SUBMARINES FOR THE RAN — GOING NUCLEAR

John Jeremy AM BE (Hons) FIEAust FRINA

The AUKUS Agreement of 2021 provides Australia with access to US and UK nuclear propulsion technology for the first time, paving the way for Australia to acquire at least eight nuclear submarines fo a British or US design

The development of the modern submarine was rapid during the first decade of the 20th Century. The British Admiralty ordered five small submarines from Vickers in 1901 and the first submarine for the Royal Navy was launched at Barrow in Furness on 2 October 1901. Built under licence from the Electric Boat Company of the United States which held the patents for US-based Irishman John Holland's designs, this small 104-ton submarine was only 63 feet 11 inches long and was the first of a long line of submarines to emerge from Barrow in Furness for the Royal Navy, including almost all British nuclear submarines.

Not all senior officers in the Royal Navy were convinced that submarines had a future. Some felt they were unethical and 'un-English…the weapon of cowards who refused to fight like men on the surface.'

Yet by mid-1914 some 400 submarines were in service in sixteen navies, an extraordinary adoption rate for a new technology, and most were based on Holland's original designs. World War I proved the value of the submarine as a weapon — primarily to sink enemy ships.

The Royal Navy's first submarine being launched on 2 October 1901

In Australia, plans for the future Royal Australian Navy which developed in the years following Federation included coastal submarines, despite the embryonic technology. In 1907 Captain W. R. Creswell, Director of the Commonwealth Naval Forces, argued strongly against submarines but, despite this advice, the Government asked Vickers in Britain to quote for the supply of submarines for Australia. Vickers offered two of the then-under-construction C-class, but the navy remained opposed to the purchase.

At one time it was suggested that Vickers might supply parts for submarines to be assembled at NSW Government-run Cockatoo Island in Sydney in the same way that the first destroyer built in Australia, HMAS *Warrego*, was constructed between 1910 and 1912. Vickers discouraged this suggestion on technical grounds and, one suspects, reluctance to lose a developing market in the Colonies. Ultimately, the Imperial Conference on Defence in London in 1909 established the concept of an Australian Fleet Unit which would include three submarines of the C-class. The C class were small submarines with low speed and limited endurance. Power for surface running and to charge the batteries was provided by petrol engines, a hazardous selection.

The proposed three C-class submarines were replaced by two of the E-class and in December 1910 the Admiralty ordered two on behalf of the Royal Australian Navy for delivery in December 1912 and January 1913. These submarines were of about 800 tons with a length of 178 feet. They had two Vickers diesels and electric motors for a speed of 15 knots on the surface and 9 knots submerged. Fifty six of boats this design were subsequently ordered and they became the backbone of the Royal Navy's submarine service during World War I. They represented the state of the art of British submarine design of the time.

Australia's first submarines, AE1 and AE2 were commissioned, a bit late, in February 1914. For such small vessels, the journey to Australia was something of a marathon and was finally completed in May 1914, partly under tow. Both were lost early in the war, AE1 in September 1914 and AE2 in the Sea of Marmora after her penetration of the Dardanelles on 25 April 1915.

Australia's first submarines, AE1 and AE2, arrived in Sydney in May 1914

The general layout of subsequent submarines did not vary much for many years, but there were some attempts to produce significantly faster submarines, notably the J class and the K class.

Following the loss of AE1 and AE2, the Commonwealth Government sought replacements from Britain but but British construction capacity was fully committed. The Australian parliament was generally in favour of replacing the submarines and, although the Government favoured building new warships in Australia, it was felt that the capability to build submarines was lacking. With continuing interest in local construction, in late 1916 the General Manager of Cockatoo Dockyard, John King Salter, sent ten men to Britain to study submarine construction. The team returned to Sydney in 1918 with considerable information on modern submarines and the equipment need for their construction, however as the end of the war approached the possibility of the gift of submarines to Australia arose and in in January 1919 the Admiralty recommended to the British Cabinet that six submarines of the J class be presented to Australia.

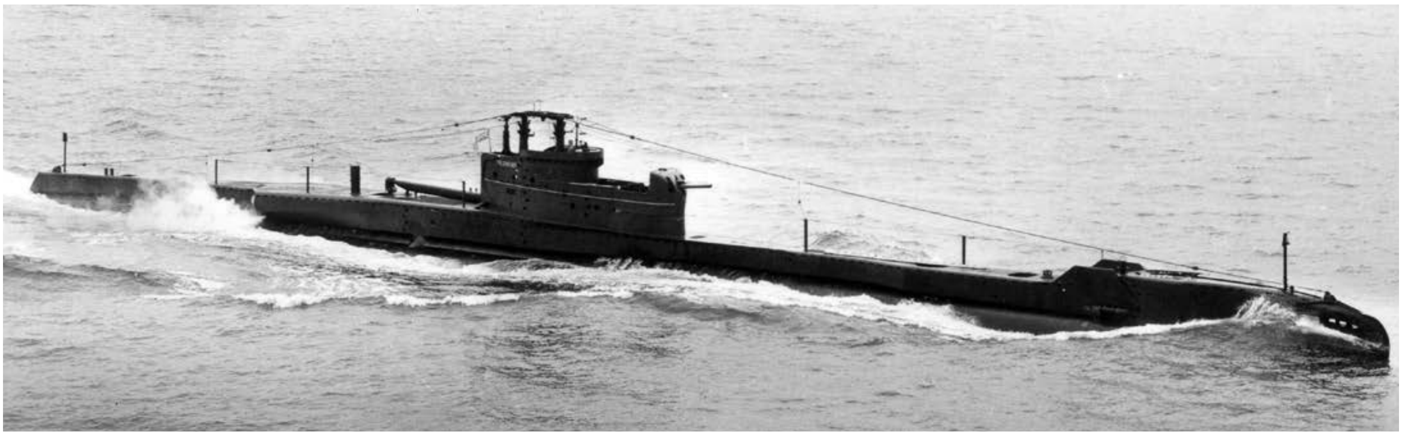
The J-class submarines were large and fast submarines capable of some 19 knots on the surface and were designed following a 1914 report (actually false) that the German Navy was building submarines capable of 22 knots on the surface. Despite their speed, the J-class boats were still too slow for a role then regarded as important — as fleet submarines operating with the battle fleet. In 1913–14 diesel engines were not believed to be able to provide the power required for this speed and design work was begun at the Admiralty in 1913 on a large steam-powered submarine capable of a surface speed of 24 knots.

In 1915 Vickers proposed a three-shaft design combining steam and diesel power with the diesel on the centre shaft. The best features of this design were combined with the 1913 Admiralty design, resulting in one of the most novel and largest submarines of the time, the K class. Twenty seven were ultimately ordered, although only 17 were completed.

The K-class submarines were complex and difficult to handle. The safe diving depth was 200 feet with a safety margin of about 50%, and the long submarine could easily exceed the safe depth when diving if great care was not taken, particularly as the hydroplanes had an unfortunate tendency to jamb. The fastest diving time recorded was 3 minutes 25 seconds. The reputation of submarines suffered from an unfortunate series of accidents and collisions but, as fleet submarines they were regarded as a success. We will never know how they might have performed with the battle fleet in action, as all were completed after the Battle of Jutland and the opportunity to test them in the role for which they were designed never arose. Only one ever engaged the enemy, hitting a U-boat with a torpedo which failed to explode. Most had a short service life — the longest was nine years. In many ways the K-class submarines were way ahead of their time. Steam power was not to return to submarines until USS *Nautilus* took the first nuclear reactor to sea in 1956.

During the wars British submarine development was largely concentrated on long range patrol submarines beginning with the O-class, two of which, *Oxley* and *Otway* were built for Australia. These two submarines displaced 2038 tons submerged and were just less than 275 feet long. These boats arrived at the onset of the Depression, and with heavy cuts in defence expenditure and restrictions on British submarine numbers imposed by the London Naval Treaty of 1930, they were given to Britain that year.

As war approached in the 1930s, British submarine development concentrated on three classes, the long range T-class submarines of about 1,575 tons submerged displacement, a smaller class for coastal operations, the S class, and a small submarine for training, the U class which were of similar size to the old E class.



HMS *Trespasser* was typical of the 53 submarines of the T class built for the Royal Navy shortly before and during World War II

The US Navy's submarine development in the period of disarmament attempts between the wars was slow, but development gathered pace after 1931. During World War II the United States built many very-long range patrol submarines. After 1941, 339 submarines were ordered to a standard design. 221 were completed during or just after the war. Very successful submarines, they could achieve 20.25 knots on the surface or 8.75 knots submerged. They had a patrol endurance of 75 days and a cruising range on the surface of 11,000 miles at 10 knots.

Despite many years of development, these World War II submarines were still only achieving submerged speeds similar to the submarines of World War I. With diesel electric propulsion, they had to spend considerable time on the surface to charge batteries rendering them vulnerable to detection, particularly from the air or by radar. The big changes were in weapon capacity, range and endurance and diving depth.

A German submarine built in large numbers, the Type VII, which caused so much damage during the Battle of the Atlantic, was also of very conventional design. This submarine, of which there were several variants, was quite small — not much bigger than AE1 and AE2. It was the most numerous class of submarine ever built, with 703 boats completed. Submerged speed was still only 7.6 knots.

The German Type VII submarine was the most numerous class of submarine ever built, with 703 constructed during WWII

Two developments were to be made during the war which radically changed the nature of submarine warfare. One was the snorkel, or snort as it is widely known, and the other was the high-speed submarine.

The snorkel, intended to enable a submarine to charge its batteries while submerged, was first patented by Scotts Shipbuilding and Engineering Company of Greenock in 1916, but the Admiralty made no use of the idea. Later, the Italians developed a similar concept but it was a Dutch snorkel which attracted the interest of the Germans. Initially regarded simply as a means of ventilating the submarine, high losses in the battle of the Atlantic during 1943 prompted its use for recharging the submarine's batteries when submerged. Snorkels were retrofitted to Type VIIC and IXC submarines and designed into later submarines. It is now commonly fitted to diesel electric submarines.

Developed during the war, the German Type XXI submarine introduced radical changes which were to greatly influence post-war submarine design. Of about 1800 tons submerged, the Type XXI had a streamlined hull which permitted higher underwater speed with much less hydrodynamic noise, a much bigger battery which improved submerged endurance, power-loaded torpedo tubes and improved crew accommodation. They were fitted with a snorkel from the outset and were the closest to a true submarine yet designed, rather than a surface vessel which could submerge to attack or escape detection. Underwater speed was increased to about 18 knots for 1.5 hours, or 12-14 knots for ten hours. At an economical speed of 6 knots they could manage 48 hours of silent running submerged.

The Germans ordered 750 Type XXI submarines, of which 118 were constructed between 1943 and 1945. The boats were assembled from eight prefabricated sections and there were many quality problems with the work from builders without previous warship and, particularly, submarine construction experience. Fortunately for the Allies, only four Type XXI submarines were operational before the end of the war and only two conducted combat patrols. With the development of one submarine, most of the large numbers of anti-submarine ships constructed during the war were rendered obsolete because they were too slow.

As a further means of achieving high underwater speeds, the Germans began construction of small submarines of about 415 tons powered by turbines with hydrogen peroxide as the source of oxygen and diesel oil as the fuel to produce steam. This dangerous method of propulsion promised submerged speeds around 25 knots. The three completed submarines were scuttled by their crews in May 1945 but U1407 was raised and rebuilt by Vickers at Barrow in Furness with a new set of machinery captured at the end of the war. Commissioned as HMS *Meteorite*, the submarine was used for trials for a few years. Britain subsequently built two HTP submarines, HMS *Explorer* and HMS *Excalibur*, at Barrow. The fastest submarines in the world when they were completed, they were commonly known as *Exploder* and *Excruciator* because of the volatile and dangerous fuel and the number of times the crews had to evacuate to the casing to escape the dense clouds of white smoke which would issue from every hatch. They were paid off in 1961 — a very expensive experiment which was overtaken by the development of nuclear propulsion.

The characteristics of the German Type XXI submarine were widely adopted after the war. Selected submarines were modernised — lengthened to accommodate larger batteries and streamlined to reduce underwater resistance. The US Navy also modernised many WWII submarines as part of the Greater Underwater Propulsive Power Program or GUPPY. New submarines designed after the war also adopted Type XXI features, like the British Porpoise and Oberon classes. With greatly enhanced batteries and more powerful electric motors, these submarines could achieve something like 17 knots submerged. The latter class was regarded by many as one of the best diesel electric submarines yet built

Australia decided to acquire a squadron of submarines again in 1960, and bought six Oberon-class submarines from Britain in a well-managed program. Between 1978 and 1985 the RAN submarines were given a world-leading Australian initiated modernisation known as the Submarine Weapons Update Program, or SWUP for short, which enabled them to fire the US Mk 48 torpedo and the Harpoon anti-ship missile with new sonars and a modern digital combat system.

HMAS *Oxley*, seen here after her SWUP modernisation, was the first of six RAN Oberon-class submarines which were based and maintained in Sydney

Despite the quality of the Oberon class, they were still designed for relative efficiency on the surface, rather than submerged. The best form for a submerged submarine is some form of prolate spheroid — or tear drop. In the early 1950s the US Navy built a diesel electric research submarine with this form, USS *Albacore*. This 1500 ton submarine introduced new pressure hull steel, HY80, and tested new hydroplane configurations, anechoic tiles to reduce detection by active sonar, new propeller configurations, new pressure hull configurations and features which are today common in submarines, conventional and nuclear. *Albacore* was capable of 33 knots submerged.

The experimental submarine USS *Albacore* at her launching on 1 August 1953

A visit to *Albacore* by the British First Sea Lord, Lord Louis Mountbatten, profoundly impressed him and greatly affected future UK submarine policy. The Oberon-class submarines nearly didn't happen.

Whilst *Albacore's* hull form was close to ideal, there are practical considerations which make it difficult for the ideal form to be used for operational submarines. These range from the simple requirement to be able to move around on deck to handle lines etc., to the necessary bottle-shaped pressure hull to provide for external ballast tanks at the ends with internal space restrictions and strength challenges as a consequence. More recently, the development of sonars has meant that high-power active sonars demand space in the bow, passive sonars demand space on as long a base line as possible within the submarine's casing and towed-array sonars need space for stowage of the array and the winch and handling equipment.

The Australian Collins-class submarines illustrate these demands very well, with a large bow for the active/passive sonar transducer, passive sonar windows in the casing, and a tail to stream a towed array clear of the propeller.

The RAN Collins-class submarine HMAS *Waller*

Most modern submarines have pressure hulls which are largely cylindrical, with streamlined ends and a faired casing. It is a hydrodynamic compromise which is necessary to make the whole system work.

Despite all these improvements, the diesel electric submarine retains the limitations imposed by its propulsion plant. It has limited range when fully submerged, depending on speed, and must either surface or use the snort mast to recharge the batteries whilst still submerged or to make a high-speed (about 10 knots) submerged transit on diesels. These needs make it vulnerable to detection, and high-speed submerged transits, often part of the life of Australian submarines, place enormous strain on masts, diesel engines and the crew. The advantages of conventional diesel electric submarines are their relatively low cost and ready supportability and particularly their ability to operate very quietly at low speeds, undetected in relatively shallow water conditions. For these loitering conditions, air-independent propulsion systems have been developed to increase underwater endurance at low speed, but these systems demand considerable space and some need volatile and dangerous fuel.

The best way to create a true submarine is to fit a power plant which does not require air and can enable a submarine to remain submerged indefinitely with its endurance limited only by that of the crew and the supplies which they require. That power plant is, of course, nuclear.

Consideration of air-independent propulsion for submarines began on both sides of the Atlantic as early as 1943. In post-war Britain, priority was given to land-based nuclear power stations, and it was not until the mid-1950s that serious work began on the development of a nuclear submarine propulsion system. Meanwhile, in the United States, Westinghouse were authorised in December 1947 to design and test a nuclear power plant for a submarine. The pressurised-water plant which was developed, known as S2W, was of quite low power (about 10 MW) but formed the basis for the subsequent reactors which have powered nuclear ships and submarines of the US Navy. Construction of the first nuclear submarine, USS *Nautilus* was begun by General Dynamics, Electric Boat Division, in June 1952 and she was completed in April 1955. Her construction was supervised by a remarkable US Navy officer, Captain (later Admiral) Hyman G Rickover, a powerful personality who propelled the US nuclear submarine program with unstoppable determination for many years. He was one of the longest-serving US Navy officers ever, finally retiring at the age of 82.

Nautilus displaced about 4,000 tons and had a submerged speed of about 23 knots. The US Navy ceased building diesel electric submarines in the 1950s.

The first British nuclear submarine was HMS *Dreadnought*, completed by Vickers at Barrow in April 1963. She had a US-supplied Westinghouse S5W nuclear plant, as fitted in the contemporary American Skipjack-class submarines. This had been made possible by a unique and exclusive agreement in 1958 to allow British access to US nuclear propulsion technology. The respectful working relationship between Rickover and Mountbatten was crucial to making this agreement happen.

USS *Nautilus* at sea in November 1955

Later British submarines had UK developed propulsion plants, although the relationship between UK and US programs, and between the US reactor builders and Rolls Royce, the manufacturer of British submarine reactors, remains close today.

Rickover had a brusque and demanding manner. He was said to unwind only in the presence of some people – The Queen, Harold Macmillan, Lord Mountbatten and, later, Sir Solly Zuckerman, the Chief Scientific Adviser at the Ministry of Defence.

He was described as having very peculiar and temperamental behaviour and considered himself sent by the Deity into this world to see that America remained supreme.

When showing Lord Mountbatten around USS *Skipjack* in 1958, Mountbatten recalled him saying "Admiral I think your British set-up is lousy…what you want to run a show like this is a real son-of-a-bitch." Mountbatten delighted Rickover with his reply: "That is where you Americans have the edge on us, you have the only real son-of-a-bitch in the business."

Early nuclear submarines might have been fast but they were noisy when compared to modern diesel electric submarines. Whilst they were said to sound like an express train, they had the advantage of speed, being able to out-run the homing torpedos of the day. They also provided a perfect platform to move the nuclear deterrent to sea in ballistic missile submarines. The first US Polaris submarine, USS *George Washington*, a stretched attack submarine, was completed in 1959, and the first British Polaris submarine, HMS *Resolution*, was completed in 1967. The adoption by Britain of the US ballistic missile was made possible by a historic agreement between President Kennedy and Prime Minister Harold Macmillan concluded in Bermuda on 21 December 1961.

It was not long after that, in 1967, that I obtained my first exposure to the world of nuclear submarine construction. In Britain on a Vickers post-graduate scholarship, I spent time at Barrow at the peak of the Polaris program. As an Australian, access to nuclear and Polaris technology was not possible, but I was able to obtain valuable knowledge of the systems used to manage the construction and trials of nuclear submarines which was of great assistance for setting up our refit procedures in Sydney for the RAN's Oberon class submarines. I was also able to meet two of the Titans of the nuclear submarine programme: Vickers' Chief Polaris Executive Len Redshaw (later Sir Leonard) and the MOD's Rowland Baker (later Sir Rowland) and to see them in action.

The Royal Navy Polaris submarine HMS *Repulse* and the attack submarine HMS *Churchill* under construction at Barrow In Furness in August 1967

The Barrow shipyard, now part of the British global defence company BAE Systems, continues to be the centre of British nuclear submarine construction today. Currently completing the Astute-class attack submarines, Barrow is also building four new-design Trident ballistic missile submarines, the Dreadnought class, to replace the existing vessels which are approaching end of life, which will maintain Britain's sea-borne nuclear deterrent. This programme is closely related to the US Columbia-class program which will occupy much of US nuclear submarine construction capability in coming years.

Astute-class nuclear submarines under construction by BAE Systems at Barrow in Furness

Today, six nations have, or are developing, a submarine-borne nuclear deterrent. Those submarines may disappear into the world's oceans to remain undetected and ready to strike, but throughout the Cold War a major role of the attack nuclear submarine was to detect an opponent's SSBNs when they left harbour, possibly in company with another submarine for protection, to shadow them while trying to remain undetected — ready to destroy the SSBN if necessary before it could unleash its destructive power. The escorting submarine's job was to try to find that shadowing submarine, ready to destroy it before it could do its duty. These roles drove efforts to make nuclear submarines quieter and, today, the modern nuclear submarine can rival a modern conventional submarine for stealth.

Submarines make particularly good anti-submarine weapons, and nuclear submarines have a major role protecting surface forces, particularly US carrier battle groups. It is the intended role of the K-class, fast forward 100 years.

The deployment of the HMS *Queen Elizabeth* task group to the Indo-Pacific last year, which was actually multi-national, also included a British nuclear submarine. It is said that a shadowing Chinese nuclear submarine was very quickly detected once the group entered the South China Sea.

What is the role of the modern submarine? All submarines continue to be very hard to detect, and this quality gives them considerable flexibility. They are able to operate covertly in areas where surface forces would be unwelcome or provocative. They provide tactical initiative, operational flexibility and strategic value. The roles of our submarines may be summarised as:

1. Covert surveillance, reconnaissance and intelligence gathering.

A submarine can loiter undetected in areas of interest gathering acoustic, visual, communications and electronic intelligence. With modern secure, high-data-rate communications, submarines can operate effectively as part of a networked force.

2. Covert insertion and recovery of Special Forces.

This was a role performed by the Royal Navy's conventional submarines during the Falklands War in 1982.

3. Covert land-strike.

Submarines can carry a significant number of long-range submarine-to-surface missiles capable of striking land targets and then clear the launch area without delay to evade counter attack. Made from the sea, such a strike does not require access to land bases or long air transit from a home base.

4. Anti-ship warfare.

Equipped with modern weapons like the Mk 48 long range homing torpedo, submarines can inflict serious losses on the naval combat and logistic support vessels of an adversary. A single Mk 48 torpedo will generally sink large surface combatants and disable bigger ships.

5. Anti-submarine warfare.

A submarine equipped with superior acoustic sensors, processing systems and torpedoes, crewed by a highly-trained team is very effective as an anti-submarine system. Correctly deployed, a submarine might be the most effective way of neutralising an adversary's submarine capability.

A new role is emerging rapidly. That of deploying UUVs, controlling UUVs, detecting and neutralising hostile UUVs which have the potential to pose a considerable threat to the defence of ports and trade routes. Protection of underwater assets, like undersea communications and power cables is also becoming vital.

Australia's Collins-class submarines are amongst the largest and most capable diesel electric submarines in the world. All submarines are expensive to operate and maintain, not least because of their complexity and the importance of submarine safety. They operate in a most demanding environment. But why do we need such big and expensive submarines? Europe, and particularly Germany, has for decades provided the world's navies with high-quality diesel electric submarines around 1500-2000 tons displacement. The latest types are, however, getting bigger but are still generally designed to operate in relatively shallow littoral waters. Germany and Norway have recently signed contracts for the construction of seven new submarines which are not only larger but adopt an unusual hullform which sacrifices some hydrodynamic performance for sonar stealth.

By contrast, the US Navy's latest class of nuclear submarine, the Virginia class Block 4, displace around 8,000 tons, have an S9G reactor of 30 MW for a submerged speed of around 25 knots, a range limited only by the endurance of the crew of 135 and their supplies, and a weapon load of torpedoes and long-range ground attack missiles. In the latest version, Block 5, they can carry a torpedo and missile load of up to 65 weapons. They are immensely powerful vessels. They are also very expensive and the design, which dates from the early 1990s, is now a bit dated. Two shipyards in the US build them, GD Electric Boat and Huntington Ingalls Industries, with a shared workload between the yards. Production of the Virginia class is expected to continue into the 2040s, but the US has recently begun the design of their successor, SSN(X), which is expected to be even larger. Construction of the first submarine of the new design is planned to begin around 2034.

The latest British attack-submarine design is the Astute-class. The design, which was prepared in close collaboration with Electric Boat, dates from the late 1990s, and the first submarine, HMS *Astute*, was completed in 2010. The last of the seven is expected

The Virginia-class submarine USS *Washington*

to be completed in 2024. The submarines are smaller than the Virginia class at about 7,400 tons and have a length of 97 metres, compared to 10,200 t and 140 m for the latest Block 5 version of the Virginia class. The complement is about 97 compared to 135 in the Virginia class. On 17 September last year the UK Secretary for Defence announced contracts for BAE Systems and Rolls Royce for the design development of a new class of submarine to succeed the Astute class.

The type of submarine for Australia depends on the payload we want our submarines to carry and the way in which we intend to operate them. The defence of Australia and our trade is a maritime task. Our maritime interests extend from the North Pacific to the western Indian Ocean. The operational areas could be a very long way from the submarines' base, currently at HMAS *Stirling* at Garden Island, south of Perth. Our submarines are required to transit long distances, undetected, from their base to their operational area and back again. Many modern submarines, like those sold in large numbers to other navies around the world, operate close to home. Australian submarines have a long way to go to work, demanding high transit speeds and long endurance. The adoption of nuclear power would make an enormous difference to the time it would take an Australian submarine to transit to a patrol area and the time the submarine can remain on station.

Surely, you might ask, if we have to go so far as quickly as we can, why have we not bought nuclear submarines in the past? It is a good question — but until now we have been unable to gain access to the nuclear technology of our principal allies. The barriers to US and UK nuclear submarine technology have been impenetrable. Access to such technology is essential if the RAN is to go nuclear. As we do not have a commercial nuclear industry a lone path to an Australian submarine reactor would take decades.

Despite the obstacles, many have promoted nuclear power for Australian submarines for years but to no avail. The momentous announcement of 16 September that the RAN will go nuclear with a planned fleet of at least eight submarines to a US or UK design has changed everything. There is now, of course, much work to do.

Establish a Naval Nuclear Regulatory framework for Australia

- Decide a procurement strategy – import one or two or build all in Australia, in Adelaide
- Decide on a location for the submarine base or bases and complete all environmental and security assessments — presumably the main base will be at HMAS *Stirling* in Western Australia
- Define the nuclear specific facilities required for the construction and support location
- Achieve local acceptance of a nuclear presence at these locations
- Establish a training programme for civilian and naval nuclear engineers
- Determine a disposal strategy for the submarines at end of life.

This work has now started.

Of course, we had entered into a relationship with France for the design of new submarines to replace the Collins-class which was to be based upon the French Barracuda-class nuclear submarines. Design work has been underway for some years on the challenging task of converting a nuclear submarine into a diesel-electric boat. It was to be, effectively, a new design – completely new aft of the engine room bulkhead and substantially new forward with changes to the combat system, weapons, weapon discharge system, masts and communications. Whilst I have no doubt that the Attack-class would have been very fine submarines, probably the best conventional diesel-electric submarines in the world, the challenges of range, speed and endurance would have remained and the new submarines would have added little capability beyond that of the Collins class.

Construction of the first of six French Barracuda-class nuclear submarines, *Suffren*, began in December 2007. She was launched on 12 July 2019 and commissioned on 6 November 2020. She is expected to be operational in 2022

One might ask, if we have decided to go nuclear, why not the French Barracuda class? Substantial redesign would be necessary in any case, but a significant consideration would be the type of nuclear reactor fitted in the French submarines. It uses fuel enriched to a lower level than the US or British reactors and the submarines would require refueling every seven to ten years, a very expensive and demanding task which, in our case, would probably have to be done overseas in the absence of a commercial nuclear industry with its associated infrastructure. The modern US and British submarines are fueled for life using highly-enriched uranium fuel.

The AUKUS agreement has admitted Australia to a club the doors of which have been firmly closed to everyone for decades.

What happens now?

On 22 November 2021 an Exchange of Naval Nuclear Propulsion Information Agreement was signed by Australia and the AUKUS partners, the United Kingdom and the United States. This agreement gives Australia access to sufficient information for determining the best route to acquiring nuclear submarines for the RAN. Once that route is determined, hopefully this year, further agreements will be necessary.

Perhaps I may now be allowed to speculate a little and draw a few mathematically perfect straight lines from unwarranted assumptions to foregone conclusions. After all, plenty of other people are!

Will we decide to build a Block 4 or 5 Virginia-class submarine or an Astute-class submarine? The US submarine and its successor is very big, demanding of crew and very expensive. Astute is closer to the right size, but the design is now a bit dated and production will end soon.

In my opinion, the nuclear submarine for Australia will be a British design. If we are to obtain the first submarines in the shortest possible time then that is Astute. The new design – let's call it Son of Astute – will have the advantage of a new reactor (PWR3 instead of the older PWR2 in Astute) and the integration of other underwater assets like UUVs would be better. It is likely to be a bit larger than the Astute class. Whilst selection of Son of Astute would probably delay the program, I find it hard to believe that the announcement of the design contracts for Son of Astute one day after AUKUS was announced was a coincidence. Perhaps the British route for us might be two Astutes followed by Son of Astute, with Australia contributing to the design of the latter.

The fourth Astute-class submarine for the Royal Navy, HMS *Audacious*, on the shiplift at Barrow in Furness. Could this class of submarine be the reference design for Australia's nuclear submarines? Construction of *Audacious* began in March 2009 and she was commissioned on 23 September 2021

Whatever submarine we decide to choose, BAE Systems, Rolls Royce and Electric Boat will have a hand in the project. Two are well established in Australia and Electric Boat has established links with ASC in Adelaide.

The next 18 months will be crucial. The project is enormous for a country like Australia — but I believe we can do it. It is a challenge similar to that faced by Britain in the early 1960s. We will need inspirational leadership — the modern equivalents of Rickover, Redshaw and Baker and the UK's Chief Polaris Executive Admiral Sir Hugh Mackenzie, to drive it forward with relentless determination and a blank cheque book.

There are also great risks in the path we have chosen, some of which are:

Firstly, to ensure that we can maintain a submarine force until the nuclear submarines come into service the life of the Collins-class must be extended, a very demanding project in itself which is scheduled to begin in 2026. There is a risk of a capability gap if programs are delayed. Some have suggested that Australia acquire a number of smaller 'off-the-shelf' conventional submarines from overseas as a gap filler, but there is really no such thing as an "off-the-shelf" submarine and managing the technical, logistic and training requirements for a third class of submarine could be a nightmare.

Secondly, we have to acquire and train the many people, in reality thousands, who will be needed to build and serve in the new submarines, and

Thirdly, we have to create new nuclear-qualified facilities in Adelaide for the construction of the submarines and in Western Australia for the submarine base and maintenance facilities.

These risks are recognised but meeting a program which aims to have a Royal Australian Navy nuclear submarine in service well before 2038, as promised by recently by the Minister for Defence, is a considerable national challenge.

There is no going back now – let's get on with it.