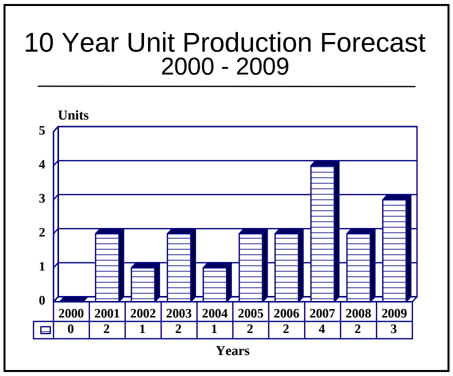
US Nuclear Propulsion - Archived 8/2001

Outlook

- Offers unbeatable range, endurance, electrical production
- Negatives: cost, safety, environment, infrastructure for refueling
- Future procurement limited to carriers and submarines
- Price, equipment size, safety an issue on other vessel types
- Rival non-nuclear technologies: fuel cells, hybrids, gas turbines



Orientation

Description. This report tracks the development and upgrading of nuclear propulsion plants for US Navy vessels.

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Licensees. No production licenses have been granted due to the sensitive nature of nuclear propulsion and the program safeguards.

Status. Production and service.

Total Produced. A force estimate suggests that about 235 reactors of assorted types have been produced for service deployment thus far.

Application. Nuclear power is used as a source of heat for propulsion and generation of electricity and steam on surface ships and submarines.

Platform. The nuclear reactors are installed on shore as well as on board the CVN, CLGN, SSN and SSBN type vessels at sea.

Price Range. The price for a submarine reactor is pegged at roughly US$100 million and for an aircraft carrier at US$200 million each.

Technical Data

Specifications

Designation	Power Output
A2W	35,000 shp
A4W/A1G	140,000 shp
C1W	40,000 shp
D2G	35,000 shp
S5W	15,000 shp
S5G	17,000 shp
S6W	35,000 shp
S8G	35,000 shp
S9G	40,000 shp

Variants/Upgrades

US nuclear reactor nomenclature began by using specific names for types of reactors and acronyms based on those names. The growing numbers of reactor types in service led to the introduction of a systematic nomenclature system in 1955. Under this system, an initial letter indicated the type of ship for which that reactor was intended (A for Aircraft carrier, C for Cruiser, D for Destroyer and S for Submarine). This was followed by a serial number, then a final letter indicating the producer (G for General Electric, W for Westinghouse, C for Combustion Engineering).

A1G. A General Electric version of the A4W (see below), physically the same reactor but using different reactor cores providing longer core life.

A4W. The Westinghouse D1W reactor was scaled up during the late 1960s to provide a powerplant for the new CVN-68 Nimitz class aircraft carriers. Power output was doubled to 120,000 shp, with two of the reactors being used for each of the new carriers, giving a total installed power of 240,000 shp (the USS *Nimitz* is reported to have developed 260,000 shp in trials). Later ships of the class may have reached 280,000 shp.

The CVN-77 is still believed to feature the same A4W/A1G pressurized water reactors as the Nimitzes, with the two reactors providing a pressure of 42.3 kg/cm². However, the subsequent carriers (CVX) are likely to have a new propulsion system still based on a nuclear reactor but with a new-design reactor and possibly electric drive. Depending on the availability of funding, their configuration may differ substantially from the preceding carriers of this series.

Advanced Fleet Submarine Reactor (AFSR). A redesigned and modernized version of the S2W reactor (see below) used on the *Nautilus* intended as an alternative to the troubled SAR program. The AFSR was redesignated the **S5W** and became an extremely successful powerplant. Originally designed to produce twice the output of the S3W, it substantially surpassed this and was rated at 15,000 shp. It was used on US ballistic missile submarines of the George Washington, Ethan Allen and Lafayette classes and hunter killer submarines of the Skipjack, Permit and Sturgeon classes. A single S5W reactor was exported to the UK to power the first British nuclear-powered hunter-killer submarine, HMS *Dreadnought*. Contrary to many published reports, the relationship between subsequent British reactors (the PWR-1 family) and the S5W is extremely limited.

D1W. The Westinghouse-designed pressurized water D1W reactor was designed to provide a new-generation powerplant for destroyers and cruisers. Limitations on the basic power output and design technology of the older generation of reactors meant that significant increases in power could only be obtained by using numbers of reactors in tandem. This reached a crux with the USS *Enterprise*, which had eight A2W reactors in machinery spaces of nightmarish and Byzantine complexity. The D1W reactor was intended to replace the pair of D2G reactors used in existing surface combatants and was intended to deliver 60,000 shp. Intended platforms included the Typhon class cruisers projected in the early 1960s. Typhon was canceled and D1W was never produced.

D2W. An upgraded version of D1W intended to power the abortive CSGN strike cruiser of the mid-1970s. The non-availability of the D2W led to D2G reactors being specified in their place. The CSGN was canceled in 1977.

High-Powered Reactor. A surface-ship offshoot of the SAR program intended to produce a reactor for destroyers and cruisers. The land-based prototype of the HPR was redesignated the **D1G,** with the service production version becoming the **D2G**. All US nuclear-powered cruisers other than the USS *Long Beach* were powered by a pair of D2G reactors. The D2G is rated between 30,000 shp and 35,000 shp.

Large Ship Reactor (LSR). A Westinghouse program to develop reactors suitable for powering large surface ships, the LSR program led to the A1W/A2W reactors used on the USS *Enterprise* and the C1W plant used on the cruiser USS *Long Beach*. The **A1W** was the shore-based version of the LSR with the **A2W** being the service variant. The A2W was rated at approximately 30,000 shp, eight of these reactors being used to power the *Enterprise*. This technology was further exploited to create the 60,000 shp **A3W** in 1962. This was intended for the projected second nuclear-powered aircraft carrier which would have had four such reactors but was abandoned when the aircraft carrier was not ordered. The **C1W** differed from the A2W by being rated at 40,000 shp.

S5G. Initial sea-going prototype of a natural circulation reactor designed by General Electric. This reactor powers the submarine USS *Narwhal*. The S5G is usually rated at 17,000 shp. The reactor requires a considerably larger pressure hull diameter than the S5W and also uses a circulating water scoop instead of pumps to circulate cooling water. This required a long water intake pipe, which is undesirable. For these reasons, natural circulation reactors have not been used in subsequent attack submarine designs.

S5W. This is the reactor still operational on board the training submarines SSBN-626 (formerly USS *Daniel Webster*) and SSBN-635 (formerly USS *Sam Rayburn*), moored in Charleston, South Carolina, as floating equipment. The submarines have been stripped of their missile compartments and are used as training facilities for nuclear power equipment, with the remaining spaces altered to facilitate training. The reactor plants are fully operational.

S5W-TED. A version of the standard S5W reactor in which the S5W is coupled with a scaled-up (by a factor of six) version of the *Tullibee*'s turbo-electric drive. The combination was rather unsuccessful since the added weight and bulk reduced the performance of the submarine and the turbo-electric machinery itself was unreliable.

S6G. The S6G arose from a requirement to produce a faster submarine than the S5W-powered generation. Options examined included a boosted S5G reactor, an S5W-powered boat with more efficient power train and a submarine version of the D2G reactor plant. The latter option proved preferable and the submarine version of the D2G was designated the S6G. It is rated at 35,000 shp and it powers the Los Angeles class submarines.

S6W. The S6W is a Westinghouse-designed pressurized water reactor of 200 Megawatts, distantly related to the D1W, used to power the three SSN-21 Seawolf class submarines. Its effective output is rated at 45,500 shp.

S7G. The adaptation of the D2G to submarine propulsion led to consideration of other reactor possibilities. One suggestion was the use of the 60,000 shp D1W as a submarine reactor. This very powerful reactor was proposed for use in a multirole submarine project designated APHNAS (Advanced Performance High-speed Nuclear Attack Submarine). This program was canceled, but the submarinized D1W reactor and its 60,000 shp rating were incorrectly reported to be the powerplants of the Ohio class SSBNs. This, in turn, led to the assumption that the S8G powerplant of the Ohios was rated at 60,000 shp.

S8G. Natural circulation reactor designed by General Electric for the Ohio class. Basically, an enlarged and enhanced S5G, rated at 35,000 shp.

S9G. New reactor developed by General Electric to power the new Virginia class SSN-774 (a.k.a. NSSN). This single pressurized-water reactor will have a core that is expected to last the 30-year life of the submarines. According to the Navy, the S9G will be "as quiet at 25 knots as an SSN-688 alongside the pier." Consequently, the S9G is now considered superior to any Russian design in its noise-reduction capabilities. A total of 30 units are projected to be built in this series.

Small Power Reactor (SPR). The SPR started as a lineal extension of the line of development with the halving of the STR output to give the SFR; halving output again opened the possibility of a reactor plant small enough to power a mass-production nuclear submarine. The reactor was redesignated **Submarine Reactor Small (SRS)**, then later became the **S1C** for the land-based prototype and **S2C** for the service reactor installed in the very small submarine USS *Tullibee*. The S2C was rated at 2,500 shp. This family of reactors was not regarded as being efficient since reactor shielding weight does not decline in proportion to reduced power output. The S2C is the only reactor system produced by Combustion Engineering.

Submarine Advanced Reactor (SAR). An advanced pressurized water reactor system intended for use in high-speed submarines. Development of the SAR was started by General Electric in April 1953. In 1955, the land prototype of the SAR was designated the **S3G,** with the ship-based version becoming the **S4G**. The SAR was specifically designed for use in a two-reactor power train. Each reactor was rated at 17,000 shp to give a total output of 34,000 shp. In fact, the power train achieved 45,000 on trials.

Submarine Fleet Reactor (SFR). A scaled-down version of the S2W for use in the first production US nuclear-powered submarines, the Skate class. Since the design is a simple extrapolation of the S2W, no land-based prototype was built. The reactor was rated at around 6,600 shp. Two configurations were adopted, the **S3W** which powered the first two submarines of the class and the **S4W** which powered the remainder. The S3W used a new arrangement in which the reactor compartment extended vertically throughout the hull, access for and aft being by a shielded tunnel. The S4W used the older arrangement pioneered by the USS *Nautilus* in which the heat exchangers were carried low, aft of the reactor, the whole assembly being covered by a thick horizontal deck. Both systems worked well, but the S3W arrangement was much more efficient and was adopted for all subsequent reactor designs.

Submarine Intermediate Reactor (SIR) Mk.A. The original General Electric-designed prototype liquid-metal-cooled reactor built on land. This reactor later became the **S1G**.

Submarine Intermediate Reactor (SIR) Mk.B. General Electric-designed liquid-metal-cooled reactor installed on the USS *Seawolf*. This reactor was later redesignated the **S2G** under the new nomenclature system. The decision to abandon liquid metal cooling technology had already been made by the time the S2G entered service, and the wisdom of this judgment was confirmed by the disastrous early experiences of the submarine.

Submarine Thermal Reactor (STR) Mk.1. The original Westinghouse-designed prototype pressurized water reactor built on land. Ordered in 1949 and later redesignated the **S1W**.

Submarine Thermal Reactor (STR) Mk.2. Westinghouse-designed pressurized water reactor installed on USS *Nautilus*. This reactor was subsequently redesignated the **S2W** when the logical designation system was introduced. The S2W was rated at around 13,400 shp.

Program Review

Background. The naval nuclear propulsion program is a joint effort by the US Department of Energy and the US Navy. Two Department of Energy-owned, contractor-operated laboratories operate exclusively for the naval reactors program. They are the Bettis Atomic Power Laboratory (Bettis) in Pittsburgh, and the Knolls Atomic Power Laboratory (General Electric) in Schenectady, New York. These facilities are used to develop technological changes and train system operators.

The goal of the DoE program is to design, develop, and test improved nuclear propulsion plants and reactor cores having long fuel life, increased reliability, improved performance, and simplified operation and maintenance requirements. The ultimate goal is to develop reactor cores that will last the life of a ship. Special emphasis is placed on obtaining advanced long-life cores needed for increased ship performance and availability. The DoE also seeks ways to safely dispose of used reactors from decommissioned submarines.

The Department of the Navy, through the Naval Nuclear Propulsion Office, is responsible for the military application of nuclear propulsion, including constructing, operating, and maintaining nuclear-powered ships, and for developing the non-reactor portions of the nuclear propulsion plants.

This office has, by nature of its work, very close ties to the DoE while maintaining a great deal of independence. The office has been traditionally led by four-star generals (admirals) with eight-year tenures.

The office is the successor to the nuclear program office founded in the late 1940s by Admiral Hyman Rickover for the development of nuclear submarine propulsion. He was able to run the office single-handedly, thanks to the total secrecy of the program funded officially by the DoE. Many of the office’s independent practices developed in that era, occasionally leading to heightened conflicts with other parts of the Navy.

The development of US nuclear propulsion technologies continued throughout the Cold War.

These efforts culminated in the development of a nuclear-powered submarine, the *Nautilus*, in the mid-1950s. From this ship onward, the US Navy had entered into a new era in its power projection capability thanks to nuclear power, which offered a virtually unlimited range of operation with no need for refueling while under way.

The size of the submarines grew progressively larger through the 1950s, '60s, and '70s, the largest ever submarine for the US Navy being the 560-foot-long Ohio class ballistic-missile launch platforms. They were designed in the 1970s and began entering service from the early 1980s onward. Meanwhile, attack submarines were being built with smaller hulls but higher top speeds for patrolling and reconnaissance missions. The Los Angeles class SSNs, which came into service in 1976, were fitted with one GE PWR S6G reactor and two turbines each, producing a top speed of more than 30 knots. The same propulsion arrangement was installed on the Ohios, but due to their massive size, their top speed was less than 30 knots.

At the individual program level, major RDT&E goals in 1982 included advanced reactors for future submarines and surface ships with the potential to put a higher power reactor in a given hull size, a submarine test core with better performance and longer core life, an advanced design propulsion plant for the ballistic missile submarines and guided missile cruisers, an advanced fleet core to extend fuel life, and materials and corrosion testing aimed at extending reactor plant life beyond 20 years.

These efforts continued in 1983. A major change was reorienting the Nuclear Propulsion Technology Program to better reflect the actual objectives of the program in reactor development. In 1984, nuclear reactor development and procurement programs saw a modest growth in RDT&E funding and more substantial growth in procurement funding. The Navy has funded up to seven major development programs for reactor RDT&E, but from 1984 through 1986, only four were active.

The S6G reactor program for the SSN-688 class submarines was absorbed into the Operational Reactor Development Program (PE#0205675N), as was the D2W reactor program. The three programs are examined in detail below.

The Nuclear Propulsion Technology Program (PE#0602324N) continued developing and qualifying advanced nuclear physics methods for improved plant performance and safety. Nuclear physics methods also were qualified to enhance design capability. The Navy qualified a vectorized three-dimensional diffusion theory to optimize nuclear design programs. A vectorized two-dimensional theory with depletion capability also was developed. Surveys were held on cores installed in prototype plants to provide physics and mechanical data. The service also continued development of structural computer program capabilities with nonlinear time-dependent response. Tests were carried out on various materials to determine their corrosion resistance, and alloys with improved corrosion resistance were developed.

In 1987 this program investigated the long-term effects of radiation, heat, and operational loads on reactor materials to ensure continued safe operation of existing plants and that developmental plants use the safest materials available. Advanced instrumentation, control and electronic technologies were developed to improve reactor plant reliability, while improved thermal and fluid transfer technology was developed to improve efficiency. New physics methods also were developed. These efforts continued in 1988, as did the development and analysis of new plant materials. New microprocessor and graphic display technology was developed for possible use in plant instrumentation and control systems.

The Advanced Nuclear Reactor Components and Systems Development Program (PE#0603570N) gained a new project in 1986, when the S6W Nuclear Propulsion Plant Project (S1914) was established. This project was to develop the nuclear reactor for the SSN-21 Seawolf class attack sub. The program was expected to see major advances in noise reduction. The Navy was developing new pumps, instrumentation and control equipment, valves, heat transfer equipment, shielding and component systems in 1985 and 1986. Other developments included testing main coolant pump subsystems, designing microprocessor-controlled instrumentation and developing new propulsion plant shielding systems. A full-scale mockup of the reactor plant was built to determine optimum system location.

During 1987 and 1988, this program continued to develop heat transfer components using stronger materials. Fluid transfer and control equipment also was developed. Shock tests were held on portions of the reactor in 1988, valves were developed for the plant and instrumentation test units were fabricated. The Navy also analyzed reactor plant foundations and piping to assess structural and acoustic adequacy, and built a plant mockup to establish arrangement details.

The second project in PE#0603570N is Advanced Nuclear Reactor Components and Systems Development (S1258), which is an integrated research project including both Department of the Navy and Department of Energy funding, with most of the funding coming from the latter. In 1985 and 1986, heat transfer technology research was conducted to improve steam generator and pressurizer performance. Steam generator shock test data were evaluated, as was the material, chemical, and radiological behavior of reactor plant components. New shielding designs were developed to assure safe radiation exposure levels for operating personnel. Another major effort involved the development of lead unit refueling equipment and shipping containers for irradiated structural components.

Year 1987 efforts in this program included the design of new and improved heat transfer equipment for greater reliability and performance. Fluid transfer material was designed and tested, as was better instrumentation and control equipment. In 1988, new concept steam generator material structures were developed, small-scale heat transfer units were fabricated and tested and the design of a large-scale unit was begun. The Navy determined the feasibility of various manufacturing methods for a new steam generator. The service also developed remote robotic steam generator inspection equipment to reduce the amount of exposure to personnel during inspections. It began designing advanced diagnostic equipment and developed and tested alternative bearing material.

The A4W/A1G Nuclear Propulsion Plant Program (PE#603578N), which developed the reactor for the CVN-68 Nimitz class aircraft carriers, saw several milestones between 1985 and 1987. In 1985 this program evaluated basic circuitry, and tested and evaluated new instrumentation and control system technologies. The Navy also tested systems for the first CVN-68 refueling. Due to the expanded operating cycles of the nuclear carriers in the early 1980s, the Navy also analyzed reactor core lifetime performance versus original core objectives. This program ended in 1987.

The Operational Reactor Development Program (PE#0205675N) developed modifications and improvements to existing naval nuclear reactors, while testing and evaluating new systems. In 1985 and 1986, reactor plant engineering, thermal and hydraulic studies were conducted, and the development of systems to ensure safe reactor operation continued. Stress, vibration and brittle fracture analysis studies were conducted, as were stress corrosion tests.

The 1987 and 1988 program plans called for continuing development and testing of reactor servicing and refueling equipment and methods to evaluate corrosion. Efforts continued to resolve design issues and evaluate engineering tests, and thermal and hydraulic analyses were conducted of operating reactor plants. Also, the service investigated ways to operate reactor plants beyond their original design lifetimes, while continuing to evaluate new prototype propulsion systems and designs to determine deficiencies.

Year 1989 efforts in PE#0602324N included the continuation of reactor materials work. Irradiation, corrosion and mechanical property were tested, and technology was further developed for cutting and welding such materials.

New technologies to be developed and tested included graphic display technology for use in advanced systems; fiber-optics; high-power semi-conductors; and microprocessor-based power conversion techniques for use in power generation, control and distribution systems. Work on improved thermal and fluid transfer systems was to continue, with major efforts emphasizing new thermal transfer technology to maximize heat exchange. Improved water chemistries to reduce corrosion were to be developed. Finally, the effects of shock vibration and high temperature on plant equipment were to be investigated.

Under the Advanced Reactor Components and Systems Program small- and large-scale tests were to be conducted to determine the optimum design features for new steam generators. Remote robotic steam generator inspection system development was to proceed, as was the design of equipment using microprocessor and graphic display technology. Also, new pumps and valves were to be developed. S6W reactor efforts were to include the development and qualification of improved heat exchanger components, including steam generator and moisture separators. Pumps, charging pumps, and charging valves were to be developed and qualified. Furthermore, new plant protection monitoring and control equipment were to be developed. Plant components and systems were to be tested to confirm designs and plant operating procedures and guidelines were to be developed.

Operational Reactor Development work was to include the design, development, test and evaluation of reactor refueling equipment and methods to support the initial SSBN-726 Ohio class refueling, the defueling of power units aboard CVN-65 USS *Enterprise* and the continued CVN-68 Nimitz class refueling. The Nimitz class equipment would provide the capability to disassemble and reuse core components. The initial refueling of the NR-1 deep submergence vehicle was to be provided for, along with the shipment of nuclear fuel and irradiated core components. Methods to avoid the need for premature component replacements were to be analyzed. Thermal, hydraulic and mechanical analyses were to continue. Finally, diagnostic test results were to be evaluated to determine plant noise performance and to improve quieting.

Recent Development Efforts. The 1990s mark the first decade since the 1950s during which expenditures on naval nuclear power went down. The Los Angeles SSN and Ohio SSBN programs have now been completed. This leaves only the new aircraft carrier and the last of the SSN-21 class and the new Virginia class attack submarine programs requiring new production. The US Navy currently has two major areas of endeavor: development of the Advanced Fleet Reactor (AFR), and the enhancement of reactors under the Reactor Development and Plant Development programs.

Under the AFR program, the US Navy is developing the reactor for the Virginia class next-generation SSN, developing advanced propulsion technology, improving existing reactors, and ensuring continued safe operation. The Virginia class submarine is the follow-on/replacement type for the SSN-21, which was limited to three units. The reactor type used on this new submarine is designated S9G, and made by General Electric.

Under reactor development, the Navy will direct several key elements. It plans to develop and qualify high-integrity nuclear fuel. The focus will be on how to extend the life of existing reactors and their cores. Additionally, work will be conducted on heat and fluid transfer to reduce size, enhance efficiency, and reduce corrosion. Work will also be performed in the area of instrumentation and controls to improve the system by incorporating microprocessors and fiber optics. Construction will be completed on the new stationary neutron radiography system. While the new facility will be strictly for research and development, it will enter operation in later in the decade. Little information is being made public.

Past experience has shown that nuclear power has limited benefits for surface ships besides aircraft carriers. For those ships, it gives a great deal of propulsion power without the need for refueling, and the size of these vessels can support the existence of a nuclear infrastructure aboard. It is very unlikely, though, that more nuclear-powered surface combatants will be ordered. They are difficult and expensive to design, their deployment carries major political costs, and the environmental effects of one hitting a mine are catastrophic.

The Naval Nuclear Propulsion Office itself is also undergoing major turmoil in its mission and leadership structure. In 1996, when the tenure of Admiral Bruce DeMars was coming to an end, a great deal of debate centered on the need to have a four-star general with an eight-year tenure in charge of the office. Furthermore, his senior position in the Department of Energy, on top of his defense duties, was also being questioned, since it may represent a compromise in the oversight of the Propulsion Office's operations.

The Navy has been critical of suggestions to reform the office leadership structure and function, citing the technological complexity of the issues involved and the necessity to maintain the office's current authority, linking those issues ultimately to nuclear safety overall. One solution may be to separate the technology development of nuclear reactors from safety issues, which would be handled by the propulsion office only. No decision has yet been made on the issues of reducing the tenure to six or even four years and having the head being of a lower rank, or of stripping the office of its Department of Energy functions and responsibilities.

The Department of Energy is also under fire and much public scrutiny these days for apparent oversights in security concerning access to sensitive nuclear weapons data by nationals of other countries, particularly China. It is highly probable that changes will be made in the organization of the DoE as a result of these lapses in security, but a definition of an exact relationship between that agency and the Defense Department on issues such as nuclear propulsion is likely to be a long, time-consuming process that evolves with the political realities of the time.

On the other hand, the issues concerning the safety of Russian submarines and their nuclear fuels being an environmental hazard may have an impact on the general perception of nuclear power's "cleanliness" and safety. In that regard, tolerance for nuclear power in general is much lower in the environmentally sensitive Europe and Japan. Consequently, the issue of ships with nuclear power or with nuclear weapons on board visiting such ports will need to be considered as well. It has already been discussed in the context of Japan not allowing nuclear-powered aircraft carriers at its ports, while the Seventh Fleet plays an important role for the US Navy's Pacific theater defense strategy.

The US Navy nuclear power program has been cut back from its heydays in the 1970s and 1980s, now comprising the completion of the last of the SSN-21 Seawolf class submarine plus one more Nimitz class aircraft carrier (CVN-77). The follow-on program to the Seawolf class, the SSN-774 Virginia class New Attack Submarine program (originally referred to as Centurion and at a time also known as the NSSN), will be nuclear powered, as will the next-generation carriers, now only referred to as the CVX class. The Virginia class development program was expanded to allow the participation of both Electric Boat and Newport News from early on, thus – at least theoretically – somewhat spreading the knowledge base of the US nuclear propulsion technology.

Some concern with the application of nuclear power even on aircraft carriers has been expressed occasionally. Although the advantages of a nuclear-powered carrier are significant and undeniable (operating range, endurance, speed and acceleration), so are the costs involved. This applies both to the procurement cost of the ship itself and to the cost of each refueling it will undertake during its operational life. A conventionally powered carrier would cost less to buy and could be built at many other yards besides Newport News. The financial savings, the argument goes, could be used for purchasing a larger ship instead. Diversifying carriers away from Newport News would entail a valuable broadening of the existing shipbuilding infrastructure.

However, as the debate surrounding the construction of both CVN-77 and the more futuristic CVX carrier concept indicates, the Navy is reluctant to abandon nuclear propulsion as the power source of these very large ocean-going vessels. Nuclear power offers the range and power sources needed by carriers which are, for all intents and purposes, miniature cities on water. Nuclear power therefore ensures extended operating times and continued power delivery, regardless of political turmoil in the oil-producing world. The operating freedom of the ships is limited only by the amount of supplies carried on board and the comfort of the crew.

The same is true for the submarine fleet, where the benefits of nuclear power are being questioned – especially now that the focus of submarine warfare has shifted from the blue oceans to littoral regions. It is possible that the US will drop to a single yard that is capable of building nuclear-powered submarines, plus one for nuclear-powered surface ships and using a single procurement source for their reactors. Trends for such consolidation are already evident in the debate surrounding the construction of the Virginia class SSNs, the future carriers and, most recently, the corporate acquisition plans as suggested by Newport News, Litton, and General Dynamics.

Funding

This program is funded through US Department of Energy and the Department of Navy. In the developmental phase, the funding had been posted mostly under DoE expenditures; when most of the activity becomes development of existing technologies and conversion of existing reactors (refueling and maintenance), much of the funding is listed as Navy expenditures.

During FY82, the total Department of Energy development budget request for naval nuclear reactors was US$361 million, a US$58 million increase over the FY81 budget. The US Navy requested US$95.3 million in FY82 as its share of naval nuclear propulsion development costs and requested $360.8 million for procurement of reactor power units and components. Funding levels declined in the subsequent years and, as stated above, are now mostly in the area of alterations and maintenance.

This activity was awarded US$189.1 million in FY92, dropping to US$139.5 million in the following year and to US$108.6 million in 1994. The next year saw an increase in funding for Nuclear Alterations activity, to US$156.8 million, dropping back to US$120.45 million the following year and even lower, to US$68.5 million, in FY97. For FY98, the President's Budget Request was US$74.1 million, but the amount bounced back to US$109.8 million in FY99. After that, a steady flow of between US$100 and US$150 million a year has been recorded for the Nuclear Alterations line item in the US national defense budget.

Funding for the development of new reactors themselves or entirely new programs is not widely publicized. The office admits to managing about US$1.6 billion a year in funding, but it is generally believed that hundreds of millions of dollars more goes under classified projects and accounts. As a result, it is very difficult to estimate the total funding made available to the Naval Nuclear Propulsion Office by the Defense and Energy departments. Hence the focus in the above discussion is on information about upgrades and modifications to existing systems.

Recent Contracts

Contractor	**Award ($ millions)**	**Date/Description**
Electric Boat	7.1	*February 1997* – Propulsion plant design analysis contract (modification to earlier issued N00024-91-C-4195).

Contractor	Award ($ millions)	Date/Description
Newport News Shipbuilding	175.9	*May 30, 1997* – Refueling, overhaul of CVN-68 and its reactor plants, to be completed by March 1998.
Newport News Shipbuilding	174.7	*Summer 1997* – Availability and reactor refit work on CVN-71 *Theodore Roosevelt.* Projected completion date July 1998.
Westinghouse Electric	49	*November 7, 1997* – Naval nuclear propulsion components contract (modification to earlier issued N00024-96-C-4050), from NAVSEA.
Bechtel National	384.6	*August 13, 1998* – Development of advanced technology and technical support for the 116 land-based Navy reactors at Bettis APL in Pittsburgh.
Westinghouse Electric	102.1	*December 4, 1998* – Naval nuclear propulsion components contract (modification to earlier issued N00024-96-C-4050), from NAVSEA.
Westinghouse Electric	70.7	*December 8, 1998* – Naval nuclear propulsion components contract (modification to earlier issued N00024-96-C-4053), from NAVSEA.
Newport News Shipbuilding	274.9	*FY99* – Multiple, ongoing USN contracts for refueling of the Navy aircraft carriers (mid-life service, overhaul).
Dresser-Rand	9	*Late-1999* – Initial phases of construction of the main propulsion system for CVN-77: four HP & LP steam turbines, totaling 250,000 shp.
KAPL	142.5	*October 20, 1999* – Naval nuclear propulsion work (modification to an earlier contract), with US$10.1 million expiring by the end of FY00.
Bechtel Bettis	33.5	*October 26, 1999* – Naval nuclear propulsion work (modification to an earlier contract), with US$12.1 million expiring by the end of FY00.
Electric Boat	13.7	*October 1999* – Reactor planning yard services (modification to an earlier contract), to be completed by September 2000.
Newport News Shipbuilding	5.4	*October 1999* – Reactor planning yard services (modification to an earlier contract), to be completed by September 2000.
Pennsylvania State University	66.3	*November 2, 1999* – Research, development, engineering, test and evaluation support for Navy and other programs re/advanced propulsors.
Bechtel Plant Machinery	198.1	*November 9, 1999* – Nuclear propulsion components (modification to an earlier contract), to be completed by January 2009.
Bechtel Plant Machinery	121.5	*November 9, 1999* – Nuclear propulsion components (modification to an earlier contract), to be completed by December 2004.
Bechtel Plant Machinery	89	*November 9, 1999* – Nuclear propulsion components (modification to an earlier contract), to be completed by December 2004.
Bechtel Plant Machinery	100.5	*November 19, 1999* – Nuclear propulsion components (modification to an earlier contract), to be completed by December 2004.
Bechtel Plant Machinery	65.9	*November 19, 1999* – Nuclear propulsion components (modification to an earlier contract), to be completed by December 2004.
Electric Boat	54.7	*November 22, 1999* – Manufacture, testing and delivery of one production main propulsion unit for SSN-777.
Newport News Shipbuilding	216.5	*January 21, 2000* – Refueling, overhaul of CVN-69 and its reactor plants, to be completed by May 2001.

Timetable

	Year	Major Development
	1948	US Navy establishes nuclear program office, headed by Admiral Rickover
	1949	Westinghouse's pressurized-water reactor prototype ordered
	1951	Contract awarded for USS *Nautilus*
	1953	GE begins development of Submarine Advanced Reactor
	1955	*Nautilus* propelled by nuclear power. Systematic naming of programs begins
	1961	USS *Enterprise,* the first nuclear-powered carrier, commissioned
	1962	Westinghouse's A3W yields 60,000 shp, developed from the LSR program
	1977	The strike cruiser project CSGN canceled (originally intended to use the D2W reactor)
	1981	Admiral Rickover dismissed by President Reagan
	1982	Design and development of SSN-21 Seawolf begins; RDT&E performed on advanced reactors for ballistic missile subs and guided missile cruisers
	1984	Modest growth in funding, although only four reactor RDT&E programs active through 1986
	1986	New S6W Nuclear Propulsion Plant Project established for the SSN-21 Seawolf class
	1987	Long-term effects of heat, radiation, operational loads of reactor material studied; noise reduction a major issue with Seawolf reactor; stronger materials sought for heat transfer
	1989	Seawolf construction begins
	1990	Studies of next-generation New Attack Submarine (NSSN, or NAS) initiated
	1990s	The first decline in funding for nuclear power funding since the 1950s. Main focus on the NSSN, with improvements being made on existing reactors and improving instrumentation, controls and efficiency
	1996	Debate over the Nuclear Propulsion Office's role, leadership growing, possibly leading to changes in the office's function and responsibilities
	1997	NRAC draft study recommends staying with nuclear power for CVX
	1998	Studies to all-electric propulsion systems gain increasing publicity; GAO report suggests non-nuclear propulsion more economical for carriers; Navy rejects calculations as incomplete
	1998	USN celebrates 50th anniversary of nuclear power
	1999	Bechtel takes over parts of Westinghouse's Navy Nuclear Propulsion Program. All-electric propulsion concept moving forward as future surface combatant power source
Dec	1999	Newport News completes first-ever Nimitz class reactor refueling

Worldwide Distribution

UK (1 S5W plant now decommissioned.)

US (A total of 237 reactors of varying types have been installed on ships. Allowing for shore-based and experimental systems, the total production probably exceeds 250 reactors today.)

Additionally, S5W technology is widely believed to have been used by France for its SSBN program, although no formal technology transfer agreement exists. It is also possible that this technology has found its way to China for the Chinese SSBN program.

Forecast Rationale

Despite all the speculation to the contrary, it is highly probable that the submarines of the US Navy will remain nuclear powered in the foreseeable future. Nuclear power has the same appear for submarines that it has for aircraft carriers: unlimited operational range and power production, low noise level, and no need for en-route refueling. Nuclear power guarantees an operating range restricted only by the amount of supplies carried on board, and the mental well-being of the crew. Even the new Virginia class attack submarine, which will be smaller than the existing submarines of the US Navy fleet, will be powered by nuclear propulsion for those very same reasons.

A return to non-nuclear submarines would be realistic only if a major change in philosophy occurred at decision-making levels. This would have to reflect a perceived need for submarines so much smaller that they physically could not accommodate a nuclear reactor and powerplant on board. Such a shift in policy is not presently in sight for the US Navy. Even with the increased emphasis on littoral regions in future naval warfare scenarios, the US Navy is reluctant to go down to the level of the European diesel-electric boats in its submarine size, at least at this conjecture. The coastal areas of the United States to be defended require platforms different in caliber from those suited for operations in the Mediterranean, parts of the Atlantic or the Baltic Sea.

The following forecast is based on the commissioning dates for platforms being procured for the present programs. The numbers provided represent the total number of reactors for those platforms, rather than the number of ships.

Ten-Year Outlook

ESTIMATED CALENDAR YEAR PRODUCTION

			High Confidence Level				Good Confidence Level			Speculative			
Designation	**Application**	**Thru 99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**Total 00-09**
US NUCLEAR PROPULSION	CVN (US)	24	0	0	0	2	0	0	0	2	0	0	4
US NUCLEAR PROPULSION	SSN (US)	135	0	2	1	0	1	2	2	2	2	3	15
US NUCLEAR PROPULSION	Prior Prod'n:	78	0	0	0	0	0	0	0	0	0	0	0
Total Production		237	0	2	1	2	1	2	2	4	2	3	19