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SPECIAL RISK REPORT

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Summary

Nuclear-powered submarines have been utilized by the militaries of the US, Russia, the UK, and China for decades. As an increased number of countries such as India, Brazil, and South Korea seek to join the relatively small group of states with nuclear submarine assets, operational and strategic risks pertaining to the deployment of such submarines may rise. While nuclear-powered submarines possess superior stealth, endurance, and speed as compared to diesel-electric models, their nuclear reactor can create long-term safety challenges for the environment if the vessels are damaged or sink. This Special Report provides insight into the various capabilities of nuclear-powered submarines, highlights risks, and offers recommendations on how to mitigate these risks.

List of Abbreviations:

AIP	Air-independent propulsion
EC	European Commission
IAEA	International Atomic Energy Agency
ICBM	Intercontinental ballistic missile
IMR	The Institute of Marine Research

Tags:

MILITARY, MILITARY STRATEGY, SUBMARINES, NUCLEAR SUBMARINES, DIESEL-ELECTRIC SUBMARINES, AIP SUBMARINES, TORPEDOES, SAFETY RISKS, STEALTH, SPEED, ENDURANCE, COST, AUSTRALIA, CHINA, FRANCE, INDIA, RUSSIA, UNITED STATES, UNITED KINGDOM.

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Introduction: An Overview of Developments in Nuclear-Powered Military Vehicles

While nuclear-powered submarines have existed for decades, India's Prime Minister Narendra Modi drew renewed international media attention to nuclear-powered submarines when he announced in November 2018 that India's first domestically constructed nuclear submarine had completed its first deterrence patrol.[1] India ranks among a number of states such as China, Russia, the US, and France that have been enhancing their nuclear submarine assets.

The first nuclear submarines began operation as early as the 1950s.[2] Nuclear-powered engines in submarines offer several benefits as compared with diesel-electric engines. While engineers also attempted to harness nuclear power for the Air Force, such projects have proved futile. As frequent and unsafe refueling of military airplanes became a serious issue for the United States and Russia during the Cold War, engineers developed nuclear airplanes. In contrast to nuclear-powered submarines, however, airplanes with a nuclear core were less safe, contaminating pilots with dangerous radiation during operation. To shield the nuclear core with a thicker protective coating would have significantly increased the weight of an airplane, which would have made the airplane's lift-off exceedingly difficult. The lighter the weight of an airplane, the easier it is for the vehicle to take off. When intercontinental ballistic missiles (ICBM) fulfilled the anticipated functions of a nuclear airplane, plans to further develop nuclear-powered aircrafts were abandoned. ICBMs do not need refueling because they have a one-destination mission and do not endanger pilots because they are unmanned.[3] Therefore, engineers working for the military focused their attention on the more fruitful mission of development of nuclear-powered submarines.

[1] Roblin, S. (2019): India is building a deadly force of nuclear-missile submarines, *National Interest*. Available at: https://nationalinterest.org/blog/buzz/india-building-deadly-force-nuclear-missile-submarines-42532 (Accessed: July 26, 2019).
[2] Roblin, S. (2016): Did Sweden make America's nuclear submarines obsolete?, *The National Interest*. Available at: https://nationalinterest.org/blog/the-buzz/did-sweden-make-americas-nuclear-submarines-obsolete-18908 (Accessed: July 26, 2019).
[3] Ruhl, C. (2019): Why there are no nuclear airplanes, *The Atlantic*. Available at: https://www.theatlantic.com/technology/archive/2019/01/elderly-pilots-who-could-have-flown-nuclear-airplanes/580780/ (Accessed: July 26, 2019).

2018 and 2019 have shown advancements in nuclear submarine capabilities across the world. Apart from India, France and Australia launched a new series of submarines in a joint cooperation project in mid-2019. French shipbuilder Naval Group developed the nuclear-powered attack submarine Suffren, a first-class Barracuda submarine which can carry F21 heavyweight torpedoes, SM39 anti-ship missiles, and MdCN-type naval cruise missiles. While France uses the nuclear engine design, the company adjusted the submarine model to accommodate Australia's order of 12 non-nuclear, diesel-electric-motored submarines.[4] Russia also introduced a new nuclear-powered submarine in April 2019, known as the K-139 Belgorod. It is referred to as the world's longest submarine with 184 meters (604 feet) in length and can be equipped with nuclear torpedoes and Poseidon underwater drones for reconnaissance.[5]

While submarines with a nuclear reactor offer many advantages in terms of stealth, endurance, and speed, nuclear accidents pose a major risk to the environment and the crew. Furthermore, due to their superior capabilities as compared with diesel-electric submarines, nuclear submarines can raise diplomatic and strategic tensions in crisis regions. The following assessment will focus on the capabilities and risks of nuclear-powered submarines.

The Capabilities and Cost of Nuclear-Powered Submarines

In spite of the risks associated with radioactivity, nuclear submarines are quieter, faster, and can remain submerged in water for longer periods of time than conventional, diesel-electric submarines. Due to these advantages, the US Navy phased out all its

[4] Mackenzie, C. (2019): France and Australia are working on the same sub, but they'll be powered differently, *Defense News*. Available at: https://www.defensenews.com/industry/techwatch/2019/07/12/france-and-australia-are-working-on-the-same-sub-but-theyll-be-powered-differently/ (Accessed: July 26, 2019); Naval Today (2019): France launches first of new class of nuclear-powered attack submarines, *Naval Today*. Available at: https://navaltoday.com/2019/07/12/live-france-launches-first-of-new-class-of-nuclear-missile-submarines/ (Accessed: July 26 2019).
[5] TRT World Now (2019): Analysis: Inside look at Russia's latest advanced nuclear submarine, *TRT World*. Available at: https://www.youtube.com/watch?v=pslHh_2xgvE (Accessed: July 26, 2019).

conventional submarines and fully switched to nuclear-powered models.[6] Other states possess either only non-nuclear submarines or a mix of nuclear and non-nuclear models. China, Russia, and India, which are among the countries with the world's largest submarine fleets, possess both conventional and nuclear submarines. Despite the fact that North Korea owns one of the world's largest submarine fleets, the North Korean military relies on conventional models only.[7] This is can be explained by the cost of nuclear submarines, which are significantly more expensive than conventional submarines.

[6] Roblin, S. (2016): Did Sweden make America's nuclear submarines obsolete?, *The National Interest*. Available at: https://nationalinterest.org/blog/the-buzz/did-sweden-make-americas-nuclear-submarines-obsolete-18908 (Accessed: July 26, 2019).
[7] Kiprop, V. (2018): Countries with the most submarines, *World Atlas*. Available at: https://www.worldatlas.com/articles/countries-with-the-most-submarines.html (Accessed: July 26, 2019).

Cost

Nuclear reactors drive up the price of submarines, making them the most expensive type of submarine as compared to conventional diesel-electric propulsion or non-nuclear air-independent propulsion (AIP) systems. A US Virginia class attack submarine costs approximately 2.6 billion USD, surpassing the earlier 2 billion USD Los Angeles class model. In contrast, AIP submarines commonly require a comparatively low budget of 200 million to 600 million USD per vehicle.[8] The Swedish Gotland class submarine, the world's first AIP submarine, is comparatively affordable at 100 million USD.[9] While the difference in cost between conventional and nuclear submarines is large, conventional AIP submarines tend to be smaller, employing a crew of 30 to 60 sailors. By contrast, nuclear vessels require crews of 100 people or more.[10]

Stealth

Nuclear submarines are silent to the extent that they may remain undetected by passive sonar, a method for identifying acoustic signals underwater. Due to the superior stealth of nuclear submarines, a French and a British nuclear ballistic submarine collided in 2009, as they did not detect each other.[11] While diesel-electric powered submarines can be comparatively quiet when they run on batteries, they are able to remain in this state for only a few hours. In contrast, the engines of AIP submarines can be as quiet or even more quiet than the reactor of a nuclear submarine, which creates sound when coolant

[8] Roblin, S. (2016): Did Sweden make America's nuclear submarines obsolete?, *The National Interest*. Available at: https://nationalinterest.org/blog/the-buzz/did-sweden-make-americas-nuclear-submarines-obsolete-18908 (Accessed: July 26, 2019).
[9] Roblin, S. (2018): How one cheap submarine from Sweden 'sank' the US Navy in 'battle', *National Interest*. Available at: https://nationalinterest.org/blog/the-buzz/how-one-cheap-submarine-sweden-sank-the-us-navy-battle-25639 (Accessed: July 26, 2019).
[10] Roblin, S. (2016): Did Sweden make America's nuclear submarines obsolete?, *The National Interest*. Available at: https://nationalinterest.org/blog/the-buzz/did-sweden-make-americas-nuclear-submarines-obsolete-18908 (Accessed: July 26, 2019).
[11] Roblin, S. (2016): In 2009, two nuclear submarines collided under the sea (and they were armed with nuclear weapons), *National Interest*. Available at: https://nationalinterest.org/blog/the-buzz/2009-two-nuclear-submarines-collided-under-the-sea-they-were-18690 (Accessed: July 26, 2019).

liquid is pumped around the reactor.[12] Hence, nuclear submarines and AIP submarines are both quiet, permitting stealthy maneuvers.

Endurance

A major asset of nuclear-powered submarines is the longevity of their power supply. Nuclear reactors are embedded in the vessel before deployment and do not need to be refueled for several years or even decades.[13] Nuclear submarines are typically refueled after a period of up to 30 to 40 years.[14] During the refueling process, the spent core is replaced with a new one.[15] Hence, a nuclear submarine may be more costly, but funds are saved in terms of fueling costs because it does not need to be refueled like a conventional vessel. This capability is particularly useful when submarines have to travel long distances across oceans.

Additionally, nuclear submarines can remain submerged under water for three to four months without resurfacing. This can improve the safety of submarines since they do not have to resurface as often as conventional vessels. Hence, opponents may find it harder to discover nuclear submarines. Submarines with snorkels or submarines that have to resurface frequently are easier to detect and thus more vulnerable to attacks. AIP submarines have to resurface every few weeks, while old diesel models can only last several days before their batteries must be recharged.[16] The endurance of nuclear submarines is therefore a significant advantage because it facilitates long-distance travel and stealth.

[12] Roblin, S. (2016): Did Sweden make America's nuclear submarines obsolete?, *The National Interest*. Available at: https://nationalinterest.org/blog/the-buzz/did-sweden-make-americas-nuclear-submarines-obsolete-18908 (Accessed: July 26, 2019).
[13] Ruhl, C. (2019): Why there are no nuclear airplanes, *The Atlantic*. Available at: https://www.theatlantic.com/technology/archive/2019/01/elderly-pilots-who-could-have-flown-nuclear-airplanes/580780/ (Accessed: July 26, 2019).
[14] World Nuclear Association (2019): Nuclear-powered ships. Available at: https://www.world-nuclear.org/information-library/non-power-nuclear-applications/transport/nuclear-powered-ships.aspx (Accessed: July 26, 2019).
[15] Ibid.
[16] Roblin, S. (2016): Did Sweden make America's nuclear submarines obsolete?, *The National Interest*. Available at: https://nationalinterest.org/blog/the-buzz/did-sweden-make-americas-nuclear-submarines-obsolete-18908 (Accessed: July 26, 2019).

Speed

The speed of a submarine with a nuclear engine surpasses that of a diesel-electric or AIP vehicle. US attack submarines can reach a speed of above 35 miles per hour underwater, whereas typical AIP submarines can dive at a speed of approximately 23 miles per hour. Increased speed improves tactical agility, yet it also produces more noise and thus decreases stealth.[17] In an open battle, however, stealth may be less important than speed, and mobility may offer a critical advantage.

Comparison between Conventional and Nuclear Submarines

Depending on the goal of a mission, nuclear submarines provide numerous advantages, yet they are not the only viable option in a cost-benefit analysis. Nuclear submarines may be the better option for improved stealth and long-distance travel, but the capabilities of conventional submarines can suffice for reconnaissance missions in littoral waters. Moreover, the high price of nuclear submarines makes purchasing a large quantity of vessels unaffordable for some countries. Diesel-electric submarines and AIP submarines may not possess the same capacities as nuclear submarines, but they can be acquired in larger quantities. This explains why North Korea, which had an estimated annual military budget of 3.35 billion USD between 2006 and 2016, possesses a large non-nuclear submarine fleet. In the same timeframe, the military expenditures of the US reached an annual average of 729 billion USD, permitting the country to procure an entirely nuclear-powered submarine fleet.[18] Weighing the cost and security goals of a state military is therefore vital in assessing to what extent acquiring nuclear submarines is financially possible and strategically rewarding.

[17] Roblin, S. (2016): Did Sweden make America's nuclear submarines obsolete?, *The National Interest*. Available at: https://nationalinterest.org/blog/the-buzz/did-sweden-make-americas-nuclear-submarines-obsolete-18908 (Accessed: July 26, 2019).
[18] US Department of State (2018): *World Military Expenditures and Arms Transfers 2018*. Available at: https://www.state.gov/world-military-expenditures-and-arms-transfers-2018/ (Accessed: July 26, 2019).

Safety and Nuclear Accidents

Nuclear submarine accidents are not uncommon; in some severe cases nuclear submarines even sink. The International Atomic Energy Agency (IAEA) counted a total of six confirmed losses of nuclear submarines at sea due to accidents between 1963 and 2001.[19] A report by Reuters indicates that more than 10 nuclear submarine accidents have occurred since 2000.[20] Most of these incidents did not result in the sinking of the vessel, but one case has gained much attention as a particularly disastrous accident that killed all 118 sailors on board the Russian Oscar-II class nuclear submarine Kursk. On August 12, 2000, the leak of highly concentrated hydrogen peroxide liquid in a torpedo

[19] International Atomic Energy Agency [IAEA] (2001): *Inventory of accidents and losses at sea involving radioactive material*. Available at: https://www-pub.iaea.org/MTCD/publications/PDF/te_1242_prn.pdf (Accessed: July 26, 2019).
[20] Cutler, D. (2011): Timeline: Worst nuclear submarine incidents, *Reuters*. Available at: https://www.reuters.com/article/us-russia-submarine-accidents/timeline-worst-nuclear-submarine-incidents-idUSTRE7BT0DJ20111230 (Accessed: July 26, 2019).

aboard the Kursk caused a massive explosion that destroyed the front of the vessel and triggered a fatal fire. The submarine sank as a result of the damage and now lies at the bottom of the Barents Sea close to the Arctic Ocean.[21] A more recent accident involving a nuclear submarine was a fire on a Russian nuclear submarine that killed 14 crew members in July 2019. Russian officials appeared reluctant to disclose detailed information on the incident, yet after Russian media pressured the government, Russia's President Vladimir Putin acknowledged Minister of Defense Sergei Shoigu's report of the safe containment of the vessel's nuclear reactor.[22]

A major concern in nuclear submarine accidents is the release of radioactive substances into the ocean. If the reactor pressure vessel, which encloses the radioactive material of a nuclear reactor, remains intact, then risks of radiation pollution of surrounding water are reportedly low.[23] Risks of radioactive pollution emerge when the protective material of reactors and nuclear warheads on board a sunken submarine is damaged, and radioactive material can leak through holes.[24] The gradual corrosion of sunken submarines and warheads pose a similar risk, yet wrecks are commonly left at accident sites because they often lie too deep in the sea – below 1,500 meters (5,000 feet) – to recover safely.[25]

In order to prevent the release of radioactive substance into the environment, the sea water, sediment, and deep-sea life surrounding wrecks can be tested for radioactivity. Furthermore, fissures and holes in sunken submarines can be monitored and repaired as exemplified by the Russian K-159 Komsomolets, which sank to the bottom of the Norwegian Sea at approximately 1,700 meters (5,600 feet) in 1989. Since plutonium could have potentially leaked from the two warheads aboard the Komsomolets, the hull of the torpedo compartment was fixed with special titanium coating, according to a 2001

[21] Ibid.; The Guardian (2001): What really happened to Russia's 'unsinkable' sub, *The Guardian*. Available at: https://www.theguardian.com/world/2001/aug/05/kursk.russia (Accessed: July 26, 2019).
[22] Osborn, A. & Kuzmin, A. (2019): Putin, after three days, says fire-hit Russian submarine was nuclear-powered, *Reuters*. Available at: https://www.reuters.com/article/us-russia-submersible-incident-nuclear/putin-after-three-days-says-fire-hit-russian-submarine-was-nuclear-powered-idUSKCN1TZ0HI (Accessed: July 26, 2019).
[23] Technology.org (2019): Do sunken nuclear submarines pose a risk of radioactive pollution, *Technology.org*. Available at: https://www.technology.org/2019/02/05/do-sunken-nuclear-submarines-pose-a-risk-of-radioactive-pollution/ (Accessed: July 26, 2019).
[24] International Atomic Energy Agency [IAEA] (2001): *Inventory of accidents and losses at sea involving radioactive material*. Available at: https://www-pub.iaea.org/MTCD/publications/PDF/te_1242_prn.pdf (Accessed: July 26, 2019).
[25] Ibid.

IAEA report.[26] The Institute of Marine Research (IMR) found another leak in the ventilation duct on the Komsomolets in 2019, indicating that radioactive cesium levels around the wreck were 800,000 times higher than average sea water levels. IMR spokesperson Hilde Elise Heldal, however, states that these levels were not "alarmingly high", posing no risk to people or marine organisms.[27] The European Commission (EC) also assessed to what extent sunken nuclear submarines pose a threat to fisheries, referring to a study by Heldal and other researchers.[28] According to the EC, continuous leakage or smaller amounts of released cesium from the Komsomolets do not contaminate fish like cod or capelin with dangerous levels of radioactivity. Nevertheless, the EC advises that the marine ecosystem in the proximity of the wreck must be further observed to eliminate doubt. The case of the Komsomolets demonstrates that sunken nuclear submarines must be regularly monitored over decades to ensure that radioactive material does not endanger the marine environment. Since wrecks are unlikely to be retrieved from the sea, the gradual underwater corrosion of metal around nuclear reactors and warheads remains a long-term risk that requires continuous attention.

Deployment, Maintenance, and Dismantling

While nuclear submarines offer improved maneuverability as compared to conventional submarines, fatal accidents and the release of nuclear substance into the ocean remain central risks. Another challenge that states with nuclear-powered submarines must anticipate is the adequate disposal of obsolete vessels. The UK's Ministry of Defense has invested roughly 600 million USD in the storage and maintenance of decommissioned submarines since the 1980s, earning criticism for struggling with plans on how to safely

[26] International Atomic Energy Agency [IAEA] (2001): *Inventory of accidents and losses at sea involving radioactive material*. Available at: https://www-pub.iaea.org/MTCD/publications/PDF/te_1242_prn.pdf (Accessed: July 26, 2019).
[27] Heldal, H. E. (2019): Researchers discovered leak from Komsomolets, *The Institute of Marine Research* [IMR]. Available at: https://www.imr.no/en/hi/news/2019/july/researchers-discovered-leak-from-komsomolets (Accessed: July 26, 2019).
[28] European Commission (2013): *Science for environment policy: What threat do sunken nuclear submarines pose to fisheries*. Available at: https://ec.europa.eu/environment/integration/research/newsalert/pdf/355na1_en.pdf (Accessed: July 26, 2019).

disassemble them.[29] Hence, deploying, maintaining, and losing or dismantling nuclear-powered submarines create a number of risks that need to be anticipated. **The following recommendations may offer guidance on how to manage these risks:**

- Ensuring the **robustness** and **safety** of the submarine hull, the protective coating of the nuclear reactor, and the material of warheads
- **Securing of warheads, torpedoes, and other weapons** aboard a submarine to avoid casualties
- **Regular maintenance** and **inspection** of vessels
- **Establishment of safety standards** and **compliance** with said standards
- Provision of **plans on how to safely dismantle** decommissioned nuclear submarines
- Employment of **well-trained personnel** that can adequately operate technologies and **perform enduring quality work**
- **Regular training of personnel** in technology updates, vessel operation, and crisis management in cases of flooding and other hazards

Strategic Summary

Opportunities

- Nuclear submarines grant militaries increased maneuverability, durability, and stealth, which also improve a country's level of military competitiveness and constitute a valuable asset in an armed conflict.

[29] BBC (2019): Nuclear submarines: MoD criticised over submarine disposal, *BBC*. Available at: https://www.bbc.com/news/uk-47792539 (Accessed: July 26, 2019).

- Even with acoustic detection equipment, nuclear submarines may be difficult to detect and locate due to their maneuverability, durability, and their quietness. These factors increase stealth and thus also the security of the vessel and the crew on board.

Risks

- Procuring nuclear submarines could potentially tip the strategic balance in a region and increase the military competition between opponents.
- The maintenance of deployed nuclear submarines as well as the adequate dismantling and disposal of decommissioned vehicles are important to keep risk levels low for the crew, the vehicle, strategic goals, and the environment.
- Due to the high cost of nuclear submarines, some militaries may not be able to procure them in high quantities. An alternative solution is the deployment of a higher quantity of conventional non-nuclear submarines instead. Taking cost into account, is important to match the quantity of nuclear and conventional submarines with the specific strategic goals of a government.

Tactical Breakdown

Strategic

- India's development and construction of its own Arihant-class nuclear submarine can pose a risk to the strategic balance in South Asia since Pakistan will aim to compete with India and build up its own sea deterrence. If conflict erupted in the region, vital sea routes may be blocked, inhibiting international trade.
- Countries like Russia and France also seek to gain a strategic advantage through the deployment of nuclear submarines in 2019. Russia may expand its fleet to project power in the Arctic Ocean, which may become an important shipping lane after Arctic ice has melted and freed the path as a consequence of global warming.

Operational

- Ensuring that submarine personnel are well trained in the technical and technological operation of the vessel is a crucial component of crisis management.
- Submarine staff should be provided with emergency guidelines. Simulations of emergencies could also help personnel learn how to react in crises.
- Nuclear submarine manufacturers should ensure that the hull of the vessel is robust and arms on board are well secured in order to prevent casualties.

Afterthoughts

The operational advantages and the deterrence potential of nuclear-powered submarines make these vessels attractive strategic assets. South Korea has expressed the intention to obtain a nuclear submarine in order to strengthen its military defense against North Korea despite US concerns that this acquisition would give North Korea the incentive to

continue its nuclear proliferation program.[30] Brazil is another country seeking to attain a nuclear submarine by 2029 in order to improve its defense capabilities and protect its long coastline of 7,000 kilometers (4,350 miles).[31] As India builds up its nuclear-powered submarine assets in South Asia and the Indian Ocean, neighboring Pakistan feels threatened and has indicated that it may attempt to build its own nuclear submarine to counter India's capabilities, raising diplomatic tensions.[32] Therefore, the proliferation of nuclear submarines may thwart regional strategic balances as neighboring states feel threatened by another state's deployment of nuclear submarines.

[30] Hippel, F. v. (2018): Mitigating the threat of nuclear proliferation from nuclear-submarine programs, *Institute for International Science and Technology Policy*. Available at: https://vcdnp.org/wp-content/uploads/2018/11/Occasional-Papers_Reducing-Risks-from-Naval-Nuclear-Fuel-2anfj76.pdf (Accessed: July 26, 2019).
[31] Ibid.; Olivares, P. (2018): Brazil take first step in program to join nuclear-powered sub club, *Reuters*. Available at: https://www.reuters.com/article/us-brazil-submarine/brazil-take-first-step-in-program-to-join-nuclear-powered-sub-club-idUSKBN1OD2CV (Accessed: July 26, 2019).
[32] Mian, Z., Ramana, M. V. & Nayyar, A. H. (2019): Nuclear submarines in South Asia: New risks and dangers, *Journal for Peace and Nuclear Disarmament*, 2(1), pp.184-202.


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