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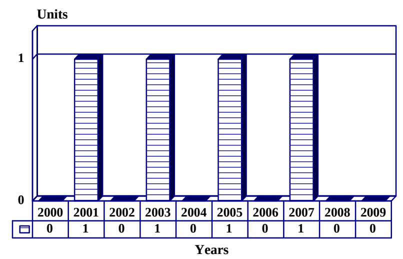
UK Nuclear Propulsion - Archived 5/2001

Outlook

- Submarines are the only application at present
- New PWR-2 core offering core-for-life
- Unique technology for UK
- New Astute class subs mean production will continue well into the future
- All-electric propulsion is a possible alternative in future ships

10 Year Unit Production Forecast
2000 - 2009



Orientation

Description. Uranium fission reactors for generation of heat, to produce steam.

Sponsor

Ministry of Defence (Procurement Executive)
CV Betts
Abbey Wood
UK
Tel: +44 117 913 3700

Contractors

Rolls-Royce & Associates Ltd (RRA)
PO Box 31
Derby DE2 8BJ
United Kingdom
Tel: +44 1332 661461
Fax: +44 1332 622929
Telex: 37616

Licensee. No production licenses have been granted.

Status. Production and service.

Total Produced. An estimated 25 PWR-1 reactor systems have been produced. Four units of the reactor type PWR-2 have been installed on the Vanguard class and one more may exist for test and evaluation purposes, bringing the current total to 30.

Application. A nuclear reactor uses fission of uranium for the generation of steam. That steam is then run through turbines to produce propulsion power as well as electricity and to operate the onboard soft-water plant. On aircraft carriers, the steam would be also used for driving the ship's catapult installations.

The use of nuclear fuel allows virtually unlimited operating endurance at low noise levels.

Platform. PWR-1 systems exist on the Swiftsure and Trafalgar class attack submarines. PWR-2 is on the Vanguard class ballistic missile submarines and will be used for the new Astute class SSN.

Price Range. A very rough estimate of the unit price suggests a price tag between US$200 and US$300 million.

Technical Data

Specifications

Output – PWR-1	15,000 shp
Output – PWR-2	27,500 shp

Design Features. The PWR-1 reactors are standard pressurized-water triple pass systems that use 35 percent enriched Oralloy fuel. The pump, turbines and piping systems are rafted; however, on the P1 versions, the rafts have to be locked down when using high-power outputs.

The P2 variant does not require locking down at high speed. It is important to note that neither the PWR-1 nor the PWR-2 reactors share any significant technology with the United States' S5W reactors.

The PWR-1/P1 reactors used in the first two classes of British attack submarines were semi-rafted designs. They featured rafting of the noise-generating main machinery to reduce noise profiles at low speed. However, when running at high speed, vibration problems forced the rafts to be locked in place. This greatly increased noise levels. The PWR-1/P1 reactor and propulsion train were redesigned and fully rafted for the Resolution class ballistic missile submarines which were being developed at the time, resulting in substantial reductions in noise level.

Operational Characteristics. The operation principle of these reactors is based on the fission of uranium to produce heat which then turns circulating water to steam. The steam is driven into turbines which are used both to run generators for electrical power and to operate the submarine's propulsion systems.

Thanks to the atomic fuel's capacity to generate intense heat for decades, the provision of steam made from the cooling water is virtually unlimited, especially in an environment where the reactor is practically surrounded by water. The only limitations to a submarine's operating endurance under water are posed by physical restrictions such as availability of food and supplies, as well as the human endurance of the crew. As a nuclear power source, submarines and aircraft carriers are almost ideal, providing large volumes of power at very low noise levels and with little regular maintenance.

The new reactor cores now being designed are built for the life of the platform, i.e., no refueling is necessary during the operational lifetime of the ship involved. The mid-life refueling now performed on nuclear vessels is a very expensive process, involving the replacement of the highly sensitive fuel rods from the reactor with new ones. Furthermore, the disposal of used fuel rods remains an issue of significant environmental and health concern worldwide.

The new PWR-2 offers about double the operating range of the current generations of reactors, allowing circumnavigation of the world about 40 times over without the need for refueling.

It is estimated that this entails savings of more than 10 percent in the submarine's lifetime operating expenses

Variants/Upgrades

PWR-1/P1. Original Rolls-Royce semi-rafted design for first six submarines. The first of these was fitted with a US-designed S5W reactor due to design and production delays.

PWR-1/P2. Enhanced and fully rafted version of PWR-1/P1.

PWR-2. The second generation reactor, PWR 2 was originally developed for the Vanguard class Trident submarines. The decision was made in the mid-1970s to design a second generation system that would be digital, and would integrate all key functions while allowing reduced manning levels by centralizing data communications and control operations.

The PWR-2 reactor is also an all-British design and construction. Its major components are the pressure vessels provided by Babcock Energy, main coolant pumps (GEC and Weir), and the protection and control instrumentation (Siemens-Plessey and Thorn Automation).

These reactors have the latest versions of long-life cores that last as long as the submarine, i.e., about 25-30 years, eliminating the need for mid-life refueling.

Program Review

Background. The UK Royal Navy (UKRN) first developed an interest in the construction of nuclear-powered submarines in 1946 when a team of British scientists set out to examine the non-destructive uses of nuclear fission. The first designs for nuclear submarine powerplants were drawn up in 1950 and a prototype submarine design using this engineering system was ready by 1952. However, the program was suspended at that point because the British uranium enrichment facility would not be ready until 1959, and the construction of nuclear warheads had priority for supplies of fissile material in the interim.

This suspension was lifted in 1956 with the decision to initiate the construction of a class of three nuclear-powered attack submarines. These three submarines, HMS *Dreadnought*, HMS *Valiant* and HMS *Warspite,* would use reactor systems and power trains designed by Rolls-Royce. The assembly of material for the lead ship of the class had already started when serious problems emerged with the construction of the submarine's machinery. In addition to designing nuclear reactors for submarines, Britain had also embarked on an ambitious program of civilian nuclear power stations. These took priority over the submarine effort and absorbed most of the efforts of the design offices. The result was a growing discontinuity between hull and machinery construction.

The problem was resolved by the British government purchasing the USN S5W reactor system for the first of the new class and suspending construction of the remaining pair until the British reactor system was available. In effect, the British bought the entire rear half of a USN Skipjack class submarine and welded it to the semi-completed bow half of HMS *Dreadnought*. The abrupt discontinuity in the hull lines where the US and British designs were joined can be clearly seen in photographs of the product. This discontinuity resulted in serious noise generation problems.

The remaining two submarines of the class were delayed by four years, but eventually entered service with their PWR-1/P1 reactors. The first UKRN submarine with a British-manufactured reactor was the HMS *Valiant*, which was commissioned in July 1966. Except for HMS *Dreadnought*, all British reactors have been based on pressurized water-cooled units designed and manufactured by Rolls-Royce. They are not copies of the US S5W system. After the first British nuclear submarine, the main US inputs were limited to procedural matters such as safety considerations, emergency practices and operational doctrine.

The PWR-1/P1 reactors used in the first two classes of British attack submarines were semi-rafted designs. These featured rafting of the noise-generating main machinery to reduce noise profiles at low speed. However, when running at high speed, vibration problems forced the rafts to be locked in place. This greatly increased noise levels. The design was revamped for the upcoming Resolution class SSBNs, with a great deal of success. The UKRN in fact claimed that the rafting techniques developed for this program were superior to those adopted by the USN, and the technology was provided to the US as payment for the technology transfer on the sale of the *Dreadnought's* S5W reactor. The new PWR-1/P2 reactor system was also introduced with the Swiftsure class attack submarines.

Britain never considered the *Dreadnought* to be a first-line submarine due to its non-standard reactor, excessive flow noise from the discontinuous hull lines and machinery noise from the unrafted power train. The submarine was mainly used for training purposes and was decommissioned in 1983. This was the beginning of a serious problem in disposing of the surplus reactors. The UKRN is still in the process of developing various means to dispose of the reactor from this and other submarine types.

In the fall of 1987, Canada announced plans to build a fleet of eight to twelve nuclear-powered submarines. Britain offered the Trafalgar design, while France offered an upgraded Rubis model.

In the mid-1980s, serious mechanical problems were discovered with the PWR-1/P1 reactor trains. This problem was first identified on the Valiant and Churchill class attack submarines during their refits and was isolated as fatigue cracking in the reactors' primary coolant system. At first this was thought to be a result of the semi-rafted configuration of the earlier attack submarines. However, when the Resolution class ballistic missile submarines were examined, it was found that they, too, were suffering from similar problems. This problem now appears common to all PWR-1 powered submarines.

First priority was to maintain the four existing ballistic missile submarines in service. A refit program was instituted for these boats, during which cracking in the reactor containment plating was discovered. All these problems exposed repair workers to low levels of radiation leakage. Keeping the four ballistic missile submarines in service meant that all such workers received the maximum permissible exposure, which left no repair teams available for the attack submarines. As a direct result of this shortage of dockyard workers, the earlier attack submarines were withdrawn from service.

By 1992, the coolant and reactor containment cracking problems had spread to the relatively new Swiftsure class. The lead ship was decommissioned in 1992 and, along with the *Dreadnought* and the five other PWR-1/P1-powered attack submarines, has been laid up without its sail pending the discovery of a safe means of disposal. As the older ballistic missile submarines of the Resolution class are withdrawn, dockyard resources to repair defects in the remaining five Swiftsure class boats will keep these in service until they are replaced by the new Astute class boats.

In 1985, the UKRN gave Rolls-Royce a contract to develop a new reactor, PWR-2, for the Vanguard class Trident ballistic missile submarines. HMS *Vanguard* began sea trials in 1992. Rolls-Royce received another contract in February 1987 to develop an advanced version of the PWR-2 to serve as the propulsion system for the UKRN's next-generation fast-attack submarine, then known as the SSN 20 W class. The first such sub was expected to be ordered in 1990, but the SSN-20 program was canceled when this order did not materialize.

Instead, the UKRN proceeded to develop the Batch 2 Trafalgar Class (B2TC, today known as the Astute class), which was originally to intended to be a radical upgrade of the original Trafalgar class. In the 1992 Defence Review, this plan was rejected, and the B2TC recommended to be virtually indistinguishable from Trafalgar. The PWR-2 powerplant would not have been used for these boats. Following the completion of the initial project definition studies in September 1993, this decision was again reversed, and now the Astutes will be equipped with the PWR-2 powerplant. This decision was made on the grounds that the added capital costs of going from PWR-1 to PWR-2 – in terms of both the reactor itself and the changes in hull design required to accommodate the different reactor – were minor, but the savings in running costs were significant.

Both the Astute class and the existing Vanguard class were intended to use the core-for-life principle in their reactors. This concept involves providing the reactor core with sufficient fissile fuel to provide an endurance of between 20 and 25 years at standard operational profiles. This compares with the 10-year life on the existing Trafalgar reactor core. The new core-for-life, designated Core H, is required to be interchangeable with the older reactor cores and thus must share their dimensions. This implies it will use very highly enriched reactor fuel. However, this reactor design was not adopted by the Vanguard class; hence, the upcoming Astute class will be the first with a core designed for the life of the submarine.

In January 1994, the US Navy review on future submarine acquisition suggested a series of options. One proposal, suggested as an extreme form of cost-cutting in the New Attack Submarine (NSSN) program, was to revert to building the old Permit class design. Since the S5W reactor used in those ships was long out of production, the civilian think-tank responsible for the idea suggested using a British PWR-2 plant instead. This seems to have been a reflection of a common belief in the USN that the PWR-2 is only a PWR-1 with modified cores and that PWR-1 and S5W are virtually identical. In fact, neither PWR-1 nor PWR-2, both of which have very different reactor and power trains, will fit into the rear end of the Permit hull form. The idea was dropped as unworkable.

In the early 1990s, there were frequent reports that an Anglo-French nuclear-powered attack submarine was in planning. These reports turned out to be rumors only, and no such program existed. In late 1994, the French Navy brought forward its new-generation attack submarine program two years early, partly in response to a growing work gap in the French nuclear submarine production facility and partly as a result of the unsatisfactory nature of the Rubis/Améthyste class. The possibility of a jointly run successor program to both remains open. However, the future of the French nuclear submarine program is not as high a priority as the British Astute program, which is in the construction phase for the first three units. The decision to exercise or decline the 1997 contract's option for two more submarines will be made sometime in 2000.

In mid-1995, reports emerged that Britain was considering nuclear propulsion for the replacements for the Invincible class air-capable ships. This appears to stem from the earliest parts of the concept formulation studies on this program (CVSG(R)) where a very wide range of options was examined. One extreme suggestion even involved the purchase of a US Nimitz class carrier.

At the moment, Rolls-Royce & Associates is the nominated subcontractor to design and supply reactor plants for the UK Royal Navy's Astute class of attack submarines. The order is the largest the company has ever received. The contract entails supplying the Navy with three PWR-2 reactors, spares, and in-service support.

The only new program in the UK utilizing nuclear power for the moment is the upcoming Astute class. That program is now in the construction phase, with the launch of three boats taking place with an interval of one or two years between each. The Strategic Defence Review of 1998 indicated that the option for all five boats will be taken in the future, while the total number of nuclear submarines in the British fleet will come down from 12 to 10.

Funding

All UK nuclear reactor work is performed under UK MoD contract.

Recent Contracts

Contractor	Award ($ millions)	Date/Description
Rolls-Royce	N/A	*1985* – UK MoD contract for development of the PWR-2 reactor system.
Rolls-Royce	N/A	*February 1987* – UK MoD contract for PWR-2 reactor modification for SSN-20 submarine.
Rolls-Royce	3,200	*March 1997* – UK MoD contract for the construction of three Astute class (Trafalgar Batch 2) nuclear submarines, using the PWR-2 reactor. An option for two more after year 2000 is included in the contract.
AEA Technology	42	*Spring 1999* – Nuclear safety consultation on submarines for the UKRN.

Timetable

Year	Major Development
1956	UK Royal Navy initiates nuclear attack submarine design
1959	UKRN purchases S5W reactor from USN
1963	UKRN commissions HMS *Dreadnought* with S5W
1967	UKRN commissions first submarine with PWR-1
1976	Program launch for developing more powerful reactor power train
1985	PWR-2 reactor system design begins
1986	UKRN begins discovering cracks in reactor cooling loops
1987	Modification of PWR-2 for SSN-20 started
1990	SSN 20 program put on hold
1993	Decision made to use PWR-2 in B2TC (Astute class)
1993	First PWR-2 powered up in HMS *Vanguard*
1997	Order for three Astute class SSNs
1999	Construction of first Astute class SSN begins
2006	Probable in-service date for the first Astute class submarine
2011	Possible service entry for the fifth unit

Worldwide Distribution

UK. Due to the proprietary nature of the technology involved, this is a UK-only program. An estimated 25 PWR-1 reactors were built in all, including five for the Valiant and Churchill classes, six for Swiftsure, seven for Trafalgar SSNs and four for Resolution SSBNs. Four PWR-2 reactors are installed on Vanguard SSBNs. Additionally, at least three PWR-1 and one PWR-2 reactors have probably been built for experimental establishments onshore.

Forecast Rationale

The following forecast is based on the completion of existing programs plus the acquisition of three Astute class submarines, followed by the optional two. No export of these systems will take place, because of the proprietary nature of the technology involved. The British submarine fleet is now all-nuclear and no plans to reintroduce diesel-electric propulsion are apparent at this time.

Any further sales of this indigenous nuclear propulsion system are contingent on the development of a successor class to the Astutes, presently referred to as the Future Attack Submarine (FASM).

The forecast does not include a provision for any British nuclear-powered aircraft carriers that have been speculated. If such plans do become reality, the forecast will be modified accordingly.

As is the case with the US Navy's current propulsion policy, Britain appears to be leaning toward gas turbine propulsion on its largest surface ships, including the new carriers (CV(F)). An all-electric propulsion system could be developed as well, possibly together with the US, whereby a smaller power generator produces enough electricity for a ship to account for both its propulsion and electricity requirements. Whether that concept involves the use of a nuclear reactor (unlikely) or gas turbine, is yet to be seen. At any rate, Britain's current approach to the CV(F) carrier project also appears to be non-nuclear in design. Consequently, the only application for nuclear reactors in the foreseeable future will be for submarines.

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**
UK NUCLEAR PROPULSION	SSN/SSBN (UKRN)	31	0	1	0	1	0	1	0	1	0	0	4