ANALYSIS

Australia Badly Needs Nuclear Submarines

The country's maritime scope, and China's rise, makes the AUKUS deal a no brainer.

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The Royal Australian Navy submarine HMAS Rankin is seen during a maritime exercise between the Royal Australian Navy and the Indian Navy in Darwin, Australia, on Sept. 5. YURI RAMSEY/AUSTRALIAN DEFENCE FORCE VIA GETTY IMAGES

It's rare that a submarine deal—or any military partnership— creates quite as many waves as the Australia-United Kingdom-United States agreement (known as AUKUS) has. The nuclear-powered submarine (SSN) club has long been limited to just six nations: the United States, the United Kingdom, France, Russia, China, and India. Becoming the seventh member is a big deal for Australia, especially since Washington has only ever shared such technology before with the United Kingdom. It also offers Australia a critical technological edge in any future tension or conflict with China—already in the nuclear-powered submarine club but working hard to upgrade its membership with Russian aid.

Despite understandable shock at Australia abruptly terminating its existing $38.6 billion and growing contract with France's Naval Group for 12 Shortfin Barracuda-based Attack-class diesel-electric submarines, there were ample indications that cost overruns, significant delays, and reduced Australian industry involvement were aggravating Australian Prime Minister Scott Morrison's government. With these cost overruns, the French Naval Group pushed the price tag of conventional submarines up into the range normally associated with nuclear-powered submarines.

All that was needed was for the United States and United Kingdom to clear the significant bureaucratic hurdle of allowing Australia access to naval nuclear propulsion technology. Meanwhile, Beijing's economic bullying, threatening language, and attempts to subvert Australian politics have caused a sea change in Australian public opinion since 2017, while some of Canberra's elite must have been monitoring unprecedented Russian assistance to China's own naval nuclear propulsion programs with mounting concern.

The politics are messy, but the reasons why countries want to be in the nuclear-powered submarine club are crystal clear. Power and endurance, both for propulsion and the need to supply electrical power for onboard systems, are critical to any navy—and nuclear power is simply the best option. Even the French deal was done on the premise that the submarines could eventually be converted to nuclear propulsion.

Propulsion determines how fast and far a ship can go; overall power determines what it can accomplish in a given location. The density of seawater (around 805 times greater than air) imposes an unforgiving reality on these dynamics: the cubic relationship between power and speed. For a ship to go two times faster, eight times the power is needed; three times faster requires 27 times the power. Long-submerged endurance requires considerable electrical power for heating/cooling, ventilation, and atmosphere control to keep the crew healthy—not to mention offering conditions favoring recruitment and retention. Lastly, advanced submarine tactical systems require high and growing amounts of power to operate and cool their associated sensors and combat systems.

Australia's submarine force has been trying to cover vast distances for years using only conventional propulsion techniques. The continent-sized island has the world's third largest exclusive economic zone—and the other four nations in the top five are SSN powers already.

A conceptual drawing shows the Virginia-class attack submarine then under construction at General Dynamics Electric Boat in Groton, Connecticut, and Newport News Shipbuilding in Newport News, Virginia, as envisioned during development in 2003. RON STERN/U.S. DEPARTMENT OF DEFENSE

Nuclear power is essential for long-term, long-range, high-performance operations. Although "baby nukes," very small (nuclear reactors, may be adequate for slow, stealthy anti-access operations close to home waters, full-scale nuclear power, which produces power in the hundreds of megawatts, is needed for high-speed, long-range submerged operations. Demanding arctic or tropical environments only increase the disparity. For example, submarines typically experience reduced maximum speed in warm-water environments, such as the Persian Gulf. The higher the water temperature, the lower the heat-rejection ability of a steam plant and the less work that can be extracted from the steam. Thermodynamics is a tough opponent.

Nuclear-powered submarines require two fundamental characteristics:

extreme high-power density (for an advantageous power-to-volume ratio) and long core life for economic and operational efficiency. A civilian nuclear industry—which Australia lacks, in any case—is not an indicator of naval nuclear competence because the technologies and skill sets are so different. High-temperature gas-cooled reactors, for instance—while exhibiting significant promise for civil land applications and studied widely in China—cannot be taken to sea because they lack requisite energy density. The cores are simply too large to fit in a ship.

That's where the United States comes in. Its Virginia-class SSN represents a modern engineering triumph. Its 34-foot-diameter pressure hull contains a S9G reactor likely rated at around 190 megawatts, comparable to the Russian OK-650 reactor in Project 971's Akula class. The Virginia class, however, has a life-of-ship reactor core life of 33 years and doesn't require refueling. These capabilities were only achieved through decades-long development of an U.S. "nuclear navy" in the form of more than 200 submarines. Overall, the U.S. Navy has logged more than 6,200 reactor years with 526 nuclear reactor cores over the course of 240 million kilometers, without a single radiological incident.

The United Kingdom has also developed and deployed nuclear submarines for decades, and the Royal Navy's Vanguard-class nuclear-powered ballistic-missile submarine (SSBN) and Astute-class SSN boast a "life-of-ship" reactor core, far superior to the once-a-decade refueling required of France's Barracuda. To achieve this, the U.S. and Royal Navies have always used very highly enriched fuel (HEU) in naval reactors. But core lifetime has vastly increased by using burnable poisons that have a great affinity for thermal neutrons and therefore permit much more of the HEU being loaded. Since the burnable poisons will be consumed at about the same rate as the HEU, the result is an almost uniform critical control rod height throughout the core's life. For the Columbia-class SSBN, the Ohio-class replacement scheduled to begin operations in 2031, the core life goals are increased by around 25 percent to achieve a life-of-ship reactor core of 42 years.

An Israeli naval officer holds the mooring rope of an INS Tanin, a Dolphin AIP-class submarine, during a ceremony upon its arrival at a naval base in Haifa, Israel, on Sept. 23, 2014. Tanin is the first German-built Dolphin AIP-class vessel ordered by Israel. AMIR COHEN/AFP VIA GETTY IMAGES

The next best thing to a nuclear power plant is an advanced variant of conventional power—which militaries restricted from using nuclear power for political reasons, like Japan and Germany, are turning to. So are countries, like China, with relatively limited SSN programs.

One approach many navies, including China's Yuan-class submarines with their Stirling engines, have adopted is air-independent power (AIP) that doesn't require, unlike most conventional power sources, regular surfacing. This greatly extends the time a submarine can cruise at low speed without draining its battery and risking detection by raising an air intake and exhaust tube (for perhaps as long as two weeks). It also saves the main storage battery's energy for relatively fast evasive maneuvers (for perhaps as long as two hours). AIP's biggest advantage is it provides tactical flexibility to the submarine commanding officer. They now have both greater luxuries to choose when they recharge their batteries and the ability to use higher speeds if the tactical situation warrants it.

The most advanced AIP system are fuel cells. They contain no moving parts, yielding a very low noise signature, and no depth constraints, with the only byproducts of combustion being pure water and heat. Only Germany has deployed this technology successfully thus far, selling it to South Korea, Greece, Portugal, Israel, and Italy with their German designed submarines. ThyssenKrupp Marine Systems proposed the Type 216 with a fuel cell AIP system during the initial bid for Australia's future submarine program.

The next most popular AIP option is the Stirling engine employed in Swedish, some Japanese, and China's current *Yuan*-class submarines has the advantage of being relatively easy to build and is less expensive. It also has the benefit of burning the same fuel as diesels. Downsides include suffering limited efficiency in using oxygen (around 35 percent as compared to upward of 60 percent for a fuel cell system) and requirements that products of combustion be pumped overboard, creating depth constraints and additional rotating machinery noises. These can be reduced with traditional passive noise isolation techniques but not eliminated.

But, despite having some fierce advocates, AIP is still distinctly inferior to nuclear power. AIP systems use liquid oxygen as the oxidizer, necessitating large, heavy tanks and cumbersome, dangerous procedures. AIP cannot be drawn down quickly: Stirling engines can run at up to 150 kilowatts per engine, and German Howaldtswerke-Deutsche Werft fuel cells can run as much as 120 kilowatts each.

AIP does not add to the time a boat can operate at its maximum speed: The rate at which it can convert stored energy to power is small. Fuel cells have highest efficiency in oxygen consumption per kilowatt, but hydrogen fuel stored in outboard aluminum metal hydride cylinders must be ultra-pure. It takes 40 to 50 hours of “soaking” the solid metal cylinders with hydrogen to refuel them. Even with AIP, a commanding officer still only has an hour or two at maximum speed as the majority of the necessary power still comes from the main storage battery, with little additional coverage.

For conventional submarine propulsion, lithium-ion batteries appear to be the wave of the future. They have great power density and weigh much less than their lead acid predecessors, but early lithium-ion batteries have a problem with thermal runaway that occasionally caused them to combust. The U.S. Navy’s Advanced SEAL Delivery System (ASDS) burned itself out due to a thermal runaway incident with a metallic lithium-ion battery. More recent technology includes composite-based plates using silicon or carbon nanoparticles. These are safer, not quite as powerful, and are batteries submariners could accept. Germany is beginning to install lithium-ion batteries in its Type 212 and Type 214 submarines, increasing stored energy as much as 400 percent compared to previous lead acid batteries.

Japan is making the most of its constrained situation. Unlike Australia, it has a politically overwhelming memory of nuclear tragedy, preponderant military threats in immediate proximity, and massive heavy industries offering best possible conventional propulsion technologies—all factors precluding nuclear propulsion for now but driving the most advanced possible alternatives. Japan's next-generation Soryu-class submarines will have lithium-ion main storage batteries instead of AIP. The rationale is very large storage tanks for liquid oxygen make AIP too volume intensive, and volume saved will be allocated to habitability.

Chinese specialists are scrutinizing these developments carefully and seek to parlay China's substantial, if still limited, lithium-ion battery industry into submarine applications. BYD, China's largest rechargeable battery manufacturer, is the world's largest producer of nickel-metal-hydride batteries. This is the basis for most automotive hybrids and some electrical cars today, although lithium-ion batteries are starting to emerge. BYD has aggressively pushed the development of lithium-iron-phosphate batteries, a metallic type that is completely recyclable. This type of battery's automotive experience is very recent.

It's still not clear whether BYD's battery design is a game changer or not, particularly from a naval perspective. Lithium-iron-phosphate batteries are not as powerful as other lithium-ion types, which may support BYD's claims that its batteries are safer. BYD's battery technology appears to be not nearly as powerful (perhaps roughly half as powerful) as the type scheduled for deployment on Japan's modified Soryu-class and is not as competitive as an AIP system. More research also needs to be done regarding BYD's safety record to see if it lives up to its advertising. Since a submarine battery is still much larger and the power requirements are considerably greater than the sort of battery BYD developed for its all-electric buses, BYD would likely have to improve power density significantly. Whether its chosen design can support this remains uncertain. And, in any case, China finally seems poised to make major nuclear-propulsion progress.

Left: A Jin-class nuclear submarine takes part in a naval parade to commemorate the 70th anniversary of the founding of China's navy in the sea near Qingdao, China, on April 23, 2019. MARK SCHIEFELBEIN/AFP VIA GETTY IMAGES
Right: Taiwanese soldiers prepare grenade launchers, machine guns, and tanks for the Han Kuang drill in the event of China's invasion, in Tainan, Taiwan, on Sept. 16. CENG SHOU YI/NURPHOTO VIA REUTERS

Mastering naval nuclear power is a key part of Beijing's global ambitions at sea. China became the first Asian country and the fifth globally to successfully design, build, and commission an SSN: the 1974 Type 091 Han-class. The first hull was laid down in 1967, but the Sino-Soviet split and Cultural Revolution delayed efforts. Beijing is now determined to achieve world-class results rapidly and continue to advance, and it should not be underestimated in the long run—especially as Russian assistance may accelerate its success substantially. In September 2010, China and Russia agreed to expand their cooperation in the development of floating nuclear power plants. Russia had finished the design for *Akademik Lomonosov*, which would have two 150 megawatt KLT-40S reactors—reactors that are closely related to OK-650 reactors on Russian third-generation submarines built in the mid-1980s through the 1990s.

Initially, China was reportedly considering importing reactor technology from Russia but later decided to use an indigenously produced 200 megawatt reactor, the ACPR50S, designed by China General Nuclear Power. This reactor started its development in 2012 and bears a striking resemblance to the Russian KLT-40S with its unique primary coolant arrangement that employs a pipe within a pipe, which is associated with Russian naval nuclear power reactors.

Today, China remains behind the United States and United Kingdom and continues to suffer major weaknesses in SSN performance and quieting. It has developed its own versions of foreign diesels and gas turbines—and if Russia has indeed shared a third-generation submarine reactor design, then the world should expect the next generation of Chinese nuclear submarines to finally close the wide technological gap. China has deployed AIP on its most advanced conventional submarines and is working to progress to next-generation lithium-ion batteries. It still lacks experience with nuclear power for aircraft carriers. All three Chinese carriers under construction or operational thus far appear to use traditional oil-fired boilers and steam plants.

The complex and demanding performance parameters of naval propulsion make this a difficult field to master. Piecing together foreign and indigenous technologies of civil and military origin has served China relatively well in some areas but will not ensure naval nuclear power success given the degree to which components must work together as a sophisticated system of systems. However, if Russia agreed to lend China technical support in designing a high-power density reactor for naval applications, such as a floating power station or a submarine, this process could be much faster. And if the Australians believe this to be the case, that may be one factor behind their own SSN decision.

Advanced types of propulsion, particularly nuclear, are guarded zealously by leading foreign powers. For these reasons, robust partnership is needed to fully access them—exactly what Australia has just achieved with the United States and United Kingdom as well as what China may be gaining, to some extent, with Russia.

Australia's way forward now certainly involves access to and incorporation of U.S. nuclear propulsion technology. The United Kingdom may play a major role in construction and supplying former Royal Navy submariners to help train and crew the new Royal Australian Navy's SSNs. This new trinational venture will take considerable time, money, and effort to achieve sea power in practice, but the logic is clear and irresistible. Canberra faces strategically seismic threats from Beijing, received an offer previously extended only to London, and understandably went all-in on one of the most game-changing military technology deals for decades.

The benefits will begin long before Australian SSNs actually hit the water—perhaps a decade hence. Trust and alliances are further cemented, sensitive information and key personnel are in the process of being exchanged, and mutual facilities access beckons. The upfront process is as useful as the eventual product. It's true that Australia's six Collins-class diesel-electric submarines must lumber on as a gap-plugger; and China may well pose its peak Taiwan Strait and regional military threat before Australia has a fully operating SSN fleet. Australia's risk, however, can be mitigated by the forward deployment of U.S. and/or U.K. SSNs to Australian bases.

But meeting the challenge starts with confronting it from the firmest possible alliance foundation. And an empowered and encouraged Australia has much to offer for immediate value—from trusted professionals to leading human and technical intelligence to uniquely situated basing and training facilities.

Australia's *fait accompli* should be celebrated by those favoring robust allied sea power as a bulwark against Chinese aggression—and at least understood by all who believe in national interests and sovereign decisions.

This updated article draws partially on Andrew S. Erickson's book Chinese Naval Shipbuilding: An Ambitious and Uncertain Course, *specifically "Underpowered: Chinese Conventional and Nuclear Naval Power and Propulsion" co-written with Jonathan Ray and Robert Forte.*

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