that it was acceptable to operate the reactor beyond 18,000 effective full power hours. Admiral Rickover hoped to go to 32,500 hours--which the station would reach about the end of 1984. He saw a unique opportunity to gain data on the maximum fuel life of the only power reactor ever to be operated using the thorium-uranium 233 fuel. If light water breeders were to take their place in the future, it was important from the standpoint of economics, the conservation of resources, and the management of nuclear wastes, to develop long-lived cores.

Toward the end of 1981 Admiral Rickover, under tight budget restraints, decided to stop power operations and move on with core examination and proof-of-breeding. He decided that Shippingport would be shut down on October 1, 1982 for end-of-life testing, defueling, and evaluation of core performance. Operation to this date has resulted in 28,730 effective full power hours. After shipment of the spent fuel, the station will be turned over to a Department of Energy decommissioning agency.

DECOMMISSIONING

There were precedents: the Atomic Energy Commission had decommissioned, decontaminated, and dismantled facilities, among them power reactors at Picqua, Ohio; Hallam, Nebraska; Punta Higuera, Puerto Rico; and Elk River, Minnesota. On January 24, 1978 Admiral Rickover informed the Department of Energy that he eventually planned to turn Shippingport over to another group in the Department for decommissioning.

On January 6, 1979 Naval Reactors and the Office of Waste Management agreed on a division of responsibilities.

The agreement covered two areas: end-of-life testing through defueling and decommissioning. In the first phase, Naval Reactors, together with Westinghouse, Bettis, and Duquesne Light, would conduct all end-of-life testing and would defuel the station. It would maintain responsibility for the activities at the station and would continue its office at the site. The Office of Waste Management, through its field office at Richland, Washington, would undertake planning, various safety analyses, and would prepare for phase two. At that stage the responsibility for Shippingport would shift from Naval Reactors to the Office of Waste Management. Through its Richland office and through contractors, the office would carry out decommissioning.

BIBLIOGRAPHICAL ESSAY

Although the Shippingport Atomic Power Station is one of the great achievements of American engineering, no books and few articles cover its entire history. The American Society of Mechanical Engineers published in 1980 a small but very useful pamphlet Historical Achievement Recognized: Shippingport Atomic Power Station, A National Engineering Landmark. Richard Rhodes in his "A Demonstration at Shippingport: Coming on Line" in American Heritage 32 (June/July 1981): 66-73, caught much of the spirit of the project. Both are nontechnical.

Terse paragraphs embedded in the semiannual and annual reports of the Atomic Energy Commission and its successor agencies, the Energy Research and Development Administration and the Department of Energy, enable a reader to follow the major events of Shippingport, but are of limited use in conveying any historical sense of the project. Far too numerous to list here are congressional hearings. The Joint Committee on Atomic Energy held annual hearings on the naval nuclear propulsion program, and the development, growth, and state of the atomic energy industry, and authorization legislation in which the status of Shippingport was frequently covered. After the demise of the Joint Committee in 1977, the House Committee on Science and Technology and the Senate Committee on Energy have held hearings on the civilian nuclear power program.

The student interested in the origin and early operations of the Shippingport Atomic Power Station should find the following works helpful. Richard G. Hewlett and Francis Duncan in Atomic Shield: 1947-1952, Vol, II of A History of the United States Atomic Energy Commission (University Park: Pennsylvania State University Press, 1962) describe the inception of the Commission's atomic energy program which did so much to influence the history of Shippingport. Nuclear Navy: 1946-1962 (Chicago: University of Chicago Press, 1974) by the same authors contains a chapter on the plant from its origins to its first start up. The Shippingport Pressurized Water Reactor (Reading, Mass.,: Addison-Wesley Publishing Co., Inc., 1958) is a very valuable source. Written by members of Naval Reactors, the Bettis Atomic Power Laboratory, and the Duquesne Light Company for the Second International Conference on the Peaceful Uses of Atomic Energy, the volume consists of a number of well-written papers, often illustrated with photographs and diagrams, which give not only a great deal of technical information but an explanation of the philosophy behind certain of the major technical decisions. A detailed summary of plant activities up to the end of 1961 can be found in Shippingport Atomic Power Station Operating Experience, Developments, and Future Plans, Dec. 5-8, 1961, WAPD-T-1429. The letters and numerals are identification symbols of reports issued by the Westinghouse Atomic Power Division. Under contract to the Atomic Energy Commission, the Bettis laboratory and the Duquesne Light Company produced a number of detailed reports on the plant operation under the general title "Shippingport Operations...." Those used here have the serial number of the Duquesne Light Company: DLCS 364,36402,36403.

Another valuable category of material considers Shippingport and its influence as a pressurized water reactor on the development of the civilian nuclear power industry. Of the industrial journals, Nucleonics, published between September 1946 and June 1967, is perhaps the best. It contains articles on various aspects of the station. Under a grant from the National Science Foundation, the RAND Corporation of Santa Monica, California in June 1977 issued a series of studies on the American civilian reactor program. Wendy Allen, Nuclear Reactors for Generating Electricity: U.S. Development from 1946 through 1963, R-2116-NSF; Elizabeth Rolph, Regulation of Nuclear Power: The Case of the Light Water Reactor, R-2104-NSF; and Robert Perry et al., Development and Commercialization of the Light Water Reactor, 1946-1976, R-2180-NSF were most useful for this study with respect to industry and the problem of regulation. Irvin C. Bupp and Jean-Claude Derain wrote an interesting and provocative study on the swift rise and subsequent difficulties of pressurized water reactor plants in: Light Water--How the Nuclear Dream Dissolved (New York: Basic Books, Inc., 1978).

Several documents are useful in describing the light water breeder reactor program. Civilian Nuclear Power...A Report to the President--1962, (U.S. Atomic Energy Commission, Division of Technical Information, 1962) and its appendices are a good source of background information on power reactor development and breeders about the time the naval nuclear propulsion organization became interested in breeding with the thorium-uranium 233 cycle. The Large Power Reactor Interim Report, WAPD-LPR-141, July 1963 states that breeding might be feasible in a light water reactor. A layman will find Light Water Breeder, an undated pamphlet published by Naval Reactors, Department of Energy, a helpful statement of program goals. Light Water Breeder Reactor (LWBR), also an undated publication by the Division of Naval Reactors, is an excellent description of the light water breeder core, containing enough information to enable the general reader to understand the technology. The four volume Draft Environmental Statement, Light Water Breeder Reactor Program, ERDA-1541, issued in July 1975, The Public Hearing Record...held December 4, 1975 on the Draft Statement..., and the five volume Final Environmental Statement, Light Water Breeder Reactor Program, ERDA-1541, June 1976, contain much technical information, historical background, and insights into public opinion. Newspapers carried ample coverage of the ceremony at the White House when President Carter ordered Shippingport brought to full power with the light water breeder core.

Documents containing specific information on the Shippingport Station include:

- The Shippingport Pressurized Water Reactor (Reading, Mass.; Addison-Wesley Publishing Company, Inc. 1958).
- The Pressurized Water Reactor Forum held December 2, 1955 at Mellon Institute, Pittsburgh; TID-8010, February 1956.

- Nuclear Navy: 1946-1962, Richard G. Hewlett and Francis Duncan (Chicago: University of Chicago Press, 1974).
- ERDA - 1541, Final Environmental Statement, Light Water Breeder Reactor Program, June 1976.
- U.S. Environmental Protection Agency (and predecessor agencies) Reports include annual Environmental Monitoring Reports for the Shippingport Station.
- Historical Achievement Recognized: Shippingport Atomic Power Station, A National Engineering Landmark: American Society of Mechanical Engineers, 1980.
- International Conference on the Peaceful Uses of Atomic Energy, Report A/CONF. 8/P/815 dated June 30, 1955: Description of the Pressurized Water Reactor (PWR) Power Plant at Shippingport, Pa. and Report A/CONF. 15/P/2462 dated August 4, 1958: Shippingport Atomic Power Station.
- Various issues of journals such as: Nucleonics, Westinghouse Engineer, The Engineer, Public Power, Nuclear Science and Engineering.
- Atomic Energy Commission film "Power and Promise," prepared for the Atoms for Peace Program.

Over 2300 technical reports have been issued on the design and operation of the station and the associated technology. These technical reports have been listed and abstracted in Energy Research Abstracts (and predecessor abstracts) published by the Department of Energy's Technical Information Center, P.O. Box 62, Oak Ridge, Tennessee 37830. The abstracts document is distributed to a number of universities and DOE facilities throughout the country or it may be obtained from the Superintendent of Documents, Government Printing Office, Washington, D.C. 20402. Most of the technical reports may be identified in the abstracts document by looking for numbers with the prefix WAPD-XXX, or DLCS-XXX or by reference to topical headings, such as: Pressurized Water Reactors, Shippingport Atomic Power Station, Breeder Reactors, LWBR Type Reactors. The National Technical Information Service, U.S. Department of Commerce, Springfield, Virginia 22161, also announced the reports in its announcement journal "Government Reports Abstracts." Unclassified reports are also available in the Science Reading Room of the Library of Congress, 2nd & Independence Avenue, Washington, D.C. Inquiries can be made to the Technical Reports Section, Science and Technology Division of the Library of Congress.

WAPD-PWR-1606 (Revised), The Shippingport Pressurized Water Reactor Project Catalog of Document Abstracts, issued in December 1961, and Addenda 1 and 2 contain a catalog of document abstracts for the Shippingport Pressurized Water Reactor Project up to the mid-1960s. The DOE Technical Information Center also maintains a cumulative title list of DOE sponsored Water Cooled Breeder Reactor Reports concerning technology associated with the third core installed in the Shippingport Station and a set of 1652 plant drawings and plans.

Historical photographs and drawings for the period 1953 to 1984 have been archived at Federal repositories and can be made available through the U.S. Department of Energy, Office of Terminal Waste Disposal and Remedial Action, Division of Remedial Action Projects (NE-24), Washington, D.C.

The Decommissioning of the Shippingport Atomic Power Station, issued by the Department of Energy in May 1982, is the best single source on the plans for decommissioning and dismantling Shippingport. "A Long Term Problem for the Nuclear Industry" by Colin Norman in Science 215 (Jan. 1982): 376-9 is an interesting treatment of the difficulties of decommissioning and dismantling power reactors.

One final word. A number of organizational changes have taken place since the decision to build Shippingport. The Atomic Energy Commission was succeeded by the Energy Research and Development Administration, which, in turn, gave way to the Department of Energy. Researchers wishing to gain information about material published by the Commission or the Administration should write to: Technical Information Center, United States Department of Energy, P.O. Box 62, Oak Ridge, Tennessee, 37830.