APPENDIX D
MILITARY REACTORS

NAVAL NUCLEAR PROPULSION PROGRAM

After World War II, the U.S. began to develop nuclear propulsion for the Navy. Admiral Hyman G. Rickover developed the U.S. Naval Nuclear Propulsion Program from the ground up. The initial ship, the U.S.S. *Nautilus* revolutionized naval warfare. Although the concept of using a reactor to produce energy was understood, no one had been successful in applying it. The difficulty was increased because the reactor was to be sent to sea where it had to operate safely and continuously to support Navy missions.

To ensure the high level of reliability needed for shipboard application of nuclear power, the program required its own special discipline, which must be adhered to—a discipline that is in effect to this day. Initially, the program had to develop new materials, design new components, ensure proper fabrication, and instill the new rigorous approach to training sailors for safe reactor operations. Then the new engineering concept had to be fitted inside a submarine pressure hull and designed to operate in the ocean depths. History shows that the program was successful in meeting all of the challenges.

One of the design challenges was to build a small reactor (to fit inside a small submarine hull) yet make it last a long time (refueling a submarine is costly and reduces its availability for fleet support). This reactor must withstand battle shock and rapid changes in power demands. These requirements led to the use of highly enriched uranium (HEU) as the nuclear fuel. As time has passed, the demands for long life and more powerful reactors have increased. These requirements have reinforced the early decisions to use HEU since it is the only way to meet the current military requirements for nuclear powered warships.

In April 1994, the U.S. Navy logged its 100 millionth mile using nuclear powered warships since the *Nautilus* radioed "Underway on nuclear power" on January 17, 1955. This has been accomplished without a nuclear accident, or harm to the public or the environment—a tribute to the thousands of people who design, build, operate, maintain, and dispose of our nuclear-powered warships.

Based on all current projections, there will continue to be a need for HEU for nuclear-powered warship fuel in the future to meet the increasing demands on the U.S. Navy of the 21st Century.

Summary of Naval Nuclear Propulsion Program

The following table summarizes the active Navy Nuclear Propulsion Program as of October 1997.

Table D-1 Summary of the Naval Nuclear Propulsion Program

Vessel Type	Hull Numbers	Number of Vessels
SSN 21 ☐ SEAWOLF	21 (22 & 23 are under construction)	1
SSN 637 ☐ STURGEON	637, 647, 660, 666, 674, 680, 681, 683, 686	9
SSN 640 ☐ BENJAMIN FRANKLIN	642 - converted from an FBM in 1992 645 - converted from an FBM in 1993	2
SSN 671 ☐ NARWHAL	671	1
SSN 688 ☐ LOS ANGELES	688, 690, 691, 697, 698, 699, 700, 701, 703, 705, 706, 707, 708, 709, 710, 711, 712, 713, 714, 715, 716, 717, 718, 719, 720, 721, 722, 723, 724, 725, 750, 751, 752, 753, 754, 755, 756, 757, 758, 759, 760, 761, 762, 763, 764, 765, 766, 767, 768, 769, 770, 771, 772, 773	54
SSBN 726 ☐ OHIO (TRIDENT)	726, 727, 728, 729, 730, 731, 732, 733, 734, 735, 736, 737, 738, 739, 740, 741, 742, 743	18
NR 1	Deep Submergence Research Vessel	1
CVN 65 ☐ ENTERPRISE (Aircraft Carrier)	65	1
CVN 68 ☐ NIMITZ (Aircraft Carrier)	68, 69, 70, 71, 72, 73, 74 (75 & 76 are under construction)	7
CGN 36 ☐ CALIFORNIA (Cruiser)	36, 37	2
CGN 38 ☐ VIRGINIA (Cruiser)	40, 41	2
S8G	Trident Prototype Reactor	1
MARF	Modification and Additions to Reactor Facility	1

Commercial Nuclear Power

As part of President Eisenhower's "Atoms for Peace" program, the Naval Nuclear Propulsion Program designed, built, and successfully operated the Nation's first civilian nuclear power plant in Shippingport, Pennsylvania. The Navy freely disseminated the design details, manufacturing specifications, and operation and maintenance procedures to the scientific and engineering community and the public through symposia and the release of over 23,000 technical documents.

The Shippingport Atomic Power Plant (SAPS) established the technology basis for the pressurized water reactor design and core configurations used in commercial reactors throughout the world.

SAPS was operated by the Duquesne Light Company in cooperation with the U.S. Navy and AEC from 1957 until 1982. During that time, the plant was used to train civilian and Navy reactor operators, investigate alternative core designs and serve as a high power research reactor.

In 1965, the AEC investigated alternative light-water breeder reactors (LWBR), which generated more fissionable material than they consumed. In 1977, the SAPS reactor core was loaded with uranium-233 as its "fissile" material, and thorium as the "fertile" material. The LWBR core proved to be very reliable and supplied power to the Pittsburgh area for five years. Extensive end-of-life testing by the Navy confirmed that the LWBR operated as planned. In fact, breeding occurred at a rate higher than predicted, and performance of the core material was excellent.

In 1982, the DOE decommissioned SAPS, removing all radioactive components and returning the site to "park land."

Army Nuclear Power Program

The Army Nuclear Power Program (ANPP) was a joint venture of the Department of Defense (DoD) and the AEC. It was the sole agency for all three military services (Army, Navy, and Air Force) responsible for developing nuclear power systems to meet defense requirements, other than for naval vessel propulsion or for air and space vehicle applications. The ANPP was initiated in 1954; during its lifetime, it designed, constructed, operated, and deactivated nine nuclear power plants as described in this appendix. By 1977, due to changing military requirements and funding limitations, major program activities had ceased when the last ANPP facility was deactivated.

Oversight responsibility for deactivated ANPP facilities rests with the U.S. Army Nuclear and Chemical Agency (USANCA) located at Ft. Belvoir, Virginia. The ANPP is not associated with the DOE, the successor to the AEC, and that the nuclear power plants developed by the ANPP were not licensed by the Nuclear Regulatory Commission (NRC); however, USANCA follows NRC requirements as close as possible.

The ANPP pioneered many technical innovations and produced many achievements during its existence, including:

- Detailed designs for pressurized water reactors (PWR), boiling water reactors (BWR), gas-cooled reactors (GCR), and liquid-metal-cooled reactors (LMCR).
- First nuclear power plant with a containment structure (SM-1 at Ft. Belvoir, Virginia).
- First use of stainless steel for nuclear fuel cladding (SM-1).
- First nuclear power plant to furnish electrical power to a commercial grid (SM-1).

- First in-place reactor vessel annealing within the U.S. (SM-1A at Ft. Greely, Alaska).
- First steam generator replacement within the U.S. (SM-1A).
- First prepackaged nuclear power plant to be installed, operated, and subsequently removed (PM-2A at Camp Century, Greenland).
- First use of nuclear power to desalinate water (PM-3A at McMurdo Sound, Antarctica).
- First land transportable nuclear power plant (ML-1 at the National Reactor Testing Station in Idaho).
- First nuclear powered closed-loop gas turbine cycle (ML-1).

Nuclear Power Plants Constructed and Operated

The two gas cooled reactors in the Army Nuclear Power Program were:

- The Gas Cooled Reactor Experiment (GCRE), located at the National Reactor Testing Station (later renamed the Idaho National Engineering and Environmental Laboratory [INEEL]), was designed by Aerojet General Corporation to test gas cooled reactor behavior, evaluate components, test fuel elements, and obtain technical information. This reactor reached initial criticality in 1959 and was shut down in 1962. Although some spent fuel was retained at INEEL, most was sent to the Savannah River Site (SRS).
- The Mobil Low Power Plant (ML-1), located at INEEL, was designed by Aerojet General Corporation to test an integrated reactor package that was transportable by military semi-trailers, railroad flatcars, and barges. This reactor reached initial criticality March 30, 1961, and was shut down in 1965. The spent fuel from this reactor was sent to SRS.

The following is a list of the six pressurized water reactors in the ANPP:

- The Mobile High Power Plant (MH-1A), located in Virginia, was designed by Martin Marietta Corporation and was installed on a converted Liberty ship named *Sturgis*. It remained moored at Gatun Lake in the Panama Canal from 1968 until 1977. This reactor reached initial criticality January 24, 1967, and was shut down in 1977. This reactor had a total of five cores and used LEU in the range of 4 to 7 percent with a total amount of uranium-235 supplied being 541.4 kg. The spent fuel from this reactor was sent to SRS.
- The Portable Medium Power Plant (PM-1) in Sundance, Wyoming, was designed by the Martin Company and provided electric power to the 731st Radar Squadron of the North American Air Defense Command (NORAD). This Plant reached initial criticality February 25, 1962, and was shut down in 1968. The reactor had two cores with the total amount of uranium-235 supplied being 60.8 kg. PM-1 operated at a uranium-235 enrichment of 93 percent. The spent fuel from the first core was sent to SRS and the fuel from the second core was sent to the Portable Medium Power Plant (PM-3A) located in McMurdo Sound, Antartica.
- The Portable Medium Power Plant (PM-2A) in Camp Century, Greenland, was designed by the American Locomotive Company to demonstrate the ability to assemble a nuclear power plant from prefabricated components in a remote, arctic location. The pressure vessel was subsequently used to investigate neutron embrittlement in carbon steel. This Plant reached initial criticality October 3, 1960, and was shut down 1963-1964. This reactor had one core with the total amount of uranium-235 supplied being 18.2 kg. PM-2A operated

at a uranium-235 enrichment of 93 percent. The spent fuel from this reactor was sent to SRS.

- The Portable Medium Power Plant (PM-3A), located in McMurdo Sound, Antartica, was designed by the Martin Company to provide electric power and steam heating to the Naval Air Facility at McMurdo Sound. This Plant reached initial criticality March 3, 1962, and was shut down in 1972. The reactor had a total of five cores with a total amount of uranium-235 supplied being 121.6 kg. PM-3A operated at a uranium-235 enrichment of 93 percent. The spent fuel from all five reactors was sent to SRS.
- The Stationary Medium Power Plant (SM-1), located at Ft. Belvoir, Virginia, was designed by the American Locomotive Company and was the first reactor developed under the Army Nuclear Power Program. This Plant was used to train Army nuclear plant operators. SM-1 was also the first reactor built with a containment structure. It reached initial criticality on April 8, 1957 and was shut down from 1973-1975. This reactor had a total of three cores with the total amount of uranium-235 supplied being 72.7 kg. SM-1 operated at a uranium-235 enrichment of 93 percent. The spent fuel from the first core was sent to INEEL, and the fuel from the second and third core was sent to SRS.
- The Stationary Medium Power Plant (SM-1A) at Ft. Greely, Alaska, was designed by the American Locomotive Company and was the first field facility developed under the Army Nuclear Power Program. This site was selected to develop construction methods in a remote, arctic location. SM-1A reached initial criticality March 13, 1962 and was shut down in 1972. This reactor had a total of four cores with the total amount of uranium-235 supplied being 117.1 kg. SM-1A operated at a uranium-235 enrichment of 93 percent. The spent fuel from the first and second cores was sent to SRS, and the fuel from the third and fourth cores was sent to INEEL.

Below is a description of the only boiling water reactor in the ANPP:

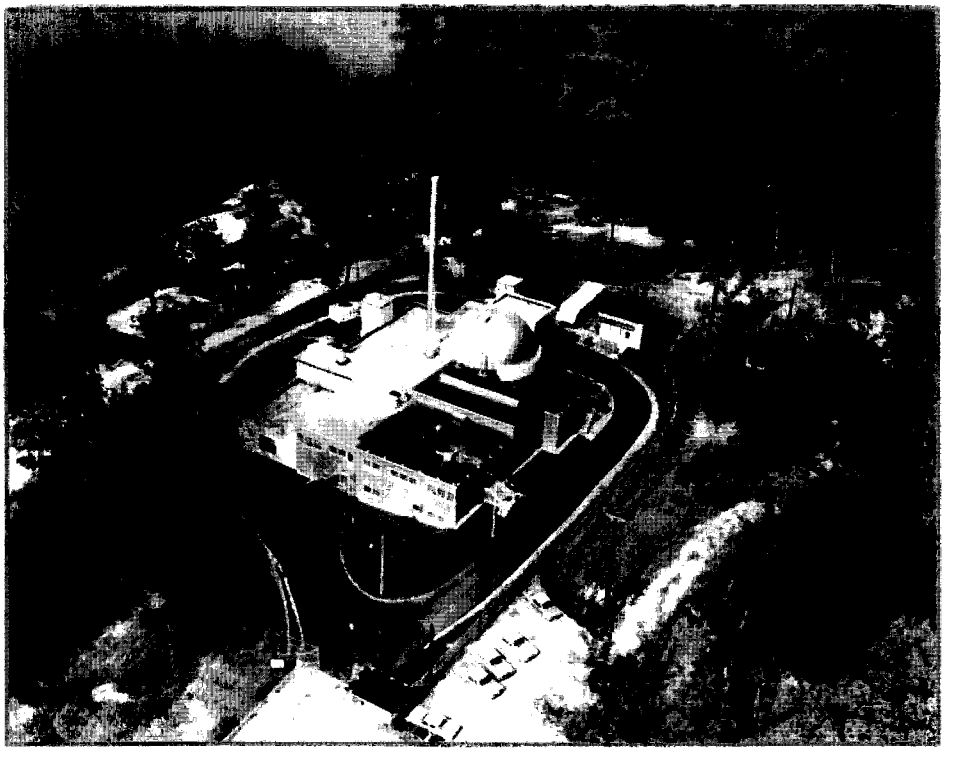
- The Stationary Low Power Plant (SL-1), located at INEEL, was designed by the Argonne National Laboratory to gain experience in boiling water reactor operations, develop performance characteristics, train military crews, and test components. The SL-1 reactor reached initial criticality on August 11, 1958 and had only one core. Combustion Engineering was awarded a contract by the AEC to operate the SL-1 and in turn employed the Army's military operating crew to continue running the plant. On January 3, 1961, the SL-1 was destroyed in an accident that caused the death of the three-man operating crew.

Other Nuclear Plant Designs and Concepts

The following is a list of proposed nuclear plants that were never built:

- The Mobil Low Power Plant (ML-1A) was to be a gas cooled reactor and the first planned field unit for the ML-1 series of reactors.
- The Portable Low Power Plant (PL-1) was to be a boiling water reactor to supply power for remote locations using 3 MW thermal power. The Plant was to be based on a low enriched tubular core with pelletized fuel. It would have been air transportable in 11 packages. The design for this Plant was completed on June 30, 1961.

- The Portable Low Power Plant (PL-2) was also intended to be a boiling water reactor and supply power for remote locations using 10 MW thermal power. The Plant was to use LEU pelletized fuel in a tubular core. It also would have been air transportable in 11 packages. The design for this Plant was also completed June 30, 1961.
- The Portable Low Power Plant (PL-3) was to be a pressurized water reactor and supply power for remote location using 9.3 MW thermal power. This Plant was to be based on high-enriched plate-type fuel.
- The Stationary Medium Power Plant (SM-2) was also intended to be a pressurized water reactor and the prototype for the SM-2 series of reactors to use 28 MW thermal power. This Plant was to be based on high-enriched plate-type fuel.
- The Stationary Medium Power Plant (SM-2A) was to be a pressurized water reactor and was intended to be the first planned field unit for the SM-2 series of reactors.
- The Military Compact Reactor (MCR) was to be a liquid-metal-cooled reactor. The development for this reactor ran from December 1955 to December 1965. The initial concept was for this reactor in a heavy overland cargo hauler. Later, it was transferred to the Nuclear Power Energy Depot program, which investigated ways to produce synthetic fuels in combat zones.



The Stationary Medium Power Plant (SM-1), located at Ft. Belvoir, Virginia, was the first reactor developed under the Army Nuclear Power Program.