Emerging Submarine Detection Technologies and Implications for Strategic Stability

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ABSTRACT

As the revolution in remote sensing, computing power, big data analytics, and the biosciences continues to accelerate, it is possible that nuclear-armed submarines (SSBNs) will become vulnerable to detection and tracking. If nuclear-armed states were to acquire submarine detection and tracking capabilities of sufficient quality—or were believed to have acquired such capabilities—the implications for strategic stability could be dire. This paper explores some of the technologies that might enable states to reliably detect and track SSBNs and how the invention or deployment of such capabilities might impact strategic stability. Different scenarios are considered, including possible U.S. superiority in submarine detection, possible adversary superiority in submarine detection, and the effects of degraded SSBN survivability on extended deterrence. As arms control fades as a tool for maintaining superpower stability, new forms of communication between countries must be developed and expanded to manage the possibility that emerging technologies, including submarine detection technologies, upend the strategic landscape in dangerous ways.

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INTRODUCTION

For decades, the logic of deterrence and strategic stability has been underpinned by an assured second-strike capability—having the means to survive a nuclear first-strike and retaliate with unacceptable damage against an adversary. For the United States, this assured retaliation capability has been cemented, operationally and conceptually, in its sea-based leg of the nuclear triad, currently comprised of 14 Ohio-class nuclear-powered and nuclear-armed submarines (SSBNs). Finding and tracking these extremely quiet and sophisticated vessels was, and currently is, so difficult that strategists and policymakers view their stealth as axiomatic.[2] By all accounts, no adversary currently has the technology or tactics to reliably locate and hold at risk SSBNs when they are deployed to their patrolling stations deep in the ocean. This provides confidence to the United States that it will possess sufficient means of retaliation even if it were attacked first and denies any adversary the ability to disarm the United States sufficiently in a crisis or a war for it to consider attempting a nuclear first-strike. Among other factors, this mutual assured destruction paradigm contributed to the United States and the Soviet Union surviving the Cold War without a nuclear exchange.

Despite considerable effort by the U.S. Navy to develop submarine detection technologies and tactics that would have undercut the logic of mutual assured destruction,[3] neither the United States nor the Soviet Union were able to acquire the capability to track and destroy the other side's SSBNs with enough certainty to completely undermine strategic stability, especially when coupled with the inability to assure complete destruction of land-based and air-based weapons. However, the very fact that the United States *attempted* to do this, even as it endorsed mutual vulnerability as the basis of its national security, shows that the drive to improve military capabilities and the allure of escalation dominance was, and likely still is, strong enough to overcome political decisions about strategic stability.

During the Cold War, the technologies for exquisite submarine detection and tracking were simply not mature enough to seriously threaten strategic stability,[4] even though recent scholarship shows that the intention to outmaneuver mutually assured destruction was clearly there.[5] It was the state of the technology—not the decision to avoid researching and deploying that technology—which accounts for the expected survivability of second-strike forces during the Cold War.

However, the state of computing power, advanced software, remote sensing technology, and biotechnology is advancing rapidly, with massive but not yet fully understood implications for international security. This technological revolution is beginning to touch the realm of undersea warfare.[6] Emerging technologies and substantial improvements in existing technologies may be on the verge of revolutionizing anti-submarine warfare (ASW) capabilities, which could, in time, enable advanced militaries to locate and track submarines, including SSBNs, with increasing reliability.

2. Linton Brooks, "Strategic Stability and Submarine Operations: Lessons from the Cold War," Carnegie-Tsinghua Center, February 11, 2015, http://carnegieendowment.org/files/Speaker_Remarks%20-%20Ambassador%20Linton%20Brooks.pdf.
3. For a comprehensive discussion on anti-submarine warfare developments during the Cold War, see Donald C. Daniel, *Anti-Submarine Warfare and Superpower Strategic Stability* (Chicago: University of Illinois Press, 1986). For more on the U.S. Navy's success in tracking and threatening the Soviet Union's SSBNs, see Austin Long and Brendan Rittenhouse Green, "Stalking the Secure Second Strike: Intelligence, Counterforce, and Nuclear Strategy," *Journal of Strategic Studies* 38, nos. 1-2 (2015): 38-73, http://www.tandfonline.com/doi/pdf/10.1080/01402390.2014.958150.
4. Daniel, *Anti-Submarine Warfare and Superpower Strategic Stability,* 201-206.
5. For a comprehensive historical overview of U.S. anti-submarine efforts, see Owen R. Cote, Jr., The Third Battle: Innovation in the U.S. Navy's Silent Cold War Struggle with Soviet Submarines (Newport: Naval War College Press, 2003).
6. Bryan Clark, *The Emerging Era in Undersea Warfare* (Washington, DC: Center for Strategic and Budgetary Assessments, January 2015), http://csbaonline.org/uploads/documents/CSBA6292_%28Undersea_Warfare_Reprint%29_web.pdf.

Many of the enabling technologies for ASW will be invented and perfected by the private sector for commercial purposes but could be adopted or adapted by governments for military use. It is likely that, as the United States and China continue to compete in the Asia-Pacific, these technologies will be developed, adopted, and deployed with conventional aims in mind—such as tracking and destroying attack submarines—without considering the possible unintended consequences of these new capabilities for nuclear deterrence.

The remote sensing technologies fueling the potential for improved submarine detection, coupled with the continued proliferation and improvement of precision strike capabilities, also pose serious risks to the survivability of ICBMs and bombers.[7] It is possible that all legs of the triad could become less secure within a relatively short window of time, introducing an uncertainty to nuclear strategy that is currently moderated by the existence of secure sea-based second-strike forces.

Of course, making predictions about the functionality and reliability of new technologies involves a great deal of speculation and is notoriously difficult. Predictions are often incomplete, untimely, or simply wrong.[8] This is especially the case when attempting to analyze a field as secretive as ASW, where so much of the relevant history and information is highly classified. It may well be that these new submarine detection technologies do not materialize in a militarily significant way or that countermeasures to new capabilities quickly negate their utility. But it is also possible that a major leap in technological progress will undermine strategic stability, especially if nuclear powers do not respond to these changes effectively and responsibly. It is important to think about possible future conditions now in order to prepare for any reality that might arise.

This paper will attempt to think through those possible future conditions and what their implications might be for strategic stability. The paper will begin with an overview of the improvements to existing ASW capabilities and possible new capabilities that threaten the ability of SSBNs to avoid detection. Because of the limitations of surveying this issue at the unclassified level, this section of the paper is intended only to provide necessary context and raise theoretical questions—it is not intended to make a definitive determination about any of these technologies, nor should it be viewed as exhaustive. The maturity of these technologies for military use, and the intentions to develop them as such, can only be speculated about.

Next, it will explore the possible impact of game-changing advancements in submarine detection on deterrence and strategic stability. If a strategic environment materialized wherein submarines could no longer be relied upon to provide an assured retaliatory capability (especially if this coincides with increasing threats to land-based nuclear weapons), how would this affect U.S. confidence during a crisis? Would this threaten U.S. extended deterrence guarantees? How will U.S. adversaries, both near-peer and regional, view the nuclear landscape and crisis bargaining in such an environment?

The paper will end with recommendations for how the United States should manage its deterrence relationships given the possibility of such technological advances. Deploying game-changing technologies, or coupling new technologies together in innovative ways, without assessing how

7. Kier A. Lieber and Daryl G. Press, "The New Era of Counterforce: Technological Change and the Future of Nuclear Deterrence," *International Security* 41, no. 4 (Spring 2017): 9-49, https://www.mitpressjournals.org/doi/full/10.1162/ISEC_a_00273.
8. C. Wes Spain, "Curious Incidents: Dogs that Haven't Barked," in *Strategic Latency: Red, White, and Blue: Managing the National and International Security Consequences of Disruptive Technologies,* eds. Zachary S. Davis and Michael Nacht (Livermore, CA: Center for Global Security Research, 2018), 52-70, https://cgsr.llnl.gov/content/assets/docs/STATEGIC_LATENCY_Book-WEB.pdf.

such actions might threaten strategic stability could increase the danger of nuclear war in the emerging second nuclear age. Reducing that danger will be one of the most important policy issues of our time.

ASW TECHNOLOGIES

CURRENT CAPABILITIES AND PROSPECTS FOR IMPROVEMENT

Submarine detection falls into two broad categories: acoustic and non-acoustic. Acoustic detection relies on detecting the sound that the submarine itself makes or the sound of its effects on its environment. Non-acoustic detection encompasses all other forms of detection. Technological progress posits significant improvements on both fronts.

ACOUSTIC DETECTION

Acoustic detection methods and technologies can further be divided into reflected acoustic signals and radiated acoustic signals.[9] Sonar—the underwater equivalent of radar—is used to detect both. Active sonar works by emitting sound and receiving the return signal with a hydrophone. Passive sonar consists of hydrophones deployed to detect radiated submarine noise.[10] These sound emitters and receivers can be deployed on a wide variety of platforms and in many different arrays to achieve different effects.

To avoid detection from active and passive sonar, SSBNs are designed to be as quiet as possible. The ocean—covering over 70 percent of the Earth, filled with marine life, and defined by temperature differentials and the attenuating properties of water—is a large, noisy, and chaotic place. Detecting and tracking a single quiet vessel in the vast expanse of the ocean through acoustic means is an expensive and difficult endeavor. Because of sensor limitations, the combination of towed and dipping sonars and sonobuoys used during the Cold War were largely limited to tracking and trailing missions, not searching wide swaths of the ocean for first contact.[11]

Those limitations appear to be washing away. Further improvements to noise reduction may not be enough to keep pace with improvements in sonar detection, especially the computer processing power and big data analytics techniques that will drastically improve the signal to noise ratio and quickly sort out the chaos of the ocean to find the submarine needle in the ocean's haystack.[12] Running sufficiently sophisticated oceanographic models quickly enough to be useful for ASW has been theoretically possible for decades, but computers and software did not have the power to do so. Now, in an age where the average smartphone has more computing power than the supercomputers of decades past, analysis of sonar signals could soon be good enough to detect SSBNs in circumstances where they previously would have been invisible.

NON-ACOUSTIC DETECTION

The range of non-acoustic detection methods and technologies are too numerous to list in detail. However, the rapid progress being made with regard to sensor accuracy, sensitivity, miniaturization, mass manufacturability, and integration affect many types of potential sensors that could be used for submarine detection.

9. Daniel, *Anti-Submarine Warfare and Superpower Strategic Stability*, 28.
10. Ibid.
11. Ibid., 67.
12. Clark, *The Emerging Era in Undersea Warfare*, 10.

DETECTION FROM AIR AND SPACE

Submarines produce wakes, called Kelvin waves, whenever they are mobile.[13] The slower and deeper under water the submarine travels, the smaller the Kelvin wave becomes. At a certain depth and speed, the wave becomes so small that it was previously immeasurable. However, with advancements in synthetic aperture radar (SAR) technology, coupled with the computing power necessary to quickly find the shape of the wake amongst the many disturbances of the ocean's surface, the wakes produced by submarines might soon be detectable from aerial and space-based platforms.[14]

New laser and interferometry capabilities might also enable detection of previously unmeasurable differences on the ocean's surface. If a sufficient number of satellites or drones were equipped with SAR or laser-enabled detection capabilities, it is not inconceivable that surveillance of the entire ocean could be possible in the future.

BIOLUMINESCENCE AND BIOSENSING

When some marine plant and animal life are disturbed, they emit light that can be observed by sensors. The United States and the USSR both attempted to harness bioluminescence for naval purposes during the Cold War, but the technology never matured to the point where it could be used for SSBN detection.[15] Significant improvements in biotechnology, however, might make bioluminescence or other novel forms of biosensing feasible for detecting submarines. The Defense Advanced Research Projects Agency (DARPA) is currently exploring the possibility of using the properties of certain marine creatures to create a sensor network capable of monitoring underwater threats to U.S. naval vessels.[16] Biosensors could also be used to detect microbial signatures from ports known to base SSBNs.

The opportunities created by the revolution in biological technologies (biomedicine, bioinformatics, synthetic biology, etc.) appear to have the potential to remake our world; ruling out the possibility that bio-enabled sensors could illuminate the oceans in ways that are currently inconceivable would be a failure to appreciate the pace at which progress is being made in the biosciences.

CONTAMINANTS DETECTION

Submarines leak or otherwise introduce trace amounts of various contaminants into the ocean, from fuel to lubricants to waste products.[17] While monitoring the entirety of the ocean for trace particles seems impossible, advancements in pollution detection (including in the parts per quadrillion, or one thousand times a trillion) may make monitoring of wide swaths of the ocean possible.

There are many other potential forms of detection, including thermal detection and electromagnetic detection, but a full detailed treatment of these technologies is beyond the scope of this paper. This section gives just a sample of some of the possible detection technologies and techniques that might degrade the invisibility of the SSBN force.

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13. G.G. Wren and D. May, "Detection of Submerged Vessels Using Remote Sensing Techniques," *Australian Defence Force Journal,* no. 127 (November/December 1997): 10, https://fas.org/nuke/guide/usa/slbm/detection.pdf.
14. Carlo Kopp, "Evolving ASW Sensor Technology," Defence Today, December 2010, 27-28 https://www.ausairpower.net/SP/DT-ASW-Sensors-Dec-2010.pdf.
15. Sarah Laskow, "How the Navy Tried to Turn Bioluminescence Against the Soviets," *Atlas Obscura,* January 13, 2017, https://www.atlasobscura.com/articles/how-the-navy-tried-to-turn-bioluminescence-against-the-soviets.
16. Todd South, "From shellfish to plankton, DARPA program turns creatures into sensors," Navy Times, February 27, 2018, https://www.navytimes.com/news/your-navy/2018/02/28/from-dolphins-to-plankton-darpa-program-turns-creatures-into-sensors/.
17. Daniel, *Anti-Submarine Warfare and Superpower Strategic Stability*, 43.

If an adversary flooded the ocean with large numbers of small, networked electronic sensors or biosensors, they would not only improve the chances of initial detection, they would improve cross correlation as well. When sensors were expensive to produce and deploy, the production and deployment scale needed for ocean-wide coverage was impossible. The revolution in electronics, which is being driven by the private sector and government research organizations like DARPA, may be changing what is possible faster than many realize.

THE STRATEGIC IMPLICATIONS OF REDUCED CONFIDENCE IN THE SEA LEG OF THE TRIAD

While the actual survivability of SSBNs during the Cold War is open to debate, the *belief* that they were survivable enough for assured destruction of countervalue targets greatly contributed to stability.[18] Even if some of the SSBN force were to suffer attrition, enough submarines would survive that the adversary would not be tempted to risk nuclear war for fear that such a war would produce unacceptable destruction.

In a hypothetical security environment wherein some or all of the technologies discussed above mature in operationally meaningful ways, what might the implications be for U.S. nuclear strategy and strategic stability? There are three vantage points from which to explore this landscape. The first is a U.S. belief in its ability to detect and track enemy submarines with much higher confidence than exists today. The second is degraded U.S. confidence in its own SSBN force's survivability due to increased adversary ability to detect and track U.S. submarines. The third is the perception of U.S. allies and the ability of the United States to maintain extended deterrence guarantees. Each of these vantage points will be surveyed in turn.

U.S. SSBN DETECTION SUPERIORITY

What issues of concern might arise if the United States possessed the ability to detect and track submarines with significantly greater confidence than exists today? The two relevant countries to this discussion are Russia and China. Both the United Kingdom and France have nuclear weapons deployed on submarines, but they are close U.S. allies, and thus their nuclear weapons are not seen as threats to the United States. India and Pakistan are both moving towards deploying nuclear weapons on submarines,[19] and while this certainly has implications for the United States, it is unlikely that the United States will be directly threatened by Indian or Pakistani nuclear forces. Therefore, nuclear deterrence is unlikely to define the U.S.-Indian or the U.S.-Pakistani relationship. Nuclear deterrence and strategic stability will, however, almost certainly loom large over the U.S. relationship with Russia and China.

The U.S.-Russia relationship is defined by Russian fear of its own weaknesses (economic, technological, etc.) and paranoia about U.S. and NATO threats to its security. Russia currently fears U.S. conventional superiority[20] and has invested in capabilities and tactics to circumvent it.[21] It is

18. For more on the logic of assured destruction and its role in shaping the Cold War, see Richard Smoke, *National Security and the Nuclear Dilemma: An Introduction to the American Experience in the Cold War* (New York: McGraw-Hill, 1993). For a more theoretical discussion of this logic, see Thomas C. Schelling, *Arms and Influence* (New Haven: Yale University Press, 2008).
19. Diana Beth-Wueger, "Deterring war or courting disaster: an analysis of nuclear weapons in the Indian Ocean," (master's thesis, Naval Postgraduate School, 2015), 1, https://calhoun.nps.edu/bitstream/handle/10945/45278/15Mar_Wueger_Diana.pdf?sequence=1&isAllowed=y.
20. Jeffrey Edmonds, "How America Could Accidentally Push Russia into a Nuclear War," The National Interest, February 6, 2018, http://nationalinterest.org/feature/how-america-could-accidentally-push-russia-nuclear-war-24378.
21. Christopher S. Chivvis, "Understanding Russian 'Hybrid Warfare' And What Can Be Done About It," The RAND Corporation

embarking on a modernization program for its nuclear weapons in part because it feels insecure about the survivability of its nuclear forces as the United States increases its progress on ballistic missile defense. If the United States were able to track Russian nuclear-armed submarines with increased confidence, it could exacerbate these Russian fears even more, causing Russia to respond in destabilizing ways.

While it is true that Russia has never relied as much on submarine-based weapons as the United States has, the degradation of the survivability of Russia's nuclear-armed submarines would likely cause Russia to compensate for this new vulnerability. This is especially true if continued advancements in precision strike make Russia's air- and land-based nuclear forces more vulnerable. If Russia can no longer rely on hardening and concealment for survivability, they may double down on redundancy, producing and deploying larger numbers of nuclear weapons to complicate U.S. targeting and increase the odds that a retaliatory capability survives any U.S. first strike. This, in turn, could put the final nail in the coffin of arms control and lead to an arms race with the United States that drains resources, intensifies mistrust, and makes miscalculation more likely. In short, a significant U.S. advantage in submarine detection (which would likely develop in parallel with a U.S. advantage in remote sensing and precision strike capabilities in other domains) would likely be destabilizing due to Russian sensitivity over its technological inferiority.

This could compel Russia not only to increase redundancy with a larger number of warheads, but to change the doctrine governing their use as well. It is possible that in an environment of degraded second-strike stability, Russia could move further towards a first-use doctrine to deter escalation and to avoid the "lose them or lose them" dilemma.

China would likely be less sensitive to advancements in U.S. submarine detection capabilities for two reasons. First, China's strategic relationship with the United States, at least currently, is not defined by an assumed need for parity but by a need for a minimum reprisal capability, which it believes it has and will continue to have in the future.[22] It currently has a much smaller nuclear arsenal than the United States and relies on hardened and road-mobile land-based ICBMs for its retaliatory capability, which it believes is sufficient as long as it can hit the United States with just a few nuclear warheads, or even a single nuclear warhead.[23]

Second, China has not historically relied on SSBNs for its second-strike capability, and even as it begins deploying a credible sea-based nuclear deterrent for the first time,[24] it recognizes that its submarines are less advanced and thus more vulnerable to ASW than U.S. submarines. Therefore, China will likely continue to rely on land-based nuclear forces.[25] The remote sensing and precision strike revolution will certainly have implications for U.S.-China relations, but in the narrow hypothetical of U.S. superiority in submarine detection, China would be less concerned than Russia. They may, however, be sufficiently concerned that they decide to expand the size of their arsenal as a hedge.

(testimony), March 22, 2017, 1, https://www.rand.org/content/dam/rand/pubs/testimonies/CT400/CT468/RAND_CT468.pdf.
22. David Logan, "Hard Constraints on China's Nuclear Forces," War on the Rocks, November 8, 2017, https://warontherocks.com/2017/11/china-nuclear-weapons-breakout/.
23. Ibid.; Fiona S. Cunningham and M. Taylor Fravel, "Assuring Assured Retaliation: China's Nuclear Posture and U.S.-China Strategic Stability," *International Security* 40, no. 2 (Fall 2015): 7-8, https://www.mitpressjournals.org/doi/pdf/10.1162/ISEC_a_00215.
24. David C. Logan, "China's Future SSBN Command and Control Structure," Institute for National Strategic Studies, SF no. 299 (November 2016), http://ndupress.ndu.edu/Portals/68/Documents/stratforum/SF-299.pdf?ver=2016-11-28-093723-680.
25. Cunningham and Fravel, "Assuring Assured Retaliation: China's Nuclear Posture and U.S.-China Strategic Stability," 28-29.

Overall, conditions under which the United States had a significant advantage in submarine detection could push some adversaries away from an assured retaliation nuclear posture and towards what Vipin Narang calls an asymmetric escalation nuclear posture.[26] An asymmetric escalation nuclear posture entails threatening to use nuclear weapons first in a conflict to deter conflict and to prevent successful counterforce targeting by an adversary. If nations currently predisposed towards adopting assured retaliation postures no longer feel that the second-strike forces necessary for such a posture are secure, they may be forced to adopt asymmetric escalation postures.

ADVERSARY ADVANCEMENTS THAT THREATEN U.S. SSBNS

If adversaries such as Russia and China develop capabilities that put U.S. SSBNs at risk, or are *perceived* to put U.S. SSBNs at risk to an unacceptable degree by U.S. leadership, what might the ramifications be? The United States places more value in its sea-based second-strike capabilities than either Russia or China, so adversary threats to the U.S. sea-based deterrent would be more destabilizing than U.S. threats to adversary sea-based nuclear weapons.

The United States does not view its nuclear weapons as a deterrent solely against enemy nuclear attack and does not rule out the possibility of using nuclear weapons first in a conflict.[27] However, it is extremely unlikely that the United States would use nuclear weapons first or use them in response to anything other than the first use of nuclear weapons by another country. Surely the extremely high threshold for U.S. nuclear first use or the use of nuclear weapons in response to a non-nuclear attack stems from the U.S. desire to preserve the taboo against first use. But it is also enabled by the confidence that the United States has in its sea-based deterrent, which gives the United States the luxury of additional decision-making time while under attack. If the insurance policy of assured second-strike capabilities were to disappear, or if confidence in those capabilities were to decrease, the psychological impact on U.S. decision-makers could be destabilizing.

Luckily, China—the U.S. adversary most likely to develop and deploy such a capability—is also the adversary for whom possession of such a capability would be less destabilizing. This is because China's nuclear arsenal is small and thus incapable of counterforce targeting against U.S. land-based ICBMs and bombers. If China were to develop sufficiently sophisticated ASW technologies and tactics, either intentionally or as a byproduct of its conventional military posture against the U.S. Navy in the Asia-Pacific, it would not be able to threaten the U.S. ability to retaliate with the air- and land-based legs of the triad. Of course, if China's nuclear arsenal grows and it develops a nuclear capability and posture similar to Russia's, this calculus would change.

Because Russia currently has (or will soon have) the ability to conduct counterforce targeting against U.S. land-based ICBMs and bombers, if it acquired the ability to track U.S. SSBNs as well, the consequences for strategic stability could be dire. U.S. confidence in its nuclear deterrent during a crisis would likely fall, creating a dynamic where the United States might feel compelled to prepare its nuclear assets for use earlier than it otherwise might. Such moves could be perceived by Russia as preparation for a first-strike, which could lead Russia to make moves that would be seen by the United States as preparations for a first-strike, causing a downward spiral of misinterpreted signals that could lead to war.

26. Vipin Narang, *Nuclear Strategy in the Modern Era: Regional Powers and International Conflict* (Princeton: Princeton University Press, 2014).
27. Rebecca Hersman, "Nuclear Posture Review: The More Things Change, The More They Stay The Same," Center for Strategic and International Studies, February 6, 2018, https://www.csis.org/analysis/nuclear-posture-review-more-things-change-more-they-stay-same.

OCEAN TRANSPARENCY, EXTENDED DETERRENCE, AND NONPROLIFERATION

In addition to adversary advancements in ASW being destabilizing in their own right, there could be ripple effects that impact U.S. extended deterrence guarantees and even the global nonproliferation regime. Extended deterrence commitments are fundamentally difficult to make credible, as they entail convincing other states that the United States would be willing to incur serious damage to itself to defend them.[28] Since the end of World War II, the United States has been impressively successful at establishing such security guarantees with many countries, including those in NATO, Japan, and South Korea. These security guarantees have dissuaded many nations from acquiring their own nuclear weapons, leading to fewer nuclear weapons worldwide and fewer opportunities for nuclear-armed states to go to war.

How would these allies view U.S. security guarantees if the United States had reduced confidence in its second-strike capabilities? If threats to U.S. SSBNs became severe enough, the United States would feel less secure and thus less willing to engage in behavior that could result in war. Because extended deterrence is, at its most basic, a series of behaviors that indicate a U.S. willingness to go to war, anything that reduces U.S. confidence in its security would also reduce the credibility of its extended deterrence commitments.

It is, of course, impossible to know exactly how states will react to any event in the future because all future variables cannot be known in advance. But given rising isolationist sentiment and growing political dysfunction in the United States, U.S. security guarantees are already coming under question in allied nations.[29] Introducing a threat to a capability that the United States views as essential to its own security is unlikely to bode well for allied faith in U.S. extended deterrence, especially in the emerging political environment. This, among other factors, could contribute to decisions by U.S. allies to develop their own nuclear weapons, leading to the degradation of the global nonproliferation regime and unpredictable consequences for international security.

POLICY RECOMMENDATIONS

As technological and scientific progress continues, often for commercial or conventional military applications, the United States and other nations must be cautious and prudent about the ramifications for nuclear stability. There is no magic bullet solution that will guarantee wise decision-making on this front. The advancement of science cannot (and should not) be stifled, and even if it were, U.S. restraint would not be reciprocated in other countries. However, there are a few things that can be done to help prepare the United States and other nations for a world without secure sea-based nuclear forces, should that reality materialize.

First, additional scholarship is needed to explore the theoretical and practical implications of such a security environment. Much of the literature about nuclear weapons and strategic stability

28. Evan Brandon Montgomery, *Extended Deterrence in the Second Nuclear Age: Geopolitics, Proliferation, and the Future of U.S. Security Commitments* (Washington, DC: Center for Strategic and Budgetary Assessments, 2016): 2, http://csbaonline.org/uploads/documents/CSBA6183-ExtendedDeterrence_PRINT.pdf.

29. President Donald Trump's statements about NATO and U.S. global commitments have exacerbated these trends and caused many foreign leaders to question the reliability of the United States. One notable example was German Chancellor Angela Merkel stating in a campaign speech that Germany "really must take our fate into our own hands." See Henry Farrell, "Thanks to Trump, Germany says it can't rely on the United States. What does that mean?" *Washington Post,* May 28, 2017, https://www.washingtonpost.com/news/monkey-cage/wp/2017/05/28/thanks-to-trump-germany-says-it-cant-rely-on-america-what-does-that-mean/?noredirect=on&utm_term=.51493ae73168. Also see Keren Yarhi-Milo, "After Credibility: American Foreign Policy in the Trump Era," *Foreign Affairs* (January/February 2018), https://www.foreignaffairs.com/articles/2017-12-12/after-credibility.

presupposes secure sea-based second-strike forces, at least for the United States and Russia. If academics, think tank researchers, and policy practitioners begin to think seriously about the possibility of degraded stealth under the world's oceans, such an eventuality will not come as a shock if it emerges. It would be extremely dangerous for the governments and militaries of nuclear-armed states to find themselves in a world with advanced technological capabilities for which they are not conceptually prepared.

Second, a renewed focus on strategic stability is needed among the world's nuclear powers—one that acknowledges the possibility of rapid technological change and puts in place mechanisms for dealing with concomitant complications from it. This will include determining how much transparency is necessary about U.S. advancements in underwater tracking and detection in order to avoid the possibility that adversaries might make unwise decisions based on U.S. capabilities that do not exist or are not yet deployed. Increased dialogue between nuclear-armed states will be critical for untangling misperceptions and strengthening the channels that can help countries avoid miscalculation. As the age of Cold War-style arms control agreements comes to an end, new forms of dialogue and communication will be needed to fill the void.

Lastly, the United States must take seriously the possibility that its submarine-based nuclear weapons could be detectable and trackable in the future and begin thinking about how it would base its nuclear weapons under such conditions. If major changes to delivery vehicle designs, positioning, or numbers will be needed, a plan for ensuring the industrial capacity exists to execute those changes should be drafted.

CONCLUSION

If history is any guide, it is unlikely that states will restrain themselves and hold back from deploying submarine detection technologies if they become viable, at least not initially. The probability that such capabilities will materialize is unknown, and it is certainly possible that even if they do, countermeasures will quickly be found to restore the status quo under the world's oceans. However, if states acquire the ability to locate and track SSBNs and no countermeasures are found (or aren't found quickly enough), it would upend decades of nuclear weapons theory and muscle memory. Ensuring that the United States and the world's other nuclear-armed nations are as prepared as possible for this contingency will be an essential component of any successful strategy for keeping the peace during the second nuclear age.