

FEBRUARY 2018

# Project on Nuclear Issues

A Collection of Papers from the 2017 Conference Series and Nuclear Scholars Initiative

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Mark Cancian

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Mitchell Armbruster  
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## Acknowledgments

This report is made possible by the generous support of the Defense Threat Reduction Agency and the National Nuclear Security Administration.

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ISBN: 978-1-4422-8055-7 (pb); 978-1-4422-8056-4 (eBook)

Center for Strategic & International Studies  
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# Introduction

The role that nuclear weapons play in international security has changed since the end of the Cold War, but the need to maintain and replenish the human infrastructure for supporting nuclear capabilities and dealing with the multitude of nuclear challenges remains essential. Recognizing this challenge, CSIS launched the Project on Nuclear Issues (PONI) in 2003 to develop the next generation of policy, technical, and operational nuclear professionals through outreach, mentorship, research, and debate. PONI runs two signature programs—the Nuclear Scholars Initiative and the Annual Conference Series—to engage emerging nuclear experts in thoughtful and informed debate and research over how to best address the nuclear community’s most pressing problems. The papers included in this volume comprise research from participants in the 2017 Nuclear Scholars Initiative and the PONI Conference Series. PONI sponsors this research to provide a forum for facilitating new and innovative thinking and to provide a platform for emerging thought leaders across the nuclear enterprise. Spanning a wide range of technical and policy issues, these selected papers further discussion in their respective areas.

PONI owes many thanks to the authors for their dedication and outstanding work. Particular appreciation goes to the PONI team for editing and reviewing all the papers, the senior experts who provided mentorship, those who came to speak with the Nuclear Scholars during their workshops, the members of the Mid-Career Cadre who guided research direction, and those who moderated conference panels. PONI could not function without the generosity of these knowledgeable individuals.

Lastly, PONI would like to express gratitude to our partners for their continued support, especially the Defense Threat Reduction Agency and the National Nuclear Security Administration.





# Improving Insider Threat Training, Awareness, and Mitigation Programs at Nuclear Facilities

Shannon Abbott<sup>1</sup>

*In recent years, insider threat programs have become an important aspect of nuclear security and nuclear security training courses. However, many nuclear security insider threat programs fail to consider both the threat and potential of information technology (IT) systems for conducting and preventing insider attacks. This failure is critical because of the importance of information technology and networks in today's world. IT systems offer an opportunity to perpetrate dangerous insider attacks, but they also present an opportunity to monitor and prevent them. This paper suggests a number of best practices, such as maintaining secure backup processes, managing access paths, and monitoring both physical and network exfiltration of important data. It also proposes the development of a new tabletop exercise for training nuclear security practitioners on how best to implement the aforementioned best practices. The development of IT insider threat best practices and a practical tabletop exercise will improve nuclear security training by integrating a critical element of insider threat prevention into the broader nuclear security system.*

## INTRODUCTION

In recent years, insider threat mitigation programs have become increasingly important at nuclear facilities. Although the nuclear security community has worked to develop insider threat mitigation programs, it very seldom focuses on mitigating threats resulting from information technology (IT)

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1. Shannon Abbott is a nuclear security intern at Sandia National Laboratories and a Master of International Affairs candidate at the Bush School of Government and Public Service at Texas A&M University. Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA-0003525.

systems. One Chatham House report on civil nuclear facilities noted that “cyber security training at nuclear facilities is often insufficient. In particular, there is a lack of integrated cyber security drills between nuclear plant personnel and cyber security personnel.”<sup>2</sup> This is despite the fact that cybersecurity at nuclear facilities is becoming increasingly important in a highly connected world. Just as insiders can have critical knowledge that allows them to physically attack nuclear facilities, they also can manipulate the IT systems at a nuclear facility, which can have disastrous impacts on the plant itself.

While the IT insider threat has been somewhat neglected at nuclear facilities, there has been significant work elsewhere. Researchers in the information technology field have devoted nearly two decades to understanding the prevention of insider attacks and, in the event that they do occur, mitigation strategies. Specifically, the Computer Emergency Response Team (CERT) Insider Threat Center at Carnegie Mellon’s Software Engineering Institute (SEI) published *The CERT Guide to Insider Threats*, which offers a comprehensive explanation of three types of insider attacks (theft, sabotage, and fraud), as well as mitigation strategies for each type of attack. Developed to address the difficulties that arise from interactions between humans and technology, *The CERT Guide* is both well known and highly respected. The CERT Insider Threat Center leverages nearly two decades of knowledge and lessons learned that can improve all aspects of insider threat mitigation training programs at nuclear facilities, including IT. Insider threat mitigation programs cannot be done effectively without addressing how humans interface with IT systems, how IT systems interface with security systems, and so forth.

This paper aims to improve insider threat training programs by incorporating IT insider threat best practices. It will do so by accomplishing two tasks: first, by understanding insider threat mitigation best practices within the IT field that can be applied to nuclear facilities; and, second, by developing the framework for a tabletop exercise that can help employees understand how to build a robust insider threat mitigation program that incorporates information technology.

## INSIDER THREAT BEST PRACTICES

*The CERT Guide to Insider Threats* outlines three types of insider threats that can occur at nuclear facilities: IT sabotage, theft of intellectual property, and insider fraud.

### IT Sabotage

The first type of insider attack, insider IT sabotage, is defined as “insider incidents in which the insider uses information technology (IT) to direct specific harm at an organization or individual.”<sup>3</sup> The Guide explores the motivating factors behind such attacks. It notes that disgruntlement and

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2. Caroline Baylon, Roger Brunt, and David Livingstone, “Cyber Security at Civil Nuclear Facilities,” September 2015, ix, [https://www.chathamhouse.org/sites/files/chathamhouse/field/field\\_document/20151005CyberSecurityNuclearBaylonBruntLivingstoneUpdate.pdf](https://www.chathamhouse.org/sites/files/chathamhouse/field/field_document/20151005CyberSecurityNuclearBaylonBruntLivingstoneUpdate.pdf).

3. Dawn Cappelli, Andrew Moore, and Randall Trzeciak, *The CERT Guide to Insider Threats: How to Prevent, Detect, and Respond to Information Technology Crimes (Theft, Sabotage, Fraud)* (Upper Saddle River, NJ: Addison-Wesley, 2012), 23.

unmet expectations are the reasons most insiders commit an IT sabotage act: the employee did not receive an expected raise, had trouble with their supervisor, was transferred to a new department, had their access to resources changed, or other such precursors. In a majority of cases in the CERT database, the saboteurs were about to be terminated from their positions.<sup>4</sup> Many disgruntlement attacks can be avoided by the implementation of strong human reliability programs (HRP) that encourage reporting strange behavior of colleagues. Because this can be a sensitive issue, organizations should also consider implementing whistle-blower protections to prevent retribution for those making such reports.<sup>5</sup> In addition, there are specific measures that organizations can take to prevent sabotage of their IT systems: carefully managing access paths, prioritizing IT alerts, targeted monitoring, securing logs, and ensuring a secure backup process.

### *Managing Access Paths*

In most organizations, employees are allowed access to the IT system so that they can use e-mail and carry out any necessary work functions. For most employees, access is a necessity. However, system administrators and some specific operators need additional access to more in-depth elements of the systems. One way to mitigate the insider threat is to ensure that employees have no more access than necessary.<sup>6</sup> For example, an administrative assistant does not need to access systems governing facility operations. System administrators need to closely monitor which individuals are granted what access privileges. It is important to monitor when accounts are created and ensure that there is a current list of who has access to shared accounts. Additionally, monitoring access paths can prevent insiders from perpetrating an attack while they are still employed at a facility. For example, a systems administrator moving to a facility operator position would not need to retain access to the previous privileges. Additionally, when employees are terminated, it is important to cut off all access paths that they had. Ensuring that employees have the proper amount of access and that former employees do not have any is an important step in mitigating the insider threat.

### *Prioritizing IT Alerts*

It is not necessary to monitor every change in an organization's network or source code—this could cause an overload of work for employees. However, in system-critical code or networks, organizations should use a configuration management system that can track changes and begin an authorization chain for changes to critical systems.<sup>7</sup> This is beneficial for two reasons: first, it forces organizations to prioritize their assets and understand what is mission-critical; second, having a configuration management system makes it considerably more difficult for an insider to change an important system that would damage the organization.

### *Targeted Monitoring*

Organizations should implement a system that allows them to record the activities their employees perform on IT systems. While it is not practical for organizations to actively monitor every

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4. Ibid., 24.

5. Ibid., 23–35.

6. Ibid., 50–52.

7. Ibid., 53–54.

employee, it is both important and feasible to collect logs for e-mail, physical access, and external media downloads. Logging a variety of activities allows organizations to more closely monitor employees who display signs of distress at work.<sup>8</sup> An employee who has come to the attention of human resources can be monitored more closely to ensure that person is not a threat for an insider attack. However, for their actions to be legally sound, organizations should have clearly documented policies, consistent with the laws of the country or state in which the facility is located, explaining why they conduct additional monitoring, when that monitoring might begin and end, and what they would monitor.

### *Securing the Logs*

Some IT-savvy insiders might cover their steps by altering or deleting the log files that are monitoring their activities.<sup>9</sup> To prevent this, organizations should secure their logs and implement continuous logging to a specifically tasked secure server. This will ensure that insiders are not able to alter the logs that would detect an attack before it occurs or would implicate them later.

### *Securing the Backup Process*

Finally, it is important for organizations to have a secure backup process so that, if an insider attack does occur, the organization can recover quickly. Backups should be stored both in physical form and digitally. The organization should implement controlled access to the facility where such backups are stored, with additional controls for access to the physical units. Additionally, when changes are made to the backup system, organizations should always require that employees comply with the two-person rule; that is, that two authorized individuals are required to make access and make changes to the system.<sup>10</sup>

## Theft of Intellectual Property

The CERT Insider Threat Center defines intellectual property (IP) as “an intangible asset created and owned by an organization that is critical to achieving its mission.”<sup>11</sup> Furthermore, it defines the theft of IP as “an insider’s use of IT to steal proprietary information from the organization. This category includes industrial espionage involving insiders.”<sup>12</sup> Unlike private businesses, nuclear facilities do not rely on their intellectual property in order to make a profit. However, they do have sensitive information—security schematics, blueprints of the plants, personally identifiable information (PII) belonging to employees—that is mission-essential and whose compromise would lead to adverse, even potentially disastrous, consequences. The two most common ways that insiders exfiltrate information is over a network through e-mail or file transfers, or by physically removing the data on laptops or removable media. While some insiders did remove physical papers, the CERT database shows that only 6 percent removed physical paper copies of intellectual property.

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8. Ibid., 55.

9. Ibid., 56.

10. Ibid., 57.

11. Ibid., 61.

12. Ibid.

### *Network Exfiltration*

Network exfiltration is typically done over e-mail or a virtual private network (VPN). Of those that do steal data, a majority do so within 30 days of leaving the organization. There may be value in checking an employee's e-mail and VPN access logs to examine their activity prior to leaving the organization. Additionally, many insiders in the CERT database used personal e-mail at work to exfiltrate data. To prevent this, some organizations have banned the use of personal e-mail accounts on a work network. Additionally, organizations should routinely inspect log files for suspicious access, large file transfers, irregular e-mails, or unusual access hours.

### *Physical Exfiltration*

Physical exfiltration generally occurs via thumb drives and portable hard drives or laptops. One way to prevent this is to bar the use of removable media or limiting who can use different types of removable media. However, if no limits are placed on the use of removable media, organizations can create log files for file transfers to removable media. This will allow organizations to monitor for suspicious use or suspiciously large downloads.

### *Insider Fraud*

The CERT Insider Threat Center defines insider fraud as "an insider's use of IT for the unauthorized modification, addition, or deletion of an organization's data (not programs or systems) for personal gain, or the theft of information that leads to an identity crime (identity theft, credit card fraud)." While all organizations, including nuclear facilities, should be concerned with protecting the PII of employees, preventing identity crimes from occurring are certainly not the most important task of nuclear operators. However, while nuclear facilities may not be concerned with preventing the same type of insider attacks that other industries are, there are still important IT best practices that apply. These lessons include maintaining a sufficient separation of duties and practicing password security.

### *Separation of Duties*

If possible, organizations should build business processes into online systems. For example, if a supervisor needs to approve an action it should be done online using that supervisor's account, not using paper forms.<sup>13</sup> While many threats arise from the use of IT systems, IT systems can also be used to strengthen security. It is significantly more difficult for an insider to obtain their supervisor's log-in credentials than it is to forge a signature. Building business processes into online systems allows organizations to promote greater security at their facilities and make it more difficult for insiders to skirt the approval process.

### *Password Security*

Training should stress that employees must not share their passwords. Employees should be aware that if someone else uses their account to commit a crime it will be difficult to prove their individual innocence.<sup>14</sup>

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13. Ibid., 125.

14. Ibid., 126.

# INSIDER THREAT EXERCISE

Tabletop exercises have helped professionals gain an understanding of how to best physically secure a facility. Sandia National Laboratories, for example, has developed a tabletop exercise to help visiting scholars and students think about who may access certain areas. Developing a tabletop to determine access to information technology at nuclear facilities may help apply insider threat mitigation best practices.

There are two approaches to developing a tabletop exercise for implementing IT-related best practices at nuclear facilities. First, the tabletop could take different job families (administrative, operator, security, support, etc.) and ask participants to assign them access to a set of computing resources based on their business requirements. Second, the tabletop could ask participants to look at case studies where IT controls have failed to prevent an insider attack and identify changes that might have prevented the insider attack in the first place.

## Job-Family Tabletop

A job-family tabletop would begin by identifying the important job families at nuclear facilities: administrative (human resources, administrative assistants, etc.), operations, security, support (IT staff, procurement, etc.), and legal.

These job categories could be divided further into smaller groups. For example, within the IT staff it may be important to separate out the systems administrators from the technologists. However, the level of stratification must be balanced against complexity and burden.

A job-family tabletop would then specify the different kinds of access a person might require (e.g., personnel records, operation-critical IT resources, IT log files, etc.).

The exercise would then require each participant or group of participants to specify what type of computing resources should be assigned to each type of job-family. Following each group's assignment, the group would talk through the decisionmaking process.

## Case Study Tabletop

A case study tabletop would have participants read a case study of an actual insider incident and then ask them to make recommendations to avoid such an incident. The recommended steps could easily be broken down into measures to prevent unauthorized access, the loss of knowledge, or left more general. The tabletop could utilize insider incidents already in the CERT database; rely on write-ups of incidents not included in the CERT database—for example, Edward Snowden and the National Security Agency; create its own fictional but realistic incidents; or use a combination of any of the above.

The case study tabletop would be much simpler to implement than the job-family tabletop. It would require preparation in putting together the case studies for use, but it would not require as much thought about splitting up resources as the job-family tabletop would. Further, the case study method may be more realistic than the job-family approach and may present a better opportunity for participants to learn in a way that replicates the real world. However, the job-family



approach would help to understand a different set of vulnerabilities and may allow participants to consider the roles of different employees at their own facilities.

The case studies should highlight both intentional and unintentional insider threats. One example of an intentional, and actual, short case study is as follows:

A consultant in the commercial facilities industry downloaded the organization's proprietary software and, upon termination, tried to sell it to another organization for nearly \$7 [million]. She also used another organization's bank account to pay for a personal credit card bill, costing the second organization more than \$425,000. It is believed that access to this account came from the consulting work from the first organization.<sup>15</sup>

Participants could examine this case study and determine that when the consultant downloaded proprietary software, it should have set off an alert that a large and important file was being removed from the network. They may also note that the consultant should not have had access to the second organization's bank roll unless she was working directly for them. These are just two examples that come directly from the best practices listed previously and are not the extent of measures that could have been taken to prevent or detect this insider attack much sooner. Many other insider cases can provide examples and teach students about how to apply best practices to real events to prevent the insider attack.

An additional example of a tabletop exercise comes from Scott Sagan and Matthew Bunn's book, *Insider Threats*. This case, which took place in 1982, allows students to consider IT insider threat mitigation in an instance where information technology did not play as large a role as it does today. It also compels students to consider IT insider threat mitigation in the context of a whole system.

Rodney Wilkinson was a South African man sympathetic to the African National Congress (ANC). Despite previously deserting from the South African military, Wilkinson was able to gain employment from the Koeberg Nuclear Power Station that allowed him access to the most sensitive areas of the plant. This was possible because Wilkinson never received a background check before beginning work at the facility. Near the end of his eighteen-month employment contract his girlfriend encouraged him to steal building plans and work with the ANC to plan an attack on the facility. He ultimately agreed, stole the plans, and began meeting with ANC officials once a month in Swaziland to plan the attack. While carrying out this process Wilkinson had to regain employment at the plant after his contract lapsed, and he was able to do so without a background check—for the second time. ANC officials had Wilkinson dig up munitions and smuggle them into the plant and take notes on the wiring and piping at the facility. However, before Wilkinson smuggled the bombs into the plant, he first tested his ability to sneak contraband items

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15. "Insider Threat Examples by Sector," *SCADA Hacker*, 2012, [https://scadahacker.com/library/Documents/Insider\\_Threats/Insider%20Threat%20Examples%20by%20Sector.pdf](https://scadahacker.com/library/Documents/Insider_Threats/Insider%20Threat%20Examples%20by%20Sector.pdf).

in by bringing a vodka bottle that was about the size of the explosives into the main control room. He was able to sneak the vodka in, and was caught drinking it while scoping the main control room. However, despite clearly breaking facility rules about drinking on site Wilkinson was never punished for his transgression and was able to plant the bombs and set off four explosions at the plant. While the explosions did not cause radiation leaks or casualties, it did cause over \$47 million in damage.<sup>16</sup>

This case study offers many lessons. For example:

- Access logs may have showed Wilkinson's movements while he was mapping the electricity and plumbing systems at the plant.
- Wilkinson was sneaking out with paper versions of the building design (though today a download of the building designs would be more likely—downloads of sensitive files should be logged and reviewed).
- Wilkinson should have received a background check and been disqualified due to his army desertion.
- Wilkinson should have been suspended for drinking on the job.

While this case study portrays a physical rather than an IT-based insider attack, it does illustrate how IT systems could help thwart a physical attack. It also puts IT insider threat mitigation in a broader systems context.

## RECOMMENDATIONS

This tabletop and the best practices will be the most useful if included in a broader discussion of the insider threat and security and safety systems at nuclear facilities. The IT insider threat is just one portion of an important problem and is wholly integrated with nuclear security. In today's world, it is unlikely that an insider would be able to perpetrate an attack without the use of some IT-connected system that, if monitored and used correctly, can help to detect the event before it occurs. However, it is also important to note that IT insider threats cannot be detected without the use of additional programs, such as human reliability programs and behavioral monitoring programs. Ultimately, nuclear security relies on organizations and people who can integrate all the programs mentioned, as well as many others, in order to ensure the security of their facilities.

To make practical use of this information, presenters could take the identified best practices and include them in overall nuclear security training courses. Additionally, they could utilize and share the IT insider threat tabletop for their courses when fully developed. A future topic of research would include determining how to utilize the IT insider threat tabletop in a broader insider threat exercise, integrating it—even as an exercise—into the whole system. Additionally, it may be useful to develop a specific IT insider threat presentation or subset of a presentation that could be given

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16. Matthew Bunn and Scott D. Sagan, *Insider Threats* (Ithaca, NY: Cornell University Press, 2016), loc. 558–632, Kindle.

separately to interested parties. Using this presentation and tabletop will also reveal lessons learned that may improve both aspects in the future.

## CONCLUSION

An increasingly interconnected world provides more opportunities for insiders to perpetrate an attack on critical infrastructure using IT systems. However, this interconnectedness also allows additional opportunities to monitor and detect insider threats before they occur. Developing IT insider threat best practices specifically for nuclear facilities and a correlating tabletop exercise adds a new aspect to nuclear security training that does not currently exist. Adding this important aspect of nuclear security allows practitioners to strengthen nuclear security. While best practices and tabletop exercises cannot eliminate the insider threat, making practitioners aware of the threat, as well as of ways to mitigate it, can reduce the likelihood and effectiveness of attacks.

# Examining Nuclear Assumptions: Five Schools of Thought

Mitchell Armbruster<sup>1</sup>

*How can we better understand the contemporary nuclear weapons debate in the United States? Following a post–Cold War lull, nuclear weapons are back on the U.S. policy agenda. However, when it comes to crucial issues, it often seems like discussants are talking past one another. This paper proposes a new way of understanding the debates about nuclear weapons in the United States by developing five schools of thought that capture different ways of thinking about nuclear weapons. After briefly examining these five schools, this paper concludes by applying the schools of thought to the contemporary debate over the Long-Range Standoff (LRSO) missile.*

## INTRODUCTION

After receding to the background of the post–Cold War national security discussion, U.S. nuclear policy has returned to prominence. As the U.S. nuclear arsenal reaches—and in some cases, exceeds—its life expectancy, the debate over the nature of nuclear modernization has reignited old controversies and sparked new ones.

Contemporary debate over U.S. nuclear weapons suffers from a lack of a shared common ground. Arguments exist over almost every aspect of U.S. nuclear weapons policy, and many participants talk past each other. This paper explores one of the most pressing issues in the current U.S. nuclear weapons debate—the Long-Range Standoff missile—by examining it through the lens of five schools of thought:

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1. Mitchell Armbruster is a senior analyst with Xator Corporation. This paper comes out of a project at National Defense University's Center for the Study of Weapons of Mass Destruction (CSWMD). The author thanks Chuck Lutes and Justin Anderson of CSWMD for their work and encouragement. Any mistakes are the author's alone.

- Nuclear abolition
- Minimal deterrence
- Balanced approach
- Flexible deterrence
- Nuclear superiority

These five categories can be thought of as distinct but permeable—at times the lines between them blur. However, this way of looking at the problem captures the significant differences between schools of thought in a rigorous, systematic way. This paper examines the distinctions between the schools by looking at how they approach five distinct areas:

- Geopolitics/international relations
- Morality and international law
- Deterrence and assurance
- Military strategy
- Nonproliferation

The schools of thought were developed by focusing on the writings and statements made by prominent thinkers. These authors may not belong cleanly in one school of thought, and this paper is not an attempt to pigeonhole thinkers into a particular school of thought. Rather, it asks, first, what are the general arguments that thinkers and policymakers put forward to support their decisions? Second, what were the general areas of disagreement? Third, what are the assumptions that undergird the arguments? This structure allows us to draw out the assumptions underneath the policy debates that monopolize nuclear weapons writing and discussion in the United States.

## NUCLEAR ABOLITIONISM

The nuclear abolitionist school of thought holds that nuclear weapons are inherently immoral and illegal, and thus should be eradicated from the earth with haste. Abolitionists believe that the elimination of nuclear weapons can be accomplished quickly and safely.

Nuclear abolitionists hold that it is possible to fundamentally alter the nature of the international system from one of anarchic self-help to one where cooperative security institutions replace the nation-state as the primary security actor. In this, the abolitionist school of thought differs significantly from the other four schools, which either believe that change to the international system will be a long-term project or that changing the nature of international politics is fundamentally impossible. Nuclear abolitionists see nuclear weapons as a solvable global problem and international security institutions as the way to address the problem. Working together, states can overcome shared common threats, including the threat of nuclear weapons.<sup>2</sup>

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2. For example, see the “Global Zero Action Plan,” <http://www.globalzero.org/get-the-facts/GZAP>, June 2017.

Like geopolitics, the biggest divide over the morality and legal issues involving nuclear weapons is between abolitionists and the other four schools of thought. Abolitionists believe that nuclear weapons are fundamentally immoral, and that any nuclear weapons use would be such a humanitarian catastrophe that no moral, legal use of nuclear weapons is possible. Abolitionists also believe that the nuclear weapons states have not moved fast enough in toward disarmament.<sup>3</sup>

Furthermore, nuclear abolitionists question the validity of nuclear deterrence. The most prominent line of thought in the abolitionist camp states that nuclear deterrence may have been effective in the bipolar, highly competitive world of the Cold War, but that in the post–Cold War world nuclear deterrence no longer makes sense.<sup>4</sup> Much of the nuclear abolitionist camp challenges the basic underlying principles and assumptions of nuclear deterrence. The abolitionist school of thought generally rejects that nuclear competition plays a role in contemporary international politics. Instead, abolitionists state nuclear deterrence does not have a role in contemporary security threats such as terrorism and state failure.<sup>5</sup>

Similarly, abolitionists do not accept that nuclear weapons should play a role in assuring U.S. allies. The abolitionist school believes that U.S. assurance guarantees could be delivered solely with conventional weapons. According to a 2012 Global Zero policy report, “In fact, strong conventional forces and missile defenses may offer a far superior option for deterring and defeating a regional aggressor. Nonnuclear forces are also far more credible instruments for providing twenty-first-century reassurance to allies whose comfort zone in the 20th century resided under the U.S. nuclear umbrella.”<sup>6</sup>

Abolitionists and minimal deterrence advocates have similar views concerning the role of nuclear weapons in military strategy. Neither see much of a role for nuclear weapons in conventional warfare. Though the abolitionists’ goal is more ambitious than the minimal deterrent proponents’ goal, they both believe that eliminating the “war fighting mission” that certain nuclear weapons systems have is crucial to reducing the overall role of nuclear weapons in U.S. strategy. The accuracy and power of conventional weapons such as guided, smart munitions and advanced drones means that there is no target that the U.S. military cannot destroy. According to Ward Wilson of the British American Security Information Council, “As we continue to develop ‘smart’ weapons—tiny, accurate, discriminate drones, for example—a world without nuclear weapons looks increasingly possible.”<sup>7</sup>

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3. The Vatican, “Message of His Holiness Pope Francis to the United Nations Conference to Negotiate a Legally Binding Instrument to Prohibit Nuclear Weapons, Leading Towards Their Total Elimination,” March 23, 2017, [https://w2.vatican.va/content/francesco/en/messages/pont-messages/2017/documents/papa-francesco\\_20170323\\_messaggio-onu.html](https://w2.vatican.va/content/francesco/en/messages/pont-messages/2017/documents/papa-francesco_20170323_messaggio-onu.html).

4. George Shultz, William Perry, Henry Kissinger, and Sam Nunn, “Deterrence in the Age of Nuclear Proliferation,” *Wall Street Journal*, March 7, 2011.

5. Gen. (Ret.) James Cartwright, Amb. Richard Burt, Sen. Chuck Hagel, Amb. Thomas Pickering, Gen. (Ret.) Jack Sheehan, *Global Zero U.S. Nuclear Policy Commission Report: Modernizing U.S. Nuclear Strategy, Force Structure, and Posture* (Washington, DC: Global Zero, May 2012), 6, [https://www.globalzero.org/files/gz\\_us\\_nuclear\\_policy\\_commission\\_report.pdf](https://www.globalzero.org/files/gz_us_nuclear_policy_commission_report.pdf).

6. *Ibid.*, 2.

7. Ward Wilson, “In an Age of ‘Smart’ Weapons, We Can Live without Nukes,” United Press International, July 19, 2016, [http://www.upi.com/Top\\_News/Opinion/2016/07/19/In-an-age-of-smart-weapons-we-can-live-without-nukes/4531468944908/](http://www.upi.com/Top_News/Opinion/2016/07/19/In-an-age-of-smart-weapons-we-can-live-without-nukes/4531468944908/).



Nuclear abolitionists see the size and capabilities of the U.S. nuclear arsenal as one of the key hindrances to global nonproliferation efforts. Unless dramatic changes are made to the U.S. (and Russian) nuclear postures, new nuclear weapons states may “copy the old U.S.-Russia model.”<sup>8</sup> Furthermore, nuclear abolitionists say that an aggressive plan to eliminate nuclear weapons can reinvigorate a moribund global arms control regime.<sup>9</sup>

## MINIMAL DETERRENCE

While minimal deterrence proponents accept that the United States needs to maintain a nuclear arsenal, they believe that all U.S. nuclear needs can be met with significantly fewer weapons than the United States has today.

Minimal deterrence thinking does not accept the abolitionist premise that the international system can be radically altered, making nuclear weapons unnecessary. In their view, nuclear weapons are only good for “existential deterrence.” Minimal deterrence advocates, while pushing for a radically smaller U.S. nuclear force, believe that global disarmament is not feasible.<sup>10</sup>

While accepting that there is nothing necessarily immoral or against international law about the United States having nuclear weapons, minimal deterrence advocates tend to be concerned about the cost of a large arsenal crowding out other priorities.<sup>11</sup> Minimal deterrence advocates also believe that maintaining only a small nuclear force, designed only to counter a nuclear attack, minimizes the chance of accidents or misuse.<sup>12</sup>

The minimal deterrence school emphasizes that nuclear deterrence is robust, meaning that a small number of nuclear weapons can deter a nuclear attack. Larger stockpiles are unnecessary, as the devastation wrought by only a few nuclear weapons would be more than enough to prevent a sane opponent from launching a nuclear attack against the United States. According to minimal deterrence advocates, the only real job that U.S. nuclear weapons are suited for is deterring nuclear attack on the United States. The role for reassuring allies should not fall to the U.S. nuclear arsenal, but instead to its overwhelming conventional military forces.<sup>13</sup>

Minimal deterrence proponents are skeptical that the United States would be willing to use nuclear weapons to deter attacks against allies. This is especially true when conventional weapons are

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8. Gen. (Ret.) James Cartwright, *Global Zero Commission on Nuclear Risk Reduction: De-Alerting and Stabilizing the World's Nuclear Force Postures* (Washington, DC: Global Zero, April 2015), 4, [http://www.globalzero.org/files/global\\_zero\\_commission\\_on\\_nuclear\\_risk\\_reduction\\_report.pdf](http://www.globalzero.org/files/global_zero_commission_on_nuclear_risk_reduction_report.pdf).

9. Ibid., 38.

10. Robert Gard and Greg Terryn, “American Nuclear Strategy: The Case for a Minimal-Deterrence Policy,” *National Interest*, December 1, 2014, <http://nationalinterest.org/feature/american-nuclear-strategy-the-case-minimal-deterrence-policy-11755>.

11. James Doyle, “The Full Price of Nuclear Deterrence,” *Bulletin of the Atomic Scientists*, February 29, 2016, <http://thebulletin.org/full-price-nuclear-deterrence9196>.

12. Gard and Terryn, “American Nuclear Strategy.”

13. Tom Nichols, “Time to Change America’s Atomic Arsenal,” *Diplomat*, March 14, 2013, <http://thediplomat.com/2013/03/time-to-change-americas-atomic-arsenal/>.

available that can have the same effect. Naval War College professor Thomas Nichols argues, “Extended deterrence has run its course. It is time to admit it, so that the United States and its allies will no longer lean on a nuclear crutch and instead begin the more difficult (and admittedly more expensive) task of preparing its conventional forces for operations in support of U.S. friends and allies across the globe.”<sup>14</sup>

Kingston Reif of the Arms Control Association employs minimal deterrence thinking when he argues that “the notion the use of nuclear weapons can be fine-tuned to carefully control escalation to a full-scale nuclear exchange is very dangerous thinking. It is highly unlikely that an adversary on the receiving end of a U.S. nuclear strike would (or could) distinguish between a large warhead and a small warhead. The fog of war is thick. The fog of nuclear war would be even thicker.”<sup>15</sup>

Minimal deterrence adherents also believe that significant reductions in the U.S. nuclear arsenal would contribute to nonproliferation goals. While not advocating for the near-term elimination of all nuclear weapons, the minimal deterrence school believes that shifting from a counterforce to a counter-value strategy would position the U.S. to dramatically cut the number of nuclear weapons, encouraging other nuclear powers to do the same.<sup>16</sup>

## BALANCED APPROACH

The balanced approach holds that while a nuclear-free world is possible in the long term, the United States needs to maintain a robust nuclear force in the present. The nature of the international system can be changed, but only slowly, and with significant effort on behalf of the United States. Any change in the nature of global politics requires the United States to mobilize the international institutions that it has developed. Proponents of the balanced approach incorporate liberal insights, especially regarding the role of international institutions.<sup>17</sup>

Balanced approach proponents point out that there is nothing in international law, including the Nuclear Non-Proliferation Treaty (NPT), that prohibits the United States from maintaining a robust nuclear weapons capability. The rules and institutions of the nuclear era give the United States the right to possess nuclear weapons. The key is that the United States work toward the eventual goal of a nuclear-free world.<sup>18</sup>

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14. Thomas M. Nichols, *No Use: Nuclear Weapons and U.S. National Security* (Philadelphia: University of Pennsylvania Press, 2013), 121.

15. Kingston Reif, “Cruise Control: Why the U.S. Should Not Buy a New Nuclear Air-Launched Cruise Missile,” *War on the Rocks*, March 21, 2016, <https://warontherocks.com/2016/03/cruise-control-why-the-u-s-should-not-buy-a-new-nuclear-air-launched-cruise-missile/>.

16. Hans Kristensen, Robert Norris, and Ivan Oelrich, “From Counterforce to Minimal Deterrence: A New Nuclear Policy on the Path toward Eliminating Nuclear Weapons,” Federation of American Scientists and Natural Resources Defense Council, April 2009, [https://fas.org/pubs/\\_docs/occasionalpaper7.pdf](https://fas.org/pubs/_docs/occasionalpaper7.pdf).

17. Rose Gottemoeller, “The Prague Agenda in 2013—Challenges and Prospects” (remarks at the Czech Ministry of Foreign Affairs, September 6, 2013), <http://www.state.gov/t/us/213961.htm>.

18. “FACT SHEET: The Prague Nuclear Agenda,” White House, January 11, 2017, <https://obamawhitehouse.archives.gov/the-press-office/2017/01/11/fact-sheet-prague-nuclear-agenda>.

The balanced approach differs from the minimal deterrence and abolitionist schools by focusing on the role the United States can play through international institutions. Promoting the Prague Agenda plan, the White House under Barack Obama stated, “We have strengthened the global nonproliferation regime by continuing to unite the international community against the proliferation of nuclear weapons and strongly respond to rule breakers. This is perhaps most notable with respect to Iran but also, as U.N. Security Council resolutions (UNSCR) 2270 and 2321 demonstrate, in relation to the Democratic People’s Republic of Korea (DPRK).”<sup>19</sup>

Instead of rapid cuts toward a nuclear-free world in the near future, the balanced approach calls for international institutions to monitor compliance of far less significant cuts. Though the end goal is the same, the process is slower with a focus on retaining a substantial nuclear arsenal for as long as nuclear weapons are a reality. Prague Agenda proponents recognize the need to strengthen global security institutions to ensure that they have the capacity to improve political-security relations.<sup>20</sup>

The balanced approach is somewhat split on the role of nuclear weapons in military strategy and war fighting. Some believe that the United States needs a force capable of fighting and prevailing in a nuclear war, specifically in more limited nuclear conflicts.<sup>21</sup> Others are more skeptical that new, more tailored-response systems are needed, or that the U.S. can afford them.<sup>22</sup> This disagreement is reflected in the debate over the LRSO.

Balanced approach thinkers tend to favor maintaining U.S. extended deterrence guarantees with nuclear weapons while moving to cut the total number of American nuclear weapons and reducing the role nuclear weapons play in defense planning.<sup>23</sup> Other factors, such as trust, aligned interests, and institutional factors, increase allies’ confidence that U.S. commitments to their defense are trustworthy. “Extended deterrence (and assurance) in particular depends on far more than numbers. It concerns the confidence that allies have—especially in a crisis—that the United States will be prepared to employ its full military arsenal, including nuclear weapons, in their defense.”<sup>24</sup>

Another key difference between balanced approach advocates and the nuclear abolition and minimal deterrence schools concerns the current U.S. nuclear arsenal, especially nuclear modernization. While aspiring to the long-term goal of a world without nuclear weapons, the balanced approach sees a relatively robust U.S. nuclear capability as necessary, even beneficial. Center for

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19. Ibid.

20. George Perkovich, “The Obama Nuclear Agenda One Year after Prague,” *Carnegie Policy Outlook*, March 31, 2010, <http://carnegieendowment.org/files/prague4.pdf>.

21. Rose Gottemoeller, “Statement of Under Secretary of State for Arms Control and International Security Rose Gottemoeller before the Senate Committee on Appropriations, Subcommittee on Energy and Water Development,” July 13, 2016, <http://www.appropriations.senate.gov/imo/media/doc/071316-Gottemoeller-Testimony.pdf>.

22. Steven Pifer, “Cancel the Long-Range Standoff Missile,” Brookings Institution, June 28, 2017, <https://www.brookings.edu/blog/order-from-chaos/2017/06/28/cancel-the-long-range-standoff-missile/>.

23. U.S. Department of Defense, *Nuclear Posture Review Report* (Washington, DC: U.S. Department of Defense, April 2010), 31–32, [https://www.defense.gov/Portals/1/features/defenseReviews/NPR/2010\\_Nuclear\\_Posture\\_Review\\_Report.pdf](https://www.defense.gov/Portals/1/features/defenseReviews/NPR/2010_Nuclear_Posture_Review_Report.pdf).

24. Steven Pifer, “Fewer Nukes Don’t Mean More Danger,” *National Interest*, December 12, 2013, <http://nationalinterest.org/commentary/fewer-nukes-dont-mean-more-danger-9549>.

Global Security Research director Brad Roberts points to the role that the U.S. nuclear deterrent plays in assuring allies that they are safe and secure without needing to build their own nuclear weapons.<sup>25</sup>

## FLEXIBLE DETERRENCE

Thinkers in the flexible deterrence school of thought seek to adapt nuclear strategy to the post–Cold War world, with a focus on how the United States nuclear arsenal can be tailored to deter limited nuclear use.

Both the flexible deterrence and nuclear superiority schools of thought subscribe to versions of realism: the international system is characterized by anarchy and is unlikely to change. Though they differ in the size and scope of the nuclear arsenal they would like to see the United States maintain, both the flexible deterrence and the nuclear superiority schools believe that the nature of the international system means that the United States must maintain a sizable nuclear force.<sup>26</sup>

The flexible deterrence school contends that nuclear deterrence is a moral approach to addressing national security threats. The scope and breadth of those threats has changed in the post–Cold War world, and U.S. nuclear strategy needs to be adaptable to keep up. In their eyes, there is nothing immoral about wielding nuclear weapons in this way; in fact, the failure to do so may lead to conflict. Unwillingness to use nuclear weapons to deter a broad range of threats can invite catastrophic outcomes, which itself could be considered immoral. The costs of failing to respond to nuclear threats—including moral ones—necessitates a powerful and adaptable nuclear arsenal.<sup>27</sup>

The flexible deterrence school of thought holds a significantly different view of deterrence than abolitionism, minimal deterrence, or the balanced approach. Unlike nuclear abolitionists, flexible deterrence sees nuclear weapons as essential and irreplaceable to deterrence, fundamentally different from deterrence with conventional weapons. The costs that U.S. nuclear weapons can credibly impose on potential adversaries are real, significant, necessary, and cannot be achieved through conventional means. The flexible deterrence school of thought, while understanding the need for “existential deterrence,” focuses more on post–Cold War deterrence issues. These challenges are more likely to be regional, characterized by limited nuclear use, and focused on escalation control and dominance.<sup>28</sup>

Flexible deterrence advocates do agree with many in the balanced approach about the usefulness of U.S. nuclear forces in providing extended deterrence to our allies around the world. Allied states

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25. Brad Roberts, *The Case for U.S. Nuclear Weapons in the 21st Century* (Stanford, CA: Stanford University Press, 2016).

26. For an example of flexible deterrence thinking on geopolitics, see Paul Bracken, *The Second Nuclear Age: Strategy, Danger, and the New Power Politics* (New York: St. Martin's Press, 2012), 249–270. Nuclear superiority thinking can be seen in Matthew Kroenig, “Nuclear Superiority and the Balance of Resolve: Explaining Nuclear Crisis Outcomes,” *International Organization* 67, no. 01 (January 2013): 141–171.

27. Elbridge Colby, *A Nuclear Strategy and Posture for 2030* (Washington, DC: Center for a New American Security, October 2015), [https://www.files.ethz.ch/isn/194861/CNASReport-NuclearStrategy2030-151020\\_0.pdf](https://www.files.ethz.ch/isn/194861/CNASReport-NuclearStrategy2030-151020_0.pdf).

28. Bracken, *The Second Nuclear Age*.

falling under the U.S. nuclear umbrella have unique security challenges, but many of them see value in the United States having a powerful and flexible nuclear force to deter the various threats they perceive. Many of these allies are skeptical of American intentions to reduce the size and scope of our nuclear force along with its role in U.S. national security. As Brad Roberts points out, “Further reductions in the role and number of U.S. nuclear weapons are troubling to allies who count on credible extended deterrence and on strategic stability between the United States and their major power neighbors.”<sup>29</sup>

Elbridge Colby, deputy assistant secretary of defense for strategy and force development, reflects the views of many in the flexible deterrence school concerning nuclear military strategy when he states that the United States should emphasize its “capability for and willingness to wield nuclear weapons discriminately.”<sup>30</sup> The ability to fight and win a limited nuclear war, while maintaining the capacity to escalate to a full-scale nuclear exchange if necessary, is critical for modern deterrence. According to Colby, the United States should invest in variable yield warheads for all its nuclear forces, along with advanced command, control, communications, computers, intelligence, surveillance, and reconnaissance (C<sup>4</sup>ISR) capabilities that can survive in a nuclear environment.<sup>31</sup> The flexible deterrence school of thought, more than any other school, is concerned with how nuclear military strategy must adapt in the modern era.

The flexible deterrence and nuclear superiority schools of thought are not hostile to nonproliferation and arms control. However, they both are skeptical that unilateral U.S. nuclear reductions would positively influence global nonproliferation. Instead, advocates of both schools believe that a relatively large and capable U.S. nuclear force contributes to nonproliferation efforts. The size and scope of the U.S. nuclear arsenal allows the United States to bring allies under U.S. protection that would otherwise be forced to consider developing their own nuclear forces.<sup>32</sup>

## NUCLEAR SUPERIORITY

The nuclear superiority school believes that a powerful U.S. nuclear arsenal offers several benefits. Not only does a superior U.S. nuclear force make deterrence more robust, but potential nuclear inferiority could be destabilizing. Nuclear superiority thinking is rooted in international relations realism: the nature of the international system is anarchical and competitive, and there is no realistic hope of this changing in the foreseeable future.<sup>33</sup>

Nuclear superiority proponents argue that far from being an irredeemable evil, nuclear weapons are a moral good. The United States nuclear arsenal not only protects the United States and its allies from nuclear attacks, but deters great power war in general. According to nuclear utility

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29. Roberts, *The Case for U.S. Nuclear Weapons in the 21st Century*, 215–216.

30. Colby, *A Nuclear Strategy and Posture for 2030*, 11.

31. *Ibid.*, 12.

32. Roberts, *The Case for U.S. Nuclear Weapons in the 21st Century*.

33. Keith Payne, “Framing the Nuclear Weapons Debate,” *Bulletin of the Atomic Scientists*, May 22, 2015, <http://thebulletin.org/framing-nuclear-weapons-debate8335>.

thinking, there is nothing wrong or immoral about fielding a large, capable nuclear weapons force. On the contrary, failure on the part of the United States to have a powerful nuclear arsenal could invite nuclear or conventional war. There is nothing immoral or contrary to international law about the United States having a cutting-edge nuclear weapons force.<sup>34</sup>

Proponents of the superiority school of thought tend to be more concerned with what they see as the destabilizing effects of nuclear inferiority. Contrary to flexible deterrence proponents who tend to focus on having capabilities to deter across the entire spectrum of potential nuclear conflict, the nuclear superiority school believes that U.S. dominance, not simply capability, is needed across the nuclear spectrum for effective and assured deterrence. Inferiority can be destabilizing, and the United States should seek to gain and maintain nuclear superiority over potential rivals.<sup>35</sup>

Nuclear superiority thinking is also aligned with flexible deterrence regarding the benefits of the U.S. nuclear umbrella for extended deterrence. The superiority school of thought worries that calls for reducing the role of U.S. nuclear weapons in extended deterrence, as many in the minimal deterrence and abolition schools of thought promote, fail to take into account allies' views. Many U.S. allies are deeply concerned with talk about reducing the role of nuclear weapons in U.S. foreign policy. Instead, nuclear superiority thinking emphasizes the importance of maintaining unmatched nuclear capabilities to assure allies.<sup>36</sup>

Nuclear superiority theorists tend to agree with flexible deterrence thinkers that a range of nuclear options must be available to deter diverse types of nuclear threats. In an attempt to move beyond Cold War nuclear thinking, some superiority advocates have sought to show how a U.S. nuclear force that is quantitatively and qualitatively superior to the nuclear forces of adversaries can be useful. Many nuclear superiority advocates reject the concept of mutual vulnerability, arguing that the United States should seek an overwhelming deterrent to protect U.S. lives.<sup>37</sup>

Proponents of both flexible deterrence and nuclear superiority point to studies indicating that unilateral cuts in U.S. nuclear forces do not prompt other nuclear powers to reciprocate. Professor Matthew Kroenig of Georgetown University notes that there is no apparent link between the number of nuclear weapons the United States has and the arsenals of other states. Kroenig writes that "state decisions on nuclear non-proliferation issues are driven by a range of other security, economic, and political factors and, once these considerations are taken into account, there is little if any remaining variance to be explained by U.S. nuclear posture or the U.S. government's commitment to nuclear disarmament."<sup>38</sup>

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34. Frank Miller, "Disarmament and Deterrence: A Practitioner's View," in *Abolishing Nuclear Weapons: A Debate*, ed. George Perkovich and James M. Acton (Washington, DC: Carnegie Endowment for International Peace, 2009), 149–155.

35. Ibid., 151.

36. Mark Schneider, "Zero Deterrent?," *Air Force Magazine*, August 2012, 50–51.

37. Keith Payne, "Survival Matters: The Cold War Is Over. Let's Defend the Population," *Weekly Standard*, June 4, 2012.

38. Matthew Kroenig, "U.S. Nuclear Weapons and Non-proliferation: Is There a Link?," *Journal of Peace Research* 53, no. 2 (2016): 167.



# NUCLEAR SCHOOLS OF THOUGHT AND THE LONG-RANGE STANDOFF CRUISE MISSILE

These diverse ways of looking at nuclear weapons are more than just an academic disagreement: there are policy implications to these schools of thought as well. This section will examine how the different schools of thought approach the current controversy over the Long-Range Standoff (LRSO) missile.

The LRSO, an air launched cruise missile (ALCM) that will replace the current U.S. nuclear cruise missile, has ignited an active and lively debate regarding the desirability and necessity for the United States to replace the ALCM.

Nuclear abolitionists are opposed to a new nuclear cruise missile. Minimal deterrence advocates suggest that the end of the Cold War means there is no longer a need for large nuclear arsenals, and that the U.S. nuclear force should not be configured for “war fighting.”<sup>39</sup> Regarding the public case being made for the LRSO, Hans Kristensen of the Federation of American Scientists said that “Statements by defense officials reveal a worrisome level of war-fighting thinking behind the LRSO mission that risks dragging U.S. nuclear planning back into Cold War thinking about the role of nuclear weapons.”<sup>40</sup>

Minimal deterrence thinkers are concerned that systems like the LRSO are designed for nuclear war fighting, not existential deterrence. Besides the enormous humanitarian disaster that even a limited nuclear exchange would entail, minimal deterrence proponents believe that nuclear escalation is inherently impossible to control.<sup>41</sup> According to Kristensen, “Statements by defense officials reveal a worrisome level of war-fighting thinking behind the LRSO mission that risks dragging U.S. nuclear planning back into Cold War thinking about the role of nuclear weapons.”<sup>42</sup> In an article defending the intercontinental ballistic missile (ICBM) leg of the triad, Tom Nichols and Naval War College professor Dana Struckman state that opponents of nuclear modernization should focus their efforts on canceling the LRSO because it is “a weapon needed not for deterrence but for protracted war fighting.”<sup>43</sup>

Balanced approach proponents are split over the need for the LRSO. While the Obama administration—which is closely associated with the balanced approach—approved development of the LRSO, many policy experts have employed balanced approach thinking in arguing against

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39. William Perry and Andy Weber, “Mr. President, Kill the New Cruise Missile,” *Washington Post*, October 15, 2015, [https://www.washingtonpost.com/opinions/mr-president-kill-the-new-cruise-missile/2015/10/15/e3e2807c-6ecd-11e5-9bfe-e59f5e244f92\\_story.html?utm\\_term=.7bba96a5d33](https://www.washingtonpost.com/opinions/mr-president-kill-the-new-cruise-missile/2015/10/15/e3e2807c-6ecd-11e5-9bfe-e59f5e244f92_story.html?utm_term=.7bba96a5d33).

40. Hans M. Kristensen, “LRSO: The Nuclear Cruise Missile Mission,” Federation of American Scientists, <https://fas.org/blogs/security/2015/10/lrso-mission/>.

41. Tom Collina, “No More Nuclear-Tipped Cruise Missiles,” *Defense One*, October 31, 2013, <http://www.defenseone.com/business/2013/10/no-more-nuclear-tipped-cruise-missiles/73010/>.

42. Hans Kristensen, “LRSO: The Nuclear Cruise Missile Mission,” Federation of American Scientists, October 20, 2015, <https://fas.org/blogs/security/2015/10/lrso-mission/>.

43. Tom Nichols and Dana Struckman, “Dumping America’s ICBMs Would Be a Big Mistake,” *National Interest*, October 5, 2016, <http://nationalinterest.org/feature/dumping-americas-icbms-would-be-big-mistake-17946>.

the LRSO. Rose Gottemoeller, former under secretary of state for arms control and international security affairs, reflected the views of balanced approach advocates who support the LRSO when she testified that “without a stand-off cruise missile option, future presidents may find themselves facing the unpalatable choice of responding to nuclear coercion or attack with SLBMs (submarine-launched ballistic missiles) or ICBMs, or attempting to employ a stealth bomber to penetrate the adversary’s territory to reach targets.”<sup>44</sup>

Others, still drawing from the balanced approach, disagree with Gottemoeller’s assessment. Steven Pifer of the Brookings Institution acknowledges the need to rebuild the U.S. nuclear triad, specifically citing the need for the Columbia-class submarine, the B-21, and the replacement ICBM. However, Pifer argues that LRSO is not essential to meet any modern deterrence requirements. Instead, Pifer believes that the U.S. government should invest the money it is currently spending on the LRSO on other, more pressing needs.<sup>45</sup>

Flexible deterrence and nuclear superiority schools lend support for the LRSO. Flexible deterrence thinking is especially supportive of weapons systems like the LRSO. Former assistant secretary of state for arms control, verification, and compliance Frank Rose writes that the LRSO is an important “stand-off capability to hold certain heavily defended targets at risk” and “ensure[s] that America’s remaining B-2 and B-52 bombers remain effective nuclear delivery platforms through the 2040s.”<sup>46</sup> Furthermore, having a variety of options for nuclear weapons employment helps confound adversary planning and shores up deterrence. Elbridge Colby uses a flexible deterrence-inspired argument for the LRSO when he writes, “Forgoing LRSO would simplify our potential adversaries’ defensive problems, allowing them to focus resources only on defending against stealth aircraft or ballistic missile attacks. But why make our potential opponents’ lives easier?”<sup>47</sup>

Nuclear superiority thinking also supports the United States having a new air launched cruise missile. Thinkers and writers employing nuclear superiority arguments question the proposition, put forward by many abolitionists and minimal deterrence proponents, that if the U.S. forgoes developing a LRSO other countries will follow suit. Michaela Dodge and John Venable of the Heritage Foundation argue that “the United States has given up around 90 percent of its nuclear arsenal since the end of the Cold War, while North Korea, India, and Pakistan obtained nuclear weapons and expanded their arsenals. China and Russia have been developing their own cruise missiles, and will continue that effort regardless of whether the United States proceeds with the LRSO. Countries follow their own national interests.”<sup>48</sup>

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44. Gottemoeller, “Statement of Under Secretary of State,” July 13, 2016.

45. Pifer, “Cancel the Long-Range Standoff Missile.”

46. Frank Rose, “Five Myths about a Controversial Nuclear Weapon,” *War on the Rocks*, June 20, 2017, <https://warontherocks.com/2017/06/five-myths-about-a-controversial-nuclear-weapon/>.

47. Elbridge Colby, “A New Nuclear Air-Launched Cruise Missile?,” *War on the Rocks*, November 22, 2013, <https://warontherocks.com/2013/11/a-new-nuclear-air-launched-cruise-missile/>.

48. Michaela Dodge and John Venable, “Why the United States Needs an LRSO Capability,” Heritage Foundation, June 17, 2016, <http://www.heritage.org/arms-control/report/why-the-united-states-needs-lrso-capability>.

## CONCLUSION

Dialogue in the nuclear weapons community is stuck in a loop: the community talks past each other because members base arguments and interpretations of reality on very different assumptions and principles. Applying the schools of thought outlined in this paper to contemporary nuclear debates can shed light on the roots of our disagreements. The debate over the LRSO is instructive: a significant part of the argument has little to do with the LRSO as a specific weapons system and more to do with divergences in underlying assumptions.

# Risk of Electromagnetic Pulse Attacks on the United States: Vulnerabilities and Motives

Logan Brandt<sup>1</sup>

*The United States' conventional military superiority has driven potential adversaries to seek alternate means of countering U.S. power. A high-altitude nuclear electromagnetic pulse (EMP) attack could provide adversaries a means to exploit U.S. vulnerabilities and gain an advantage. There are three different stages to a nuclear EMP, each with different effects. The first two, E1 and E2, cause damage to integrated circuits and personal electronics. The third, E3, can destabilize and potentially cripple the U.S. electric grid. The Commission to Assess the Threat to the United States from EMP Attack confirmed that the United States is vulnerable to an EMP attack. The war-fighting strategies and doctrine of potential adversaries may look to exploit these vulnerabilities through the use of a high-altitude nuclear detonation. Such an attack would be asymmetric in its effects and provide an advantage to both near-peer and regional potential adversaries. While the greatest vulnerabilities lie in a strategic attack on the U.S. homeland, a more likely scenario constrains the use of a nuclear EMP attack to a localized area to accomplish an operational objective for the adversary while staying below the threshold for retaliation.*

## INTRODUCTION

Global nuclear dynamics are shifting. Smaller regional actors are seeking to gain global influence by acquiring nuclear weapons. Larger nuclear powers are attempting to establish themselves as

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peers with the United States. Tensions are rising as both types of actors look for means of offsetting U.S. conventional forces that place a heavy emphasis on advanced technology. Modernization and technological improvements have driven U.S. dependence on electronic devices and reliable power. These systems have enabled advantages in both the military and civilian realms of society but also have created severe vulnerabilities. Potential adversaries may seek to capitalize on these vulnerabilities through an electromagnetic pulse (EMP) attack, which could cripple everything from consumer electronics to large portions of the power grid. A nuclear weapon detonated at high altitude can provide the desired EMP attack over a sizable geographical region and could be an attractive option to a nuclear armed opponent in a future conflict. Nuclear EMP attacks pose a threat to the United States, and several potential adversaries have the means and motives to carry out such an attack.

## ELECTROMAGNETIC PULSE

To adequately assess the threat of a nuclear EMP attack, it is necessary to first understand that an EMP is a release of high-intensity electromagnetic radiation. It can come from a variety of sources, such as geomagnetic disturbances initiated by solar flares, nonnuclear radio-frequency weapons, and high-altitude nuclear detonations. While similar outcomes can be produced by all three sources, high-altitude nuclear detonation scenarios are more complex. Nuclear weapons create a variety of effects upon detonation, with the most commonly anticipated effects being thermal damage and shock waves that cause visible destruction of the target and surrounding area. However, in addition to the visible effects, nuclear detonations also produce an EMP that can propagate through the atmosphere over long distances and damage many electronic systems. These may resemble the fictional description presented in William Forstchen's book *One Second After*.<sup>2</sup>

### EMP Creation and Effects

When a nuclear device detonates, a fraction of the yield is released as electromagnetic radiation in the form of gamma rays. This initial release of gamma energy is known as the prompt gamma yield. These gamma rays expand radially outward from the detonation point until they interact with some form of matter. At altitudes above 30 kilometers (km), the lower density of the atmosphere allows the gammas to travel over long distance without material interaction. As radiation enters the denser atmosphere at lower altitudes, it interacts with the atmospheric molecules and produces a phenomenon known as Compton scattering. In these interactions, the atmospheric molecules absorb a portion of the gamma energy and release an electron that travels in approximately the same direction as the initial radiation. As this newly created free electron travels toward the ground, it interacts with the planet's magnetic field and produces more electromagnetic radiation in the same direction, increasing the EMP's magnitude.<sup>3</sup> The strength of the earth's magnetic field at the location of the nuclear detonation will have a significant effect on the strength of the EMP. For

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2. William Forstchen, *One Second After* (New York: Forge, 2009).

3. Samuel Glasstone and Philip J. Dolan, *The Effects of Nuclear Weapons*, 3rd ed. (Washington, DC: U.S. Department of Defense and Energy Research and Development Administration, 1977), <http://fissilematerials.org/library/gla77.pdf>.

example, a high-altitude nuclear detonation over the equator would produce an EMP with approximately half of the strength of an EMP if that same weapon was detonated over the United States, Europe, or Russia.

## E1

With many of these Compton electrons radiating simultaneously, the amount of electromagnetic radiation multiplies, creating electric fields with strengths of tens of kilovolts per meter on the surface of the earth.<sup>4</sup> The small time scales at which this phenomenon occurs produces a rise time of the pulse on the order of nanoseconds, which is several orders of magnitude faster than lightning.<sup>5</sup> This effect, known as E1, is the fast pulse component of the EMP and is unique to nuclear weapons. It allows the pulse to couple to electronic systems regardless of the length of their penetrating cables and antenna lines, inducing currents on the order of 1,000 amperes.<sup>6</sup> For comparison, a typical wall outlet is rated for around 15 amperes.

The E1 component of an EMP is unique to a nuclear detonation. The extremely fast rise time of the pulse sets it apart from natural phenomena; therefore, most existing power surge protection does not have a quick-enough response rate to prevent the pulse from reaching sensitive electronics. Additionally, the dependence of modern society on microelectronics makes it severely vulnerable to such a pulse.<sup>7</sup> Microchips packed with transistors in today's electronic devices are very sensitive to EMP due to their inability to handle such a large spike in current so quickly. They have no means of dissipating the heat created by the surge, so the components will overheat or melt.

## E2

A second component of EMP, E2, is produced in a similar manner to E1 but on a slightly slower time scale. Both the E1 and E2 components of the EMP cover a broad geographic region of the earth, only limited to the line of sight of the detonation.<sup>8</sup> Controlling the height of burst of the weapon adjusts the size of the affected region; a detonation at a higher altitude will cover a greater geographic area than if that same detonation occurred at a lower altitude.

This slightly delayed E2 pulse closely resembles a power surge produced in electronic circuits from a lightning strike.<sup>9</sup> In a typical scenario, regular surge protection equipment, designed to protect against lightning and other natural phenomenon, could prevent the E2 pulse from damaging

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4. Ibid.

5. Ibid.

6. George H. Baker, "The EMP Threat: The State of Preparedness against the Threat of an Electromagnetic Pulse (EMP) Event" (testimony before the House Committee on National Security and the Committee on Oversight and Government Reform, May 13, 2015), <https://oversight.house.gov/wp-content/uploads/2015/05/Baker-Statement-5-13-EMP.pdf>.

7. John S. Foster Jr. et al., *Report of the Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack: Critical National Infrastructures* (McLean, VA: Electromagnetic Pulse Commission, April 2008).

8. Glasstone and Dolan, *The Effects of Nuclear Weapons*.

9. John S. Foster Jr. et al., *Report of the Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack: Vol. 1: Executive Report* (McLean, VA: Electromagnetic Pulse Commission, 2004).

electronics.<sup>10</sup> However, the speed and destructiveness of the E1 pulse will likely degrade the protective systems in place to guard against E2 pulses. The synergistic effects of E1 and E2 pulses make it difficult to predict damage.<sup>11</sup>

### E3

Additionally, the third EMP component of a high-altitude nuclear detonation produces a slow pulse known as E3. The nuclear blast produces an electrically conductive fireball that will distort a portion of the earth's magnetic field and yield similar effects to a geomagnetic disturbance produced by a solar flare.<sup>12</sup> The E3 component is a low-frequency pulse and couples into long cables and conductors such as power lines and telecommunication lines, inducing strong currents.<sup>13</sup> These pulses create disruptive currents in lengthy transmission lines leading to "grid instability and increased heat in transformers. If the E3 pulse is high enough and long enough it can result in grid collapse and potentially damage transformers."<sup>14</sup> A collapse of the power grid could leave a significant portion of the country without power for an extended period of time. The sequence of E1, E2, and E3 components of an EMP allow maximum damage to electrical systems as each pulse increases the effectiveness of the subsequent components.<sup>15</sup>

## U.S. VULNERABILITIES

The Commission to Assess the Threat to the United States from EMP Attack confirmed that the United States was vulnerable to an EMP attack. Its 2004 executive summary reported:

EMP is one of a small number of threats that can hold our society at risk of catastrophic consequences and might result in the defeat of our military forces. EMP has the capability to produce significant damage to critical infrastructures . . . as well as to our ability to project influence and military power abroad. . . . Our vulnerability is increasing daily as our use and dependence on electronics continues to grow. . . . Correction is feasible and well within the nation's means and resources to accomplish.<sup>16</sup>

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10. Ibid.

11. Foster Jr. et al., *Report of the Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack: Critical National Infrastructures*.

12. Baker, "The EMP Threat."

13. Foster Jr. et al., *Report of the Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack: Vol. 1: Executive Report*.

14. U.S. Government Accountability Office (GAO), *Critical Infrastructure Protection: Federal Agencies Have Taken Actions to Address Electromagnetic Risks, but Opportunities Exist to Further Assess Risks and Strengthen Collaboration* (Washington, DC: GAO, March 2016), 6, <https://www.gao.gov/products/GAO-16-243>.

15. Foster Jr. et al., *Report of the Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack: Vol. 1: Executive Report*.

16. Ibid.



The commission reported again in 2008 about the vulnerabilities within the entire electrical power system:

Because of the ubiquitous dependence of U.S. society on the electrical power system, its vulnerability to an EMP attack, coupled with the EMP's particular damage mechanisms, creates the possibility of long-term, catastrophic consequences. . . . A single EMP attack may seriously degrade or shut down a large part of the electric power grid in the geographic area of EMP exposure, effectively instantaneously. There is also a possibility of functional collapse of grids beyond the exposed area, as electrical effects propagate from one region to another.<sup>17</sup>

The commission's analysis not only concluded that independent electronics and individual transformers would be disabled, but also that an EMP attack could cause propagating failures of substations and transformers throughout the power grid. The result could be the overload and ultimate collapse of the power grid itself.

The lack of power would lead to degradation in other critical infrastructures necessary to sustain modern life, such as the supply and distribution of food, water, fuel, communications, finances, and emergency services. George H. Baker, who served as principal staff to the EMP commission, testified before the House Committee on National Security in May 2015 that the EMP threat and its effects were "particularly challenging in that they interfere with electrical power and electronic data, control, transmission, and communication systems organic to nearly all critical infrastructures. The affected geography may be continental in scale. EMP . . . events thus represent a class of high-consequence disasters that is unique in its coverage, ubiquity, and simultaneous system debilitation."<sup>18</sup> No other phenomena would have such a wide-reaching effect across so many aspects of society than an EMP attack.

## ADVERSARY MOTIVES

Because an EMP holds the potential to cause widespread damage across a vast geographic region and the United States has severe vulnerabilities to such an attack, it would be a prime weakness for an adversary to exploit. In fact, the 2004 EMP commission report stated, "The impact of EMP is asymmetric in relation to potential protagonists who are not as dependent . . . on modern electronics. The current vulnerability of [the U.S.] critical infrastructures can both invite and reward attack if it is not addressed and corrected."<sup>19</sup> The war-fighting strategies and doctrine of potential adversaries may look to exploit these vulnerabilities. The remainder of this paper examines two illustrative cases, a near-peer adversary (Russia) and a regional adversary (North Korea).

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17. Foster Jr. et al., *Report of the Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack: Critical National Infrastructures*.

18. Baker, "The EMP Threat."

19. Foster Jr. et al., *Report of the Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack: Vol. 1: Executive Report*.

## Russia

The United States' superiority in conventional forces has driven potential adversaries to examine ways of conducting war without directly confronting U.S. forces and instead negating U.S. conventional forces' advantage via asymmetric means. An EMP attack could provide that asymmetric advantage, as it might degrade U.S. capabilities to a far greater degree than those of the adversary. Many potential adversaries observed the so-called revolution in military affairs that the United States demonstrated in the first Gulf War, as it used air power to rapidly remove the enemy communication and control networks. The Russian general Vladimir Slipchenko coined the phrase "sixth-generation warfare" and "non-contact warfare" to describe a new method of fighting that attempts to limit direct engagement with the enemy while preventing the opponent from retaliating.<sup>20</sup>

In concert with this new means of thinking, Russian strategy has shifted from a general war to one that is regionally focused on advancing its political objectives without drawing the North Atlantic Treaty Organization (NATO) and the United States into a conflict. Instead of traditional war, Russian theory has produced the events unfolding in Crimea and eastern Ukraine, capitalizing on the interactions of information warfare, special operations forces, and, if necessary, the means of countering possible escalations by the United States. If such an escalation seems likely, Russia holds credible capabilities to "manage the risks of escalation against a conventionally superior, nuclear-armed alliance."<sup>21</sup> In his book, *The Case for U.S. Nuclear Weapons in the 21st Century*, Brad Roberts states,

Russia has developed both horizontal and vertical options to counter and disincentivize Western escalation. Horizontal escalation would encompass standoff strikes on targets beyond the immediate zone of hybrid combat but within the "strategic direction." Vertical escalation would encompass strikes by both nuclear and non-nuclear means (whether kinetic or nonkinetic). . . . The Russians also have a significant capability for lateral escalation into the cyber and space domains.<sup>22</sup>

Russia places high value on being able to keep the United States and its conventionally superior forces at bay. To accomplish this, Russian military doctrine of "escalate to de-escalate" uses non-strategic nuclear weapons to play a central role in the deterrence and defeat of U.S./NATO forces. Roberts goes on to point out nonstrategic nuclear use would likely be "preemptive in nature and intended to de-escalate a conflict . . . while being sufficiently limited not to risk a strategic response."<sup>23</sup>

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20. Jacob W. Kipp, "Russian Sixth Generation Warfare and Recent Developments," *Eurasia Daily Monitor* 9, no. 17 (January 25, 2012), <https://jamestown.org/program/russian-sixth-generation-warfare-and-recent-developments/>.

21. Brad Roberts, *The Case for U.S. Nuclear Weapons in the 21st Century* (Stanford, CA: Stanford University Press, 2016), 133.

22. Ibid.

23. Ibid., 134.

A scenario could be imagined in which a nonstrategic nuclear weapon was detonated at a high enough altitude to induce EMP effects while sufficiently low enough to confine the EMP effects to a regional conflict or operational theater. While employing a weapon in this manner could degrade the capabilities of U.S. and NATO forces to conduct operations, it might be perceived to be below the threshold of nuclear retaliation. Additionally, such an attack may be seen by some in the international community as a more humane way of conducting a war, as it does not involve the massive loss of life that conventional strikes would have inflicted to degrade the same war-fighting capabilities.<sup>24</sup>

Beyond limited regional conflicts, the vulnerabilities of the United States homeland are known to potential adversaries. Former Soviet ambassador to the United States Vladimir Lukin threatened an EMP attack in 1999 over the conflict in Serbia, referencing “the ultimate ability to bring you down.”<sup>25</sup> Near-peer potential adversaries would seek to exploit any advantage they can in order to gain the upper hand in a severe conflict with the United States. Peter Pry, the executive director of the Task Force on National and Homeland Security, suggests that a nuclear EMP attack, combined with cyberattacks and sabotage, may spell the next revolution in military affairs. He likens the combination to the German’s blitzkrieg strategy leading up to WWII, utilizing speed and surprise to defeat an enemy psychologically as well as materially.<sup>26</sup> Such an attack could be launched as an initial strike and holds the potential to overthrow a modern civilization in a matter of hours. A strategic attack in this manner falls within the non-contact warfare doctrine Russia has begun to adopt.

## North Korea

As a regional actor, North Korea does not seek parity with the United States on a strategic level, but instead seeks to utilize nuclear weapons, through blackmail and brinkmanship, to achieve political ends within the region; namely, an end to the confrontation on the Korean peninsula on terms favorable to the North and survival of the regime.<sup>27</sup> However, the lack of a clearly defined nuclear doctrine from North Korea leaves room for assumptions about their probable actions in a variety of possible scenarios.

Some U.S. intelligence officials believe North Korea may use nuclear weapons to ensure the survival of the current regime.<sup>28</sup> The question is when the North would calculate the regime to be at risk. The conventional superiority of the U.S. military forces leaves North Korea with high incentives to use nuclear weapons quickly, prior to the loss of command and control of its nuclear assets. Additionally, North Korea has demonstrated space launch capability and currently has two satellites

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24. Peter V. Pry, *The Long Sunday: Election Day 2016–Inauguration Day 2017: Nuclear EMP Attack Scenarios* (Washington, DC: Center for Security Policy, November 2016), <https://www.centerforsecuritypolicy.org/2016/11/29/dr-peter-vincent-pry-highlights-americas-present-failure-of-imagination-in-the-long-sunday/>.

25. U.S. Congress, House Committee on Armed Services, *The Report of the Commission to Assess the Threat to the U.S. from Electromagnetic Pulse Attack*, 108th Cong., 2nd sess., July 22, 2004, [http://commdocs.house.gov/committees/security/has204000.000/has204000\\_0.HTM](http://commdocs.house.gov/committees/security/has204000.000/has204000_0.HTM).

26. Pry, *The Long Sunday*.

27. Roberts, *The Case for U.S. Nuclear Weapons in the 21st Century*.

28. Ibid.

in orbit. If the regime felt its survival was threatened and decided to attack the United States in retaliation, it could place a nuclear device into orbit with the intent to conduct an EMP attack.

Such an attack would not require the development of reentry vehicles or precision strike capabilities to inflict great damage. The weapon would simply need to pass over the continental United States within an altitude range of several hundred kilometers prior to detonation.<sup>29</sup> A high-altitude nuclear EMP may be seen as the most efficient way of inflicting maximum damage on the United States with the limited number of weapons available to North Korea. Unlike a conflict with Russia, such a North Korean attack is likely to induce a massive response by the United States and guarantee the end of the regime, due in large part to the escalatory dominance held by the United States. In his book, Roberts reminds the audience that “vengeance is a powerful motivator and North Korean leaders may, like other leaders before them, believe that gravely wounding their enemy in retribution may be a form of victory in its own right, even if the war itself is a lost cause.”<sup>30</sup> An EMP attack may be an attractive option, enabling the smaller nuclear arsenal of a regional actor to inflict large-scale damage on the United States in a manner that would not be possible if that same weapon was used on a single population center.

A more limited scenario could also play out. If a conflict arises, North Korea may decide its nuclear threat lacks enough credibility to deter the U.S. and allied forces from engaging in a limited regional war. To bolster the credibility of its nuclear threats, the North Korean regime may see a demonstration of their nuclear weapons as a means of reestablishing their deterrent. Such a demonstration must be limited in scope to be below the perceived nuclear retaliation threshold of the United States. A regional EMP attack might accomplish this outcome.<sup>31</sup> North Korea may judge that employing a nuclear weapon in this nonlethal capacity would both demonstrate its commitment to using nuclear weapons if escalation continues, while simultaneously achieving desired war-fighting effects in the ongoing conflict. Such an attack would be asymmetric in its effects and provide an advantage to the North Korean military as it faces the capabilities of a more technologically dependent opponent.

## CONCLUSION

The United States’ conventional superiority has driven potential adversaries to seek out asymmetric approaches in future conflicts. Thus, these adversaries will look to domains in which the United States has exploitable vulnerabilities. U.S. dependence on reliable power, electronic systems, and advanced technology has provided both a significant advantage but also created an Achilles’ heel. Both near-peer and regional actors understand this vulnerability and have means and motives to use high-altitude nuclear EMP attacks to exploit it. While the greatest vulnerabilities lie in the realm of a strategic attack on the U.S. homeland, a more likely scenario constrains the use of a nuclear EMP attack to a localized area to accomplish an operational objective for the adversary while staying below the threshold for retaliation.

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29. Pry, *The Long Sunday*.

30. Roberts, *The Case for U.S. Nuclear Weapons in the 21st Century*, 65.

31. Ibid.

# Deterrence in the Age of Asteroid Mining: Nuclear Strategy and the Commercialization of Space

Kit Conklin<sup>1</sup>

*Emerging and disruptive commercial space technologies pose new challenges to U.S. space superiority and traditionally accepted nuclear deterrence doctrines. The growing business market in space systems is fueling a technology shift from government to industry. This shift is creating an influx of private-sector capabilities that were once monopolized by states. New capabilities include reusable space launch vehicles (SLVs), satellite repair systems, nanosatellites, and mineral exploitation platforms designed to rendezvous with asteroids. Even though the commercialization of space is in its infancy, private companies are already transforming the research, development, and acquisition of space systems. For example, SpaceX is developing SLVs 50 percent faster than the U.S. government, while Google plans to launch a constellation of 180 small satellites by 2020 to provide global imaging and Internet services.<sup>2</sup> While some of these systems have purely commercial applications, other systems such as satellite repair and servicing systems represent a growing dual-use counterspace threat. These new dual-use commercial space platforms offer evidence to support claims outlined in the 2010 U.S. National Security Space Strategy that warned space is becoming increasingly congested, competitive, and contested.<sup>3</sup> This research therefore assesses how emerging and disruptive commercial technologies will challenge U.S. space superiority through increased space congestion and competition. Understanding the new space environment helps prevent strategic surprise and provides the foundation from which it is possible to assess how disruptive dual-use commercial technologies could affect strategic deterrence.*

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1. Kit Conklin is an emerging and disruptive technology specialist focusing on space and nuclear weapons issues.

2. Liam Tung, "Google to Launch 180 Satellites in \$1bn Plan to Cover the Unwired," *ZDNet*, June 2, 2014, <http://www.zdnet.com/article/google-to-launch-180-satellites-in-1bn-plan-to-cover-the-unwired/>.

3. Office of the Director of National Intelligence, "National Security Space Strategy: Unclassified Summary," January 2011, 1.

# EMERGING CHALLENGES TO U.S. SPACE SUPERIORITY

In 2014 General William Shelton, then commander of Air Force Space Command, stated that space superiority remains vital to U.S. national security. Space superiority refers to three key concepts: the ability to maintain complete space situational awareness (SSA), the ability to defend U.S. space assets from hostile attack, and the ability to deny adversaries the use of space. Historically, the United States has maintained space superiority through its near monopoly on advanced space-based command, control, communications, computers, intelligence, surveillance, and reconnaissance (C<sup>4</sup>ISR) infrastructure. Such infrastructure includes the Space-Based Infrared System (SBIRS) used for missile early warning, the Air Force's Advanced Extremely High Frequency communications constellation, weather satellites, and dozens of other space-based critical infrastructure systems.<sup>4</sup> Technical issues notwithstanding, the ability to continually operate these platforms is partially the result of a nearly 50-year period in which the space environment was a relatively peaceful sanctuary. However, space is becoming increasingly congested as technology advances and more states and commercial entities field their own space-based systems.

## Congested

There are roughly 1,200 active satellites in various orbits around earth and this number is predicted to increase exponentially as small satellites become increasingly advanced. For example, 2,750 small satellites (weighing less than 50 kilograms) are anticipated to be launched by 2020, more than four times the amount of satellites launched between 2000 and 2012.<sup>5</sup> Small, nanosatellites (weighing between 1 to 10 kilograms), and picosatellites (> 1 kilogram) are substantially more cost-effective for a variety of reasons, including their manufacturability and low launch costs.<sup>6</sup> Conventional satellites can weigh thousands of pounds and cost hundreds of millions or billions of dollars to develop, build, and place on-orbit. As small satellite technology advances, space industry watchdogs predict that more companies will shift their resources from developing large bus-size systems to more diverse and cost-effective constellations composed of small satellites.<sup>7</sup> Google is already seeking to field such a system for its Internet service (Sky-Fi) constellation of over 100 small satellites. This shift to more robust constellations with smaller satellites is a key reason space is predicted to become increasingly congested.

An additional reason why space is becoming increasingly congested concerns the growing amount of debris in orbit. Space debris includes inactive satellites, launch components, and other

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4. U.S. Department of Defense, "Selected Acquisition Report: SBIRS High (RCS: DD-A&T(Q&A)823-210)," May 21, 2013, 3.

5. Elizabeth Buchen and Dominic DePasquale, "2014 Nano/Microsatellite Market Assessment," Spaceworks Enterprises Incorporated, 2014, [http://www.sei.aero/eng/papers/uploads/archive/SpaceWorks\\_Nano\\_Microsatellite\\_Market\\_Assessment\\_January\\_2014.pdf](http://www.sei.aero/eng/papers/uploads/archive/SpaceWorks_Nano_Microsatellite_Market_Assessment_January_2014.pdf).

6. Jeff Foust, "Small Satellites, Small Launches, Big Business?," *Space Review*, August 11, 2014, <http://www.thespacereview.com/article/2577/1>.

7. Ibid.



man-made pieces of debris created as the result of collision or kinetic anti-satellite (ASAT) tests.<sup>8</sup> An example of how an ASAT test can produce debris concerns the Chinese kinetic intercept of a satellite in low earth orbit (LEO). In 2007, the Chinese military successfully conducted an ASAT test that destroyed the 750-kilogram Fengyun 1-C, an aging Chinese weather satellite. While the satellite was destroyed over 500 miles above earth, the National Aeronautics and Space Administration (NASA) assesses that the resulting debris cloud extends from “less than 125 miles to more than 2,292 miles, encompassing all of low earth orbit. The majority of the debris have mean altitudes of 528 miles or greater, which means most will be very long-lived.”<sup>9</sup> Initial estimates assessed that the ASAT test created a few hundred pieces of debris ranging in size from smaller than a dime to larger than a few feet. However, as SSA technology progressed, the NASA estimate was revised to include over 150,000 pieces of debris scattered across the LEO band.<sup>10</sup> Nearly eight years later, the resulting debris field still poses operational challenges to civilian and military infrastructure in LEO.<sup>11</sup>

While NASA assesses that the Chinese ASAT test was the single largest debris-creating event in history, numerous other activities have created thousands of additional pieces of debris scattered across various orbits. The 2009 collision between an inactive Russian satellite and an active U.S.-based Iridium communications satellite created roughly “2,000 pieces of debris, measuring at least four inches in diameter, and many thousands more of smaller pieces.”<sup>12</sup> The creation of space debris is not always the result of kinetic collisions, though—every space launch vehicle that reaches orbit creates debris (fuselages, screws, etc.). Without an internationally approved mechanism to limit launch-created space debris, the amount of debris in orbit is likely to increase as more commercial entities enter the launch business.

Space congestion expands beyond the number of physical objects on-orbit (e.g., satellites, debris, etc.) to include the radio frequency spectrum and, specifically, issues concerning frequency fratricide. Frequency fratricide refers to the increasing problems associated with the number of satellites operating in the same radio frequency bands. Satellites operating near one another could either accidentally or intentionally interfere with the signals from other satellites. As with debris and the increasing number of small satellites, frequency interference can occur in all orbits. Overall, increased congestion of small satellites, space debris, and frequency fratricide jeopardize U.S. space superiority by decreasing the amount of available space “real estate” and increasing the number of objects that the United States must monitor and track. While tracking more and smaller objects is technologically feasible in some circumstances, for U.S. policymakers to maintain

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8. Mark Garcia, “Space Debris and Human Spacecraft,” NASA, September 26, 2013, [http://www.nasa.gov/mission\\_pages/station/news/orbital\\_debris.html](http://www.nasa.gov/mission_pages/station/news/orbital_debris.html).

9. Leonard David, “China’s Anti-Satellite Test: Worrisome Debris Cloud Circles Earth,” *Space.com*, February 2, 2007, <http://www.space.com/3415-china-anti-satellite-test-worrisome-debris-cloud-circles-earth.html>.

10. NASA, “Two Minor Fragmentations End Worst Debris Year Ever,” *Orbital Debris Quarterly News* 12, no. 1 (January 2008), <https://www.orbitaldebris.jsc.nasa.gov/quarterly-news/pdfs/odqnv12i1.pdf>.

11. Leonard David, “Russian Satellite Hit by Debris from Chinese Anti-Satellite Test,” *Space.com*, March 8, 2013, <http://www.space.com/20138-russian-satellite-chinese-space-junk.html>.

12. Brian Weeden, “2009 Iridium-Cosmos Collision Fact Sheet,” Secure World Foundation, November 10, 2010, [http://swfound.org/media/6575/swf\\_iridium\\_cosmos\\_collision\\_fact\\_sheet\\_updated\\_2012.pdf](http://swfound.org/media/6575/swf_iridium_cosmos_collision_fact_sheet_updated_2012.pdf).



complete situational awareness they must also be able to effectively and in near-real-time distinguish dual-use satellites systems (e.g., commercial satellites that can be used for military purposes) from LEO all the way to geosynchronous orbit. However, complete SSA will become increasingly difficult as satellites become smaller and competition fuels more commercial entities to field space systems.<sup>13</sup>

## Competitive

The National Security Space Strategy states that space is becoming increasingly competitive. Competition in space is driven by the growing international space economy, which as of 2014 totaled roughly \$314 billion in government funding and commercial revenues.<sup>14</sup> While the space economy is growing overall, it is important to highlight that global government spending decreased by 1.3 percent between 2012 and 2013, while commercial-sector growth increased roughly 7 percent. Commercial investments in new SLVs and space-based infrastructure provide the foundation for much of the space economy growth.<sup>15</sup> This growth is fueling competition between states and private-sector entities vying for increased access to space markets. Perhaps more important, commercial entities are now fielding robust space capabilities that were once the sole purview of nation-states. For example, SpaceX is developing the reusable Falcon Heavy SLV, which has successfully delivered payloads to orbit and returned to earth. Reusable rockets will fundamentally alter the space launch business by eliminating the most expensive portion of the launch process—the rocket itself. SpaceX spends \$56.5 million to launch a payload onboard the Falcon rocket. Of this total cost, only \$200,000 is spent on fuel and oxygen; the remaining costs are associated with producing the rocket itself. According to Elon Musk, the founder and CEO of SpaceX, if the company is able to field reusable Falcon rockets the cost of placing payload in orbit shrinks from nearly \$10,000/pound to less than \$500/pound.<sup>16</sup> Lowering launch costs does more than simply increase profit margins—it forever alters the current space status quo by removing many of the prohibitive barriers (e.g., costs) associated with fielding space capabilities.

## Contested

As barriers to space are removed, new technologies will further degrade U.S. space superiority by creating a more contested operating environment in all orbits. Threats to U.S. space infrastructure include those posed by other states (e.g., kinetic kill vehicles mounted in modified ballistic missiles, laser blinders, etc.) as well as a growing number of dual-use platforms. Potentially dangerous dual-use capabilities are diverse, but perhaps the most destabilizing emerging technology concerns on-orbit satellite servicing. Satellite servicing refers to the concept of using one satellite

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13. Elizabeth Howell, "Tiny Sphere Satellite Will Test Future Space Surveillance Network," *Live Science*, December 11, 2014, <http://www.livescience.com/49094-spinsat-space-surveillance-network.html>.

14. Space Foundation, "Space Foundation's 2014 Report Reveals Continued Growth in the Global Space Economy in 2013," May 19, 2014, <http://www.spacefoundation.org/media/press-releases/space-foundations-2014-report-reveals-continued-growth-global-space-economy>.

15. Ibid.

16. Tibi Puiu, "How SpaceX's Elon Musk Wants to Drop Space Launch Prices 100 Fold with Reusable Rockets," *ZME Science*, August 21, 2013, <http://www.zmescience.com/space/spacex-reusable-rocket-100-times-cheaper-0432423/>.

on-orbit to repair, refuel, or refit another spacecraft. Satellite servicing systems require frequent and sustained rendezvous and proximity operations (RPOs). RPOs are orbital maneuvers during which two spacecraft arrive at the same orbit close to one another. Historically, RPOs have involved astronauts docking with a space station or a lunar module. As technology progresses, however, more entities are developing advanced RPO technologies to support asteroid mining and satellite servicing platforms.<sup>17</sup>

RPOs between two satellites are very complex operations that require fully autonomous guidance software to perform demating, separation, departure, rendezvous, proximity, and capture operations.<sup>18</sup> In addition to autonomous software onboard the servicing satellite itself, successful RPOs also require extensive ground and space infrastructure to support the operation. For example, in a recent NASA-sponsored RPO, ground controllers utilized the Global Positioning System constellation as well as ground-based orbital determination systems to track both satellites as they performed the operation.<sup>19</sup> This data was then combined with highly sensitive instrumentation onboard the satellite to execute the final segments of the RPO mission. While NASA successfully demonstrated this technology, government organizations are not the only entities developing satellite servicing and RPO capabilities—private-sector companies are also seeking to field similar capabilities. Commercial benefits derived from servicing are immense because the technology would enable life extension programs for satellites on-orbit as well as for on-orbit construction (via 3D printing) of new spacecraft, which would further eliminate the need for expensive launch vehicles.<sup>20</sup>

Commercial applications for satellite servicing include refueling satellites once their energy supplies have been exhausted, station-keeping activities, reconfiguring/updating hardware and software, and repositioning customer satellites in order for them to perform new missions.<sup>21</sup> While each of these commercial missions requires tailored servicing platforms, the fundamental technologies that enable these capabilities have already been developed in the private sector. For example, MacDonald, Dettwiler and Associates Ltd. (MDA), a company that helped develop the robotic arms for the space shuttle and the International Space Station, is developing the Space Infrastructure Servicing (SIS) vehicle.<sup>22</sup> The SIS vehicle is scheduled to be launched into geosynchronous orbit

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17. Planetary Resources, "Company Overview," April 2015, <http://www.planetaryresources.com/company/roadmap/#core-technologies>.

18. Cornelius Dennehy, "A Summary of the Rendezvous, Proximity Operations, Docking, and Undocking (RPODO) Lessons Learned from the Defense Advanced Research Project Agency (DARPA) Orbital Express (OE) Demonstration Vehicle," NASA Langley Research Center (NASA/TM-2011-217088), April 2011, 20.

19. Ibid.

20. Robert Hoyt, "SpiderFab: Process for On-Orbit Construction of Kilometer-Scale Apertures," NASA, November 30, 2016, [https://www.nasa.gov/directorates/spacetech/niac/2012\\_phase\\_I\\_fellows\\_hoyt\\_spiderfab.html](https://www.nasa.gov/directorates/spacetech/niac/2012_phase_I_fellows_hoyt_spiderfab.html).

21. Dave Belcher, Scott Freese, Katrina Laygo, and Daniel Osborn, "United States Legal and Policy Impediments to On-Orbit Satellite Servicing Activities, with Recommended Policies and Legal Implementations," Capstone Papers, George Washington University, 2014, <https://iistp.elliott.gwu.edu/sites/iistp.elliott.gwu.edu/files/Belcher%202014.pdf>.

22. Intelsat, "Intelsat Picks MacDonald, Dettwiler and Associates Ltd. for Satellite Servicing," press release, March 15, 2011, <http://www.intelsat.com/news/press-release/intelsat-picks-macdonald-dettwiler-and-associates-ltd-for-satellite-servicing/>.

(GEO) to provide commercial servicing. Once in GEO, the SIS vehicle's robotic arm will be used for refueling and "to perform critical maintenance and repair tasks, such as releasing jammed deployable arrays and stabilizing or towing smaller space objects or debris."<sup>23</sup> While the commercial benefits of such technology are enormous, satellite servicing represents an emerging and disruptive technology that could negatively affect the safety and security of U.S. space infrastructure.

Satellite servicing capabilities are a dual-use technology that could be used for counterspace objectives. As such, it is important to understand how these capabilities could be used by potentially hostile actors to threaten U.S. space infrastructure. Satellite servicing systems essentially act as co-orbital counterspace platforms. Co-orbital ASAT systems involve "reach out and touch" satellites capable of moving into orbit next to another satellite, latching on, and using robotic arms to manipulate the host satellite, with or without the host satellite's permission.<sup>24</sup> Permission is central to understanding the dual-use nature of servicing. While MDA developed its co-orbital platform to perform a specific \$280 million service for Intelsat, companies may not always be forthcoming about their space clients. Thus it may not be possible to fully understand if an entity is launching a co-orbital platform for commercial purposes (e.g., refueling another company's satellites) or if the platform is being placed on-orbit as a counterspace hedge.

The era in which space is a sanctuary no longer exists. Dual-use systems pose complex challenges to U.S. space superiority. New commercial satellite systems are increasing congestion, while industrial competition is lowering launch costs by orders of magnitude. When combined, each of these issues forms a pillar of the new space environment—one in which commercial entities and dual-use technologies are proliferated throughout space. While these advances are anticipated to be worth billions of dollars, it remains unclear how potentially hostile foreign states could field counterspace platforms under the guise of commercial activities. From a strategic stability perspective, it therefore becomes increasingly important to understand how the United States can ensure deterrence against all counterspace activities—both overt and covert—in the new congested, competitive, and contested space environment.

## DETERRENCE: SEPARATING SPACE FROM NUCLEAR

The new space environment challenges traditionally accepted deterrence strategies by increasing the amount of dual-use space systems on-orbit. To understand these new challenges, it is first necessary to understand how space deterrence has historically been interwoven with nuclear deterrence. U.S. policymakers have employed various nuclear deterrence concepts since the dawn of the Cold War.<sup>25</sup> These concepts evolved as new technologies—long-range bombers,

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23. Ibid.

24. Ian Eason, "China's Secret Co-orbital Satellites: The Quiet Surge in Space," *AsiaEye* (blog), November 9, 2010, <http://blog.project2049.net/2010/11/chinas-secret-co-orbital-satellites.html>.

25. New Deterrent Working Group, *U.S. Nuclear Deterrence in the 21st Century: Getting It Right* (Washington, DC: Center for Security Policy Press, July 2009), <http://www.centerforsecuritypolicy.org/upload/wysiwyg/center%20publication%20pdfs/NDWG-%20Getting%20It%20Right.pdf>.

intercontinental ballistic missiles (ICBMs), submarine-launched ballistic missiles (SLBMs), missile defenses, etc.—were fielded by Washington and Moscow. As the triad forces modernized, command, control, communications, and intelligence (C<sup>3</sup>I) infrastructure also evolved to support the more technologically advanced deterrent. Given the dispersed and global nature of a triad system, the United States and the Soviet Union fielded ever more advanced C<sup>3</sup>I systems in space. In addition to providing global command and control capabilities, the space-based C<sup>3</sup>I infrastructure served as a deterrent itself by providing early warning detection for ballistic missile launches—a system that in theory could detect where (and therefore who) launched an attack. Due to their physical location and role supporting attribution, space-based early warning satellites represent a unique bridge between space and nuclear deterrence doctrines.

Both the Soviet Union and the United States developed counterspace capabilities that could threaten hostile space-based infrastructure, including missile early warning satellites. However, as the Cold War progressed and norms became more established and institutionalized, neither Washington nor Moscow attacked space infrastructure. Space deterrence was maintained in part because the major powers considered “warfare in space to be linked to nuclear warfare.”<sup>26</sup> C<sup>3</sup>I infrastructure played a fundamental role in shaping this posture. For example, if the Soviet Union attacked U.S. early warning satellites then U.S. policymakers could reasonably infer that the space attack was tied to a larger terrestrial nuclear conflict. Once blinded in space, U.S. ballistic missile defense (BMD) systems would have to rely on ground-based assets (e.g., over-the-horizon radar) to detect incoming Soviet attacks. The elimination of space-based indication and warning systems would further jeopardize the effectiveness of BMD by substantially lowering response times. These factors contributed to a quasi counterspace détente. Washington and Moscow maintained a counterspace hedge, yet they also recognized that an attack on a space asset would likely be viewed as one segment of a much larger conflict, not necessarily as a conflict confined to the vacuum of space. In this environment, space conflict was treated as a subset of a broader nuclear deterrence strategy. While this strategy proved effective during the bipolar Cold War era, the current space environment demands a new approach to space deterrence, one that partially dissociates space conflict from nuclear deterrence.

Segregating space conflict from nuclear deterrence raises numerous issues concerning the so-called weaponization of space. Like nuclear deterrence, theories on the weaponization of space date back to Cold War–era nuclear strategies. Perhaps the most poignant reminder of these ties concerns the 1967 Outer Space Treaty (OST), which affirms that “states shall not place nuclear weapons or other weapons of mass destruction in orbit or on celestial bodies or station them in outer space in any other manner.”<sup>27</sup> Associating the peaceful uses of space with nuclear weapons

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26. Michael Krepon and Julia Thompson, eds., *Anti-Satellite Weapons, Deterrence, and Sino-American Space Relations* (Washington, DC: Stimson Center, September 2013), <https://www.stimson.org/content/anti-satellite-weapons-deterrence-and-sino-american-space-relations>.

27. “Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies,” UN Office of Outer Space Affairs, October 1967, <http://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/introouterspacetreaty.html>.

provided an institutional framework that helped form U.S.-Soviet counterspace doctrine.<sup>28</sup> This was partially the case because counterspace systems in the 1960s primarily involved nuclear weapons technology (e.g., high-altitude nuclear explosions were one of the few methods that states could employ to destroy adversary satellites). As more advanced nonnuclear counterspace technologies were developed (e.g., lasers, jammers, etc.), states further ingrained the weaponization of space within their nuclear deterrent doctrines. Perhaps more important, however, the proliferation of counterspace technologies has created a space environment that requires a new approach to deterrence strategy.

## TAILORING DETERRENCE FOR THE NEW SPACE ENVIRONMENT

The proliferation of advanced space capabilities to nonnuclear states and commercial entities requires a new framework to address space deterrence. Such a framework needs to include the traditional elements of deterrence: imposing costs, denying benefits, and encouraging restraint. However, unlike traditional deterrence, the new framework must be capable of accomplishing these objectives without needing to rely on the nuclear stockpile. A space deterrence strategy that relies solely on nuclear weapons is a relic of Cold War strategic thinking, one that fails to address the challenges associated with a space environment where advanced dual-use technologies and capabilities exist within the commercial sector and not solely nuclear-armed adversaries. Therefore, the first step in the development of a new framework is to identify strategies that incorporate commercial and nongovernmental dual-use counterspace technologies.

Incorporating dual-use counterspace technologies into the new space deterrence framework requires employing flexible responses to space aggression. Flexibility is needed because the “threshold for deterrence in a space context varies based on both weapon and target, creating a situation where deterrence holds for some targets while simultaneously failing for others.”<sup>29</sup> Unlike the U.S.-Soviet space deterrence relationship, which relied on kinetic ballistic missile intercepts or nuclear weapon detonations, the new framework must be capable of deterring nonpermanent counterspace capabilities as well. Reversible counterspace capabilities include laser dazzlers, jammers, as well as satellite servicing platforms that could use their onboard robotic arms to temporarily hold U.S. satellites hostage.<sup>30</sup> From a conflict escalation perspective, the new framework must be flexible enough to address the full space conflict continuum: from temporarily denying systems access to permanent damage or destruction of an asset. Another aspect of the space conflict continuum that must be addressed concerns the growing challenges associated with attribution.

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28. Johannes M. Wolff, “‘Peaceful Uses’ of Outer Space Has Permitted Its Militarization—Does It Also Mean Its Weaponization?,” *Disarmament Forum*, no. 1 (2003): 5–13, [https://www.peacepalacelibrary.nl/ebooks/files/UNIDIR\\_pdf-art1883.pdf](https://www.peacepalacelibrary.nl/ebooks/files/UNIDIR_pdf-art1883.pdf).

29. Ibid.

30. Kevin Pollpeter, “China’s Space Robotic Arm Programs,” *SITC Bulletin Analysis* (October 2013): 5, <https://escholarship.org/content/qt2js0c5r8/qt2js0c5r8.pdf>.

In the new space environment, states will become increasingly able to field covert dual-use counterspace systems under the guise of commercial applications. Fielding dual-use counterspace capabilities as commercial platforms also represents a unique force multiplication capability for states seeking to hedge counterspace systems. For example, dual-use constellations would allow states to field a potentially destabilizing amount of counterspace assets on-orbit without drawing attention to the system. Potentially hostile states could also field satellite servicing constellations without explicitly violating any perceived international norms against the weaponization of space—for example, the proposed Prevention of an Arms Race in Outer Space (PAROS) Treaty. Overall, dual-use constellations directly challenge cost-imposing deterrence strategies by increasing ambiguity and allowing hostile governments to maintain plausible deniability leading up to, during, and after an attack. In times of potential conflict, dual-use systems on-orbit will shorten the counterspace attack timeline. If a state were able to covertly field a dual-use counterspace system on-orbit, it could decrease the amount of time the United States would have to react and/or conduct defensive countermeasures. The importance of complete SSA therefore increases proportionally as more ostensibly commercial entities field satellite servicing platforms as well as potentially threatening small, micro, and picosatellites. In addition to complete SSA, the United States must also be capable of defending against emerging and disruptive dual-use space technologies.

## Defending U.S. Space Infrastructure

Defending U.S. space infrastructure from potentially hostile dual-use systems requires increasing resilience at both the system and constellation levels. At the system level, the United States must recognize that space is no longer a sanctuary. As such, satellite systems themselves must be capable of surviving and maintaining mission-critical functions during adversarial interference, including by hostile satellite servicing platforms. At the constellation level, U.S. policymakers must recognize that new commercial platforms could also be used to increase the deterrent capacity of U.S. space systems. For example, Google's plan to launch a 180-satellite constellation to provide Internet services and imagery represents a unique and affordable approach to support some C<sup>4</sup>ISR missions. An additional example concerns Planet Labs' constellation of 33 earth-imaging nanosatellites. According to NASA, the company's satellites "revisit the same areas more frequently than any existing government or commercial satellite."<sup>31</sup> More important from a space deterrence perspective, larger constellations of smaller satellites increase the survivability of the system writ large. In this environment, redundancies are built into the constellation itself, not necessarily mission-specific systems and subsystems onboard individual satellite busses. Such an architecture supports mission resilience by increasing the number of satellites a potentially hostile state must strike in order for the risk to outweigh the gain. What is more, robust small satellite constellations are easier to repopulate when compared to more traditional military constellations, which can take up to a decade to build and place on-orbit.<sup>32</sup>

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31. Robbie Schingler, "NanoRacks-Planet Labs-Dove (NanoRacks-Planet Labs-Dove)," NASA, November 11, 2016, [https://www.nasa.gov/mission\\_pages/station/research/experiments/1326.html#overview](https://www.nasa.gov/mission_pages/station/research/experiments/1326.html#overview).

32. "Defense Support Program (DSP) Satellites," Los Angeles Air Force Base, February 23, 2011, <http://www.losangeles.af.mil/About-Us/Fact-Sheets/Article/343738/defense-support-program-dsp-satellites/>.



Historically, repopulation of space infrastructure has been prohibitively expensive and technologically infeasible. With new advances in commercial capabilities, however, the U.S. ability to repopulate lost infrastructure could play a pivotal role in emerging space deterrence strategies. At the center of this strategy is the reusable SLV technology currently being developed by SpaceX. When combined, reusable SLVs and smaller, more cost-effective satellites provide the technology hedge that would allow the United States to repopulate lost infrastructure in the event of a conflict. Rapid repopulation of mission-critical functions supports U.S. deterrence objectives by complicating an adversary's ability to impose costs against U.S. systems. To successfully downgrade U.S. capabilities, an adversary would need to launch both counterspace attacks as well as attacks against the terrestrial entities that support repopulation. In this case, commercial technologies provide the technological foundation from which it is possible to deny an adversary the ability to impose costs against the U.S. infrastructure. Therefore, somewhat ironically, the same commercial technologies that challenge some U.S. deterrence objectives can also be used to support U.S. efforts to maintain space superiority.

## CONCLUSION

Emerging and disruptive commercial technologies are fueling the growth of a new space environment that is increasingly congested, competitive, and contested. Technology advances and the rapidly growing space economy provide the foundation for sustained, long-term commercial investments in space. In this new space environment, states no longer maintain a monopoly on space systems. For example, small commercial satellites will increase congestion, while the growing affordability of space launches will fuel increased global competition. As costs lower and barriers to space are removed, the United States must begin to assess how the new space environment will challenge traditional security strategies.

Commercial technologies challenge traditionally accepted deterrence doctrines by introducing new actors capable of threatening U.S. space infrastructure. Dual-use counterspace platforms also complicate efforts to understand escalation dynamics. Reversible counterspace systems (e.g., on-orbit satellite servicing) require a new approach to deterrence, one that is flexible enough to address the full space conflict continuum: from temporary system denial to permanent destruction of an asset. Simply put, a space deterrence posture must be capable of responding to a wide range of aggressive behavior—some of which could be conducted covertly by dual-use spacecraft. In this new space environment, the efficacy of the flexible deterrent therefore relies on the ability to attribute attacks on U.S. infrastructure to the responsible actor.

Over 1,000 satellites are anticipated to be launched by 2020. Ensuring that the United States is capable of identifying, tracking, and differentiating potentially hostile dual-use spacecraft should be a central pillar of any future space deterrence strategy. In times of heightened tension, it is critical that policymakers have the capability to monitor and correctly attribute hostile activity. Without credible attribution data, policymakers risk strategic surprise and the collapse of a space deterrent capability. In order to ensure a flexible space deterrent, it therefore becomes increasingly important to further assess how emerging and disruptive commercial space technologies challenge U.S. security objectives.



# Brexit: The Unappreciated Threats to Nuclear Security

Daniel Davies<sup>1</sup>

*Nuclear policy did not play a large role in the United Kingdom's decision to leave the European Union. The ramifications of leaving, however, will affect all facets of nuclear policy in the United Kingdom. While some nuclear challenges have been examined since the referendum results were announced in June 2016, a number of topics remain underappreciated, including nuclear security. Although nuclear security ultimately remains the responsibility of individual states, the European Union has assumed an ever-growing role supporting the ability of its states to prevent, detect, and respond to the misuse of nuclear material. Losing this support would be contrary to the interests of the United Kingdom. To safeguard its best interests in nuclear security, the United Kingdom should, first, recognize the full role of the European Union in nuclear policy and, second, temper its approach to negotiations to better allow it to retain the cooperative elements of the relationship.*

## INTRODUCTION

Nuclear policy guided very few—if any—members of the British electorate on June 23, 2016. Instead, issues of trade, immigration, and sovereignty dominated both the “Leave” and “Remain” campaigns. The decision to leave, however, will have a definitive impact on the nuclear field, which stands—alongside trade and industry—as one of the original pillars of European integration.<sup>2</sup> British politicians have only recently begun to assess seriously Europe’s importance on nuclear issues and the impact that Brexit will have on research, regulation, and industry following the referendum.

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2. “Regional” or “European” will be used to denote that relating to the European Union, unless otherwise indicated.

While this attention is welcome, elements of the United Kingdom's nuclear relationship with Europe nonetheless remain largely neglected.

One such important element that decisionmakers continue to overlook is nuclear security: the ability of a state to prevent, detect, and respond to the "theft, sabotage, unauthorized access, illegal transfer or other malicious acts involving nuclear material."<sup>3</sup> This is understandable to some degree: Nuclear security is ultimately a national rather than regional responsibility and includes the use of the state security apparatus to protect nuclear infrastructure and material.<sup>4</sup> To this end, the Office for Nuclear Regulation (ONR) is responsible for maintaining nuclear security in the United Kingdom, as described in the 2013 Nuclear Industries Security Regulations Act, while a special branch of the police force—the Civil Nuclear Constabulary—is tasked with securing civil nuclear material. Moreover, the European Union's role in nuclear security is far less noticeable than the role it plays in nuclear safeguards, for instance, where a clear, treaty-based institutional framework exists.

However, underestimating the full extent of cooperation within the European Union on nuclear security could prove harmful to the United Kingdom's best interests. The European Union provides significant support through collaborative mechanisms to the prevention, detection, and response elements of nuclear security in the United Kingdom. The United Kingdom benefits from this regional cooperation in the nuclear field, from training and research to more traditional elements of security like intelligence sharing and border control.

In this regard, the United Kingdom must first recognize and respond to the impact that departing the European Union will have on its nuclear security. This must begin with a fuller appreciation of the effects that Brexit could have on what is deemed solely a national responsibility. Without doing so, the United Kingdom could lose the beneficial elements of the relationship without having replaced or reconstituted these frameworks at a national or multilateral level. Second, the United Kingdom must temper its approach to the negotiations with the European Union. The position of Theresa May's government that "no deal is better than a bad deal"<sup>5</sup> and the emphasis on a "Global Britain"<sup>6</sup> could inadvertently constrain the United Kingdom from safeguarding its interests in nuclear security while charting its exit from the bloc.

## THE EUROPEAN NUCLEAR PROJECT

There is a strong precedent of regional collaboration on nuclear issues in Europe. The European Atomic Energy Community, also known as Euratom, stands as one of the key pillars of postwar

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3. International Atomic Energy Agency (IAEA), "Nuclear Safety and Security: Concepts and Terms," accessed, August 17, 2017, <http://www-ns.iaea.org/standards/concepts-terms.asp>.

4. Marcy Fowler and Alisa Carrigan, "Nuclear Security in European Union Member States," *Non-Proliferation Papers*, no. 44 (April 2015): 1, <http://www.nonproliferation.eu/web/documents/nonproliferationpapers/nuclear-security-in-european-union-member-states-45.pdf>.

5. Her Majesty's Government, *The United Kingdom's Exit from and New Partnership with the European Union* (London: Her Majesty's Stationery Office [HMSO], 2017), 65, [https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/589191/The\\_United\\_Kingdoms\\_exit\\_from\\_and\\_partnership\\_with\\_the\\_EU\\_Web.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/589191/The_United_Kingdoms_exit_from_and_partnership_with_the_EU_Web.pdf).

6. *Ibid.*, 3.

European integration. Euratom, along with the European Coal and Steel Community and the European Economic Community (EEC), provided the political and legal foundations on which the European Union was built. The three major communities represented assumptions about the direction of regional reconstruction and economic growth after the war: a regional market fueled by the industrious use of raw materials (coal and steel) and—in Harold Wilson’s words—the “white heat of technology” in the form of nuclear energy.<sup>7</sup> Euratom, in particular, was designed to contribute to “raising the standard of living in Member States and to the development of commercial exchanges with other countries.”<sup>8</sup>

Weighing its comparative advantage in the field, its relationship with the United States, and fear of being left behind, the United Kingdom penned a bilateral agreement with Euratom in 1959.<sup>9</sup> As one of the first instances of a formal relationship between the United Kingdom and the nascent European project, the agreement demonstrates how important the United Kingdom perceived nuclear cooperation with the Continent to be. It broadly supported nuclear research, training, and the exchange of information, alongside commercial opportunities such as the exchange of nuclear services and materials.<sup>10</sup> Following its eventual membership of the European Communities in 1973, however, much of the United Kingdom’s nuclear regulation, external cooperation, and safeguarding began to be decided—with significant UK influence—at a regional level.

Subsequent and successive bouts of integration led to the merger of the original communities into the present-day European Union in 1992. However, because Europe remains divided about the utility of nuclear energy, Euratom has not undergone the same transformation.<sup>11</sup> The institutions of the European Union—the European Council, Commission, and Court of Justice—govern Euratom, but the Community has retained its legal character as a separate entity. For this reason, during the referendum campaign, it remained unclear how the United Kingdom’s exit from the European Union would affect its relationship with Euratom. This has only started to be addressed since the United Kingdom confirmed its decision to formally leave the European Union.

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7. Reuben Efron and Allan S. Nanes, “The Common Market and Euratom Treaties: Supranationality and the Integration of Europe,” *International and Comparative Law Quarterly* 6, no. 4 (October 1957): 671.

8. Treaty Establishing the European Atomic Energy Community (Euratom), Article 1 (1957), [https://www.ab.gov.tr/files/ardb/evt/1\\_avrupa\\_birligi/1\\_3\\_antlasmalar/1\\_3\\_1\\_kurucu\\_antlasmalar/1957\\_treaty\\_establishing\\_euratom.pdf](https://www.ab.gov.tr/files/ardb/evt/1_avrupa_birligi/1_3_antlasmalar/1_3_1_kurucu_antlasmalar/1957_treaty_establishing_euratom.pdf).

9. Stuart Butler, “The Struggle for Power: Britain and Euratom 1955–63,” *International History Review* 36, no. 2 (2014): 330.

10. Agreement between the Government of the United Kingdom of Great Britain and Northern Ireland and the European Atomic Energy Agency (EURATOM) for Co-operation in the Peaceful Uses of Atomic Energy, Articles I–VI (1959), [http://treaties.fco.gov.uk/docs/fullnames/pdf/1959/TS0028%20\(1959\)%20CMND-702%201959%204%20february,london%3b%20agr%20between%20govt%20of%20uk&ni&the%20european%20atomic%20energy%20community%20for%20co-operation%20in%20the%20peaceful%20uses%20of%20atomic%20energy.pdf](http://treaties.fco.gov.uk/docs/fullnames/pdf/1959/TS0028%20(1959)%20CMND-702%201959%204%20february,london%3b%20agr%20between%20govt%20of%20uk&ni&the%20european%20atomic%20energy%20community%20for%20co-operation%20in%20the%20peaceful%20uses%20of%20atomic%20energy.pdf).

11. Nicola Newson, “Leaving the European Union: Euratom,” House of Lords Library Note, February 23, 2017, 1, <http://researchbriefings.parliament.uk/ResearchBriefing/Summary/LLN-2017-0010#fullreport>.

## NUCLEAR REACTION TO THE REFERENDUM

Despite being an integral element of European integration, Euratom was barely a consideration for the campaigns, much less those casting a ballot. Issues such as migration, the economy, and national identity instead dominated the referendum debate. Nuclear issues have, however, garnered more attention in the aftermath, particularly as decisionmakers begin seriously to assess the impact of what was assumed to be an unlikely outcome.

Euratom became a talking point after the submission of the European Union (Notification of Withdrawal) Bill on January 26, 2017, which provided the prime minister with the authority to trigger the United Kingdom's departure from the European Union. The bill included a reference to Euratom, confirming the UK position that, under the 2008 European Union (Amendment) Act, the referendum result also applied to UK membership in Euratom.<sup>12</sup> While some have subsequently challenged the legal basis of the government's interpretation, the bill provoked a flurry of interest in the press and references in Hansard, the official report of proceedings in both the House of Commons and the House of Lords.<sup>13</sup> This initial interest in Euratom was, however, limited in scope. The leaders of the discussion were members of Parliament whose constituencies stood to lose from the withdrawal of research funding, in particular Oxfordshire MPs who were worried about the impact on the Joint European Torus Project.<sup>14</sup>

Euratom nevertheless increasingly began to represent a litmus test for domestic and regional debates on the outcome of the referendum. To this end, members of both houses unsuccessfully attempted to amend the bill to exempt Euratom from the Article 50 process.<sup>15</sup> The topic has since emerged as a cause for those eager to push the government to renege on a "hard Brexit," or a clean break with the European Union. Additionally, as the principal argument for leaving the Community was to limit the remit of the European Court of Justice, it has become a case study as to how much sovereignty the United Kingdom might be willing to cede in order to retain certain beneficial elements of its European Union membership.

The growing attention obliged the government to detail the effects of leaving Euratom in a February 2017 white paper, "The United Kingdom's Exit from and New Partnership with the European Union," which outlined the government's plans to implement the results of the referendum. In it, the government confirmed its interest in retaining a level of cooperation in nuclear safeguards,

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12. UK Houses of Parliament, "European Union (Notification of Withdrawal) Bill: Explanatory Notes," January 26, 2017, <https://www.publications.parliament.uk/pa/bills/cbill/2016-2017/0132/en/17132en.pdf>.

13. Jonathan Leech and Rupert Cowen, "Brexit White Paper Confuses Euratom Debate," *World Nuclear News*, February 8, 2017, <http://www.world-nuclear-news.org/V-Brexit-white-paper-confuses-Euratom-debate-08021702.html>.

14. See, for example, John Howell in UK Parliament, "European Union (Notification of Withdrawal) Bill Debate," February 1, 2017, [https://hansard.parliament.uk/Commons/2017-02-01/debates/5B0251FC-94E6-4216-8830-4F85E0EC2250/EuropeanUnion\(NotificationOfWithdrawal\)Bill](https://hansard.parliament.uk/Commons/2017-02-01/debates/5B0251FC-94E6-4216-8830-4F85E0EC2250/EuropeanUnion(NotificationOfWithdrawal)Bill).

15. UK House of Lords, "European Union (Notification of Withdrawal) Bill: Second Marshalled List of Amendments," Amendment No. 23, February 27, 2017, <https://www.publications.parliament.uk/pa/bills/lbill/2016-2017/0103/17103-II.pdf>; UK House of Commons, "European Union (Notification of Withdrawal) Bill: Committee of the Whole House," Amendment No. 27, February 8, 2017, [https://www.publications.parliament.uk/pa/bills/cbill/2016-2017/0132/amend/european\\_daily\\_cwh\\_0207.pdf](https://www.publications.parliament.uk/pa/bills/cbill/2016-2017/0132/amend/european_daily_cwh_0207.pdf).

safety, and trade, although it did not specify what form this cooperation would take or how it would be retained. This was elaborated on in Queen Elizabeth II's speech after the June 8 general election, in which she confirmed that the government would produce a specific bill on nuclear safeguards and a subsequent position paper on "Nuclear Materials and Safeguards Issues" that confirmed the "U.K.'s ambition is to maintain a close and effective relationship with the European Community" in this field.<sup>16</sup>

The government has, as a result, increasingly recognized the effects of the referendum on nuclear issues in the United Kingdom. This has in part been a natural process, as commentators and politicians have had time to digest the ramifications of the result. However, the government's reduced majority following the June 8, 2017, general election has also weakened its position on Brexit and made Euratom a more attractive topic of debate for opponents demanding concessions. Nonetheless, the response has remained superficial. The white paper overemphasizes the commercial sector, neglecting some of the more important elements of the relationship with Europe, including nuclear security. Moreover, while the government has suggested it wishes to maintain cooperation on issues such as safeguards, safety, and research, it has not yet indicated how it wishes to do so and whether this cooperation will be comparable to current mechanisms. The position paper, while recognizing the complexity of withdrawing from Euratom, has also been criticized by industry representatives as "containing very little detail."<sup>17</sup> In this regard, the current approach continues to neglect important aspects of the United Kingdom's nuclear relationship with the European Union which, if not addressed during the negotiation period, could harm UK interests in the field.

## NEGLECTING NUCLEAR SECURITY

Nuclear security—the ability to prevent, detect, and respond to malicious acts using nuclear materials—is one such omission in the post-referendum nuclear policy discussion. The omission is perhaps understandable, as the European Union's contribution to nuclear security is not so easily defined. Nuclear security is the responsibility of individual states, as it concerns the physical security of nuclear installations and nuclear material. Moreover, other elements of nuclear policy are more clearly defined in European law. The Euratom Treaty and associated regulations outline nuclear safeguards, whereas the European Union's Basic Safety Standards Directive (96/29/Euratom) details nuclear safety. The word security—and nuclear security as a concept—does not appear in the Euratom Treaty, other than a reference to the handling of information "liable to harm the defence interests of one or more Member States."<sup>18</sup>

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16. Her Majesty's Government, *Nuclear Materials and Safeguards Issues: Position Paper* (London: HMSO, 2017), 1, [https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/627909/FINAL\\_OFF\\_SEN\\_Position\\_Paper\\_HMG\\_Nuclear\\_materials\\_and\\_safeguards\\_issues\\_Position\\_Paper\\_FINAL\\_120717\\_\\_3\\_.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/627909/FINAL_OFF_SEN_Position_Paper_HMG_Nuclear_materials_and_safeguards_issues_Position_Paper_FINAL_120717__3_.pdf).

17. Nuclear Industry Association (NIA), "NIA Reaction to Government Position Paper on Euratom," press release, July 13, 2017, <https://www.niauk.org/media-centre/press-releases/nia-reaction-government-position-paper-euratom/>.

18. Treaty Establishing the European Atomic Energy Community (Euratom), Section 3 (1957).

However, this position disregards the European Union's contribution to the capacity of its member states to prevent, detect, and respond to nuclear security threats. While the United Kingdom is an established nuclear state and many of its practices exceed those required under European law or have been drafted at the national level, its departure from the current mesh of nuclear policy, information sharing, and best practice will still produce gaps in its approaches and capacity. The United Kingdom will struggle to fill these gaps as it transfers European law into national law, especially before the scheduled date of leaving the European Union on March 29, 2019.

It should also be remembered that, while a leader in the field, the UK system is by no means perfect. The UK Civil Nuclear Police Authority has reported 148 security breaches and incidents since 2011,<sup>19</sup> while the Nuclear Threat Initiative's Nuclear Security Index ranked the United Kingdom as 24th globally in terms of the quantity of nuclear material in Britain and the sites that house it.<sup>20</sup> This performance may worsen as the bodies responsible for nuclear security—specifically the Office for Nuclear Responsibility—lose European support and are required to replicate former regional processes at the national level.<sup>21</sup> The UK government must first recognize and then protect or replace these regional mechanisms that support the United Kingdom's nuclear security capacity so that it can maintain its ability to prevent, detect, and respond to malicious acts using nuclear material.

The United Kingdom's ability to prevent, for instance, the theft of or unauthorized access to nuclear sources is contingent on other planks of European nuclear policy, namely strong nuclear safeguards and safety regimes.<sup>22</sup> These fall squarely in Euratom's remit. On leaving Euratom, the United Kingdom will be responsible for reconstituting a system of safeguards previously carried out regionally, as well as instigating a new state system of accounting for and control of nuclear material (SSAC).<sup>23</sup> Whether the United Kingdom has the national capacity to do so before it leaves the European Union has already been called into question. David Senior, director of assurance, policy and international, at the UK Office for Nuclear Regulation, reported to the Parliamentary Business, Energy, and Industrial Strategy Committee that to implement even a basic replacement

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19. Civil Nuclear Police Authority, *Annual Report and Accounts 2015/16* (London: HMSO, 2016), 28, [https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/538844/CNPA\\_annual\\_report\\_2015-16.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/538844/CNPA_annual_report_2015-16.pdf).

20. Nuclear Threat Initiative (NTI) Nuclear Security Index, "Country Profile: United Kingdom," accessed August 17, 2017, <http://ntiindex.org/countries/united-kingdom/?index=theft>.

21. Two of the strategic goals of the Office for Nuclear Responsibility, according to its 2017–2018 Corporate Plan, already relate to leaving Euratom, demonstrating the growing proportion of capacity required to chart the United Kingdom's departure from the European Union. Ironically, a further goal is implementing a European Directive on safety standards, which the United Kingdom is obliged to do until it formally leaves. See Office for Nuclear Regulation (ONR), *Our Corporate Plan 2017/18: En Route to 2020* (London: HMSO, 2017), 1–2, <http://www.onr.org.uk/documents/2017/onr-corporate-plan-2017-2018.pdf>.

22. Olli Heinonen, "Nuclear Safety, Safeguards, and Security—Strengthening the Global Nuclear Order" (talking points for Panel on the Challenge of Implementing International Commitments, International Conference on Nuclear Security Commitments and Actions, IAEA, Vienna, December 7, 2016), <https://www.belfercenter.org/sites/default/files/files/publication/Talking%20points.pdf>.

23. Daniel Davies, "Brexit Effects: The Future of Safeguards in the United Kingdom," *Trust & Verify*, no. 153 (Summer 2016), <http://www.vertic.org/media/assets/TV/TV153.pdf>.



of the current arrangements would be “challenging” in terms of resources, infrastructure, and ownership of the safeguarding equipment currently in use.<sup>24</sup>

Losing access to training and research facilities will also affect the United Kingdom’s ability to detect breaches in nuclear security. These include the European Nuclear Security Training Centre (EUSECTRA), which provides training on counter-trafficking and border control to the security services of interested states,<sup>25</sup> and the Illicit Trafficking Radiation Assessment Program (ITRAP+10), a joint EU-U.S. effort to improve detection of chemical, biological, radiological, and nuclear (CBRN) material. The loss of capacity building and training in nuclear forensics at the Joint Research Center, which hones the regional ability to trace nuclear material found being illicitly transported or used in a security incident, will also prove detrimental to the United Kingdom’s ability to respond to nuclear security incidents. Losing access to capacity building will be compounded as the United Kingdom’s departure from the single market complicates its access to the pool of skilled Europeans. This will exacerbate a “skills gap” that already poses problems for nuclear projects, including security upgrades under the Sellafield Security, Emergency Management, and Resilience Program.<sup>26</sup>

The United Kingdom could also be cut out of the information exchange in the nuclear and security fields, further impacting the United Kingdom’s ability to detect threats to nuclear security and respond to them. Pooled intelligence on suspects, plots, or vulnerabilities from membership in Europol is integral to the United Kingdom’s regional security understanding. In the words of the British director of Europol, Robert Wainwright, the United Kingdom has become “increasingly dependent [on European Union instruments] to secure its interests in fighting crime and terrorism.”<sup>27</sup> In particular, Europol’s EU Bomb Data System provides information and intelligence on radiological and nuclear related incidents. The United Kingdom also stands to lose access to new regional initiatives through both the European Commission and Europol to tackle cyberattacks against critical infrastructure, including nuclear facilities.<sup>28</sup>

In this regard, the European Union plays a significant, albeit not singular role, in nuclear security. While not responsible for the nuclear security of its member states, it provides mechanisms to

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24. David Senior, “Oral Evidence: Leaving the EU: Negotiation Priorities for Energy and Climate Change Policy, HC 909,” Business, Energy and Industrial Strategy Committee, UK House of Commons, February 28, 2017, <http://data.parliament.uk/WrittenEvidence/CommitteeEvidence.svc/EvidenceDocument/business-energy-and-industrial-strategy/leaving-the-eu-energy-and-climate-negotiation-priorities/oral/48479.pdf>.

25. S. Abousahl et al., “The Nuclear Safeguards and Security Activities under Euratom Research and Training Programme” (presentation at Symposium on International Safeguards, Vienna, October 23, 2014), [http://www.iaea.org/inis/collection/NCLCollectionStore/\\_Public/46/066/46066195.pdf](http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/46/066/46066195.pdf).

26. UK Houses of Parliament, “Nuclear Security,” *PostNote*, no. 540 (October 25, 2016), 3, <http://researchbriefings.parliament.uk/ResearchBriefing/Summary/POST-PN-0540#fullreport>.

27. Quoted in Joanna Dawson, “Brexit: Implications for National Security,” Briefing Paper CBP7798, House of Commons Library, March 31, 2017, 8, <http://researchbriefings.parliament.uk/ResearchBriefing/Summary/CBP-7798>.

28. Examples are outlined in Energy Expert Cyber Security Platform (EECSP) Expert Group, *Cyber Security in the Energy Sector: Recommendations for the European Commission on a European Strategic Framework and Potential Future Legislative Acts for the Energy Sector* (Brussels: EECSP, 2017), 71, [https://ec.europa.eu/energy/sites/ener/files/documents/eecsp\\_report\\_final.pdf](https://ec.europa.eu/energy/sites/ener/files/documents/eecsp_report_final.pdf).



improve capacity, adopt best practices, and share information, all of which benefit national nuclear security. The United Kingdom stands to give up these benefits on leaving the European Union, unless due attention is paid by policymakers to nuclear security alongside other nuclear issues as they plan and engage in the negotiations to leave the European Union.

## LOOKING TOWARD MARCH 29, 2019

Recognizing the importance of nuclear security during the negotiations, perhaps in tandem with discussions on the future relationship with Euratom, would be an important first step toward protecting the UK interest in this field. However, the United Kingdom's current approach to these negotiations could pose a barrier to doing so. Prime Minister Theresa May first outlined this position in January 2017 at Lancaster House, where she detailed 12 priorities the government will use to negotiate Brexit. These were later formalized in the February white paper, "The United Kingdom's Exit from and New Partnership with the European Union," which confirmed that the United Kingdom would completely remove itself from the single market and customs union to avoid "anything that leaves us half-in, half-out."<sup>29</sup> Along with the deadline of March 29, 2019, to complete negotiations and focus on a distinct group of subjects, this "hard Brexit" position may complicate retaining the beneficial elements of European collaboration.

The adherence to the strict two-year negotiating period laid out in Article 50 is too short to construct the national nuclear infrastructure and expertise necessary to replace membership in Euratom, to the extent that the Business, Energy, and Industrial Strategy Committee advised the government to delay the United Kingdom's departure from Euratom.<sup>30</sup> May's snap parliamentary election—called on June 8, 2017—further limited the time devoted to understanding the impact of Brexit, planning exit negotiations, and instigating the measures needed to replace the European Union's role. Moreover, the result undermined the position of the government, reducing its political capital in negotiations on critical issues in Europe and at home. This time frame—alongside the legitimate public expectation that negotiations will focus on the campaign issues of trade, immigration, and sovereignty—will stretch the finite capacity of ministers and civil servants. Nuclear security is unlikely to receive the attention it is warranted.

The government has few options to address the risks to nuclear security posed by the time frame and priorities of the negotiations. The two-year time frame could be extended, but would require unanimous agreement among the remaining 27 EU member states, allowing them to demand concessions of the United Kingdom.<sup>31</sup> Moreover, the remaining members of the European Union

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29. Theresa May, "The Government's Negotiating Objectives for Exiting the EU" (speech, Lancaster House, January 17, 2017), <https://www.gov.uk/government/speeches/the-governments-negotiating-objectives-for-exiting-the-eu-pm-speech>.

30. UK House of Commons, *Leaving the EU: Negotiation Priorities for Energy and Climate Change Policy*, Fourth Report of Sessions 2016–17, Business, Energy, and Industrial Strategy Committee, April 25, 2017, 34, <https://publications.parliament.uk/pa/cm201617/cmselect/cmbeis/909/909.pdf>.

31. Treaty on European Union, Article 50(3), 2009, <http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3AC2010%2F083%2F01>.

are eager to avoid the negotiations affecting the European elections in June 2019.<sup>32</sup> Finally, the issues that guided the British public's decision to leave the European Union should legitimately receive due attention, even if they do not adequately reflect the full extent of the United Kingdom's relationship with Europe. However, the rhetoric used and its approach to negotiations are broadly within the government's control.

In this regard, the United Kingdom could still mitigate some risks posed by its approach to the negotiations. Two elements in the Lancaster House speech, the February 2017 white paper, and later pronouncements by government figures could prove particularly counterproductive for many elements of the current UK-EU relationship that are in the United Kingdom's best interest to retain or replace, including nuclear security cooperation. One statement—"no deal is better than a bad deal"—and one aspiration—"a more Global Britain"—are two key pillars of the government's stance that risk complicating any efforts to retain beneficial access to regional cooperation. These positions should be tempered for the United Kingdom to secure its interests in collaborative fields like nuclear security.

Both the "no deal" and "Global Britain" stances are clearly directed to some degree by political considerations. The government must be mindful of the public, skeptical members of Parliament, and European negotiators when publicly voicing its position. As such, the statements from both negotiating parties should be viewed in the context of speaking to a particular audience. However, leading politicians have consistently repeated the "no deal" and "Global Britain" narratives, the former appearing in the 2017 Conservative Party Manifesto<sup>33</sup> and the latter repeated no fewer than 10 times in the Lancaster House speech.<sup>34</sup> To this end, even if the phrases are intended as rhetorical devices, such consistency in message shapes expectations of the public, making the position difficult to change later, and expectations of European negotiators, who will adapt their own positions and could complicate compromise on issues of mutual interest.

## No Deal

"No deal is better than a bad deal" has become a key phrase for senior ministers to signal their resolve during the upcoming negotiations with the European Union. This position represents the United Kingdom's preparedness to leave negotiations and sever the country from its current arrangements with the European Union should it feel that the EU's demands are untenable. There are feasible benefits to a "no deal" scenario. Nuclear suppliers in the United Kingdom could benefit as European regulation is removed. Fewer reporting requirements and challenges through the European Court of Justice will reduce the costs of increasing the United Kingdom's current fleet of nuclear power plants.<sup>35</sup> Moreover, if the United Kingdom left without having negotiated a

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32. "Brexit Deal Needed before 2019 Elections—EU's Verhofstadt," *BBC News*, September 13, 2016, <http://www.bbc.co.uk/news/world-europe-37350794>.

33. Conservative and Unionist Party, *Forward, Together: Our Plan for a Stronger Britain and a Prosperous Future*, Conservative and Unionist Party Manifesto, London, 2017, 36, <https://www.conservatives.com/manifesto>.

34. May, "The Government's Negotiating Objectives for Exiting the EU," <https://www.gov.uk/government/speeches/the-governments-negotiating-objectives-for-exiting-the-eu-pm-speech>, January 17, 2017.

35. UK House of Commons, "Oral Evidence: Leaving the EU: Negotiation Priorities for Energy and Climate Change Policy, HC 909," February 28, 2017, Q.138.

replacement to current collaboration, it could look toward other international mechanisms that also support nuclear security, including ones for training, information sharing, and research.

However, while industry may gain from the United Kingdom becoming more competitive, such advantages would not accrue in areas that have traditionally benefited from cooperation. The “no deal” narrative threatens the retention of any mutual advantages that the United Kingdom and the European Union share past the negotiation period. In addition, no other existing international mechanisms can adequately replace the European Union, as they focus on different issues and are less tailored to UK needs. The International Atomic Energy Agency (IAEA) and Interpol, for instance, can replace the roles of Euratom and Europol to a degree, but they lack the regional focus and relevance of the European Union. The United Kingdom may also find itself reluctant to engage with alternative organizations as closely as it has done with European partners, particularly those whose memberships extend beyond an established regional alliance, especially when sharing information on nuclear security practices or providing access to nuclear installations.

It should be noted that none of the European mechanisms that currently support UK nuclear security are contentious or contested. In July 2012, the then coalition government launched “the most extensive analysis ever undertaken of the UK’s relationship with the EU.”<sup>36</sup> The Balance of Competences Review did not raise the European Union’s role in nuclear security as a concern and only ventured so far as to criticize nuclear cooperation in terms of the limited promotion of nuclear energy and the occasional creep beyond its remit.<sup>37</sup> Perhaps more importantly, security remains one area where the United Kingdom hopes to retain some level of cooperation,<sup>38</sup> suggesting that it was not seen as a burden in the present relationship. This remains true today. In this regard, simply allowing the current mechanisms to lapse under a “no deal” scenario would prove disastrous for nuclear security, as the United Kingdom would immediately lose access to the training, research, and information exchange outlined previously.

## Global Britain

The understanding that the United Kingdom will adopt a global, rather than regional, stance following its departure from the European Union is based on the desire to seek trade deals with partners outside of Europe. The February 2017 white paper makes clear that the United Kingdom will not remain a member of the single market or customs union.<sup>39</sup> Although it does not signal a complete break with European partners, the position embodies a desire to become less regionally focused, particularly in trade. Certain sectors of the UK economy would stand to benefit. In the

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36. UK Foreign and Commonwealth Office, “Final Reports in Review of EU Balance of Competences Published,” press release, December 18, 2014, <https://www.gov.uk/government/news/final-reports-in-review-of-eu-balance-of-competences-published>.

37. Her Majesty’s Government, *Review of the Balance of Competences between the United Kingdom and the European Union: Energy Report* (London: HMSO, 2014), 68–70, [https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/332794/2902398\\_BoC\\_Energy\\_acc.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/332794/2902398_BoC_Energy_acc.pdf).

38. Theresa May, Letter to Donald Tusk Triggering Article 50, March 29, 2017, 4, [https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/604079/Prime\\_Ministers\\_letter\\_to\\_European\\_Council\\_President\\_Donald\\_Tusk.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/604079/Prime_Ministers_letter_to_European_Council_President_Donald_Tusk.pdf).

39. Her Majesty’s Government, *The United Kingdom’s Exit from and New Partnership with the European Union*, 35.

nuclear field, the country could tap into the global market for small modular reactors and offer services to countries outside Europe, where growth in nuclear technology is stronger than on the Continent.<sup>40</sup> However, this focus on trade and competition could unduly harm other important cooperative elements of the UK relationship with Europe.

While nuclear security remains the responsibility of individual states, it lends itself to regional projects. In terms of developing nuclear security practices, the United Kingdom shares the understanding, values, and technical level of its neighbors. It also shares borders with the European Union, rendering border controls and anti-trafficking measures of joint interest. As two experts make clear, “states are aware that if nuclear security were to fail in one state, the implications of an incident would probably extend beyond that state’s national borders.”<sup>41</sup> This is particularly relevant for neighboring states. In this regard, the UK withdrawal of funding and expertise supporting nuclear security in Europe—and beyond the Continent through the Centers of Excellence Initiative—could negatively impact its own security.<sup>42</sup>

Moreover, despite a renewed “global” focus, the United Kingdom will remain distinctly interested in the European Union’s future, although less able to influence it to meet its own interests. In the words of the former foreign secretary Malcolm Rifkind, the United Kingdom will be in the position of “having given up the power to either control or influence policy, but seeking as outsiders nevertheless to influence it anyway, because the outcome would be very important to us.”<sup>43</sup> The European Union is also now represented in most international forums on nuclear matters, influences international standards, and remains the United Kingdom’s primary partner in nuclear-related trade. Without the United Kingdom, however, the European Union’s character as an international actor will change, particularly with regard to nuclear issues as the bloc loses a prominent pro-nuclear voice. The lack of formal ties could place a sizable burden on the United Kingdom’s diplomatic service, as it attempts to influence the European Union from the outside while developing ties elsewhere.

In this regard, the United Kingdom should identify and attempt to retain as much of the beneficial collaboration in nuclear security under its current relationship with Europe as possible. This, however, is also fraught with difficulties. While it could be argued that mutual interests could lead to the agreements simply being maintained, it overlooks the difficulties inherent in doing so. Precedents do exist for non-EU members to cooperate: several non-European states participate in

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40. Institution of Mechanical Engineers “Leaving the EU: The Euratom Treaty: Part 2: A Framework for the Future,” May 2017, <https://www.imeche.org/policy-and-press/reports/detail/leaving-the-eu-the-euratom-treaty-part-2-a-framework-for-the-future>.

41. Fowler and Carrigan, “Nuclear Security in European Union Member States,” 1.

42. The EU Chemical, Biological, Radiological, and Nuclear (CBRN) Risk Mitigation Centers of Excellence (COE) Initiative was launched in 2010 in response to the need to strengthen the institutional capacity of countries outside the European Union to mitigate CBRN risks.

43. Malcolm Rifkind, “Oral Evidence to the Foreign Affairs Committee: Costs and Benefits of EU Membership for the UK’s Role in the World Enquiry,” April 26, 2016, <http://www.parliament.uk/business/committees/committees-a-z/commons-select/foreign-affairs-committee/inquiries1/parliament-2015/eu-membership-foreign-policy/>.

EUSECTRA, while Europol currently has 18 bilateral agreements with non-EU states.<sup>44</sup> However, the United Kingdom cannot expect to exceed these precedents significantly; its current level of access and ability to influence direction will be curtailed. Non-EU states are, for instance, unable to access Europol information directly and must go through the secretariat, leading its current director to warn that the United Kingdom would find itself a “second-tier member” upon exiting the European Union.<sup>45</sup>

If the United Kingdom successfully renegotiates partnerships or associations with European bodies it may still not maintain its previous benefits. Switzerland, for instance, enjoys full access to Euratom research programs, but any British desire to surpass this may prove politically unpalatable, as it would invite the continued authority of the European Court of Justice in Britain.<sup>46</sup> To avoid these outcomes, the United Kingdom could attempt to negotiate a bespoke agreement with Euratom, as with Europol or other bodies, but doing so would require exceptions to be granted, thus consuming finite stocks of political capital during the current negotiations. Securing access to EU projects, such as nuclear research, could also be problematic in the longer term, and it may be used as leverage in other negotiations. Switzerland, for example, had its access to research funding restricted for over two years during a fight over the free movement of labor.<sup>47</sup> The sudden withdrawal of access could similarly be used as leverage against the United Kingdom on issues of migration or trade.

## POTENTIAL SOLUTIONS

The United Kingdom remains in a position to address the risks to its nuclear security as it disentangles itself from the European Union. Initially, interest in nuclear policy and Euratom could be broadened to cover all levels of nuclear cooperation the United Kingdom shares with the European Union. This would allow the government to assess the impact of leaving the mesh of mechanisms supporting UK nuclear security and to decide what can be reconstituted at a national level or replaced by other instruments and what should be prioritized in the exit negotiations. As stated previously, the government would also have to alter its approach to the negotiations to best safeguard British interests relating to the cooperative elements of the UK relationship with Europe. This will prove politically challenging and could be attended by several calculated risks, as noted already.

However, the United Kingdom does have flexibility when approaching the issue. First, nuclear security was not a contentious topic during the referendum. To date, this has resulted in the

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44. Europol, “Partners & Agreements,” accessed August 17, 2017, <https://www.europol.europa.eu/partners-agreements>.

45. Quoted in Joanna Dawson, “Exiting the EU and Security, Law Enforcement, and Criminal Justice,” House of Commons Library Debate Pack, January 13, 2017, 4, <https://researchbriefings.parliament.uk/ResearchBriefing/Summary/CDP-2017-0015#fullreport>.

46. European Commission, “Swiss Participation in Horizon 2020,” January 2017, 1, [http://ec.europa.eu/research/participants/data/ref/h2020/other/hi/h2020-hi-swiss-part\\_en.pdf](http://ec.europa.eu/research/participants/data/ref/h2020/other/hi/h2020-hi-swiss-part_en.pdf).

47. *Ibid.*, 2.

neglect of nuclear security, although it does mean that the United Kingdom is freer to decide how this element of the relationship should look following negotiations. In this vein, the February white paper outlines six individual international arbitration mechanisms, which may indicate the United Kingdom is willing to engage in previous areas of cooperation, such as in the nuclear field, but not under the jurisdiction of the European Court of Justice.<sup>48</sup> Second, both parties have emphasized their interest in retaining security cooperation. Theresa May's letter to Donald Tusk,<sup>49</sup> as well as the European Council's public negotiating platform,<sup>50</sup> reference security as an area where both parties have strong mutual interests. While mutual interests alone will not lead to an agreement, joint recognition of shared objectives in the security fields is a first step.

## CONCLUSION

The United Kingdom must recognize the challenges to safeguarding its nuclear security interests as it plans its departure from the European Union. The European Union contributes more than is commonly accepted to the nuclear security of its member states, albeit in a supporting role. As there are clearly shared interests in maintaining elements of the United Kingdom's current relationship in the field of nuclear security, policymakers must identify what it should retain, replace, or replicate. The United Kingdom must also understand the complexities inherent in doing so and, in this regard, amend its narrative. The position that "no deal is better than a bad deal" and the emphasis on a "Global Britain," as outlined in the February 2017 white paper, is applicable to trade, but clearly not appropriate for important areas of collaboration where the European Union is a natural partner. As such, while incorporating considerations of nuclear security into its negotiating platform and post-Brexit plans, the United Kingdom must reassess its current approach to these negotiations, especially on issues that did not guide the British public's decision to leave the European Union. To do otherwise would risk losing both a key partner and access to mechanisms that improve the United Kingdom's ability to prevent, detect, and respond to nuclear security threats.

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48. Her Majesty's Government, *The United Kingdom's Exit from and New Partnership with the European Union*, 69–72.

49. May, Letter to Donald Tusk Triggering Article 50, 4.

50. European Council, "European Council (Art. 50) Guidelines following the United Kingdom's Notification under Article 50 TEU," press release, April 29, 2017, sec. IV, para. 22, <http://www.consilium.europa.eu/en/press/press-releases/2017/04/29-euco-brexite-guidelines/>.



# Challenges That Arise from the Implementation of Distinctive Technologies within Nuclear Safety and Security

David N. Etim<sup>1</sup>

*The development of recent nuclear security technology has entered a period of generational change that poses great challenges to the computing industry and to scientific users but also presents an exciting opportunity to raise the awareness of science and technology within the field and how work in various disciplines will help address rising challenges. The management and operation of nuclear weapons has changed over the years because of technology that has transformed our daily lives. Peer-to-peer software, infrastructure transition for machines, expanded memory storage, and massive data collection capabilities have changed computing for nuclear security tools. Scientific and technical challenges in nuclear security are enabled by the emergence of extreme-scale computing and the development of modern technology for nuclear safety and security resources. Over the past decade, high-performance computing (HPC) architectures and their software and hardware components have undergone transitions to avoid being technologically disruptive while on the path toward new HPC for extreme-scale or exascale systems. These architectures have required substantial improvements to keep up with the processing and storage of large amount of data generated (so called "big data"), each year. Mathematical models,*

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*numerical algorithms, programming models and computer languages have all gone through substantive changes to stay valuable in each system.*

## INTRODUCTION

Developments in HPC, computational mathematics and physics, and constitutional theory have combined to make significant advances in simulation capability for complex multi-physics application areas. Fundamental theory has advanced through more sophisticated experiments that have opened the possibility for predictive capability when modeling multi-physics processes.<sup>2</sup> Nuclear science is essential in recent technologies because the energy that is being produced in nuclear processes has no carbon emissions and is sustainable. Nuclear reactions are the critical source of energy in various applications, including National Ignition Facility (NIF) capsules, energy production, and global threat reduction. Nuclear physics, materials science, and nonproliferation are also apparent in nuclear safety and security challenges, and each of their computational challenges factor into the advantages and disadvantages of recently developed technology.

To address recent challenges in nuclear security practices, the objective is to investigate research on related disciplines, analyze existing data, and provide analysis of the rising technological challenges in nuclear safety and security. The studies explained in this paper will go further into the advantages and disadvantages of their methodologies and serve as a step toward resolving various problems in nuclear technology. The president and his administration have invested time and resources in the nuclear security enterprise and scientific community to help meet challenges with innovation in science, technology, and engineering. These breakthroughs will improve nuclear security standards in an evolving national security frontier and, as new work emerges, could change the scientific and technological community within nuclear security.

This paper describes technologies from three major areas critical to nuclear modernization but that need technological reforms if they are to continue improving productivity. First, the paper will review work done in nuclear physics data management and the necessary capability for HPC to store data and research reproducibility. Next, it will review material science and the challenges of mechanistic understanding of environmental degradation and atomistic simulation on engineering time scales. Then, the paper examines nuclear nonproliferation science, with a discussion on improving the effectiveness of physical devices in proliferation detection and detailed explanations on aggregating large and diverse datasets and information exploration. Finally, the paper concludes with a summary of recent challenges in technologies involving nuclear safety and security and what can be done to continue addressing these problems.

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2. Alan Bishop et al., *Scientific Grand Challenges in National Security: The Role of Computing at the Extreme Scale*, (Washington, DC: U.S. Department of Energy, 2009), [https://science.energy.gov/~media/ascr/pdf/program-documents/docs/Nnsa\\_grand\\_challenges\\_report.pdf](https://science.energy.gov/~media/ascr/pdf/program-documents/docs/Nnsa_grand_challenges_report.pdf).

# NUCLEAR PHYSICS

Nuclear physics computations are relevant to all nuclear security applications, including advanced nuclear energy systems; global security applications such as nuclear detection, nonproliferation, nuclear forensics, and the physics of nuclear weapons; safety applications, including nuclear criticality safety, radiation protection, and shielding; and both diagnostic and therapeutic medical applications.<sup>3</sup> The simulation accuracy of the physics packages used in modeling all of these applications depends on the accuracy of a large phase space of nuclear data derived from nuclear physics theory, models, and experiments.<sup>4</sup>

An experiment that can be replicated by researchers independent from those that conducted it initially is called “reproducible research.” According to research conducted at Iowa State University, provenance, the beginning of one’s existence, is introduced to another scientific domain known as “ab-initio” nuclear physics calculations.<sup>5</sup> This term is defined as “started from the beginning,” corresponding with its relationship to provenance. Through a data management system, provenance information is recorded thoroughly for post-processing, verification, and research purposes. Because there is a large volume of data generated in each large-scale simulation of a nuclear physics experiment, the need for a data management system supplements the valuable high-performance computing capability of archiving information.

## Provenance

The provenance of an experiment is stored in the form of research papers, log books, and technical reports at national laboratories. Scientific endeavors have expanded in the past 10 years and the volume, difficulty, and availability of these reports has increased significantly. Consider a high-energy physics experiment, which requires conducting hundreds of tests and analyzing results, likely in multiple locations. Data must be exchanged during some point of the experiment, which leads to the following questions: Who performed the experimental tests? How were they performed? Are there multiple or duplicate results for the tests? Addressing the steps and variables in the environment is significant in answering these questions. Also, locating observations and describing the subject are significant in documentation of this experiment. If this information is available to those in charge of the experiment, or to the general public at any time, it is the application of provenance in reproducible research.

## Reproducible Research

Reproducible research (RR), research targeting a problem or reporting an innovation archived in the form of publications, has garnered attention in computer science. The main categories of

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3. G. Hagen, D.J. Dean, M. Hjorth-Jensen, T. Papenbrock, “Complex Coupled-cluster Approach to an Ab-Initio Description of Open Quantum Systems,” *Physics Letters B* 656, nos. 4–5 (November 2007): 169–173, <http://www.sciencedirect.com/science/article/pii/S0370269307010593>.

4. P. Navaratil, J.P. Vary, and B.R. Barrett, “Large-Basis Ab Initio No-core Shell Model and Its Application to  $^{12}\text{C}$ ,” *Physical Review C* 62, no. 5 (October 2000): 054311.

5. Fang Li et al., “A Data Management System for Ab-Initio Nuclear Physics Applications” (paper for the *Proceedings of the 19th High Performance Computing Symposium*, Boston, Massachusetts, April 3–7, 2011).

reported work are theory, physical experimentation, and numerical simulation. Theory is the only category derived through proofs, along with some assumptions and approximations. Therefore, this research can be understood and reproduced completely with sufficient theoretical and mathematical tools.<sup>6</sup> The disadvantage of RR is that physical experimentation and numerical simulation both correspond to the factors that change with time and environment, creating challenges for those hoping to demonstrate the same experiment or re-create the same simulation. RR aims to account for many variables in the computational simulation and can be enabled in nuclear physics applications. However, RR reduces the validation of the experiment if it cannot be re-created.

## Ab-Initio Nuclear Physics

Configuration interaction (CI), one computational approach in nuclear physics, provides a sufficiently large space to obtain numerically converged results when solving algorithms. CI code for ab-initio nuclear physics has been developed by James P. Vary and his collaborators at Iowa State University, and the software application Many Fermion Dynamics for nucleons (MFDn) is part of the United States Department of Energy (DOE) Scientific Discovery through Advanced Computing (SciDAC)/Universal Nuclear Energy Density Functional (UNEDF) project.<sup>7</sup> In MFDn, the nuclear quantum many-body Hamiltonian algorithm is evaluated in a large basis constructed from determinants of oscillator single-particle states and inclined by iterative techniques to obtain eigenvalues and eigenvectors. The eigenvectors are used to evaluate an array of experimental quantities to test credibility.

MFDn has good scaling properties using a combination of Message Passing Interface (MPI) and OpenMP, an application programming interface (API) for multi-platform, shared-memory parallel programming, on existing supercomputing architectures.<sup>8</sup> Algorithmic improvement has made a magnificent impact on overall performance in documenting and storing results as well as the essential provenance information for MFDn executions in a database for future information retrievals.

The justifications for a result-archiving system include:

- Avoiding repeats of similar calculations to increase efficiency in the use of resources,
- Promoting efficient and precise research by facilitating comparison of results between alternative methods and different input data,
- Providing a convenient technique to allow people to access well-formed nuclear structure calculations.

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6. Kiran-Kumar Muniswamy-Reddy, David A. Holland, Uri Braun, and Margo Seltzer, "Provenance-Aware Storage Systems" (paper for the *Proceedings of the Annual Conference on USENIX: '06 Annual Technical Conference*, Boston, Massachusetts, May 30–June 3, 2006).

7. Phillip Sternberg et al., "Accelerating Configuration Interaction Calculations for Nuclear Structure" (paper for the *Proceedings of the 2008 ACM/IEEE conference on Supercomputing*, Austin, Texas, November 15–21, 2008).

8. Pieter Maris et al., "Scaling of Ab-Initio Nuclear Physics Calculations on Multicore Computer Architectures," *Procedia Computer Science*, International Conference on Computer Science, no. 1 (May 2010): 97–106. <http://www.sciencedirect.com/science/article/pii/S187705091000013X>.

## Database Management System

A database management system (DBMS) should be consistent in the following functions:

- Inquiry or retrieval activity that amasses previously stored data to determine the recorded status of a real-time entity or relationship,
- Updating, including original storage of data, repeated modification as things change, and deletion from the system when the information or entry is no longer necessary.

Today, database management systems have database administrators who specialize in controlling database development, maintenance, creation, and optimization of database schema and queries. This work seeks to create a more user-friendly system, conversant with formal data management systems (DMS).

## Challenges

To ensure the DMS provides all the required data for research reproducibility, the following challenges need to be addressed:

- *Client-Server Computing.* There are two methods to record provenance information from an application: a provenance tool, which provides an instrumentation library inserted into an application, or a script that captures the experiment-related data and generates a purpose output for future data recording. The first method is called tight coupling, which gives completeness and consistency of the resulting provenance but can enforce substantial performance. This requires the DMS to provide the API for MFDn code to use when inserting experimental data to the database. The second method is called loose coupling, which allows the MFDn code and the DMS to run separately. The provenance information about the application is stored in a file during each run. This file contains all the information necessary to rerun the application, as well as results for future analysis and validation. Loose coupling is preferred because of its simplicity and superior modularity.
- *Large Output Files.* During a run on MFDn, a wavefunction file can be terabytes in size, which introduces HPC challenges of storing and accessing files. Database indexing and storage can become very slow for large volume databases. Large files (wavefunctions), as well as duplicates of smaller files can be typically stored in a High-Performance Storage System (HPSS). A strategy adopted here is to store the file path instead of the files themselves. The provenance and log files are also stored as their paths. When the files are moved to different storage locations, a script is needed to run updates on the database records with the new file paths.
- *Assuring Provenance.* Provenance information associated with MFDn can efficiently store the information file including the input, environment variables, and output of a run. This information can be a crucial factor for future runs, especially for computational runs that are considerably large. The log of each run is also needed for a reproducible run. Another file is used to store this step-by-step log of the Python script generator so that a reproducible run can be generated based on this file.

- *Ensuring Security.* A database administrator grants the database privileges, or permissions to access the DMS. For a user viewing information online, they can only read, and not alter, data, which reduces the risk of data corruptions. Permissions on the file system level are granted by storage authorities where the results of the MFDn are stored. Files may be transferred to various locations over a certain time, care must be taken to update these locations, and an authorization is required to update information. A web server separates the user from the actual results and code to ensure a better scheme of authorizations. Some users may have complete access to the code, data, and results, while others may have access to none of the data or results but still be able to access the database content online.

## MATERIALS SCIENCE

Computability and fidelity have remained two key challenges for materials simulation on petascale platforms. Much attention has been given to improving the accuracy of material models, and more progress could be achieved through improvements in simulation efficiency. For the affiliation between synthesis, processing, microstructure evolution, and resulting material properties, a simulation should cover relevant scale challenges, such as simulation time periods and platform space. Of these two challenges, simulation time is less likely to benefit directly from running existing material simulations on ultra-parallel exascale platforms as space can be effectively partitioned; but time cannot because time integration is innately sequential. Therefore, extending time scales accessible for materials simulations remains a difficult challenge and demands massive computing power.

### Mechanistic Understanding of Environmental Degradation

Another challenge remains the gaining of a mechanistic understanding of environmental degradation in which chemistry and stress effects are evaluated equally through a combination of electronic structure, atomistic, and mesoscale simulations, as well as validation experiments. Corrosion is a pervasive phenomenon intermediate to scientific studies and technological applications. It could be the oxidation of a high-temperature ceramic component in an aircraft engine or the weakening of quartz in the Earth's mantle.<sup>9</sup> Weapons materials are also known to corrode in the presence of oxygen, hydrogen, and water vapor. Scientists can identify a basic process that is essential to understanding the chemical mechanics of materials. At the conceptual level, the most compelling questions are about the interactions between the environments, the surface film, the underlying substrate, the presence of a corrosive species, and the spatial-temporal evolution of the film-substrate system to the point of collapse.

A phenomenon of very broad interest is stress-corrosion cracking.<sup>10</sup> One attempt to approach this process through multiscale modeling is to focus on the formation of a passive ultrathin oxide film

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9. Ken-ichi Nomura et al., "A Metascale Computing Framework for Large Spatiotemporal-Scale Atomistic Simulations" (paper for the *Proceedings of the International Parallel and Distributed Processing Symposium*, Rome, May 23–29, 2009).

10. Matteo Ciccotti, "Stress-Corrosion Mechanisms in Silicate Glasses," *Journal of Physics D: Applied Physics* 42, no. 21 (October 2009): 1–34.

and its evolution to the onset of structural breakdown.<sup>11</sup> At the molecular level, scientists need to treat charged defect transport and electron transfer in the aggregation of cation vacancies that eventually lead to film-substrate de-coherence and pit nucleation. This is an example of combining unit process, or charged transport, to study system-level behavior. Furthermore, by considering substrates of iron and nickel-chromium-iron alloys in a systematic study of pit nucleation and crack propagation simulations under controlled atmosphere and high-temperature and stress environments, scientists hope to achieve predictive insights into transgranular versus intergranular cracking in structural materials.

Materials failure at elevated temperatures and stresses, and in harsh chemical and radiation environments, remains a scientific challenge with far-reaching impact in national security and nuclear technology. It involves premature and catastrophic failure resulting from a complex combination of stresses and corrosive reactions further accelerated in the presence of high-radiation fluxes. Atomistic-level understanding of corrosion-initiation mechanisms is critical to microstructure optimization leading to the design of materials resistant to environmental degradation in general and stress corrosion cracking specifically. This is possible through the development of models capable of describing crack-tip behavior in an environment of hot temperatures, chemical attacks, and concentrated stress loading. Such models will be necessarily more sophisticated than the crack propagation models currently available. Using atomistic simulations to demonstrate stress corrosion cracking, distinct size domains will have to be considered with each requiring a different computational approach. The domains must be nested because regions far from process zones do not require the detailed description necessary for accurate prediction near the crack tip. Experience from these simulations will be useful for extracting an atomistic-level understanding of a broad class of materials-failure phenomena where corrosion plays a significant role.

### Atomistic Simulation on Engineering Time Scales

Accurate multiscale models for microstructural evolution on engineering time scales and deformation and failure under extreme conditions or environmental attack are necessary to meet certification challenges for nuclear weapons. Materials challenges essential for nuclear security span a wide range of issues, including radiation damage, thermal and irradiation creep, corrosion, plastic deformation, and material failure.<sup>12</sup> To address these developments, modeling methods that can reach time scales of milliseconds and shorter, as well as length scales of microns and beyond, need to be developed. A significant slice of essential physics lies at the mesoscopic scale, involving processes such as grain growth, annealing and interaction of radiation damage cascades, nucleation of phase transformations, and entanglement of dislocations. Multiscale approaches such as dislocation dynamics, thermochemical modeling, and phase field models can be applied in this regime. However, they need to be carefully parameterized and benchmarked. Molecular dynamics, with its atomistic fidelity, can provide the necessary input and validation results for the

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11. Bilge Yildiz, Anna Nikiforova, and Sidney Yip, "Metallic Interfaces in Harsh Chemo-Mechanical Environments," *Nuclear Engineering and Technology* 41, no. 1 (February 2009): 21–38.

12. Sidney Yip, "Multiscale Materials," in *Multiscale Methods: Bridging the Scales in Science and Engineering*, ed. Jacob Fish (New York: Oxford University Press, 2009).



higher-level methods. However, molecular dynamics, in its traditional implementation, has difficulties with reaching long time scales, a long-standing challenge still unresolved.

## Overall Challenge for Materials Research

Achieving a predictive, mechanistic understanding of real materials is also an overarching challenge to address. In these circumstances, microstructures and interfaces, kinetics, and environments all matter. The recent arrival of exascale computing, or computing systems that are capable of a billion calculations per second, allows for predictive capabilities to manipulate microstructures to enable the design and development of advanced materials.

## NONPROLIFERATION

Nuclear nonproliferation refers to preventing the spread of nuclear weapons both directly and indirectly through control of the nuclear materials and technologies required to make a usable weapon.<sup>13</sup> Nonproliferation is one of the most complex activities for the U.S. government due to the significant political and technological difficulties associated with the spread of nuclear technologies. Establishing nonproliferation policy is difficult because almost all aspects of the nuclear weapons development process have a complementary peaceful process associated with nuclear energy production or general scientific research.

Nonproliferation sciences seek to precisely identify entities engaged in acquiring the means to develop nuclear capabilities for testing, distributing, or acquiring nuclear devices or components. These processes are very data-driven. Information science techniques dominate this field, especially as data sets become larger. Determining better ways to extract and warehouse data, as well as finding more efficient ways to access and explore that data, continue to be difficult challenges. Approaches such as model building and validation for nonproliferation will certainly help, but will require the use of large and diverse data sets. Recent technology in nonproliferation depends on a massive amount of data processing and storage. This problem extends to a possible use of algorithms, such as Monte Carlo, as well as other analyses and techniques.

### Improving the Effectiveness of Physical Devices in Proliferation Detection and Data Analysis

Much of the limitation in identifying nonproliferation comes from physical detection abilities. For ground-based radiation detection, this includes gamma and neutron detection, and for remote sensing, detection consists of better observational capabilities for satellites. Both can be significantly helped by advances in materials science and manufacturing to build better physical devices. However, improving the physical devices is just one step toward advancing the effectiveness of proliferation detection. Considerable progress remains to be made in analyzing the data from physical devices. In most cases, the data contain uncertainties associated with, but not limited to, device imperfections, fundamental physical limitations, and statistical noise.

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13. Bishop et al., *Scientific Grand Challenges in National Security*.



Researchers are in an era with an increasingly large amount of data being generated in nonproliferation activities.<sup>14</sup> This includes spectral data associated with sensors, image data, text data that have been generated through several sources, and even observations of human activity. All of this information must eventually be aggregated so that it can be optimally used in modeling and analysis. Bringing together disparate data for effective use remains a difficult computer science problem for nonproliferation and for the broader Internet community. There are currently simple, ad hoc means of doing this for specialized situations, but understanding how to do this aggregation in a general sense for abstract data types remains a distant goal.

The effectiveness of collected data is only as useful as the information that an analyst can extract or mine from it. After distinct types of data have been collected, techniques for an analyst to explore the data will be needed. This mining process can involve specific types of queries where an analyst must have a means of phrasing a complex question of the data and have the computer return one or more potential answers and the associated confidence with the answer. Perhaps more powerful would be enabling an analyst to explore the data in a more nonspecific way, to look for potential patterns or anomalies.

Potentially, researchers' abilities to perform inversions on sensor data would remarkably reduce the uncertainty in the results of their sensors. This is significant in areas where the resolution of their sensors cannot be improved because of physical or geographical constraints. Using existing technology to produce raw data with less uncertainty would significantly decrease the risk in very consequential decisions made on sensitive nonproliferation issues.

## Information Extraction and Aggregation

A variety of data types are used to build information about nonproliferation. For instance, in spectra collected from sensors, the relationship between the data and what information it represents is relatively straightforward. In other instances, the data must be significantly processed to extract information. One of the most well-known cases is image data. Many overhead images have been collected and are constantly being collected by several different means. Image data are an excellent example of pure "data," because they are simply a collection of bits that are information free until examined by a human analyst. Before this happens, the bits are converted to a set of colored and spatially structured pixels from which an analyst can pick specific patterns and spatial relationships that represent information. This process of identifying the patterns and spatial relationships in images has long been the target of an enormous amount of research in computer science, and it remains one of the areas that HPC could affect enormously, and not only for nonproliferation, but for many other areas of science and society.

There are two primary reasons why using computation to extract information from images could change the landscape of how scientists work in the nuclear security field. First, annotating images is currently a rate-limiting step in many types of analyses because there is often a human in the loop. Progress in solving the computer image analysis problem would allow the current process to go much faster and could enable a completely new paradigm in imaging where a much larger

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14. E.N. Avrorin, A.N. Chebeskov, "Fast Reactors and Nuclear Nonproliferation Problem," *Nuclear Engineering and Technology*, no. 1 (February 2015): 1–7.

number of images could be obtained and analyzed through advanced digital image processing, or the capability to perform operations to produce an enhanced image and extract useful information from it. The second driver for computational image analysis is somewhat more revolutionary and is very tightly coupled to the notion of translating data to information. There is a strong need to capture the information in images in a way that can be used by computers to turn that information into knowledge. This means not only trying to identify features in an image, but capturing the list of features and the relationships between them in a way that can be meaningfully used in a computational way. This could lead to a reduction by many orders of magnitude in storage costs if users did not need to store the images themselves but just the information contained in them.

Another important source of data is text, especially in electronic or online form. Most publicly available text data are available through the Internet, and even confidential data usually have an electronic representation that can be easily used.<sup>15</sup> Text is data and not information until the relevant information can be extracted. Textual analysis and summarization can also be a “bottle-neck” if completed by a human analyst. Another tool called natural language processing is a rapidly maturing field in computer science that deals with extracting information from text. This can be completed with a specific analytical end in mind or in a more discovery-focused way through which anomalous events can be found. Human-behavior observational data are a related type of data. This information is often recorded as a text description and must be summarized in a way that can be used by machines.

## Information Exploration

Information exploration is an iterative, user-driven process in which users interact with data to discover, develop, and refine hypotheses from the data through sorting, filtering, projection, classification, clustering, and other mathematical techniques. Unfortunately, most users currently must make the choice between throwing away data because they are too voluminous—a process that will prevent one from finding the unexpected—accepting “heroic” computing times as the rate-limiting step in the analysis process, which could be from months to years. Neither option is acceptable in nonproliferation sciences where the results of conclusions, which drive the severity of actions, require extreme fidelity. Also, acceptability is impacted by the time sensitivity of arriving at an actionable conclusion.

## Potential Impact on Nuclear Safety and Security

The United States Department of Energy has a long body of research in nonproliferation sciences that would provide a sound basis for national security at the extreme scale. DOE is uniquely positioned to integrate extreme-scale computing into nonproliferation sciences because of its leadership role across the HPC spectrum. DOE houses mature applications for data management, integration, and workflow development, as well as visualization. There will likely be a strong mathematical research element to algorithms that operate on data at the extreme scale. Applications will have to deal with missing data, corrupt data, uncertainty quantification and aggregation, data fusion, statistical issues that arise with extremely large data sets, and other challenges. These research

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15. Bishop et al., *Scientific Grand Challenges in National Security*.

areas already have many mature applications within the government's research portfolio. It is expected that similar expertise to that which has advanced basic and applied sciences can be brought to bear on proliferation sciences. Successfully enabling nonproliferation sciences at the extreme scale will enable researchers to rapidly find the unexpected and transform the security landscape from hypothesis driven to data driven, where the best hypothesis is discovered rather than guessed. This can be done through data-driven analysis that is informed by the complete body of data available to researchers and decisionmakers by integrating extreme-scale computing, algorithmic advances, sophisticated visual metaphors, and browsing capabilities in integrated workflows.

## CONCLUSION

The development of nuclear security technologies has entered a period of generational change that poses great challenges to the computing industry and scientific users. Also, it is an exciting opportunity to raise the awareness of science and technology within the field and how work in various disciplines will help address recent challenges. Disciplines such as nuclear physics, materials science, and nuclear nonproliferation are key fields because they make up part of the nuclear security enterprise and how experiments, research, and program management are performed. This paper has highlighted work from those disciplines and recent challenges that had been worked on or are still unresolved. It is important to give a detailed background on the various fields within nuclear security and what are key factors in technology that affect nuclear issues. The U.S. government has invested time and resources in the scientific community to help meet our challenges with innovations in science, technology, and engineering. These breakthroughs will benefit our country's future in nuclear safety and security as we continue to stay aware of our national security frontier and adapt to new work that could change the scientific and technological community within the nuclear realm.

# A Nuclear South Korea

April R. Gillens<sup>1</sup>

*Known for its robust reactor industry, South Korea is a leading producer of nuclear energy. However, given lasting tensions with its northern neighbor, it is possible that South Korea desires its own nuclear deterrent for national security. The U.S.-Republic of Korea Civil Nuclear Cooperation Agreement, more commonly known as the 123 Agreement, signed in June 2015, may allow South Korea to pursue nuclear reprocessing in the future. This will close the loop on South Korea's nuclear fuel cycle and alleviate the burden of maintaining interim spent fuel storage pools, but also provide a pathway for the production of weapons-usable nuclear material. This paper evaluates steps in South Korea's nuclear fuel cycle to show how they might overcome the technical barriers needed to acquire nuclear weapons if granted reprocessing privileges from the U.S.-South Korea Joint Fuel Cycle Study commissioned by the 123 Agreement. South Korea's nuclear latency lies within its reactor industry, which produces a combined annual average of 10 tons of plutonium (Pu). Political considerations aside, South Korean advances in nuclear reprocessing may allow Seoul the technological knowledge to advance its nuclear ambitions.*

## INTRODUCTION

From a technological standpoint, the possibility of South Korea following in North Korea's footsteps and developing nuclear weapons may not be far-fetched. South Korea could obtain privileges to enrich uranium and reprocess spent nuclear fuel as a result of the U.S.-South Korea Joint Fuel Cycle Study commissioned by the U.S.-Republic of Korea Civil Nuclear Cooperation Agreement, commonly known as the 123 Agreement, signed in June 2015.<sup>2</sup> South Korea has practical reasons for acquiring advanced nuclear technology. In 2014, South Korea ranked number nine in

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1. At the time of writing, April Gillens was a National Nuclear Security Administration (NNSA) graduate fellow supporting the Defense Program's Office of Research and Development. Gillens is now a contractor to the NNSA supporting Defense Nuclear Nonproliferation's Office of International Nuclear Safeguards. The views expressed in this paper are her own and do not reflect those of the NNSA and its contractors.

2. Sharon Squassoni, "U.S.-South Korean Peaceful Nuclear Cooperation Agreement," *CSIS Critical Questions*, October 2, 2016, <https://www.csis.org/analysis/us%E2%80%93south-korean-peaceful-nuclear-cooperation-agreement>.

global energy consumption, consuming more energy than France and the United Kingdom.<sup>3</sup> South Korea depends on foreign sources of energy to meet the majority of its demand, and about 35 percent of its electricity production comes from nuclear reactors.<sup>4</sup> Reprocessing would help South Korea fill this energy shortfall by utilizing spent fuel in its reactors. Other reasons are fiscal; South Korea asserts that it would enrich uranium at more competitive rates than current commercial enrichers.<sup>5</sup> While these reasons seem harmless, there is always a potential for a peaceful nuclear energy program to be diverted for production of nuclear weapons; North Korea is a prime example.

Technically, South Korea is still bound to the 1992 Joint Declaration on the Denuclearization of the Korean Peninsula, which prevents North and South Korea from advancing nuclear technologies to enrichment and reprocessing. This bilateral agreement has clearly been violated by North Korea through the duration of its nuclear weapons program, though in theory South Korea remains bound to the treaty. While South Korea currently shows no signs of abrogating its commitment to the treaty and its claims of energy security seem innocuous, South Korea's history would suggest that a dash toward nuclear weapons is possible.

Claims for energy security were partially the reason South Korea covertly initiated its first weapons program after news broke of its negotiations with the French to purchase a reprocessing plant in 1975.<sup>6</sup> Following the implementation of the 1969 Guam Doctrine by U.S. President Richard Nixon, South Korea lost support of the American Seventh Infantry Division. Although the United States provided continued military support in South Korea with the Second Infantry Division and with nearly 700 nuclear weapons deployed in South Korea, President Park Chung-Hee chose to investigate a nuclear option following the recommendation of his Weapons Exploitation Committee, which was a "covert, ad hoc governmental committee responsible to the Blue House for weapons procurement and production."<sup>7</sup> This option was well investigated by two ad hoc working groups that studied how the South Korean nuclear arms industry could be upgraded. Established in 1970, the South Korean Agency for Defense Development (ADD) researched strategies to modernize its military nuclear capabilities and, by late 1973, a long-term plan for nuclear weapons development was completed. According to the ADD, the program would take six to 10 years and cost \$1.5 billion to \$2 billion. The program involved more than 20 scientists who reported monthly research results

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3. U.S. Energy Information Administration (EIA), "International Energy Data and Analysis," 2016, <http://www.eia.gov/beta/international/>.

4. World Nuclear Association, "Nuclear Power in South Korea," July 2017, <http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/south-korea.aspx>.

5. Sharon Squassoni, "Unique Nuclear Allies: The New U.S.-South Korea Nuclear Cooperation Agreement," *CSIS Policy Perspectives*, October 1, 2016, <https://www.csis.org/analysis/unique-nuclear-allies-new-us-south-korea-nuclear-cooperation-agreement>.

6. Andrew Mack, ed., *Asian Flashpoint: Security and the Korean Peninsula* (St. Leonards, NSW: Allen & Unwin, 1993).

7. U.S. Congress, House Committee on International Relations, *Investigations of Korean-American Relations, Report of the Subcommittee on International Organizations*, 95th Cong., 2nd sess., 1978, 79, <https://archive.org/details/investigationofk00unit>. This document is sometimes referred to as the Fraser Report, after the subcommittee's chairman, Representative Donald Fraser.

to President Park Chung-Hee.<sup>8</sup> The largest technical barrier that prevented South Korea from obtaining special nuclear material (highly enriched uranium, uranium-235, plutonium-239, and uranium-233) was a lack of access to nuclear reprocessing, which necessitated negotiations with France. Eventually, South Korea abandoned its nuclear program amid threats from the United States and signed the Non-Proliferation Treaty (NPT) in 1975.

For states that have signed the NPT, the International Atomic Energy Agency (IAEA) has the responsibility to detect the diversion of nuclear materials from civilian to military purposes. Showing its effectiveness in international safeguards, the IAEA confirmed Iraq's illicit nuclear weapons program after the country lost the 1991 Gulf War. However, the Iraqi weapons program went unnoticed for four years because many of its nuclear facilities were undeclared and not subject to IAEA inspections. To correct this oversight, NPT nations adopted the Additional Protocol to standing safeguards agreements, which grants the IAEA greater access to inspect state facilities and gain information about a state's nuclear activities.<sup>9</sup> South Korea has been fully compliant with the Additional Protocol since its entry into force in 2004.<sup>10</sup>

Both South Korea's pledge to not acquire nuclear weapons and its compliance with nuclear safeguards are promising, but there may remain a temptation for diversion from peaceful nuclear technology into a weapons program. While the international nonproliferation regime has proved to be robust, it cannot always stop a state from going rogue. The question will always remain as to whether South Korea will trek its former nuclear path to covertly develop weapons by bluffing IAEA safeguards agreements or by completely withdrawing from its international obligations. Although South Korea has legitimate reasons for obtaining privileges to nuclear reprocessing, this will give the country a foot in the door to overcoming the technological hurdle that prevented South Korea from developing nuclear weapons in the 1970s.

Storage issues with spent nuclear fuel (SNF) present another reason South Korea might need technological advances to its nuclear fuel cycle (NFC). As South Korea continues to operate its 26 nuclear power plants, concerns of SNF management grow. Although South Korea has depended on Japan for reprocessing its SNF, this is not economically feasible.<sup>11</sup> South Korea would benefit from having its own reprocessing capability to alleviate its temporary SNF storage facilities and to achieve independence in its NFC. However, reprocessing, which separates plutonium from uranium in used fuel, would allow South Korea to hedge its bets in obtaining nuclear material for a covert nuclear weapons program.

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8. See the remarks of Republic of Korea (ROK) National Assemblyman Kang Chong-sung in relation to an ongoing parliamentary investigation of the ADD, in *Hanguk Kyongje Sinmun*, "Emerging Nuclear Potential," Foreign Broadcast Information Service (FBIS), October 6, 1995, 10.

9. James E. Doyle, *Nuclear Safeguards, Security, and Nonproliferation* (Amsterdam: Elsevier Butterworth-Heinemann, 2008), 6.

10. International Atomic Energy Agency, "Status of the Additional Protocol," July 2017, <https://www.iaea.org/topics/additional-protocol/status>.

11. Mack, *Asian Flashpoint*.

South Korea is determining if pyroprocessing (detailed below) is a technically and economically realistic path to resolving current SNF storage problems.<sup>12</sup> Many consider pyroprocessing to be a proliferation-resistant form of reprocessing because it does not produce a pure stream of plutonium. Instead, plutonium is separated with other transuranic elements and uranium with fission products—both unattractive for use in nuclear weapons. The plutonium and transuranic elements from pyroprocessing can be recycled in fast breeder reactors. This will lessen the radioactive waste requiring geological disposal in South Korea, making this form of reprocessing more attractive to manage the vast amount of spent fuel rapidly accumulating every year.

The United States has not issued advanced consent required by the 123 Agreement for South Korea to employ pyroprocessing. Instead, the agreement yields a possibility that the United States will consider such technology after completion of the U.S.-South Korea Joint Fuel Cycle Study in 2021, which will determine the feasibility and ability to safeguard pyroprocessing.<sup>13</sup>

Although necessary to divert a peaceful nuclear energy program, reprocessing is only one step in the NFC. While pyroprocessing is “proliferation resistant,” there are multiple proliferation pathways in the NFC that could lead to the production of weapons-usable material for a covert nuclear weapons program. It is possible that South Korea is hedging its bets to advance in nuclear technologies for the purpose of acquiring nuclear weapons by using issues of energy demand and spent fuel management as plausible deniability.

## TECHNICAL BARRIERS AND SOUTH KOREA’S NFC

In a paper describing the technical barriers to proliferation and the possibility of early detection, H. L. Chang states that “technical barriers to proliferation can be categorized as barriers representing technical difficulty in making weapons and barriers representing the difficulty in handling and processing material.”<sup>14</sup> In addition to these barriers, the risk of detection will also make diversion a challenge. There are multiple avenues in the NFC that may present proliferation pathways for plutonium production and highly enriched uranium. The generalized steps of the NFC are illustrated in Figure 1.

The two most common types of NFCs are open and closed. An open NFC directly disposes SNF in a deep geological repository, while a closed NFC recycles fissile nuclides, mainly uranium-235 (U-235) and plutonium-239 (Pu-239), via reprocessing of SNF. South Korea has an open NFC, but there is no deep geological repository for storage of high-level radioactive waste.

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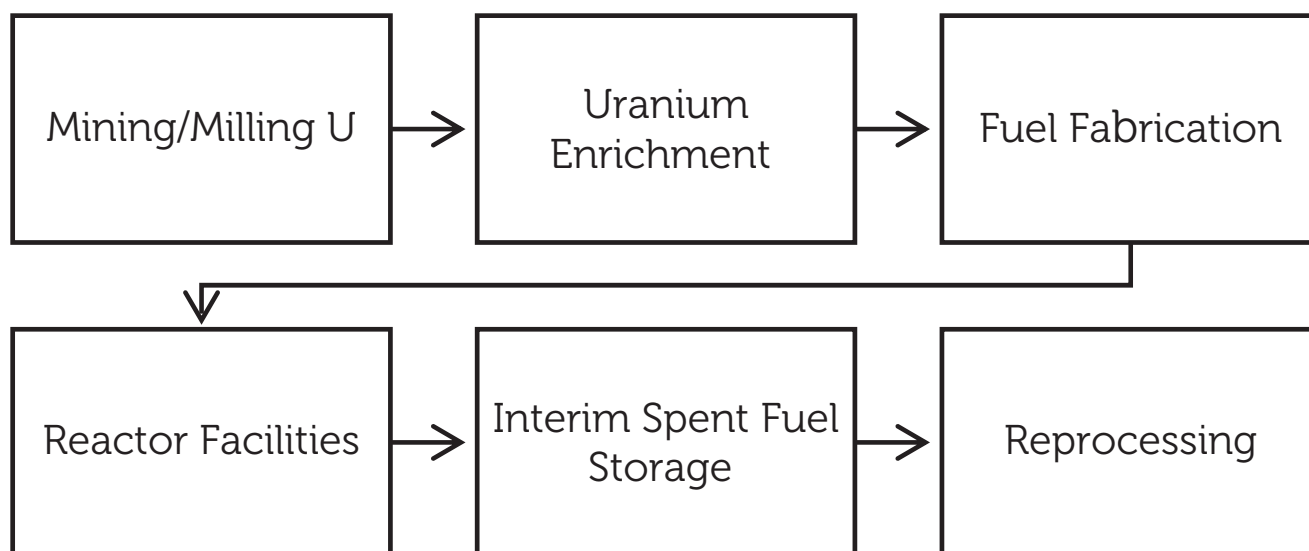
12. Sungki Kim et al., “Advanced Depreciation Cost Analysis for a Commercial Pyroprocess Facility in Korea,” *Nuclear Engineering and Technology* 48, no. 3 (June 2016): 733–743, <http://www.sciencedirect.com/science/article/pii/S1738573316000449>.

13. Dueyon Kim, “Decoding the U.S.-South Korea Civil Nuclear Cooperation Agreement: From Political Differences to Win-Win Compromises,” *CSIS Korea Chair Platform*, September 30, 2015, <https://www.csis.org/analysis/decoding-us-south-korea-civil-nuclear-cooperation-agreement>.

14. H. L. Chang, W. I. Ko, and H. D. Kim, “Technical Barriers to Proliferation,” *Transactions of the Korean Nuclear Society Spring Meeting*, Jeju, Korea, May 17–18, 2012.



**Figure 1. General Steps of the Nuclear Fuel Cycle**



### Mining/Milling of Uranium

Because South Korea lacks uranium deposits, it imports uranium from Australia, Canada, Kazakhstan, Niger, and other countries for use in nuclear reactors.<sup>15</sup>

### Uranium Enrichment

There is no independent uranium enrichment capability or technology in South Korea. Enriched uranium comes mainly from U.S. and French enrichment services. South Korea has invested resources in a long-term program with AREVA NP for stakes in enrichment services at the Georges Besse II plant in France.<sup>16</sup>

### Fuel Fabrication

South Korea owns and operates a fuel fabrication plant at Daejeon. The plant was constructed in 1986, began operation in 1989, and delivered fuel rods for the Kori 2 reactor in 1990.<sup>17</sup> South Korea continues to fabricate and supply its own nuclear fuel for legacy and advanced design reactors.

### Reactor Facilities

The irradiation of fuel in a reactor leads to the production of fissile Pu-239, which can be used directly in a nuclear weapon upon reprocessing. South Korea has progressively expanded its reactor facilities over the years (Table 1). Now operating 26 reactors, South Korea has a total net capacity of 24 gigawatt-electric (GWe). The pressurized water reactors (PWRs) were supplied by

15. World Nuclear Association, "Nuclear Power in South Korea: Fuel Cycle: Front End," July 2017, <http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/south-korea.aspx>.

16. Ibid.

17. Mack, *Asian Flashpoint*.

**Table 1. Operating Power Plants in South Korea**

Reactor	Type	Net capacity (MWe <sup>1</sup> )	Operation (mo/yr)
Kori 1	PWR <sup>2</sup> —Westinghouse	576	4/78
Kori 2	PWR—Westinghouse	640	7/83
Wolsong 1	PHWR—CANDU 6	657	4/83
Kori 3	PWR—Westinghouse	1011	9/85
Kori 4	PWR—Westinghouse	1012	4/86
Hanbit 1, Yonggwang	PWR—Westinghouse	996	8/86
Hanbit 2, Yonggwang	PWR—Westinghouse	988	6/87
Hanul 1, Ulchin	PWR—Framatome	969	9/88
Hanul 2, Ulchin	PWR—Framatome	965	9/89
Hanbit 3, Yonggwang	PWR (System 80) <sup>3</sup>	994	12/95
Hanbit 4, Yonggwang	PWR (System 80)	970	3/96
Wolsong 2	PHWR—CANDU <sup>4</sup>	647	7/97
Wolsong 3	PHWR—CANDU	651	7/98
Wolsong 4	PHWR—CANDU	653	10/99
Hanul 3, Ulchin	OPR-1000 <sup>5</sup>	997	8/98
Hanul 4, Ulchin	OPR-1000	999	12/99
Hanbit 5, Yonggwang	OPR-1000	998	5/02
Hanbit 6, Yonggwang	OPR-1000	993	12/02
Hanul 5, Ulchin	OPR-1000	998	7/04
Hanul 6, Ulchin	OPR-1000	997	4/05

*(continued)*

**Table 1. (continued)**

Reactor	Type	Net capacity (MWe <sup>1</sup> )	Operation (mo/yr)
Shin Kori 1	OPR-1000	997	2/11
Shin Kori 2	OPR-1000	997	7/12
Shin Wolsong 1	OPR-1000	997	7/12
Shin Wolsong 2	OPR-1000	993	7/15
Shin Kori 3	APR1400 <sup>6</sup>	1383	12/16
Shin Kori 4	APR1400	1400	3/17
<b>Total: 26</b>		<b>24,481</b>	

Source: World Nuclear Association, "Nuclear Power in South Korea: Nuclear Facilities," July 2017, <http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/south-korea.aspx>. World Nuclear Association.

1. Megawatt-electric
2. Pressurized Water Reactor (light water reactor)
3. PWR designed by Combustion Engineering
4. Canada Deuterium Uranium Reactor (pressurized heavy water reactor)
5. Optimized Power Reactor
6. Advanced Pressurized Reactor

the United States and the pressurized heavy water reactor (PHWR) by Canada. The optimized power reactor (OPR) was designed and developed by Korea Hydro & Nuclear Power (KHNP) and the Korea Electric Power Cooperation (KEPCO) as Generation II reactors. Also developed by KEPCO, the advanced pressurized reactor (APR) is a Generation III reactor. South Korea is expected to commercialize its Generation IV reactors by 2030.

South Korea continues to increase self-sufficiency and technological independence in obtaining and maintaining the industrial infrastructure and manufacturing needed for a robust nuclear energy program. In addition to the reactors in operation, South Korea plans to expand its inventory, nearly doubling its operating capacity by 2030. Table 2 shows reactors planned and under construction.

South Korea needs a robust nuclear energy enterprise because of its growing energy demands. In 2010 alone, South Korea imported roughly 97 percent of its electrical energy (fossil fuel) from the United States for a price of \$122 billion. While nuclear energy provides a pathway for South Korea to become self-reliant in electrical energy, it also increases the production of weapons-usable Pu-239. Table 3 shows the amount of Pu-239 produced per reactor type.

**Table 2. South Korean Reactors under Construction or Planned**

Reactor	Type	Gross capacity (MWe) <sup>1</sup>	Start construction	Operation
Shin Hanul 1, Ulchin	APR1400 <sup>2</sup>	1400	July 2012	April 2018
Shin Hanul 2, Ulchin	APR1400	1400	June 2013	February 2019
<b>Tot. Under Const: 2</b>		<b>2800</b>		
Shin Kori 5	APR1400	1400	Early 2017	March 2021
Shin Kori 6	APR1400	1400	September 2017	March 2022
Shin Hanul 3, Ulchin	APR1400	1400	May 2017	December 2022
Shin Hanul 4, Ulchin	APR1400	1400	2018	December 2023
Cheonji 1	APR+	1500	2022?	December 2026
Cheonji 2	APR+	1500	2023?	December 2027
Cheonji 3/Daejin 1	APR+	1500	2025?	2029?
Cheonji 4/Daejin 2	APR+	1500	2026?	2029?
<b>Total Planned: 8</b>		<b>11,600</b>		

1. Megawatt-electric

2. Advanced Pressurized Reactor

The values from Table 1 can be used to quantify the amount of Pu-239 that South Korea is capable of producing, using the following equation:<sup>18</sup>

$$\text{Amount of fissile Pu-239 (tons)} = \text{PR} \left( \frac{\text{g}}{\text{MWe}} \right) \times \text{NC} \left( \frac{\text{MWe}}{\text{yr}} \right) \times \text{CF} \times 1.10 \times 10^{-6} \left( \frac{\text{tons}}{\text{g}} \right)$$

Where PR is the production rate of Pu-239 from Table 3, NC is the net capacity of reactor production from Table 1, and CF is the assumed capacity factor for PWRs and PHWRs in South Korea. The capacity factor is the ratio (or percentage) of the net electricity generated, for the time considered, to the energy that could have been generated at continuous full-power operation during the same

18. Ibid.

**Table 3. Plutonium Production per Reactor Types**

Reactor Type	Irradiation amount of heavy metal (MWd/kg) <sup>1</sup>	Average enrichment (% U-235)	Initial fuel inventory (kg/MWe) <sup>2</sup>	Pu-239 production (g/MWe/yr) <sup>3</sup>
PWR <sup>4</sup>	22.6	2.3	365	255
PHWR (CANDU) <sup>5</sup>	6	0.711	143	490

Source: B. Jasani, "Introduction," in *Nuclear Energy and Nuclear Weapon Proliferation*, ed. F. Barnaby et al. (London: Taylor and Francis, 1979), 2–3.

1. Megawatt-day per kilogram

2. Kilogram per megawatt-electric

3. Gram per megawatt-electric per year

4. Pressurized water reactor

5. Pressurized heavy water reactor Canadian Deuterium Uranium

period.<sup>19</sup> The capacity factor for PWRs and PHWRs is about 82 percent.<sup>20</sup> With 21 PWRs and 4 PHWRs, South Korea has produced 5.86 tons of Pu-239 in 2016 alone (assuming that all reactors ran optimally and that no Pu-239 was recycled).

By using the same equation above and the information from Tables 1 and 3, Figure 2 illustrates the tons of Pu-239 produced per year in South Korea. Figure 3 gives the cumulative values of Pu-239. Data in these figures assume that no Pu-239 has been recycled.

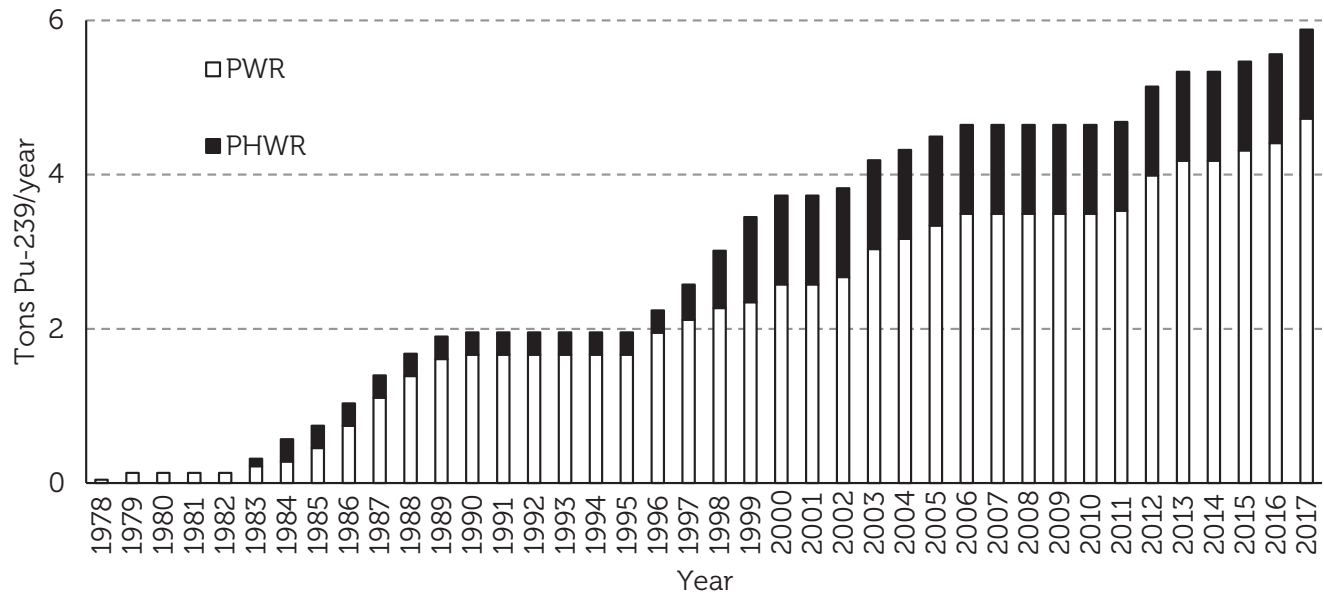
### Interim Spent Fuel Storage

South Korea has a spent fuel management problem. Figure 3 shows that South Korea will accumulate nearly 120 tons of Pu-239 by the end of 2017. Pu-239 is only a small component of spent nuclear fuel, which is comprised of transuranic elements, activation products, fission products, and uranium. Altogether, South Korea is discharging approximately 760 tons of spent fuel annually from its 26 nuclear reactors. Space for spent fuel is becoming a serious problem, and with plans for additional reactors, there is great concern for how to manage the amassing spent fuel. South Korea currently stores its spent fuel at its four reactor sites: Kori, Ulchin, Yonggwang, and Wolsong. While there are plans to increase existing spent-fuel pool storage capacities at the four reactor sites, the current and future storage capacity will not be enough to handle the expected 51,000 tons of spent PWR fuel and 20,000 tons of spent PHWR fuel to be generated from the 35 PWR and

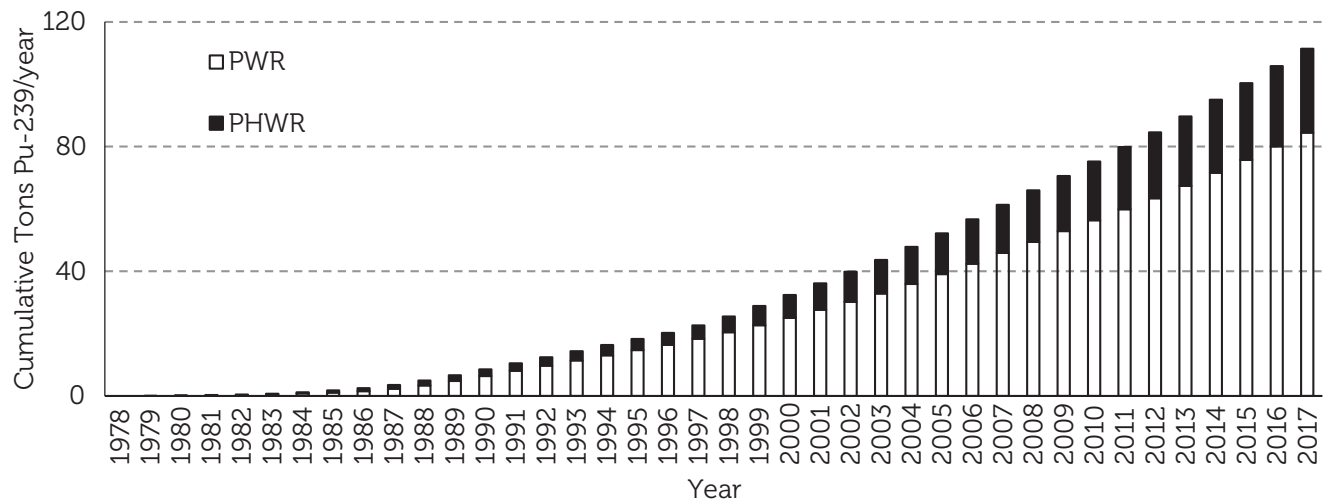
19. U.S. Nuclear Regulatory Commission (NRC), "Glossary—Capacity Factor (net)," April 2017, <https://www.nrc.gov/reading-rm/basic-ref/glossary/capacity-factor-net.html>.

20. World Nuclear Association, *World Nuclear Performance Review 2016* (London: World Nuclear Association, 2016), <http://world-nuclear.org/getmedia/b9d08b97-53f9-4450-92ff-945ced6d5471/world-nuclear-performance-report-2016.pdf.aspx>.

**Figure 2. Pu-239 Production per Year in South Korea**



**Figure 3. Cumulative Pu-239 Production of Pu-239 per Year**



4 PHWR units that will be deployed by 2035.<sup>21</sup> These concerns gave rise to the interest in pyroprocessing as a spent fuel management option.

## Reprocessing Facilities

Initiated by the Korean Atomic Energy Research Institute (KAERI), pyroprocessing electrochemically separates plutonium and other transuranics from uranium and other fission products and then dissolves spent fuel into molten salt. The proliferation-resistant features of pyroprocessing will provide a barrier against South Korea developing a nuclear weapons program. While pyroprocessing may be a feasible solution to South Korea's spent fuel management problem, the United States

21. Jung Min Kang, "The Search for Interim Spent Nuclear Fuel Storage in South Korea," *Global Energy Monitor* 3, no. 5 (May 2015), <http://www.egskorea.org/en/egs/egs02.php>.

may not grant such privileges because doing so might increase difficulties in convincing North Korea to cease its reprocessing and enrichment operations.

## CONCLUSION

While South Korea may not have uranium reserves, enrichment facilities, or full-scale reprocessing technologies, it has a robust reactor industry and tons of SNF that could lead to nuclear weapons production. South Korea could build facilities to reprocess SNF and build nuclear weapons following in the footsteps of North Korea. While South Korea has overcome many hurdles in acquiring nuclear weapons, it lacks the technology to produce and recover the fissile material needed to manufacture a nuclear weapon. In addition to obtaining special nuclear material, South Korea would also need to build weapons facilities to weaponize its fissile material. Many of the activities needed to foster a nuclear weapons program would go under the radar to maintain the appearance of a peaceful nuclear energy program. However, if South Korea were to go rogue and violate its peaceful nuclear cooperation agreement with the United States, it would likely be advanced enough in technological readiness to obtain weapons-usable material for weapons fabrication.

Although South Korea has plausible reasons for requesting advances in nuclear capabilities to enrich uranium and reprocess SNF because of its energy demands and competitive enrichment rates for the current commercial market, its ultimate motive for this advance could be to develop a nuclear weapons program. If the results of the U.S.-South Korea Joint Fuel Cycle Study lead to a decision where consent is given for South Korea to proceed with pyroprocessing, South Korea could follow the steps of North Korea and obtain the means to produce nuclear weapons in the future. This action would set a precedent for many other nonnuclear weapons states to receive “peaceful” nuclear technologies with potential for diversion. Upon evaluation of South Korea’s NFC, this paper concludes that South Korea has not overcome technical barriers to hedge its bets in acquiring nuclear weapons. Even if such were true, the will to divert a peaceful nuclear energy program is not plausible for South Korea, given the potential stakes in losing its alliance with the United States.



# Technological Approaches to the Problem of Counterproliferation in a Nuclear Energy Rich World

Jeffrey J. Graham<sup>1</sup>

*Nuclear energy is on the rise worldwide as countries look to provide large amounts of reliable, clean, and sustainable power to fuel their economies. Advanced fuel cycles could enable more energy independence and the reduction of operational burdens to new nuclear-employing nations. At the same time, the growing footprint of nuclear technology—with some 57 reactors under construction at the time of this writing—and the basic requirement of nuclear fuel increases the possibility for nuclear weapon proliferation. Reactor start-ups frequently tout their technologies as being proliferation resistant but often do not provide substantial evidence or arguments supporting their claims. This paper seeks to provide a high-level discussion of reasonable technical metrics for proliferation-resistant reactors, thereby offering general rules and background that may be used to determine relative assessments of reactor technologies. The paper then applies the resulting tools to several reactor types currently proposed and in development. Generally, there are advantages of proliferation resistance in the more advanced reactors, with some utility to be had in the less technologically aggressive reactors. All can have positive impacts on nuclear nonproliferation. Policies to support new reactors should be implemented, and include increasing public investment in converter and plutonium-utilizing reactors; developing and leasing small modular reactor technology; investing in waste reprocessing and solving the ongoing problems of waste management; and dramatically increasing public education on the advantages of peaceful nuclear energy.*

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## INTRODUCTION

Nuclear energy is inevitable. To meet the world's energy and climate goals, nations are turning to it as a source of sustainable power. Around the world, the quantity and logistics tail of nuclear energy is increasing. Reactor complexes are under construction in the United Arab Emirates,<sup>2</sup> Britain,<sup>3</sup> India,<sup>4</sup> and Russia.<sup>5</sup> China alone has 20 reactors under construction. Belarus, hoping to reduce its dependence on foreign energy supplies,<sup>6</sup> has begun work on its first two reactors expected to come on line sometime around 2020. The list goes on. The World Nuclear Association reports that "over 20" currently nonnuclear countries have plans to acquire nuclear energy, and more are considering it.<sup>7</sup>

The Non-Proliferation Treaty (NPT) acknowledges that every nation has the inalienable right to pursue nuclear energy for peaceful purposes.<sup>8</sup> At the same time, the increased global demand for nuclear energy generates risks for proliferation, which nuclear operators are obliged to minimize. Previous efforts to control the risk of proliferation have focused, with some success, on international safeguards designed to account for nuclear materials of significant quantity and limit the need for independent enrichment capability. Yet, as an International Atomic Energy Agency (IAEA) safeguards document argues, "as the number of fuel cycle facilities and the amount of nuclear material under safeguards expands, the IAEA is challenged to develop more efficient ways to implement effective safeguards."<sup>9</sup> There may be innovations in nuclear technology that can provide a new component of counterproliferation safeguards.

## CONSIDERING THE ADVERSARY OF COUNTERPROLIFERATION

Authors vary in their definitions of *proliferation resistance*, but a common theme is that it is a relative measure of the difficulty that a proliferator would experience if attempting to divert a significant quantity (SQ) of weapon-usable material from a peaceful power program into a nuclear

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2. Emirates Nuclear Energy Corporation, "Barakah Nuclear Energy Plant," accessed March 2017, <https://www.enec.gov.ae/barakah-npp/>.

3. EDF Energy, "Hinkley Point C," accessed March 2017, <https://www.edfenergy.com/energy/nuclear-new-build-projects/hinkley-point-c>.

4. World Nuclear Association, "Nuclear Power in India," October 2017, <http://www.world-nuclear.org/information-library/country-profiles/countries-g-n/india.aspx>.

5. American Nuclear Society, "Unit 1 at Russia's Novovoronezh II Is First Gen III+ Reactor to Go Commercial," *Nuclear News* 60, no. 4 (April 2017), [http://www.ans.org/pubs/magazines/nn/y\\_2017/m\\_4](http://www.ans.org/pubs/magazines/nn/y_2017/m_4).

6. World Nuclear Association, "Nuclear Power in India."

7. World Nuclear Association, "Emerging Nuclear Energy Countries," September 2017, <http://www.world-nuclear.org/information-library/country-profiles/others/emerging-nuclear-energy-countries.aspx>.

8. Treaty on the Non-Proliferation of Nuclear Weapons, 1968, <https://www.un.org/disarmament/wmd/nuclear/npt/text/>.

9. International Atomic Energy Agency (IAEA), *International Safeguards in the Design of Nuclear Reactors*, No. NP-T-2.9 (Vienna: IAEA, 2014).

weapon.<sup>10</sup> It is, needless to say, a relative measure—this paper does not anticipate a time when a fuel cycle will be declared absolutely proliferation proof—and its relevance depends significantly on the resources that a proliferator can bring to bear on the problem. For this reason, the Generation IV International Forum’s definition places the emphasis on a state actor: “that characteristic of a nuclear energy system that impedes the diversion or undeclared production of nuclear material or misuse of technology by the Host State”<sup>11</sup> This might be objectionable on grounds that various terror groups have declared their interest in acquiring nuclear weapons,<sup>12</sup> but in fact provides no substantial restriction: a terrorist group has less access and fewer resources, making it a lesser included threat. The definition as it stands focuses on the more difficult aspects of counterproliferation.

In the case of the nonstate actor, illegal seizure is the most likely path to weapon acquisition. It follows that, in this case, resistance to illicit proliferation may be regarded much as any other security problem as pertains to guarding assets of significant value: the host state can harden the target and make the expected outcome of any effort to acquire a significant quantity of weapons-usable material unfavorable to an adversary. Host states can increase force protection and fixed defenses according to the risk of a particular facility. The United States has done this successfully at locations where it stores significant quantities of weapons-usable material—for example, the Highly Enriched Uranium facility at Oak Ridge National Laboratory’s Y-12 complex and the Device Assembly Facility at the Nevada National Security Site.

The risks increase when the proliferator is a government with control over the reactor and surrounding infrastructure. In this case, the physical guard force becomes irrelevant, as it may be assumed that it has been completely subsumed into the clandestine proliferation effort. Thus, lacking the canonical “guards, gates, and guns,” proliferation resistance must lie within the particular reactor and fuel cycle itself. Indeed, any fuel cycle that can hinder a state actor from acquiring a significant quantity of weapon-usable material will likewise prevent a nonstate actor from acquiring a significant quantity.

To prevent a state from acquiring an SQ of weapon-usable material, it either must be denied the capability to acquire that material or deterred from acquiring it by the threat of consequences. The latter hinges on the efficient detection of proliferant behavior, particularly illustrated by the IAEA safeguards program: detection of diversion of material from peaceful purposes and deterrence by

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10. Michael D. Zentner et al., “Interpretation and Use of the Results of Proliferation Resistance Studies,” *Nuclear Technology* 179, no. 1 (July 2012): 106–111; and William S. Charlton et al., “Proliferation Resistance Assessment Methodology for Nuclear Fuel Cycles,” *Nuclear Technology* 157, no. 2 (February 2007): 143–156.

11. Proliferation Resistance and Physical Protection Evaluation Methodology Working Group of the Generation IV International Forum, *Evaluation Methodology for Proliferation Resistance and Physical Protection of Generation IV Nuclear Energy Systems: Revision 6* (Washington, DC: Gen IV, 2011), [https://www.gen-4.org/gif/jcms/c\\_40413/evaluation-methodology-for-proliferation-resistance-and-physical-protection-of-generation-iv-nuclear-energy-systems-rev-6](https://www.gen-4.org/gif/jcms/c_40413/evaluation-methodology-for-proliferation-resistance-and-physical-protection-of-generation-iv-nuclear-energy-systems-rev-6).

12. Rolf Mowatt-Larssen, “Al Qaeda’s Pursuit of Weapons of Mass Destruction,” *Foreign Policy*, January 25, 2010, <http://foreignpolicy.com/2010/01/25/al-qaedas-pursuit-of-weapons-of-mass-destruction/>.

detection.<sup>13</sup> An example of the former would be the Joint Comprehensive Plan of Action with Iran, which specifically contains “limitations on all uranium enrichment” in order to cut off an internal path to a significant quantity of special nuclear material.<sup>14</sup> Deterrence and denial both have applicable mechanisms for designing new reactors.

## FACTORS FOR EVALUATING PROLIFERATION RESISTANCE AND REQUIREMENTS FOR NEW TECHNOLOGY

Several attributes of a fuel cycle serve as a basis for assessing the relative difficulty of turning it into a proliferation pathway:

- Reducing the quantity of special nuclear material (SNM) in the fuel cycle, and avoiding the separation of fissile isotopes from weapon-inhibiting species<sup>15</sup>
- Increasing the difficulty of the technical barriers between a fuel cycle product and weapons material<sup>16</sup>
- Increasing the likelihood of detection that material has been subverted
- Minimizing the number of handling operations

New reactor technologies can make gains in each of these areas. Like all engineering problems, however, there are limitations and trade-offs. The boundaries are set by a number of factors, each with its own range and implications.

### Beginning Fuel Enrichment

Every reactor design specifies the range of acceptable starting proportions of fissile material within its fuel. For a country operating an acknowledged civilian nuclear program, the highest enrichment called for by its reactors may be regarded as the baseline enrichment expected to be on hand and the richest product that any fuel production facilities will be expected to produce. The difference between this enrichment and the point of weapons usability is a direct measure of the additional separative work that would need to be accomplished to transform the original material into a weapons-usable substance—nominally 20 percent uranium-235 (U-235).

Achieving 20 percent is technically feasible for a country operating its own enrichment facilities. It takes roughly 42 kilograms (kg) of natural uranium to produce 1 kg of 20 percent enriched uranium, or 205 kg of natural feed to produce 1 kg of 95 percent enriched material. Likewise, the difference in separative work units, a measure of the amount of energy taken to achieve a

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13. IAEA, *International Safeguards in Nuclear Facility Design and Construction*, No. NP-T-2.8 (Vienna: IAEA, 2013), 10, [http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1600\\_web.pdf](http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1600_web.pdf).

14. Joint Comprehensive Plan of Action, July 14, 2015, <https://www.state.gov/documents/organization/245317.pdf>.

15. Charlton et al., “Proliferation Resistance Assessment Methodology for Nuclear Fuel Cycles.”

16. Proliferation Resistance and Physical Protection Evaluation Methodology Working Group of the Generation IV International Forum, *Evaluation Methodology for Proliferation Resistance and Physical Protection of Generation IV Nuclear Energy Systems*.

particular enrichment with respect to the method used, remains essentially linear, from natural abundance (0.711 percent) all the way to 95 percent pure U-235. Speed notwithstanding, any enrichment equipment will suffice to take highly enriched material to weapons grade if it can be used iteratively. Given that a typical light water reactor, producing slightly over 1,000 megawatts for the electrical grid, requires 30 to 40 tons of 1–3 percent enriched uranium per year,<sup>17</sup> a small amount could easily be siphoned off and undergo continued processing, either by a smaller enrichment cascade or by recycling through the original cascade and accepting increased inefficiency.

Low enriched uranium fuel has, therefore, two advantages: first, enrichment to the weapons-grade threshold would require additional work proportional to the difference between the starting and ending material, giving the IAEA or other organization a greater likelihood of intervening; second, the amount of material required to be siphoned off would be inversely proportional to the original enrichment, requiring a greater diversion of feed material. Naturally, it is easier to notice a deviation of several percent enrichment against 1–2 percent expected enrichment, versus 15 percent, simply as a matter of signal-to-noise, but this work assumes that intermediate steps of enrichment will be hidden to the utmost possible degree and that finding hidden stocks or clandestine facilities would provide sufficient evidence of proliferation on their own.

## Fuel Handling and Logistics

The IAEA considers two misuse or diversion scenarios for material attractive to proliferators: undeclared production and diversion from declared inventory.<sup>18</sup> Both of these risks increase with the number of operating reactor, enrichment capacity, and reprocessing or disposal sites, because the number of areas that must be monitored increases, while the proliferator can distribute actions over a larger number of individual locations and reduce any given signature.

It has also been suggested that the form factor of the fuel—that is, the physical disposition for use, to include integrated mechanical support—contributes to its degree of proliferation resistance. The fuels that are more enclosed and require greater amounts of processing in order to provide a significant quantity of weapons-usable material are less attractive targets. In the case of a state that maintains its own fuel enrichment and fabrication facilities, this is no longer a hindrance. If, however, a state leases fuel—as has been suggested by several different international initiatives<sup>19</sup>—a more robust fuel unit would be easier to track. Moreover, the majority of civil fuel today is in the form of uranium oxide, a refractory ceramic. This fuel would need to be disassembled, converted to uranium hexafluoride, and then enriched further. Though none of these obstacles are insurmountable, each step would take time and could leave noticeable signatures, increasing the likelihood of detection. Large, preassembled fuel bundles, as are assembled for use in current light water reactors (LWRs), would be particularly easy to track and, conversely, difficult to subvert from a fuel chain without being noticed.

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17. Ronald Allen Knief, *Nuclear Engineering: Theory and Technology of Commercial Nuclear Power*, 2nd ed. (La Grange Park, IL: American Nuclear Society, 2008), 710.

18. IAEA, *International Safeguards in the Design of Nuclear Reactors*.

19. Mark A. Christopher, “International Fuel Supply Guarantees,” *Nuclear Scholars Initiative: A Collection of Papers from the 2008 Nuclear Scholars Initiative* (Washington, DC: CSIS, 2008), 21–36.

## Burnup, Conversion, and Plutonium

A significant factor in the design of a plant's core is known as its burnup, the amount of thermal energy (megawatt-days) the core generates per ton of uranium over its lifetime, and likewise a measure of the amount of neutron radiation that the core has been exposed to throughout its operational life. Part of this is an economic concern: higher burnup cores go longer between each refueling than lower burnup cores at equivalent power generation, thereby reducing fuel and outage costs. As of 1990, "most commercial plants in the United States [had] already switched from a 12- to an 18-month cycle," simply to save on these costs.<sup>20</sup> In 2011, purchasing replacement power to account for an off-line 980 MW (megawatt, thermal) ran between \$1 million and \$2 million a day.<sup>21</sup> It is therefore attractive on its own—but it also has significant counterproliferation advantages.

First, the level of protection increases along with burnup. One way to evaluate the risk that nuclear material is misused is as the product of risk and time for each environment it passes through (fabrication, transport, the core, etc.), summed over its entire life. Considering that the radioactivity of an operational core makes fuel located inside it essentially self-protecting, it follows that a longer period between refuelings will increase resistance to misuse. Likewise, the IAEA observes that "reduced core access and reduced refueling makes misuse . . . much more difficult."<sup>22</sup> In the case of a pressurized water reactor (PWR) or boiling water reactor (BWR), the core cannot be opened without bringing the reactor off-line, and this would be immediately obvious to any organization monitoring the power supplied. After that point, the fuel would still have to cool down for months<sup>23</sup> before it could be handled, adding additional opportunities for detection.

An objection to increased burnup is that it requires higher enrichments in the initial fuel assembly, which is a problem discussed previously. This is compensated, however, in that as burnup increases by 50 percent, the initial enrichment increases by roughly 30 percent, the quantity of fuel decreases by approximately 5 percent, and the number of fuel assemblies drops by nearly 25 percent.<sup>24</sup> It is also worth noting that a study on proliferation resistance noted a "standard PWR cycle has slightly higher proliferation resistance than a standard [Canadian Deuterium Uranium (CANDU)] cycle . . . in part due to the lower burnup of CANDU fuel and the online refueling capabilities of the CANDU."<sup>25</sup> Indeed, the online refueling capabilities are necessary to keep the reactor running, as it would otherwise not have enough reactivity.<sup>26</sup> It follows that, at least until the fuel reaches 20 percent U-235, higher burnup is probably preferable over lower enrichment.

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20. Robert G. Cochran and Nicholas Tsoulfanidis, *The Nuclear Fuel Cycle: Analysis and Management*, 2nd ed. (La Grange Park, IL: American Nuclear Society, 1990), 190.

21. Peter Bacqué, "Nuclear Plant Outages Costly," *Richmond Times-Dispatch*, September 25, 2011, [http://www.richmond.com/business/nuclear-plant-outages-costly/article\\_da2b7cbe-b2ef-567c-a28d-694459d0b726.html](http://www.richmond.com/business/nuclear-plant-outages-costly/article_da2b7cbe-b2ef-567c-a28d-694459d0b726.html).

22. IAEA, *International Safeguards in the Design of Nuclear Reactors*.

23. Samuel Glasstone and Alexander Sesonske, *Nuclear Reactor Engineering* (Princeton, NJ: Van Nostrand, 1963), 486.

24. Cochran and Tsoulfanidis, *The Nuclear Fuel Cycle*, 189.

25. Charlton et al., "Proliferation Resistance Assessment Methodology for Nuclear Fuel Cycles."

26. Knief, *Nuclear Engineering*, 293.



A further concern about burnup is the production of plutonium that could be separated for weapon use. All uranium reactors produce some plutonium; placing sufficient U-238 in an environment marked by an abundance of free neutrons will necessarily lead some of the nuclei to undergo a neutron capture reaction, becoming U-239 before decaying to plutonium-239 (Pu-239). This is a fissile isotope and the most useful from the perspective of the nuclear weapon proliferator. As it remains in the reactor, however, some of the Pu-239 will capture additional neutrons, and while more than half of these reactions will cause fission,<sup>27</sup> some will form a relatively stable isotope, Pu-240. This even-numbered isotope is harmful to a proliferator, as it is nonfissile and serves to denature the material. This is, in fact, true of all the even-numbered isotopes of plutonium; Pu-241 is fissile and Pu-242 is not. Each is created by successive neutron capture, starting from U-238, so that the proportion of the even isotopes increases as the fuel remains exposed to the neutron-rich environment in the reactor. Separation of the Pu-239 is not practical. With a large centrifuge cascade, it is possible to separate fissile U-235 from U-238. In the case of Pu-239 and Pu-240, however, the mass difference between the two isotopes reduces the effective separability to one-ninth that of the uranium case.<sup>28</sup> Rephrased, it requires almost 10 times the investment of energy and enrichment equipment sufficient to enrich uranium to do the same for plutonium. The optimum case for a proliferator, then, is to expose fertile material—that is, material that can be made fissile by neutron irradiation—to a neutron flux just long enough to build up a supply of fissile isotopes and separate them chemically, before they can be burnt up or transmuted. Contrariwise, from a proliferation-resistance standpoint, it is desirable to leave fuel in a reactor for as long as possible so that the plutonium burns or becomes useless for weapons. This is equivalent to saying that the fuel should receive higher burnup; it follows that proliferation resistance increases with burnup.

All of the above are important, but a further elaboration on reactor designs is possible and has been explored in a number of test installations: the creation of a reactor that produces more fissile fuel than it consumes, or a breeder reactor. Though attractive from the standpoint of fuel availability—a fast breeder reactor might utilize 30 times more of its original fuel loading than a LWR—plutonium production and reprocessing have been a significant counterproliferation concern. Many of the reactors that offer this capability have remained experimental or been canceled in part for these reasons (e.g., Idaho National Laboratory's Experimental Breeder Reactor II); likewise, U.S. fuel reprocessing suffered a blow from which it has not recovered when it became national policy to forgo the technology due to perceived proliferation risk.<sup>29</sup>

Short of an actual breeding cycle, however, there is always some generation of new fissile material (as discussed previously), and some reactors make use of this fact. These enhanced conversion reactors extend their fuel supply by burning the plutonium generated *in situ* so that some of the fuel extension benefits accrue without having to separate new material. A number of these reactor types have been theorized, including highly optimized light water reactors, graphite moderated

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27. Brookhaven National Nuclear Data Source, ENDF/B-VII.1 (USA, 2011), accessed March 2017, <http://www.nndc.bnl.gov/endl/b7.1/>.

28. Cochran and Tsoulfanidis, *The Nuclear Fuel Cycle*, 67.

29. Jimmy Carter, "Nuclear Power Policy Statement on Decisions Reached Following a Review," April 7, 1977, online by Gerhard Peters and John T. Woolley, The American Presidency Project, <http://www.presidency.ucsb.edu/ws/?pid=7316>.



reactors, and even reactors employing thorium as the fuel. Regardless of the fuel type, however, if such reactors can be achieved, the benefits could be substantial. In lieu of enrichment, fuel would be generated in the reactor, which, as noted, is generally self-protecting; fuel would not be available outside the reactor; signatures would be available if the reactor were shut down prematurely; and the spent fuel, when retrieved, would be far from ideal for the manufacture of a weapon.

## PROLIFERATION RESISTANCE IN VARIOUS PROPOSED REACTOR TYPES

There is a large variety of reactor designs currently proposed and in various stages of development in the United States. Frequently, they claim proliferation resistance, but do not always thoroughly develop the point with evidence. Using the factors previously developed—initial enrichment, fuel handling, logistics, burnup, and utilization—it is possible to evaluate the relative proliferation resistance of various proposed reactors with respect to the current U.S. fleet of pressurized water reactors (PWRs) and boiling water reactors (BWRs)—collectively light water reactors (LWRs). Note that nothing in this report should be construed to say that a given reactor type is a guaranteed proliferation risk. No reactor is guaranteed against proliferation. Some, however, are better than others.

### High-Temperature Gas-Cooled Reactors (HTGR)

This term refers to reactors that use graphite for moderation and helium to carry heat from the core to the steam generators. There are a number of core designs that match this description, but of most interest at the moment is the aptly named pebble-bed reactor. In this design, enriched uranium fuel is contained within graphite spheres—the pebbles—which are in turn loaded into what is essentially a hopper. Addition or removal of these pebbles provides the primary control method for the reactor, making online refueling a necessity in the design.<sup>30</sup>

The initial enrichment may vary according to the design. China's HTR-10 calls for 17 percent initial enrichment, with 5 grams (g) of uranium per fuel element;<sup>31</sup> one American R&D company is working on a reactor with a proposed 15.5 percent enrichment;<sup>32</sup> Germany's high-temperature reactor prototypes have enrichments ranging from 9.82 percent to 16.76 percent.<sup>33</sup> All of these initial enrichments are two to five times higher than the 3–5 percent commonly seen in LWRs.

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30. Knief, *Nuclear Engineering*, 301.

31. Fu Li, "HTR Progress in China" (presentation, Technical Meeting on the Safety of High Temperature Gas Cooled Reactors in the Light of the Fukushima Daiichi Accident, Vienna, April 8–11, 2014), [https://www.iaea.org/NuclearPower/Downloadable/Meetings/2014/2014-04-08-04-11-TM-NPTDS/2\\_Li01.pdf](https://www.iaea.org/NuclearPower/Downloadable/Meetings/2014/2014-04-08-04-11-TM-NPTDS/2_Li01.pdf).

32. X-Energy, "X-Energy and the Xe-100" (presentation, monthly meeting of the Washington, DC, section of the American Nuclear Society, April 5, 2017), [http://local.ans.org/dc/wp-content/uploads/2014/01/ANS\\_Xe-100-Overview\\_04052017.pdf](http://local.ans.org/dc/wp-content/uploads/2014/01/ANS_Xe-100-Overview_04052017.pdf).

33. Michael J. Kania, Heinz Nabelek, and Karl Verfondern, "German TRISO Fuel Performance Envelope and Limits—Normal Operations and Accident Conditions" (presentation, IAEA, Vienna, June 10, 2013), [https://www.iaea.org/NuclearPower/Downloadable/Meetings/2013/2013-06-10-06-12-TM-NPTD/12\\_german\\_fuel\\_performance.pdf](https://www.iaea.org/NuclearPower/Downloadable/Meetings/2013/2013-06-10-06-12-TM-NPTD/12_german_fuel_performance.pdf).

Although still considered low enriched uranium, the previous discussion about initial enrichments shows that this level of initial enrichment is more a proliferation risk than a benefit.

The fuel handling capability also presents a small cause for concern, owing to the particular form factor of the fuel elements. Fuel pebble sizes are on the order of inches—perhaps the size of a racquetball—and are allowed to move independently. It is possible for a fuel handler to pick one up entirely unaided. If this technology is adopted, stringent controls and counting mechanisms would have to be employed to guarantee that no pebbles are diverted at any point in the fuel chain. However, in fairness to reactor and fuel developers, a reference pebble contains only about 2 g of uranium;<sup>34,35</sup> it would take 37,500 of such pebbles to assemble a significant quantity of uranium, assuming perfect recapture. This is 17 percent of a proposed fuel loading,<sup>36</sup> and so should be a noticeable diversion once the proposed accounting systems are in place.

The pebble bed does make plutonium extraction more difficult. While it does require online refueling, in this reactor type the pebbles circulate from bottom to top, and only a fraction of the irradiated elements are actually removed from the cycle at a given time. This is unlike the CANDU reactor discussed previously, in which the fuel bundles only pass through the reactor once and acquire a limited amount of burnup, some 8,000 Megawatts a day per Metric Ton (MWd/MTU). In the HTGR, the cycling of fuel elements in the pebble-bed could achieve an estimated 100,000 to 163,000 MWd/MTU. At the high end, this would have a plutonium composition containing only 60 percent fissile isotopes. Fuel removed at the end of the cycle is not likely to constitute a viable weapons pathway.

There is an alternative, of course, open to the plant operator: removal of pebbles from the cycle prematurely. This would be foolhardy for an individual, as exposure to an irradiated fuel element would prove very quickly fatal. Depending on the final design, it would not necessarily require separate handling machines that would need to be explained. Removal of insufficiently consumed fuel elements, however, would cause loss of reactivity within the reactor, which is necessary to keep it operating. Whether this would produce a detectable signature in the movement of fuel rods or the insertion of new material fuel ahead of schedule is uncertain, but the need for definitive accounting of material throughout the cycle, and assay of material being removed from the reactor, is clear.

## Small Modular Reactors (SMR)

Several companies<sup>37</sup> have been working on reactor designs that integrate previously separate components of a nuclear power installation into a single manufacturable and transportable package. Many of these are pressurized water reactors, the same sort of reactor used in the U.S. Navy

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34. Scott Nagley et al., "Fabrication of Uranium Oxycarbide Kernels for HTR Fuel" (paper for the *Proceedings of HTR 2010*, Prague, Czech Republic, October 18–20, 2010), <https://inldigitallibrary.inl.gov/sites/sti/sti/4886646.pdf>.

35. X-Energy, "Pebble Fuel," 2017, <https://www.x-energy.com/copy-of-xe-100-reactor>.

36. Ibid.

37. American Nuclear Society, "Special Section: Advanced Reactors," *Nuclear News* 57, no. 13 (December 2014), 43–88, <http://terrestrialenergy.com/wp-content/uploads/2015/01/ANS-NN-2014-12-ws.pdf>.

and a substantial proportion of the U.S. civil reactor fleet. This study will focus on those companies that have publicly available filings with the Nuclear Regulatory Commission.

Given the economic basis of the SMR concept—simplifying existing technology, improving manufacturability, and achieving economies of scale—the SMRs proposed have strong similarities with existing PWR installations. Enrichments are listed between 1–5 percent, with refueling on a 24-month cycle.

From a purely isotopic (burnup) standpoint, these reactors may not be better than existing PWR installations. One firm's submission was notable in that it has a cycle burnup of 12,000 MWd/MTU,<sup>38</sup> significantly lower than the 30,000 MWd/MTU of a first generation PWR.<sup>39</sup> Still, there are some possible advantages from a logistics standpoint, which may overshadow the low burnup. If an installation were to use the reactors as swappable items and leave refueling to a central location—which is possible, given their design for shipping—it would be possible to forgo all in-field refueling operations. In essence, fuel would be leased from the company producing the reactor modules. Yue, Cheng, and Bari have estimated that probability of successful proliferation is always decreased when fuel is leased, because of “reduced availability of uranium-related material.”<sup>40</sup> Rephrased, the leasing country has no pretext to handle or modify the fuel—in the case of a sealed reactor, no pretext to access it at all. It is also possible that the mechanical design of the reactor could be made such that it would be entirely sealed when it departs from the factory, with active tamper monitoring. In this case, the probability of detection of removal of material could be increased, thereby deterring proliferation.

### Traveling Wave Reactor (TWR)

The traveling wave reactor, sometimes known as the CANDLE reactor (for Constant Axial shape of Neutron flux, nuclide densities and power shape During Life of Energy production), is a speculative design currently under development in the United States and China.<sup>41</sup> The physics, at least, has been subject to study since the concept was originally proposed in 1958,<sup>42</sup> and it may be conceptualized much like a cigar or candle: an initial region of enriched fissile material is placed against a column of fertile material—that is to say, an isotope that can be made fissile by neutron capture. U-238, of course, is fertile and produces, which begins a reaction that propagates by converting the fertile material to Pu-239, and then subsequently burning it.

There are significant advantages here, most notably that enrichment is not necessary for the majority of the fuel within the reactor. The enriched kick-off slug may be of concern, depending

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38. NuScale Power, LLC, “NuScale Standard Plant Design Certification Application: Chapter Four: Reactor,” December 2016, 4.3–4.5, <https://www.nrc.gov/docs/ML1701/ML17013A274.pdf>.

39. Cochran and Tsolufanidis, *The Nuclear Fuel Cycle*.

40. Meng Yue, Lap-Yang Cheng, and Robert A. Bari, “Relative Proliferation Risks for Different Fuel Cycle Arrangements,” *Nuclear Technology* 165, no. 1 (January 2009): 1–17, <http://www.tandfonline.com/doi/abs/10.13182/NT09-A4058?journalCode=unct20>.

41. TerraPower, LLC, “Technologies,” accessed March 2017, <http://terrapower.com/technologies>.

42. S. M. Feinberg, “Discussion Comment,” *Record of Proceedings. Session B-10*, International Conference on the Peaceful Uses of Atomic Energy (Geneva: United Nations, 1958).

on the final design; one exploratory design indicated a maximum initial enrichment of 15.75 percent.<sup>43</sup> This is significantly higher than the LWRs discussed, but nonetheless lower than the low enriched uranium (LEU) to highly enriched uranium (HEU) transition. However, as this is a one-off item, the enrichment capacity needed to produce the kick-off slug is inversely proportional to the core life and directly proportional to the number of cores to be ignited in the reference period; capacity need would be substantially reduced. This would undermine any pretext of maintaining a substantial enrichment capability. As discussed in the earlier section on enrichment, once such facilities are in place, it becomes significantly easier to create a significant quantity of highly enriched uranium—but absent those facilities, it is functionally impossible, and the proliferator would be stuck with the black market.

At least one traveling wave reactor design, which produces 1200 MW (thermal), claims that refueling cycles would be on the order of 40 years.<sup>44</sup> Assuming that this is possible from an engineering perspective, the elimination of fuel movement, reprocessing, or disposal for such a period is a substantial benefit. Though the original paper does not mention an exact fuel weight to begin with, it might be estimated by using a theoretical minimum TWR burnup of 200,000 MWd/MTU,<sup>45</sup> the nominal power, and 40-year duration to achieve approximately 90 tons of uranium fuel. By way of comparison, the Westinghouse AP1000 PWR is rated at 3415 MW(thermal)<sup>46</sup> and is expected to refuel every 18 months.<sup>47</sup> Given its fuel weight<sup>48</sup> and assuming a one-third core replacement during each refueling, the reactor would discharge approximately 56 tons of irradiated fuel every three years, and perhaps 600 tons over the 40-year life of the TWR. Even taking a third of this value to account for the difference in power generated, the PWR would generate 200 tons to the TWR's 40—and most of it would need to be secured by something other than the intrinsic safety of the reactor.

As for the isotope concentrations in the spent fuel region of the reactor, one model puts the concentration of plutonium species at about 10 percent of the total leftover material, 77 percent of

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43. Pavel Hejzlar et al., "TerraPower, LLC Traveling Wave Reactor Development Program Overview," *Nuclear Engineering and Technology* 45, no. 6 (November 2013): 731–744, <https://www.scopus.com/record/display.uri?eid=2-s2.0-84888798439&origin=inward&txGid=6ef5b4c8be0ec773fe98a187d478e235>.

44. Charles Ahlfeld et al., "Conceptual Design of a 500MWe Traveling Wave Demonstration Reactor Plant" *Proceedings of International Congress on Advances in Nuclear Power Plants 2011*, paper 11199 (Paris: Societe Francaise d'Energie Nucleaire, May 2–5, 2011), [http://terrapower.com/uploads/docs/ICAPP\\_2011\\_Paper\\_11199.pdf](http://terrapower.com/uploads/docs/ICAPP_2011_Paper_11199.pdf).

45. Ehud Greenspan, "Physics of Breed and Burn Nuclear Reactors" (presentation, Reactor Physics Summer School, University of California, Berkeley, June 14, 2010), [http://bnrc.berkeley.edu/documents/forum-2010/Presentations-SS/Greenspan\\_TWR.pdf](http://bnrc.berkeley.edu/documents/forum-2010/Presentations-SS/Greenspan_TWR.pdf).

46. Westinghouse Electric Company, "AP1000 Design, Safety Technology, Operability Features, and Current Deployment Projects" (presentation, IAEA International Workshop on Advanced Nuclear Reactor Technology, Vienna, July 5, 2011), [https://www.iaea.org/NuclearPower/Downloads/Technology/meetings/2011-Jul-4-8-ANRT-WS/2\\_USA\\_UK\\_AP1000\\_Westinghouse\\_Pfister.pdf](https://www.iaea.org/NuclearPower/Downloads/Technology/meetings/2011-Jul-4-8-ANRT-WS/2_USA_UK_AP1000_Westinghouse_Pfister.pdf).

47. Westinghouse, "Westinghouse AP1000 Design Control Document Rev. 19—Tier 2" (Nuclear Regulatory Commission filing, June 2011), 4.3–4.7, <https://www.nrc.gov/docs/ML1117/ML11171A500.html>.

48. Ibid., 4.1–4.8.

which would be Pu-239.<sup>49</sup> Ronald Allen Knief suggests that 95 percent might be considered a lower limit for Pu-239 concentration to be considered “weapons grade.” The IAEA, in one of its manuals, refers to “weapons-grade plutonium” several times without explicitly defining the term.<sup>50</sup> Nonetheless, the concentration of weapons-usable plutonium isotopes in the system’s discharge are well below Knief’s notion of weapons usable.

There is a danger that the system might be interrupted in its operation, and that a segment at the front of the wave, which had experienced the transmutation to Pu-239 but not had a chance for higher isotopes to build up, could be preferentially separated from the reactor as a whole. While it is not impossible and a potential source of weapons-usable material, the loss of electricity to the grid that it had previously been supplying would have to be made up in some fashion. This would very probably be rapidly detectable, thereby providing the deterrent effect. Furthermore, the reactor would have to be restarted in some fashion. Absent an enriched source to kick off the propagating reaction, the operator would either have to sacrifice all future power from the reactor or find some means of supplying the necessary material to restart the reactor.

## POLICY TOWARD NEW NUCLEAR REACTOR DEVELOPMENT

Although new reactor technologies have some nonproblematic advantages, it is still important that they be built and utilized with nonproliferation in mind. This requires a drive to do so, and the United States can best achieve this through active engagement in the nuclear energy field. To participate constructively in a global nuclear economy, however, the United States must have more to offer in terms of power generation than aging experience. In support of this goal, this work presents several policy recommendations.

### Continue and Increase Investment in Converter and Plutonium-Utilizing Reactors

As discussed already, utilizing reactors with increased burnup provides a relative improvement in proliferation resistance. Developing and building a reactor that is capable of creating its own fuel *in situ* by conversion of fertile but nonweaponizable U-238 would provide proliferation-resistant nuclear energy by minimizing concentrations of SNM at all locations save the self-protecting operational reactor. It is in the best interest of the United States to develop this technology rapidly. Some initiatives are already underway at the Department of Energy (DOE). The Gateway for Accelerated Innovation in Nuclear initiative, launched in the fall of 2015, represents one such activity. Nonetheless, it has set its goals for demonstration “in the 2035 time frame,” using only a \$6 million initial investment.<sup>51</sup> To make progress in a time frame relevant to other countries and the international nuclear market, the United States must move forward at a more aggressive pace. Power

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49. Hiroshi Sekimoto and Kouichi Ryu, “A New Reactor Burnup Concept ‘CANDLE’” (paper for the *Proceedings of PHYSOR 2000*, Pittsburgh, Pennsylvania, May 7–11, 2000), <https://www.ipen.br/biblioteca/cd/physor/2000/physor/010.pdf>.

50. IAEA, *Management of High Enriched Uranium for Peaceful Purposes: Status and Trends* (Vienna: IAEA, 2005), [http://www-pub.iaea.org/MTCD/publications/PDF/te\\_1452\\_web.pdf](http://www-pub.iaea.org/MTCD/publications/PDF/te_1452_web.pdf).

51. *Ibid.*

plants, particularly reactors, have a very long capital turnover time, and if the reactors are not ready when countries seeking new power supplies need them, the United States will not have another opportunity for decades.

### Develop and Employ Small Modular Reactor Technology on a Lease Basis

This may seem an odd recommendation, given the lackluster assessment of the SMR concept with respect to intrinsic proliferation resistance. It is, however, the most mature of the new reactor designs that the United States currently has to offer and could be fielded in relatively short order. Its basis in the PWR design, and the fact that some designs are already under review by the Nuclear Regulatory Commission (NRC), give it a distinct advantage in the near term.

The small size also gives it a lower cost of entry—one of the chief attributes pointed out by the type's proponents—and therefore could make it more attractive to prospective operators who are disinclined to build something gigawatt-class. If the SMR reactor community sees some of its more aggressive goals realized, small reactors could be used to power cities in locations where major fuel or railroad lines have heretofore not been practical, making it difficult to justify larger installations. Such installations would serve as an intermediate means of contributing to an energy economy while enabling the United States to assert influence over the operation of reactors in foreign countries. Rose Gottemoeller noted that such interactions are a means of exporting U.S. norms of facility operation and counterproliferation practice.<sup>52</sup> Other, more advanced and more technologically proliferation-resistant reactor types are more desirable, but establishing international relationships now will be valuable for laying the groundwork for future, more advanced reactor installations. To paraphrase President Theodore Roosevelt, the United States should do what it can, with what it has, where it is.

Leased fuel, likely a key component of such an operation, has a significantly lower chance of being used by a proliferating nation. In a similar vein, the manufacture of the reactor in the United States (or some other trusted country) enables U.S. agents to confirm that the reactor contains nothing more, and nothing less, than what should be in it in the first place. It is, in fact, a form of supply chain security in support of counterproliferation. Furthermore, known behaviors of the reactor, borne of standardization, might enable a better characterization of its operating parameters and increase the potential for any kind of malfeasance (or misfeasance) to be detected. For an example of the reverse, one need only consider the difficulty of U.S. nuclear operators after the Three Mile Island accident as they worked to determine if their reactors were susceptible to the same failure mode. Every plant of that era was a unique design and build so that the observation of a problem in one was not necessarily or directly applicable to any other.

A more aggressive option, if technically feasible, would be to transport a full reactor module after it has been spent. As a large and sealed container, it might act as an armored car and provide substantial security to the irradiated fuel. This is not to underestimate the very significant technical challenges associated with the movement of such a reactor after its irradiation, nor the challenges

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52. Rose Gottemoeller, "Geopolitics and Nuclear Energy: The View from the State Department" (speech, Nuclear Energy Institute, Washington, DC, May 15, 2013), <https://2009-2017.state.gov/t/us/209768.htm>.



associated with building the reactor support depot, but the approach should be examined for technical viability.

## Invest in Waste Reprocessing and Disposal

A continuing difficulty for the U.S. nuclear enterprise is the lack of a final nuclear waste disposal plan. At the moment, the DOE's Waste Isolation Pilot Plant (WIPP) is the most probable long-term solution, but it is still something of a long shot. In 2014, it suffered some contamination and only reopened at the start of 2017.<sup>53</sup> Whether it will come into full operation remains to be seen. It is likely, in fact, that such plant might go the way of the Yucca Mountain repository at the Nevada National Security Site (formerly the Nevada Test Site). This installation saw significant study and development, but was canceled in 2009 in the face of strenuous local opposition. One obstruction, which may be regarded as typical, came in the form of a lawsuit that went against the facility. The judgment held in part: "Nevada first challenges [the Environmental Protection Agency] EPA's decision to establish a compliance period that extends only 10,000 years into the future," which the court upheld as a violation of section 801 of the Energy Policy Act.<sup>54</sup> While this paper does not deny that the parties bringing the suit were sincere in their concerns, it also notes 10,000 years is longer than extant recorded history and that building for such a duration is already a monumental task. Without a specific and achievable statutory standard for the duration that Yucca Mountain, or any other facility, must endure, it seems unlikely that any facility could be built without running afoul of some party for whom no level of security or duration will be sufficient to overcome the specter of radioactivity.

Alternatively, waste reprocessing can generally separate the longest-lived and therefore most problematic radioisotopes. Incorporated into new reactor fuel, their radioactivity becomes irrelevant. The remaining high-level waste is more radioactive precisely because it undergoes substantially more decays per unit time and therefore cools more quickly—"the candle that burns twice as bright burns half as long"—and need not be managed for the same duration. Moreover, given the separation and concentration, the volume of high-level waste is dramatically reduced: "roughly 2.5–3.0 cubic meters (m<sup>3</sup>) for each [gigawatt-electric]-year of electricity generated . . . viewed another way, the average U.S. family of five deriving all their electricity from nuclear power would have an annual waste contribution that would occupy the volume of a standard aspirin bottle."<sup>55</sup>

Unfortunately, there are no U.S. reprocessing plants, nor are any likely to arise from private investment in the near term. Given the experience of Allied-General plant at Barnwell, South Carolina, terminated by President Jimmy Carter's reprocessing ban,<sup>56</sup> the amount of capital lost so

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53. James Conca, "WIPP Nuclear Waste Repository Reopens for Business," *Forbes*, January 10, 2017, <https://www.forbes.com/sites/jamesconca/2017/01/10/wipp-nuclear-waste-repository-reopens-for-business/#67810b7d2052>.

54. Nuclear Energy Institute, Inc. et al. [Plaintiff] v. Environmental Protection Agency, No. 01-1258 (District of Columbia Court of Appeals, 2004).

55. Knief, *Nuclear Engineering*, 571.

56. Cochran and Tsoulfanidis, *The Nuclear Fuel Cycle*, 220.



quickly—some \$250 million in construction costs as of 1983—is enough to give even the most adventurous investor pause.<sup>57</sup>

For now, spent U.S. nuclear fuel remains in its cooling ponds outside the nuclear reactors. From a security and safety perspective, this is probably the worst of all the locations for it to remain in. Long-term participation in a proliferation-resistant nuclear economy requires that the United States have solutions to all aspects of the fuel cycle. Though some of the technologies discussed reduce the waste burden substantially, it still needs to be addressed. The United States cannot provide full-scale fuel services to nuclear-utilizing states if it cannot reasonably dispose of their waste.

Utilizing Yucca Mountain would be a satisfactory course of action, as the facility does appear to be extremely robust and satisfactory to the 10,000-year limit.<sup>58</sup> In the longer term, the DOE should be funded and directed to reopen or construct a suitable nuclear fuel reprocessing facility, utilizing processes that do not separate uranium from plutonium but merely extract both. In the interim, international agreements between the United States and countries that operate such plants could provide practical experience with reprocessed fuel and reduce the quantities of waste currently on hand. Nonetheless, licensure for use of mixed-oxide and otherwise reprocessed fuels should be a key activity for the NRC to make safe and effective use of the products of such a plant.

## Dramatically Increase Public Education on Nuclear Energy

There has been a consistent fear of all things nuclear in the United States, and the Three Mile Island accident only gave it more strength. The evacuations, closures, and—not to put too fine a point on it—neuralgic reaction that attended that event have colored the discussion of nuclear power since.<sup>59</sup>

The protests against Yucca Mountain are only one manifestation of this fear, which along with others have made it extremely difficult to develop nuclear resources in the United States. Another example comes from the disruption of construction of new reactors in the first place. Take Beyond Nuclear, an antinuclear advocacy group that claims that it and several like-minded groups had “intervened” and their “three dozen filed contentions [have] likely delayed Fermi 3’s groundbreaking by several years.”<sup>60</sup> This paper admits that their claim to delaying the building of the Fermi 3 BWR in Michigan is probably accurate, without giving credence to any of their other arguments. These delays can do economic damage to energy companies, many of whom have substantial debts on projects and accumulate yearly interest payments.

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57. Michael Hirsley, “Politics Dumps Nuclear Plant,” *Chicago Tribune*, September 19, 1983.

58. “Yucca Mountain Myths and Facts Opponents Distort or Ignore Research,” Nuclear Energy Institute, February 2011, <https://www.nei.org/Master-Document-Folder/Backgrounders/Fact-Sheets/Yucca-Mountain-Myths-and-Facts-Opponents-Distort-o>.

59. Ben A. Franklin, “Nuclear Foes See Grave Risk in Pennsylvania Mishap, but Utility Aides Are Unalarmed,” *New York Times*, March 30, 1979.

60. Beyond Nuclear, “NRC Rubber-stamps Proposed New Fermi 3 Reactor License, Beyond Nuclear Vows Legal Appeals,” press release, April 30, 2015, <http://www.beyondnuclear.org/home/2015/4/30/nrc-rubber-stamps-proposed-new-fermi-3-reactor-license-beyon.html>.

It is therefore necessary to illustrate how nuclear energy is, in fact, safe. Education and messaging through advertising, social media, and effective word-of-mouth discussion would all be acceptable mechanisms, particularly when tailored to a nontechnical audience. As for the content, the narrative that radioactivity, no matter how little, will be lethal and give rise to cancer, etc., must be countered by showing how radioactivity is a natural phenomenon that originates from naturally occurring decay and cosmic ray bombardment in the upper atmosphere. Just as individuals become inured to the dangers of driving, and accept that risk out of habit, so it may be possible to encourage individuals to approach radioactivity in the same way.

Likewise, the narrative that nuclear plants are a tremendous danger is belied by the nearly 100 operational nuclear power plants in the United States, to say nothing of those the world over. Addressing the concerns of Fukushima, Chernobyl, and Three Mile Island will be necessary, but it is also necessary to demonstrate that the problems that made those events so significant have been solved. Still, even the best apologist for nuclear energy will remind people of the negatives when focusing on those three elephants, rather than discussing how nuclear energy operates cleanly and effectively for continuous-load power supply. One can argue, on the other hand, the positive local impacts of nuclear energy, namely in the form of high-tech jobs and economic advantages for the communities in which it operates.

Finally, we must adopt a new approach to understanding radiation exposure. If all radiation, no matter the intensity, is assumed to be harmful, then any discussion of nuclear energy can become hung up on even trace amounts of release. Yet this is not the case. Cosmic rays and naturally occurring radionuclides provide continuous exposure worldwide. Medical procedures add a significant amount of radiation dosage in the form of X-rays. Nonetheless, fears of even trace radioactivity hinder forward motion with questions of whether radiation release has been minimized. It would be productive to establish, by statute, a standard that is good enough. This would benefit designers and engineers, and it would send a message that radioactivity below a certain level really is not a danger to human or environmental health. With time, proximity and interaction can bring an acceptance of those things previously feared. Once familiarity with radioactivity rises in the population, it is probable that the public will learn to accept radiation as the naturally phenomenon that it is, and gain a more objective perspective on the actual advantages and risks of nuclear energy.

## CONCLUSION

Advanced nuclear reactor technologies offer significant improvements to proliferation resistance, and the United States should therefore pursue their development at an increased pace to see these enhancements implemented, and at a reduced cost of development and construction. A comprehensive approach, entailing not only technological and manufacturing development, but also statutory support and public outreach, should be implemented in order to bring such a massive project to fruition.

# The Evolution of CNEN Regulation on Radiological Materials with Medical Applications before and after the Goiânia Radiological Accident of 1987

Chelsea Green<sup>1</sup>

*In September 1987, an abandoned teletherapy machine was dismantled by local scavengers in Goiânia, Brazil, and its radiation source, cesium-137 taking the form of iridescent blue powder, was distributed throughout the small community. The resulting deaths, injuries, environmental contamination, and cleanup, which occurred only one year after the Chernobyl disaster, made the Goiânia accident one of the first radiological accidents to garner worldwide attention. An International Atomic Energy Agency (IAEA) report drawing lessons from the accident determined that Brazil's regulatory framework on radiological materials was sound. However, this research casts doubt on that conclusion, particularly because several key changes were implemented in the two years immediately following the accident. A national legislative mandate expanded the responsibility of Brazil's nuclear regulatory body, CNEN (Comissão Nacional de Energia Nuclear), to authorize oversight of activities already under the agency's practical purview, suggesting that the regulatory body had operated outside of its legislated mandate for years. Furthermore, regulations that had been under consideration for years before the accident were implemented within the following year. These findings suggest a possible causal linkage between nuclear accidents and subsequent regulatory reform. They also deliver relevant lessons for regulators, policymakers, and experts striving to improve nuclear regulatory frameworks and, ultimately, radiological safety and security.*

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## INTRODUCTION

What ultimately led to 4 deaths, 249 contaminated individuals, 112,000 individuals under monitoring, 3,000 cubic meters of radiological waste, and an international panic all began with an abandoned teletherapy machine. The device, which contained a highly dispersible source of cesium-137, was left behind at the abandoned facility of the Goiânia Institute of Radioteletherapy, which failed to notify the licensing authority of this source as CNEN requirements dictated. Scavengers found the device in September 1987. After disassembling it and dismantling the head of the teletherapy machine, they discovered a glistening blue powder—the deadly cesium-137 source. Believing it might be valuable or possess supernatural powers, they distributed powder among family and friends. Once authorities realized that a serious radiological accident had occurred, a massive and costly cleanup began. This occurred on the heels of the disastrous Chernobyl nuclear accident. Worldwide sensitivity to radiation was high, and as a result, Goiânia was the first major radiological accident of its kind to not only garner the attention of international experts, but also of the international public.<sup>2</sup> The accident itself resulted not only in lingering long-term effects of radiation exposure, but also incalculable psychological harm and social stigma for residents of Goiânia throughout Brazil.

In an article discussing the accident's legacy, Eliana Amaral, former director of Radiation Transport and Waste Safety at the IAEA, emphasizes Goiânia's role in highlighting the inherent weakness of approaches taken up to that point regarding radioactive safety. "Before the 1987 accident the regulations were weak when it came to controlling radiation used in medicine and industry worldwide," states Amaral. The former director explains that the accident fostered awareness that sources should be controlled from "cradle to grave"—from the production of the radiological or nuclear materials to their eventual disposal—and that the public should not be able to access them.<sup>3</sup> The Goiânia accident ultimately shaped global conceptions of nuclear and radiological safety and security, which today not only emphasize the importance of safety and security culture, but also of sound nuclear regulatory structures.

Consequently, an examination into how Brazilian regulation on radiological materials evolved following the accident delivers insights into how a nation recovering from the world's most dramatic radiological accident to date reformed its regulations in the initial years that followed. First, this study uses publicly available CNEN reports, academic articles, CNEN regulations, and national legislation to provide an overview of the mandate that guided CNEN and the regulations governing individuals and entities that use radiological sources for medical and radiotherapy purposes.<sup>4</sup>

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2. N. Pelzer, "Preventing Radiological Accidents and Emergencies by Legislative and Regulatory Means," in *Goiânia: 10 Years Later: Proceedings of an International Conference, Goiânia, Brazil, October 26–31, 1997* (Vienna: IAEA), 83–91, [http://www.iaea.org/inis/collection/NCLCollectionStore/\\_Public/30/008/30008035.pdf](http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/30/008/30008035.pdf).

3. Kirstie Hansen, "Goiânia's Legacy Two Decades On," International Atomic Energy Agency (IAEA), March 7, 2008, <https://www.iaea.org/newscenter/news/goi%C3%A2nia%C2%B4s-legacy-two-decades>.

4. While Brazil's National Health Advisory, the Ministry of Health, and the Ministry of Labor and Employment, among others, have all issued regulations on radiological protection and other related functions, each body operates under a unique mandate assigned by Brazil's legislature. These distinct mandates empower bodies to create regulation for different purposes in unique operational areas and with varying consequences for implementation. As an example, see

Evaluating the regulatory body's mandate from before and after the accident allows us to compare two sets of legislated mandates and assess how they influence the scope of CNEN's oversight of radiological materials within Brazil's borders. Second, this study analyzes specific regulatory reforms implemented after the major radiological incident, providing evidence that suggests that accidents may explain the timing and the implementation of reforms in this case. Finally, a review of some specific regulatory reforms illustrates what regulatory improvements following a major radiological accident can look like, with lessons that can be tailored and adapted in modern contexts.

## WHY REGULATION MATTERS AND HOW TO IMPLEMENT EFFECTIVE STANDARDS

By establishing enforceable standards and dictating how facilities can operate in a legal manner, nuclear regulatory frameworks encourage organizations and individuals to use radiological materials safely and securely. Key technical elements to ensuring radiation protection include mandating that entities justify their practices and optimize protection, safety, and dose limitation. Legal principles supporting radiological safety include "the principle of prior notification, the principle of prior registration or license and the principle of permanent state supervision of licensed activities."<sup>5</sup> Ultimately, incorporating scientific measures for radiation protection into the legal framework governing the use of radiological materials can address disagreements as to what situations merit state control and supervision.<sup>6</sup>

Nation-states are responsible for regulating the use of radiological materials within their borders and approaches to ensuring the safety and security of these materials. Participants in a breakout session at the 2016 Solutions for a Secure Nuclear Future, the nongovernmental organization (NGO) side summit to the Nuclear Security Summit, identified several major challenges. These included a weak international regime for the security of radiological materials, gaps in national legislation and regulation addressing radioactive materials, poorly secured and open facilities, weak cradle-to-grave controls on radioactive materials, and complexity in tracking radioactive sources.<sup>7</sup> Among their recommendations, the group emphasized the importance of an independent and expert regulatory body in implementing "appropriate national laws and regulations that cover radioactive sources across their entire lifecycle."<sup>8</sup>

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National Health Advisory Resolution N. 6 of December 21, 1988. Resolution 6 aims to supplement other CNEN regulations on radiological protection and safety and establishes general technical regulations to protect the health of patients, professionally exposed individuals, and the public.

5. Pelzer, "Preventing Radiological Accidents and Emergencies by Legislative and Regulatory Means."

6. Ibid.

7. Christopher Hobbs and Ioanna Iliopoulos, "Controlling and Minimizing Radioactive Sources" (paper presented at Solutions for a Secure Nuclear Future, Washington, DC, March 30, 2016), <http://ssnf2016.org/wp-content/uploads/2016/03/SSNF-Session-on-Rad-Source-Security-March-2016.pdf>.

8. Ibid.

Recommendations delivered by senior regulators from 22 IAEA member states shed light on some helpful best practices that one might expect to see among improvements to Brazil's nuclear regulations after 1987. For example, the regulators emphasized that the government establish the mission of the regulatory body and stressed that the stated mission and legal underpinnings of the regulatory body should emphasize safety.<sup>9</sup> Regulatory standards, according to their analysis, should be subject to regular reviews and should be updated according to need. Regulatory standards and guides should be "clear, complete and have been regularly reviewed and suitably amended."<sup>10</sup> While too many changes in requirements might suggest a "lack of foresight by the regulatory body," regulators should also attempt to anticipate challenges in a timely manner so that they might effectively address them when they arise.<sup>11</sup> Finally, the report points to the number of changes to regulatory requirements after an incident or accident as an indicator reflective of regulatory body performance.<sup>12</sup>

While the reports mentioned here emphasize the importance of strengthening regulatory practices and deliver broad recommendations on how to achieve reform, they do not provide specific case examples to demonstrate what improvement might look like, particularly following a major radiological accident. The following section provides a Brazilian case study.

## AFTER THE ACCIDENT, CNEN'S MANDATE EXPANDS

In the year following the accident, the IAEA published a report entitled *The Radiological Accident in Goiânia*. The agency affirms in the report that radiation sources should be secured and under control.<sup>13</sup> Nevertheless, two developments after the accident worked to overcome weaknesses in Brazil's pre-Goiânia nuclear regulatory system. Brazil's National Congress expanded CNEN's mandate, and CNEN introduced and improved several regulations critical to controlling the use of radiological sources:

The legislative mandate of CNEN in place during the Goiânia accident, adopted in 1962 and amended in 1974, granted the regulatory body oversight of the use of nuclear energy for peaceful purposes within Brazil's borders. CNEN was responsible for creating standards, granting licenses, and establishing authorizations related to nuclear facilities, the possession, use, storage,

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9. IAEA, *Assessment of Regulatory Effectiveness: Peer Discussions on Regulatory Practices* (Vienna: IAEA, 1999), 3, [http://www-pub.iaea.org/MTCD/publications/PDF/pdrp\\_004\\_prn.pdf](http://www-pub.iaea.org/MTCD/publications/PDF/pdrp_004_prn.pdf).

10. Ibid., 8.

11. Ibid.

12. Ibid., 10.

13. International Atomic Energy Agency, *The Radiological Accident in Goiânia* (Vienna: IAEA, 1988), 87, [http://www-pub.iaea.org/MTCD/publications/PDF/Pub815\\_web.pdf](http://www-pub.iaea.org/MTCD/publications/PDF/Pub815_web.pdf). At the time of the Goiânia accident, Brazil's National Nuclear Energy Commission (CNEN) and federal and state health secretaries regulated the use of radiological materials in medical facilities. Of the three research institutes under CNEN's direct control, the Institute of Radiation Protection and Dosimetry (IRD) held primary responsibility for radiation protection issues and provided a significant proportion of the staff that responded to the Goiânia accident. For more information, See IAEA, *The Radiological Accident in Goiânia*, 15.



and transport of nuclear material, and the commercial uses of nuclear material. In addition, it was required to “issue regulation and safety and security standards related to a) the use of nuclear materials and facilities; b) the transport of nuclear materials; c) the handling of nuclear materials; d) the treatment and disposal of radioactive waste; e) the construction and operation of establishments destined to produce nuclear materials and for the use of nuclear energy.”<sup>14</sup>

The legislation thus gave CNEN broad oversight over nuclear materials within Brazil’s borders.

In June 1989, Brazil’s National Congress and its president of the Senate, Nelson Carneiro, amended CNEN’s mandate and significantly expanded its legislated responsibilities.<sup>15</sup> Under the 1989 amendments, CNEN gained explicit responsibility for authorizing and supervising activities involving radiological materials, promoting R&D, and “[producing] radioisotopes, radioactive substances and nuclear sub products, and [exercising] their trade.” The regulation also granted CNEN the responsibility to authorize the use of radioisotopes for research, medicine, agriculture, industrial uses, and analogous activities.<sup>16</sup> The regulatory body was now also mandated to “authorize and inspect the construction and operation of radioactive facilities regarding the commercial activities of radioisotopes.”<sup>17</sup> Language adopted in the 1989 amendment also extended CNEN’s responsibilities to include “[downloading] specific guidelines for radioprotection and nuclear safety, scientific and technological activity, industries and further nuclear applications” as well as “[receiving] and [depositing] radioactive waste.”<sup>18</sup> Whereas the previous mandate referred only to CNEN’s responsibility for nuclear materials, the updated version critically expanded its legislated control over the construction, authorization, use, and inspection of facilities using radiological sources.

The 1989 amendments seem to authorize activities that CNEN was already carrying out. CNEN authorized the use of radioisotopes for research, medicine, agriculture, and industrial uses well before 1989, as illustrated in CNEN’s 1985 Annual Report. The report illustrates that in 1985, CNEN licensed 2,325 radioactive facilities. In the medical applications alone, 1,730 of those registered entities were medical facilities and 163 individuals were granted credentials to handle radiological materials in the medical industry that year.<sup>19</sup> Furthermore, even the IAEA’s report on the accident states that CNEN’s IPEN (Instituto de Pesquisas Energéticas e Nucleares) research reactor produced many of Brazil’s radiological sources for medical and industrial applications, supervision of which was not required of CNEN until the 1989 amendments. It is unclear why the legislature did not pass amendments solidifying CNEN’s authority in these realms much earlier.

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14. Law N. 6.189, of December 16, 1974, Presidency of the Republic Civil House, Sub-Office for Legal Affairs, Article IV.

15. The 1989 law amended Articles 2, 10, and 19 of the most recent version of the mandate, amended in Lei N. 6.189 on December 16, 1974.

16. Lei N. 7.781, de 27 de junho de 1989, Presidência da República, Casa Civil, Subchefia para Assuntos Jurídicos, Article 2, XVI–XVIII. Translated from Portuguese.

17. Ibid., Article 2, XVIII. Translated from Portuguese.

18. Ibid., Article 2, II and VI. Translated from Portuguese.

19. National Nuclear Energy Commission (CNEN) Annual Report 1985, 49.



The fact that CNEN widely authorized and supervised the use of radiological sources before the 1989 amendment—in addition to creating many radioisotopes used for medical and industrial purposes—suggests that for multiple years, Brazil’s nuclear regulatory body operated outside of its legislative mandate. Several possibilities might explain this discrepancy. CNEN may have been experiencing the burden of legislative lag that is a common occurrence in democratic systems of governance. Brazil’s National Congress may not have expanded CNEN’s mandate earlier due to political circumstances or concerns about funding. The widened mandate seems to reflect a legislature correcting the inappropriately narrow mission previously assigned to CNEN.

Because regulatory bodies are held accountable for activities outlined in their legislated missions, CNEN may not have been held accountable for the licensing, oversight, and inspection of facilities using radiological materials to the same degree as it was for nuclear materials. It also may not have received adequate funding to oversee the use of radiological sources because that was outside of its legal mandate. The inconsistency between CNEN’s legislated mandate and its actual activities suggests that inappropriately defined missions could have dangerous implications for regulatory accountability and effectiveness. However, the 1989 amendments to CNEN’s mandate seems to illustrate regulatory responsiveness in action. Regardless of the IAEA report’s failure to highlight the gap between the legislated mandate and actual activities of Brazil’s nuclear regulatory body, national authorities made significant improvements to the existing structure.

## THE EVOLUTION OF REGULATION IN EFFECT BEFORE AND AFTER THE GOIÂNIA ACCIDENT

In the year following the Goiânia, the Brazilian national authorities implemented every regulation relevant to radiological security in medical facilities that were under development when the accident occurred. The last publicly available annual CNEN report from before the accident, the *1985 Annual Report*, indicates that several regulations relevant to radiological safety were in development at the time (see Table 1).<sup>20</sup> It would require data beyond the scope of this analysis to unequivocally point to the Goiânia accident as the primary motivator for the timing of regulatory implementation for standards long under development. However, the timeline below, constructed to reflect historical evidence collected from the report, certainly suggests that may have been the case.

Analysis of historical evidence also reveals that several regulations remained in effect for years without being updated (Table 2). Meanwhile, others were revoked and replaced in the two years immediately following the accident (Table 3), and a couple regulations with consequences for radiological safety in medical applications were introduced within the three years immediately following the accident that did not have precursors (Table 4). While this paper does not strive to deliver a complete account detailing the how, when, and why each regulation was introduced, revoked, or replaced, the following sections will dive into three examples of regulations that were replaced or introduced after the accident. While these regulations differ in purpose and content,

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20. Being able to view annual reports from 1986 and 1987 might have illuminated further information about additional regulations under development between the end of 1985 and September 1987.

**Table 1. Regulations on the Access and Use of Radiological Materials Listed as “in Development” in the 1985 Annual CNEN Report**

Regulation	Regulation (in Portuguese)	Date of issue
Basic Guidelines for Radioprotection	Diretrizes Básicas de Radioproteção	July 19, 1988
Services of Radioprotection	Serviços de Radioproteção	August 1988
Certification of Qualifications of Radioprotection Supervisors	Certificação da Qualificação de Supervisores de Radioproteção	September 1988
Transport of Radioactive Materials	Transporte de Materiais Radioativas	January 1988

**Table 2. Regulations Implemented before 1987 That Were Not Updated before 1990**

Regulation (English translation)	Regulation (in original Portuguese form)	Date implemented	Date revoked
Authorization for the Operation of Individual Monitoring Service Laboratories	CNEN NE 3.04, Autorização para Funcionamento dos Laboratórios de Serviços de Monitoração Individual—Resolução CNEN n. 12/81	November 19, 1981	Revoked in 1995
Authorization of Individuals for the Preparation and Use of Unsealed Radioactive Sources	CNEN NE 6.01, Autorização a Pessoas Físicas para o Preparo e Uso de Fontes Radioativas Não Seladas—Resolução CNEN 10/80	January 21, 1981	Revoked and substituted in 1997
Licensing of Radioactive Facilities	CNEN NE 6.02, Licenciamento de Instalações Radiativas—Resolução CNEN N. 09/84	December 14, 1984	Revoked and substituted in 2011
Management of Radioactive Waste in Radioactive Facilities	CNEN NE 6.05, Gerência de Rejeitos Radioativos em Instalações Radiativas—Resolução CNEN 19/85	December 17, 1985	Revoked and substituted in 2014

**Table 3. Regulations Revoked and Replaced before 1990, within Two Years of the Goiânia Radiological Accident**

Regulation (English translation)	Regulation (in original Portuguese form)	Date implemented	Date revoked	Replacement Regulation (English translation)	Replacement Regulation (in Portuguese)
Regulations for the Licensing of Individuals for the Use of Radioisotopes (Unsealed Sources)	Normas para Licenciamento de Pessoas Físicas para Uso de Radioisótopos (Fontes não Seladas) em Medicina Nuclear— Resolução n. 02/75	February 1975	Revoked and replaced on February 2, 1989	Requirements of Radioprotection and Safety for Nuclear Medicine Services	CNEN NE 3.05 (Requisitos de Radioproteção e Segurança para Serviços de Medicina Nuclear)
Basic Regulations of Radiological Protection*	Normas Básicas de Proteção Radiológica — Resolução n. 06/73 — DOU 19.09.1973	September 19, 1973	Revoked and replaced on July 19, 1988	Basic Guidelines of Radio- protection	Diretrizes Básicas de Radioproteção
Accreditation of Individuals or Legal Entities for the Supervision and Application of Methods of Radiological Protection	Credenciamento de Pessoas Físicas ou Jurídicas para Super- visão e Aplicação das Medidas de Proteção Radiológica — Resolução n. 03/1974	March 1974	Revoked and replaced in September 1988	Certification of Qualification of Radioprotection Supervisors*	CNEN NE 3.03 (Certificação da Qualificação de Supervisores de Radioproteção)

Note: Those marked with an asterisk (\*) were in development as early as 1985 and were issued after the accident took place in September 1987.

**Table 4. Regulations Implemented after 1987 That Did Not Specifically Replace a Regulation Already in Effect**

Regulation (English translation)	Regulation (in original Portuguese form)	Date implemented
Services of Radioprotection*	CNEN NE 3.02 (Serviços de Radioproteção)	August 1988
Transport of Radioactive Materials*	CNEN NE 3.01 (Transporte de Materiais Radioativas)	January 1988
Requirements of Radioprotection and Safety for Radiotherapy Services	CNEN NE 3.06 (Requisitos de Radioproteção e Segurança para Serviços de Radioterapia—Portaria CNEN Dext de 30.03.1990)	March 1990

Note: Those marked with an asterisk (\*) were in development as early as 1985 and were issued after the accident took place in September 1987.

an evaluation of each presents unique takeaways about how regulatory improvements can take form.

## A LESSON IN EMPHASIZING BROADER PRINCIPLES: “BASIC REGULATIONS OF RADIOLOGICAL PROTECTION” (1973) REPLACED BY “BASIC GUIDELINES OF RADIOPROTECTION” (1988)

While both the 1973 and 1988 versions of this regulation intended to establish radiation dose limits for various classes of individuals (see Table 3), the updated standard differs from its predecessor by introducing general principles that emphasized radiological protection for individuals before specifying the maximum radiation doses they should receive. At the outset of the document, the 1988 regulation states the following: “No worker should be exposed to radiation without: a) it being necessary; b) being aware of the radiological risks associated with its work; and c) being adequately trained for the performance of their functions.”<sup>21</sup> By emphasizing the purpose of the regulation, this updated standard goes beyond mandating that operators solely abide by the letter of the regulation, namely by not exceeding maximum radiation doses. It encourages operators to abide by its spirit and protect individuals from unnecessary exposure to radiation.

In addition, the 1988 version introduces concepts like the “principle of optimization” that uniquely encourage facilities and operators to emphasize safety by going above and beyond the call of compliance. The principle states that “the project, the plan of use and the operation of the facility and of radiation sources should be done in a way that guarantees that exposures will be reduced

21. “Resolution CNEN N. 12, of July 19, 1988. ‘Basic Guidelines for Radioprotection,’” 5.1.1 a–c. Translated from Portuguese.

as much as reasonably achievable, taking into consideration social and economic factors.”<sup>22</sup> Inclusion of this principle encourages foresight by entities that will utilize radiological materials. It also distinguishes safety as a broader norm to govern a wide set of practices rather than a narrow set of rules to be obeyed. By encouraging intentional planning to account for potential safety concerns, the regulation is constructed to incentivize accident prevention over accident response.

## A LESSON IN THE IMPORTANCE OF SCOPE AND DEFINITIONS: “ACCREDITATION OF INDIVIDUALS OR LEGAL ENTITIES FOR THE SUPERVISION AND APPLICATION OF METHODS OF RADIOLOGICAL PROTECTION” (1974) REPLACED BY “CERTIFICATION OF QUALIFICATION OF RADIOPROTECTION SUPERVISORS” (1988)

These two regulations share a common purpose: to describe how individuals can become supervisors of radiological protection in their facilities (see Table 3). Still, they differ in significant ways, starting with scope. The 1974 regulation resembles an all-in-one document, covering the accreditation of human and legal entities, as well as how those entities should execute supervision and application of CNEN’s Basic Regulations of Radiological Protection. By attempting to synthesize the requirements of both groups and individuals into a single regulation, the 1974 version fails to address any topic in any particular depth. For example, it describes the conditions required for legal entities to receive qualifications, broadly addresses their responsibilities for ensuring the radiological protection of individuals, and also loosely establishes responsibilities for credentialed radioprotection supervisors. These responsibilities include “verifying operating conditions, and promoting, when necessary, the calibration of radiation measurement devices and supervising the operation of devices and systems of alarm and control,” among others.<sup>23</sup>

The 1988 regulation, on the other hand, is significantly more scoped and tailored to focus on one particular issue. It describes the specific conditions required for individuals applying for certification as radioprotection supervisors in radioactive and nuclear facilities.<sup>24</sup> By focusing closely on how individuals can become certified, this reform improves upon its predecessor by successfully tackling a single issue and allowing other regulations to assume the responsibility for describing other related, but distinct, duties and principles.<sup>25</sup>

Second, the “Certification of Qualification of Radioprotection Supervisors” regulation more precisely defines terms and areas of qualification than its predecessor. The 1974 regulation broadly

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22. Ibid., 4.2. Translated from Portuguese.

23. “Accreditation of Physical or Legal Persons for the Supervision and Application of Radiation Protection Measures—Resolution n. 03/1974,” 7.2.1(c). Translated from Portuguese.

24. The regulation also applies to radioprotection supervisors involved in the transport of nuclear materials.

25. For example, the broader duties and general principles for radioprotection supervisors outlined in the 1974 regulation no longer exist in the 1988 version of the regulation. Rather, they are embedded within and expanded upon in other regulations implemented after the accident, such as CNEN-NE-3.02 “Services of Radioprotection.”

defines the materials under radiological protection as “all activities that utilize radiation sources” and states that all individuals and entities should explicitly declare the area of qualification in which one wishes to gain accreditation.<sup>26</sup> It then broadly requires that candidates receive an area-specific certification, without thoroughly defining the areas. The 1988 regulation, on the other hand, includes definitions of terms critical to understanding the document’s intent and scope, clearly delineating examples of what qualifies as a nuclear or radioactive facility. It also explains that area-specific certifications are required under the fields it outlines, with radioactive facilities divided into the industrial, health, physical medicine, and research fields. For example, radiology, radiotherapy, nuclear medicine, laboratory applications “in vitro” and “in vivo,” preparation of unsealed radioactive sources, and veterinary medical applications are all included as subheadings within the health and physical medicine fields. By defining key terms, the reformed regulation clarifies what facilities fall under the scope of CNEN’s oversight and provides more accessible guidelines for individuals hoping to become certified users of radiological materials.

## A LESSON IN DELEGATING RESPONSIBILITY: “SERVICES OF RADIOPROTECTION” (1988)

Implemented the year following the Goiânia accident, the “Services of Radioprotection” regulation had no precedent (see Table 4). Drawing only from the responsibilities for radiological protection assigned to legal entities in the 1974 regulation, “Accreditation of Individuals or Legal Entities for the Supervision and Application of Methods of Radiological Protection,” this regulation explicitly assigns responsibilities for radiological protection to a radioprotection service (RS), which is to be created by each facility that is authorized to possess radiation sources.

First, the regulation defines the terms and scope of its applications before detailing the requirements for radiological protection services staff and their responsibilities as a department. After stating that the regulation applies to both radiological and nuclear facilities, it defines a radioprotection service as “an entity constituted specifically with a view on execution and maintenance of the radioprotection plan of the facility.”<sup>27</sup> According to the regulation, the RS should be the only entity responsible for the radioprotection services covered under the regulation, should directly report to facility management, and should not be “structurally linked to groups that maintain or operate the facility.”<sup>28</sup> The regulation also designates the mandatory qualifications for upper-level and mid-level technicians and empowers the radioprotection service, stating that it should be accommodated by the facility’s staff and is responsible for approving procedures pertaining to the “use, handling, packaging, transport, and storage of radiation sources.”<sup>29</sup>

Under this regulation, the radiological protection service is not only required to perform many responsibilities, but also acts as a first line of defense in preventing and responding to a

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26. “Credenciamento de Pessoas Físicas ou Jurídicas para Supervisão e Aplicação das Medidas de Proteção Radiológica—Resolução n. 03/1974,” 388. Translated from Portuguese.

27. “Radioprotection Services,” CNEN NE 3.02, August 1988, 3.30. Translated from Portuguese.

28. Ibid., 4.1.1–4.1.2. Translated from Portuguese.

29. Ibid., 5.1–5.3, 6.4.2.1. Translated from Portuguese.

radiological accident. According to the regulation, the RS is required to control workers, areas, the environment and population, radiation sources, waste, equipment, worker training, registration of information, and preparation of reports.<sup>30</sup> Not only is the RS responsible for preventing workers from experiencing excessive radiation exposure, it is also required to conduct individual monitoring on a regular basis and when exposure is suspected. Overall, the “Services of Radioprotection” regulation embodies language and responsibilities that are central to control over radiological sources. That control encompasses restriction of access to radiological sources, supervision of sources, control over equipment, management of radiological waste, and registration of records regarding all aspects of a facility’s radiological protection system.

The regulation includes the responsibility to restrict access to radiological sources, a key principle for the fields of nuclear safety and security. For example, the regulation mandates that only individuals authorized by the facility’s management, under the control of RS, should be allowed access to restricted areas of the facility. Furthermore, those restricted areas “must be provided for with adequate means to control their access.”<sup>31</sup> The radiological protection service is instructed to establish and maintain a system of records, restricted only to authorized users, for tracking radiological protection at a facility. The updated and centralized system of records should include information about the structure of the radioprotection service, the “radioprotection plan, procedures, regulations, functions, activities, reports, and all of the additional information required by CNEN.”<sup>32</sup> By including provisions for restricting access to radiological materials and maintaining records about their status, the “Services of Radioprotection” regulation embodies several principles that are central to “cradle to grave” control over sources.

In addition, the radioprotection service is responsible for establishing supervision over sources, monitoring restricted areas, and acting as a gatekeeper for changes in facility structure. The regulation states that the RS should “establish and execute a program of supervision for the radiation sources of the facility, aimed at verification of the following items and aspects: a) its presence in the correct location, properly marked; b) physical state, existence of contamination and weakness; c) correct conditions of use, shielding, packaging, safety, transport and storage.”<sup>33</sup> In addition, the regulation requires that modifications to “equipment, structures, systems or operations of restricted areas should not be introduced” without the approval of the radioprotection service, previous planning, and adequate area monitoring.<sup>34</sup> As these various elements demonstrate, the updated regulation assigns a single organization the primary responsibility for ensuring the exercise of radiological protection, safety, and security best practices.

In the event of an accident, the radiological protection service is responsible for taking the lead role in addressing the crisis and communicating with the facility’s management any potential radiation exposure. RS is responsible for areas subjected to radiation contamination, must determine the critical population group affected due to facility activities, and must “communicate

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30. Ibid., 6 a–g. Translated from Portuguese.

31. Ibid., 6.2.2.1–6.2.2.2. Translated from Portuguese.

32. Ibid., 6.7.1.1–6.7.1.3. Translated from Portuguese.

33. Original emphasis on “contamination” was removed by this author.

34. “Serviços de Radioproteção,” CNEN NE 3.02, August 1988, 6.2.4.3. Translated from Portuguese.



immediately, to the management of the facility, any event that occurs or that could have occurred to the environment and the exposure to the population.”<sup>35</sup> Additionally, the regulation’s preventive measures assign control over radioactive waste produced by the facility to the radioprotection service. In accordance with the IAEA report on lessons learned from the Goiânia accident, the regulation articulates that this waste should be “properly identified, marked and registered, in conformity with the requirements of this regulation and of the specific regulations.”<sup>36</sup>

The regulation also assigns several responsibilities that are critical for ensuring oversight of the radiological sources to a radioprotection supervisor serving under the umbrella of RS. For example, the radioprotection supervisor is responsible for training facility workers and approving written procedures for “the use, handling, packaging, transport, and storage of radiation sources, in conformity with this regulation and with specific regulations.” In addition, the radioprotection supervisor is required to periodically evaluate and classify areas according to several clearly delineated standards. These include “a) safety and reliability of structures and equipment associated with radiation sources; b) levels of external radiation and of contamination; c) access and movement of workers and of radiation sources, both for normal working conditions and for emergency situations; and d) location of radiation sources and waste.”<sup>37</sup>

By advising facilities to designate a department and supervisors specifically dedicated to radioprotection and radiological safety, CNEN encourages facilities to designate guardians acting within. This approach is particularly useful to regulators, whose limited resources render consistent on-the-ground oversight of all facilities impossible.

## CONCLUSION

In the aftermath of a large radiological accident that sparked nationwide panic and rang international alarm bells, Brazil and its nuclear regulatory body invested in recovery efforts, participated in discussions with the international community, and contributed to their developing nuclear safety and security movements. More important, the Brazilian government made improvements in its own backyard, with CNEN updating regulations related to the use of radiological materials and the legislature updating CNEN’s mandate, granting the nuclear regulatory body the legal responsibility to exercise many of the activities it had been conducting for years. The textual analysis conducted in this research establishes that in the two years following the Goiânia accident, regulations and the regulator’s legislated mandate were more robust than in the years leading up to the accident.

Nuclear safety and security regulation ultimately aims to protect occupationally exposed workers, patients, and the public from accidental or intended exposure to radiation. Comparing the findings from this study with recommendations provided by regulators from 22 member states illustrates how Brazil’s nuclear regulatory structure improved during the two years following the Goiânia accident. The IAEA best practices report states, “A regulatory body needs to be provided on a legal

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35. Ibid., 6.3.4. Translated from Portuguese.

36. Ibid., 6.4.1. Translated from Portuguese.

37. Ibid., 6.2.1.1 a–d. Translated from Portuguese. Original emphasis on “contamination” was removed by this author.

basis with powers to set standards and powers to perform licensing, inspection, review and assessment, and enforcement functions as well as to regulate these processes.”<sup>38</sup> Evaluating the evolution of Brazil’s legislative mandate in light of these recommendations affirms that by expanding CNEN’s mission, Brazil appropriately provided its nuclear regulatory body with the standards and power to regulate the use of radiological materials on its territory. In addition, the best practices report concludes regulatory effectiveness could be improved by ensuring that regulatory standards and guides are “clear, complete, and up to date.”<sup>39</sup> In several of the case studies presented here, regulations issued during the two years following the accident accomplish this by updating those in place, introducing appropriate new regulations, enhancing the clarity of responsibilities and scope, and filling in regulatory gaps.

The IAEA report issued in 1988, *The Radiological Accident in Goiânia*, failed to address important issues undermining CNEN’s legislative mandate and the strength of CNEN regulations in effect at the time of the Goiânia accident. However, the report certainly shed greater light on how responses to the accident unfolded—a sensible focus given that it constituted the first major radiological accident addressed after the passage of the Convention on Early Notification of a Nuclear Accident in 1986. And more important, despite the fact that IAEA did not call attention to weaknesses endemic to the Brazilian system governing use of radiological materials, government officials and regulators in Brazil took critical steps to improve the underlying structure. This study can fill gaps in the nuclear safety and security literature by delivering several lessons relevant not only to Brazil’s regulation of radiological materials immediately before and after the Goiânia accident, but also to modern policymakers, regulators, and experts hoping to improve nuclear regulatory frameworks today.

Further research should aim to fill gaps in the nuclear safety and security literature inherent to solely text-based approaches to this specific topic. Internal regulatory guidance and personal accounts of those involved in the rule creation and implementation process might support the argument that the Goiânia accident led to subsequent regulatory improvements. In any case, additional context to textual analysis would provide valuable behind-the-scenes insight on why regulators issue rules, whether they are implemented, and how regulators go about that process.

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38. IAEA, *Assessment of Regulatory Effectiveness*, 3.

39. *Ibid.*, 10.

# A Policy Roadmap for Improved Comprehensive Test Ban Treaty Monitoring

Stephen Herzog<sup>1</sup>

*Just over two decades since the Comprehensive Test Ban Treaty (CTBT) opened for signature, a total of 183 states have signed and 166 have ratified the accord. However, the treaty cannot enter into force until all 44 “nuclear-capable” states listed in its Annex 2 deposit their instruments of ratification. Eight of these states have not ratified the test ban. In light of this situation, it is nearly second nature for academic and policy discussions of the CTBT to overwhelmingly focus on the political roadblocks obstructing its entry into force. By contrast, this paper contends that the politics of treaty ratification are not the only dimension to the test ban discussion. Instead, it highlights a series of overlooked or understudied aspects of nuclear explosion monitoring. States can undertake a number of scientific and technical initiatives to strengthen CTBT monitoring, even in the absence of entry into force. In turn, by engaging in these types of projects, states do not merely create a more difficult climate for evasive nuclear testing; they may also bolster long-term prospects for the treaty’s ratification. This roadmap lays out a number of complementary efforts that policymakers may pursue toward this end.*

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## INTRODUCTION

Diplomatic endeavors to ban nuclear explosive testing date back to the 1946 proposals of the U.S. Baruch and Soviet Gromyko Plans for nuclear disarmament.<sup>2</sup> The international community has made a number of achievements to eliminate testing since then, including the Partial Test Ban Treaty of 1963, the Threshold Test Ban Treaty of 1974, and the Peaceful Nuclear Explosions Treaty of 1976.<sup>3</sup> Yet, it was not until September 24, 1996, that the CTBT opened for signature at the United Nations (UN) in New York, following long and often contentious negotiations at the Conference on Disarmament in Geneva.<sup>4</sup> The treaty represents the culmination of decades of work by governments, international organizations, and transnational advocacy networks to put an end to nuclear tests. U.S. President Bill Clinton even went so far as to refer to it as “the longest-sought, hardest-fought prize in the history of arms control.”<sup>5</sup>

The ban has successfully ushered in a new era of pronounced normative prohibitions against nuclear explosive testing. Of the 2,056 tests conducted around the globe since the 1945 U.S. Trinity test, only 10 have taken place since the CTBT opened for signature.<sup>6</sup> While India and Pakistan both tested in 1998, neither state has an active and ongoing nuclear explosive testing program to evaluate its stockpile or develop new warhead designs. This leaves North Korea—an international pariah—as the only country still testing. Pyongyang is under severe economic and financial sanctions for its transgressions of these norms. Overall, the current security and normative environment marks a stark departure from the days of the Cold War, when the great powers routinely conducted nuclear tests. For example, 116 such tests took place in 1958, and 178 in 1962 amid the tensions surrounding the construction of the Berlin Wall and the Cuban Missile Crisis.<sup>7</sup>

The normative power of the treaty has been insufficient for bringing about the accord’s entry into force. While 183 states have signed the CTBT and 166 have ratified it, the agreement cannot enter into force until 44 states listed in its Annex 2 ratify the treaty. These parties are the “nuclear-capable”

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2. Jenifer Mackby, “Still Seeking, Still Fighting,” *Nonproliferation Review* 23, no. 3–4 (March 2017): 262; Pierce S. Corden, “Historical Context and Steps to Implement the CTBT,” in *Banning the Bang or the Bomb? Negotiating the Nuclear Test Ban Regime*, ed. Mordechai Melamud, Paul Meerts, and I. William Zartman (Cambridge: Cambridge University Press, 2014), 18.

3. These years denote the conclusion of negotiations. The Partial Test Ban Treaty entered into force on October 10, 1963, while the Threshold Test Ban Treaty and Peaceful Nuclear Explosions Treaty both entered into force on December 11, 1990.

4. For the full text, see “Comprehensive Nuclear-Test-Ban Treaty,” Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO), September 10, 1996, <https://www.ctbto.org/the-treaty/treaty-text/>. On the history of the CTBT negotiations, see Rebecca Johnson, *Unfinished Business: The Negotiation of the CTBT and the End of Nuclear Testing* (Geneva: UN Institute for Disarmament Research, 2009); Jaap Ramaker et al., *The Final Test: A History of the Comprehensive Nuclear-Test-Ban Treaty Negotiations* (Vienna: Preparatory Commission for the CTBTO, 2003); and Melamud, Meerts, and Zartman, *Banning the Bang or the Bomb?*

5. Quoted in James Bennett, “Clinton, at UN, Says He’ll Press Senate on Test Ban Pact,” *New York Times*, September 23, 1997.

6. Arms Control Association, “The Nuclear Testing Tally,” fact sheet, September 2017, <https://www.armscontrol.org/factsheets/nucleartesttally>.

7. Ibid.

states that participated in the ban negotiations and possessed nuclear energy programs or research reactors at the time.<sup>8</sup> To date, eight holdouts remain from among the Annex 2 states. China, Egypt, Iran, Israel, and the United States have signed but not ratified the treaty. India, North Korea, and Pakistan have not signed. The participation of other notable nonsignatories, such as Saudi Arabia and Syria, is not necessary for entry into force because these states were not listed in Annex 2. As a result of the treaty's status, several states have diplomatic outreach programs aimed at expediting further Annex 2 ratifications. The UN Secretary General has also convened 10 Conferences on Facilitating Entry into Force of the CTBT, or Article XIV Conferences, since 1999 in both New York and Vienna. And in September 2016, the UN Security Council drew attention to the treaty's 20th anniversary by adopting Resolution 2310, which "recognizes international support for the accord, reinforces the global norm against nuclear test explosions created by the treaty, underscores the value of the global monitoring system to verify treaty compliance, and calls on all remaining states to sign and ratify to facilitate its 'early entry' into force."<sup>9</sup>

The appearance of a standstill in Annex 2 ratifications—dating back to Indonesia's ratification in 2012—often produces frustration among arms controllers, but the politics of ratification should not be policymakers' sole focus. No other arms control treaty contains monitoring and verification regimes that even remotely rival the level of scientific and technical sophistication of those of the CTBT. Although the status of the treaty precludes the use of on-site inspection (OSI) verification procedures prior to its entry into force, robust global monitoring is taking place at this moment by sensors deployed around the world.<sup>10</sup> Even if entry into force appears stalled, there are ways to improve on these already strong monitoring capabilities.

This paper discusses a series of technical initiatives that form a roadmap for national and multilateral efforts to enhance nuclear explosion monitoring and complement political promotion of the test ban. First, it briefly surveys the relevant academic and policy literature on the CTBT. Next, the roadmap identifies multifarious opportunities for states to bolster monitoring in three core focus areas: the International Monitoring System (IMS), the International Data Center (IDC), and collaborative national activities. The paper then concludes by offering thoughts pertaining to the future of the test ban regime.

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8. For details on why the negotiators created such difficult entry into force conditions see Mackby, "Still Seeking, Still Fighting," 271–275. And for a discussion of the treaty's legal status and the obligations of states signatories prior to entry into force, see Masahiko Asada, "CTBT: Legal Questions Arising from Its Non-Entry-Into-Force," *Journal of Conflict and Security Law* 7, no. 1 (April 2002): 85–122; Yasuhito Fukui, "CTBT: Legal Questions Arising from Its Non-Entry into Force Revisited," *Journal of Conflict and Security Law* 22, no. 2 (July 2017): 183–200; David A. Koplow, "Sherlock Holmes Meets Rube Goldberg: Fixing the Entry-into-Force Provisions of the Comprehensive Nuclear Test Ban Treaty," *Duke Journal of Comparative & International Law* 28, no. 1 (Fall 2017): 1–57.

9. Stephen Herzog, "The Nuclear Test Ban: Technical Opportunities for the New Administration," *Arms Control Today* 47, no. 1 (January/February 2017): 26; UN Security Council, S/Res/2310, September 23, 2016.

10. The evolution and sophistication of these technologies was on display at a November 30, 2016, event in Washington, DC, cosponsored by the U.S. Departments of Energy and State, entitled "Nuclear Explosion Monitoring: 60 Years of Science and Innovation." See National Nuclear Security Administration, "Technologies Enabling Nuclear Explosion Monitoring and Verification Highlighted on Capitol Hill," press release, December 2, 2016, <https://nnsa.energy.gov/mediaroom/pressreleases/technologies-enabling-nuclear-explosion-monitoring-and-verification>.

## POLITICAL SCIENCE AND POLICY LITERATURE

Nuclear security has shown its durability as an academic and policy studies discipline in the post-Cold War era. In political science and international affairs scholarship, an ongoing “renaissance” in nuclear security studies appears to have both methodological and thematic drivers. The first major factor underlying these recent developments stems from the opening of previously closed Cold War archives and the application of statistical and formal modeling techniques to data.<sup>11</sup> And the second notable driver has its roots in contemporary era concerns regarding proliferation (Iran, Iraq, Libya, North Korea, etc.). As a result, many scholars have made insightful and methodologically rigorous contributions that help us to better understand the proliferation of nuclear weapons. On the policy side, nongovernmental research and advocacy organizations produce a steady stream of reports and articles on nuclear issues for a policymaker and general audience. Specialty publications that rose to prominence during the Cold War, such as *Arms Control Today* and the *Bulletin of the Atomic Scientists*, also remain influential. Furthermore, prominent sites in the blogosphere, such as Arms Control Wonk, alongside Twitter, offer experts fast and direct channels to communicate their analyses of breaking events. But even with this large availability of literature and new means of communicating, dialogue about the CTBT is somewhat one-dimensional; ratification remains virtually the sole focal point.

Among academic political science and international affairs circles, the Non-Proliferation Treaty (NPT) receives much more attention than the CTBT. A number of recent articles have put forward theories dealing with NPT compliance and noncompliance, as well as the treaty’s effectiveness.<sup>12</sup> This trend likely stems in part from political scientists’ aforementioned emphasis on horizontal proliferation. Scholars of international law have dedicated comparatively more attention to the test

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11. For scholarship making use of archival sources, see Jacques E. C. Hymans, *The Psychology of Nuclear Proliferation: Identity, Emotions, and Foreign Policy* (Cambridge: Cambridge University Press, 2006); Francis J. Gavin, *Nuclear Statecraft: History and Strategy in America’s Atomic Age* (Ithaca, NY: Cornell University Press, 2012); Gene Gerzhoy, “Alliance Coercion and Nuclear Restraint: How the United States Thwarted West Germany’s Nuclear Ambitions,” *International Security* 39, no. 4 (Spring 2015): 91–129; and Alexandre Debs and Nuno P. Monteiro, *Nuclear Politics: The Strategic Causes of Proliferation* (Cambridge: Cambridge University Press, 2016). For examples using statistical techniques, see Sonali Singh and Christopher R. Way, “The Correlates of Nuclear Proliferation: A Quantitative Test,” *Journal of Conflict Resolution* 48, no. 6 (December 2004): 859–885; Dong-Joon Jo and Erik Gartzke, “Determinants of Nuclear Weapons Proliferation,” *Journal of Conflict Resolution* 51, no. 1 (February 2007): 167–194; Matthew Kroenig, *Exporting the Bomb: Technology Transfer and the Spread of Nuclear Weapons* (Ithaca, NY: Cornell University Press, 2010); and Nicholas L. Miller, “The Secret Success of Nonproliferation Sanctions,” *International Organization* 68, no. 4 (Fall 2014): 913–944. For literature employing formal modeling, see Andrew J. Coe and Jane Vaynman, “Collusion and the Nuclear Nonproliferation Regime,” *Journal of Politics* 77, no. 4 (October 2015): 983–997; Muhammet A. Bas and Andrew J. Coe, “A Dynamic Theory of Nuclear Proliferation and Preventive War,” *International Organization* 70, no. 4 (Fall 2016): 655–685; and Debs and Monteiro, *Nuclear Politics*.

12. Mariana Budjeryn, “The Power of the NPT: International Norms and Ukraine’s Nuclear Disarmament,” *Nonproliferation Review* 22, no. 2 (February 2016): 203–237; Coe and Vaynman, “Collusion and the Nuclear Nonproliferation Regime”; Livi Horovitz, “Beyond Pessimism: Why the Treaty on the Non-Proliferation of Nuclear Weapons Will Not Collapse,” *Journal of Strategic Studies* 38, no. 1–2 (July 2015): 126–158; and Matthew Fuhrmann and Yonatan Lupu, “Do Arms Control Treaties Work? Assessing the Effectiveness of the Nuclear Nonproliferation Treaty,” *International Studies Quarterly* 60, no. 3 (September 2016): 530–539.



ban than their political science counterparts, studying topics such as the agreement's status prior to entry into force.<sup>13</sup> Most of the contemporary scholarly work on the CTBT that does not appear in law reviews is published in the *Nonproliferation Review*, a journal attracting academics and policy experts alike. However, even there, the dialogue tends to overwhelmingly highlight the politics of ratification and entry into force.<sup>14</sup> One notable exception is a recent article by Paul Richards discussing future advancements in underground nuclear explosion monitoring in a manner accessible to policymakers without a scientific background.<sup>15</sup> There is, of course, a considerable body of scientific scholarship that pertains to the CTBT's monitoring and verification capabilities, as well as some attempts to explain the relevant technologies to nonspecialists.<sup>16</sup> Regardless, the test ban remains understudied outside the context of Annex 2 states and the prospects for its entry into force.

The body of policy-oriented literature for specialists—and a wider public audience—contains significantly more content pertaining to this subject than does academic scholarship. That said, the usual subjects dealt with by analysts are treaty ratification, entry into force, and the need or lack thereof for certain countries to pursue explosive testing.<sup>17</sup> There are a few counterexamples.

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13. Asada, "CTBT: Legal Questions Arising from Its Non-Entry-Into-Force"; Anguel Anastassov, "Can the Comprehensive Nuclear-Test-Ban Treaty Be Implemented before Entry into Force?," *Netherlands International Law Review* 55, no. 1 (May 2008): 73–97; Lisa Tabassi, "The Nuclear Test Ban: Lex Lata or de Lege Ferenda?," *Journal of Conflict and Security Law* 14, no. 2 (January 2009): 309–352; Fukui, "CTBT: Legal Questions Arising from Its Non-Entry into Force Revisited"; and Koplow, "Sherlock Holmes Meets Rube Goldberg."

14. Stephen Herzog and Jonathon Baron, "Public Support, Political Polarization, and the Nuclear Test Ban: Evidence from a New National Survey," *Nonproliferation Review*, forthcoming 2018; David Hafemeister, "Assessing the Merits of the CTBT," *Nonproliferation Review* 16, no. 3 (October 2009): 473–482; Kaegan McGrath, "Verifiability, Reliability, and National Security: The Case for U.S. Ratification of the CTBT," *Nonproliferation Review* 16, no. 3 (October 2009): 407–433; Liviu Horovitz and Robert Golan-Villela, "Comprehensive Nuclear-Test-Ban Treaty: How the Dominoes Might Fall after U.S. Ratification," *Nonproliferation Review* 17, no. 2 (June 2010): 239–252; Christopher M. Jones and Kevin P. Marsh, "The Odyssey of the Comprehensive Nuclear-Test-Ban Treaty: Clinton, Obama, and the Politics of Treaty Ratification," *Nonproliferation Review* 21, no. 2 (October 2014): 207–227; Rose Gottemoeller, "Rebuilding American Support for the CTBT," *Nonproliferation Review* 23, no. 3–4 (March 2017): 363–368; and Edward Ifft, "The Comprehensive Nuclear-Test-Ban Treaty and U.S. Security," *Nonproliferation Review* 23, no. 3–4 (March 2017): 385–396.

15. Paul G. Richards, "The History and Outlook for Seismic Monitoring of Nuclear Explosions in the Context of the Comprehensive Nuclear-Test-Ban Treaty," *Nonproliferation Review* 23, no. 3–4 (March 2017): 287–300.

16. For examples of the scientific literature on the test ban, see Frédéric Hourdin and J. P. Issartel, "Sub-surface Nuclear Tests Monitoring through the CTBT Xenon Network," *Geophysical Research Letters* 27, no. 15 (August 2000): 2245–2248; Gerhard Wotawa et al., "Atmospheric Transport Modelling in Support of CTBT Verification: Overview and Basic Concepts," *Atmospheric Environment* 37, no. 18 (June 2003): 2529–2537; and Charles Carrigan and Yunwei Sun, "Detection of Noble Gas Radionuclides from an Underground Nuclear Explosion during a CTBT On-site Inspection," *Pure and Applied Geophysics* 171, no. 3–5 (August 2014): 717–734. Examples of work on CTBT monitoring and verification accessible to those without a scientific background include Ola Dahlman, Svein Mykkeltveit, and Hein Haak, *Nuclear Test Ban: Converting Political Visions to Reality* (New York: Springer, 2009); Ola Dahlman et al., *Detect and Deter: Can Countries Verify the Nuclear Test Ban?* (New York: Springer, 2011); and Andreas Persbo, "Compliance Science: The CTBT's Global Verification System," *Nonproliferation Review* 23, no. 3–4 (March 2017): 317–328.

17. Jaswant Singh, "Against Nuclear Apartheid," *Foreign Affairs* 77, no. 5 (September/October 1998): 41–52; Kingston Reif, "How to Ratify the Test Ban Treaty," *World Politics Review*, November 2, 2009, <http://www.worldpoliticsreview.com/articles/4538/how-to-ratify-the-test-ban-treaty>; Charles D. Ferguson and Stephen Herzog, "Kyl Should



For instance, in 2015, Michael Schoeppner and Ulrich Kühn wrote a piece for the *Bulletin of the Atomic Scientists* recommending improvements to the IMS noble gas monitoring network.<sup>18</sup> In January 2017, *Arms Control Today* also published my article about technical policies the administration of U.S. President Donald Trump might consider to strengthen global detection of nuclear tests.<sup>19</sup> The aforementioned works are generally exceptions rather than the rule regarding the scope of such literature.

Outside of work on ratification and entry into force, academic and policy literature discussing aspects of the test ban is relatively scarce. This may sometimes create the illusion that the CTBT is a “dead” treaty or that there is nothing for policymakers to do on this front aside from encouraging Annex 2 holdouts to deposit their instruments of ratification. Such a perception does not mirror reality, as states may pursue many policies to enhance the international norm against nuclear explosive testing. Besides spelling out some of these policy options, this roadmap recommends greater attention to different elements of the CTBT in the literature.

## FOCUS AREA 1: THE INTERNATIONAL MONITORING SYSTEM

When we talk about monitoring in the context of the CTBT, one of the first subjects that comes to mind is almost inevitably the IMS. Thus, it is important to be precise about the nature of this system, as well as its capabilities and the processes behind its operation. A clear understanding of the monitoring system is instrumental to making informed policy recommendations aimed at its improvement.

When complete, the IMS (displayed in Figure 1) will consist of 321 monitoring stations and 16 radionuclide laboratories around the globe. Operating, maintaining, and upgrading the IMS are among the primary duties of the Provisional Technical Secretariat (PTS) of the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO). The text of the Protocol to the CTBT specifies that the system shall include 50 primary seismic stations, 120 auxiliary seismic stations, 11 hydroacoustic stations, 60 infrasound stations, 80 radionuclide stations, and 16 radionuclide laboratories. Seismic sensors enable the detection of waveform events traveling through the earth’s lithosphere (crust and upper mantle) and are the key to locating underground nuclear tests. While the CTBTO runs the primary seismic network, host countries are responsible for the auxiliary stations, which enhance primary event location accuracies. The primary seismic network contributes data to the CTBTO’s IDC in Vienna around the clock on a

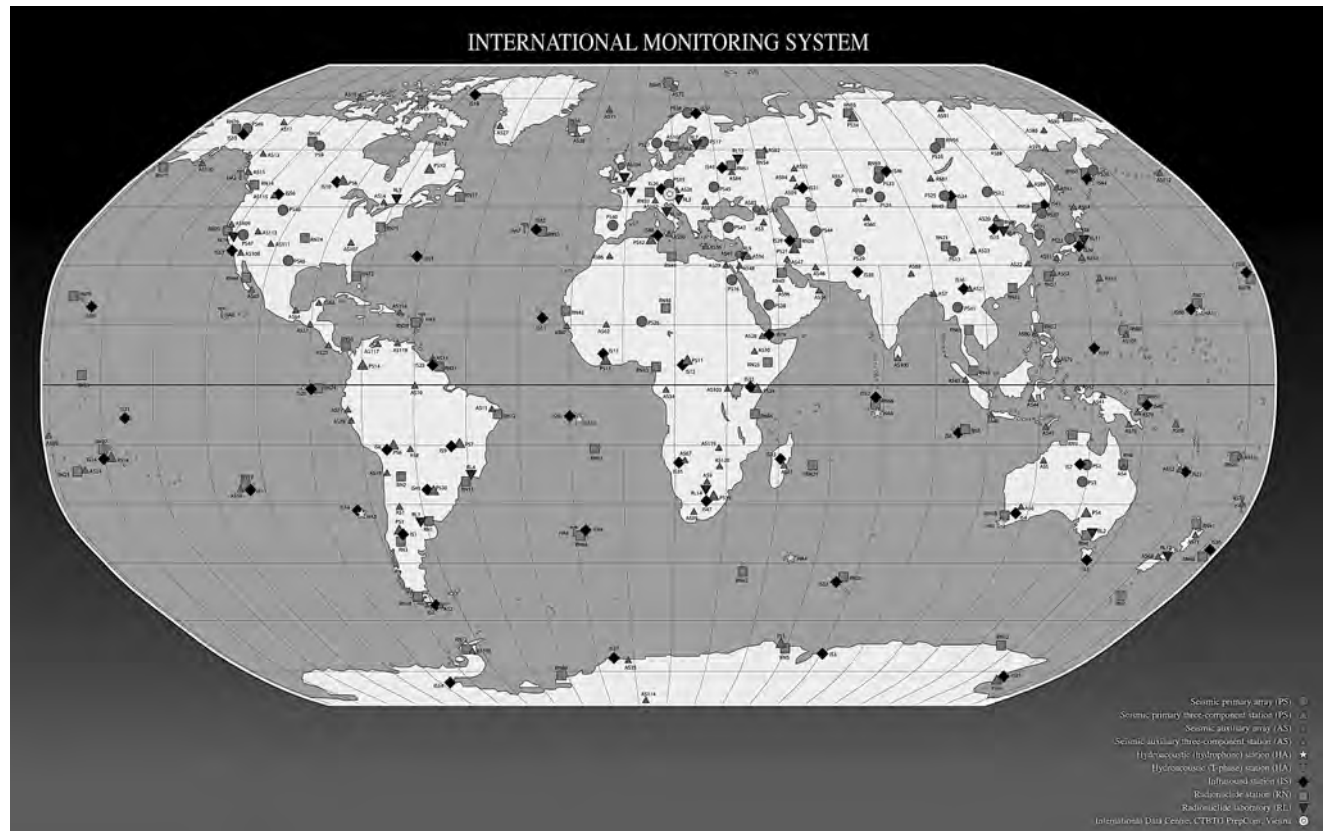
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Reconsider Opposition to Nuclear Test Ban,” *The Hill*, March 30, 2011, <http://thehill.com/blogs/congress-blog/technology/152843-kyl-should-reconsider-opposition-to-nuclear-test-ban>; Jon Kyl and Douglas J. Feith, “Evading the Constitution to Ban Nuclear Tests,” *Wall Street Journal*, August 15, 2016, <https://www.wsj.com/articles/evading-the-constitution-to-ban-nuclear-tests-1471303498>; and Jeffrey Lewis, “Not Even Rick Perry Is Stupid Enough to Resume Testing Nuclear Weapons,” *Foreign Policy*, January 9, 2017, <http://foreignpolicy.com/2017/01/09/not-even-rick-perry-is-stupid-enough-to-resume-testing-nuclear-weapons/>.

18. Michael Schoeppner and Ulrich Kühn, “Improve the Nuclear Test Monitoring System,” *Bulletin of the Atomic Scientists*, February 9, 2015, <http://thebulletin.org/improve-nuclear-test-monitoring-system7980>.

19. This roadmap offers an expanded technical analysis of my earlier article, but with more of an international—rather than American—focus. See Herzog, “The Nuclear Test Ban.”

**Figure 1. Planned International Monitoring System**



Source: CTBTO, "IMS Map," July 2003, [https://www.ctbto.org/fileadmin/content/reference/outreach/ims\\_mapfront.pdf](https://www.ctbto.org/fileadmin/content/reference/outreach/ims_mapfront.pdf).

Note: In the figure, the CTBTO makes the distinction between seismic arrays and three-component seismic stations. Essentially, the difference here is that a three-component broadband seismic station is best for global seismic event monitoring purposes, while a seismic array involves a configuration of several seismometers—some may be broadband sensors and others may be short-period sensors—working together to yield both regional and global waveform data coverage.

continuous basis. Auxiliary data can be made available to the IDC at the request of states-parties to the treaty. Hydroacoustic stations monitor for underwater nuclear explosions and are very accurate in detecting soundwaves in the oceans due to water's propagation characteristics. This monitoring technology comes in two variants: six hydrophones (underwater microphones) and five T-phase stations "[consisting] of one or more seismometers located near-shore, typically on mid-ocean islands."<sup>20</sup> The final waveform technology is infrasound, wherein sensors detect low-frequency sounds that might come from atmospheric nuclear tests. Beyond waveform monitoring, the IMS also includes radionuclide stations that sample the atmosphere for airborne radioactive elements—like certain isotopes of xenon and argon—that would be produced by nuclear explosions. The treaty notes that 40 of the radionuclide stations will have the capability to monitor noble gases alongside particulates, for which the entire 80-station network is equipped. The IMS

20. Jeffrey Hanson et al., "Operational Processing of Hydroacoustics at the Prototype International Data Center," *Pure and Applied Geophysics* 158, no. 3 (March 2001): 427.

radionuclide laboratories then process these samples and can confirm whether a nuclear test has occurred—something that waveform data by themselves cannot reveal.<sup>21</sup>

What is the status of the monitoring system today? The past two decades have seen remarkable progress in building a global network for monitoring nuclear explosions. At the time of writing, of the 337 IMS facilities, 292 were certified and transmitting data in real time to the IDC, 13 were installed and awaiting certification, 7 were under construction, and 25 still remained in the planning process.<sup>22</sup> Recent developments include the June 2017 certification of a radionuclide station on the Galapagos Islands, Ecuador. And during that same month, the CTBTO certified the last of the 11 IMS hydroacoustic network stations, located on the Crozet Islands in the Southern Indian Ocean. Even before entry into force, the IMS is monitoring the globe for nuclear tests and has experienced much success. Right now, the system is sending data from distant corners of the planet to Vienna through the Global Communications Infrastructure satellite network. The monitoring system detected all six of North Korea's nuclear tests. In addition, IMS radionuclide data were integral to disaster assessment during the 2011 Fukushima Daiichi crisis, while infra-sonic array data assisted in analyzing the low-frequency sounds emitted during the eruption of the Icelandic volcano Eyjafjallajökull in 2010. This sort of field-testing is critical; after entry into force, the international community will use IMS data to define the inspection area for treaty OSI.<sup>23</sup> The performance of—and data from—the IMS led an influential National Academy of Sciences study by American technical experts to conclude in 2012 that global and U.S. national capabilities make it extremely unlikely that any state could carry out evasive nuclear tests of military significance.<sup>24</sup>

It is possible to improve the IMS, even with this strong track record of success. First and foremost is the completion of the system. Two main complications underscore the difficulties in accomplishing this objective: resources/logistical issues and politics. Annex 1 to the treaty's protocol lays out the national locations (and in most cases, coordinates) for the IMS stations in a manner best suited to monitoring a zero-yield test ban. Changing these locations would require amending or renegotiating the treaty and might compromise the CTBT's verifiability. To be fair, some station locations in places like Antarctica and Mount Everest face challenging conditions, due to terrain and/or remoteness, for installing sensors as well as high maintenance costs. Political issues represent a greater obstacle to the IMS. China, Egypt, Iran, Pakistan, and Saudi Arabia are among the treaty holdouts slated to host currently noncertified stations. In the case of China, the process of certifying the stations has begun and the sensors are sending data to the IDC. However, the

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21. As discussed later in this paper, it is important to remember that the CTBTO does not make the final determination about whether a test has occurred. This is left to the states-parties.

22. CTBTO, "Map," December 2017, <https://www.ctbto.org/map/>.

23. In fact, the international community has extensively tested and refined the treaty's OSI procedures through the CTBTO's Integrated Field Exercises in Kazakhstan in 2008 and Jordan in 2014. See Oliver Meier, "Special Report: Major Exercise Tests CTBT On-Site Inspections," *Arms Control Today* 38, no. 9 (November 2008): 32–38; Jenifer Mackby, "Special Report: Did Maridia Conduct a Nuclear Test Explosion? On-Site Inspection and the CTBT," *Arms Control Today* 45, no. 1 (January/February 2015): 16–22.

24. National Academy of Sciences, *The Comprehensive Nuclear Test Ban Treaty: Technical Issues for the United States* (Washington, DC: National Academies Press, 2012), 35–76, 139–179.

construction of several stations in other states has not broken ground. Between logistics and politics, there remain numerous incomplete IMS stations. For this reason, states-parties should endeavor to provide relevant technical assistance to the PTS and consider provisioning Voluntary Contribution funds toward getting these stations installed and certified. Furthermore, at the political level, states should encourage others to move forward with their hosted IMS stations pursuant to the treaty. This process should mainly focus on the technical utility of sensors for nuclear test detection and deterrence, alongside civil-scientific applications of derivative data products. The politics of treaty ratification are hardly an ideal starting point for discussing the IMS, and there is a precedent for states installing stations prior to national ratification.

Among the various technologies, noble gas detection remains the most underdeveloped component of the IMS. Only 25 of 40 such facilities are certified at the moment.<sup>25</sup> The disparity between the status of the noble gas network and the other monitoring capabilities comes from the relative newness of the technology. Noble gas monitoring for CTBT purposes began in 1999 as part of the International Noble Gas Experiment, and in March 2011 only three such stations were certified.<sup>26</sup> Other issues extend beyond the relatively unfinished status of this network. First, simulations by researchers have suggested that the location of the noble gas monitoring sensors, combined with different atmospheric transport patterns around the equator, could greatly complicate detection.<sup>27</sup> These simulations also involved the ideal assumption that all 40 stations were operational. Unlike the other components of the IMS, the treaty does not specify the locations of the noble gas facilities. The number of noble gas stations cannot change without amending the treaty, but if such blind spots truly exist, it would be instructive for experts at the CTBTO's Working Group B (WGB) on verification issues to reevaluate whether these sensors are located in an ideal configuration for monitoring. Second, the production of medical isotopes results in radioxenon discharges that may prove another hurdle to nuclear explosion monitoring. While several major radioisotope producers have concluded agreements with the CTBTO to minimize these emissions, medical isotopes will remain a problem, particularly with the current trajectory of increasing global demand for nuclear medicine.<sup>28</sup> To that end, industry should take the lead in developing processes to prevent confusing and potentially dangerous monitoring situations from arising. Even with extant declaratory statements to support this agenda, states should also consider new regulations to encourage and mandate industrial compliance. Another possibility is for companies to share their production information with the CTBTO, "allowing the organization to gain a better understanding of the radioxenon background and so to make more accurate predictions of expected concentrations

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25. CTBTO, "Map."

26. Ibid.; CTBTO, "Monitoring Technologies: How They Work," 2017, <https://www.ctbto.org/verification-regime/monitoring-technologies-how-they-work/radionuclide-monitoring/page-5/>.

27. Michael Schoeppner, "Performance Assessment of the CTBTO Noble Gas Network to Detect Nuclear Explosions," *Pure and Applied Geophysics* 174, no. 5 (May 2017): 2161–2171; Schoeppner and Kühn, "Improve the Nuclear Test Monitoring System."

28. CTBTO, "Medical Isotope Producers and the CTBTO Join Forces to Reduce Radioxenon Emissions," 2013, <https://www.ctbto.org/press-centre/highlights/2013/medical-isotope-producers-and-the-ctbto-join-forces-to-reduce-radioxenon-emissions/>.

at monitoring stations.”<sup>29</sup> Corporate volunteerism of this type is easier said than done, however, as it risks revealing trade secrets.

If certification of all the noble gas and other IMS stations became a reality, this would still not necessarily indicate the system’s permanence or smooth operability. Obtaining these conditions requires what is called a Facility Agreement between the PTS and the monitoring facility’s host state. According to the CTBTO, “Facility Agreements help to address the entire bandwidth of issues regarding IMS facilities between the hosting Member States and the CTBTO.”<sup>30</sup> Accordingly, they “cover matters such as IMS technical upgrades, station operator training, and the legal aspects of CTBTO access to monitoring sites.”<sup>31</sup> The Facility Agreements regime applies to all 89 countries hosting IMS stations, but so far, participation is far from universal. A total of 41 agreements have been ratified, with eight signed and 40 awaiting signature. Agreements that have entered into force cover only about half of all facilities.<sup>32</sup> This is not to say or imply that countries without Facility Agreements do not give access to CTBTO personnel and live up to the spirit of the regime. But in the absence of a legally binding agreement between the organization and host states, few barriers prevent willful obstruction of the monitoring system. By concluding Facility Agreements with the PTS and encouraging others to do so, states would set important examples and signal that the IMS is here to stay.

Lastly, what is to be done about gaps in the IMS if the number and location of stations remains essentially unchangeable before entry into force? The treaty permits states to send data from their own national monitoring stations—external to the IMS—to the CTBTO to supplement the international data. This raises a few problems. States may be hesitant to provide such data since it risks revealing the sources and methods of intelligence and national technical means. Additionally, states may be reluctant to trust data from others, particularly their adversaries, out of fear of alteration or “spoofing.” A possible solution to the data authentication dilemma lies in the treaty’s little-known provision for Cooperating National Facilities (CNFs). Per this provision, states may choose to build stations at their own expense to supplement the IMS, which then receive certification by the CTBTO upon successful inspection and establishment of the requisite data links to Vienna. These CNFs can be of any type from among the four IMS technologies and function in the same manner as an auxiliary seismic station. That is, their data can be made available to the IDC on request.

Several states have discussed prototype CNFs with the CTBTO, but thus far there has been little progress toward their physical and legal establishment.<sup>33</sup> The main issue is that CNFs must receive certification from the Technical Secretariat, which cannot exist until the treaty enters into force,

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29. Schoeppner and Kühn, “Improve the Nuclear Test Monitoring System.”

30. CTBTO, “Facility Agreements: The Cement between Member States, IMS Stations, and the CTBTO,” 2017, <https://www.ctbto.org/member-states/facility-agreements/>.

31. Herzog, “The Nuclear Test Ban,” 28.

32. CTBTO, “Facility Agreements: The Cement between Member States, IMS Stations, and the CTBTO.”

33. CTBTO, e-mail correspondence with author, September 2016. For a discussion of the potential benefits of CNFs from an Israeli perspective, see Yair Bartal et al., “Optimal Seismic Networks in Israel in the Context of the Comprehensive Test Ban Treaty,” *Bulletin of the Seismological Society of America* 90, no. 1 (February 2000): 151–165.



hence the current “Provisional” body. Regardless, CNFs have been a subject of WGB meetings in recent years, with some states interested in authorizing data transmission from national stations prior to the CTBT’s entry into force. To the extent they are financially capable, states with such an interest should consider developing prototype CNFs and advocating for processes to make national data contributions to the IDC in the interim before the remaining Annex 2 ratifications. Wealthier states could provide financial and technical assistance to less able states pondering the CNF option. And importantly, prototype CNFs in regions with planned IMS stations might offer a “proof of concept” to hosts of noncertified IMS stations.

## FOCUS AREA 2: THE INTERNATIONAL DATA CENTER

After the monitoring stations collect waveform and radionuclide data, the data travel via satellite to the IDC in Vienna. On the waveform side of the house, event data undergo three rounds of automatic processing and result in the dissemination of Standard Event Lists to states-parties, which provide parametric event data detailing attributes such as “arrival time, amplitude, frequency, direction, [and] estimate of the travel path.”<sup>34</sup> A team of trained analysts in the IDC’s control room assesses the third event list in order to validate and correct automated processing, thereby producing perhaps the most important IDC product: the Reviewed Event Bulletin. The data center also releases the Standard Screened Radionuclide Event Bulletin in response to the detection of high concentrations of radionuclides. In addition, it has fusion capabilities to assess events based on a combination of all four types of monitoring data. All in all, this is a massive undertaking, with states receiving an average of 21,000 different data products from the IDC on a monthly basis.<sup>35</sup> State-parties to the treaty also have continuous access to the IMS data in its raw form alongside these IDC data products.

One would think that all treaty-ratifying states would benefit from the monitoring data and IDC data products, but surprisingly, this has not proved to be the case. Any state that has signed the CTBT is able to designate 28 authorized users and six institutions among its government ministries and research community to access the real-time data and data repository on a website called the IDC Secure Web Portal.<sup>36</sup> Given the pool of 183 States Signatories, as many as 5,124 authorized users could have access to the portal. However, only 139 countries have designated such users, totaling approximately 1,500 people with portal access.<sup>37</sup> About a quarter of all states with eligibility to receive CTBT-related data are not taking advantage of the opportunity to do so, while many of those that are have only extended access to a limited number of individuals. States that are not looking at IMS data and IDC bulletins miss out on valuable data that can be used for nuclear explosion monitoring and a number of civil and scientific activities, which I discuss below.

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34. CTBTO, “Data Processing at the International Data Centre,” 2001, <https://www.ctbto.org/press-centre/highlights/2001/data-processing-at-the-international-data-centre/>.

35. Ibid.

36. Ibid.; CTBTO, “CTBTO Upgrades Online Services for Member States,” 2014, <https://www.ctbto.org/press-centre/highlights/2014/ctbto-upgrades-online-services-for-member-states/>.

37. Ibid.; CTBTO, e-mail correspondence with author, May 2017.

Accordingly, it would be quite beneficial for states to begin using the web portal and to designate additional authorized users. States that are familiar with these outputs are in a position to promote their use to allies and regional neighbors.

Making use of IMS data is of the utmost importance. The CTBTO lacks the relative authority and autonomy of the International Atomic Energy Agency. After the treaty's entry into force, the decision to initiate an OSI requires 30 supportive votes from state members of the organization's 51-member Executive Council, elected on the basis of a fair regional distribution. CTBTO experts do not have the legal authority to launch an OSI, which may only occur based on national votes. The decision to levy sanctions upon a country for violating the global norm against nuclear explosive testing is a similarly political decision. The data are thus often the key to technical analyses informing national security decision-makers around the world.

A related component of the global system of nuclear explosion monitoring is the institution of national data centers (NDCs). These nationally designated research institutions employ waveform and radionuclide data analysts to evaluate suspicious events, often alongside other civil and scientific pursuits. NDCs are the hub of national analysis efforts on IMS data, IDC data products, and information received from other monitoring stations that are not part of the CTBTO network.<sup>38</sup> In this respect, NDCs should in theory be a country's first line of sight for determining whether a geophysical event is natural or artificial. At the moment, 130 of 183 States Signatories have designated an institution to serve as their NDC.<sup>39</sup> Roughly 30 percent of states have not established an NDC for national monitoring purposes. States without an NDC could enhance the rigor of their technical analyses and soundness of corresponding political decisions by moving toward establishing an NDC. And states that are supportive of the nuclear explosion monitoring agenda could allocate cost-free expertise or aid funding to assist others interested in NDC development. These efforts can range from simply promoting the value of NDCs for security and research purposes, to more advanced scientific training for nascent and developing centers.<sup>40</sup>

But why do so many states either not access the available data from the dense network of IMS sensors, or not designate an NDC for CTBT-related analytic pursuits? Of course, politics is the clear driver when it comes to cases like those of India and Pakistan. By contrast, political factors of this type fail to explain why dozens of countries that have either signed or ratified the CTBT are not making use of the data or have not designated an NDC. A lack of funding and technical expertise is one possible explanation, and international assistance would help some states play a more extensive role in global nuclear explosion monitoring. The CTBTO and many highly developed states have capacity-building programs of this nature, but there is always space for these efforts to become more robust. Another explanation is that nuclear explosion monitoring is simply not a high priority for all countries, particularly those in the developing world that have more pressing issues for taking care of their respective populations. Leaders from many states perceive such

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38. For further discussion of national data centers (NDCs), see Dahlman, Mykkeltveit, and Haak, *Nuclear Test Ban*, 173–181; Dahlman et al., *Detect and Deter*, 51.

39. CTBTO, e-mail correspondence with author, May 2017.

40. Stephen Herzog, "NNSA, Thailand, CTBTO Host ASEAN Nuclear Explosion Monitoring Workshop," *NIS Highlights* (Spring 2013), 1–2.



monitoring as an endeavor for great powers or states located in dangerous “nuclear neighborhoods.” The international security implications of nuclear tests do not stop at geopolitical borders, though, and the process behind authorizing a future OSI or implementing an effective sanctions regime requires global participation. Even this rationale for actively participating in the test ban is not sufficiently compelling to all governments. In many cases, the extensive civil and scientific benefits of the IMS data will be more important to states than nuclear explosion monitoring. The CTBTO now promotes these elements of the treaty, as indicated by the wide range of panels and poster sessions dedicated to them at its recent Science and Technology 2017 Conference. It would be very useful for national governments and the scientific community to do so as well, particularly in their interactions with counterparts from states with limited engagement with the CTBTO and its activities.

The civil and scientific applications of IMS data are vast. As mentioned previously, the data were integral in disaster response efforts to the Fukushima and Eyjafjallajökull crises.<sup>41</sup> After the deadly 2004 Indian Ocean tsunami, the availability of waveform data from monitoring stations spurred cooperative agreements on real-time tsunami warning between 14 states and the CTBTO.<sup>42</sup> Many countries have used data for seismic hazard mapping to protect cities and to improve building codes for construction projects. The data also have utility for a wide array of scientific research, including but certainly not limited to iceberg monitoring, whale migration pattern tracking, climate change studies, and atmospheric transport modeling. Many of these applications would be useful even to leaders who are disinterested in nuclear explosion monitoring, as they help to advance science and save lives. If more states receive data from the web portal and engage in NDC build-out, these civil and scientific applications could even open the door to further engagement with the CTBTO and exposure to modern techniques and computer software for monitoring nuclear tests.

New opportunities for academic and industrial institutions to benefit from the IMS data would offer another promising avenue to bolster the treaty. As noted in my previous article, “Many technical experts in academia and private industry have a professional interest in disaster response, geophysical hazard mitigation, nuclear explosion monitoring, and other related scientific endeavors.”<sup>43</sup> Consequently, the CTBT Science and Technology 2017 Conference involved participants from universities and private industry around the world, alongside government-affiliated personnel. In the past, the ability to use IMS data has come with sharp limitations due to the process for states designating authorized users to the portal. The CTBTO now has a procedure to

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41. See Robert Golan-Vilella, “CTBT Monitors Assist in Fukushima Aftermath,” *Arms Control Today* 41, no. 4 (May 2011): 31–32; Gilbert Le Petit et al., “Analysis of Radionuclide Releases from the Fukushima Dai-Ichi Nuclear Power Plant Accident Part I,” *Pure and Applied Geophysics* 171, no. 3 (March 2014): 629–644; and Martin Kalinowski, “Civil and Scientific Applications of CTBT Verification Technologies: Detection and Response to the Fukushima Nuclear Crisis” (paper presented to the CTBT Intensive Policy Course, Vienna, July 19, 2012), [https://ktp.ctbto.org/pluginfile.php?file=/2404/mod\\_page/content/19/4.%20Martin%20Kalinowski%2C%20The%20Civil%20and%20Scientific%20Applications%20of%20Verification%20Technology.pdf](https://ktp.ctbto.org/pluginfile.php?file=/2404/mod_page/content/19/4.%20Martin%20Kalinowski%2C%20The%20Civil%20and%20Scientific%20Applications%20of%20Verification%20Technology.pdf).

42. CTBTO, e-mail correspondence with author, May 2017; and Wendy Watson-Wright, “Buttressing the Global Tsunami Warning Network,” *CTBTO Spectrum*, no. 18 (March 2012): 33–35.

43. Herzog, “The Nuclear Test Ban,” 31.

request archived event data for studies through its Virtual Data Exploitation Center. Data received through this platform are “not useful for monitoring and may not be published in . . . raw form.”<sup>44</sup> Obviously, the event-specific format of these deliveries results in constraints on nongovernmental uses of IMS data. By making the full repository of IMS data available—with a time lag to prevent real-time monitoring by nonsignatories—the CTBTO would likely trigger marked increases in data usage, possibly even among states that are outside of the test ban regime or have limited engagement with the organization. Such an action could only be beneficial to the cause of prohibiting nuclear explosions.

## FOCUS AREA 3: COLLABORATIVE NATIONAL ACTIVITIES

Day and night, the IMS and IDC are constantly at work to detect potential nuclear tests. Be that as it may, states have many opportunities to build on the strength of these capabilities. States can also pursue a number of policies to reinforce and expand on nuclear explosion monitoring activities external to the official CTBTO framework. The discussion herein now turns to potential projects of this nature at the national level.

For many policymakers, arms controllers, and diplomats, monitoring of the test ban centers around the 337 IMS facilities and the IDC. Despite the impressive scope and performance of treaty-affiliated monitoring stations, they are but one component of the international monitoring infrastructure. Countless other networks of sensors collect waveform and radionuclide data, a product of the dual-use nature of this data for civil-scientific projects and CTBT functions. The government of Azerbaijan maintains a network of 35 seismic monitoring stations for hazard mitigation, natural resource extraction, and scientific research projects.<sup>45</sup> On the Big Island of Hawaii, six infrasound arrays keep tabs on the Mauna Loa and Kīlauea volcanoes and support academic volcanology studies.<sup>46</sup> Networks exist all throughout the world for purposes such as these, and their data make significant contributions to CTBT monitoring. For instance, data from the seismic network of the Korean Institute of Geoscience and Mineral Resources have been useful for locating North Korea’s explosive tests at the Punggye-ri site.<sup>47</sup> When states—and research institutes—build and expand on national networks for geophysical monitoring, they help to detect and deter CTBT noncompliance while reaping a multitude of civil-scientific benefits. National stations also have the potential to contribute data toward transparency and confidence building, particularly in regions rife with political tensions where it is vital to avoid misperceptions about the character of events. States may also integrate national network data with IMS data in order to improve the accuracy of regional event locations and other NDC analyses. National data both complements

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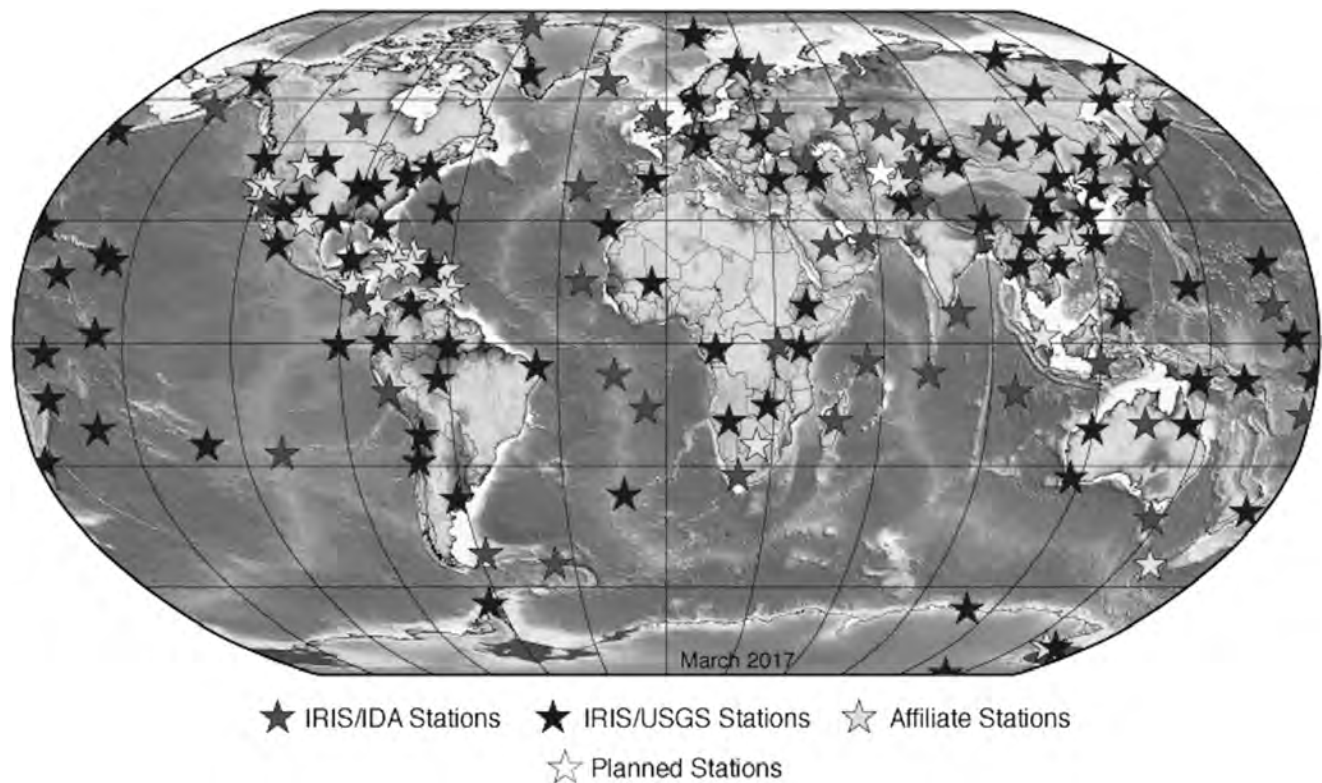
44. Ibid.

45. Kinemetrics, “National Seismic Network—Azerbaijan,” 2017, <https://kinemetrics.com/portfolio/national-seismic-network-azerbaijan/>.

46. Weston Thelen et al., “Infrasound Monitoring Network of the Big Island of Hawaii” (paper presented to the European Geosciences Union General Assembly, Vienna, April 7–12, 2013).

47. David Coblenz and Frank Pabian, “North Korea’s Punggye-ri Nuclear Test Site: Analysis Reveals Its Potential for Additional Testing with Significantly Higher Yields,” *38 North*, March 10, 2017, <http://www.38north.org/2017/03/punggye031017/>.

**Figure 2. Global Seismographic Network**



Source: Incorporated Research Institutions for Seismology (IRIS), "Global Seismographic Network," March 2017, <https://www.iris.edu/hq/programs/gsn>.

and supplements the IMS, and may thus be instrumental in shaping national decisions with regard to whether a nuclear test has occurred.

Bilateral, regional, and global data-sharing agreements offer another opportunity to buttress transparency initiatives, civil-scientific collaboration, and nuclear explosion monitoring. Perhaps the most prominent data-sharing activities occur in the field of seismology, but there are few compelling reasons why cooperation cannot occur with respect to all relevant technologies. After the 2010 earthquake in Haiti, the country began building an advanced seismic network and quickly forged bilateral partnerships with research institutes in Canada and the United States.<sup>48</sup> Another example is the Red-Dead Sea water conveyance proposal that will require seismic data sharing between Israel, Jordan, and Palestine in order to provide new sources of potable water and improve desalination prospects. There are also a number of multilateral efforts of global scope. For instance, the International Seismological Center in London offers regular bulletins of parametric data from member institutions spanning the globe. And the U.S.-based Incorporated Research

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48. Stephen Herzog, "Assessing the Role of Seismic Data Sharing in CTBT Monitoring," in *Nuclear Scholars Initiative: A Collection of Papers from the 2012 Nuclear Scholars Initiative*, ed. John K. Warden (Washington, DC: CSIS, October 2012), 189, [https://csis-prod.s3.amazonaws.com/s3fs-public/legacy\\_files/files/publication/121017\\_Spies\\_NuclearInitiative\\_Web.pdf](https://csis-prod.s3.amazonaws.com/s3fs-public/legacy_files/files/publication/121017_Spies_NuclearInitiative_Web.pdf).

Institutions for Seismology (IRIS) operates what is called the Global Seismographic Network, which relies on station host countries. The network shown in Figure 2 “is a 150+ station, globally distributed, state-of-the-art digital seismic network that provides free, [real-time], open access data,” and IRIS maintains a repository of the archived waveforms.<sup>49</sup> Participation in collaborative multinational efforts such as these, and other opportunities to share data and work on joint civil projects, is a win-win situation for global security and the national interests of states.

## CONCLUSION

The preceding roadmap illustrates a multitude of reasons why discussions of the nuclear test ban need to evolve beyond their current one-dimensional dynamic. Still, it is important to recognize that ratification and entry into force are the gateway to unlocking the treaty’s well-developed OSI verification provisions.<sup>50</sup> Scholars and analysts should, however, address other important questions: What can the international community do now to improve its ability to police the globe against nuclear explosive testing? How do science, technology, and politics intersect within the realm of nuclear arms control? And what steps could be taken to overcome the collective action problem related to improved treaty monitoring and verification?

It is clear that much can be done toward this objective at the IMS, IDC, and collaborative national levels—both inside and outside the CTBTO context. These initiatives also complement the politics of treaty ratification and entry into force.<sup>51</sup> By illustrating the importance and benefits of waveform and radionuclide data for security and civil-scientific ends, states can set an example for others and encourage greater engagement with the CTBTO and the global monitoring community. Technical projects with benefits extending beyond explosion monitoring also hold promise for forward movement on the remaining planned IMS stations, especially in countries where political justifications hold their construction hostage. Given the grave consequences of horizontal proliferation, even leaders who are not CTBT advocates should have an interest in enhanced global detection capabilities.

At the end of the day, it is national governments that will ultimately make decisions about treaty ratification and punishments for transgressions of the norm against nuclear testing. Increased data availability, analysis sophistication, transparency, and sharing will all result in an improved grasp of suspicious geophysical events and the technical intricacies of the CTBT’s monitoring and verification regimes. The only proverbial losers are those intending to carry out nuclear tests in contravention of well-established international norms.

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49. Incorporated Research Institutions for Seismology (IRIS), “Global Seismographic Network,” March 2017, <https://www.iris.edu/hq/programs/gsn>.

50. Meier, “Special Report: Major Exercise Tests CTBT On-Site Inspections”; Mackby, “Special Report: Did Maridia Conduct a Nuclear Test Explosion?”

51. Herzog, “The Nuclear Test Ban,” 31–32.

# Producing Second Strike

Isaac Jenkins<sup>1</sup>

*Strategic deterrence relies in part on second-strike capabilities. As the most survivable leg of the nuclear triad, strategic ballistic missile submarines (SSBNs) are vital to second strike. The production and sustainment of SSBNs is therefore an important concern for nuclear-armed states. National defense industrial base policy guides the production decisions that states make. This paper outlines the production decisions of SSBN-capable states and identifies the trade-offs involved in different choices to identify key considerations for U.S. policymakers in strengthening the U.S. industrial base. States face a set of core trade-offs in SSBN production. First, they face a trade-off in cost versus control of production, wherein states can leverage comparative advantages in production at the expense of domestic control or else seek a domestic supply chain at great cost. States also face both risks and benefits in choosing interdependent production or attempting exclusively domestic production, primarily in the degree to which they strengthen relationships with security partners. Each SSBN state has unique aspects to its defense industrial policies, but in general, trends such as technology proliferation and increasing indigenous production will define SSBN building for the coming decades. The paper draws on this analysis to identify the main challenges to U.S. and allied SSBN supply chains, which include cybersecurity, supply chain health and viability, and foreign acquisition of critical producers.*

## INTRODUCTION

Second-strike capability is the basis of strategic nuclear deterrence, and arguably the most critical military capability available to the modern state. As Kenneth Waltz wrote in 1981, “Deterrence is achieved not through the ability to defend but through the ability to punish.”<sup>2</sup> The ability to survive a first strategic nuclear strike and retaliate with overwhelming force is vital to nuclear

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1. Isaac Jenkins is a PhD candidate in political science at the University of Michigan and a consultant to the U.S. Department of Defense.

2. Kenneth Waltz, “The Spread of Nuclear Weapons: More May Be Better,” *Adelphi Papers* 21, no. 171 (1981): 3.



deterrence and the final guarantor of security.<sup>3</sup> The production of second-strike capability is one of the most essential tasks a great power must execute, a core priority for the state's defense policy.

Second strike is largely dependent on the undersea deterrent: ballistic missile submarines.<sup>4</sup> While nuclear states can also maintain strategic bombers and intercontinental ballistic missiles (ICBMs), it is the submarine-launched ballistic missile (SLBM) that is most survivable and therefore essential for a second strike. In a hypothetical first strike by an enemy, all identified ICBM silos and all identifiable strategic bombers would be targeted, potentially eliminating the capacity to launch a retaliatory strike by air or land.<sup>5</sup> Submarines, however, are extremely difficult to find, hidden within the wide expanses of the ocean, and in the case of U.S. submarines, can launch their onboard arsenal—around half the total U.S. arsenal—within minutes.<sup>6</sup> This technology eliminates the advantages of strategic first strike designed to prevent retaliation. Ballistic missile submarines (SSBNs), through their deterrent capabilities, play an important role in providing a failsafe in international crises, keeping conflicts at the conventional level and, thus far, averting direct great power conflict.<sup>7</sup>

Eight countries currently field, possibly field, or are attempting to field an undersea deterrent, including either ballistic or nuclear-armed cruise missile capabilities. The United States, the United Kingdom, France, and Russia were the first countries to deploy SSBNs on patrols in the 1950s and 1960s. China developed submarine-launched nuclear capabilities in the 1980s and at present is planning substantial growth to its submarine fleet. At some point between the 1990s and the present, Israel possibly developed a submarine-launched nuclear capability, though this remains unconfirmed. India and Pakistan have also made strides toward fielding a credible undersea deterrent, and tests of newly commissioned vessels and new missile classes continue as of this writing.<sup>8</sup>

Ballistic missile submarines are also extraordinarily challenging to build, but nuclear-armed states have demonstrated increasing interest in fielding and improving the capability. For all of these players, submarines with second-strike capability are a long game, requiring governments to

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3. Albert Wohlstetter, "The Delicate Balance of Terror," P-1472 (Santa Monica: RAND, December 1958), <https://www.rand.org/about/history/wohlstetter/P1472/P1472.html>.

4. Peter M. Swartz, "American Naval Policy, Strategy, Plans and Operations in the Second Decade of the Twenty-first Century," in *Routledge Handbook of Naval Strategy and Security*, ed. Joachim Krause and Sebastian Bruns (New York: Routledge, 2016), 229–267.

5. A possible exception is the increased survivability of road-mobile ICBMs, such as Russia's SS-25 (RS-12M Topol), which are harder to track and target than stationary silos. Pavel Podvig, ed., *Russian Strategic Nuclear Forces* (Cambridge, MA: MIT Press, 2001), 220.

6. Federation of American Scientists, "SSBN-726 Ohio-Class FBM Submarines," accessed May 10, 2017, <https://fas.org/nuke/guide/usa/slbm/ssbn-726.htm>.

7. Designated SSBN by the U.S. Navy (SS for submarine, B for ballistic, and N for nuclear-powered), I employ SSBN throughout to designate submarines of any country capable of launching nuclear missiles, though some in fact are diesel-powered submarines.

8. North Korea has also attempted to develop capabilities, but it is far from deploying a credible undersea deterrent and is not discussed in this chapter.



harness innovation and sustain highly specialized industrial capabilities on a permanent basis. The future of strategic deterrence through second strike and the ability to produce and sustain SSBN fleets is ultimately grounded in defense industrial policy. The very prosaic questions of supply chain maintenance, acquisition of critical materials, and the availability of metalworkers and engineers require answers before a state is able to field, or continue fielding, nuclear-armed submarines. This study asks: How do the major powers organize their production of SSBNs? What are the trade-offs of each approach? And how might the experience of SSBN-producing states inform U.S. policymaking today?

This article follows the logic that strategic deterrence relies on second strike, which is enabled by SSBNs—the product of defense industrial base policy decisions. It is therefore important to understand different defense industrial policies, identify their relative strengths and weaknesses, and apply insights to U.S. defense industrial policy. The paper begins with a brief definition of the defense industrial base, followed by an overview of defense industrial base policy, which encapsulates state decisionmaking on the production of military power. It follows with a description of the defense industrial choices made by states in the production of SSBN capabilities—how states build ballistic missile submarines. It identifies the trade-offs of such decisions and assesses the implications of state choices for future production capabilities, highlighting the key risks to U.S. and allied production of ballistic submarines. The paper concludes with recommendations for advancing secure U.S. SSBN production.

## THE DEFENSE INDUSTRIAL BASE

Undersea deterrence requires convincing potential adversaries that the state can sustain resource-intensive submarine operations continuously. Such operations necessitate many inputs, from research and development to manpower to nuclear fuel, but the hardware component requires the production and maintenance of highly complicated machines. The deterrent capabilities of a deployed SSBN rely on defense industrial capabilities: whether the state can procure and sustain platforms that provide a high-confidence deterrent.

The defense industrial base (DIB) describes the set of industrial capabilities available to a state for the production of military power. The U.S. DIB comprises both the prime defense contractors that supply the Department of Defense (DoD) with platforms, systems, weapons, munitions, and services, and the thousands of supporting subcontractors at multiple tiers down the supply chain. The U.S. defense industry, once dozens of prime contractors, has consolidated to just five major companies, each a conglomerate leveraging its own arsenal of corporate acquisitions in the quest for more capable products. The five major prime contractors, and a handful of smaller specialty prime contractors, provide engineering, production, and assembly work and targeted expertise from acquired companies, but they also require inputs from many specialist suppliers for materials, parts, and other inputs.<sup>9</sup> The U.S. DIB serves one primary customer, DoD, though the major

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9. Nayantara D. Hensel, *The Defense Industrial Base* (Farnham, UK: Ashgate, 2015), 49–85.

defense firms are increasingly looking to foreign military sales (FMS) and commercial products as revenue sources.<sup>10</sup>

U.S. DIB policy is managed via a set of initiatives taken by DoD; the Departments of Commerce, State, Justice, and Homeland Security; Congress; and the president. DIB policy has one overall goal: the secure and sustainable procurement of weapons and supporting capabilities. Policymakers attempt to balance the competing priorities of ensuring the continued advancement and production of the world's most capable platforms to serve the needs of the war fighter, and extracting the maximum value for the taxpayer from a secure supply chain. U.S. DIB policy includes the full life cycle of all defense products, from the design and engineering of a new concept through the production, maintenance, and sustainment of platforms. DIB policy in the United States takes many forms, but generally the government relies on a combination of carrots and sticks to incentivize the production of arms and prohibit anticompetitive behavior. The primary tools available to policymakers are the funding of research and development (R&D) through public, private, and joint initiatives; the funding of production capabilities; the purchase of defense products; the facilitation of foreign sales; the operation of government-owned facilities by government or contractors; the deployment of limited equity investment vehicles; and where deemed necessary, the direct sustainment of industrial capabilities required for future defense production.

DoD, through an interagency process, is also able to shape the DIB via blocking mergers and acquisitions (M&A) activity that may negatively affect the DIB.<sup>11</sup> DoD can advise the blocking of domestic M&A that would threaten competition within the DIB, and the Committee on Foreign Investment in the United States (CFIUS), an interagency group, can block international acquisitions of U.S. companies that threaten U.S. defense industrial capabilities.<sup>12</sup>

The U.S. Navy's industrial based has been challenged since the end of the Cold War. A reduced shipbuilding program has led to a smaller fleet and fewer orders from shipyards. Furthermore, build plans have produced fewer ships at a time, to spread government financial obligations over decades of fleet building instead of years. This makes good sense for the budget, but means limited work orders for specialty suppliers, fewer consistent jobs for specialized shipbuilders, and more companies facing cash-flow issues. Companies facing sporadic demand may end up backing out of the enterprise or leaning on government funds for sustainment.

But change is on the horizon, as the navy works to fulfill a 355-ship fleet plan. The 14 Ohio-class SSBNs that have underpinned U.S. security since the 1970s will be phased out starting in 2027, to be replaced with the Columbia-class SSBN, also known as the Ohio-class replacement program (ORP). The fleet build-out plan will last over 20 year, and will coincide with a number of other major ship class build-outs: the Ford-class carrier will replace the USS *Nimitz*, the Virginia-class attack submarine will replace the *Los Angeles*, the modernization of some Arleigh Burke-class

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10. Ibid., 167–185.

11. Office of the Deputy Under Secretary of Defense for Industrial Policy, *Defense Industrial Base Capabilities Study: Force Application* (Washington, DC: U.S. Department of Defense, 2004), 37.

12. U.S. Department of the Treasury, "The Committee on Foreign Investment in the United States (CFIUS)," last updated December 20, 2012, <https://www.treasury.gov/resource-center/international/Pages/Committee-on-Foreign-Investment-in-US.aspx>.

destroyers (DDG) will be accompanied by the building of the DDG-51 Flight III and the scrapping of some earlier ships, and the Littoral Combat Ship (LCS) will continue its run, among others. This vast workload represents an opportunity and a challenge for the defense industrial base, at a time when the navy has made extensive efforts to ensure that shipyards have enough work—for example, by refusing to choose just one LCS model, which guarantees that two shipyards, and two different suppliers, will stay in business.<sup>13</sup>

Globally, states take many approaches to managing the procurement of weapons. Acquisition requires expertise in many areas, vast industrial capabilities, and accompanying funding. But states can also buy weapons and platforms from foreign suppliers. Thus, states must decide whether they will produce arms or procure them from abroad. For most states, the demands of an industrial base capable of producing aircraft, ships, and other platforms are prohibitive. If states produce weapons domestically, they must choose whether arms production will be executed by the state or by the private sector. While the United States, the United Kingdom, and a handful of other states prioritize private-sector arms production, most other arms-producing states employ state-owned enterprises, at least for downstream assembly of platforms.<sup>14</sup> France, Italy, China, Russia, and India, for example, maintain total or majority ownership of their largest defense suppliers. Finally, states must also decide whether arms will be produced using entirely domestic supply chains or internationalized supply chains, and how they will manage relationships with foreign suppliers.

## THE ORGANIZATION OF SSBN PRODUCTION

Eight states are confirmed to possess, likely possess, or be in the advanced stages of testing submarine-launched second-strike capabilities: the United States, Russia, China, the United Kingdom, and France, with capabilities increasingly developing in India and Pakistan, and unacknowledged but likely capabilities in Israel. External factors, such as existing industrial capabilities and material resources, constrain state choices. However, states also have broad latitude to make consequential decisions when organizing the acquisition of submarine-launched nuclear capabilities. States build submarines domestically through private-sector corporations, state-affiliated private-sector corporations, public-private partnerships, autonomous state-owned enterprises, and the state or military bureaucracy itself. They buy them from other states or foreign private companies, develop jointly, buy platforms and customize using indigenously developed systems, or lease from foreign powers. Some have internationalized their supply chains, while others have attempted to vertically integrate theirs. Given the centrality of SSBNs to nuclear deterrence, understanding the trade-offs between these choices is essential to understanding the long-term effects of developing second strike capabilities and the viability of those capabilities. Finally, it sheds light on how the United States should prioritize DIB policy choices.

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13. Sydney Freedberg Jr., “Half of Shipbuilders ‘1 Contract Away’ from Bust: Stackley,” *Breaking Defense*, March 18, 2015, <http://breakingdefense.com/2015/03/half-of-shipbuilders-1-contract-away-from-bust-stackley/>.

14. A. Fleurant et al., “The SIPRI Top 100 Arms-producing and Military Services Companies,” fact sheet, Stockholm International Peace Research Institute (SIPRI), December 2016, <https://www.sipri.org/research/armament-and-disarmament/arms-transfers-and-military-spending/arms-production>.

## Private Defense Production

The United States is the most capable second-strike power. The United States possesses 18 Ohio-class nuclear-powered ballistic submarines (SSBNs), 14 of which are armed with nuclear SLBMs. Though not essential for the ballistic missile launch capability, nuclear power is the gold standard for second-strike submarines. Whereas diesel-powered submarines can remain submerged for weeks, their nuclear-powered cousins can remain submerged for months, the only restriction being resupply for the crew. Because the value of the platform comes from the inability of adversaries to detect its location, the extended deployment time is a great advantage. Despite the essential need of SSBNs for U.S. security, private companies are responsible for the production and many aspects of the maintenance of these capabilities.

The U.S. SSBN fleet was built by the private sector: publicly traded defense suppliers built the Ohio class and will build its replacement Columbia class. Today, General Dynamics and Huntington Ingalls shipbuilders contract with the U.S. government in a complicated arrangement, but ultimately the creation of the capability lies in the hands of profit-making businesses.<sup>15</sup> These publicly traded firms raise capital from the market, pay dividends to global investors, and suffer when the market is down or the government is not placing new orders. But they are responsible for providing the platforms on time and on budget and they increase their returns by designing innovative platforms, operating efficiently, and managing large-scale multidecade projects. The U.S. government and the builders have a relationship characterized both by close cooperation and by strains, but ultimately the government does not possess the authority to compel either producer to build submarines and is in fact prohibited by law from producing items itself that could be procured from the private sector.<sup>16</sup>

The United Kingdom also relies on private corporations to build and maintain core defense needs. The United Kingdom's Vanguard and planned Dreadnought classes are built by private components makers, systems integrators, and shipbuilders on government contracts.<sup>17</sup> Notably, the United Kingdom's smaller industrial base leads it to integrate component systems built abroad, especially in Italy and France. Unlike the United States, which is home to five large companies capable of assembling platforms, the United Kingdom is home to only one, increasing its dependence on both a single domestic prime contractor, BAE, and on foreign subcontractors.

## Semi-Privatized and State-Owned Enterprises

France built its four Triomphant-class submarines quite differently. Naval Group (formerly DCNS), France's defense giant, began as a collection of shipyards, both public and private, which by the 1950s was administered by the French military. It was subsequently transferred to the government,

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15. Ronald O'Rourke, *Navy Columbia Class (Ohio Replacement) Ballistic Missile Submarine (SSBN(X)) Program: Background and Issues for Congress* (Washington, DC: Congressional Research Service, 2017), 4, <https://www.hsdl.org/?view&did=801023>.

16. For example, the 1994 Federal Acquisitions Streamlining Act instructs the government to use commercial off-the-shelf (COTS) products where possible.

17. Mark V. Arena et al., *The United Kingdom's Naval Shipbuilding Industrial Base: The Next Fifteen Years* (Santa Monica, CA: RAND, 2005), [https://www.rand.org/content/dam/rand/pubs/monographs/2005/RAND\\_MG294.pdf](https://www.rand.org/content/dam/rand/pubs/monographs/2005/RAND_MG294.pdf).

then slowly privatized in the 1990s by issuing shares, though those only went to the state, the workers, and eventually, another French defense giant—Thales—in which the state also owns a significant minority stake. France's Naval Group is an example of a privatized, mostly publicly owned defense contractor, with the government's controlling stake guaranteeing the company will move in favorable directions. The United States and the United Kingdom's private systems and, to a lesser degree, France's semi-privatized systems are designed to reduce the burden on the state to manage the building of these complex platforms. They sacrifice a degree of control in exchange for the greater perceived expertise and efficiencies of the private sector.

Like France, Russia also employs state-owned enterprises, but maintains a greater degree of direct control over its defense production. Under the Soviet Union, all defense production was state-owned, though production occurred both in the USSR and in Soviet satellite states. Though Russia had largely dismantled the state-owned defense industry by 2000, President Vladimir Putin made reconsolidation of defense production a priority, and most defense capabilities were subsequently repurchased by the state.<sup>18</sup> Russia's Delta submarine classes were produced by state-owned enterprises during the Cold War. Its new Borei class is being produced by subsidiaries of Russia's United Shipbuilding Corporation (USC). USC, a conglomerate of shipyards and production facilities, is an "open joint stock company" in which the state owns 100 percent of the shares. USC comprises military and civilian shipbuilding subsidiaries, with mostly Soviet legacy infrastructure, most of which was privatized partially or wholly in the 1990s. Today, USC's subsidiaries include shipyards purchased far under market value during the Putin era.<sup>19</sup>

During the Soviet era, defense producers from across Warsaw Pact countries contributed to the USSR's arsenal.<sup>20</sup> This practice helped solidify interdependence between the states, and it continued for decades after the Cold War. However, Russia has recently faced the prospects of diminished cooperative relationships with foreign suppliers. The 2014 conflict in Ukraine led the new Ukrainian government to cancel contracts for naval engines, which delayed a Russian naval buildup by at least three years, with possible downstream effects for decades.<sup>21</sup> Russia has also come to rely increasingly on the export of submarines to sustain its domestic industry,<sup>22</sup> while simultaneously relying on imported European ships for its highest technology platforms.<sup>23</sup> Despite

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18. Cédric Durand, "Between Developmentalism and Instrumentalization: The Comeback of the Producing State in Russia," *Journal of Innovation Economics and Management* 2, no. 2 (2008): 171–191.

19. For a summary of this tactic, see Richard J. Anderson, "A History of President Putin's Campaign to Re-Nationalize Industry and the Implications for Russian Reform and Foreign Policy" (USAWC Civilian Research Project, Fletcher School of Law and Diplomacy, Tufts University, Medford, Massachusetts, August 2008), <http://www.dtic.mil/dtic/tr/fulltext/u2/a493664.pdf>.

20. Yudit Kiss, *Arms Industry Transformation and Integration: The Choices of East Central Europe* (Oxford: Oxford University Press, 2014).

21. Sam LaGrone, "Russian Navy Faces Surface Modernization Delays without Ukrainian Engines, Officials Pledge to Sue," *USNI News*, June 10, 2015, <https://news.usni.org/2015/06/10/russian-navy-faces-surface-modernization-delays-without-ukrainian-engines-officials-pledge-to-sue>.

22. Kyle Mizokami, "The Kilo-Class Submarine," *National Interest*, October 23, 2016, <http://nationalinterest.org/blog/the-kilo-class-submarine-why-russias-enemies-fear-the-black-18140>.

23. Ivana Kottasova, "From Guns to Warships: Inside Europe's Arms Trade with Russia," *CNN*, July 31, 2014, <http://www.cnn.com/2014/07/31/business/russia-arms-trade-explained/>.

Russian naval ambitions, its shipbuilding industry is still working to overcome obstacles throughout its supply chain. Centralized control of shipbuilding in general, and submarines in particular, has led to greater emphasis on domestic production by the Russian state.

Similarly, China's People's Liberation Army–Navy (PLAN) submarines have been built by its state-owned China Shipbuilding Industry Corporation, one of two commercial and military conglomerates created by the state. The massive conglomerates report directly to the State Council, the highest administrative body in the People's Republic of China.<sup>24</sup> The companies collaborate in design and construction to improve efficiency, which has enabled China to become the world's largest shipbuilder. The Chinese shipbuilding industry is viewed as a strategic asset, with an emphasis on domestic production wherever possible and acquisition of foreign intellectual property where necessary. China limits foreign ownership of its many smaller private shipbuilding companies and has leveraged lower production costs to undercut foreign shipbuilders as well. China's commercial ships have carried its commercial products to global markets, creating a virtuous cycle benefiting the growing shipbuilding industry. This increases the revenues to state-owned enterprises, while challenging the commercial viability of foreign builders, many of which also supply the defense market. This in turn forces adversaries to increase their support to domestic shipbuilders or risk losing industrial capacity.

Along with nuclear-attack and diesel-attack submarines, China's tightly controlled supply chain produces JIN-class SSBNs designed to carry the CSS-NX-12 (JL-2) SLBM, which will establish China's first credible long-range, sea-based deterrent.<sup>25</sup> While China's shipbuilding defense industrial base was formerly limited by lack of technological sophistication in design and building processes, technical cooperation agreements and joint ventures with foreign firms allowed Chinese companies to learn advanced techniques. "As a result, military shipbuilding programs—which are usually collocated at Chinese shipyards engaged in mostly commercial activities—have been able to leverage these considerable infrastructure and software improvements when it comes to design, development, and construction," resulting in more capable outputs to PLAN.<sup>26</sup> Greater efficiency and cheaper labor have also allowed China's producers to export to developing navies, undercutting competition to sell prestigious, and capable, submarines to countries with greater budget constraints.<sup>27</sup>

## International Sales and Indigenized Production

A central theme in SSBN acquisition is the initial procurement of submarines from abroad and the subsequent development of domestic production capabilities. China purchased its early fleet from

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24. Gabriel Collins and Michael C. Grubb, *A Comprehensive Survey of China's Dynamic Shipbuilding Industry: Commercial Development and Strategic Implications* (Newport, RI: U.S. Naval War College, 2008), <http://www.dtic.mil/dtic/tr/fulltext/u2/a519030.pdf>.

25. Office of the Secretary of Defense, *Annual Report to Congress: Military and Security Developments Involving the People's Republic of China 2016* (Washington, DC: U.S. Department of Defense, 2016), <https://www.defense.gov/Portals/1/Documents/pubs/2016%20China%20Military%20Power%20Report.pdf>.

26. Richard Bitzinger, *Arming Asia: Technonationalism and its Impact on Local Defense Industries* (London: Routledge, 2016).

27. Evan S. Medeiros et al., *A New Direction for China's Defense Industry* (Santa Monica, CA: RAND, 2005), 152, [https://www.rand.org/content/dam/rand/pubs/monographs/2005/RAND\\_MG334.pdf](https://www.rand.org/content/dam/rand/pubs/monographs/2005/RAND_MG334.pdf).



Russia, and these purchases make part of the PLAN fleet similar to those of the remaining and suspected SSBN states. India, Pakistan, and Israel have all procured submarines from other states, although each has pursued distinct strategies. India and Pakistan have worked to obtain an under-sea deterrent by incorporating foreign designs into domestic production capabilities. They began by developing relationships with foreign sources to purchase vessels, then jointly developed them with the requirement to produce at least part of the platforms in-country, then finally began indigenizing production entirely.

India tried a plethora of strategies to obtain its initial capabilities. It purchased submarines from the USSR and Germany, leased them from Russia, and entered agreements with France to jointly produce Naval Group designs in India.<sup>28</sup> India has purchased and leased these high-end platforms while increasingly encouraging in-country production by foreign firms, whether private or state-owned, with a long-term goal of domestic self-sufficiency in platform production. The strategy is slowly paying off: India's first indigenous vessels are being built by a military-run, government-owned shipbuilder, using some domestic private-sector inputs, and India has recently opened military shipbuilding competitions to the private sector as well.<sup>29</sup> With the testing of its K-4 missile advancing, India is on its way to a credible undersea regional deterrent. Pakistan has followed a similar path by buying from and later developing jointly with France and China, and eventually producing some vessels through its state-owned Karachi Shipyards. Each is still working to obtain the full capacity to build SSBNs end-to-end and reduce reliance on foreign suppliers.

Israel has thus far not professed an explicit strategy to indigenize submarine-building capabilities. Instead, Israel has developed a comparative advantage in systems and software, purchasing its larger platforms from the international market and installing after-market upgrades to increase lethality. For its submarines, which have been hinted at as carrying nuclear payloads,<sup>30</sup> Israel has purchased customized Dolphin-class submarines from the shipbuilding subsidiary of the German industrial giant ThyssenKrupp.<sup>31</sup> Israeli state-owned enterprises, such as Israel Aerospace Industries and Rafael, then further tailor the vessels to specifications. This strategy leaves Israel dependent on foreign producers for submarines and some other platforms, which has backfired in the past.

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28. David Scott, "India's Drive for a 'Blue Water' Navy," *Journal of Military and Strategic Studies* 10, no. 2 (2008), <http://jmss.org/jmss/index.php/jmss/article/view/90>.

29. Vivek Raghuvanshi, "Indian Navy to Buy Vessels from Private Shipyards in Policy Change," *Defense News*, May 4, 2017, <http://www.defensenews.com/articles/indian-navy-to-buy-vessels-from-private-shipyards-in-policy-change>.

30. Israeli prime minister Benjamin Netanyahu's comments are the most authoritative source for speculation that Israel has an undersea deterrent. In January 2016, he said, "Our submarine fleet serves as a deterrent to our enemies who seek our destruction. . . . They need to know that Israel is capable of hitting with very great force anyone who tries to harm us. And Israel's citizens need to know that Israel is a very strong country that is doing everything to defend them, everywhere and on every front." Herb Keinon, "Netanyahu, IDF High Command Tout New German-Made Submarine," *Jerusalem Post*, January 12, 2016, <http://www.jpost.com/Breaking-News/Netanyahu-IDF-high-command-tout-new-German-made-submarine-441243>. The submarines are also not true SSBNs, as they are Air Independent Propulsion diesel-powered.

31. In an arrangement evocative of the bizarre complexity of the international arms trade, as of this writing, Israeli companies are slated to modify new German submarines, allegedly negotiated by Prime Minister Netanyahu's personal lawyer, built by a publicly traded German company owned in part, and thus paying millions in dividends to, the Iranian government.

Israel suffered setbacks in its arms procurement due to the 1968 decision by the government of France's Charles de Gaulle to establish an arms embargo affecting some Israeli orders. The incident spurred Israel toward a policy of increasing its domestic production capabilities.<sup>32</sup> However, Israel's dependence on ThyssenKrupp and continued German government support will likely require it to sustain parts and maintenance agreements with Berlin for the coming decades.

## TRADE-OFFS IN SSBN STRATEGIES

Each DIB strategy entails trade-offs, primarily related to the burden of supporting an industrial capability versus the degree of security that ownership of standing capabilities engenders. States also operate in a dynamic environment in which the goals of producers and the goals of buyers are not entirely compatible, and are often partially in conflict.

### Cost versus Control

To sustain a credible undersea deterrent, states must be capable of deploying and supporting an SSBN fleet, which requires consistent access to spare parts and maintenance services. States that rely on foreign producers must maintain strong relationships with supplier governments. Prolonged disagreements may lead to reduced support for defense products, including SSBN support, and a less credible deterrent. States that buy from private domestic producers gain market efficiencies, but lack the ability to compel production. Reliance on state-owned organizations provides the benefits of greater control and oversight, though it also burdens the state with production, limits competition, and opens opportunities for corruption throughout the supply chain. In short, states face an overarching trade-off between cost and control. They chose the degree to which they are willing to bear the financial obligations of investment, research, production, and vast supply chains, or offload them onto the private sector or other countries.

In Figure 1, the SSBN states are shown on a spectrum of the degree of control they exercise directly over production. Domestic production implies greater control than foreign, domestic supply chains imply greater control than internationalized, and state-owned enterprises (SOEs) imply greater control than private contractors.

China, Russia, and France produce domestically using SOEs, with China making the greatest effort to control its supply chain entirely, Russia pursuing similar policies since the Ukraine conflict, and France maintaining an international supply chain. Two states, the United States and the United Kingdom, acquire their capabilities from private, domestic industry, which produces many domestic and some foreign components. India, Pakistan, and Israel have historically purchased submarines from foreign suppliers, although India and Pakistan are making a concerted effort to learn the design, production, and assembly processes domestically. India and Pakistan are employing SOEs in this effort.

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32. Sylvia K. Crosbie, *A Tacit Alliance: France and Israel from Suez to the Six Day War* (Princeton, NJ: Princeton University Press, 2015).

**Figure 1. State Control over SSBN Production**



### Interdependence versus Self-Reliance

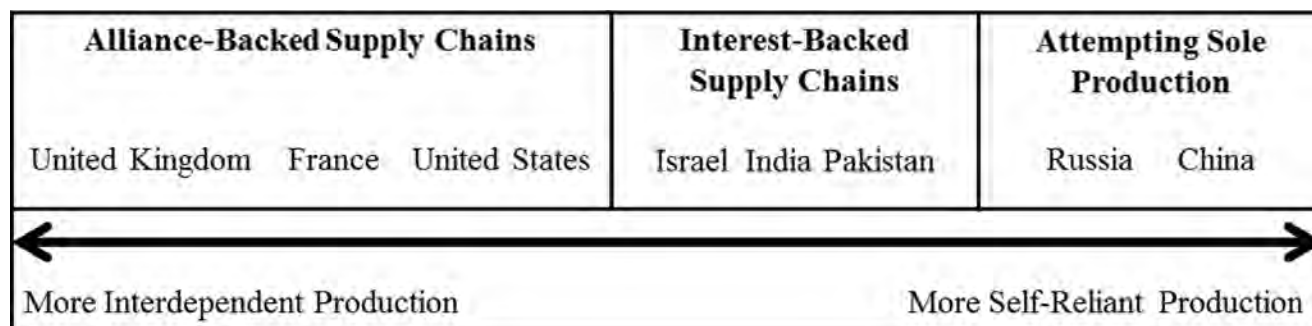
Defense industrial policy can also be used as a tool of statecraft. Interdependent production ties states' defense capabilities together, improves alliance bonds, allows for specialization, and enhances interoperability. It also inserts risk into supply chains via physical distance, potentially divergent security policies, and different legal and business environments. Buyers and sellers have both overlapping and competing interests. Buyers are important sources of revenue, but locking a buyer into a long-term support relationship can also give a seller a degree of influence over the buyer's policy choices. Where policies between buyer and seller diverge too greatly, sellers have an arsenal of levers available to deny buyers capabilities, from operations and support contracts to spare parts to continued sales. For a buyer state with limited domestic production capabilities, the relationship entails risk. However, for a buyer with policy preferences closely aligned to a seller's, the seller can effectively offload some "deterrent responsibility" to its buyer, to the benefit of both.<sup>33</sup> In Figure 2, the SSBN states are shown on a spectrum of the degree of interdependence in naval production.

The French and British SSBN supply chains crisscross NATO producers, with major systems and components produced in the United States and elsewhere in Europe. The United States explicitly ties other countries to its National Technology Industrial Base (NTIB): the United Kingdom, Canada, and Australia.<sup>34</sup> Though interdependence entails risk, these states have chosen to intertwine industrial production among alliance partners. Israel, India, and Pakistan have interest-based relationships with their submarine suppliers. They rely on fewer countries for SSBNs—Israel on Germany, India on France and Russia, Pakistan on France and China. They also have long-standing relationships with their suppliers—the USSR offset U.S. power by selling to nonaligned India, China offsets Indian power by working with Pakistan. During the Warsaw Pact era, Russia pursued a policy similar to the NATO states, but the increasing policy divergence between Russia and its most industrialized suppliers has led the Kremlin to prioritize domestic substitutes. China, which has a close security relationship only with North Korea, has worked to rely solely on state-controlled

33. For an overview of how this dynamic in international alliance politics, see Glenn H. Snyder, "The Security Dilemma in Alliance Politics," *World Politics* 36, no. 4 (1984): 461–495.

34. The expanded definition of the NTIB first appears in the 2017 National Defense Authorization Act.

**Figure 2. SSBN Production Interdependence**



production to the degree possible, an effort aided by generous state funding across the supply chain and lower relative cost of labor.<sup>35</sup>

## TRENDS IN SSBN PRODUCTION

This overview of state production decisions highlights the major trend in submarines: proliferation. SSBN capabilities are currently extending to all nuclear weapons states, with North Korea aiming for capabilities in the future as well.<sup>36</sup> In addition to the proliferation of nuclear weapons themselves, submarine-launched nuclear proliferation is being driven by three industrial factors: technology gains in developing countries, increased competition among arms suppliers, and advances in diesel engine air efficiency. Technology gains have made the dream of indigenizing production a reality—India and Pakistan can leverage their increasing scientific prowess to improve industrial capabilities and produce ever more complicated platforms. Key to this effort has been increased competition among arms suppliers. The end of the Cold War left excess capacity in military shipbuilding countries, and newer producers, such as South Korea, simultaneously became shipbuilding powerhouses.<sup>37</sup> Stiffer competition has favored the few developing countries willing and able to buy and operate submarines. Foreign military sales provide needed revenues and jobs to builders in producer states, and states are willing to support joint ventures, joint development, and technology sharing to guarantee the income. Competition among arms sellers leads to further diffusion of technology, though supplier states are often hesitant to allow their buyers total independence of operations.<sup>38</sup> As industrial bases in Pakistan and India become more advanced, those states will also likely sell submarines to foreign buyers to bring in revenues and increase their influence, further proliferating the platforms.

35. Medeiros et al., *A New Direction for China's Defense Industry*.

36. Attack submarines are proliferating to an even greater extent; more countries will be operating submarines by 2020 than ever before.

37. Tim Colton and LaVar Huntzinger, *A Brief History of Shipbuilding in Recent Times* (Alexandria, VA: CNA, 2002), [https://www.cna.org/CNA\\_files/PDF/D0006988.A1.pdf](https://www.cna.org/CNA_files/PDF/D0006988.A1.pdf).

38. For a well-documented example of supplier-buyer technology transfer dispute, see the recent India-Russia dispute over sales of Russian Sukhoi aircraft. Franz-Stefan Gady, "Will India, Russia Co-develop a New 5th Generation Stealth Fighter?," *Diplomat*, March 25, 2017, <http://thediplomat.com/2017/03/will-india-russia-co-develop-a-new-5th-stealth-fighter/>.

Proliferation of SSBN capabilities presents a second trend: proliferation of doctrines. While the United States, the United Kingdom, France, and perhaps Russian doctrines are well understood, China, India, Pakistan, and Israel present challenges to students of the role of undersea deterrence. China's current capabilities are likely regional in focus, but the JIN and subsequent classes will expand to cover global interests in the coming decades.<sup>39</sup> India, Pakistan, and Israel will also likely maintain regional interests in the short term, though the specific doctrines guiding operations may continue to develop alongside their industrial capabilities. Leaders responding to a complex international crisis in 2030 may have to account for the differing doctrines, standards, quality of communications, fleet sizes, and effective ranges of eight SSBN states.

## FUTURE THREATS AND RECOMMENDATIONS

The previous analysis of national industrial policies has implications for the United States and its allies as they sustain an SSBN capability over the long term. The United States and its allies have chosen internationalized, alliance-based production, mainly via the private sector. This has further integrated their collective defense institutions, but has also inserted vulnerabilities in terms of distance, supply chain opacity, and alliance politics. For these countries, understanding the SSBN supply chain is paramount. The supply chain faces a number of risks that can create serious challenges for the U.S. Navy to fulfill its SSBN needs. Over the long term, this may reduce the ability to field sufficient SSBNs to guarantee the global coverage the United States has historically maintained. The key supply chain risks that require monitoring follow, with one basic takeaway: understanding the supply chain is vital to the future of the U.S. SSBN advantage.

### Single Points of Failure

The United States produces only two submarines per year, and fewer in some years since the Cold War. Limited orders have hurt the navy's supply chain, especially for companies that produce the most specialized technologies. The supply chain is now rife with single points of failure: companies with specific capabilities, retiring workers with specific know-how, and aging capital equipment. Failure at any point could lead to costly delays, longer maintenance availabilities, and lower global coverage. The navy has made extensive efforts to understand critical producers and should receive support to continue its mitigation efforts. This effort should also extend to Canada, Australia, France, the United Kingdom, Italy, Spain, and other NATO members that play important roles in NATO's ship- and submarine-building industrial capabilities. Because U.S. policy rests on a strong alliance, mutual assistance, and capable allies, it is essential to eliminate points of failure across NATO.

### Foreign Acquisition

Low visibility into defense supply chains, especially among private companies, small technology development firms, and emerging technologies leads to the potential for foreign acquisition of capabilities vital to a continued high-confidence U.S. deterrent. At a minimum, foreign acquisitions

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39. Office of the Secretary of Defense, *Annual Report to Congress: Military and Security Developments Involving the People's Republic of China 2016*.

could lead to proliferation of sensitive technologies. At most, this could prevent U.S. producers from acquiring essential inputs. Understanding the supply chain goes both ways: suppliers must be made aware of their importance and mergers and acquisitions activity should be reported, assessed, and prevented where necessary at the supply chain level of analysis. DoD should also have more tools made available to help innovative companies, thus ensuring continued secure supply and a technological edge. This effort should also include coordination with NATO allies. U.S. efforts are able to prevent hostile acquisition of key technologies and resources only where it can make a jurisdiction claim. Aligning U.S. policy in this realm with NATO allies will provide a substantially more robust defense to the allied industrial base and prevent the flight of important defense technologies to adversaries.

## Diversity of Inputs

An important consideration in the submarine supply chain is the challenge of supporting the full array of industries necessary for production of large platforms. Even if a state assists advanced components producers, underwriting all the industries involved—from metals to microelectronics—is prohibitively expensive over the long term. But this also means it is essential to understand a far wider swath of the industrial base than merely the “defense” portion of the SSBN supply chain. Though mechanisms exist to mitigate shortfalls in industrial capabilities, they are constrained in application and limited in funding. Generating the political will to understand and assist strategic industries that ultimately feed into defense platforms will reduce the threats to SSBN production and sustainment. This effort must extend to the highly interconnected supply chain far upstream: while protecting U.S. primary materials producers might be a step forward, protecting allied materials producers will provide greater gains to both U.S. producers and NATO allies.

## Alliance Political Stability

The U.S. DIB strategy rests on its core alliances with NATO and Five Eyes members. Tensions and changes in trade relationships among member states could derail the fluid business along the defense supply chains. The outcome of Brexit negotiations, for example, is unknown, but could lead to increased barriers to trade affecting British and European defense producers. Impediments to integrated international defense supply chains will only hurt U.S. security, which relies on open international cooperation among its suppliers and healthy capabilities among its allies. The United States should stress the importance of seamless defense supply chains as its allies weather political challenges.

## Cyber

Cyberattacks by foreign adversaries have stolen an enormous amount of research data, technical information, and other secrets from U.S. and European companies.<sup>40</sup> Having chosen a diverse, private-sector supply chain across multiple states, DoD faces many obstacles to securing all the technical data vital to the SSBN enterprise. With limited visibility into upstream suppliers, DoD risks insufficient protections for critical producers, especially those that produce many dual-use

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40. Riley Walters, “Cyber Attacks on U.S. Companies in 2016,” *Heritage Issue Brief*, December 2, 2016, <http://www.heritage.org/defense/report/cyber-attacks-us-companies-2016>.



technologies or prioritize commercial sales. The department must continue its efforts to improve cyber resilience throughout the supply chain, extending to the lowest-tier suppliers. Coordination with allies and across the National Technology Industrial Base is essential. Technology sharing and advanced allied capabilities make defense firms in allied states likely targets, to the detriment of U.S. security.

## CONCLUSION

The undersea deterrent, and all the capabilities required to create it, is among the most technically impressive achievements of modern industry. It is unsurprising that an enormous industrial effort undergirds the global U.S. SSBN presence. As undersea deterrence proliferates, it is vital for policy-makers to protect U.S. and allied defense industrial capabilities. These industrial capabilities enable credible strategic deterrence. The United States and allies must also understand adversary supply chains because it is adversaries' industrial policies that underscore the credibility of their deterrents. And it is perhaps most important for all SSBN states to communicate openly and clearly about doctrine and intentions and to find common ground for cooperation and limitations, to reduce the risks of a more crowded undersea environment.

# The *Arihant*-Class SSBN and the Advent of Sea-Based Nuclear Forces in India, China, and Pakistan

Nathan Powell<sup>1</sup>

*With the commissioning of the INS Arihant in 2016, India inaugurated the third leg of its nuclear triad and became the sixth country to possess a strategic ballistic missile submarine (SSBN). This chapter places the Arihant's development into the context of development of India as a nuclear power along with its regional rivals, Pakistan and China. India's development of an SSBN force is part of larger post-Cold War developments in the region that have resulted in India adopting a more proactive policy in countering Chinese military capabilities. The development of this SSBN force has already led to Pakistan's own highly insecure sea-based nuclear force of conventionally powered submarines and cruise missiles. The Arihant class may also lead to changes in the nuclear posture of Pakistan's land-based nuclear forces, such as mating nuclear weapons to launch vehicles. The trilateral nuclear competition between India, China, and Pakistan is strongly influenced by China's nuclear relationship with the United States. Chinese nuclear developments are driven by the need to deter the United States, giving the United States the ability to influence Asian nuclear developments through China. The potential exists for the United States to reduce the possibility of a regional nuclear arms race at sea and promote strategic stability in Asia by building a more stable nuclear relationship with China.*

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# INTRODUCTION

The trilateral nuclear competition involving India, Pakistan, and China is among the most challenging security dilemmas facing the world. New developments in the nuclear capabilities of any one of these three countries will trigger a reaction from the other two as they seek to maintain their perceived security interests in the face of perennial regional security competition.<sup>2</sup>

This dynamic emerged out of the armed conflicts that occurred between India and Pakistan, as well as India and China, in the period following the termination of British colonial power in the region. Competing land claims between India and Pakistan over Kashmir has resulted in three conflicts in 1947, 1965, and 1999; it was also a battleground in the Indo-Pakistani War of 1971.<sup>3</sup> None of these wars have resolved the underlying question of which country Jammu and Kashmir rightfully belongs to. The result has been a decades-long military standoff where both sides feel they must match the military capabilities of the other or face defeat in the next war.

The Kashmir question became even more important to the geopolitics of the region when, in 1957, India discovered that China had built a military road through the Aksai Chin region claimed by India as part of Kashmir and by China as part of the Xinjiang Autonomous Region. Indian efforts to force China to negotiate over the region resulted in the Sino-Indian War of 1962, when China invaded both Kashmir and the Indian state of Arunachal Pradesh, much of which it also claims.<sup>4</sup> The brief war left China in control of Aksai Chin, but after making significant advances into Arunachal Pradesh, China voluntarily withdrew its troops to the prewar lines of control while maintaining its claim to the region.<sup>5</sup> As with the Indo-Pakistani conflict, the territorial dispute underlying the Sino-Indian conflict has never been resolved.

The Sino-Indian War of 1962 heralded the start of a new era of strategic competition between the two nations that has lasted up to the present day. China's testing of a nuclear weapon in 1964, their threat to open a second front in support of Pakistan during the Indo-Pakistani War of 1965, and the Indian government's failure to secure security guarantees from the existing nuclear powers shaped India's decision to pursue a nuclear weapons program.<sup>6</sup>

The 1965 war proved pivotal for Pakistan as well. The failure of the Pakistani military to make significant gains against India, combined with President Lyndon Johnson administration's decision to cut off aid as punishment for initiating the conflict, shattered Pakistani confidence in its conventional

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2. Feroz Hassan Khan, "Going Tactical: Pakistan's Nuclear Posture and Implications for Stability," *IFRI Security Studies Center Proliferation Papers*, no. 53 (September 2015): 9.

3. Navnita Chadha Behera, "The Kashmir Conflict: Multiple Fault Lines," *Journal of Asian Security and International Affairs* 3, no. 1 (March 2016): 41–63.

4. Amit Ranjan, "India-China Boundary Disputes: An Overview," *Asian Affairs* 47, no. 1 (March 2016): 101–14.

5. Ibid.

6. S. Paul Kapur, *Dangerous Deterrent: Nuclear Weapons Proliferation and Conflict in South Asia* (Stanford, CA: Stanford University Press, 2007), 4.

forces and U.S. support.<sup>7,8</sup> Pakistan's defeat in the Indo-Pakistani War of 1971, where it lost the former East Pakistan (present-day Bangladesh), banished any remaining thoughts that Pakistan could counter an increasingly strong India through conventional forces alone and resulted in the decision to develop nuclear weapons.<sup>9</sup>

While both India and Pakistan had clearly taken the decision to acquire nuclear weapons as a means to deter one another, as well as China in the case of India, both confronted international political challenges that the previous five nuclear powers never confronted. The growing awareness of the dangerous environmental effects of nuclear radiation from nuclear tests resulted in the negotiation of the Partial Test Ban Treaty (PTBT) of 1963, banning all nuclear tests except those conducted underground.<sup>10</sup> India under Prime Minister Jawaharlal Nehru was in fact the first national to call for a halt to nuclear weapons testing in 1954, and India became a driving force behind the PTBT negotiating process, helping to establish its credentials in the Non-Aligned Movement as a country that could stand up to the great powers.<sup>11</sup>

Despite India's integral role in initiating what would become the global nonproliferation regime, the structure of the regime quickly evolved in a way that made it impossible for India to continue its past leadership role. The Non-Proliferation Treaty (NPT) restricted the number of recognized nuclear weapons states (NWS) to the five states (the United States, the Soviet Union, the United Kingdom, France, and China) that had successfully conducted nuclear test prior to January 1, 1967.<sup>12</sup> By setting January 1, 1967 as the cutoff date to be officially considered an NWS, the NPT created a regime that would legally bar India from developing a nuclear capability it felt was necessary to counter China, and prevent Pakistan from in turn countering India. When the NPT was signed in 1968 India, China, and Pakistan all refused to become parties to the treaty, citing concerns ranging from national security, to the treaty being a plot by the United States and Soviet Union to maintain nuclear supremacy.<sup>13</sup>

Despite not signing the NPT, India's legacy and international reputation as the first country to call for a ban on nuclear weapons tests and a leader in the PTBT negotiation process continued to hold importance both within the country and abroad. This legacy is apparent in the rhetoric that surrounded India first nuclear test (Pokhran I) in May 1974. The test was referred to as a peaceful

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7. Ibid.

8. Max Frankel, "Pakistan and the U.S. Discussion between Johnson and Ayub Expected to Be a Major Turning Point," *New York Times*, December 13, 1965, <http://query.nytimes.com/mem/archive-free/pdf?res=9801E3D61639E33ABC4B52DFB467838E679EDE>.

9. Lowell Dittmer, ed. *South Asia's Nuclear Security Dilemma: India, Pakistan, and China* (Armonk, NY: M. E. Sharpe, 2005), 99.

10. Mary Milling Lepper, *Foreign Policy Formulation: A Case Study of the Nuclear Test Ban Treaty of 1963* (Columbus, OH: Merrill Publishing, 1971).

11. David M. Malone, C. Raja Mohan, and Srinath Raghavan, eds., *The Oxford Handbook of Indian Foreign Policy* (Oxford: Oxford University Press, 2015).

12. U.S. Department of State, "Treaty on the Non-Proliferation of Nuclear Weapons," 2010, <https://www.state.gov/documents/organization/141503.pdf>.

13. Arpit Rajain, *Nuclear Deterrence in South Asia: China, India, and Pakistan* (Thousand Oaks, CA: Sage, 2005), 178; Bhumitra Chakma, *Pakistan's Nuclear Weapons* (New York: Routledge, 2009), 17.

nuclear explosion and the India defense minister Jagjivan Ram publicly questioned the strong international reaction to the test stating, "We are doing this for peaceful purposes not for military uses."<sup>14</sup>

Despite India's insistence to the contrary international developments, such as the emerging détente between China and the United States as well as China's growing military relationship with Pakistan, the Indian government made clear that the test had definite military and political purposes.<sup>15</sup> The result was widespread international condemnation against India. Canada, which had supplied much of India's nuclear technology, quickly moved to cut off assistance and led calls for other nations to do the same.<sup>16</sup> In the United States, the test led directly to the Nuclear Non-Proliferation Act of 1978 that restricted access to nuclear technology, both to prevent further proliferation and hinder India's nuclear program.<sup>17</sup>

The international pressure did little to stop the nuclear weapons programs of India and Pakistan, but it did leave a lasting impression about the political costs of testing. Indira Gandhi again considered testing nuclear weapons in 1982–1983, after the full extent of China's assistance to Pakistan's nuclear weapons program came to light, but under international pressure decided against testing.<sup>18</sup> In the absence of nuclear testing, India turned to missile development and testing to demonstrate military strength. Pakistan, despite achieving a nuclear weapons capability by 1987, choose to refrain from testing and maintained an official policy of strategic opacity in regards to its nuclear weapons capability.<sup>19</sup>

This status quo lasted through the end of the Cold War, but the collapse of the Soviet Union altered the geopolitical calculus in the region and the long South Asian nuclear pause began to weaken. A key pillar of India's security through the late Cold War period was the 1971 Indo-Soviet Treaty of Friendship and Alliance.<sup>20</sup> For India, the treaty served as a counter to the growing relationship between the United States and China. The treaty became even more important to India following the Soviet invasion of Afghanistan in 1979 and the resulting rejuvenation of the relationship between the United States and Pakistan under the administration of President Ronald Reagan.<sup>21</sup> To many in India, it seemed that they were in danger of being surrounded by a tripartite alliance of the United States, China, and Pakistan.

Without the backing of a strong alliance with the Soviet Union, India's strategic situation appeared far weaker. A succession of military confrontations in Kashmir in the early 1990s, the revelation that China had supplied Pakistan with M-11 missile systems, and public statements by Pakistani officials

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14. Bernard Weinraub, "Indian Rules Out Atomic Weapons," *New York Times*, May 23, 1974, <http://www.nytimes.com/1974/05/23/archives/indian-rules-out-atomic-weapons-minister-of-defense-insists-nuclear.html>.

15. V. N. Khanna, *India's Nuclear Doctrine* (New Dehli: Samskriti, 2000), 50.

16. Robert Trumbull, "Canada Suspends Atom Aid to India," *New York Times*, May 23, 1974, <http://www.nytimes.com/1974/05/23/archives/canada-suspends-atom-aid-to-india-calls-on-other-governments-to.html>.

17. Khanna, *India's Nuclear Doctrine*, 54.

18. *Ibid.*, 57.

19. Dittmer, *South Asia's Nuclear Security Dilemma*, 98.

20. Sumit Ganguly, "India's Pathway to Pakhran II," *International Security* 23, no. 4 (Spring 1999): 148–176.

21. *Ibid.*

about their country's nuclear capability created pressure for India to mount some sort of response.<sup>22</sup> In its 1998 election manifesto, the Bharatiya Janata Party (BJP) promised to review India's nuclear policy and stated that the nuclear policies of Pakistan and China dictated that tests be conducted.<sup>23</sup>

The tests conducted by both India and subsequently Pakistan in May 1998 inaugurated a new era in the nuclear history of Asia.<sup>24</sup> The era of strategic ambiguity was over, and both countries embraced their status as nuclear powers, quickly moving to integrate nuclear weapons into their military doctrines and advance both their weapons technology and delivery capabilities. India's development of a sea-based nuclear force, consisting of both nuclear-armed cruise and ballistic missiles, is a direct result of this new era of open nuclear competition.

## THE *ARIHANT* CLASS

The genesis of the *Arihant* class can be found in China's growing power in the Indian Ocean and development of its own strategic ballistic missile submarine (SSBN) force.<sup>25</sup> China's development of its current SSBN force was aided by decades of experience with nuclear submarines beginning with the commissioning of China's first nuclear-powered submarine, the *Chang Zeng 1* (Long March 1) in 1971.<sup>26</sup> This was followed in 1981 by a single example of the Type 092 Xia-class SSBN, equipped with 12 JL-1 ballistic missiles possessing a range of 1,770 kilometers (km).<sup>27</sup> While these early Chinese nuclear submarines were far from satisfactory, emitting too much noise and posing a serious danger to those unlucky enough to crew them, they afforded Chinese designers and engineers an important opportunity to gain firsthand experience.<sup>28</sup>

Confronted by China's development of a nuclear-powered submarine force, the Indian Navy conducted studies into the possibility of building a nuclear-powered attack submarine in 1971.<sup>29</sup> Institutional opposition toward the project arose within the navy from officials who feared funding would be diverted from conventionally powered weapons systems prevented the project from advancing for over a decade, until 1988 when India-leased the nuclear-powered Charlie-class

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22. Bhumitra Chakma, "Toward Pokhran II: Explaining India's Nuclearisation Process," *Modern Asian Studies* 39, no. 1 (February 2005): 189–236.

23. Scott D. Sagan, ed., *Inside Nuclear South Asia* (Stanford, CA: Stanford University Press, 2009), 39.

24. John F. Burns, "Nuclear Anxiety: The Overview; Pakistan Answering India, Carries Out Nuclear Tests; Clinton's Appeal Rejected," *New York Times*, May 29, 1998, <http://www.nytimes.com/1998/05/29/world/nuclear-anxiety-overview-pakistan-answering-india-carries-nuclear-tests-clinton.html>.

25. Dittmer, *South Asia's Nuclear Security Dilemma*, 75.

26. Mei Ping Leong et al., "A Review of China's Technological Developments in the 20th Century," *Applied Mechanics and Materials* 7 (2015): 871–74.

27. Kyle Mizokami, "China's First Nuclear Powered 'Boomer' Submarine Was a Total Disaster," *National Interest*, January 14, 2017, <http://nationalinterest.org/blog/the-buzz/chinas-first-nuclear-powered-boomer-submarine-was-total-19054>.

28. Lyle Goldstein and William Murray, "Undersea Dragons: China's Maturing Submarine Force," *International Security* 28, no. 4 (Spring 2004): 161–196.

29. Dittmer, *South Asia's Nuclear Security Dilemma*, 80.



cruise missile submarine K-43 from the Soviet Union.<sup>30</sup> The original terms of the lease allowed India to operate the submarine for a 10-year period, but it was returned in 1991 after only three years in the Indian Navy.<sup>31</sup> Nevertheless, the experience gained with the K-43 provided a launch pad for India's domestic nuclear submarine program. The existence of an Indian SSBN program was confirmed publicly after the 1998 nuclear tests, with the decision that India's future nuclear deterrent force would consist of a nuclear triad.<sup>32</sup>

The product of this development program was the INS *Arihant*, the first of at least four ships that will make up the class of the same name. The INS *Arihant*, which was launched in 2009 and commissioned into service in August 2016, is best viewed as a scaled-down test bed for its sister ships.<sup>33</sup> The INS *Arihant* is equipped with four launch tubes that can be equipped with four of the still-in-development K-4 intermediate range (3,500 km) ballistic missiles or 12 K-15 short range (750 km) ballistic missiles that are currently in service utilizing an adapter that allows for three missiles to be fitted in each launch tube.<sup>34</sup> Future vessels in the class will have eight launch tubes instead of four and feature a more powerful reactor and other improvements developed as a result of experience gained operating the INS *Arihant*.<sup>35</sup>

In theory, nuclear-armed ballistic missile submarines should help India establish a more survivable and effective nuclear deterrent. However, it faces several obstacles in achieving this outcome. The first obstacle is the short range of the K-15 and even K-4 missiles. The estimated 3,500-km range of the K-4 is little more than a fourth of the estimated 12,000-km range of the Trident II D-5.<sup>36</sup> While the K-15 is capable of threatening much of Pakistan and the K-4 can hold all of Pakistan at risk and can reach as far as Beijing, the operational space in which the submarines would need to operate to reach many of their targets, particularly those in China, is relatively small.<sup>37</sup> For example, to threaten Beijing from the India Ocean a submarine equipped with the K-4 missile would need to operate in the very northern reaches of the Bay of Bengal.

India could choose to deploy SSBN's farther afield in the Pacific Ocean, but reported noise problems with the class raises concerns about survivability of *Arihant*-class ships outside of friendly

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30. Pradeep Barua, *The State of War in South Asia* (Lincoln: University of Nebraska Press, 2005), 281.

31. Ibid.

32. Brajesh Mishra, "Draft Report of National Security Advisory Board on Indian Nuclear Doctrine," Indian Ministry of External Affairs, August 17, 1999, <http://mea.gov.in/in-focus-article.htm?18916/Draft+Report+of+National+Security+Advisory+Board+on+Indian+Nuclear+Doctrine>.

33. PTI Visakhapatnam, "India Reaches Milestone with Launch of N-Powered Submarine," *DNA*, July 26, 2009, <http://www.dnaindia.com/india/report-india-reaches-milestone-with-launch-of-n-powered-submarine-1277227>; and Franz-Stefan Gady, "India Quietly Commissions Deadliest Sub," *Diplomat*, October 19, 2016, <http://thedi diplomat.com/2016/10/india-quietly-commissions-deadliest-sub/>.

34. Gady, "India Quietly Commissions Deadliest Sub."

35. Ibid.

36. "Trident Missile Factfile," *BBC*, September 23, 2009, <http://news.bbc.co.uk/2/hi/uk/4438392.stm>.

37. Pushan Das, "How Does India's Launched K-4 Stack Up against Pakistan, China?," *Quint*, January 31, 2017, <https://www.thequint.com/opinion/2017/01/31/how-does-india-submarine-launched-k-4-stack-up-against-pakistan-china-ssbn-navy-ballistic-missile>.

waters already dominated by the Indian Navy.<sup>38</sup> Whatever India chooses to do with its SSBN force in the future, it represents a lasting addition to the regional nuclear balance and is certain to have strategic implications for India's regional rivals, Pakistan and China, as well as for the United States, given the great strategic and economic importance of the area.

## STRATEGIC IMPLICATIONS

Current information available on both India and China's nuclear submarine forces suggest that while both countries have made significant strides in submarine and missile technology, they still lag far behind the United States, Russia, France, and the United Kingdom. It is clear that both nations aim to develop an effective nuclear triad, but achievement of that goal remains somewhat distant. For now, the *Arihant* as well as its sister ships will remain a secondary part of India's nuclear force, but they are likely to have an outsized impact in the region despite their clear limitations.

### Pakistan

The most obvious impact is Pakistan's development of its own sea-based nuclear force. Given Pakistan's more limited resources, the political dominance of the army, and China's apparent unwillingness to provide Pakistan with nuclear submarine technology, the platform for this force will be conventionally powered submarines armed with relatively short-range missile systems. While India's rapidly growing economy gives it a clear means of developing quieter nuclear submarines and longer-range missiles, Pakistan's prospects appear much more limited.

Pakistan's sea-based force therefore is likely to amount to little more than a symbolic capability intended to ensure national pride by being able to say that Pakistan can match India's nuclear achievements. The bulk of Pakistan's nuclear arsenal will remain with the army. The question therefore is whether the development of an SSBN force by India will have any impact on Pakistan's land-based nuclear forces.

Both India and Pakistan are currently believed to keep their nuclear weapons de-mated from their launch systems.<sup>39</sup> Given the difficulties of mating a nuclear weapon to a launch vehicle in a submarine, India's SSBN force will almost certainly deploy with nuclear weapons mated to their launch vehicles, as will Pakistan's. If Pakistan is content with simply having a sea-based nuclear force to match India, there will be no need to change existing policy for land-based forces. However, Pakistan may decide that a new force posture is needed to counter India's SSBN force. The inability of Pakistan to develop a SSBN force equivalent to India's will mean that the task of countering India's SSBN fleet will fall to the Pakistani Army. Faced with a threat to key military

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38. Franz-Stefan Gady, "How China and India's Noisy Nuclear Subs Contribute to Instability in Asia," *Diplomat*, September 9, 2015, <http://thediplomat.com/2015/09/how-china-and-indias-noisy-nuclear-subs-contribute-to-instability-in-asia/>.

39. Ashley J. Tellis, "China, India, and Pakistan—Growing Nuclear Capabilities with No End in Sight" (testimony before Senate Armed Services Committee, Subcommittee on Strategic Forces, February 25, 2015), <http://carnegieendowment.org/2015/02/25/china-india-and-pakistan-growing-nuclear-capabilities-with-no-end-in-sight-pub-59184>.

installations, Pakistan may decide that the historic policy of de-mating nuclear weapons from launch vehicles is no longer strategically viable.

The pattern of nuclear proliferation in Asia clearly demonstrates that an action by Pakistan will trigger a reaction by India and vice versa. As a result, the advent of a Pakistani policy of keeping land-based nuclear weapons mated to their launch vehicles is almost certain to be reciprocated by India. This, in turn, will heighten the perceived threat level in Pakistan, possibly prompting further action, such as developing multiple independently targetable reentry vehicle (MIRV) launch systems in pursuit of counterforce capabilities to deny India a secure second-strike capability.<sup>40</sup>

The ability of Pakistan's land-based nuclear force to provide a secure second-strike capability and counter India's developing SSBN force will depend largely on how India chooses to deploy its submarines. If India chooses to mirror the practice of the Russia by keeping their nuclear submarines in port the majority of the time, Pakistan may believe that in the event of war it may be possible to knock out India's SSBN force.<sup>41</sup> This would require Pakistan to catch India's submarine while in port, which would likely only be possible if Pakistan were to attack India first at a time when tensions are not high.

The best way to avoid Pakistan believing that it may be able to neutralize India's SSBN force is for India to adopt a policy of maintaining a continuous at-sea deterrent. Unfortunately, India's ability to adopt such a posture with its SSBN will take many years to achieve. It will require the completion of several further *Arihant*-class submarines, the successful fielding of the K-4 missile, a secure command and control architecture, training the submarine crews and land-based personnel to support continuous deployments, and the mustering of the political and financial resources to pay for all of this. Until this happens, India's SSBN force will be a destabilizing force in the Indo-Pakistani nuclear relationship, prompting Pakistan to create an inherently vulnerable submarine nuclear force, possibly resulting in land-based weapons being mated to their launch vehicles on a routine basis and dangerous plans to strike India first in order to neutralize India's SSBN force while in harbor.

## China

China's SSBN force development is currently well ahead of India's. China has commissioned four 094 Jin-class SSBNs and may increase that number to eight by the end of the decade before moving to the development of a successor class.<sup>42</sup> Reportedly, China either has or soon will begin conducting regular deterrent patrols utilizing its fleet of Jin-class submarines, firmly establishing the third leg of the Chinese triad after the failure of the 092 Xia-class SSBN of the 1980s.<sup>43</sup> China's

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40. Sadia Tasleem, "Pakistan's Nuclear Use Doctrine," Carnegie Endowment for International Peace, June 30, 2016, <http://carnegieendowment.org/2016/06/30/pakistan-s-nuclear-use-doctrine-pub-63913>.

41. Hans M. Kristensen, "Russian SSBN Fleet: Modernizing but Not Sailing Much," Federation of American Scientists, May 3, 2013, <https://fas.org/blogs/security/2013/05/russianssbns/>.

42. Tong Zhao, "China's Sea-Based Nuclear Deterrent," Carnegie-Tsinghua Center, June 30, 2016, <http://carnegietsinghua.org/2016/06/30/china-s-sea-based-nuclear-deterrent-pub-63909>.

43. Ibid.

advances in the deployment of its SSBN force can be expected to influence the development and deployment of India's SSBN force.

While India's development of an SSBN force is primarily motivated by need to counter its regional rivals, China and Pakistan, China's SSBN force is motivated in large part by the United States. Chinese concern about the survivability of China's land-based nuclear forces in the event of U.S. first strike have been the main factor driving investment in China's SSBN force.<sup>44</sup> As the United States continues to invest in missile defense technology and conventional prompt global strike capabilities that pose a threat to China's land-based missile forces, it is reasonable to expect China to depend more on its SSBN force for nuclear deterrence.

Reported noise problems with the Jin-class submarines and resultant vulnerability to detection mean that, while the Jin class is a huge improvement over the previous Xia class, it too is likely to simply be a stepping stone on the way to something better.<sup>45</sup> The exact capabilities of China's third-generation SSBN remain unknown. But the great strides that China has made in developing, producing, and deploying the Jin class, the continued substantial increases in its military budgets, and China's strategic shift to a smaller, more technologically advanced force focused more on sea power suggest it will be a substantial improvement and can be expected to appear in the relatively near future.<sup>46</sup>

China's successor to the Jin class will in turn prompt an Indian response in the form of a substantially improved variant of the Arihant class or a successor class. Given China's existing lead over India in SSBN development and substantially larger economic base with which to pay for new military procurement, China can be expected to lead the way in the development of SSBN technology in Asia, with India playing catch up.

## THE ROLE OF THE UNITED STATES

The United States has clear interests in ensuring strategic stability in region. As the United States is the main target of China's nuclear deterrent (the SSBN force, in particular), the actions of the United States will have major ramifications for the region. Strategic ties with India and Pakistan add to the importance of U.S. actions.

While the United States does not have the power to diffuse the nuclear competition that exists between India, Pakistan, and China, or to stop the expansion of that competition into the naval domain, it can still influence development through the strategic nuclear relationship with China.

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44. Lyle Goldstein and Andrew S. Erickson, *China's Nuclear Force Modernization* (Newport, RI: Naval War College Center for Naval Warfare Studies, 2005).

45. Jeffrey Lewis, "China's Noisy New Boomer," *Arms Control Wonk*, November 24, 2009, <http://www.armscontrolwonk.com/archive/202544/chinas-noisy-new-boomer/>.

46. Jane Perlez, "China to Raise Military Spending, but Less Than in Recent Years," *New York Times*, March 4, 2017, <https://www.nytimes.com/2017/03/04/world/asia/china-to-raise-military-spending-but-less-than-in-recent-years.html>; and Edward Wong, Jane Perlez, and Chris Buckley, "China Announces Cuts of 300,000 Troops at Military Parade Showing Its Might," *New York Times*, September 2, 2015, <https://www.nytimes.com/2015/09/03/world/asia/beijing-turns-into-ghost-town-as-it-gears-up-for-military-parade.html>.

The unwillingness of the United States to accept mutual vulnerability with China as the basis for strategic relations, along with continued investment in missile defense and prompt global strike technology, are key factors that create unease among Beijing's policymakers.<sup>47</sup> The United States is not going to cease investing in the development of missile defense or prompt global strike, but investing in both technologies does not preclude accepting mutual vulnerability with China. In fact, the United States has existed in a state of mutual vulnerability with China since the deployment of the DF-5 in 1981. The idea that the United States will ever be able to return to a time when it was immune to Chinese nuclear attack is a fantasy.<sup>48</sup>

The United States should accept mutual vulnerability with China as the basis of strategic stability between the two countries and open a dialogue on strategic stability with China to develop avenues of communication and relations between the strategic communities in both nations. This process will be particularly important in the near future as North Korea continues to improve its nuclear weapons and missile technology. The United States has no choice but to accept mutual vulnerability with China, but it does not need to accept mutual vulnerability with North Korea. Indeed, accepting mutual vulnerability with North Korea would very likely push South Korea and possibly Japan closer to developing their own strategic deterrents, creating an even more complicated nuclear environment in Asia.

Avoiding strategic vulnerability with North Korea will necessitate improvements in missile defense technology and possibly an increase in the number of deployed interceptors. This in turn will lead to a response from China increasing the strength of its nuclear forces and then spiral through India and Pakistan. Unfortunately, this dynamic is unavoidable, but the United States can seek to limit the extent of the Chinese reaction and, in so doing, limit the subsequent reactions of India and Pakistan.

Limiting the extent of Chinese reaction and slowing down the reaction cycle at play in Asian nuclear relations will contribute to development and maintenance of strategic stability in the region. The growing economic power, and as a consequence military potential, of India and China have created the conditions needed for the outbreak of a new nuclear arms race focused on SSBN development between two great powers and Pakistan, a weak and unstable regional power. The development of these capabilities cannot be stopped, but the United States should seek to adopt policies that foster confidence and avoid encouraging an increase in the pace of the development and deployment of Asian SSBNs or a substantial increase in the size of regional nuclear arsenals.

## CONCLUSION

The deployment of India's first SSBN, the INS *Arihant*, marks the completion of India's nuclear triad and the introduction of a new variable into Asian nuclear security. While the advent of an India SSBN has the potential to become a stabilizing factor in the region, the day when that potential

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47. CSIS Project on Nuclear Issues Working Group on U.S.-China Nuclear Dynamics, *Nuclear Weapons and U.S.-China Relations: A Way Forward* (Washington, DC: CSIS, March 2013), [https://csis-prod.s3.amazonaws.com/s3fs-public/legacy\\_files/files/publication/130307\\_Colby\\_USChinaNuclear\\_Web.pdf](https://csis-prod.s3.amazonaws.com/s3fs-public/legacy_files/files/publication/130307_Colby_USChinaNuclear_Web.pdf).

48. John Wilson Lewis and Hua Di, "China's Ballistic Missile Programs," *International Security* 17, no. 2 (Fall 1992): 5–40.

turns into a reality appears to be years and possibly decades away. In the near term, the *Arihant* class will result in Pakistan developing its own, even more destabilizing, submarine force and possibly adopting a new force posture for its land-based nuclear force in an attempt to counter India's growing sea-based nuclear capabilities. While Pakistan tries to catch up to India, India in turn will continue to try to catch up to China's growing SSBN capabilities. The regional nuclear dynamic between India and China offers the United States an opportunity to influence the pace of nuclear developments in the region. As Chinese nuclear SSBN advances appear primarily aimed at deterring the United States, U.S. actions to ensure strategic stability with China in the nuclear realm may have a positive impact throughout Asia. The United States cannot stop the development and deployment of new nuclear weapons and delivery systems in Asia, but it can avoid taking actions that would make an SSBN-focused regional arms race more likely.



# Missile Defenses' Role in Twenty-First-Century Deterrence

Wes Rumbaugh<sup>1</sup>

*As missile systems proliferate and states develop new doctrines for the use of nuclear weapons, missile defenses can contribute to resolving some of the security challenges the United States faces. An analysis of the role that missile defenses can play in offsetting the viability of anti-access/area denial (A2/AD) strategies and doctrines of limited nuclear use gives insight into their potential usefulness in the modern security environment. While missile defenses cannot provide a perfect shield, they can raise the perceived costs of such strategies as part of a broader deterrence strategy. Thus, missile defenses, despite their costs and technical limits, are an important part of the future of American deterrence strategy.*

## INTRODUCTION

As missile defenses have grown as an element of U.S. national security, the discussions surrounding them seem stuck. Even as administrations from both political parties push forward with deploying missile defenses, a handful of seemingly intractable issues have emerged. This has contributed to a significant polarization of analysis about both the cost and technical feasibility of fielding missile defenses. Because of this polarization, discussion of the deterrence value of missile defense has faded into the background, even though implicit assumptions about strategic value influence the levels of acceptable cost and technical risk.

While many policy and strategy documents allude to a relationship between missile defense and deterrence, a more clear articulation of the nature of the relationship is often lacking.<sup>2</sup> The 2001

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2. See, for example, Department of Defense, *Ballistic Missile Defense Review Report* (Washington, DC: Department of Defense, 2010); Department of Defense, *Nuclear Posture Review Report* (Washington, DC: Department of Defense, 2010); Martin E. Dempsey, *Joint Integrated Air and Missile Defense: Vision 2020* (Washington, DC: Joint Chiefs of Staff, 2013); Department of Defense, *Strategy for Countering Weapons of Mass Destruction* (Washington, DC: Department of

*Nuclear Posture Review* (NPR) represents the last significant government document to attempt to formulaically address the connections between deterrence and missile defense in its description of how missile defense contributes to deterrence, assurance, dissuasion, and defeat.<sup>3</sup> A child born the same year that NPR was released could now legally drive a car. While many of the themes of the 2001 NPR remain relevant, new thinking is now required.

This paucity of discussion suggests it is again important to examine both the primary security challenges facing the United States and whether a limited but capable missile defense system can contribute to resolving them. Two pressing security challenges, those of anti-access/area denial (A2/AD) strategies and emerging doctrines for limited nuclear use to deter the United States, stand out as areas where missile defense can contribute. Articulating the deterrence benefits of missile defense in relation to these challenges offers a path to change the conversation on the value of these systems in American national security strategy.

## THE GROWING MISSILE PROBLEM

Two trends in the security environment stand out as drivers for emergent challenges to deterrence. The first problem comes from the vast proliferation of missiles, described by General Martin Dempsey as “a full spectrum of air and missile threats—ballistic missiles, air breathing threats (cruise missiles, aircraft, [unmanned aerial systems]), long-range rockets, artillery, and mortars—all utilizing a range of advanced capabilities—stealth, electronic attack, maneuvering reentry vehicles, decoys, and advanced terminal seekers with precision targeting.”<sup>4</sup> Russia not only inherited the Soviet missile arsenal, but has also continued to modernize those missiles and become even more reliant on them for strike.<sup>5</sup> China has developed a large and diverse arsenal of both short- and long-range missiles as part of an extensive modernization of its missile forces, including a diversity of cruise missiles and maneuvering and multiple reentry vehicles.<sup>6</sup> North Korea has aped many of its missile designs based on the import of Russian technology, and has also made significant progress in its own programs.<sup>7</sup> Iran continues to develop a growing arsenal of missiles as well—despite the Joint Comprehensive Plan of Action to limit its nuclear program—focusing on upgrades to guidance systems to improve accuracy.<sup>8</sup>

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Defense, 2014); Department of Defense, *Quadrennial Defense Review* (Washington, DC: Department of Defense, 2014); Barack Obama, *National Security Strategy of the United States* (Washington, DC: The White House, 2015).

3. Department of Defense, *Nuclear Posture Review* (Washington, DC: Department of Defense, 2001).

4. Dempsey, *Joint Integrated Air and Missile Defense*, 2.

5. Hans M. Kristensen and Robert S. Norris, “Russian Nuclear Forces, 2017,” *Bulletin of the Atomic Scientists* 73, no. 2 (2017): 115–126.

6. Office of the Secretary of Defense, *Military and Security Developments Involving the People’s Republic of China* (Washington, DC: U.S. Department of Defense, 2016), 25.

7. Ian Williams and Thomas Karako, “North Korea’s New Missiles on Parade,” *CSIS Commentary*, April 18, 2017, <https://www.csis.org/analysis/north-koreas-new-missiles-parade>.

8. Thomas Karako and Ian Williams, “Missiles: A Critical Tool in Iran’s Defense Posture and Power Projection,” in *Deterring Iran after the Nuclear Deal*, ed. Kathleen H. Hicks and Melissa G. Dalton (Washington, DC: CSIS, 2017), 54–56,

This expansive missile proliferation makes sense for states that may have interest in challenging the United States in their own regions. Building an air force capable of challenging the United States and conducting long-distance precision strike missions is an expensive and difficult task. Missiles offer a more affordable and less risky means to achieve similar results.

Secondly, new adversaries with different goals and risk tolerances than the former Soviet Union pose new challenges for deterrence. While the Cold War allowed the United States to focus on deterring another large power with global ambitions, many of the most pressing modern deterrence challenges deal with states focused on affairs within their respective regions. For example, North Korean and Iranian ambitions are limited to manipulating the security environments in their near-abroad to maximize regime security. Even larger powers like Russia and China focus more on securing influence in areas proximate to their borders, rather than attempting to project power or spread an ideology around the globe like the Soviet Union did. The proximity of these goals to the core security interests of these nations raises the perceived stakes, and encourages more risk tolerance to overturn existing security architectures.

In light of these trends, missile defenses can play an expanded role in helping to resolve core deterrence problems facing the United States. They cannot solve these problems on their own, but they do complement other capabilities that, when arrayed together, can create a new deterrence framework. Thinking of missile defense as a complementary and integrated capability, rather than either a taboo or panacea, will be important to reconceptualizing its role in deterrence. To accomplish this, analysts should consider how missile defenses can potentially offset some of these strategies and strengthen deterrence.

## THE REGIONAL ANTI-ACCESS/AREA DENIAL CHALLENGE

The first deterrence challenge missile defenses can address is the development of A2/AD strategies to deny U.S. forces the ability to operate in foreign regions and undermine Washington's security guarantees to partner nations. The United States must balance global commitments in its allocation of forces, and relies to some degree on the ability to mobilize and surge forces into a theater should conflict break out. These strategies, which attempt to offset U.S. conventional superiority while staying under the nuclear threshold, undermine deterrence by making conflict less risky for a determined state.

To accomplish this, logistical points of debarkation must be available, which would be prime targets for an adversary attempting to cement gains after an initial *fait accompli*.<sup>9</sup> Adversaries with sufficiently long-range missile forces would likely target such facilities.<sup>10</sup> Furthermore, missiles

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[https://csis-prod.s3.amazonaws.com/s3fs-public/publication/170313\\_Hicks\\_DeterringIran\\_Web.pdf?GwRM1vOIS4wvH67bb359MogE8MWl2DJg](https://csis-prod.s3.amazonaws.com/s3fs-public/publication/170313_Hicks_DeterringIran_Web.pdf?GwRM1vOIS4wvH67bb359MogE8MWl2DJg).

9. Brad Roberts, "On the Strategic Value of Ballistic Missile Defense," *Proliferation Papers* 50 (June 2014): 16, <http://www.ifri.org/sites/default/files/atoms/files/pp50roberts.pdf>.

10. Mark Gunzinger and Bryan Clark, *Winning the Salvo Competition: Rebalancing America's Air and Missile Defenses* (Washington, DC: Center for Strategic and Budgetary Assessments, 2016), 1–5, <http://csbaonline.org/research/publications/winning-the-salvo-competition-rebalancing-americas-air-and-missile-defenses/publication>.

provide an important enabling capability in many A2/AD strategies, allowing potential adversaries to threaten large forward air bases or surface vessels, like aircraft carriers, from which most American strike power comes. Future adversaries could also use missiles to splinter alliances by targeting allies whose support is necessary to carry out operations.

Examples of such a potential strategy abound. In the Baltics and Black Sea, Russia threatens NATO members with missile strikes to undermine collective defense.<sup>11</sup> These former Soviet nations represent important strategic depth from Moscow's perspective, part of the reason that it protested the enlargement of NATO in these states. China similarly has developed its missile arsenal to be able to target U.S. forces meant to assist regional allies in a conflict over disputed territories.<sup>12</sup> Iran has lined the Strait of Hormuz, an important global shipping chokepoint, with antiship cruise missiles as a means to deny access to U.S. forces should conflict break out there.<sup>13</sup> Similarly, North Korea has tested its missile arsenal at ranges designed to target important American facilities in Japan, South Korea, and Guam.<sup>14</sup>

The role that missile defenses are likely to play in A2/AD is evident in the way that those attempting to deny access are investing in similar capabilities. For example, Russia has deployed air and missile defenses almost continuously from the Arctic to Syria.<sup>15</sup> While simply mirroring the deployments of our adversaries would be a misguided strategy, when their tactics make sense for the United States, they should be considered. In this case, Russian air and missile defense systems are intended to blunt U.S. air power in a potential conflict. Moscow's S-300 and S-400 batteries are intended to complement its air forces, which on their own cannot deny the United States air superiority.

Since many potential U.S. adversaries have largely replaced their respective air forces with missiles, American missile defense forces perform a similar role to that of Russia's air defense systems.<sup>16</sup> In the competition for air superiority, the modern environment requires consideration not only of traditional fixed wing aircraft, but also cruise and ballistic missiles. American forces have long taken traditional air superiority for granted, but the changing context calls into question some of its assumptions. In fact, the trends in proliferation of both air defense and long-range strike missiles are already driving the U.S. Army and Marine Corps to develop the Multi-Domain Battle concept.<sup>17</sup>

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11. Thomas Karako, "Looking East: European Air and Missile Defense after Warsaw" CSIS, July 14, 2016, 2–3, [https://csis-prod.s3.amazonaws.com/s3fs-public/publication/160714\\_Karako\\_LookingEast\\_Web.pdf](https://csis-prod.s3.amazonaws.com/s3fs-public/publication/160714_Karako_LookingEast_Web.pdf).

12. Gunzinger and Clark, *Winning the Salvo Competition*, 1–4.

13. Karako and Williams, "Missiles: A Critical Tool in Iran's Defense Posture and Power Projection," 52–53.

14. Jeffrey Lewis, "North Korea Is Practicing for Nuclear War," *Foreign Policy*, March 9, 2017, <http://foreignpolicy.com/2017/03/09/north-korea-is-practicing-for-nuclear-war/>.

15. Kathleen Hicks et al., *Evaluating Future U.S. Army Force Posture in Europe: Phase II Report* (Washington DC: CSIS, 2016), 36–37, [https://csis-prod.s3.amazonaws.com/s3fs-public/publication/160712\\_Samp\\_ArmyForcePostureEurope\\_Web.pdf](https://csis-prod.s3.amazonaws.com/s3fs-public/publication/160712_Samp_ArmyForcePostureEurope_Web.pdf).

16. Peppi DeBiaso, "Proliferation, Missile Defense, and the Conduct of Modern War," *Comparative Strategy* 25, no. 3 (2006): 158.

17. Gen. David Perkins, "Multi-Domain Battle: Joint Combined Arms Concept for the 21st Century," Association of the United States Army, November 14, 2016, <https://www.ausea.org/articles/multi-domain-battle-joint-combined-arms-concept-21st-century>.

An essential part of realizing the vision of Multi-Domain Battle will be air and missile defense systems that can protect maneuver forces in a missile-rich environment.

For the United States, missile defenses are particularly important because it will likely have to move its forces around the globe to meet a committed challenger. Missile defenses could play a significant role in preserving the mobility of American forces.

While some would suggest these only apply once deterrence has already broken down, the perceived operational effectiveness of theater U.S. forces is an essential ingredient in preventing conflict in the first place. An adversary that thinks it can sideline the United States by using its missile arsenal to conduct deep strikes on important operational targets would perceive lower costs to an aggressive foreign policy. Missile defenses raise the costs of these actions by protecting the survivability and mobility of U.S. forces in a conflict, ensuring that the United States can bring to bear its significant offensive capability.

In fact, offensive forces that are vulnerable to missile strikes are in some ways destabilizing. This point is well established in the nuclear deterrence literature; forces that can be nullified by a first strike create the pressure to make the first move on both sides. One side must take quick action to preserve the survivability of its forces and the other must act first to gain the full benefits of its capabilities. Thus, imbalanced forces that rely only on offense to break through anti-access/area denial thickets are likely to be more destabilizing than forces that rely on an offense-defense mix to both survive a first strike and also retaliate effectively. Even limited regional missile defenses that are allocated effectively to enable combat and logistics operations, when combined with effective offensive forces to overturn any *fait accompli*, would bolster deterrence.<sup>18</sup>

## MISSILE DEFENSES AND DETERRING LIMITED NUCLEAR USE

The second element defining the strategic landscape is the development of thinking about limited nuclear conflict. While there was significant thinking in the Cold War on this subject, a few trends in the post-Cold War environment have returned the issue to prominence. The first is doctrinal in nature. Russia has responded to the general decline of its conventional forces by potentially lowering its threshold for nuclear use; what has been termed an “escalate to deescalate” strategy.<sup>19</sup> While some have pointed to similarities to the U.S. strategy of Flexible Response during the Cold War, the new Russian strategy would likely support territorial encroachment into surrounding areas rather than operate as a response to conventional or nuclear attack.<sup>20</sup> This raises the possibility that Russia could attempt a territorial annexation, similar to its actions in Crimea, then resort to nuclear use upon encountering resistance to attempt to regain the initiative.

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18. Karako, “Looking East,” 4–5.

19. Brad Roberts, *The Case for U.S. Nuclear Weapons in the 21st Century* (Stanford, CA: Stanford University Press, 2016), 128–132.

20. Elbridge Colby, “The Role of Nuclear Weapons in the U.S.-Russian Relationship,” Carnegie Task Force on U.S. Policy toward Russia, Ukraine, and Eurasia, February 26, 2016, <http://carnegieendowment.org/2016/02/26/role-of-nuclear-weapons-in-u.s.-russian-relationship-pub-62901>.

This renewed concern about limited nuclear conflict raises a number of questions for older assumptions about strategic stability and deterrence. All-out nuclear response is a less credible response to limited nuclear strikes. This is in fact the guiding rationale for these doctrines: an attempt to thread the needle between creating decisive effects and also falling below the perceived retaliatory threshold. If adversaries believe that they can exploit this gap, deterrence would be undermined. If the United States changes nuclear policy in an attempt to lower its perceived threshold for nuclear retaliation, this could create negative effects for strategic stability by creating “use or lose” pressures for adversaries during a crisis, as such a posture may appear preemptive. This would be especially true if the only deterrence tool the United States has is its offensive forces.

While many question whether a regional nuclear war could stay contained at such a level, the trends in defense thinking among potential adversaries suggest such thinking may be necessary to reinforce deterrence. After all, potential adversaries do get some say in whether they are deterred. As a result, nuclear stability will not simply be determined by looking at an aggregate of nuclear forces around the world. If an adversary believes it can limit the scope of a nuclear conflict, regional deployed forces that can complicate such a strategy will be essential for deterrence.

Because of the limited nature of the attacks, missile defenses are better equipped to deter limited nuclear attacks than the sort of all-out attacks considered the proper metric by some missile defense critics. This capability reduces the pressure on the United States to act preemptively in a crisis that could involve limited nuclear use, and also buys time for negotiations and discussions to prevent conflict from spiraling. Without missile defenses, the United States must rely exclusively on the threat of retaliation to deter any nuclear attack, or preemption if the goal is some form of damage limitation. The conceptual underpinning of limited nuclear war-fighting options assumes that there is a possibility of nuclear use that falls below the retaliatory threshold of the United States but also creates meaningful effects, particularly in terms of allied cohesion or resolve. This calls into question the credibility of these retaliatory threats and their sufficiency in deterring conflict on their own.

By raising the threshold for conducting a successful attack, missile defenses reduce the attractiveness of these doctrines. The more nuclear forces a state must commit to an attack, the less plausibly they can reassure themselves that their strikes were limited and not worthy of escalation and response by the United States. This reduces the probability that an adversary would calculate that it was possible to conduct an effective attack that also falls below the retaliatory threshold of the United States. Missile defenses also limit the number of target options for adversary planners, reducing flexibility and complicating the task of precisely calibrating a nuclear attack.

This condition holds even if countries respond to the presence of missile defenses by increasing their stockpiles of missiles. The requirement to saturate the defenses also raises the cost of an attack to potentially unacceptable levels because the intent is to limit its nature so as not to trigger retaliation. This mitigates some of the concerns of missile defense critics who fear that defenses will inevitably trigger a destabilizing arms race. Even if nations build more missiles in response to defenses, the fact that there are more missiles does not mean they are more likely to be used.



By strengthening alliance resolve and cohesion, missile defenses provide another means to deny adversaries the intended strategic effects of limited nuclear doctrines. By deploying missile defenses in foreign territory, the United States creates a visible sign of commitment to the security of that state, both demonstrating alliance cohesion to possible adversaries and assuring allies of continued U.S. presence. Foreign sales of U.S. missile defense assets similarly create a sense of commitment and also foster interoperability between U.S. and partner militaries, further bolstering extended deterrence. Like any forward-deployed U.S. forces, these missile defenses manned by U.S. personnel also create a “trip wire” effect.<sup>21</sup> This would introduce a further deterrent, as any attack on a U.S. missile defense facility would almost ensure a U.S. response.

## NORTH KOREAN ICBMs AS THE COMBINATION OF A2/AD AND LIMITED NUCLEAR DOCTRINES

North Korea’s development of an intercontinental ballistic missile (ICBM) represents a secondary variation on the anti-access tactic. By threatening the United States homeland, Pyongyang hopes to raise the cost of U.S. involvement in a regional conflict enough to deter it from intervening.<sup>22</sup> Without offsetting U.S. defenses such a condition may convince an American leader to back down to North Korean provocations rather than risk the destruction of a West Coast city. Former president Bill Clinton summarized this strategic problem succinctly, warning, “You can’t be an internationalist if you allow yourself to be blackmailed.”<sup>23</sup> If allies become convinced that the United States could be successfully deterred by a North Korean ICBM, they may feel isolated and question American security commitments.

Adding to this problem is the prospective size of Pyongyang’s nuclear arsenal. States like North Korea will be unable to build the same sort of nuclear arsenals that the United States and Soviet Union did in the Cold War.<sup>24</sup> Thus, the defining feature of strategic stability cannot be mutual vulnerability in the same way. While North Korea can improve the survivability of its nuclear forces by deploying weapons on mobile missiles, it is unlikely to feel assured of a secure second-strike capability in the same way that larger nuclear arsenals of the Soviet Union were, creating significant pressure for Pyongyang to use its weapons early in a conflict.

In response to a potential North Korean nuclear-tipped ICBM, missile defenses bolster deterrence by introducing uncertainty for Pyongyang about whether such a strike would have its intended

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21. Stephan Frühling, “Managing Escalation: Missile Defence, Strategy, and U.S. Alliances,” *International Affairs* 92, no. 1 (2016): 87.

22. Roberts, “On the Strategic Value of Ballistic Missile Defense,” 16.

23. Bradley Graham, *Hit to Kill: The New Battle over Shielding America from Missile Attack* (New York: Public Affairs, 2003), 96–99, 379.

24. David Albright, *Future Directions in the DPRK’s Nuclear Weapons Program: Three Scenarios for 2020* (Washington, DC: US-Korea Institute at SAIS, Johns Hopkins University, 2015), [http://uskoreainstitute.org/wp-content/uploads/2016/02/NKNF\\_Future-Directions-2020.pdf](http://uskoreainstitute.org/wp-content/uploads/2016/02/NKNF_Future-Directions-2020.pdf).

effect, effectively taking the option of a cost-free “cheap shot” off the table.<sup>25</sup> By introducing this uncertainty, and the potential reputational costs of a failed ICBM strike, the United States could reduce the likelihood that Pyongyang would choose that course of action during a conflict to attempt to break it off from defending its allies in South Korea or Japan.

Some argue that the only way that North Korea would launch such an attack would be as an act of desperation, an action that defenses cannot deter. While the United States certainly cannot deter the acts of a desperate leadership attempting to hold on to power, the deterrent effects of limited homeland missile defenses happen far before that point. A North Korean regime that became convinced that it could simply coerce the United States by threatening an undefended American city may become emboldened, resulting in more crises that could cause outright war. This sort of prewar deterrence happens before desperation would set in.

An example from 2006 is instructive in how these sorts of crisis dynamics may play out. As North Korea prepared a launch of its Taepodong-2 space launch vehicle, which some analysts considered a possible ICBM delivery vehicle, former secretary of defense William Perry and future secretary of defense Ash Carter wrote an article in support of destroying the potential missile on the launch pad.<sup>26</sup> Their argument was that the costs of surprise should the Taepodong actually be a functioning nuclear missile were so high as to justify a preemptive attack. The George W. Bush administration rather concluded that the protection afforded by the new Ground-Based Midcourse Defense system served as a hedge against that surprise, allowing the United States to instead retaliate to any surprise attack rather than needing to preempt.<sup>27</sup> In this case, missile defenses bought time to prevent a destabilizing first strike, a decision that would have had significant consequences for both American troops in the region and also South Korea and Japan.

During the Cold War, NATO feared that missile defenses for the United States would allow it to retreat back across the Atlantic, effectively decoupling American security from that of NATO's.<sup>28</sup> In many ways, this concern stemmed from an overestimation of how effective missile defenses were likely to be. Unless the United States developed an impenetrable shield around its homeland, it was not likely to retreat into a “Fortress America” because it maintained an interest in security around the globe, not only to preserve stable regional orders but also to preserve a stable economic and political order. Ultimately, decoupling is a choice. Having some sort of defense gives the United States some insurance against the potential costs of these forward deployments, whereas without defenses its forces would be entirely vulnerable.

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25. Roberts, “On the Strategic Value of Ballistic Missile Defense,” 24.

26. Ashton Carter and William Perry, “If Necessary, Strike and Destroy,” *Washington Post*, June 22, 2006, <http://www.washingtonpost.com/wp-dyn/content/article/2006/06/21/AR2006062101518.html>.

27. Thomas Karako, Ian Williams, and Wes Rumbaugh, *Missile Defense 2020: Next Steps for Defending the Homeland* (Washington, DC: CSIS, 2017), 5, [https://csis-prod.s3.amazonaws.com/s3fs-public/publication/170406\\_Karako\\_MissileDefense2020\\_Web.pdf?rgfZJOoY5AJY5ScsfZQW8z7Bn7dtSlrr](https://csis-prod.s3.amazonaws.com/s3fs-public/publication/170406_Karako_MissileDefense2020_Web.pdf?rgfZJOoY5AJY5ScsfZQW8z7Bn7dtSlrr).

28. Camille Grand, “Missile Defense: The View from the Other Side of the Atlantic,” *Arms Control Today*, September 1, 2000, <https://www.armscontrol.org/print/725>.

## CONCLUSION

As the global security environment changes, so must old nostrums about missile defense and its role in the deterrent posture of the United States. Previous assumptions about the destabilizing effects of missile defense do not apply as well to a threat environment that is more saturated with missiles and against adversaries more willing to use nuclear weapons in limited ways to achieve political goals. In this environment, missile defenses can function as a bulwark of stability, reducing incentives to conduct limited nuclear operations, reducing the effectiveness and attractiveness of current A2/AD postures, and assuring allies of the United States commitment to their security.

Much remains to be done to develop a more effective and efficient missile defense architecture to support these goals. Future missile defense policy and posture must prioritize defenses against the most plausible threats that enable both A2/AD and limited nuclear options to succeed. In many cases, this will require a prioritization of defending important operational assets, such as points of debarkation and command and control centers, rather than committing to the defense of entire territories.

Such a posture will also likely require more missile defenses than the United States currently deploys. To some degree this is the result of budgetary austerity caused by self-imposed budget caps.<sup>29</sup> As a result, missile defense forces are currently some of the most high-demand, low-density assets in the United States military. The Patriot missile defense force is already under significant strain, and the deployment of a THAAD battery to South Korea threatens to exacerbate the strain on that force as well.<sup>30</sup>

While debates about efficacy and cost should inform the horizon of possibility for future missile defense programs, they are not so conclusive as to preclude any value for missile defense. By establishing a role for missile defense that recognizes both its difficulties and also possibilities, the path to a more rational missile defense conversation becomes clearer.

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29. The topline budget of the Missile Defense Agency (MDA) declined from \$11 billion in 2007 to \$8.4 billion in 2016, in adjusted 2017 dollars. Thomas Karako, with Wes Rumbaugh and Ian Williams, *The Missile Defense Agency and the Color of Money* (Washington, DC: CSIS, 2016), 8, [https://csis-prod.s3.amazonaws.com/s3fs-public/publication/160721\\_Karako\\_MDAColorOfMoney\\_HiRes-compressed.pdf](https://csis-prod.s3.amazonaws.com/s3fs-public/publication/160721_Karako_MDAColorOfMoney_HiRes-compressed.pdf).

30. Sydney J. Freedberg Jr., "Army Missile Defense Stretched Thin: Readiness, Crisis Response at Risk," *Breaking Defense*, February 12, 2015, <http://breakingdefense.com/2015/02/army-missile-defense-stretched-thin-readiness-crisis-response-at-risk/>.

# Selling the Bomb: Making the Case for British Nuclear Deterrence in the Twenty-First Century

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*In July 2016, the British Parliament voted to replace the submarines carrying the United Kingdom's strategic nuclear deterrent. Procurement of these new submarines—the Dreadnought class—will ensure that the United Kingdom remains a nuclear-armed state until the 2050s. The May government's handling of the vote has been marred by the failure of a Trident missile test launch from a Royal Navy submarine days before the vote, and its delayed disclosure in January 2017. This led to allegations of a "cover-up" and familiar questions surrounding secrecy, transparency, and its effect on the public debates.*

*Using the missile test controversy as a jumping-off point, this paper places the government's efforts to make the case for the deterrent to the public in 2016 in historical context. The paper argues that the government's justification for Britain's possession of nuclear weapons has evolved since the end of the Cold War from a deterrent against the Soviet Union toward "insurance" against an uncertain future. The British government has also started to exploit new mediums in its nuclear public relations efforts. The "cover-up" of the Trident missile failure shows that while the government has made much progress in its public relations efforts since the 1980s, official secrecy still presents barriers to effective public relations, and that poorly handled events can undermine the government's justification of the United Kingdom's nuclear status.*

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# INTRODUCTION

In July 2016, just days after Theresa May became prime minister, the House of Commons voted to endorse the existing plans to build four new successor submarines to carry the British nuclear deterrent.<sup>2</sup> This decision means that—pending any shock developments—the United Kingdom will continue to be a nuclear-armed state into the 2050s. The period around this debate in the Commons saw a significant effort by the UK Ministry of Defence (MOD) to make the case for continued possession of nuclear weapons to a variety of audiences, including members of Parliament (MPs), allies, journalists, experts, and the general British public, using both traditional and new social media.

As the MOD made a public case for retention of nuclear weapons, a Trident missile launch from a Royal Navy submarine failed in June just days before the vote.<sup>3</sup> The missile—drawn from the shared UK-U.S. pool—had been launched by HMS *Vengeance* as part of a demonstration and shakedown operation following a refit. An unnamed senior naval source allegedly told *The Times*:

Ultimately Downing Street decided to cover up the failed test. If the information was made public, they knew how damaging it would be to the credibility of our deterrent . . . the upcoming Trident vote made it all the more sensitive.<sup>4</sup>

The leak of the failed test in January 2017 led to allegations of a cover-up. It showed that secrecy can be used for political purposes, as well as for security rationales. Secrecy has—since the beginning of the nuclear age—impacted public debates regarding nuclear weapons. Secrecy has also sometimes come into conflict with efforts to justify the possession of nuclear weapons to the public.

Considering the 2016 vote and the later controversy surrounding the 2016 test, this paper places efforts to make the case for the United Kingdom's retention of nuclear weapons in a broader historical context. It argues that the justification provided by the government has shifted in the post-Cold War era toward "insurance" against an uncertain future. Social media have been increasingly used to put forward this case. Efforts to justify the replacement decision in 2016 saw the government engage with a larger audience than in previous attempts to make the case for the United Kingdom's independent strategic deterrent, such as around the 2006 Trident white paper and the 2007 House of Commons vote, and during the early 1980s when the decisions to procure the current Trident system were made. However, while a wider audience was exposed to government public relations (PR) efforts than ever before, this did not necessarily mean a more informed public, a higher quality of public discussion, or a more successful case was made by the government.

After assessing secrecy, transparency, and PR, the paper concludes that the evolving secrecy of basic policy information related to the United Kingdom's nuclear program has largely been shaped by political factors. Withholding the information regarding the 2016 failed test was most likely a political decision and avoiding pressure in the short-term created difficulty for the government in

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2. "MPs Vote to Renew Trident Weapons System," *BBC News*, July 19, 2016.

3. "No 10 Covered Up Trident Missile Fiasco," *Times*, January 22, 2017.

4. *Ibid.*

the longer term. The paper suggests that government PR efforts—which became more extensive in 2016—are not the same as increasing transparency and questions whether the trajectory toward greater transparency will continue to be seen in the UK case.

## JUSTIFYING THE DETERRENT

In the nearly four decades since Margaret Thatcher entered office in 1979, the United Kingdom has become more open in its approach to the presentation of basic nuclear policy information. Several factors led to significant change in the early 1980s. Thatcher and a Conservative government were openly pro-nuclear deterrence, and with no internal divisions on the nuclear issue (unlike their Labour predecessors). Thatcher's government had no qualms about making the case for nuclear deterrence. Michael Quinlan, MOD policy director and defense intellectual, played a crucial role in facilitating a more open approach, having the ability to articulate British policy and believing an open debate was necessary.

This willingness and ability to make the case combined with a rising need to justify Britain's nuclear status as the country considered new, expensive, and controversial systems and confronted a vocal "peace movement." In the late 1970s, it became necessary for the United Kingdom to consider a replacement system for Polaris. The boats had been in service since the late 1960s, and would end their lives in the early 1990s. Also, around this time, NATO was moving toward deployment of Long Range Theater Nuclear Forces in Europe as part of the "dual track" approach to Soviet intermediate-range missile upgrades. This would involve the controversial Ground Launch Cruise Missile (GLCM) deployment at two sites (Greenham Common and Molesworth) in the United Kingdom. These decisions—especially the very controversial GLCM deployment—resulted in the growth of the "peace movement." Such organized opposition to nuclear weapons had not manifested itself since the late 1950s to early 1960s.

These factors drove government officials to make a public case for the possession of nuclear weapons. As a by-product of making this public case, the government became slightly more open in its presentation of nuclear policy. Priming the public for the announcement that the United Kingdom would be purchasing Trident, the government officially revealed the Chevaline upgrade program in the House of Commons for the first time, in what was the first parliamentary debate on nuclear weapons in 15 years.<sup>5</sup> Following the Trident purchase announcement in July 1980, the government released an "Open Government Document" that justified the Trident I C-4 purchase.<sup>6</sup> A further paper was released in 1982 to justify the decision to pursue the larger and more expensive Trident II D5 missile.<sup>7</sup>

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5. Work to upgrade the front end of the United Kingdom's Polaris missiles to improve penetration capability had been under way since the late 1960s in secret. See "Nuclear Weapons," Hansard, January 24, 1980, <http://hansard.millbanksystems.com/commons/1980/jan/24/nuclear-weapons>.

6. Her Majesty's Government (HM Government), "The Future of the United Kingdom Strategic Nuclear Deterrent Force," Defence Open Government Document 80/23, July 1980.

7. HM Government, "The United Kingdom Trident Programme," Defence Open Government Documents 82/1, March 1982.



The 1980 Open Government Document became the fullest and most authoritative public statement for the United Kingdom's possession of nuclear weapons up to that point. The paper laid out the basic rationale for Britain's independent capability: the "contribution it makes to NATO's strategy of deterrence and thus to our own national security" before presenting the "second center" argument and laying out the rationale behind the choice of Trident.<sup>8</sup> The concept of deterrence sought to pose "a potential threat to key aspects of Soviet state power."<sup>9</sup> The "second center" argument suggested that adding a second center of nuclear decisionmaking, among the European allies inside the NATO command structure, would enhance NATO's deterrence overall.<sup>10</sup>

While efforts to make the case for the United Kingdom's independent strategic capability were significant, the attempts by British government officials to justify the GLCM deployment represented the more formative PR experience. Following the announcement of the "dual track" approach in December 1979, the government made some largely unsuccessful early efforts to present the deployment to the public. As the "peace movement" grew, the government's PR effort became more refined, more organized, and more vocal. It also sought to persuade larger audiences. By the 1983 general election, government ministers were actively opposing the "peace movement" in speeches and through media work.

## A Post–Cold War Identity Crisis

The dissolution of the Soviet Union in the early 1990s and end of the Cold War saw Britain, as one informed insider put it, "confronted with a post–Cold War crisis of nuclear identity."<sup>11</sup> As MOD policy director Quinlan noted, "We now have to think about nuclear weapons in a radically altered framework."<sup>12</sup> However, early statements from the defence secretary, while announcing reductions in the United Kingdom's force structure, indicated significant continuity in policy from the Cold War. The UK nuclear policy remained NATO and Russia-centric. As Nicholas Witney noted, the British government was "very careful" to avoid justifying Britain's nuclear arsenal as a means to discourage or "face down" proliferators.<sup>13</sup>

During this post–Cold War period, the United Kingdom did take some further steps to release information regarding its nuclear capability—particularly disclosing the number of warheads. This allowed the United Kingdom to put a tangible number on what it described as a "minimum deterrent." Emphasising the minimum nature of the capability helped justify continued possession in a world where the main threat to the UK security was radically changed.

Although featuring in internal government discussions during the Cold War, and in a limited manner in public debates of the 1980s, the minimum deterrence concept did not become a commonplace phrase until the post–Cold War period. This was despite the government's claim to have

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8. HM Government, "The Future of the United Kingdom Strategic Nuclear Deterrent Force," 3.

9. Ibid., 6.

10. Ibid., 4–5.

11. Nicholas Witney, "British Nuclear Policy After the Cold War," *Survival* 36, no. 4 (1994): 105.

12. Michael Quinlan, "The Future of Nuclear Weapons: Policy for Western Possessors," *International Affairs* 69, no. 3 (July 1993): 486.

13. Witney, "British Nuclear Policy after the Cold War," 103.

“long emphasized” that the United Kingdom deployed only the “minimum deterrent required for our security needs.”<sup>14</sup> The phrase was used marginally in 1990, when the government spoke of “the minimum capability necessary to maintain an effective deterrent.”<sup>15</sup> By 1998 “minimum” or “minimum credible” had become a much-repeated phrase—occurring eight times in the main body of the *Strategic Defence Review* and a further three times in the appendices.<sup>16</sup>

In the early 1980s there was little information in the public domain regarding the size of the UK nuclear weapons stockpile. The announcement that the United Kingdom would procure the Trident II D5 missile rather than the Trident I C4 in 1982 helped to give some sense of the future size of the arsenal. The government publicly stated the United Kingdom would unilaterally limit itself to a maximum of eight warheads per missile.<sup>17</sup> Effectively, this figure alongside the numbers of submarines and missile tubes and dual-use systems such as aircraft were the only official figures disclosed that could give a sense of the size of the UK arsenal to outside observers, although there were clearly massive variables that prevented accurate estimate.<sup>18</sup> While arms control negotiation and treaties between the two superpowers had seen significant public commentary on U.S. and Soviet nuclear forces, little was seen on the smaller nuclear capabilities of the P5—the United Kingdom, France, and China.<sup>19</sup> Early nongovernmental estimates for British nuclear forces only started to be published in the mid-1980s.<sup>20</sup>

In 1990, the first defense white paper after the fall of the Berlin Wall, there was no mention of warhead numbers.<sup>21</sup> The upper limit of 128 per submarine was reiterated in 1992 and 1993.<sup>22</sup> Late 1993 saw the defense secretary announce that this upper limit per submarine was reduced to 96.<sup>23</sup> In 1995, for the first time, an aspirational upper limit for the United Kingdom’s full arsenal was declared at 300 by the end of the decade.<sup>24</sup>

The *Strategic Defence Review* (SDR) of 1998 went further than before in detailing warhead numbers. The SDR was one of the first actions taken on defense by the New Labour government of

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14. HM Government, *Defending Our Future: Statement on the Defence Estimates 1993*, Command Paper (Cm) 2270 (London: Her Majesty’s Stationery Office [HMSO], 1993), 14.

15. HM Government, *Statement on the Defence Estimates 1990*, vol.1, Cm 1022 (London: HMSO, 1990), 16.

16. HM Government, *Strategic Defence Review 1998*, Cm 3999 (London: HMSO, 1998).

17. The Trident II D5 missile was originally designed to carry 14 warheads. This was more than the eight carried by the Trident I C4. HM Government, “The United Kingdom Trident Programme,” 6.

18. Estimates over the size of the United Kingdom’s then current arsenal suffered due to confusion regarding the warhead configuration on Polaris and Chevaline front ends.

19. See, for example, the Natural Resource Defense Council’s “Nuclear Notebook,” published in the *Bulletin of the Atomic Scientists* from 1987 and the Stockholm International Peace Research Institute (SIPRI) Yearbooks.

20. See, for example, SIPRI, *World Armaments and Disarmament: SIPRI Yearbook 1985* (London: Taylor & Francis, 1985), 65; SIPRI, *World Armaments and Disarmament: SIPRI Yearbook 1986* (London: Taylor & Francis, 1986), 62; “Chewing on Trident,” *Bulletin of the Atomic Scientists* 43, no. 20 (1987): 52.

21. HM Government, *Statement on the Defence Estimates 1990*.

22. See HM Government, *Defending our Future: Statement on the Defence Estimates 1993*, Cm 2270, 14.

23. Michael Evans, “Britain to Cut Nuclear Firepower by a Quarter,” *Times*, November 17, 1993.

24. HM Government, *Statement on the Defence Estimates 1995: Stable Forces in a Strong Britain*, Cm 2800 (London: HMSO, 1995), 39.

Tony Blair, who sought to break with Labour's unilateralist past and placed great emphasis on transparency in nuclear policy. The document suggested a need for a "stockpile of less than 200" and reduced the number of warheads that would be carried on patrol to 48.<sup>25</sup> In the supporting essays, the document included a graph with actual "nuclear weapons holdings" (450 in the 1970s and 400 in the 1980s) alongside the planned ceilings announced in 1995 and 1998 (300 and 200, respectively).<sup>26</sup> These actual figures went further than the inventive graphs (arsenal size displayed relative to 1.0 and as "relative megatonage," for example) and percentages found in previous documents.<sup>27</sup> Since the turn of the century, more information has been disclosed, with ceilings provided for total and operational warhead stockpiles and warheads deployed on submarine patrols.<sup>28</sup>

The 1998 SDR was also significant in presenting rationales for nuclear possession—detering the threat or use of nuclear weapons in a "smaller scale but still militarily demanding regional crisis or conflict" and a "strategic attack on NATO," of which it was noted "no threat on this scale is in prospect."<sup>29</sup> The government returned to these themes after the turn of the century.

## Making the Case for Nuclear Deterrence in the Twenty-First Century

In the early twentieth century, the United Kingdom moved toward another "replacement" or "renewal" debate. The four *Vanguard*-class submarines were scheduled to start leaving service in the early 2020s, and the MOD had assessed that 17 years would be required to design and manufacture replacements.<sup>30</sup> In December 2006, the government presented a white paper to Parliament advocating what became known colloquially as like-for-like replacement—the replacement of the four *Vanguard*-class strategic ballistic missile submarines (SSBNs) with four new SSBNs.<sup>31</sup> A missile to replace the D5 and a new warhead would be decided on later.

The government's white paper was 40 pages long and presented several rationales for continued possession of nuclear weapons—some of these were novel. The United Kingdom's weapons would "deter and prevent nuclear blackmail and acts of aggression against our vital interests that cannot be countered by other means."<sup>32</sup> More specific rationales included the "second center of decisionmaking" argument, and three types of nuclear threats: the "reemergence of a major nuclear threat," "emerging

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25. HM Government, *Strategic Defence Review 1998*.

26. Ibid.

27. Percentages were first used by Malcolm Rifkind in 1993 and stated in documents from 1994. See HM Government, *Statement on the Defence Estimates 1994*, Cm 2550 (London: HMSO, 1994), 19. Graphs of the "total stockpile," "stockpile explosive power," "operational numbers," and "operational explosive power" relative to 1.0 in the 1970s were included in the 1995 estimates. See HM Government, *Statement on the Defence Estimates 1995*, 39.

28. See, for example, HM Government, *The Future of the United Kingdom's Nuclear Deterrent*, Cm 6994 (London: HMSO, 2006); Richard Norton-Taylor, "Britain's Nuclear Arsenal Is 225 Warheads, Reveals William Hague," *The Guardian*, May 26, 2010; HM Government, *Securing Britain in an Age of Uncertainty: The Strategic Defence and Security Review*, Cm 7948 (London: HMSO, 2010), 38.

29. HM Government, *Strategic Defence Review 1998*, paras. 55 and 56.

30. HM Government, *The Future of the United Kingdom's Nuclear Deterrent*.

31. Ibid.

32. Ibid., 17.

nuclear states,” and “state-sponsored terrorism.”<sup>33</sup> Underpinning these rationales was that of future uncertainties—an element that has since become a central element of the government’s narrative. As Prime Minister Tony Blair noted in the foreword: “An independent British nuclear deterrent is an essential part of our insurance against the uncertainties and risks of the future.”<sup>34</sup>

It was not the first time that the metaphor of “insurance” had been used to justify the United Kingdom’s nuclear status. In 1964, for example, the *Statement on Defence* noted, “Our nuclear contribution is vital as an insurance for the future—indeed, as an assurance that we shall have a future.”<sup>35</sup> The term had seen wider use from time to time in the context of defense spending. Use of an “insurance metaphor” in relation to nuclear weapons became more popular from the late 1970s onward. For example, in 1979, the former chief of the defense staff suggested that the United Kingdom’s strategic deterrent was “a form of insurance policy against the withdrawal of United States support for the defence of Western Europe, including Britain.”<sup>36</sup> The secretary of state for defense, Francis Pym, alluded to this argument in 1980.<sup>37</sup> The following year, his successor suggested that Britain’s deterrent was an insurance against Soviet miscalculation that the United States would abandon Europe.<sup>38</sup> The metaphor also formed a central element of a glossy brochure that was distributed to towns around the GLCM bases in the United Kingdom in 1980 entitled “Cruise Missiles: A Vital Part of the West’s Life Insurance.”<sup>39</sup>

The metaphor has also seen use in the post–Cold War environment. Britain’s first post–Cold War defense secretary used the metaphor, noting that expenditure of a small proportion of the defense budget was “an economical insurance and the ultimate safeguard against nuclear blackmail.”<sup>40</sup>

Michael Quinlan has used the term, noting:

Beyond that there will remain—probably for longer still, if not indefinitely—a cogent case for the free world to maintain and support some nuclear weapon capability to underpin war prevention, to close off nuclear adventurism and to serve as a low-key element of insurance, not directed against specific adversaries, in support of world order.<sup>41</sup>

From 2006 onward, the insurance language has been adopted by the government as a key pillar of its case. Although the metaphor itself does not really work if played through (insurance does not deter disaster, and nuclear weapons do not provide a payout in the event of loss), it does capture the concept of hedging against low-probability eventualities. Alongside the reference to rapidly

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33. Ibid., 19.

34. Ibid., 5.

35. HM Government, *Statement on Defence 1964*, Cm 2270 (London: HMSO, 1964), 7.

36. “Appendix 3: Britain’s Strategic Nuclear Deterrent Force—Letter from Field-Marshal Lord Carver,” in *Defence and External Affairs Sub-Committee, Sixth Report from the Expenditure Committee, 1978–1979*, 211.

37. “Nuclear Weapons,” Hansard, January 24, 1980.

38. “Nuclear Deterrent,” Hansard, March 3, 1981, <http://hansard.millbanksystems.com/commons/1981/mar/03/nuclear-deterrent>.

39. HM Government, “Cruise Missiles: A Vital Part of the West’s Life Insurance,” June 1980.

40. “Trident,” Hansard, December 17, 1991, <http://hansard.millbanksystems.com/commons/1991/dec/17/trident>.

41. Quinlan, “The Future of Nuclear Weapons,” 496.

evolving or apparently unforeseen threats, it provides an argument that is easy for government officials to communicate to the public.

## The 2010 Coalition Government: Alternatives? There Are No Alternatives!

The 2010 general election presented a “wild card,” seeing a Conservative-Liberal Democrat coalition government assume office. The contrasting manifesto positions of the two parties (the Conservatives supported the 2007 plans, while the Liberal Democrats ruled out “like-for-like replacement” as being “unaffordable, and Britain’s security would be better served by alternatives”<sup>42</sup>) led to compromise. The Coalition would ensure that existing plans were “scrutinised to ensure value for money”; meanwhile the Liberal Democrats would “continue to make the case for alternatives.”<sup>43</sup>

The 2010 *Strategic Defence and Security Review* (SDSR)—entitled “Securing Britain in an Age of Uncertainty”—emphasized similar themes and reiterated the arguments originally made in the 2006 white paper regarding terrorism threats.<sup>44</sup> In a 2013 op-ed timed to coincide with the 100th *Vanguard* patrol, David Cameron also emphasised “uncertainty.” He stated: “The nuclear threat has not gone away. In times of uncertainty and potential risk it has, if anything, increased.”<sup>45</sup> Also, reflecting the “value for money” theme of the Coalition Agreement and the 2010 SDSR, he argued the relative value of the deterrent.<sup>46</sup>

The Coalition Agreement stating that the Liberal Democrats would continue to make the case for “alternatives” led to a cabinet office “Alternatives Review.” This was released by the government in mid-2013.<sup>47</sup> The 60-page document concluded that, although there are alternative systems and postures, none “offers the same degree of resilience” or a “prompt response in all circumstances.”<sup>48</sup> Citing the uncertainties posed by Iran and North Korea, and preempting the outcome of the review, the secretary of state for defense, Philip Hammond, argued that “the alternatives to Trident carry an enormous risk” and that they are “less capable, less credible and more expensive.”<sup>49</sup>

## Selling *Dreadnought*<sup>50</sup>

In 2015 David Cameron’s Conservative government was reelected with a small majority—allowing members of the Conservative Party to proceed with their manifesto promise to build four

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42. Liberal Democrats, “Liberal Democrat Manifesto 2010,” April 2010, 65.

43. HM Government, “The Coalition: Our Programme for Government,” May 2010, 15.

44. HM Government, *Securing Britain in an Age of Uncertainty*, 37.

45. David Cameron, “We Need a Nuclear Deterrent More Than Ever,” *Telegraph*, April 3, 2013.

46. Ibid.

47. HM Government, “Trident Alternatives Review,” July 16, 2013.

48. Ibid., 10.

49. Philip Hammond, “The Alternatives to Trident Carry an Enormous Risk,” *Telegraph*, February 2, 2013; Philip Hammond, “No Time to Lower Our Guard: The Defence of This Country Means Being Ready for the Unexpected,” *Daily Mail*, July 14, 2013.

50. It was announced that the submarine class to succeed the *Vanguard*-class would be called the “*Dreadnought* class” on October 21, 2016.

successor SSBNs.<sup>51</sup> The 2015 SDSR again alluded to future threats: “Recent changes in the international security context remind us that we cannot relax our guard. We cannot rule out further shifts which would put us, or our NATO Allies, under grave threat.”<sup>52</sup> Significantly, the document saw references to an expanding Russia following the annexation of Crimea in 2014, under a section entitled “the resurgence of state-based threats.”<sup>53</sup>

Following the EU referendum, Cameron resigned, and one of his last acts in office was to ensure that one of Theresa May’s first acts was to oversee a Trident vote in the House of Commons. As the prime minister’s spokesperson noted at the time, Trident renewal was the “ultimate insurance to protect from future threats into the 2030s, 40s and 50s.”<sup>54</sup> May’s speech to the House of Commons just six days later, on the July 18, 2016, reiterated similar themes and concerns. Trident was, she noted, “our ultimate insurance against nuclear attack.”<sup>55</sup>

Almost a year to the day after the Iran and the P5+1 had concluded the nuclear deal, May’s speech explicitly stated that the threats posed by “Russia and North Korea . . . remain very real.”<sup>56</sup> Again emphasising future uncertainties, she went on to state:

It is impossible to say for certain that no such extreme threats will emerge in the next 30 or 40 years to threaten our security and way of life. And it would be an act of gross irresponsibility to lose the ability to meet such threats by discarding the ultimate insurance against those risks in the future.<sup>57</sup>

It was with these justifications that Parliament endorsed the “renewal” plans.

In sum, the justification for Britain’s possession of nuclear weapons has evolved since the end of the Cold War. Cold War justifications—as more elaborately expressed around 1980—were clearly focused on deterring the Soviet Union. Since 1990, as predicted by those with inside insights, justifications that highlighted Russia and the second center of decisionmaking have been viewed as having reduced salience.<sup>58</sup> From 2006 onward, the dominant narrative has been one of readiness for an uncertain future, often next to an analogy of retaining Trident as insurance against future uncertainties. Alongside this narrative, minor changes have been seen relating to specific threats. For example, May’s justification before the 2016 vote did not feature Iran or state-sponsored terrorism, but did prominently feature Russia.

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51. The Conservative Party, “Strong Leadership, a Clear Economic Plan, a Brighter, More Secure Future,” Manifesto 2015, April 2015, 78.

52. HM Government, *National Security Strategy and Strategic Defence and Security Review 2015: A Secure and Prosperous United Kingdom*, Cm 9161 (London: HMSO, 2015), 35.

53. *Ibid.*, 18.

54. Anushka Asthana, “Cameron Pushes for Trident and Life Chances Plan at Last Cabinet Meeting,” *Guardian*, July 12, 2016.

55. “PM Commons Statement on Future of Trident,” July 18, 2016, <https://www.gov.uk/government/speeches/pm-commons-statement-on-future-of-trident-18-july-2016>.

56. *Ibid.*

57. *Ibid.*

58. Quinlan, “The Future of Nuclear Weapons”; Witney, “British Nuclear Policy after the Cold War.”



## MEDIUMS OLD AND NEW: TWEETING THE CASE

How British government officials have sought to engage the public has undergone a drastic change in more recent debates and was particularly evident surrounding the July 2016 vote. Efforts to justify the UK procurement of Trident in the early 1980s were explicitly targeted at a narrow audience of MPs, journalists, and defense intellectuals. The dry, almost imageless, Open Government Documents were not designed for consumption by the wider public. However, the growing “peace movement” in the early 1980s caused the British government to expand its nuclear PR effort and to seek to win over the large group of those undecided on the nuclear issue.

The 2016 debate saw several familiar PR mediums used by the government. Op-eds and articles making the government’s case were published in newspapers by prominent figures such as the defense secretary, as seen in previous periods.<sup>59</sup> Fact sheets were created by the government—in a similar vein to those published in the early 1980s—and were now able to reach larger audiences online.<sup>60</sup> Journalists were also given access to the submarine program, including interviews with crew members.<sup>61</sup> Although rare—apparently the first time in 10 years—it was also not unprecedented.

The growth of social media in the 2000s vastly expanded the prospects for reaching out and making the case, or informing, the general population. This featured prominently around the 2016 parliamentary debate. Starting in late 2015—less than a year before the 2016 debate—the MOD posted videos, basic infographics, and quote graphics (quotes that have been created as an image). Infographics provided stats on the submarines and key facts on Continuous at Sea Deterrence (CASD).<sup>62</sup> Quote graphics included a graphic of a roulette wheel with a quote from the defense secretary, Michael Fallon, which stated, “We should not gamble with our national security.”<sup>63</sup> There were recognizable upsurges in PR efforts at certain points: for example, when Fallon visited Faslane in January, when the Campaign for Nuclear Disarmament (CND) organized a large demonstration in late February, and in the days leading up to the parliamentary vote in July 2016, which was live-tweeted by the MOD.

The reach of new social media was clear when the Royal Navy Facebook account shared a video about Trident uploaded to the content-sharing website UNILAD. The video gained almost a million

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59. Michael Fallon, “Amid Danger and Uncertainty, Renewing Trident Is a Very Cheap Insurance Policy,” *Telegraph*, July 17, 2016. See, for example, Peter Hill-Norton, “After Polaris,” *Economist*, September 15, 1979.

60. Peter Hennessy, “Defence Ministry Goes on the Offensive,” *Times*, May 5, 1981; “Policy Paper: UK Nuclear Deterrence: What You Need to Know,” updated March 24, 2016, <https://www.gov.uk/government/publications/uk-nuclear-deterrence-factsheet/uk-nuclear-deterrence-what-you-need-to-know>.

61. See, for example, Ewen MacAskill, “Onboard a Trident submarine: ‘If I Have to Pull the Trigger, Deterrence Has Failed,’” *Guardian*, January 21, 2016.

62. Ministry of Defence, “Find out about the Successor to the Vanguard submarines,” Twitter post, July 10, 2016, 7:01 p.m., <https://twitter.com/DefenceHQ/status/752201048358588416>.

63. Ministry of Defence, “‘2/2 DefSec:’ It’s about the threats we may face over generations,” Twitter post, March 23, 2016, 11:25 a.m., <https://twitter.com/DefenceHQ/status/712601217382359040>.

views and 20,000 interactions (likes, shares, and comments) in 48 hours.<sup>64</sup> New media present new opportunities for the government's nuclear PR. However, it is also difficult to measure their impact on the government's efforts to make a case.

## SECRECY, THE PUBLIC DEBATE, AND THE FUTURE OF TRANSPARENCY

These efforts to justify the United Kingdom's nuclear status have occurred in the context of great secrecy surrounding the weapons program—a characteristic of all nuclear programs around the world. A veil of secrecy surrounding elements of the British program was seen from its earliest days and in many dimensions endures to this day. Secrecy has surrounded the technical and operational aspects of Britain's nuclear enterprise and deployments, seeking to ensure the survivability and penetration capability of the deterrent. It has also been used by the British nuclear program to comply with its nonproliferation obligations and to ensure the security of its broader nuclear assets and infrastructure.

Secrecy has frequently surrounded basic policy information such as the capability of weapons systems, warhead numbers, and even the basic rationales for Britain's possession of nuclear weapons. The lack of policy information has largely been political in nature, often resulting from unresolved internal debates as to whether disclosure would be advantageous or reflecting internal party political concerns. Political secrecy reached its height in the 1970s under the Labour governments. Labour's position was contradictory: publicly declaring the party would not "move to a new generation of strategic nuclear weapons" while continuing with an extensive modernization program—*Chevaline*—behind closed doors.<sup>65</sup> To avoid charges of hypocrisy, exposing internal party divisions, and alienating supporters, the government avoided discussion of nuclear policy.

A variety of factors have challenged elements of this secrecy over time. Opposition politicians, antinuclear weapons activists, and investigative journalists have called for more openness. Arms control agreements and nuclear security initiatives have led to some public disclosures. These challenges to nuclear secrecy came alongside general demands for greater government transparency across the board. Another important factor that has seen the British government become more "open" in its presentation of nuclear issues is the need to make a public case for controversial and expensive nuclear policies.

### The Public Debate

The period surrounding the 2016 debate saw a significant number of people engaged on the issue of the United Kingdom's nuclear capability. The CND protest in February 2016 was described in the

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64. Although shared by the Royal Navy, the origins of the video are unclear. It is important to note that a video covering the February 2016 anti-Trident protest uploaded by the website was also viewed by over half a million people. UNILAD, Facebook post, March 4, 2016, <https://www.facebook.com/uniladmag/videos/2207952312561149/>.

65. Lawrence Freedman, *Britain and Nuclear Weapons* (London: Palgrave Macmillan, 1980), 55.

media as the biggest since the early 1980s, which had seen a significant nuclear war scare.<sup>66</sup> The MOD's PR effort—rather than targeted at this opposition to nuclear weapons, which it would be hard to shake—was directed at those without such strong opinions on the nuclear issue.

Efforts to make the case in 2016, although engaging many people, did not necessarily increase the levels or quality of debate. Much of the engagement through social media—for example, the 1 million people that viewed the protest video—was likely superficial. The debate surrounding the 2016 vote, like that in the 2000s and 1980s, has mostly played out in Parliament, among the think tank community, and within the now leaner antinuclear movement. Large swathes of the British public view Britain's nuclear status as a low-priority issue, especially compared to other issues such as the economy, health care, and housing.

Whether the government's PR efforts have been successful is difficult to say. Opinion poll figures outlining support or opposition for retention vary, depending on the specific question posed. Support increased in Parliament between 2007 and 2016 (from a 248- to a 355-vote majority), although it should be noted that the Parliament had shifted from Labour to Conservative control.

### Testing Times? The Failed 2016 Test

The controversy surrounding the leak of the failed test in January 2017 showed that, although the British government has taken great steps and shown signs of learning in talking about the bomb, policy presentation in this area is still challenging. There has been a suggestion that the Barack Obama administration pressured the UK government not to comment on this particular incident.<sup>67</sup> Although the full reasons for the decision not to disclose the test are unclear, and will likely remain so, Cameron and May were aware of the failure, despite early claims to the contrary.<sup>68</sup>

While not disclosing the failed test prior to the debate may have prevented some headlines, greater scandal is usually created by a cover-up if it eventually leaks. As the academic Lawrence Freedman noted shortly after the failed test was revealed:

As the recent rumpus over the failure of a missile test demonstrates, it has yet to be fully appreciated in government that withholding information just because its release would be inconvenient makes things worse over the longer term.<sup>69</sup>

Although the timing was sensitive—just prior to the 2016 Parliamentary “renewal” debate—the government was unlikely to lose a Commons vote because of its majority and the party whip system. Revealing that the test had failed would have provided the antinuclear movement with some ammunition, but outlining the Trident D5 missile's phenomenal overall success rate might

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66. Mark Townsend, “Trident Rally Is Britain's Biggest Anti-Nuclear March in a Generation,” *Guardian*, February 27, 2016.

67. “Trident: Barrack Obama Administration Asked David Cameron to Keep Failed Nuclear Missile Test Launch Secret,” *Independent*, January 24, 2017.

68. Rowena Mason and Anushka Asthana, “Theresa May Knew about Trident Failure before Renewal Vote,” *Guardian*, January 23, 2017.

69. Lawrence Freedman, “Historical Research and Political Accountability” (speech to Strand Group, London, March 6, 2017), <https://www.kcl.ac.uk/sspp/policy-institute/Strand-Group/THE-BENEFIT-OF-HINDSIGHT.docx>.

have mitigated that. However, not disclosing the test likely had more enduring implications for public confidence in the government and the British nuclear program and may make the public less likely to believe government PR efforts in the future.

## Transparency and Its Future?

The failed test and its handling raise a variety of broader questions, including: How open can and should government be in its efforts to present nuclear weapons policy? Are there limits to transparency?

The United Kingdom has clearly taken steps to be more transparent with its nuclear capability. In 2009, the government noted that it has “sought to lead the way in being transparent” about its nuclear weapons holdings.<sup>70</sup> Release of warhead numbers and government documents outlining the merits of relative systems were a part of a broader effort, including the release of the first figures of the United Kingdom’s fissile material holdings.<sup>71</sup> However, there are still clear limits to the UK government’s desire and ability to be transparent.

These limits stem from security concerns and are reinforced by the small size of Britain’s capability. Not only is there less to be transparent about, but because the United Kingdom is a minimum deterrent power operating a single platform, transparency could create vulnerability. However, calculated operational security measures and the United Kingdom’s use of a submarine-based platform and a CASD policy does help to make the UK arsenal less vulnerable in this respect.

It is also important to note that while the government’s disclosure of certain policy information for the first time has run parallel with PR efforts, these are not one and the same. PR has been focused on making the case for the government’s nuclear decisions. Disclosure of previously classified information has sometimes helped to make this case. However, much of the PR effort involves reiterating pieces of information, arguments, and justifications that have been in the public domain for many years. Much of the UK nuclear program—technically, operationally, and in terms of strategy—remains opaque. Criticisms regarding a lack of accountability and openness have continued to be leveled at the UK nuclear enterprise by nongovernmental observers.<sup>72</sup>

Debates following the 2017 test controversy suggest that the trajectory that the United Kingdom has been on since the early 1980s, toward more disclosure of information and more extensive justification for its nuclear status, may not continue. As Defense Secretary Michael Fallon noted to the House of Commons following the revealing of the failed test, “I don’t believe in greater transparency to this house when it comes to our nuclear deterrent.”<sup>73</sup> This runs counter to much of the

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70. Foreign and Commonwealth Office, *Lifting the Nuclear Shadow: Creating Conditions for Abolishing Nuclear Weapons* (London: Foreign and Commonwealth Office, February 2009), 43.

71. HM Government, *Strategic Defence Review 1998*.

72. See, for example, Nuclear Information Service (NIS), “Standards of Accountability and Openness at Atomic Weapons Establishment Rated ‘Poor’ in Annual Review,” January 3, 2014, <https://www.nuclearinfo.org/article/awe-aldermaston-awe-burghfield-nis-reports/standards-accountability-and-openness-atomic>.

73. Rowena Mason and Ewen MacAskill, “Michael Fallon Accused of Keeping MPs in Dark over Trident Failure,” *Guardian*, January 24, 2017.

narrative since the end of the Cold War, which has emphasized the importance of transparency and openness when possible.

## CONCLUSION

The changed threat environment since the end of the Cold War has meant the British government's justification for the retention of nuclear weapons has evolved. By the mid-2000s the analogy of "insurance" against an uncertain future was becoming prominent. This newer argument has frequently been supported by a variety of threats—reemerging ones such as Russia, emerging threats such as Iran and North Korea, and less frequently nonstate threats. The media used by the government to make the case have also changed. As a result, PR efforts surrounding the 2016 parliamentary vote on replacement reached a larger audience than ever before. While these efforts have seen the case—or elements of it—presented to a wider audience, this has not necessarily enhanced the quality or scope of debate.

The dissolution of the Soviet threat in the early 1990s led to an "identity crisis" and made the United Kingdom's nuclear status more difficult to justify. The British government and other nuclear armed states will likely face new challenges in justifying their capability after a "nuclear ban" treaty was passed at the UN in July 2017.<sup>74</sup> Although the United Kingdom and the other NPT nuclear weapons states did not take part in negotiations, they are likely to come under new pressure to disarm from other states and domestic pressure groups as most countries around the world supported the treaty. These factors may mean that the government's efforts to conduct PR and justify the deterrent become more important over time.

The British government has clearly come a long way in terms of efforts to justify its nuclear status since the debates of the 1980s. However, the government's handling of the failed Trident test in early 2017 shows the difficulty when secrecy conflicts with public relations in making a consistent and coherent case for nuclear retention. Cover-up can relieve political pressure in the short term. However, more importantly, it can create problems in the longer term when it leaks, undermining confidence in the government and the broader nuclear enterprise.

The trajectory in the recent British nuclear experience has been toward increased openness regarding basic policy information and transparency where possible. This paper has argued that the government's increased efforts to make the case is not necessary one and the same as transparency. While the British government has undoubtedly become better at talking about the bomb since the 1970s, much remains secret. The trajectory toward greater transparency in nuclear policy should also not be taken for granted.

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74. Ian Sample, "Treaty Banning Nuclear Weapons Approved at UN," *Guardian*, July 7, 2017.

# The Birth of a Ban: A Comparative Analysis of WMD Prohibition Treaties

Alicia Sanders-Zakre<sup>1</sup>

*The Treaty on the Prohibition of Nuclear Weapons, adopted by a vote of 122-1-1 on July 7, 2017, at the United Nations, is not the first to seek to prohibit the use or possession of a category of weapons. Five other treaties and agreements—the 1925 Geneva Protocol, the Biological Weapons Convention, the Chemical Weapons Convention, the Mine Ban Treaty, and the Convention on Cluster Munitions—all attempted similar ambitious goals. The prohibition treaty joins the Mine Ban Treaty and the Convention on Cluster Munitions in its emphasis on the humanitarian impact of the weapons and the critical role of civil society in pushing for the ban. Like these treaties, advocates of the nuclear prohibition treaty maintain that the treaty will strengthen the norm against the weapon's possession and use, leading to eventual complete disarmament. Some intend for the nuclear ban treaty to be an interim, norm-building prohibition to pave the way for a comprehensive nuclear prohibition convention, as the 1925 Geneva Protocol was for the Biological Weapons Convention and Chemical Weapons Convention. Like other prohibition treaties, one of the most challenging aspects of the nuclear prohibition was negotiating its verification clauses. In other ways, the nuclear prohibition treaty is distinct from those that came before, due to the unique role of nuclear weapons in security doctrines and existing legal architecture surrounding nuclear weapons.*

## INTRODUCTION

The negotiations for a treaty prohibiting nuclear weapons grew out of nonnuclear armed states' frustrations with the slow pace of nuclear disarmament, the growing risk of nuclear weapons use,

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and the concern about their catastrophic humanitarian consequences. Following the report of a series of three open-ended working groups on disarmament, the UN General Assembly voted to begin negotiations in 2017 on a treaty banning nuclear weapons. The conference met for two sessions: one week in March and just over three weeks from June to July, adopting a treaty on July 7.

Throughout the debate at the United Nations for a nuclear prohibition treaty, both in the UN General Assembly First Committee in October and at the actual negotiations in March, states referenced previous weapons prohibitions that could serve as an example for a nuclear ban treaty. Many argued that in order for a verifiable and comprehensive treaty to be concluded, the norm on the weapon in question must be changed, and that one way to do so is through the normative prohibition of the weapon. This process follows the model set forth in the Biological and Chemical Weapons Conventions, treaties which some contend were sparked by the normative prohibition of use of biological and chemical weapons in 1925. During the first week of negotiations in March, Ambassador Guilherme de Aguiar Patriota of Brazil stated,

Prohibition comes often before elimination. A telling example of this reasoning is the chemical weapons process: the 1925 Geneva Protocol set out the prohibition of those whereas the Chemical Weapons Convention (CWC) adopted in 1993 established verification and elimination mechanisms. Those who advocate the prohibition of nuclear weapons only as the final installment of nuclear disarmament process might be underestimating the influence of norms on international politics. . . . Once those norms become part of customary international law, pressure will be generated on actors that stick to deviating patterns. Brazil is convinced that the norm setting out a prohibition of nuclear weapons will be an effective step towards nuclear disarmament.<sup>2</sup>

Others contended that the Mine Ban Treaty or Convention on Cluster Munitions could serve as models for the nuclear prohibition treaty. Austria stated just this in an intervention during the first round of negotiations: “The treaties outlawing anti-personnel mines and cluster munitions also provide examples of existing and demonstrably effective international law prohibiting specific indiscriminate and inhumane weapons.”<sup>3</sup>

While each treaty contains its own unique intricacies, as a body, weapons prohibition treaties share several common elements and challenges. Through a series of case studies of previous weapons prohibitions, this paper will examine trends and distinctions in legal multilateral disarmament treaties and place the treaty prohibiting nuclear weapons in a historical context.

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2. Statement by H. E. Ambassador Guilherme de Aguiar Patriota, United Nations Conference to Negotiate a Legally Binding Instrument to Prohibit Nuclear Weapons, Leading towards Their Total Elimination, March 29, 2017, [http://www.reachingcriticalwill.org/images/documents/Disarmament-fora/nuclear-weapon-ban/statements/29March\\_Brazil-T2.pdf](http://www.reachingcriticalwill.org/images/documents/Disarmament-fora/nuclear-weapon-ban/statements/29March_Brazil-T2.pdf).

3. Statement by Austria, United Nations Conference to Negotiate a Legally Binding Instrument to Prohibit Nuclear Weapons, Leading towards Their Total Elimination, March 29, 2017, <http://statements.unmeetings.org/media2/14683377/austria.pdf>.

## CASE STUDIES

### 1925 Geneva Protocol for the Prohibition of the Use in War of Asphyxiating, Poisonous or Other Gases

The Protocol for the Prohibition of the Use in War of Asphyxiating, Poisonous or Other Gases, and of Bacteriological Methods of Warfare, commonly known as the 1925 Geneva Protocol, preceded the Biological and Chemical Weapons Conventions as one of the earliest comprehensive modern legal prohibitions of a category of weapons.

Although the Geneva Protocol was the first complete prohibition of the use of chemical weapons, previous agreements had restricted the use of certain types of chemical weapons. In the 1675 Strasbourg Agreement, Britain and France agreed to prohibit poison bullets for the duration of the war. In the 1899 Hague Declaration Concerning Asphyxiating Gases, chemical weapon use was prohibited in the battlefield. A conference was convened in 1922 to constrain the battle use of new technology, including chemical weapons and submarines. After the United States proposed banning the trade of chemical weapons at the 1925 Geneva Conference for the Supervision of International Traffic in Arms, France suggested a protocol on banning their use, and Poland recommended adding bacteriological weapons.<sup>4</sup> The text, now known as the 1925 Geneva Protocol, entered into force on February 8, 1928.<sup>5</sup> It was called a protocol because it was expected that it would be followed by a comprehensive disarmament treaty to be negotiated in a later conference.<sup>6</sup> The protocol itself is very short and does not include verification provisions or an implementation support group.

Thirty-eight states signed the Geneva Protocol when it opened for signature on June 17, 1925, and it took several years to several decades for most states to ratify the treaty. The U.S. Senate did not vote on the treaty in 1926 and it remained unsigned until President Harry Truman eventually withdrew the treaty from the Senate.<sup>7</sup> The Geneva Protocol did not have the support of all states that possessed chemical or biological weapons when it initially entered into force. Two major chemical weapons possessors were absent—the United States and Japan—although both had ratified by 1975. Even without ratifying the agreement, the United States abided by its terms in World War II. Notably, many of those who did ratify initially attached reservations to their compliance with the accord.

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4. "Protocol for the Prohibition of the Use in War of Asphyxiating, Poisonous or Other Gases, and of Bacteriological Methods of Warfare (Geneva Protocol)," U.S. Department of State, September 25, 2002, <https://www.state.gov/t/isn/4784.htm>.

5. "1925 Geneva Protocol," UN Office of Disarmament Affairs, <https://www.un.org/disarmament/wmd/bio/1925-geneva-protocol>.

6. Jean Pascal Zanders, "International Norms against Chemical and Biological Warfare: An Ambiguous Legacy," *Journal of Conflict & Security Law* 8, no. 2 (2003): 391–410, <http://www.the-trench.org/wp-content/uploads/2013/06/200312-JCSL-International-norms.pdf>.

7. "Protocol for the Prohibition of the Use in War of Asphyxiating, Poisonous or Other Gases, and of Bacteriological Methods of Warfare (Geneva Protocol)."

Despite the weaknesses of the Protocol, it has been heralded as a key marker in the evolution of biological and chemical disarmament. As Jean-Pascal Zanders declared in “International Norms against Chemical and Biological Warfare,”

Despite the fact that many contracting powers attached reservations to the Geneva Protocol, effectively turning it into a pledge of no-first use, the document constituted the core of the norm against chemical and biological warfare [CBW] for most of the 20th century. . . .

Although it was violated several times (most recently in the 1980–88 Iran–Iraq war), it definitely had a restraining influence on CBW armament programmes. Most importantly, as it affected the military rationale for their employment, the Protocol laid the foundations for a total ban on their development and possession.<sup>8</sup>

## Biological Weapons Convention

The Biological Weapons Convention (BWC) opened for signature in 1972 and entered into force in 1975. It prohibits the acquisition, stockpiling, retention, or transfer of biological weapons, as well as the assistance with acquisition of biological weapons. The BWC does not ban the use of biological weapons; rather, it references the 1925 Geneva Protocol, which already did. States-parties are required to destroy biological weapons as well as their means of delivery within nine months of the treaty’s entry into force. To date, 178 states have ratified the convention.<sup>9</sup>

The 1925 Geneva Protocol banning the use of biological and chemical weapons is often referenced as the beginning of the process to prohibit biological weapons. In 1969, Britain proposed a draft convention to eliminate biological weapons to the Eighteen Nation Disarmament Conference.<sup>10</sup> The United States, under President Richard Nixon, chose to unilaterally renounce its biological weapons in November 1969 and resubmit the 1925 Geneva Protocol to the Senate. The United States and the Soviet Union submitted a redraft of the United Kingdom’s initial biological weapons prohibition, which diluted some of its original terms, on August 5, 1971.<sup>11</sup> After negotiations, this draft was adopted by the UN General Assembly on December 19, 1971.

The treaty has often been criticized for its lack of verification provisions. If a state-party believes another state-party is violating the agreement, it can issue a complaint to the UN Security Council to investigate. However, Russia, among others, is believed to still maintain a biological weapons program.

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8. Zanders, “International Norms against Chemical and Biological Warfare.”

9. “About the Biological Weapons Convention,” UN Office at Geneva, accessed May 5, 2017 [http://www.unog.ch/80256EE600585943/\(httpPages\)/77CF2516DDC5DCF5C1257E520032EF67?OpenDocument](http://www.unog.ch/80256EE600585943/(httpPages)/77CF2516DDC5DCF5C1257E520032EF67?OpenDocument).

10. Zanders, “International Norms against Chemical and Biological Warfare.”

11. Nicholas Sims, *The Evolution of Biological Disarmament* (Stockholm: Stockholm International Peace Research Institute, 2001).

## Chemical Weapons Convention

The Chemical Weapons Convention is by far the most comprehensive of weapons prohibitions in its verification and implementation. The convention prohibits the acquisition, stockpiling, retaining, transfer, and use of chemical weapons, or the assistance with any of these prohibited activities.<sup>12</sup> Currently, there are 192 states-parties to the treaty.<sup>13</sup> Negotiations on the Chemical Weapons Convention began in 1980 at the Conference on Disarmament. It opened for signature on January 1993 and entered into force in April 1997.<sup>14</sup> In advance of the CWC entering into force, the United States and the Soviet Union signed a bilateral agreement to stop producing chemical weapons, reduce their current stockpiles, and begin destruction by 1992, although it never entered into force. As with the BWC, the United States and the Soviet Union were key contributors to the CWC negotiations. The chemical industry also was engaged in the negotiations.

The mission of the treaty is carried out by a 500-person staffed organization—the Organization for the Prohibition of Chemical Weapons (OPCW), which is the only organization outside of the UN Office of Disarmament Affairs to administrate a weapons prohibition treaty. States-parties must declare stockpiles and then allow the OPCW to inspect the facilities. States-parties were obligated to begin destroying their stockpiles within two years of the treaty's entry into force and all states should have completed the destruction of their arsenals by April 29, 2012, although several states received extensions on their destruction deadlines.

Ninety-five percent of declared stockpiles of states-parties under the Chemical Weapons Convention have been eliminated. By the third review conference of the Chemical Weapons Convention in 2014, India completed destruction of its chemical weapon stockpile. Libya destroyed 51 percent of its arsenal, Russia destroyed 64 percent of its arsenal, and the United States had destroyed about 90 percent of its arsenal. In September 2017, Russia announced that it was weeks away from completing destruction of its chemical weapons arsenal. However, the use of chemical weapons still remains a threat. Recent attacks in Syria point to the ongoing existence and use of chemical weapons.<sup>15</sup>

## Mine Ban Treaty

The Convention on the Prohibition of the Use, Stockpiling, Production and Transfer of Anti-Personnel Mines and on Their Destruction, also known as the Anti-Personnel Mine Ban Convention, the Mine Ban Treaty, or the Ottawa Treaty, opened for signature in 1997 and entered into force in 1999. It includes a similar list of prohibitions to other weapons prohibition treaties

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12. "Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and on their Destruction," Article I, Organization for the Prohibition of Chemical Weapons, accessed April 3, 2017, <https://www.opcw.org/chemical-weapons-convention/articles/article-i-general-obligations/>.

13. "Chemical Weapons," UN Office of Disarmament Affairs, accessed April 3, 2017, <https://www.un.org/disarmament/wmd/chemical/>.

14. "The Chemical Weapons Convention at a Glance," Arms Control Association, October 2015, <https://www.armscontrol.org/factsheets/cwcglance>.

15. "Review of the Operation of the Chemical Weapons Convention since the Second Review Conference," Working Group for the Preparation of the Third Review Conference, October 5, 2012, [https://www.opcw.org/fileadmin/OPCW/CSP/RC-3/en/wgrc3s01\\_e\\_.pdf](https://www.opcw.org/fileadmin/OPCW/CSP/RC-3/en/wgrc3s01_e_.pdf).

including use, production, development, acquisition, retaining, and stockpiling. There are currently 162 states-parties to the treaty, or over 80 percent of the world's population.<sup>16</sup> It has 22 articles and a preamble, covering general obligations, definitions, destruction of landmines, transparency measures, meetings of states-parties, review conferences, and entry into force.

The path to the Anti-Personnel Mine Ban Treaty is described as "the Ottawa Process" and began in the aftermath of the 1980 Convention on Certain Conventional Weapons with the leadership of Canada. The Convention on Certain Conventional Weapons does list landmines under Protocol II, but it does not regulate their production, storage, or export.<sup>17</sup> In December 1996, the UN General Assembly adopted a resolution calling on all countries to conclude a new international agreement to prohibit landmines. Austria circulated a draft text and a series of conferences on the landmine treaty followed, from February 12–14, 1997 in Austria, from April 25–26, 1997 in Germany, and from June 24–27, 1997 in Brussels. The Brussels meeting concluded with the "Brussels Declaration," which called for a conference to be held in Oslo to formally negotiate a treaty. At the end of the Oslo Diplomatic Conference on a Total Ban on Anti-Personnel Mines (held from September 1–18, 1997), 89 states adopted the convention. An implementation support unit was created to support the work of the convention.<sup>18</sup>

Many landmines still exist, however, marking the difficulty involved in implementing weapons prohibition treaties. Nearly 50 million landmines remain stockpiled around the world, mostly by China, Russia, the United States, India, and Pakistan, none of which have signed the treaty. In 2016, Syria, Myanmar, and North Korea, which also are not signatories to the treaty, used landmines. In 2015, the casualty total was the highest since 2006.<sup>19</sup> Landmines are still mass-produced in Russia, China, Pakistan, and Iran.

However, overall use of mines has decreased since the treaty was adopted. In 1999, approximately 25 people were killed by landmines each day, while by 2012, the number was less than half of that total.<sup>20</sup> The treaty has arguably had some impact on nonstates-parties. Although the United States has not signed the treaty, it has attended review conferences as an observer and former president Barack Obama indicated his intent to one day join the treaty. On September 23, 2014, the United States announced a new policy regarding landmines, whereby it outlawed the use of landmines everywhere except for Korea.<sup>21</sup>

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16. Emily Dugan, "IoS Investigation: The Shocking Truth about Landmines," *Independent*, October 13, 2012, <http://www.independent.co.uk/news/world/politics/ios-investigation-the-shocking-truth-about-landmines-8210468.html>.

17. "Convention on Certain Conventional Weapons," UN Office of Disarmament Affairs, accessed March 4, 2017, <https://www.un.org/disarmament/geneva/ccw>.

18. Jim Wurst, "Closing In on a Landmine Ban: The Ottawa Process and U.S. Interests," *Arms Control Today*, June 1997, <https://www.armscontrol.org/print/225>.

19. "Why Landmines Are Still a Problem," International Campaign to Ban Landmines, accessed April 25, 2017, <http://www.icbl.org/en-gb/problem/why-landmines-are-still-a-problem.aspx>.

20. "Landmine Monitor 2013," International Campaign to Ban Landmines, November 2013, <http://www.the-monitor.org/media/1641630/Landmine-Monitor-2013.pdf>.

21. "United States Landmine Policy: Questions and Answers," Human Rights Watch, October 3, 2014, <https://www.hrw.org/news/2014/10/03/united-states-landmine-policy-questions-and-answers>.

## Cluster Munitions Convention

The Cluster Munitions Convention prohibits the use, production, and stockpiling of cluster munitions.<sup>22</sup> The pathway to the Cluster Munitions Convention is well known as the Oslo process. Cluster munitions were not included in the 1980 Convention on Certain Weapons. In February 2007, 46 states signed the Oslo Declaration on Cluster Munitions to negotiate a legally binding prohibition of these weapons.<sup>23</sup> The Cluster Munitions Convention was adopted on May 30, 2008, by 107 states and then signed on December 3, 2008. To date, it has 102 states-parties.<sup>24</sup> An implementation support unit was established to coordinate the activities of states-parties to the convention in 2015.

To track and improve implementation, the Convention on Cluster Munitions put forward two action plans at the end of each review conference: first, the Vientiane Action Plan in 2010 and, second, the Dubrovnik Action Plan in 2015. States-parties have destroyed 80 percent of their declared stockpiles collectively as of 2015.<sup>25</sup>

## Treaty on the Prohibition of Nuclear Weapons

Advocates for nuclear disarmament have existed almost from the beginning of the atomic age, starting notably with many of those who helped to create the bomb. Albert Einstein and Robert Oppenheimer both became outspoken advocates against nuclear weapons after playing instrumental roles in their development. The recent movement to create a legally binding treaty to prohibit nuclear weapons originated in the recognition among nonnuclear weapons states of the increasing threat and drastic humanitarian consequences of nuclear weapons and the slow pace of nuclear disarmament.<sup>26</sup> These states lament that the Conference on Disarmament has not so much as adopted a program of work, or agenda, in many years.

In response to these concerns, nonnuclear weapons states organized three conferences on the humanitarian consequences of nuclear weapons in Oslo, Nayarit, and Vienna from 2013 to 2014, at the end of which 127 states endorsed a “humanitarian pledge,” recognizing the humanitarian consequences of nuclear weapons and calling on nuclear weapons states to fulfill their obligations under Article VI of the NPT to “pursue negotiations in good faith towards complete disarmament.”<sup>27</sup> Following these conferences, a series of open-ended working groups took forward multilateral disarmament negotiations in Geneva in 2016. In October 2017, the First Committee of the UN

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22. “Convention on Cluster Munitions,” Diplomatic Conference for the Adoption of a Convention on Cluster Munitions, May 30, 2008, [http://www.unog.ch/80256EDD006B8954/\(httpAssets\)/CE9E6C29A6941AF1C12574F7004D3A5C/\\$file/ccm77\\_english.pdf](http://www.unog.ch/80256EDD006B8954/(httpAssets)/CE9E6C29A6941AF1C12574F7004D3A5C/$file/ccm77_english.pdf).

23. “Declaration, Oslo Conference on Cluster Munitions,” February 23, 2007, <http://www.clusterconvention.org/files/2012/11/Oslo-Declaration-final-23-February-2007.pdf>.

24. “Dubrovnik Action Plan,” Convention on Cluster Munitions, 2015, <http://www.clusterconvention.org/wp-content/uploads/2016/04/The-Dubrovnik-Action-Plan.pdf>.

25. Ibid.

26. Kingston Reif and Alicia Sanders-Zakre, “States Seek Ban Treaty by Summer,” *Arms Control Today*, May 2017, <https://www.armscontrol.org/act/2017-05/news/states-seek-ban-treaty-summer>.

27. UN General Assembly Resolution, “Humanitarian Pledge,” December 9, 2014, [http://www.icanw.org/wp-content/uploads/2015/03/HINW14vienna\\_Pledge\\_Document.pdf](http://www.icanw.org/wp-content/uploads/2015/03/HINW14vienna_Pledge_Document.pdf).



General Assembly, by a vote of 123–38 with 16 abstentions, adopted a resolution to convene a conference to negotiate a treaty to prohibit nuclear weapons—a resolution that was subsequently adopted by the UN General Assembly in December.<sup>28</sup> The first conference to negotiate a legally binding treaty prohibiting nuclear weapons met in New York from March 27–31, 2017, bringing together 132 nonnuclear weapons states. The second conference met from June 15 to July 7 and adopted the treaty by a vote of 122-1-1 on July 7.

From the outset, the initiative sparked fierce criticism from nuclear weapons states and NATO members that receive security guarantees from the United States. The Netherlands was the only NATO member to attend the negotiations, and although Japan, a strong U.S. ally, attended the first day of the March negotiations, it gave a speech explaining why it could not participate and promptly left. On May 22, 2017, the president of the negotiations, Ambassador Elayne Whyte Gomez, introduced a draft text of the treaty, which compiled many of the participating states' arguments from the first round of negotiations.<sup>29</sup> The negotiations in June and July proceeded swiftly, with around 130 states participating and considerable civil society observation. States conducted a thorough review of the first draft, after which the president released a second draft, which was similarly critiqued and debated. The third draft, released July 3, 2017, underwent a few technical changes before being submitted as the final draft on which states voted on July 7.

The treaty's preamble acknowledges the catastrophic humanitarian consequences of nuclear weapon use, the importance of existing nuclear disarmament and nonproliferation agreements, such as the nuclear Non-Proliferation Treaty (NPT), and the right of states-parties to peaceful nuclear energy. The treaty prohibits the use, threat of use, development, production, manufacture, acquisition, possession, stockpiling, transfer, stationing, or installation of nuclear weapons, and assistance with any prohibited activities. It also contains positive obligations for states to assist victims of nuclear use and testing and for international cooperation. The treaty provides two pathways for nuclear weapons states to join the treaty: nuclear weapons states can either join the treaty and then destroy their nuclear arsenals or destroy them first and then join the treaty. It requires all states-parties to have at minimum a comprehensive safeguards agreement with the International Atomic Energy Agency (IAEA) without prejudice to any higher level of safeguards they have or may possess in the future.<sup>30</sup>

The nuclear prohibition treaty shares many components with other treaties, particularly the Mine Ban Treaty and the Convention on Cluster Munitions. However, it is distinct in other ways, given the unique role of nuclear weapons in security doctrines, the expressed intent of the treaty, and the extensive existing legal frameworks on nuclear disarmament and nonproliferation.

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28. UN General Assembly First Committee Resolution, "Taking Forward Multilateral Nuclear Disarmament Negotiations," October 14, 2016, <http://www.reachingcriticalwill.org/images/documents/Disarmament-fora/1com/1com16/resolutions/L41.pdf>.

29. "Draft Convention on the Prohibition of Nuclear Weapons," UN Conference to Negotiate a Legally Binding Instrument to Prohibit Nuclear Weapons, Leading towards Their Total Elimination, May 22, 2017, <https://s3.amazonaws.com/unoda-web/wp-content/uploads/2017/05/A-CONF.229-CRP.1.pdf>.

30. Alicia Sanders-Zakre, "Nuclear Weapons Ban Treaty Adopted," *Arms Control Today*, July/ August 2017, <https://www.armscontrol.org/act/2017-07/news/nuclear-weapons-ban-treaty-adopted>.

## SIMILARITIES

### Participants

The nuclear prohibition treaty mirrors the Mine Ban Treaty and the Cluster Munitions Convention in its high degree of civil society participation. The International Campaign to Abolish Landmines earned a Nobel Prize for its work to eliminate landmines following the adoption of the convention. The International Campaign to Abolish Nuclear Weapons played a critical role in the nuclear prohibition treaty negotiations, similarly earning a Nobel Prize in October 2017.

The nuclear prohibition treaty is unusual in that it is the only treaty to prohibit a type of weapon that does not have any weapons possessors involved in the negotiation of the treaty, but it is not the first to have an overwhelming lack of weapons possessors involved. Both the Mine Ban Treaty and the Convention on Cluster Munitions were driven by civil society and states that do not possess weapons, and many weapons possessors remain outside these treaties today.

Many of the same countries that were leaders in the conventions on landmine and cluster munitions were also leaders for the nuclear prohibition treaty. Austria and Ireland played key roles in the nuclear prohibition treaty, as they have in previous prohibition treaties. Norway, however, which facilitated conferences for both the Anti-Personnel Mine Ban Treaty and the Cluster Munitions Convention, did not participate in the nuclear weapons prohibition treaty negotiations, although it did organize the first of three humanitarian conferences on nuclear weapons.

### Norms

Without major weapon possessors participating, those who supported the Mine Ban Treaty, the Convention on Cluster Munitions, and the nuclear prohibition treaty argued that the treaty could play a critical role in changing the norm on the weapon, which would then persuade weapons possessors to pursue disarmament.

Simone Wisotzki, senior researcher at the Peace Research Institute Frankfurt, discussed the role of “norm entrepreneurs” in advancing the landmine treaty, Cluster Munitions Convention, and Arms Trade Treaty, adopted in 2013 to restrict the flow of arms:

One particular characteristic of humanitarian arms control is its norm-generating stakeholders, also called norm entrepreneurs, who are particularly active in developing new institutions. What is striking about all three regimes is the fact that small and medium-sized states committed themselves to negotiating a new arms control agreement in close cooperation with transnational networks of non-governmental organizations. Moreover, they succeeded despite the declared opposition of major powers. NGOs made the start by identifying the demand for a regime and regulatory gaps. They received support by international organizations, particularly the United Nations. Together, they managed to achieve a change in discourse, since concurring interpretations regarding the security and military relevance of these weapons existed in all three cases. The NGO campaigns initially also met with opposition from the later like-minded states which they had to convince through

“better” arguments. Together with these like-minded states, they then sought to increase the group of supportive states.<sup>31</sup>

The role of norms in the creation of the nuclear prohibition seems to follow the same model Wisotzki described for the landmines and cluster munitions conventions. Austria and Ireland were among the committed mid-sized states that cooperated with the International Campaign to Abolish Nuclear Weapons, among other nongovernmental organizations (NGOs), to push the agenda forward.

Because of the treaty’s potential to shape norms, supporters of the nuclear prohibition treaty argue that participation by large weapons possessors, while appreciated, is not required for the prohibition treaty to move disarmament forward. With or without initial weapon possessor participation, they claim, the prohibition of the weapon will lead to its stigmatization and eventual elimination. The effectiveness of this attempt to change international norms on nuclear possession remains to be seen. However, one cannot deny the increased discussion among policymakers and stakeholders about nuclear disarmament since the start of the nuclear ban treaty initiative. As pointed out by a report from a prominent Washington think tank on the ban treaty, nuclear weapons states have never specified what pursuing negotiations in good faith toward nuclear disarmament would look like.<sup>32</sup> If they are forced to do so as a result of the ban treaty negotiations, one could argue that such negotiations pushed the dialogue on nuclear disarmament forward. Although the United States did not accede to the Ottawa Treaty, it has a policy not to use anti-personnel landmines outside the Korean peninsula, which some argue proves that the norm against landmine use was strengthened by the treaty.<sup>33</sup>

The Biological and Chemical Weapons Conventions were not created to establish a norm against a type of weapon, given that a strong norm against chemical and biological weapons already existed at the time that major weapons holders agreed to disarm. Earlier chemical prohibitions, like the 1925 Geneva Protocol, may have helped to establish that norm. Jean Pascal Zanders has observed that norms played a critical role in the restriction on chemical and biological weapon use, even before the CWC and BWC were adopted:

Contrary to other highly lethal types of weaponry, such as nuclear and certain conventional arms, CBW [chemical and biological warfare] bear a moral opprobrium, which it is claimed is rooted in their perfidy and insidiousness. They are described as indiscriminate agents of unnecessary suffering and their use is said to contradict the universal and chivalrous principles of conduct in war. The immorality of CBW is often presented as an article of faith. . . . The belief system nevertheless constitutes a reality in decision-making processes:

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31. Simone Wisotzki, “Between Morality and Military Interests: Norm Setting in Humanitarian Arms Control,” PRIF-Reports No. 92, Peace Research Institute Frankfurt, July 2014.

32. George Perkovich, *The Nuclear Ban Treaty: What Would Follow?* (Washington, DC: Carnegie Endowment for International Peace, May 2017), [http://carnegieendowment.org/files/CP\\_309\\_Perkovich\\_Nuclear\\_Treaty\\_Final\\_Web.pdf](http://carnegieendowment.org/files/CP_309_Perkovich_Nuclear_Treaty_Final_Web.pdf).

33. Ibid.

moral and legal constraints have been of critical importance in preventing widespread use of CBW.<sup>34</sup>

## Humanitarian Consequences of Weapon Use

To fully advocate for a change in norms about a weapon, civil society and non-weapon-possessing states emphasized the humanitarian impact of the weapon. The Mine Ban Treaty and the Cluster Munitions Convention were driven by a recognition of the humanitarian consequences of the use of the prohibited weapon. The nuclear prohibition treaty fits squarely in this camp: the three earliest conferences leading to the final conferences to negotiate a treaty prohibiting nuclear weapons were convened to discuss humanitarian consequences. The humanitarian consequences of biological and chemical weapons may have also played a role in their prohibition. The 1925 Geneva Protocol was established in the aftermath of World War I, when chemical weapons were used on a large scale in warfare, causing drastic humanitarian consequences, and it was with World War I in mind that many states sought to restrict the use of such weapons.

## Pace and Process of Disarmament Negotiations

It took longer to ban biological and chemical weapons than to ban landmines, cluster munitions, and nuclear weapons. Efforts to restrain biological and chemical weapons began in the early twentieth century and concluded toward the century's end. Although efforts to reduce nuclear weapons stockpiles have been ongoing since the end of the height of the arms race, the push for a nuclear weapons prohibition treaty began only in the past decade, quite recently relative to the process for some other prohibition treaties.

The nuclear prohibition treaty, along with the Mine Ban Treaty and Cluster Munition Convention, was negotiated outside the Conference on Disarmament (CD), while the BWC and CWC were both negotiated within the consensus-based forum. It is no coincidence that the negotiations for the recent treaties moved outside the CD. The lack of support for each treaty from weapons possessors gave these treaties no hope of succeeding, or even starting negotiations, within the consensus-based forum.

However, this has led to contention from some states. In the case of cluster munitions and landmines, opposing states, including the United States, the United Kingdom, and Australia, attempted to establish an alternative to the Ottawa Process within the Conference on Disarmament.<sup>35</sup> During the negotiations for a nuclear weapons ban treaty, the ambassador to the Netherlands expressed concern that the prohibition treaty review conference would open up an alternative negotiating forum to the CD, and detract from its work.

## Verification

All prohibitions have continued to face difficulties with verification and implementation. Even the Chemical Weapons Convention, with its 500-person staffed OPCW, has failed to completely and verifiably eliminate chemical weapons, as ongoing use of chemical weapons by one state-party,

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34. Zanders, "International Norms Against Chemical and Biological Warfare."

35. Ibid.

Syria, demonstrates. The OPCW has succeeded in facilitating the removal and elimination of Syria's declared chemical weapons stockpile with the assistance of several states. However, Syria's chemical weapons declaration to the OPCW was incomplete, making the verification of the elimination of its total stockpile extremely challenging. The Biological Weapons Convention has often been criticized for its lack of verification measures, and some contend that the threat of a biological weapons attack is growing with advancing biological development and the lack of accompanying verification measures.<sup>36</sup> Others argue that the risk of biological attack is low considering that deliberate disease or toxins have killed fewer than 100 people since the BWC's entry into force in 1975.

During the negotiations of the nuclear prohibition treaty, several of the most contested articles were those related to verification. Sweden and Switzerland expressed dissatisfaction, even after voting for the treaty, that it had not imposed a higher level of safeguards on states-parties, and verification of the nuclear treaty's provisions has been flagged as a key point of concern among many experts.<sup>37</sup> However, it is worth noting that, for many negotiating states, the prohibition treaty is not to be the definitive nuclear convention, and therefore does not need to contain comprehensive disarmament verification clauses.

## DIFFERENCES

### The Role of Nuclear Weapons in Security Doctrines

Some argue that the norms surrounding nuclear weapons are different from other weapons because of the role they play in security doctrines, namely through the doctrine of deterrence. According to nuclear deterrence theory, nuclear weapon possession will prevent nuclear use and conflict by nuclear possessors due to the fear of intolerable nuclear retaliation and a subsequent nuclear war. To those who subscribe to this theory, possessing nuclear weapons does not mean that they will be used, and thus a norm against nuclear possession is not necessary for a norm against nuclear use. Although a strong norm against nuclear use may exist already, the same cannot be said of a norm against nuclear possession, largely due to deterrence theory.<sup>38</sup> If the intent of nuclear prohibition is to prevent nuclear war, some contend that strengthening the norm of nonuse, nonproliferation, and deterrence should be adequate to achieve that end because of this unique role of nuclear weapons, rather than eliminating the weapons themselves.<sup>39</sup> The perceived success of deterrence wrought by nuclear possession has and continues to be a major justification for the maintenance and modernization of nuclear arsenals, an argument which is all but absent in the discourse surrounding the prohibitions of other weapons of mass destruction.

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36. Perkovich, *The Nuclear Ban Treaty*.

37. Ibid.

38. Nina Tannenwald, "The Nuclear Taboo: The United States and the Normative Basis of Nuclear Non-Use," *International Organization* 53, no. 3 (1999): 433–468, <http://www.jstor.org/stable/2601286>.

39. Lawrence Freedman, "Disarmament and other Nuclear Norms," *Washington Quarterly* 36, no. 2 (Spring 2013): 93–108, [https://csis-prod.s3.amazonaws.com/s3fs-public/legacy\\_files/files/publication/TWQ\\_13Spring\\_Freedman.pdf](https://csis-prod.s3.amazonaws.com/s3fs-public/legacy_files/files/publication/TWQ_13Spring_Freedman.pdf).

The concept of extended deterrence, by which states allied with nuclear weapons states benefit from the threat of use of nuclear weapons, is a concept unique to nuclear weapons as well, and thus a ban of nuclear weapons has unique implications for allies who benefit from security guarantees from nuclear weapons states. With the nuclear prohibition treaty, it was not only weapon possessors who opposed the treaty, but also NATO members who rely on the United States for a security guarantee. Countries that supported other weapons prohibition treaties were unable to participate in negotiations or sign the nuclear prohibition treaty, due to their obligations as NATO members and their belief in their enhanced security through extended deterrence.

## Intent of Nuclear Ban Treaty

Unlike the CWC, BWC, Mine Ban Treaty, and Convention on Cluster Munitions, most negotiators of the nuclear prohibition treaty openly acknowledge that it is not intended to be the definitive nuclear disarmament treaty and instead is only one of many steps toward complete disarmament. In this scope, the nuclear prohibition treaty only matches the Geneva Protocol, which was not a definitive weapon prohibition, but led to the Chemical Weapons Convention and the Biological Weapons Convention. As Austrian Ambassador Alexander Marschik, one of the leaders of the prohibition talks, stated in an address to the first round of negotiations,

The prohibition treaty is just one element; a necessary first step that would need to be complemented by a comprehensive set of additional sequenced measures to achieve the total elimination of nuclear weapons. We know that will take time. But that should not deter us. We should take the first step by laying out the goal of the process—a legal prohibition of nuclear weapons.<sup>40</sup>

The Mine Ban Treaty and Convention on Cluster Munitions, however, were not expected to be followed by additional treaties.

The intended impact of the nuclear prohibition treaty, as outlined by the Austrian ambassador and other leading negotiating states, is to de-legitimize the possession of nuclear weapons in order to pressure nuclear weapons states to comply with NPT obligations to pursue disarmament negotiations. While the Geneva Protocol and the nuclear prohibition treaty may share the same goal, significant differences in form exist between the two agreements. The Geneva Protocol was signed and ratified by most major powers and weapons possessors and was significantly less comprehensive in its prohibitions, positive obligations, and verification obligations than the Treaty on the Prohibition of Nuclear Weapons.

## Existing Legal Frameworks

Nuclear weapons, more so than other weapons of mass destruction, already have legal frameworks intended to prevent their proliferation and work toward their eventual disarmament. Although states were constrained by the 1925 Geneva Protocol before the Chemical Weapons Convention or Biological Weapons Convention entered into force, there was little concern

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40. "Statement by Ambassador Alexander Marschik," United Nations Conference to Negotiate a Legally Binding Instrument to Prohibit Nuclear Weapons, Leading towards Their Total Elimination, March 27, 2017, <http://statements.unmeetings.org/media2/14683246/austria.pdf>.



expressed that the BWC or CWC would contradict the Geneva Protocol. The Geneva Protocol did not hold the same weight as the nuclear Non-Proliferation Treaty does today, with many states arguing that the NPT is the cornerstone of the nonproliferation regime. In the debate leading up to the nuclear prohibition treaty, therefore, unlike with other prohibition treaties, states who opposed the treaty expressed concern that it would conflict with existing nuclear weapons restriction treaties, specifically the NPT and the Comprehensive Nuclear Test Ban Treaty (CTBT).

## CONCLUSION

The nuclear prohibition process and treaty is a strong fit in its prohibitions, structure, and process to the model established by the Cluster Munitions Convention and treaty against anti-personnel landmines. It also shares some characteristics, including difficulty with drafting and implementing effective verification measures, with the Biological and Chemical Weapons Conventions. Many elements of the Treaty on the Prohibition of Nuclear Weapons are unique, such as the role of nuclear weapons in security doctrines, the intent of the treaty, and the multitude of existing legal frameworks around nuclear weapons. The study of the prohibition of weapons of mass destruction provides important lessons about the nature of present and future international legal disarmament and indicates how the controversial nuclear prohibition treaty fits into historical precedents.

# The Frontiers of Technology in Warhead Verification

Henrietta Toivanen<sup>1</sup>

*How might new technical verification capabilities enhance the prospects of success in future nuclear arms control negotiations? Both theory and evidence suggest that verification technologies can influence the dynamics of arms control negotiations by shaping and constraining the arguments and strategies that are available to the involved stakeholders. The challenge of warhead authentication is one illustrative example of a verification issue where the current lack of technical capabilities has prevented certain measures of arms control from being implemented, and where a breakthrough in verification technologies could have a significant impact in shifting the dynamics of the political discussions. This report focuses on a set of emerging warhead authentication approaches that intend to solve prevailing technical challenges and that could create new opportunities for future disarmament scenarios that may address fewer warheads, limit new categories of warheads, and involve nuclear weapons states other than the United States and Russia.*

## INTRODUCTION

Over the past several decades, the United States and Russia (formerly the Soviet Union), negotiated warhead reductions that brought the global stockpile of nuclear weapons to only a fraction of what it was at the height of the Cold War. These disarmament agreements focused on limiting warheads affiliated with operationally deployed strategic delivery systems, verifying reductions through monitoring the delivery platforms.<sup>2</sup> Disarmament in the U.S.-Russia context, however, is

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2. Operationally deployed strategic warheads refer to strategic nuclear weapons that are mounted on their ballistic missile launchers or that are located at aircraft bases, although the definition is somewhat dependent on the context. See Hans Kristensen and Robert Norris, "Status of World Nuclear Forces," Federation of American Scientists, July 8,

unique in many respects and this past strategy of warhead reductions will cease to be feasible in the future stages of arms control. The past definition of treaty-accountable nuclear weapons will become insufficient in future disarmament scenarios, which include addressing lower numbers of warheads, where the diversion of even one warhead becomes increasingly significant; considering new categories of weapons under limitations, including tactical and nondeployed; and engaging other nuclear weapons states than the United States and Russia.<sup>3</sup> All of these factors contribute to the need to shift from a verification approach based on delivery systems to a verification approach focused on the warheads themselves.

These verification challenges may be in the longer-term horizon, but overcoming them will be essential for making future steps in disarmament possible. It is critical to think about these challenges now, even if further bilateral reductions in warheads between the United States and Russia are highly uncertain, not to mention the prospects of negotiations with countries such as North Korea or Pakistan. While these are the geopolitical realities now, it does not mean that the circumstances cannot change relatively rapidly. Furthermore, there is an argument to be made that these interval periods are exactly the time new verification approaches can be conceptualized and developed.

These efforts are also driven by the increasing pressure from the international community toward the nuclear weapons states, particularly in the context of the humanitarian movement to bring attention to the catastrophic consequences of nuclear weapons. As reflected in the Resolution A/C.1/71/L.41 that was passed in the United Nations General Assembly in October 2016 to begin negotiations of a nuclear weapons ban treaty, the international community is increasingly willing to call for the nuclear weapons states to move toward disarmament, as outlined in their obligations under Article VI of the Non-Proliferation Treaty (NPT).<sup>4</sup> The key question now is how the P5 states, or the five nuclear weapons states defined under the NPT, are going to respond to this pressure and engage with the rest of the international community. Beyond the P5, the nuclear weapons states outside the NPT framework are creating increasing anxiety within the international

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2017, <https://fas.org/issues/nuclear-weapons/status-world-nuclear-forces/>. The process of verification involves collecting the information relevant to the treaty, which is referred to as monitoring, and assessing what it signals about compliance, which is verification. In this paper, I focus on this process as a whole and use the term verification.

3. The State Department defines warhead categories as follows:

The *nuclear stockpile* includes both active and inactive warheads. *Active warheads* include strategic and nonstrategic weapons maintained in an operational, ready-for-use configuration, warheads that must be ready for possible deployment within a short time frame, and logistics spares. They have tritium bottles and other Limited Life Components installed. *Inactive warheads* are maintained at a depot in a nonoperational status, and have their tritium bottles removed. A retired warhead is removed from its delivery platform, is not functional, and is not considered part of the nuclear stockpile. *Warheads awaiting dismantlement* constitute a significant fraction of the total warhead population and will continue to grow as the New START Treaty is implemented and as unneeded warheads are retired. A *dismantled warhead* is a warhead reduced to its component parts.

U.S. Department of State, "Fact Sheet: Transparency in the U.S. Nuclear Weapons Stockpile," April 27, 2015, <https://2009-2017.state.gov/documents/organization/241377.pdf>.

4. UN General Assembly, "General and Complete Disarmament: Taking Forward Multilateral Nuclear Disarmament Negotiations," October 14, 2016, [http://www.un.org/ga/search/view\\_doc.asp?symbol=A/C.1/71/L.41](http://www.un.org/ga/search/view_doc.asp?symbol=A/C.1/71/L.41).

community. The nuclear balance in South Asia remains a key security concern for many, as does North Korea.

The problems associated with the verification of individual warheads are multifold. The core technical verification challenges in this disarmament scenario relates to the high-security authentication of warheads, their unique identification, maintaining the continuity of knowledge throughout their life cycle, and several other issues.<sup>5</sup> In addition to this technical dimension, it is also critical to acknowledge the political underpinnings of the greater debate about the role of verification technologies and approaches in the politics of verification. Verification technologies constrain the arguments and strategies that are available to the involved stakeholders, since the available capabilities determine what can or cannot be verified, and with what degree of confidence. This allows them to expand the possibilities and likelihood of new disarmament efforts under the right conditions. Therefore, the development of novel verification approaches, as discussed in this paper, could be a significant new capability for furthering progress in nuclear arms control in the future.

First, this paper explains the core challenge associated with warhead verification—maintaining secrecy while providing transparency. Next, it discusses how past warhead reduction measures have addressed this seemingly intractable trade-off. After this, it focuses on a set of novel approaches developed over the past years, based on zero-knowledge proofs, where the core idea is that the classified design information is not measured by the verification system in the first place. Lastly, this report discusses the implications of developing these verification approaches and how they might contribute to the future directions of global nuclear arms control efforts. This paper argues that while novel verification approaches, such as zero-knowledge verification, may never be fully implemented as such in an arms control treaty, their development is important regardless—both for opening the dialogue on new treaty architecture options, as well as shaping the political dynamics of the treaty negotiations themselves.

## ZERO-KNOWLEDGE VERIFICATION

The core challenge in nuclear warhead verification is balancing the concerns of the host state in maintaining a strict level of confidentiality and the interests of other involved parties in establishing confidence in the verification process. This balance between secrecy and transparency has been discussed in relevant arms control literature and evidenced in the negotiating dynamics of past disarmament efforts. The current verification approaches place more significance to host-state concerns, as has been evidenced in the context of disarmament between the United States and Russia. Multilateral disarmament is likely to introduce even deeper and more complex anxieties about the confidentiality and transparency dimensions of nuclear arms control verification processes. Overall, the use of verification approaches that would allow warhead authentication are inherently intrusive and can reveal extremely detailed, classified information about warhead

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5. Nuclear Threat Initiative (NTI), *Innovating Verification: New Tools and New Actors to Reduce Nuclear Risks: Verifying Baseline Declarations of Nuclear Warheads and Materials* (Washington, DC: NTI, 2014), [http://www.nti.org/media/pdfs/WG1\\_Verifying\\_Baseline\\_Declarations\\_FINAL.pdf?\\_id=1405443895](http://www.nti.org/media/pdfs/WG1_Verifying_Baseline_Declarations_FINAL.pdf?_id=1405443895).

design. This is a nonnegotiable for nuclear weapons states, as the information could be exploited by other states, could reveal vulnerabilities in warhead function, and would also place the states in noncompliance with Article I in the NPT, which prohibits nuclear weapons states from disclosing proliferation-sensitive information.<sup>6</sup>

The conceptualization of this balancing act as a zero-sum game, however, may be misguided. Novel verification technologies and approaches could contribute to adjusting the scale between confidentiality and transparency, enabling future disarmament verification provisions to equalize these critical interests. Specifically, in the context of warhead verification, emerging approaches that employ physical cryptographic protocols aim to create a mechanism of high-security warhead verification where neither confidentiality nor transparency would need to be sacrificed.

## PAST VERIFICATION APPROACHES

Prior efforts to overcome this challenge have explored the use of an attribute verification approach, combined with information barriers that employ complex algorithmic mechanisms embedded to the equipment software or hardware.<sup>7</sup> Attribution verification intends to authenticate a warhead by confirming that the claimed item conforms to a predefined set of characteristics, such as the presence of nuclear material, its isotopic composition, and mass above a certain threshold.<sup>8</sup> One of the challenges with this approach is whether it can use sufficiently targeted attributes to authenticate and distinguish warheads.<sup>9</sup> The selected attributes must be unclassified, as they are known to all involved parties, which limits the options that could be considered.<sup>10</sup> States may be concerned that defining the specific attributes of a certain treaty-limited warhead would disclose too detailed information about their design and functional characteristics. In the case of the Intermediate Nuclear Forces (INF) Treaty, for example, the Soviet Union needed to provide detailed information that would allow the differentiation between the treaty-accountable SS-20 intermediate-range ballistic missiles from the nonlimited SS-25 intercontinental ballistic missiles.<sup>11</sup> The challenge was that the missile types used the same first stages, including engines

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6. Hugh Chalmers, *The IAEA and Nuclear Disarmament Verification: A Primer*, VERTIC Research Reports, No. 11 (London: VERTIC, 2015), <http://www.vertic.org/media/assets/Publications/VM11%20WEB.pdf>.

7. NTI, *Innovating Verification*.

8. Jie Yan and Alexander Glaser, "Nuclear Warhead Verification: A Review of Attribute and Template Systems," *Science & Global Security* 23, no. 3 (2015): 157–179.

9. Richard Garwin, "Technologies and Procedures to Verify Warhead Status and Dismantlement" (paper presented at SIPRI Workshop, Paris, February 8–9, 2001), <https://fas.org/rlg/010208-sipri.htm>; R. Scott Kemp et al., "Physical Cryptographic Verification of Nuclear Warheads," *Proceedings of the National Academy of Sciences* 113 (2016): 8618–8623.

10. D. W. MacArthur et al., "The Effects of Information Barrier Requirements on the Trilateral Initiative Attribute Measurement System (AVNG)" (paper presented at the Institute of Nuclear Materials Management [INMM] 42nd Annual Meeting, Indian Wells, California, July 15–19, 2001), 2.

11. Chantell L. Murphy, M. W. Johnson, and James Doyle, "Recovering START Institutional Knowledge" (paper presented at INMM 52nd Annual Meeting, Palm Desert, California, July 17–21, 2011), 2, <http://permalink.lanl.gov/object/tr?what=info:lanl-repo/lareport/LA-UR-11-04129>.

and fuel tanks, and were indistinguishable based on external characteristics.<sup>12</sup> In this case, determining the crude fingerprint with a simple neutron detector was sufficient to distinguish the missiles accurately and was acceptable to both the United States and the Soviet Union.<sup>13</sup> Identifying and distinguishing other types of treaty-accountable items, however, may require much more detailed information. The use of nonnuclear attributes has also been proposed in differentiating between weapons types, but these may also be classified and thus unavailable for use as attributes.<sup>14</sup>

The attribute verification approach makes it essential to use information barriers to protect the measurement information. This, however, also makes the measurement system inaccessible to the verifier and thus makes it difficult to establish trust in the obtained data.<sup>15</sup> These requirements result in highly complex systems, making it difficult to simultaneously achieve equipment certification by the host and authentication by the inspector.<sup>16</sup> For information protection purposes, the information barrier used in the Trilateral Initiative contained a threshold comparison analyzer, an output data barrier, a security status monitor, cabinets and cable shielding, and other structures intended to protect the measurement information.<sup>17</sup> For data collection, the system employed a multiplicity shift register and a multichannel analyzer, as well as an input data barrier, that aimed to ensure legitimate data collection capability.<sup>18</sup> The host concern with the analysis equipment and software, however, is that extraneous code could be integrated to the system.<sup>19</sup> In addition, these systems must be used with trusted processors, which must adhere to equally strict requirements for nonintrusiveness, transparency, authenticity, and validity.<sup>20</sup> Mistrust in the use of information barriers also emerges at the processor level, as reflected in Russia's engagement in developing its own trusted processor design based on a specific set of priorities.<sup>21</sup>

Information barriers are necessary for the system's ability to protect information, but on the other hand, they also make certifying and authenticating the equipment very difficult. This may be

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12. Ibid.

13. Ibid., 5.

14. James Fuller, "Verification on the Road to Zero: Issues for Nuclear Warhead Dismantlement," *Arms Control Today*, December 2010, [https://www.armscontrol.org/act/2010\\_12/%20Fuller](https://www.armscontrol.org/act/2010_12/%20Fuller).

15. MacArthur et al., "The Effects of Information Barrier Requirements on the Trilateral Initiative Attribute Measurement System (AVNG)," 1.

16. National Nuclear Security Administration, "Joint U.S.-U.K. Report on Technical Cooperation," May 2015, 4, [https://nnsa.energy.gov/sites/default/files/Joint\\_USUK\\_Report\\_FINAL.PDF](https://nnsa.energy.gov/sites/default/files/Joint_USUK_Report_FINAL.PDF); and MacArthur et al., "The Effects of Information Barrier Requirements on the Trilateral Initiative Attribute Measurement System (AVNG)," 2.

17. MacArthur et al., "The Effects of Information Barrier Requirements on the Trilateral Initiative Attribute Measurement System (AVNG)," 5.

18. Ibid., 6.

19. Ibid.

20. Vyacheslav Kryukov et al., "Trusted Processor: A Result of the Evolution of Information Barrier Technologies" (paper presented at INMM 48th Annual Meeting, Tucson, Arizona, July 8–12, 2007), 2, <https://www.osti.gov/scitech/servlets/purl/1141347>.

21. Ibid., 1.



technically feasible, especially as their development goes further. From a political perspective, however, this complexity and lack of transparency could be used against them. It would be easy to argue—as the Russians did toward the end of the Trilateral Initiative—that they will require a significant amount of time to certify the equipment, and even then, they may not be able to gain sufficient confidence that it would not conduct proscribed measurements or collect the data clandestinely. This time burden and trust deficiency could eventually be used as a reason to disqualify these systems from actual use, which would facilitate a justification for not proceeding with disarmament. This highlights the dual-use nature of verification as a political tool—it can be used as a confidence-building asset, but also as a means of fostering suspicions.

The template approach employs a different strategy in warhead verification, relying on differential measurements between an inspected item and one that is known to be authentic.<sup>22</sup> The basic axiom is that if an item is sufficiently similar, in ideal conditions identical, to a warhead that has previously been proven as authentic, it can legitimately be declared as a warhead as well.<sup>23</sup> Comparative measurement systems based on the template approach can be designed to be simpler and easier to authenticate and certify, but in traditional template verification systems, information barriers are still needed to protect the collected data.<sup>24</sup> These past efforts to develop template-based approaches include the Nuclear Material Identification System (NMIS) by the Oak Ridge National Laboratory; the Controlled Intrusiveness Verification Technology (CIVET) system, developed by the Brookhaven National Laboratory; the Trusted Radiation Identification System (TRIS) by the Sandia National Laboratories; and the Next Generation Trusted Radiation Identification System (NG-TRIS) by Sandia as well.<sup>25</sup> The development of these systems has also been driven by the need of nuclear weapons states to identify their own warheads.<sup>26</sup> These measurements systems have a demonstrated ability to distinguish between warhead and component types, but all of them rely on information barriers, and as a Russian assessment of the CIVET system shows, important concerns about intrusions remain.<sup>27</sup> Particularly, the systems preserve the template data, which represents the classified warhead signature and thus needs to be protected throughout the verification process.<sup>28</sup> Most systems developed thus far have used gamma-ray or neutron

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22. Differential measurement refers to the fact that only the difference between two physical quantities is being measured, rather than the absolute amounts. See Yan and Glaser, “Nuclear Warhead Verification.”

23. Kemp et al., “Physical Cryptographic Verification of Nuclear Warheads.”

24. Peter Merkle et al., “Next Generation Trusted Radiation Identification System” (paper presented at INMM 51st Annual Meeting, Baltimore, Maryland, July 11–16, 2010); Peter Marleau and Erik Brubaker, “An Implementation of Zero Knowledge Confirmation Using a Two-dimensional Time-Encoded Imaging System” (paper presented at INMM 57th Annual Meeting, Atlanta, Georgia, July 24–28, 2016), 2.

25. Committee on International Security and Arms Control, *Monitoring Nuclear Weapons and Nuclear-Explosive Materials: An Assessment of Methods and Capabilities* (Washington, DC: National Academies Press, 2005), 99; Yan and Glaser, “Nuclear Warhead Verification,” 160.

26. Committee on International Security and Arms Control, *Monitoring Nuclear Weapons and Nuclear-Explosive Materials*, 99.

27. Peter Vanier et al., “Study of the CIVET Design of a Trusted Processor for Non-Intrusive Measurements” (paper presented at INMM 42nd Annual Meeting, Indian Wells, California, July 15–19, 2001).

28. Office of Nonproliferation and Arms Control, National Nuclear Security Administration, “Highlights,” February 2011, 5, <https://nnsa.energy.gov/sites/default/files/nnsa/inlinefiles/NIS%20February%202011%20Highlights.pdf>.

spectra as the signature, but it would be possible to use other, nonnuclear characteristics as well.<sup>29</sup>

## PHYSICAL CRYPTOGRAPHIC APPROACHES

Novel verification protocols developed in the past several years aim to overcome the use of information barriers by employing physical measurement methods that inherently protect classified information.<sup>30</sup> These protocols employ physical cryptography to protect classified information, conforming to the idea of zero-knowledge proofs. Their strength in circumventing the use of information barriers by using the zero-knowledge property, however, has also created challenges that remain unsolved. First, while these novel approaches push the issue of information protection from electronic barriers to physical ones, all implementations thus far require the host to keep some aspects of the measurement system secret to maintain the zero-knowledge property of the protocol. Second, all the current implementations of these protocols are based on template verification protocols, which rely on the use of an authentic reference warhead. Even if the measurements conclusively prove that the two compared items are identical, this result does not provide assurance of the authenticity of the reference warhead. This “golden warhead” issue remains the core challenge in all template verification systems, whether based on traditional or zero-knowledge protocols.

Applying the idea of physical zero-knowledge proofs to warhead verification could be instrumental for addressing the conflict between state interests in confidentiality and inspector concerns about transparency.<sup>31</sup> When applied in this context, the host state serves in the role of the prover and the inspecting agent or agency conforms to the role of the verifier.<sup>32</sup> The nature of the propositions, relating to warhead properties, defines the conditions of the protocol and could theoretically represent either an attribute or template verification approach. Proving a proposition such as “*The fissile material at the core of this warhead has a ratio of plutonium-240 (PU-240) to PU-239 of less than 0.1 and thus represents an authentic warhead*” would represent an attribution statement, derived from the conditions defined in the Trilateral Initiative, and could be assessed using physical zero-knowledge proofs.<sup>33</sup> The statement “*The radiographic signature of this warhead is statistically indistinguishable from that of a pre-authenticated warhead of the same type and thus*

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29. Committee on International Security and Arms Control, *Monitoring Nuclear Weapons and Nuclear-Explosive Materials*, 99.

30. Sébastien Philippe, Boaz Barak, and Alexander Glaser, “Designing Protocols for Nuclear Warhead Verification” (paper presented at INMM 56th Annual Meeting, Indian Wells, California, July 12–16, 2015).

31. Uriel Feige, Amos Fiat, and Adi Shamir, “Zero-Knowledge Proofs of Identity,” *Journal of Cryptology* 1 (1988): 77, <http://s3-ap-southeast-1.amazonaws.com/erbuc/files/a60459e4-bcf1-421c-a3a5-9e8f79aa8be8.pdf>; and Shafi Goldwasser, Silvio Micali, and Charles Rackoff, “The Knowledge Complexity of Interactive Proof-Systems,” *SIAM Journal on Computing* 18, no. 1 (1989): 186, <http://crypto.cs.mcgill.ca/~crepeau/COMP647/2007/TOPIC01/GMR89.pdf>.

32. Goldwasser, Micali, and Rackoff, “The Knowledge Complexity of Interactive Proof-Systems,” 186.

33. Thomas Shea and Laura Rockwood, *Nuclear Disarmament: The Legacy of the Trilateral Initiative*, Deep Cuts Working Paper No. 4 (Hamburg: Institut für Friedensforschung und Sicherheitspolitik an der Universität Hamburg [IFSH], 2015), 15, [https://www.files.ethz.ch/isn/192450/DeepCuts\\_WP4\\_Shea\\_Rockwood\\_UK.pdf](https://www.files.ethz.ch/isn/192450/DeepCuts_WP4_Shea_Rockwood_UK.pdf).

*the warhead is authentic,*” on the other hand, would refer to a template verification protocol and could similarly be proven using physical zero-knowledge proofs.<sup>34</sup>

The concept of physical zero-knowledge proofs has been demonstrated in practice using the template verification approach.<sup>35</sup> These proposals employ physical measurement systems that inherently protect the sensitive information contained by warheads. These measurement systems are nonelectronic, which prevents interference and tampering with the system before, during, or after the measurement.<sup>36</sup> The approaches have been proven capable of achieving the principles of completeness, soundness, and zero-knowledge in the correct conditions.<sup>37</sup> The last principle only remains true if the host maintains honesty.<sup>38</sup> Thus, the zero-knowledge property requires the host to follow the procedure, but it is resistant to verifier cheating—no sensitive information can be leaked even if the verifier does not follow the protocol.<sup>39</sup>

Current research is exploring different physical implementation systems of these warhead verification systems, which include using differential measurements of the neutron radiographic profiles, isotopic tomography, and time-encoded neutron radiographs.<sup>40</sup> These physical cryptographic protocols based on the zero-knowledge property do not rely on electronic information barriers that can be impossible to authenticate for the verifier.<sup>41</sup> Thus, they are able to solve one of the key challenges that all previous verification systems, both attribute- and template-based, have faced. Physical cryptographic verification systems inherently protect sensitive information based on the measurement technologies employed in the protocols, which never measure the sensitive information itself.<sup>42</sup> Proper design can ensure easy certification and authentication of the systems for all parties involved and can theoretically be implemented with any equipment, making the issue of host- or verifier-supply insignificant.<sup>43</sup>

The most significant challenge with the current implementations of physical cryptographic verification approaches, as with all template-based verification systems, relates to the question of trusting the reference warhead.<sup>44</sup> In all forms of template verification, an authentic “golden

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34. Philippe, Barak, and Glaser, “Designing Protocols for Nuclear Warhead Verification,” 7.

35. Alex Glaser, Boaz Barak, and Rob Goldston, “A New Approach to Nuclear Warhead Verification Using a Zero-Knowledge Protocol” (paper presented at INMM 53rd Annual Meeting, Orlando, Florida, July 15–19, 2012), 1.

36. Sébastien Philippe, Robert Goldston, Alexander Glaser, and Francesco d’Errico, “A Physical Zero-Knowledge Object-Comparison System for Nuclear Warhead Verification,” *Nature Communications* 20, no. 7 (September 2016), <http://www.nature.com/articles/ncomms12890>.

37. Philippe, Barak, and Glaser, “Designing Protocols for Nuclear Warhead Verification,” 7.

38. Goldwasser, Micali, and Rackoff, “The Knowledge Complexity of Interactive Proof-Systems,” 196.

39. Ibid.

40. Philippe, Goldston, Glaser, and d’Errico, “A Physical Zero-Knowledge Object-Comparison System for Nuclear Warhead Verification”; Kemp et al., “Physical Cryptographic Verification of Nuclear Warheads”; Peter Marleau et al., “Zero Knowledge Protocol: Challenges and Opportunities,” 2015, 2, <https://www.osti.gov/scitech/servlets/purl/1261022>.

41. Philippe, Barak, and Glaser, “Designing Protocols for Nuclear Warhead Verification,” 3.

42. Ibid., 9.

43. Ibid.

44. Marleau et al., “Zero Knowledge Protocol: Challenges and Opportunities,” 5.

warhead” must be established, allowing the comparison of this reference to an item under inspection.<sup>45</sup> When considering this challenge, one important question relates to terminology. In the traditional template approach literature, the reference *measurement*, not the item, is considered as the template. In the context of warhead verification, this would translate to considering the radiological signature or other measurement result of the warhead as the template, not the physical reference warhead itself.<sup>46</sup>

Several ideas have been proposed for ensuring the authenticity of the reference warhead. The inspector could be allowed to select the reference warhead from active delivery systems, as states would be highly unlikely to deploy counterfeit warheads in these conditions and undermine the deterrent capability of the weapons.<sup>47</sup> Deception mechanisms are still conceivable—for example, consider a situation where the host state learns beforehand which actively deployed warheads would be selected as templates and can replace them with blanks. Furthermore, this template selection mechanism could not be used for nonstrategic nuclear warheads deployed in dual-capable systems or those located in storage. Chain-of-custody methods could be one possible solution, but states may be unwilling to allow this level of access to their critical defense facilities and information.<sup>48</sup> The Strategic Arms Reduction Treaty (START I) and New START contained provisions for verifying the nonnuclear nature of warheads through radiological measurements, but confidentiality concerns prevented more intrusive measurements on nuclear warheads.

## FUTURE DIRECTIONS

The fundamental assumption in zero-knowledge verification protocols is that no information should be released, or even measured, beyond the validity of the proposition under consideration. This property makes it inherently impossible to infer anything about the reference warhead. Would it be possible to allow some measurement information to be accessible to the verifier, however, for the purpose of authenticating the reference warhead? Relaxing the condition of zero-knowledge could open new opportunities for solving the golden warhead challenge. Verification protocols that rely on electronic information barriers aim to do this by allowing the measurement of classified information, but then concealing it behind a trusted information barrier and only displaying an unclassified result.<sup>49</sup> This gain in the legitimacy of the measurement results, however, comes with the increased vulnerability to intricate spoofing attempts from either the host or the verifier.<sup>50</sup> Thus, both mechanisms of information integrity have inherent trade-offs. Creating a verification

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45. Ibid.

46. Ibid.

47. Philippe, Goldston, Glaser, and d’Errico, “A Physical Zero-Knowledge Object-Comparison System for Nuclear Warhead Verification.”

48. Kemp et al., “Physical Cryptographic Verification of Nuclear Warheads.”

49. Yan and Glaser, “Nuclear Warhead Verification.”

50. Philippe, Barak, and Glaser, “Designing Protocols for Nuclear Warhead Verification,” 9.

system that would integrate both the attribute approach and the template approach could be one potential way to balance the different advantages and obstacles.<sup>51</sup>

The question is, then, what should be measured about the reference warhead to establish confidence in its authenticity. These forms of information can be categorized in three groups—basic information, quantitative information, and disarmament information.<sup>52</sup> In the Trilateral Initiative, the United States and Russia followed a modest and careful approach, essentially establishing the lowest common denominator in deciding what characteristics could be determined. They agreed to measure three attributes that would provide basic information about the warheads and thus provide assurance of warhead authenticity: whether fissile material was present; whether its isotopic composition was typical for nuclear weapons; and whether the mass of the fissile material was above a minimum threshold, defined by the context where it was deployed.<sup>53</sup>

These attributes, however, only establish basic information about the warhead and remain at the lowest ladder of informational value. A further step into certifying the authenticity of a warhead would be using measurement approaches that provide quantitative information about the fissile material: the establishment of the exact mass of the material or certification that the mass is within certain limits.<sup>54</sup> Going beyond fissile material, the last category of questions would probe into the fundamental characteristics of “warheadedness”: whether the object contains core nuclear weapons components, such as the physics package, pits, or secondaries, and whether the specific model of these components can be identified and confirmed.<sup>55</sup> Further challenges will arise in the context of authenticating the reference warhead. Modern cryptography contains several concepts that could prove useful for this challenge, such as image-reconstruction algorithms, signatures built on nonuniform inputs, and threshold homomorphic encryption schemes.<sup>56</sup>

Trust in the integrity and confidentiality of nuclear disarmament verification is a critical precipitating factor that allows states to engage in disarmament. The risks of unauthorized access and illegitimate disclosures can emerge both from the technologies utilized as well as the human

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51. Committee on International Security and Arms Control, *Monitoring Nuclear Weapons and Nuclear-Explosive Materials*, 100.

52. Ibid.

53. Ibid.

54. Ibid.

55. Ibid.

56. Allen Seifert et al., “Outcomes of a Workshop on Techniques for Information Protection of Imaging Information” (paper presented at INMM 57th Annual Meeting, Atlanta, Georgia, July 24–28, 2016), 3; Allen Seifert et al., “Imaging for Dismantlement Verification: Information Management and Analysis Algorithms,” *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors, and Associated Equipment* 662, no. 1 (January 2012): 81; Yevgeniy Dodis, Leonid Reyzin, and Adam Smith, “Fuzzy Extractors: How to Generate Strong Keys from Biometrics and Other Noisy Data,” in *Proceedings from EUROCRYPT 2004: Advances in Cryptology*, Lecture Notes in Computer Science, vol. 3027 (Berlin: Springer, 2004), 2, [http://crypto.di.uoa.gr/class/Kryptographia/Metaptychiakoi\\_2015\\_files/DRS04.pdf](http://crypto.di.uoa.gr/class/Kryptographia/Metaptychiakoi_2015_files/DRS04.pdf); Jean-Paul Linnartz, “A Communication-Theoretical View on Secret Extraction,” in *Security with Noisy Data: On Private Biometrics, Secure Key Storage and Anti-Counterfeiting*, ed. Pim Tuyls et al. (London: Springer, 2007), 67; Cagatay Karabat et al., “THRIVE: Threshold Homomorphic Encryption Based Secure and Privacy Preserving Biometric Verification System,” *EURASIP Journal on Advances in Signal Processing* 71 (2015): 1.

interaction with these systems. Verification protocols founded on physical zero-knowledge proofs would be an instrumental contribution to addressing these verification concerns. Their successful development and implementation could precipitate a paradigm shift in disarmament treaty architecture, enabling agreements that limit individual warheads. Conceptually, the veil that physics provides to these approaches enables inherent secrecy, but this lack of transparency also prevents trust-building.

Even though the prospects for further reductions in the near term are bleak, it is essential to invest and engage in this fundamental research now to create new verification tools and confidence-building assets for when political interests become aligned with disarmament goals. Critically, this process must be carried out in collaboration with all states with nuclear weapons capabilities, especially those that have thus far been isolated from the international nuclear policy architecture and security collaboration. Future verification conditions are likely to engage new states, address novel categories of nuclear weapons, and target much lower arsenal sizes, all of which create unique pressures for the verification mechanisms employed. Having the capacity to confidently authenticate, track, and dismantle individual warheads will become the priority in these conditions. The failure to develop sufficient readiness for these new verification requirements could become a significant barrier for future disarmament efforts.

## CONCLUSION

The challenge of warhead authentication is an illustrative example of a verification issue where the current lack of technical capabilities has prevented certain measures of arms control from being implemented, and where a breakthrough in verification technologies could have a significant impact in shifting the dynamics of the political discussions. This illuminates how the connection between the technical and political dimensions of verification technologies are manifested in practice. The development of zero-verification approaches would eliminate the technical argument that warhead reductions cannot be verified with a high level of accuracy, or that the verification process would reveal classified information and therefore threaten national security.<sup>57</sup> Thus, these novel verification capabilities would influence the arguments available both to arms control opponents and proponents, facilitating new treaty architecture options for further warhead reductions.

It must be recognized that novel verification technologies, such as zero-knowledge verification approaches, will not be a panacea for making arms control possible. Changes in the available verification capabilities cannot single-handedly make an arms control agreement possible, in the

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57. These arguments were visible, for example, in the U.S.-Russian transparency and irreversibility dialogue between 1994 and 1995. See Steven Pifer, *The Next Round: The United States and Nuclear Arms Reductions after New START*, Arms Control Series Paper 4 (Washington, DC: Brookings, 2010), 31, [https://www.brookings.edu/wp-content/uploads/2016/06/12\\_arms\\_control\\_pifer.pdf](https://www.brookings.edu/wp-content/uploads/2016/06/12_arms_control_pifer.pdf); and Eugene Miasnikov, "Non-strategic Nuclear Weapons in Europe: Possible Scope and Conditions for Information Sharing, Transparency Measures, and Verification" (paper presented at the Warsaw Workshop: Prospects for Information Sharing and Confidence Building on Non-Strategic Nuclear Weapons in Europe, Warsaw, Poland, February 7–8, 2013), 3, [https://www.pism.pl/files/?id\\_plik=12843](https://www.pism.pl/files/?id_plik=12843).



absence of political will. They can, however, shift the dynamics of the negotiations by changing the arguments available to the different stakeholders and creating new, feasible verification options. This is where the importance of verification technologies lies—they can increase the likelihood of achieving an agreement in verification provisions and thus enhance the prospects of future rounds of arms control.

This is why the development of novel verification capabilities is important. Even if the new verification capabilities are never fully implemented in an arms control agreement, their existence matters, because these new capabilities can both open the dialogue on new treaty architecture options as well as shape the political dynamics of the treaty negotiations themselves. In the case of warhead authentication methods relying on zero-knowledge proofs, these mechanisms may be implemented jointly with an authentication system relying on the attribute approach or otherwise be combined with verification mechanisms that do not rely on ideas drawn from physical cryptography. Even if this new innovation in warhead authentication methods was not implemented in its full capacity, the development of this verification approach would have an impact by allowing policymakers to envision the possibilities of verifying the next stages in warhead reductions and by shaping the dialogue on these next steps in arms control.

No verification option will be perfect, and there will always be gaps in confidence about compliance, which can be operationalized by the opponents of arms control. As was discussed earlier, however, other factors and processes can help compensate for these gaps in technical capabilities. Iterated interactions are one important reason why even imperfect verification capabilities can be sufficient for facilitating cooperation on arms control. Furthermore, as has been discussed, each larger verification challenge can be disaggregated into separate, specific challenges. Warhead authentication, for example, is only one of the challenges related to verifying disarmament agreements that focus on individual warheads; among other challenges are tracking the warheads, managing access to the dismantlement facilities, and detecting undeclared warhead stockpiles. It is not necessary to have all of the verification challenges solved before negotiations can begin, because solutions in one of the areas can compensate for less progress in another one. In this view, a feedback loop also exists in the way that these different segments of the greater verification issue interact with each other. When combined with the fact that the negotiating dynamics themselves also help fill the technical gaps that may remain, it is possible to envision how progress can be driven by incremental enhancements in the available technical verification capabilities.

Future stages of nuclear disarmament will be more challenging than the efforts undertaken in the past, for the reasons discussed in this paper: addressing lower numbers of warheads, where uncertainty becomes riskier; considering new categories of weapons under limitations, where past verification approaches will become impossible; and involving other nuclear weapons states that see verification in a different light and may have less advanced capabilities in national technical means. Especially when thinking about the “hardest” cases of nuclear disarmament, such as between India and Pakistan or with Israel, concerns about the trade-offs between secrecy and transparency will become prioritized. Especially in these types of conditions, novel verification capabilities can make or break future prospects for arms control.

Important future work needs to be done on the technical side of the verification challenges discussed in this paper, as well as on other prevailing verification issues. In addition to this technical development work, the political dynamics referred to earlier will require more research. One important question for future investigation is how changes in norms and perceptions about scientific knowledge, particularly among political elites and leaders, influences the impact of verification technologies in promoting arms control. In a world where scientific expertise is being contested and “alternative facts” are understood as a part of reality, how is the influence of science and technology on public policy modified? As has been discussed here, technologies are often politicized, but this phenomenon of politicization becomes more complex when our understanding of what constitutes a scientific fact is distorted.

Ultimately, nuclear weapons states’ decisions to disarm their nuclear capabilities are going to be shaped by a range of strategic, political, and other factors both at the domestic and international levels. As has been illuminated in this paper, however, verification capabilities can play a part in shaping the dynamics of the states’ decisionmaking processes, especially if and when they engage in direct negotiations over disarmament efforts. Looking into the future, the technical development of verification capabilities can be an important path toward making multilateral negotiations on warhead reductions possible, in parallel with other confidence-building measures among the nuclear weapons states and with the rest of the international community.



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