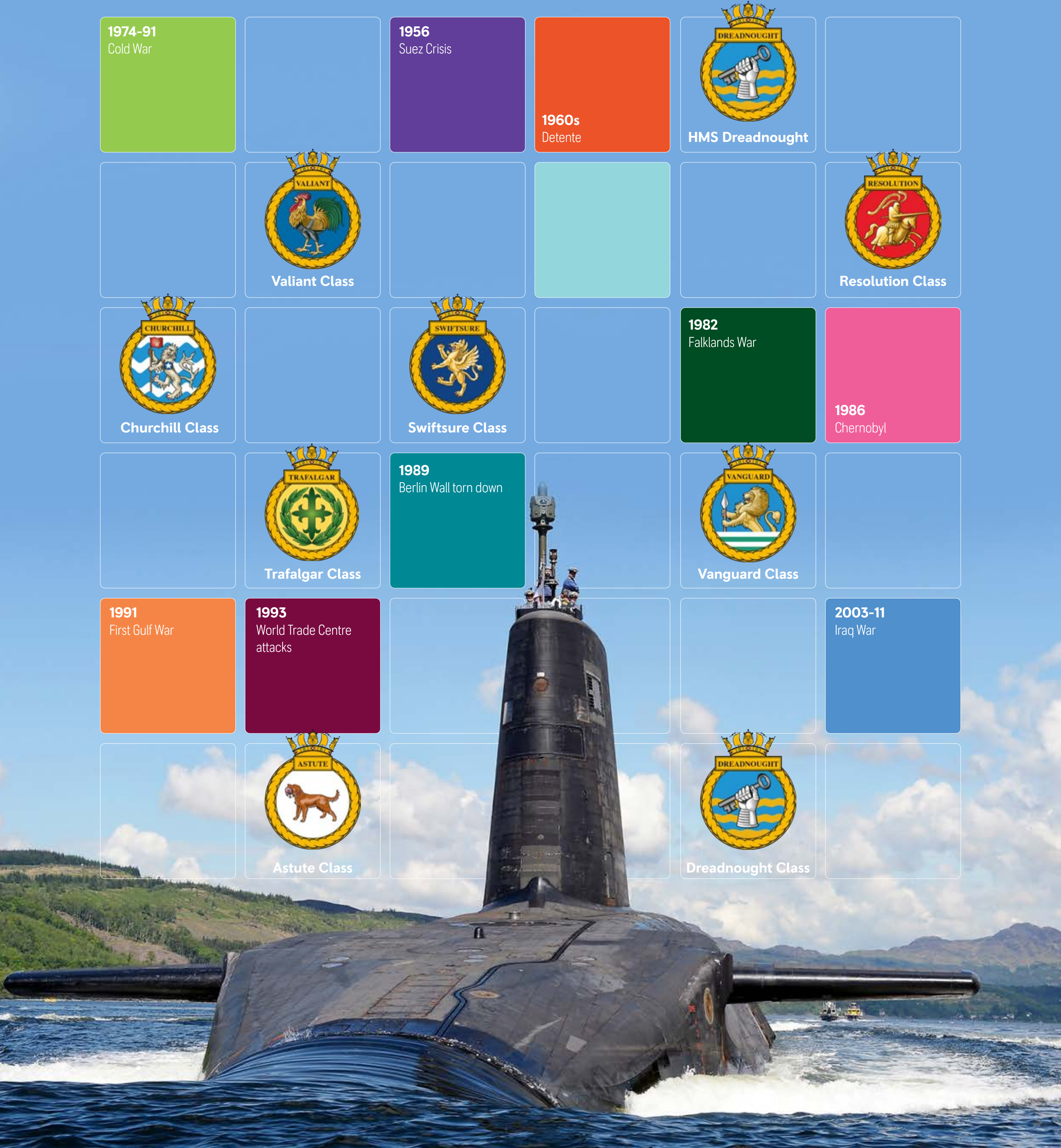
Our Submarines Business

THE UK ROYAL NAVY HAS MAINTAINED A BALLISTIC DETERRENT SUBMARINE AT SEA 24 HOURS A DAY, 365 DAYS PER YEAR SINCE 1969.



Introduction

Rolls-Royce is a world leader in submarine propulsion systems and support services incorporating design, procurement, and manufacture. For the past 60 years we have been the technical authority for the Nuclear Steam Raising Plant (reactor), which provide power for all of the UK's nuclear submarines.

The key role of the submarine fleet

Only five nations possess a submarine nuclear deterrent capability US, Russia, France, China, and UK.

The UK Royal Navy has maintained a Continuous At Sea Deterrence (CASD) capability since 1969 in the form of the Vanguard class submarines and its predecessors. This means one deterrent submarine is on operational patrol and in a position to launch a nuclear missile 24/7, 365 days a year.

In July 2013 the coalition government carried out a review of nuclear possible deterrent platforms. Among the conclusions was the statement that:

None of the alternative systems and postures considered offer the same degree of resilience as the current posture of Continuous at Sea Deterrence, nor could they guarantee a prompt response in all circumstances.

The operational submarine and deterrent capability
The Royal Navy's current submarine fleet comprises two submarine types: The larger Vanguard class ballistic deterrent submarine (SSBN) and the Trafalgar and Astute class attack submarines (SSN). The Dreadnought Class is due to be operational in the early 2030s and will replace the Vanguard boats.

The smaller SSNs operate with a crew of around 100 with the larger deterrent class having a crew of around 135. In comparison to the latest Queen Elizabeth aircraft carrier which has a crew complement approaching 700.

The entire submarine fleet of SSBNs is now fitted with our most advanced reactor cores with enough fuel to operate for over 25 years.

What submarines do

- Provide the UK's Continuous-At-Sea-Deterrent.
- Surveillance and information gathering - Sonar capable of detecting large ships up to 3,000 miles away.
- Communication of data - The submarines have high-precision echo sounders, two non-hull-penetrating masts—in place of conventional periscopes—which carry thermal imaging and low-light TV.
- Landing of special operations forces – facilitated by a removable module, which allows deployment whilst the submarine is submerged.
- Land targets - The Tomahawk missiles are capable of hitting a target to within a few metres up to a range of 1,240 miles (2,000 kilometres).

Unlike previous diesel powered submarines nuclear powered submarine's dived endurance is only limited by the amount of food that can be carried and the endurance of the crew.

The submarine reactor plant emits a similar noise profile as a car engine at idle.

ROLLS-ROYCE AND ASSOCIATES FORMED FROM ROLLS-ROYCE, FOSTER WHEELER, BABCOCK AND VICKERS.

Our nuclear submarine history

The use of nuclear power as a form of naval propulsion was first considered as far back as 1939. During the second world war many of Britain's greatest scientific minds worked in the US on projects around nuclear fission for military purposes. However, the McMahon act of 1947 in the US restricted the release of any atomic technology to any country, even to its allies here in Britain.

After independent UK and US research the McMahon restrictions were eased in 1956 which resulted in the signing of the 1958 Co-Operation Agreement on the Uses of Atomic Energy for Mutual Defence Purposes. The agreement enabled a British government's appointed agent to purchase a complete nuclear propulsion system in exchange for details of UK work on commercial gas-cooled power reactors. The partner organisation Rolls-Royce & Associates was formed as the government's appointed agent, and then purchased a US Westinghouse S5W Skipjack reactor plant, including full access to design philosophy for the reactor plant. The plant went on to power HMS Dreadnought, Britain's first nuclear powered submarine.

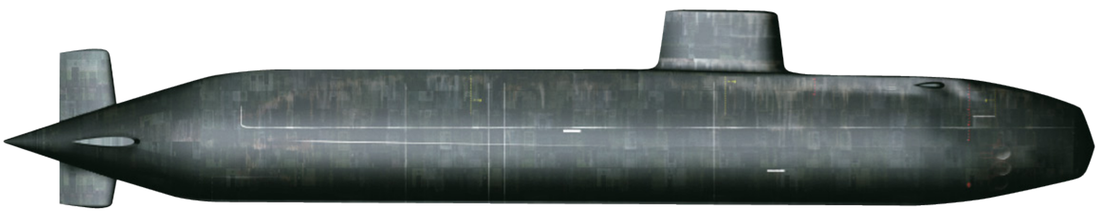
The first nuclear submarine to be built wholly in the UK was HMS Valiant launched in 1963. Shortly after being fully commissioned, she completed a fully submerged run of 12,000 miles over 28 days, setting the record at this time.

In 1954, the UK and US agreed to develop a joint programme to deliver a nuclear weapons deterrent, the UK was to investigate the medium range solution. The Blue Streak missile system and Blue Steal aircraft solution were found to have limitations of range and or vulnerability. In 1963, the UK signed an agreement with the US to purchase the Polaris submarine launched missile system which required a new type of submarine SSBN (Ship Submersible Ballistic Nuclear). The first of four built, HMS Resolution was launched in September 1966 which hailed the start of what is now the longest ever military operation, Operation Relentless; a Continuous At Sea Deterrence.

Rolls-Royce & Associates became fully part of Rolls-Royce in 1994.

We are proud to have delivered safe, reliable power to the Royal Navy Submarine flotilla for nearly 60 years.

The Royal Navy's Nuclear Submarines have travelled over 18 million miles on Rolls-Royce nuclear power.



A ROLLS-ROYCE NUCLEAR POWER PLANT HAS A SIMILAR POWER AND VOLUME TO A TRENT XWB, WITH ENOUGH FUEL FOR 25 YEARS OF OPERATION.

Technology and people

Rolls-Royce Raynesway (Derby) is responsible for delivering Nuclear Steam Raising Plants (NSRP), and parts of the Secondary Propulsion systems to the Defence Nuclear Organisation and managing these assets across the full Concept, Assessment, Demonstration, Manufacture, In-Service and Disposal (CADMID) lifecycle. To achieve this, we employ world class engineers from a variety of backgrounds, and similarly skilled functional staff to support safe and timely delivery and cost effective engineering solutions to the customer..

Our engineers design and substantiate the safety for the entirety of the NSRP including; the Reactor Cores, Primary Systems Pipework and Valves, Major Vessels, the Electronic Control Systems, and also parts of the Secondary Equipment; the Turbo-Generators and Propulsors.

We are continually working on developing new methods of manufacture to improve both safety and efficiency within our products.

- We specialise in a number of high integrity welding and cladding applications, including automated arc and power beam welding processes. We are also developing cutting edge welding technologies for future products that will deliver significant improvements in productivity and quality. For example electron beam welding of thick section pressure vessels.
- Additive Manufacture is a method of creating components by selective addition of material, much like 3D printing. We have successfully used this technique to manufacture a number of test rig components and are developing the use of Additive Manufacture to produce components that will eventually form part of the in-service reactor systems.
- Hot isostatic pressing (HIP) is a process that applies high gas pressures at elevated temperatures to materials. It can be used to convert metallic powder in the solid state to fully dense components, resulting in better physical properties than those achieved by traditional manufacturing technologies. The powder can be encapsulated in shaped sheet metal and HIP'ed to produce near complete parts that require much less machining. A number of submarine parts utilise the HIP process. HIPing can replace the need for complex welds and the associated Non Destructive Examination (NDE), all of which have significant cost and time saving benefits.

We are proud to provide on-going support to the Royal Navy Submarines that use our reactor plants, either in build or in-service. We provide frontline Submarine Support for the reactor plant equipment via the Operations Centre in Derby, the Barrow Shipyard and the Naval Bases at Devonport and Faslane.

Engineering population growth over 14 years from circa 900 in 2005 to 1,600 in 2019.

THE SUBMARINES ENTERPRISE IS COMMITTED TO £900M OF SAVINGS OVER 10 YEARS.

Image courtesy of BAE Systems

Submarine enterprise and the Dreadnought Alliance

A collaborative partnership comparison to Aerospace

In the Aerospace world it is the norm that a jet engine manufactured by Rolls-Royce is fitted to an airframe built by Boeing and maintained through a third-party contract for British Airways. In a similar way Rolls-Royce build the reactor for a submarine that is then assembled by BAE Systems, maintained by Babcock and operated by the Royal Navy.

The Submarine Enterprise Performance Programme (SEPP) is a joint Ministry of Defence (MoD), Babcock Marine, BAE Systems and Rolls-Royce initiative to optimise the Industrial footprint through a collaborative working programme.

SEPP is focused on transforming the way we jointly develop, deliver and manage the Submarine Enterprise through progression towards a number of new commercial arrangements for the design, build and through life support of Nuclear Submarines.

SEPP will deliver three key objectives:

Sustainability Secured - UK must retain and sustain the capability to design, build and support nuclear submarines, and must meet the commitment to a successor for the Vanguard class submarines

Cost Down – Realise significant savings through (i) rationalisation of facilities; (ii) adoption of a holistic and inclusive approach to design, build and support; and (iii) the exploitation of our collective buying power

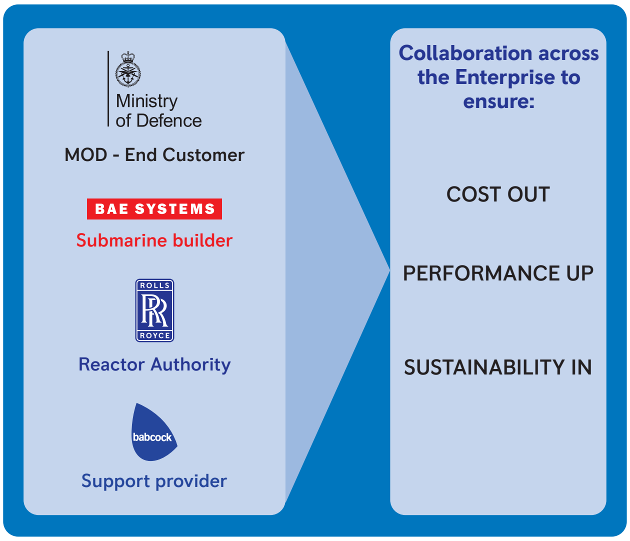
Performance Up - Work together to improve performance on new and existing submarine classes (on time, delivery and availability). Strengthen linkage between customer requirements and Submarine Operating Centre outputs.

DREADNOUGHT ALLIANCE

The Dreadnought nuclear-powered, ballistic missile submarine programme will be the ultimate deterrent against the more extreme threats to the UK's way of life – both now and in the future.

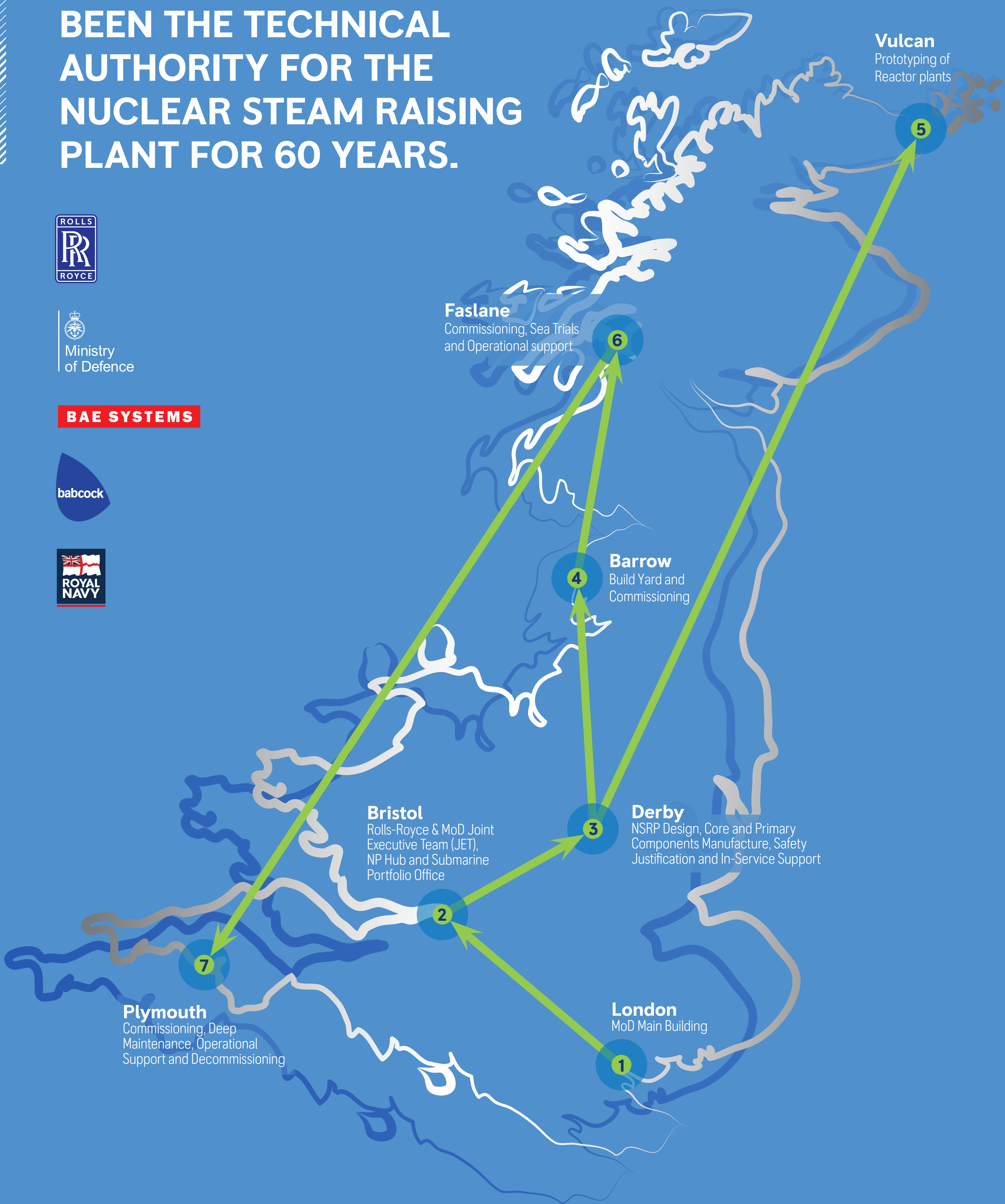
Since 1 April 2018, a new Alliance construct has had responsibility for delivery of the Dreadnought submarine programme. This Alliance was formed between the Ministry of Defence's Submarine Delivery Agency, BAE Systems and Rolls-Royce. This innovative approach meets the recommendation of the 2015 Strategic Defence and Security Review to harness effective working relationships between the MoD and its partners and improve performance.

The Alliance's mission is to deliver four Dreadnought submarines for £31 billion, with the first one ready for patrol in the 2030s. We have Vanguard platforms at sea and they must be replaced on time to maintain Continuous At Sea Deterrence.



The Vanguard replacement submarine Dreadnought currently being built for the Royal Navy will be safer, more efficient and have lower through life maintenance costs due to the collaborative partnership.

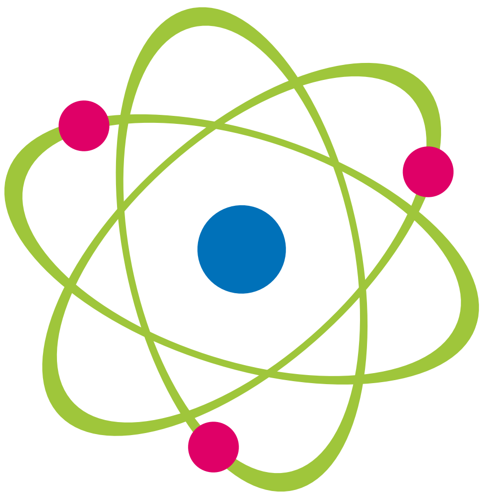
ROLLS-ROYCE HAS BEEN THE TECHNICAL AUTHORITY FOR THE NUCLEAR STEAM RAISING PLANT FOR 60 YEARS.



Submarine sites and service delivery

The Life Cycle of a UK Nuclear Steam Raising Plant (NSRP)

1. The Defence Nuclear Organisation (DNO) sets the submarine capability requirements, and negotiate for the required funding from Her Majesty's Treasury (HMT).
2. The MoD Abbey Wood (Bristol) houses the Submarine Delivery Agency. They are responsible for the acquisition of submarines against DNO requirements, and also responsible for in-service support to current submarines.
3. Rolls-Royce Raynesway (Derby) is responsible for delivering a Nuclear Steam Raising Plant (NSRP), and parts of the Secondary Propulsion systems across the full Concept, Assessment, Demonstration, Manufacture, In-Service and Disposal (CADMID) cycle.
4. BAES (Barrow-In-Furness) operates the shipyard for building the Royal Navy's nuclear submarines, and has constructed all but three of the Royal Navy's nuclear-powered submarines since the commissioning of HMS Dreadnought in 1963.
5. The Vulcan Naval Reactor Test Establishment (Caithness), has been the home for the MoD prototype nuclear propulsion plant for over 50 years. It has tested operation of 5 generations of reactor core and two reactor designs PWR1 and PWR2.
6. HM Naval Base Clyde (Faslane) is home to the Submarine Service, including the nation's nuclear deterrent, and hunter-killer submarines. Faslane provides the Operational Base for Commissioning and Sea Trials of new Submarines.
7. Babcock Marine (Devonport Naval Base, Plymouth) operates the base for performing major maintenance and de-commissioning of in-service Submarines.



The shore test facility has operated two fully operational reactor plants, PWR1 and PWR2 to verify and validate our reactor plant performance.

IN 2006 THE UK/ US TECHNOLOGY EXCHANGE PROGRAMME RE-STARTED. THE ESTIMATED BENEFIT IN TERMS OF TECHNOLOGY EXCHANGE TO THE UK IS IN THE REGION OF £5BN.

Rolls-Royce - mutual benefit

Rolls-Royce is synonymous with world class engineering in many markets and has been influential in growing high value engineering design, development and manufacturing across the UK . This deserved reputation and engineering pedigree is built on a depth of capability across many engineering disciplines and is extended by the Rolls-Royce University Technology Centre network worldwide which delivers innovative research and technology.

This know-how is all available to the Submarines business along with the expertise in engineering and manufacturing governance and new product introduction processes which come with being part of Rolls-Royce.

The Submarines business is a pioneer of one of the most important and challenging advances in nuclear technology – its use in nuclear propulsion. This strategic national capability brings with it a high profile for Rolls-Royce across UK government and recognition that we are part of a national endeavour with UK strategic assets – ie Royal Navy submarines, whether they maintain Continuous At Sea Deterrence (CASD) or they are performing surveillance and information gathering operations.

Rolls-Royce is the only commercial organisation which delivers nuclear propulsion and the last 15 years has seen a huge investment in capabilities (people and facilities) - a regeneration which will provide sustainable capability to meet the UK's submarine programme requirements for the next 50 years.

This level of experience in nuclear engineering and technology means we have world class experts who are active in key nuclear engineering bodies and professional engineering forums in the UK. Our experience also provides the platform for Rolls-Royce to grow into nuclear markets worldwide – whilst remembering the unique responsibility of the Submarines business as guardian of the UK's naval nuclear propulsion technology.

Electron beam circumference welds can be produced in less than a third of the time of conventional thick-section high integrity arc welding.

DREADNOUGHT DUE TO BE OPERATIONAL IN EARLY 2030s.

The future

Equipment

The detailed design of the wholly new PWR3 rector plant was completed on time in December 2014. The design has been successfully underpinned by a series of rig test packages which has meant that a critical prototype was no longer required. The PWR3 design project is the second largest new product design programme in Rolls-Royce.

Significant collaborative design work with BAE Systems has integrated the reactor into the submarine whole boat design. At main gate we have jointly passed concurrent design gates that demonstrate the design interfaces are managed.

Rolls-Royce has implemented an extensive production readiness programme, 42 new manufacturing capabilities and 77 cross functional teams to de-risk production. The supply chain design reduces the number of suppliers, utilises US experience where cost effective, and the planned long lead orders have been placed.

Key facts:

1. Reduced through life cost
2. 30% fewer parts than PWR2
3. Further significant improvements in reactor and submarine safety.

This programme has rejuvenated the nuclear propulsion capability and we are working with the MoD to ensure this can be sustained in the long term.

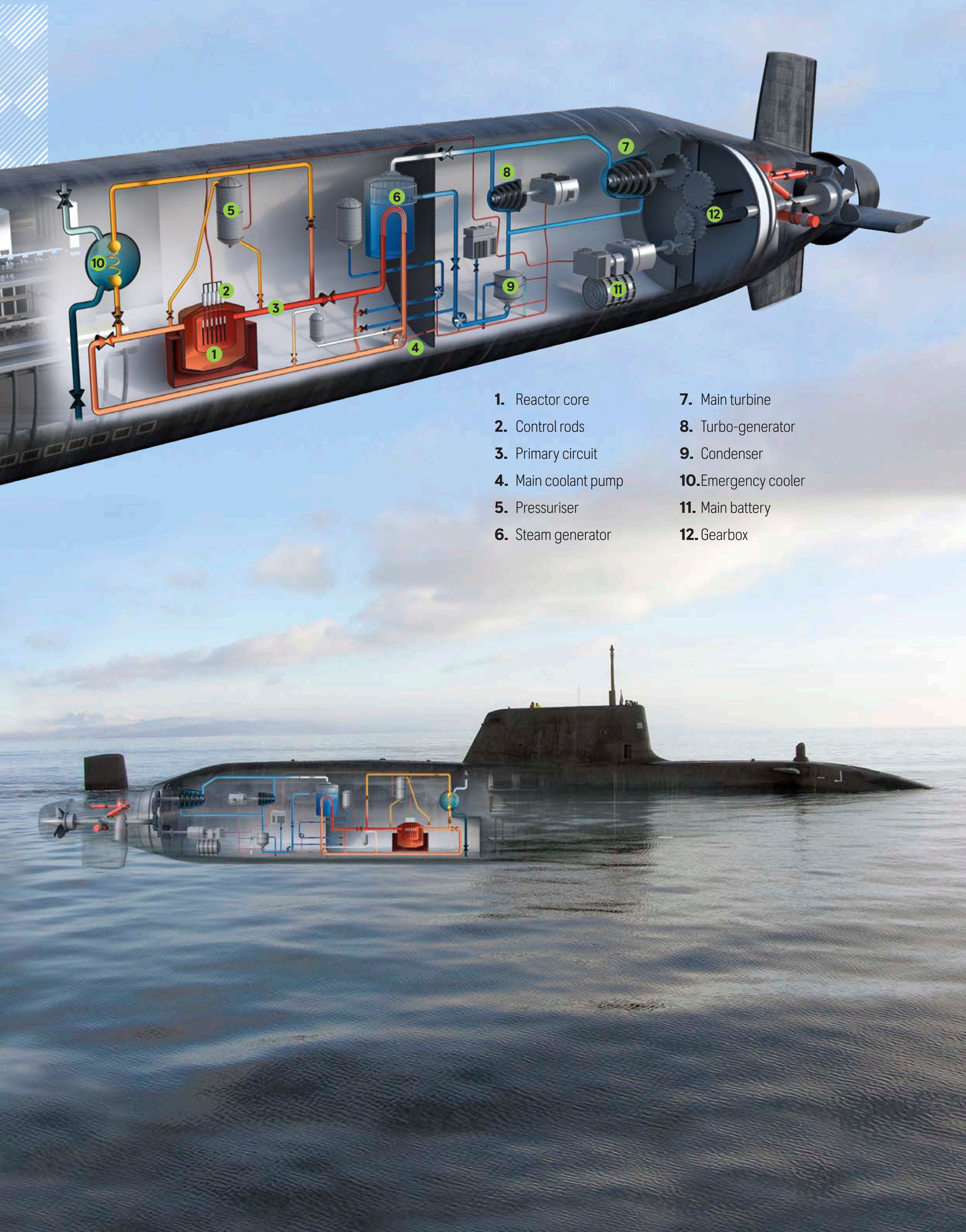
Delivery of key components to Barrow for first of class Dreadnought has already started.

Infrastructure timeline:

The Raynesway site started operations during the 1960s. Following the Government decision in 2007 to support an enduring submarines programme a major site regeneration project is underway supported by MoD and Rolls-Royce:

- Atlantic House - £20M – opened 2013
- Primary Components - £35M – opened 2012
- Primary Components extension - £38m - opened 2019
- Core Factory regeneration – £350m – first phase opened 2016 to be complete by 2023

Raynesway infrastructure will receive investment of £500m between 2008 and 2023.


1. Reactor core
2. Control rods
3. Primary circuit
4. Main coolant pump
5. Pressuriser
6. Steam generator
7. Main turbine
8. Turbo-generator
9. Condenser
10. Emergency cooler
11. Main battery
12. Gearbox

How a nuclear reactor works

A submarine Pressurised Water Reactor

A submarine Pressurised Water Reactor (PWR) is very similar in design and engineering terms to a civil PWR used for electricity generation. Clearly, the whole plant has to be designed to fit into the confines of a submarine pressure hull, while still leaving space within the submarine hull to allow the submarine to be an effective warship and weapons platform.

The reactor core (1) is housed within a thick walled, water filled pressure vessel called the Reactor Pressure Vessel (RPV). The core contains the nuclear fuel, uranium 235. Energy is produced in the reactor by the 'fission' or splitting of the uranium 235 atoms, a process which releases energy in the form of heat.

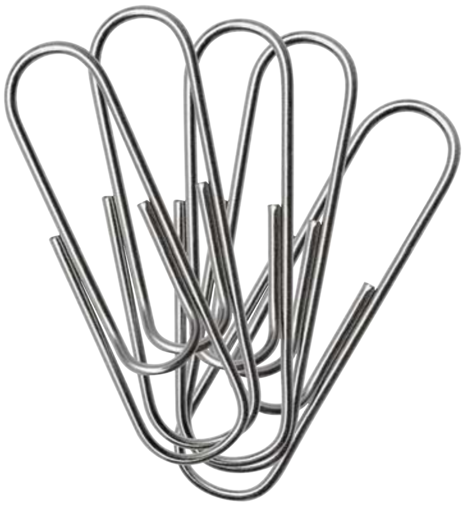
Primary Circuit coolant water (3) causes a slowing down of the neutrons produced in the core to allow the fuel to undergo fission; it also provides a medium to transfer the heat produced in the core to the Steam Generators (SGs) (6): the Primary Circuit coolant being pumped around the primary reactor plant by electrically driven Main Coolant Pumps (MCPs) (4).

Heat from the Primary Circuit coolant passes through the SG tubes, causing the Secondary water on the outside of the tubes to boil. The steam produced is used to drive propulsion steam turbines, which turn the propeller (propulsor) via reduction gearing. The steam also drives Turbo-Generators (TGs) (8) that provide ac power supplies for submarines services.

Control rods that can be moved up and down within the core by Control Rod Drive Mechanisms (CRDMs) (2) are used to start up and shut down the reactor - they are also used to carry out reactivity adjustments in the core to compensate for fuel burn-up.

Once the reactor has been taken critical (when the fission process is self-sustaining at constant power), the power produced by the reactor core is directly related to steam demand. The response of the reactor to an increase or decrease in steam demand is rapid and automatic, the reactor being virtually self-regulating at power.

To prevent the coolant boiling and to ensure that the steam is at a high enough temperature and pressure to allow efficient operation, the Primary Circuit coolant is pressurised by means of a separate pressure vessel called the Pressuriser (5). This vessel is partly filled with water that is heated by electric immersion heaters to ensure boiling at a constant temperature.



A fully submerged circumnavigation of the world by a Trafalgar class submarine can be completed on the energy released from just a teaspoon of uranium.

Pioneering the power that matters

Dreadnought	Valiant Class	Resolution Class	Churchill Class	Swiftsure Class	Trafalgar Class	Vanguard Class
PWR 1	PWR 1	PWR 1	PWR 1	PWR 1	PWR 1	PWR 2

Astute
Class
PWR 2
ASTUTE
ANSON
AMBUSH
AGAMEMNON
ARTFUL
AJAX
AUDACIOUS
Dreadnought
Class
PWR 3
DREADNOUGHT
VALIANT
WARSPITE
KING GEORGE VI