STOCKPILE STEWARDSHIP IN AN ERA OF RENEWED STRATEGIC COMPETITION

BRAD ROBERTS, EDITOR

Center for Global Security Research
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George Miller served as director of Lawrence Livermore National Laboratory from 2006 until 2011. He joined the laboratory scientific staff in 1972 and served in multiple leadership positions, including as associate director for defense and nuclear technologies and for national security, before his appointment as director. He received his PhD in physics from the College of William and Mary. In 2022 he was awarded the John S. Foster medal in recognition of his exceptional leadership in support of U.S. nuclear security.

James Peery is the director for Sandia National Laboratories. Prior to his appointment in 2020, he served as Oak Ridge National Laboratory's associate laboratory director for national security sciences and Sandia's vice president for defense systems and assessments. He has also been the principal associate director for the nuclear weapons program at Los Alamos National Laboratory. He received his PhD in nuclear engineering from Texas A&M University.

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Introduction

Brad Roberts

Stockpile stewardship was born in a particular moment in the security environment—in that optimistic period after the end of the Cold War marked by rising confidence that major power confrontation would turn to major power concert in support of a new world order. Accordingly, this was a moment when the United States sought to lead in reducing proliferation risks and nuclear instability, in part by the exercise of strategic restraint of various kinds. Stockpile stewardship was designed to utilize scientific means to safeguard the U.S. nuclear deterrent without recourse to underground explosive nuclear testing and without pursuing new military capabilities.

Alas, this moment has now passed. A new world order has not emerged; instead, the U.S.-led orders in Europe and Asia are hotly contested by Russia and China. Cooperation among the major powers has waned, while competition and rivalry have intensified. What does this imply for the ambition to reduce nuclear dangers through the exercise of strategic restraint? How, if at all, should the United States modify its approach to maintaining a nuclear deterrent in light of the new, more competitive relationships with Russia and China?

These questions came into sharper focus with revelations in 2018 about novel Russian nuclear systems and in 2021 about China's covert program to deploy large numbers of new weapons. In reaction, CGSR launched a project in 2021 designed to address a few key questions:

- How have the United States, Russia, and China approached the maintenance of their nuclear deterrents in a changing security environment?
- Where do their approaches align and differ?
- Do the asymmetries matter?
- How competitive is the U.S. approach?

Answers to these questions should help to inform discussion of what the United States should now do, if anything, to ensure its deterrence posture remains fit for purpose in the new security environment.

This volume is the result. It begins with a review of the U.S. stockpile stewardship program, and its results, by one of its co-creators, George Miller. It then looks at the future of the program, as now conceived, from the perspective of a recent laboratory leader, Bill Goldstein. The approaches of Russia and China to the long-term development of their deterrents are then reviewed by Mike Albertson and Mike Anastasio. I then offer a comparison of the three approaches and an assessment of the ways in which the asymmetries matter. The volume closes with a strategy for strengthening U.S. competitiveness, written by the current directors of the three nuclear weapons laboratories, Kim Budil, Thom Mason, and James Peery.

Our aspiration is to encourage a more informed discussion of these important issues among key stakeholders in the United States and allied countries. We also seek to encourage further analysis of these timely and important questions.

Stockpile Stewardship: What Were We Thinking? How Did It Work Out?

George Miller

Introduction

A variety of factors came together in the last decade of the 20th century to force a rethinking of the basis used to ensure confidence in the nation's nuclear deterrent. The process used during the previous 40 years had relied on a dynamic, integrated system of evolving designs, relatively short stockpile lifetimes as requirements changed, and major production capabilities. These system elements were underpinned by a robust laboratory complex capable of performing full-scale nuclear explosive tests, computational simulations, non-nuclear tests, and basic science investigations of the underlying physics, chemistry, and materials science. Many elements of this system were disrupted and inalterably broken in the years leading up to this "confidence crisis" of the 1990s. While much focus has been on the loss of nuclear testing, it is important to understand that the basis of confidence in the nuclear deterrent was really founded on confidence in the nuclear enterprise, which required all the above-mentioned elements to be robust—yet they were all broken to one degree or another.

Into this environment was thrust a bold vision: to change the basis of ensuring confidence in the nuclear deterrent by fundamentally changing the basis of confidence in the nuclear enterprise. This bold vision, which came to be called stockpile stewardship, was initially referred to as science-based stockpile stewardship because of the initial focus on repairing the damaged laboratory complex. This vision had four main elements and strategies associated with each:

- Significantly increasing in the capability of the laboratory complex—providing an integrated experiment, theory, and simulation-based approach to confidence in the warheads themselves that was based on science.
- Conducting a major consolidation and modernization of the production complex to make it more cost effective and providing greater flexibility, using modern manufacturing techniques that produced less waste.
- Developing a better approach to stockpile sustainment. The previous approach required over-building each warhead in the stockpile and tearing a few apart each year. Advanced surveillance would use embedded sensors and advances in materials science and simulation to provide more quantitative and predictive information about the aging of the stockpile. This approach would permit longer lifetimes and improve planning for replacements.
- Creating a warhead replacement program that would use the above tools to move away from the highly optimized warheads of the Cold War toward designs,

materials, and components with more robust performance margins, longer lifetimes, and easier fabrication and maintenance.

The future stockpile was presumed to contain a diverse mix of about 1,500 deployed warheads and a reserve of about the same number.

Taken together, this bold vision of stockpile stewardship was revolutionary. However, it presented significant inherent risks—particularly when considering the importance of the nuclear deterrent in national security. Its success required the very best of the country's science and technology enterprise.

The Laboratory Complex

As Vic Reis, architect of the U.S. stockpile stewardship program often observed, "The body will die without a head." Hence, the laboratory complex received major attention. This science-based part of the stewardship vision included investments in a major computational simulation initiative, the Accelerated Strategic Computing Initiative (ASCI), and experimental facilities for both high-energy-density science and hydrodynamic testing. The major facilities were the National Ignition Facility (NIF) (high-energy-density science), and the Dual Axis Radiographic Hydrodynamic Test Facility (DARHT) and the Advanced Hydrodynamic Test Facility (AHF) (hydrodynamic testing). Because Reis's vision also recognized that "each laboratory needed a Nordstrom in its mall," a major facility was planned for each site in addition to the strictly science-based part of the initiative. Thus, supercomputing would be at each laboratory in addition to NIF at Livermore; the Microsystems Engineering, Science and Applications Facility (MESA) at Sandia; DARHT and the Accelerator Production of Tritium (APT) at Los Alamos; and AHF at the Nevada National Security Site. MESA and APT were to be constructed not only for the science part of the vision, but also because their operation played an important role in production.

Accelerated Strategic Computing Initiative

ASCI was a bold, game-changing initiative directed at accelerating the pace of both the hardware and software associated with large-scale computational simulation. Unlike past approaches in which the government paid for highly specialized hardware optimized for a particular purpose, this approach used government funds to accelerate the "business plan" of companies in the computer industry. The bold initiative necessitated a movement to "massively parallel" hardware architectures that used thousands to millions of central processing units (CPU). This entailed significant risks in both the hardware and software, such as: From a hardware perspective, could you keep the machine working properly long enough to do a useful calculation? From a software perspective, could you figure out how to parse the tightly integrated physics of a nuclear weapon across a massive hardware system? The initial goal was an approximately 100,000- to 1 million-fold increase in sustained performance to greater than 100 teraflops. This level of performance required increases in both hardware and software capability and would permit a full-scale weapon simulation. It was widely recognized that this goal was barely entry level with respect to the scale that would be needed for fully resolved, three-dimensional calculations—even with the then-current level of physics approximations. This goal was judged to be appropriately challenging and would elucidate issues that needed to be addressed to progress to the next level.

ASCI, now known as just ASC (Advanced Simulation and Computing), has been wildly successful by all accounts and when viewed from any perspective. The U.S. computing industry, both with respect to supercomputing and commodity computing, has been completely revitalized and is back to being a world leader. The National Nuclear Security Administration (NNSA)'s national laboratories are successfully performing simulations on machines with peak speeds in the tens of petaflops and looking toward exaflops. These simulations have revealed many important features of the operation of nuclear devices and have begun to resolve long-standing mysteries. From a broader perspective, these NNSA and DOE efforts have helped to widely establish computational simulation as a vital scientific and technical tool. A key to the success of this initiative has been establishing strong partnerships between the laboratories, NNSA, and U.S. industry.

In addition to the obvious application of conducting the physics simulations of nuclear weapons, ASCI has also been essential in furthering the laboratories' leading role in engineering and materials science simulations. The technologies behind the current buzz words of "Model Based Systems Engineering (MBSE)" were pioneered at these institutions. ASCI helped ensure that these key technologies continued to advance and be adapted more widely throughout U.S. academia and industry.

The ASCI initiative has been wildly successful. Just as important, it continues to both receive strong support and make progress in its scientific achievements.

National Ignition Facility

The majority of the physics of a nuclear device, including fusion, occurs in a high-energy-density regime where few opportunities for experimental validation are available short of a nuclear explosion. Like ASCI, NIF represented a major step forward—in this case, the science and technology of using lasers to investigate high-energy-density physics and fusion. From a technology point of view, the facility enabled a 100-fold increase in capability that required significant advances in materials and precision optics, among other technologies. Seven technological "miracles" were required to complete NIF, including scientific advances and engineering feats that had never been done before—much less in the middle of a multi-billion dollar construction project. Like the Inertial Confinement Fusion Program (ICF) initiated by DOE Secretary James Schlesinger, NIF was to serve three functions: weapons science that included ignition, energy, and basic science.

In recommending that NIF be built at an energy of 2 megajoules (MJ), the National Academy of Sciences realized that the probability of getting ignition would be at best a 50-50 proposition: 2 MJ was an appropriate scale-up and that, even if unsuccessful, the community would learn the appropriate scale for a high gain facility. Within

Livermore, there was the strong view that it would take at least three major campaigns to fully understand if ignition was possible at this level of laser energy.

NIF was controversial within the community due to competing capabilities at other institutions, the cost of the facility, and differing judgements on the importance of the physics that could be investigated at NIF. NIF's construction was approved by Secretary of Energy ADM James Watkins, and strongly supported by Reis. The three NNSA laboratory directors recommended proceeding with construction. Its approval required a major effort.

Early on, the project suffered from significant project management shortcomings and recognition that the initial cost estimates were wrong. Following a major re-baselining effort and approval of a significant cost increase, a new team successfully completed the project on time, on cost, and met its original technical requirements. As a result, the project received a national award. From a technology and project management point of view, this major accomplishment demonstrated that given the right environment, the NNSA laboratories can execute extremely complicated and technically challenging projects with confidence.

Following the completion of the construction project, additional effort was required to turn NIF into a user facility with a full suite of diagnostics and experimental teams. To facilitate this transition, Livermore initiated the National Ignition Campaign (NIC), focusing on fusion ignition as a way of bringing together the diagnostics and systems required for a fully functioning facility. While Livermore accepted the goal of demonstrating fusion ignition as important for focusing attention on NIF's diagnostic and experimental needs, there was full recognition that this goal was very challenging. Unfortunately, NNSA and Congress saw the "goal" as a requirement. NIC was extremely successful in transitioning NIF from a construction project to a user facility. However, even with the significant advancement in understanding the issues surrounding fusion ignition in the laboratory, the failure to achieve ignition resulted in NIF being seen as a failure.

Since the planned completion of NIC in 2009, continued progress has been made in understanding the requirements for fusion ignition in the laboratory. Experiments in several geometries have produced approximately 1.3 MJ of fusion energy—an amount that is very close to ignition. The Laboratory has characterized this accomplishment as "a Wright Brothers moment. Our result is a significant step forward in understanding what is required for fusion to work."[1]

In other areas of weapon science, NIF has also been very successful, providing important benchmarks in the areas of hydrodynamics, atomic physics, material science (including plutonium), and system-level vulnerability and hardening. In the area of basic science, important contributions to both astrophysics and planetary science have been made in conjunction with various academic institutions.

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[1] Lawrence Livermore National Laboratory, "Building a Solution: The Elements of a Fusion Breakthrough" (November 2, 2021). https://lasers.llnl.gov/news/building-to-a-solution-elements-of-a-fusion-breakthrough. Accessed December 21, 2021.

In both attracting and training new scientists, NIF has been an outstanding success. Importantly, NIF is one of the few areas where weapons scientists can integrate complicated physics, simulations, and experiments to resolve complex issues. These activities test both their competence and technical judgement. NIF and the experiments that have been performed there provide an important part of the confidence we continue to have in the nuclear stockpile. They also do a fine job of resolving specific issues that have arisen. Nevertheless, I would judge that NIF still exists somewhat on the margins of the core weapons program, as the people who pursue fusion ignition and weapons physics experiments are not the same individuals who are directly responsible for the stockpile weapons—or for developing the major life extension programs.

Overall, NIF has been a success and an important part of the system to ensure confidence in the nuclear stockpile. A major shortcoming is that we continue to lack a way to conduct experiments to investigate the single most important piece of weapons physics—fusion.

Hydrodynamic Testing

One of the most important experimental capabilities in maintaining confidence in the nuclear stockpile is the ability to collect data on the high explosive or hydrodynamic phase of primary operations. X-rays produced with an accelerator are used to take a picture of an imploding primary. Through most of its history, the nuclear design laboratories used a single linear accelerator to take a single picture. While extremely valuable, it was long recognized that a single picture was inadequate to fully describe what was happening during this phase of operation. More pictures were required in (1) the time dimension to follow the evolution and (2) the space dimension to permit 3-D image reconstruction. Another shortcoming was that only surrogate material could be used; the use of plutonium would result in an explosion.

The first step in this evolution was the construction of a dual-axis capability with the ability to take multiple pictures over time. Using an induction LINAC to create the X-rays, this capability was provided by DARHT, completed at Los Alamos in 2009. DARHT was supplemented by sub-critical experiments at the Nevada Test Site (NTS) where sophisticated diagnostics elucidate the dynamic behavior of small samples of plutonium driven by high explosives. Together they have been a major success and served as a tireless workhorse for the nuclear enterprise. The second step—currently under construction—is a single beam located underground at the Nevada National Security Site that will allow contained, sub-critical tests using plutonium. These tests will validate our understanding of the differences between plutonium and the surrogates that are more regularly used.

The third step was planned to be the construction of a multi-GeV proton accelerator at the Nevada National Security Site. Protons are far more penetrating than X-rays and can give pictures with much higher resolution. The nature of proton accelerators also easily allows for multiple pictures in time and the five to nine different axis views that are necessary for true 3-D reconstruction.

The hydrotesting strategy has certainly been successful in making the high-quality images from DARHT available. The significant delay in the availability of plutonium hydrotesting data and the lack of any multi-time, multi-axis facility capable of 3-D reconstruction are major shortcomings.

Microsystems Engineering, Science and Applications Facility

The Microsystems Engineering, Science and Applications Facility at Sandia has clearly been a major success. It has provided a home for Sandia's scientific and engineering work such as material growth and process development for silicon and compounds, device and product design, advanced packaging technologies for 3-D integration, and reliability and failure analysis expertise. These technologies are an important part of Sandia's nuclear weapon responsibilities and have also played a major role in Sandia's broad engagement in the U.S. national security issues, particularly in rad-hard electronics and trusted systems.

From the point of view of direct engagement in the nuclear weapons enterprise and as a place that attracts high quality scientists and engineers, MESA has been an unqualified success. The one area of disappointment is that it has yet to lead to a significant reduction in the cost of Sandia's part of a nuclear weapon or in a reduction in the cycle time.

Accelerator Production of Tritium

Accelerator Production of Tritium (APT) was a dual-track strategy to both provide Los Alamos a flagship capability and assure a source of tritium for the nuclear weapons enterprise. The need for an assured source of tritium had been recognized for years and DOE had made multiple attempts to move forward on a new production reactor. The APT strategy was intended to alleviate the extreme difficulties that surrounded getting approval, funding, construction, and permitting of a new tritium nuclear reactor. APT was judged to be an acceptable way to produce this essential material by avoiding many of the pitfalls inherent in a nuclear reactor. While technically appealing, APT had its own set of problems—many based on misunderstandings, some of which were based on disagreements over how it would have to be licensed and technical questions about the target system itself. Fundamentally, APT wasn't selected as the approach to an assured source of tritium because of cost, as it was approximately 10 times the cost of using existing TVA reactors. In addition, there was substantial technical risk compared to the use of the existing reactors.

In many respects the issue of a flagship science facility for Los Alamos has never been solved. The current proposal, Matter-Radiation Interactions in Extreme (MaRIE), a materials science-oriented capability, has yet to be implemented in any serious way. Los Alamos has a number of very important science-user facilities, such as the Los Alamos Neutron Science Center (LANSCE), the National High Magnetic Field-Pulsed

Field Facility (NHMFL-PFF) and the Center for Integrated Nanotechnologies (CINT), but nothing of the size and scale that would be provided by MaRIE.

This strategy clearly failed.

Production

Along with the cessation of nuclear testing, the lack of assured production capability was the most obvious difficulty facing the nuclear weapons enterprise. The age of the complex and the attendant problems had been recognized since the Goodpaster study of the late 1970s. While many studies had been completed, few real improvements had been implemented and the production complex was close to non-functional. The production strategy entailed two elements: consolidation and process modernization. With the likelihood of a significantly smaller stockpile, the production complex could also be smaller, and in the extreme version, fewer sites would be required. Likewise, the production processes themselves were antiquated, inefficient, and generated huge amounts of waste.

In the ultimate consolidation, it was felt that the Nevada Nuclear Security Site could provide both assembly/disassembly and production of plutonium parts. Many of the other production processes could be performed in a commercial setting, with special materials and research and development conducted at the laboratories. As with any consolidation, there were many opportunities—particularly in the most expensive processes—to modernize approaches that could provide significant improvements in efficiency, flexibility, cost effectiveness, and reduced waste generation.

Very little of this strategy was implemented. There was significant reluctance, particularly on the part of the congressional delegations from each site, to support any consolidation. Similarly, there was significant reluctance on the part of both the production plants themselves and the Navy to accept any new production processes.

One major opportunity remains: plutonium manufacturing. The current NNSA two-track approach to establish 30 pits/year capacity at Los Alamos and greater than 80 pits/year capacity at Savannah River offers a real opportunity to both protect the plutonium manufacturing process as well as develop a thoroughly modern capability.

Even today the U.S. production capability is woefully lacking and that which exists has limited capability. The U.S. has managed to execute a few modest life extension programs (LEPs), albeit over very long timescales. The country has spent a tremendous amount of money on improving the production capability of its nuclear enterprise with very little to show for it. Leadership, not money, has been the problem—principally the schism that was purposefully created between the laboratories, the production complex, and NNSA headquarters. This strategy has largely been a failure, with one major opportunity remaining.

Sustaining the Stockpile

The process by which warheads in the stockpile are sustained through their decades-long life cycle involves surveillance, assessing how the warheads are aging, and selective replacement of parts whose lifetime has been exceeded. The core of the surveillance program has always been both non-destructive and destructive observations of actual weapons from the stockpile. Because as many as 10 weapons a year of each type are pulled from the stockpile and up to two are destructively analyzed, this program is both expensive and logistically intensive. To support this program, new warheads must be produced in addition to those required for the deployed stockpile. In the era when fewer weapons are deployed, this surveillance pipeline can be a significant part of the initial build. To alleviate these issues, the Advanced Surveillance strategy was created to focus on advancing non-destructive capabilities (e.g., 3-D tomography, embedded sensors, and predictive aging). This strategy is intimately tied to a better and more detailed understanding of materials science through focused experiments with better diagnostics and more sophisticated computational simulation. These elements add not only to a more fundamental understanding of the basic materials science but also to the multiple, complicated, and non-linear pathways that lead to aging.

Like other parts of the Stockpile Stewardship Program, this approach had some major successes but was more limited in other areas because of inadequate funding. Some major new diagnostic capabilities were implemented (e.g., radiography and gas sampling) that helped avoid more costly destructive approaches. An important contribution of this program was an initial assessment of plutonium aging. In addition, a multi-laboratory effort that included extensive experiments and modeling and simulation pointed to the need to reestablish a plutonium manufacturing capability. This provided assurance that the radioactive plutonium in weapons had a long enough lifetime to permit a more measured approach to constructing a plutonium manufacturing complex.

The stockpile sustainment approach has been successful in developing a better understanding of how materials age. It has also helped NNSA and the laboratories avoid costly, emergency retrofits; this is particularly true in the case of plutonium aging. However, in the area of embedded sensors and the wish to phase out the large number of destructive evaluations, it has been less effective principally because of the lack of focus on this aspect of enhanced surveillance.

Replacing Warheads

From the earliest development of the Stockpile Stewardship Program, DOE scientists recognized that one of its initial responsibilities would be to sustain existing warheads, surveil them, and make minor modifications when required. In many respects the job of making sure the maintained warheads functioned just like they were originally built was a very difficult task because the production processes were inadequately documented and those weapons were optimized against a set of criteria that presumed a limited stockpile life. It was also recognized that the skills required to design a nuclear weapon are different than those necessary to “maintain” a weapon: in many respects, the difference between creating and analyzing.

Numerous attempts were made to implement a program that would replace the existing stockpile with more robust, easier to manufacture, and easier to maintain weapons. These attempts started with the Navy SSP Stockpile Warhead Protect Program (SWPP) and extended into the Reliable Replacement Program. The intention was to move beyond simple LEPs and focus on a new set of requirements based on manufacturing and sustainment issues. While maintaining consistency with the Perry-Schlesinger Congressional Commission recommendations on no new military requirements, these programs ran afoul of a prohibition on "new" warheads.

The current LEPs for the W80-4 cruise missile warhead and the W87-1 Ground-Based Strategic Deterrent warhead are beginning to move away slightly from its approach to make it exactly like older warheads. The W87-1 modernization program, in particular, is the first LEP in which the warhead will be entirely manufactured from scratch. The W93 replacement for the Navy will likely be the first warhead designed specifically against a new set of "sustainment" requirements.

The Stockpile Stewardship Program has successfully ensured confidence in the country's nuclear warheads by designing and certifying small changes in the deployed stockpile and implementing them through LEPs. However, NNSA and the laboratories have missed opportunities to implement changes that create "new" warheads that are more robust, easier to manufacture, or easier to sustain because of concerns that they might also have different military characteristics. Small and incremental—yet important—changes in this area are just now being considered. I would judge the warhead replacement program to be successful but disappointing because of missed opportunities and the slow speed with which important changes have been implemented.

Risk

Often missing in an explicit fashion is a discussion of risk as it pertains to stockpile stewardship. The risk question is often cast in confidence terms (e.g., "Do you have confidence that the system will work?"). I believe it's important to deal with risk explicitly to ensure that the risks are clearly understood and mitigated to the extent possible. From a technical point of view, there is no such thing as a "risk-free" decision, so it's about having an acceptable level of risk. A properly framed discussion, in my view, should be about both risks and benefits. Importantly, risk is contextual: risk "to do what?" In the context of stockpile stewardship, the risks associated with properly assessing the state of the deployed stockpile today are different than those associated with its likely state at some point in the future. Likewise, the risks associated with developing a modified design for the stockpile differ depending on how close the design is to a warhead that was extensively tested. This is because in an extensively tested design it is straightforward to ensure that the margin between successful operation and failure is appropriate. In comparison, developing a modified design for a warhead that was only tested a few times means that it is only partially understood and the difference between success and failure is clouded by those uncertainties (i.e. it has small margins).

The risks in undertaking a movement to the stewardship approach were enormous, as each of the strategy's elements to improve NNSA's nuclear weapons complex had huge technical risks. There were major concerns that the fundamental approach—which eliminated the need for full-scale nuclear testing—was fundamentally breaking the scientific paradigm of balancing theory and experiment. Recasting the production complex required a questionable presumption that the performance of aging warheads would remain within acceptable bounds until new production was available and that the threat from our adversaries would continue to decline such that the current stockpile would remain a viable deterrent. Underlying both of these major risk questions was the question of whether the laboratories—along with their people, facilities, and capabilities—would be up to the task of confidently assessing and assuring the country's leadership that the stockpile was safe, secure, and effective. The intervening 25 years have shown that the Stockpile Stewardship Program as envisioned and executed was up to the task.

As circumstances (including the threat from our adversaries) continue to change, the assessment of the Stockpile Stewardship Program's success to date begs the question of whether the program meets the country's current needs. More directly stated: What are the current major risks to continued success of the Stockpile Stewardship Program? I would judge that there are three major risks:

- **The production complex.** The current production complex is fragile at best, unable to respond quickly to problems that might occur in the stockpile or the need for new capabilities in response to adversary actions. The timescales for any response are long, it remains very expensive, and it lacks the flexibility or capacity to handle multiple problems at once.
- **The warheads.** The deployed warheads are design legacies of the Cold War. The United States is just beginning to implement designs that, while functionally and militarily the same, are more robust and easier to manufacture and maintain. While the ability of the nuclear enterprise to assess and extend the life of the deployed stockpile has been very successful, exercising the skills necessary to make major modifications has atrophied, and there are risks and benefits associated with this task.
- **The laboratory complex.** While more experimental and computational capability would be helpful, the major risk for the laboratory complex is overconfidence. Stated most succinctly: Do the people making the judgements about the stockpile have an appropriate understanding for what they know and what they don't know?

To sustain confidence in the entire nuclear enterprise, it is fundamental to focus on how NNSA and laboratory personnel can competently make sound judgements about the stockpile while not being overly confident at the same time. I recently wrote a response to an article advocating a return to testing that partially discusses this issue:

> *In my view, the question of nuclear testing (as well as many other aspects of the Stockpile Stewardship Program) is all about risk management. There were plenty of risks even with nuclear testing.*
>
> *As a technical person, I think data is the heart of our enterprise—data of all types. However, data is not free; within the context of most federal programs, to get more data of one type, you have to sacrifice something else. Balancing across all the needs is paramount—e.g., if you have to give up continuing to advance computing or all "laboratory experiments" to afford full-scale nuclear testing, it's a poor bargain, in my opinion.*
>
> *With very few exceptions, no stockpiled weapon was ever tested in anything that resembles the way it was intended to be used. Compromises, in some cases extensive ones, were made. Technical judgement, computations etc., were used to infer the relationship of the actual tested device to the stockpile.*
>
> *Which brings me to my most important perspective: nuclear weapons were never certified by nuclear tests; nuclear tests were important, but frequently not even the most important part of the process because there were never enough nuclear tests over the full range of conditions to provide certification based on the empirical data from those tests. Certification was a statement of confidence and the judgement of technical experts based on a rigorous process that considered all the available data, computational simulations, considerations of margins, etc.*
>
> *So my biggest worry is: How do you have confidence in the judgement of the people making the certification decisions? There is, in my view, a very long discussion that needs to take place about this issue. While I have my own views about how much confidence is justified based on the current approach and the risks we are taking, I believe strongly that a serious review by serious, knowledgeable people is appropriate at this juncture.*[2]

Stated most simply, my biggest worry is becoming overconfident. Absent the humility and necessity for self-evaluation, overwhelming rigor, and extensive review that come from confronting Mother Nature and failing, I worry about errors of judgement. My hope is that the University of California's high standards for research activities and the Laboratories' culture of extensive, technical rigor, and review will continue to be applied to the Laboratory's vital national security activities.

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[2] George Miller, written email to the author of an article advocating a return to nuclear testing and quoted in Paul Brown, *The Comprehensive Test Ban Treaty: Lawrence Livermore Laboratory's Impact on U.S. Nuclear Policy From 1958 to 2000* (Livermore, CA: Lawrence Livermore National Laboratory, Office of Defense Coordination, 2019), pp141-142. https://cgsr.llnl.gov/content/assets/docs/Brown-CTBTbook.pdf. Accessed January 7, 2022.

Former Laboratory director Michael May, in a July 2000 Stanford roundtable, expressed an important comment with respect to the future of the Laboratory's nuclear weapons program:

> *Over the years, the need to certify the reliability of weapons which have been the subject of more and more changes, with the tests more and more distant in the past, and the new tools more and more expensive and needing justification, all this may eventually have a corrosive effect on laboratory leadership and scientific personnel. The best scientists may stay away from that situation. I don't know how future military leaders responsible for procuring new weapons systems will respond. Changes are still being called for. The history of procuring untested weapon systems is not conducive to optimism. This culture must change. The stewardship program is just what the words imply, a program to maintain what exists, not a program to replace nuclear tests for the purpose of further weapons development. It could not do the latter now, and it will be even less able to do it in the future.*[3]

Years earlier, I distinctly remember similar words from May associated with a briefing I presented to Roger Batzel, Carl Haussman, and May on the design implications of the Threshold Test Ban Treaty (TTBT). Paraphrased, May said:

> *I'm not so much worried about you and the judgements you will make, although I'm a little worried even then, but about the designers who come after you and the ones after that. They will begin to believe their calculations of increasing sophistication and make errors in judgement based on their misplaced confidence in themselves.*

Vic Reis observed the central role of the laboratories at the onset of the stewardship journey.

With broad application, the laboratories' technical approach to judgements and managing risk is to appropriately understand and manage margins and uncertainties: that is, if you can appropriately understand the uncertainties in the system and ensure that the margins between proper system function and failure are larger than the uncertainties, then you can have adequate technical confidence in the system performance. This approach is a generalization of engineering safety margins. In a system as complicated and non-linear as a nuclear weapon, understanding and bounding uncertainties is a difficult challenge. This approach ultimately relies on the judgements of the weapon scientists and engineers. Confidence in the system is, in reality, a statement of confidence in the people. In my judgement, this is an ongoing and unresolved issue.

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[3] Stanford Center for International Security and Cooperation and The Lawyers Alliance for World Security, "The Comprehensive Test Ban: Next Steps," roundtable discussion (July 19, 2000).

Conclusion

The Stockpile Stewardship Program, a new vision of how to ensure confidence in the nation's nuclear deterrent, has successfully ensured confidence by designing and certifying small changes in the deployed stockpile and implementing them through Life Extension Programs. The essential idea was to replace full-scale nuclear testing with a better and more fundamental understanding of the physics, engineering, and materials science processes that affect nuclear weapons performance. The approach, which was initially known as science-based stockpile stewardship (SBSS), was both bold and revolutionary while possessing significant inherent risks. The SBSS vision involved strategies and projects that would significantly enhance the capability of the laboratory complex, modernize the production complex, revise the process for sustaining the stockpile, and provide a mechanism for replacing warheads in the stockpile when needed.

In accomplishing its most important mission—sustaining confidence in the country's deployed nuclear forces without nuclear testing—stockpile stewardship has been spectacularly successful. The directors of the three National Nuclear Security Administration (NNSA) laboratories and the commander of the United States Strategic Command (USSTRATCOM) have assessed the nuclear stockpile each year since 1996 and assured the U.S. president that the country's nuclear forces remain safe, secure, and effective. This annual assessment is a tribute to the successful implementation of the SBSS vision and strategies for modernization of the NNSA laboratory complex.

With respect to the other elements of the SBSS vision, progress has been mixed. Although several Life Extension Programs (LEPs) have been successfully concluded, they often encountered significant difficulties. The NNSA production infrastructure remains very fragile and capacity limited with major improvements (particularly with respect to plutonium-containing components) not occurring until several years in the future. An evaluation of the program that physically evaluates stockpile components each year would come to similar conclusions. The technology necessary for implementing the SBSS production vision is readily available, as evidenced by the state of a modern commercial integrated design, development, and production enterprise, yet the current plans largely reproduce the technology that was originally deployed during the Cold War. Even though there have been several attempts to implement programs that could provide replacement warheads if needed, all have been marginalized or cancelled before they came to fruition.

Numerous risks remain with respect to an assessment of whether the Stockpile Stewardship Program meets the country's current needs, particularly as our peer adversaries continue to enhance their nuclear capabilities. The current production complex is fragile at best and the deployed warheads are design legacies of the Cold War. The biggest risk in my judgement is overconfidence of the current stockpile stewards who lack the experience of actually designing a warhead for the stockpile and the successes and failures of actual nuclear tests. To sustain confidence in the entire nuclear enterprise, it is fundamental to focus on how NNSA and laboratory personnel can competently make sound judgements about the stockpile while not being overly confident at the same time.

Taken together, the Stockpile Stewardship vision, the willingness to take on significant risks, and the program's successes represent a shining example of this country's dedication and ability to take on and solve extremely difficult problems.

Stockpile Stewardship: The Pathway Forward

Bill Goldstein

I.

By most measures, the stockpile stewardship program—initiated in the 1990s—has been spectacularly successful. It was designed to sustain confidence in the existing stockpile systems, even as they aged well past their design lifetimes, without explosive nuclear testing. The program developed an extensive set of concepts, methods, and scientific facilities to characterize the consequences of aging and other anomalies. The intellectual core of nuclear weapon design physics and engineering has been maintained at the national labs to evaluate and certify the condition of the stockpile and to hedge against potential technical or geopolitical surprises.

If the implementation fell short of the full vision in some respects—for example, the recapitalization of the production complex and new approaches to surveillance—the program can nevertheless still claim credit for 25 years of successfully maintaining the stockpile without underground nuclear testing. Some have argued that thanks to stockpile stewardship, we have a firmer scientific understanding of nuclear weapon performance than would otherwise have developed, and I believe that to be the case. Physics uncertainties associated with the current stockpile have been more rigorously quantified and in many cases reduced, and progress has been made in isolating the details that matter most for predictability in performance. New facilities have been instrumental in resolving high-consequence questions about materials, including plutonium, which deserves its reputation as the most complicated and difficult element in the periodic table. Increases in computer power have finally allowed us to simulate diverse systems with unified performance models, a huge step towards ultimate understanding of nuclear performance.

But stewardship was designed in anticipation of a security environment that has not taken hold. Actions by the United States to reduce the role of nuclear weapons in its national security posture—reflected in decisions to reduce the stockpile, end new weapon development, and curtail investment in production capability, as well as refrain from nuclear testing—did not coincide with or induce similar behavior by other states. The turn away from "great power" competition as the new century dawned has provided an opportunity for adversaries to make unilateral gains in weapon deployment, while the United States practiced restraint. Russia and China have tested new capabilities and have substantially rebuilt or expanded their arsenals while the United States watched its existing stockpile and infrastructure grow old and, in some ways, obsolete. In Russia, doctrine has apparently evolved to lower the boundaries between conventional and nuclear warfighting, and on the ground both Russia and

China practice new forms of provocation and novel attack vectors. Both have tested anti-satellite capabilities in public, spectacular, and dangerous fashion.

In terms of its nuclear stockpile, which has been recognized as essential to the deterrence of both nuclear and conventional aggression, the United States has responded to these technical and geopolitical developments with a minimalist program to produce new versions of the systems currently comprising the stockpile. This stockpile modernization program—also called the "program of record"—began conceptually with the 2010 Obama Nuclear Posture Review (NPR), which committed to life-extend the W76 SLBM warhead and the B61 bomb, and to study LEP options for the W78 ICBM warhead. The program was expanded in the NPR of 2018, which rechristened the W78 LEP as the W87-1, and added the W-88 Alt 370. The W78 LEP has been rechristened the W87-1 and has been joined by the W-88 Alt 370, which updates the second SLBM warhead, and the W80-4, which replaces the warhead currently on the Air Launched Cruise Missile. This basically replaces the full suite of 1990s warheads and bombs. With the single exception of a low-yield variant of the W76, the modernized systems will essentially reproduce the capabilities of their predecessors. In fact, changes in capability will be limited to upgrades in safety, surety, durability, and reliability.

Despite the seemingly modest aims of the program of record, it is a prodigious undertaking for the nuclear complex, after years of primarily intellectual rather than productive exercises. It depends on significant innovation and involves considerable risk, some of which has been retired, but much of which is still to be faced. While stockpile stewardship—as implemented—has ensured that the foundational skills and capabilities are available on which to build stockpile modernization, the complex has fallen dangerously behind in the ability and capacity needed to respond to requirements in a timely way, and add new capabilities needed just to maintain the deterrent posture of the 1990s.

A close study of how stewardship and modernization have interacted provides useful guidance in defining the critical characteristics of the future weapons complex and the next stage of stockpile stewardship. In this chapter, I will touch on three of the most important of these lessons. First is simply the requirement to support the current stockpile without losing the ability to support needed replacement, a situation that has much to do with the time and cost pressures being experienced in modernization. The second lesson is that production needs modernization too, and that this ought to proceed together with an expansion in design options that will allow tight integration and maximum optimization. Third, I'll touch on the exceptional scientific pursuits of the stewardship program that have been critical in enabling modernization to succeed in meeting new and unforeseen requirements, and in ensuring that the intellectual capacity of the complex is up to the task.

II.

It has become clear that the capabilities needed to maintain the stockpile, and the deterrence posture it helps provide, go well beyond those implemented under stockpile stewardship. This defines the first requirement for a program going forward: it must be capable of sustaining deterrence without nuclear testing. The challenges entailed in meeting this goal—political, managerial, and technical—are precisely those faced right now in attempting to rebuild the enterprise to meet the requirements of modernization.

Perhaps the greatest of these arise from the constrained capability and capacity in the NNSA production complex, and the fact that major new facilities—for uranium processing, lithium processing, and pit production—are scheduled to come online just in time to supply unique parts. A delay in any one of these mega-projects could have a domino effect on the rest of the program. The danger of schedules being upset owing to production constraints recently played out on a small scale when the W88 Alt 370 and B61-12 were delayed by supply chain issues and throughput limitations at the Kansas City National Security Campus.

The nuclear design labs bring their own uncertainties to timely and effective program execution. Since the early ’90s they have been focused on the fairly stately and choreographed process of stockpile assessment. Designing modernized systems—whether with reused, refurbished, or replacement parts, or, as turns out to be the case, all three—is a step beyond the focus of preceding decades on honing the understanding of existing systems as they aged.

The challenge for the national labs is compounded by the fact that they are in the midst of a major turnover in workforce, driven both by the retirement of the generation that last engaged in nuclear testing and more-or-less continuous stockpile renewal, and the need to expand to meet the needs of modernization.

In addition, the national lab complex, like the plants, must deliver novel, new capabilities just in time to help reduce risk in the modernization program. Specifically both the El Capitan exascale computer at Livermore, and the Enhanced Capability for Subcritical Experiments (ECSE) under construction at the Nevada National Security Site, figure prominently in the certification plan for the W87-1. These projects carry risks associated both with substantial construction work, and all the uncertainty of delivering first-of-its-kind scientific capability.

Thus, a goal for redesigning stewardship would be to avoid the “boom and bust” cycle of activity that we have experienced since the end of the Cold War. The current crush to create or recreate processes, capabilities, science, and engineering, ought not be permitted to happen again. An appropriate level of readiness and balance must be maintained in production, design, and science to achieve this.

It is precisely this problem that was identified in the most recent NPR as the main challenge to achieving an effective and resilient infrastructure: the need to maintain design, development, manufacturing, and testing capabilities during the lengthy periods of time between rebuilding. An active discussion has been underway on specific approaches to this goal, but I think most important at this point would be a commitment to conducting a critical review of stockpile stewardship and modernization over the past 30 years in order to issue recommendations for alternative paths forward.

III.

Since the first NPR was issued in 1994, each subsequent version has identified a resilient and responsive nuclear infrastructure as essential to deterrence, assurance, and the establishment of a hedge against adverse developments. Modernization has clearly demonstrated that production constraints play a critical role in realizing this goal. Thus optimizing product realization—that is, implementing the interdependent processes of designing parts and systems along with rapid, low-cost production methods, and tight integration between them—has arisen as a rich target for finding savings in time and cost. This requires investigating and possibly adopting new manufacturing processes, along with the developing an expanded range of nuclear design options that can overcome constraints and take advantage of new methods.

This is a tall order, since the complex is well on its way to largely reproducing the production capabilities (if not capacity) that built the Cold War stockpile, a project that forms a major cost driver for modernization. Plutonium and uranium parts, as well as specialized non-nuclear components, will all be produced in new facilities for at least some part of the rebuilt stockpile using legacy processes. It seems unlikely that this complex will be supportable for the long term from both a cost and responsiveness point of view, which makes it important to plan for its future evolution.

These things are needed: tight collaboration between the design and production of stockpile parts and systems; new, modern tools and methods optimized for the unique materials, applications, and small batches for weapons; and scientific tools sufficient to design and certify new components produced using novel methods. In embryonic, ad hoc form, these advances are already underway, driven by the exigencies of modernization. But these goals ought to be built into the base program to ensure that the production complex of the future is robust and cost effective.

The national labs have started to focus on "production-aware design," an approach built on programs in advanced manufacturing that were initiated under stockpile stewardship. At Livermore, cost- and space-saving manufacturing technologies are being matured for the W80-4 and W87-1, and subsequently transferred to the plants. In collaboration with the Kansas City National Security Campus, Livermore has even opened a small production enclave onsite to improve integration of design and production teams—and provide backup or surge capacity—if ever needed. These are among a number of innovations being rapidly introduced to better execute on modernization in the near term, that with full commitment can help establish a more responsive complex for the long run.

In a further demonstration of the power of tight integration and collaboration to overcome obstacles, the "pit" design and production agencies Livermore and Los Alamos National Laboratories have worked together to resolve a daunting set of challenges to delivering parts on time for the W87-1. The current two-track plan for pit production is a target of opportunity for the future complex, a chance to explore novel approaches to a costly, high-impact part of the production footprint. Right now the plan is for the Savannah River site to reproduce exactly the production techniques being used at Los Alamos. A redesign could allow both the legacy process to meet demand and provide infrastructure to support more modern approaches.

Investments should be made in developing promising new manufacturing technologies—even at early stages—to address the unique needs of the nuclear stockpile. In some cases, technologies that were discarded should get a fresh look given new, relaxed requirements for production volume and throughput. Agile processes, including rapid prototyping, digital engineering, and the development of materials by design should be adopted wherever applicable.

Most important, nuclear design and testing tools have to be expanded to provide credible pathways to the certification of materials, parts, assemblies, and systems that make full use of these modern approaches and processes. Many of the building blocks for this exist today within the complex, and proper integration is needed. But the ability to access material properties at the so-called mesoscale is a crucial unmet experimental need. Moreover, if certification is to be put on a firm basis, critical research is needed to better understand and quantify performance uncertainties introduced into performance by new materials and manufacturing methods.

IV.

Despite the significant scale and complexity of the modernization that is underway, this program if carried out as currently envisioned will lead (in the 2030s) to much the same deterrent posture the United States fielded in the 1990s in terms of both the stockpile and the nuclear weapons infrastructure. Given the scope of technological and geopolitical developments since then—and taking into account a range of possible future developments—it seems unreasonably optimistic to rely on the possibility that the current round of stockpile modernization will be the final word.

If we can sustain the nuclear weapons enterprise over time by smoothing the boom-and-bust cycle that threatens to recur and pursue a path to a resilient and cost-effective production complex, we will have provided a basis for meeting deterrence needs in the long term. But to fully prepare for future uncertainties, we must continue our bold, robust pursuit of the science and technology that advances the frontiers of knowledge in fields relevant to nuclear weapons. It is this pursuit of new knowledge that will attract, challenge, and instruct the best and brightest in each generation to the program, and provide the best hope for meeting and controlling uncertainty.

While perhaps not explicitly part of the original stockpile stewardship vision, this perspective was, in practice, very much of its essence. The program committed to leadership in technologies including high performance computing and high energy lasers, aimed specifically at providing platforms for advancing our underlying understanding of physics and improving predictive capability for nuclear performance.

It identified and made marked progress on scientific grand challenges derived from our history of nuclear testing, including inertial confinement fusion and plutonium aging; and it provided the freedom to open new fields of research such as additive manufacturing, that, in the event, have helped enable the complex to better meet the “surprising” and time-urgent demands of modernization. In fact, while it is hard to imagine modernization succeeding without the stewardship program as a whole to build on, the research and development component by itself has been decisive.

In addition, in the post-testing era, continued investment in underlying science and technology (S&T) is the best way to continuously confront weapons scientists and engineers with new data that independently tests their acumen, maintains open minds, and challenges complacency and over-confidence. At the same time, to the extent work is open and publishable, it helps demonstrate in a direct way the scientific power that underwrites the effectiveness of the U.S. deterrent.

An effective S&T program accommodates continuous recruitment, training, and knowledge transfer in the workforce, ameliorating one of greatest threats of the cyclical approach to stockpile modernization that threatens to set in. Tying it to possible objectives related to rapid response—for example, limited builds of modified components or systems—would expand these benefits to the production sites and workforce, promote collaboration and integration, and help create the future production complex described above.

As technology advances, adversaries will adapt them to their own deterrence postures, and we must understand them as potential offensive threats. Hypersonic flight or anti-satellite weapons, for example, impact the both the survivability and effectiveness of the U.S. stockpile. Countering such threats—some of which confront us today—often have clear nuclear dimensions.

Modernization will succeed largely because it is reproducing the systems that already existed. To the extent modifications are being made, they are clearly within the compass of our nuclear test experience, augmented modestly—but crucially—by scientific tools introduced by stockpile stewardship. To be responsive will ultimately require the ability to certify well-defined excursions from current designs with quantitative uncertainties. The conceptual machinery to do this is within reach. Similarly, we are approaching the computational power that will be required to achieve modernization through a combination of high-performance simulation, machine learning, and experimental capability (in particular burning plasmas at the National Ignition Facility). This work, taking place largely on the fringes of a program preoccupied now with the near-term problems of meeting modernization milestones, provides a core for the next round of stockpile stewardship research and development.

V.

For 25 years the stockpile stewardship program has focused on the scientific goals of developing a predictive capability for the performance and aging of nuclear weapons, maintaining skills through annual assessment, and achieving deterrence through stockpile life extension programs. Despite its relatively modest goals with respect to updating the nation's deterrence posture, the current modernization program (driven by unexpected developments in geopolitics) has already overtaken and exposed the shortcomings of stockpile stewardship as implemented, if not envisioned. The nuclear enterprise is nevertheless poised to deliver on modernization, in no small part owing to what the original stewardship program got right: the deployment of next-generation science and engineering to maintain confidence in an aging stockpile.

The experience of the past 25 years, including the transition from stewardship to modernization, requires new thinking about how to approach an increasingly uncertain and less stable nuclear deterrence future. In particular, a "boom and bust" profile for the nuclear enterprise must be avoided and the infrastructure should be configured to prepare for change, even as it enables support for the current stockpile. The design agencies and production complex should look ahead and lay the groundwork for a subsequent round of capitalization that takes advantage of modern, cost-effective, and responsive product realization capabilities. This future must be firmly anchored in continuing advances in underlying science, technology, and engineering, as well as recognize the likelihood of new challenges and the demonstrated value of such investments.

As this goes to press, the Russian Federation has invaded Ukraine in an act of aggression without precedent on the European continent since World War II. Apparently the progress of the invasion has been slowed sufficiently, or the western response has been just strong enough, that the Russian President, Vladimir Putin, has put his nuclear forces on heightened alert status. These events together, if not alone, indicate that it is time to tear up our understanding of the risk calculus at work in the Kremlin. Under such rapidly evolving circumstances, it should go without saying that time is of the essence in developing and implementing a future stockpile stewardship and modernization program, and the complex needed to execute.

Russia’s Approach to Stockpile Modernization[4]

Michael Albertson

Understanding Russia’s nuclear weapons complex is vital to examining Moscow’s relative strengths in bilateral and multipolar strategic competition, perceiving how the post-Cold War era shaped present thinking, and recognizing how nuclear weapons will endure as a central feature to future competitive dynamics. In the United States, national security objectives and focus areas have been in constant flux during this period, with nuclear weapons thinking and expertise often shunted far off to the sidelines. Conversely, nuclear weapons in Russia have always remained at the center of the highest levels of policy and military discussions. As many studies of Russian power dynamics have noted, nuclear weapons are one of Russia’s few acknowledged and enduring “face cards.”[5] The robust Russian nuclear weapons complex of today required consistent senior level political and military attention, funding, and effort following the collapse of the Soviet Union and the perceived U.S.-imposed humiliations of the 1990s. Weaknesses were diagnosed, analyzed, and corrected. Risks were taken, with failures as frequent as successes. But the long-term goal was clearly understood, attention and funding were sustained, and the results can be clearly seen today.

Russia’s nuclear weapons complex casts a long shadow over many other aspects of the approach that the United States and its allies have taken to Russia: the pronouncements of Russia as a great power, the nuclear threats Russia makes against its neighbors, the Russian military’s highly integrated approach with nuclear weapons always at the center, the questions surrounding the future of arms control and Russia’s compliance with existing agreements, the Russian defense industry as a driver of scientific and technological innovation, and the questions surrounding Russia’s doctrine concerning the early use of nuclear weapons in a conventional conflict. Russia’s nuclear complex lies at the foundation of all these issues. To better explore the dynamics driving each of these aspects of strategic competition, this chapter examining the Russian nuclear weapons complex will be broken into six main sections: the political context, the military context, Russia’s changing nuclear arsenal, Russia’s nuclear weapons complex, Russia’s implementation of test constraints, and Russia’s nuclear future.

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[4] A special thank you goes to Dr. Brad Roberts and Dr. Anna Péczeli for their careful review of this chapter and their helpful edits and advice throughout the process.

[5] See for example Matthew Rojansky, “Russia and Strategic Stability” in *Strategic Stability: Contending Interpretations*, Elbridge A. Colby and Michael S. Gerson, eds. (Carlisle, PA: U.S. Army War College Press, 2013), p303.

The Political Context: Russia's Post-Cold War Era Approach to Nuclear Modernization

In the post-Cold War era, Russia was faced with a dramatic shift in the conventional balance. For the first time since the outbreak of World War II, Russia was faced with a situation of perceived conventional weakness along its vulnerable frontiers. Thus, for the last 30 years, a strong, capable nuclear force has always been seen as key to the survival of the Russian state and the ultimate guarantor against outside aggression or coercion. Because of its centrality in Russian defense planning, it has likewise received close attention from Russian political leadership. One lesson popularized from Russian history is that whenever Russia is militarily weak or politically divided, it is vulnerable to invasion by an outside power. The consequences of these invasions, ingrained in both Russian high culture and pop culture through literature and film, are immense in terms of their duration or their material and human cost to Russia. Therefore, perception to the outside world is critical: it is vitally important for Russia to be strong, or at least be seen as being strong; to Russia, strength in the modern era still comes from being a nuclear power.[6]

The other lesson from Russian history is that worst case scenarios can and do come true, with devastating consequences for the country. As Russian President Vladimir Putin said in 2004 after the terrorist attack on a school in Beslan, "We demonstrated weakness and the weak are beaten."[7] It is therefore vitally important to think about worst-case scenarios in detail, develop the necessary capabilities and operations to counter these scenarios, exercise against these scenarios, and then add in a degree of additional margin of error in case even worst-case analyses prove optimistic. Russian nuclear weapons are by default the final margin of safety in Russian security calculations. Anything that can impact that margin or sow doubt on the efficacy of nuclear weapons—such as the forward basing of adversary military forces, long-range conventional strike, missile defenses, space-based weapons, and so on—becomes of much more importance to a Russian audience than an outside observer would assume. As Putin remarked in his 2012 article "Strength is the Guarantee of Security for Russia," "as long as the 'powder' of our strategic nuclear forces created by the tremendous efforts of our fathers and grandfathers remains dry, nobody will dare launch a large-scale aggression against us."[8] The question then becomes how much powder Russia needs to achieve its perceived political and military objectives.

For Russian political leadership, nuclear weapons are a multifaceted tool that provide domestic and international benefits. First, they are important for international great power politics and respect. In Putin's mind, Russia has been consistently

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[6] For a wonderful study of the Russian regime's changing use of history see Mark Galeotti, *A Short History of Russia: How the World's Largest Country Invented Itself, from the Pagans to Putin* (Toronto: Hanover Square Press, 2021).

[7] Steven Lee Myers, *The New Tsar: The Rise and Reign of Vladimir Putin* (New York: Alfred A. Knopf, 2015), p260.

[8] Vladimir Putin, "Strength is the Guarantee of Security for Russia," *Rossiskaya Gazeta* (February 20, 2012).

sidelined and disrespected by the United States and its allies. It is not taken seriously by Washington as a great power: Russian concerns are ignored, Russian businesses are sanctioned, and Russian proposals are rejected. The West is not interested in a meaningful partnership or Russian integration into Europe, at least not under the conditions Russia has outlined. The West is also not a trustworthy partner, having shown multiple times that it will walk away from agreements that Russia values or break understandings Russia believes it has received. Putin's March 2018 speech on new kinds of nuclear-powered, nuclear-equipped strategic offensive arms amply demonstrated that nuclear weapons force the West to sit and listen to what Russia has to say, reminding the United States that Russia is a great power with enormous destructive potential.

> *After the collapse of the USSR, Russia, which was known as the Soviet Union or Soviet Russia abroad, lost 23.8 percent of its national territory, 48.5 percent of its population, 41 of the GDP, 39.4 percent of its industrial potential (nearly half of our potential, I would underscore), as well as 44.6 percent of its military capability due to the division of the Soviet Armed Forces among the former Soviet republics. The military equipment of the Russian army was becoming obsolete, and the Armed Forces were in a sorry state…*
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> *Apparently, our partners got the impression that it was impossible in the foreseeable historical perspective for our country to revive its economy, industry, defence industry and Armed Forces to levels supporting the necessary strategic potential. And if that is the case, there is no point in reckoning with Russia's opinion, it is necessary to further pursue ultimate unilateral military advantage in order to dictate the terms in every sphere in the future...*
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> *So, what have we done, apart from protesting and warning? How will Russia respond to this challenge? This is how.*[9]

Second, nuclear weapons development and production are state-led drivers of Russian science and technology. Nuclear weapons spending also serves an important mechanism for ensuring loyalty in Russian internal politics and with the military services. Unlike many fields in the global technology sector which are based on a sense of freedom and unorthodox risk taking inimical to a regime such as Putin's, the nuclear weapons complex can be directly overseen by the regime and used to support Kremlin policy. Its successful technological innovations—many which were developed in the formerly "closed cities" of the Soviet Union—can be controlled within the defense industry and the state apparatus. Within Putin's quasi-feudal governance system, nuclear weapons modernization allows the regime to distribute money, power,

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[9] Vladimir Putin, "Presidential Address to the Federal Assembly" (March 1, 2018). http://en.kremlin.ru/events/ president/ news/56957. Accessed February 10, 2021.

and prestige through the defense industrial complex and in various regions of the Russian state. Unlike the West, there is no domestic political opposition in Russia to spending more money on nuclear weapons or on the country's supporting complex. There is broad consensus within the Duma on the centrality of nuclear weapons in the Russian defense budget. Likewise, with nuclear weapons in every branch of the Russian armed forces and a clear recognition of the primacy of nuclear weapons in the budget, there is only competition among the military services to ensure their slice of the nuclear spending pie, rather than having to make hard budgetary choices between nuclear and non-nuclear systems.[10]

Third, the nuclear weapons complex and the Russian nuclear forces are in many respects a domestic and international representation of the vitality and power of the regime and its leader. Putin has gone out of his way throughout his tenure in office to be seen as directing Russia's nuclear forces and engaging with its systems hands on, a public embrace very different than seen in Western democracies. The Russian leader is depicted in state media as someone intimately familiar with all the aspects and details of his nuclear forces—operating the systems, observing exercises, executing missile launches, and questioning military and defense officials about minute programmatic delays and budgetary details.

President Putin preparing to fly a Tu-160 Blackjack strategic bomber in 2005.[11]

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[10] One recent example of nuclear weapons in the Russian defense budget can be seen at: Alexander Bratersky, "Russian nuclear weapons stand out in defense budget request," *Defense News* (November 1, 2021). https://www.defensenews.com/global/europe/2021/11/01/russian-nuclear-weapons-stand-out-in-defense-budget-request/. Accessed November 3, 2021.

[11] Photo featured in The Aviation Geek Club, "The Story of Russian President Vladimir Putin ride in a Tupolev Tu-160 Blackjack during a tactical exercise involving the launch of Kh-555 cruise missiles" (August 23, 2021). https://theaviationgeekclub.com/the-story-of-russian-president-vladimir-putin-ride-in-a-tupolev-tu-160-blackjack-during-a-tactical-exercise-involving-the-launch-of-kh-555-cruise--missiles/. Accessed January 14, 2022.

Russian President Vladimir Putin observes an exercise in the Barents Sea from aboard a submarine (February 2004).[12]

Putin examining the Topol-M mobile ICBM in December 2006 with deputy Prime Minister and Defense Minister Sergei Ivanov.[13]

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[12] Reuters photo featured in NATO Review, “50 years ago: The origins of NATO concerns about the threat of Russian strategic nuclear submarines” (March 24, 2017). https://www.nato.int/docu/review/articles/2017/03/24/50-years-ago-the-origins-of-nato-concerns-about-the-threat-of-russian-strategic-nuclear-submarines/index.html. Accessed January 14, 2022.

[13] Photo featured in The Kremlin. http://en.kremlin.ru/events/president/news/36825. Accessed January 14, 2022.

The preferred narrative arc of Putin's rule of Russia—that he inherited a crumbling and weak nation and rebuilt it into a power to be respected and feared—dovetails with that of the nation's nuclear weapons complex and the Russian military more generally. Nuclear modernization was made a clear priority early on in his first term. Significant time and energy were devoted to the complex's refurbishment and growth. Mistakes and missteps occurred and were overcome. The complex is now depicted as robust and able to tackle a wide variety of potential future challenges.

Lastly, Putin recognizes that a strong nuclear weapons complex provides Russia with options and flexibility, the illusion (if not the reality) of a strong set of cards in the player's hand. Russia's economy may languish. Its global importance can be questioned. But strength in this area allows Russia to punch above its geopolitical weight, "for its nuclear arsenal is the one area where Russia remains America's equal (and China's superior), and as such represents for many the most reliable guarantee of its continuing status as a global power."[14] It gives clout to Russian presence in multilateral groups such as the United Nations Security Council or the P-5 and in bilateral arrangements like the strategic partnership with China or strategic security/strategic stability dialogues with the United States. References to nuclear weapons are liberally sprinkled into Putin's speeches for international audiences, either with a direct reference to a hammer held in the speaker's hand or done more subtly as a dagger known to be hidden up the speaker's sleeve. At the bilateral negotiating table, Russia can sit back and see what the United States proposes for future arms control, confident that it is well positioned for an unconstrained competitive environment if it is unsatisfied with the proposals. It is a shadow which hangs over every potential military engagement on Russia's periphery, involving either NATO members or non-members of the alliance. If Putin is Russia, then nuclear weapons are his strong right hand, and he is quick to frequently remind domestic and international audiences of this fact.

The Military Context: Integration, Suffusion, and Predominance of Nuclear Weapons in Russia's Military Strategy

Since the beginning of the atomic age, Soviet military thinkers devoted a great deal of strategic thinking about the warfighting utility of nuclear weapons, the nuclear strategies and capabilities of the adversary, and the capabilities and operations necessary to achieve victory at various levels of conflict.[15] This carried over into the post-Cold War period. The Russian military of the post-Cold War era was left with a strong intellectual foundation and apparatus devoted to holistic analysis of the

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[14] Bobo Lo, *Russia and the New World Disorder* (London: Chatham House, 2015), p50.

[15] For a small sampling of the available literature see "The Soviet Approach to Deterrence" in *The Evolution of Nuclear Strategy*, 3rd ed., Lawrence Freedman, ed. (New York: Palgrave Macmillan, 2003), pp243-257; Joseph D. Douglass Jr., *The Soviet Theater Nuclear Offensive*, Studies in Communist Affairs, Vol. 1 (Washington, DC: U.S. Government Printing Office, 1976); Leon Goure et al., *The Role of Nuclear Forces in Soviet Strategy* (Washington, DC: Center for Advanced International Studies, 1974); V.D. Sokolovskii, *Soviet Military Strategy* (Rand Corporation translation, R-416-PR, 1963); and Raymond Garthoff, *Soviet Strategy in the Nuclear Age* (New York: Praeger, 1958).

nuclear problem set: studying a changing security environment (threat analysis), determining the potential role and utility of nuclear weapons within this environment (capabilities analysis), specifying nuclear requirements needed to address capability gaps (requirements analysis), designing the strategies, operations, and tactics to integrate nuclear weapons (operational art), and conducting the necessary training and exercises to ensure military readiness. Excellent work has been done in the last several years on the centrality of Russian nuclear weapons in Russian military strategy.[16] Rather than repeating these efforts, this chapter will instead highlight a few main aspects of how nuclear weapons are approached differently in Russia than in the West: the integration of conventional and nuclear thinking and operations; the suffusion of nuclear weapons throughout the forces and the Russian conception of the conflict spectrum; and the predominance of nuclear weapons in Russian military thinking and exercises. Russia regularly conducts snap exercises, simulated attacks on NATO member countries, clear preparation for both horizontal and vertical escalation, and large troop movements across long distances—always casting a nuclear shadow over any exercise by putting nuclear capabilities on high alert and dispersing dual-capable systems.

The Russian military of the 1990s was left with a significant strategic problem. Its longtime adversary, the United States, had just demonstrated a shockingly fast and comprehensive conventional victory over one of the largest and most capable regional military actors in Iraq, a country which had been supplied with the latest in Soviet military export equipment. The United States was at its military apogee, increasingly and openly thinking of its role as the world's sole military superpower and the transformative effects which could be achieved in this unipolar moment. While the United States was at its relative strongest point, Russia was arguably at its weakest, perhaps weaker than it had been since the end of World War I and the Russian Civil War. Its military forces and defense industrial complex were reduced, weakened, and fragmented with the breakup of the Soviet Union. Equipment was not being maintained, training and exercising were not occurring, and salaries were not being paid: all for the lack of funding, leadership, and organization in the midst of chaos. Symbolic of this time was the once vaunted Red Army suffering massive casualties from separatist forces in the ruins of the Chechen capital of Grozny.

Russian military thinkers were left with the realization that they only had two rungs on the escalatory ladder—an extremely weakened conventional force and a wide variety of strategic and non-strategic nuclear weapons—with which to defend a huge open periphery against a strengthened and seemingly emboldened adversary. Time, money, and sustained effort would be needed to deter aggression against Russia while it reconstituted its military during a time of conventional weakness. The solution

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[16] I would highlight in particular the work done by Michael Kofman, Anya Fink, and Jeffrey Edmonds at CNA. An example of their excellent publication record on Russian nuclear strategy is Michael Kofman, Anya Fink, and Jeffrey Edmonds, *Russian Strategy for Escalation Management: Evolution of Key Concepts* (April 2020). https://www.cna.org/CNA_files/PDF/DRM-2019-U-022455-1Rev.pdf. Accessed October 19, 2021.

was thus to take a page from NATO's playbook during the Cold War—an increased reliance on nuclear forces for deterrence to overcome conventional force weakness. As the 2010 Russian military doctrine highlighted, "nuclear weapons will remain an important factor for preventing the outbreak of nuclear military conflicts and military conflicts involving the use of conventional means of attack (a large-scale war or regional war)."[17]

For all the recent debates about increased Russian doctrinal reliance on nuclear weapons in its military strategy, this shift occurred fairly early after the collapse of the Soviet Union. Out of military necessity, Russia dropped its Soviet-era no-first-use pledge in its military doctrine unveiled in 1993. Its new pledge noted nuclear weapons were "a means of deterrence against the launching of aggression against the Russian Federation and its allies."[18] Russian Defense Minister Grachev commented that this was a necessary shift in light of economic and military realities, simply putting Russian declaratory policy in line with that of other nuclear powers.[19]

Russian military doctrine on the role of nuclear forces has evolved along these lines since the early 1990s, as Moscow has clarified that nuclear weapons could be used in a wide variety of situations which threaten the security of the Russian state. The 1997 National Security Concept commented on "the right to use all forces and means at its disposal, including nuclear weapons, in case an armed aggression creates a threat to the very existence of the Russian Federation as an independent sovereign state."[20] The 2000 Military Doctrine noted that Russia "reserves the right to use nuclear weapons in response to the use of nuclear weapons or other weapons of mass destruction against itself or its allies and also in response to large-scale aggression involving conventional weapons in situations that are critical for the national security of the Russian Federation and its allies"—a revision highlighting the role of strategic ambiguity in Russian doctrine as well as an increasing potential for use in response to regional wars.[21] The 2010 and 2014 updates were slightly more specific, but largely carried over this language on responses to conventional aggression "when the state's very existence has been threatened." Most recently a 2020 nuclear policy document signed by President Putin further expanded circumstances for nuclear use to include non-nuclear actions with strategic effects against critical Russian state or military facilities.[22]

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[17] *2010 Russian Military Doctrine*. Available at https://carnegieendowment.org/files/2010russia_military_doctrine.pdf. Accessed October 19, 2021.

[18] Daniel Sneider, "Russia Drops No-First-Use Pledge on Its Nuclear Weapons," *Christian Science Monitor* (November 4, 1993). https://www.csmonitor.com/1993/1104/04011x.html. Accessed October 25, 2021.

[19] Ibid.

[20] Nikolai Sokov, "Russia's 2000 Military Doctrine," *Nuclear Threat Initiative* (September 30, 1999). https://www.nti.org/analysis/articles/russias-2000-military-doctrine/. Accessed October 25, 2021.

[21] Ibid.

[22] *The Moscow Times*, "Russia Allows Nuclear Response to Conventional Attacks" (June 3, 2020). https://www.themoscowtimes.com/2020/06/03/russia-allows-nuclear-response-to-conventional-attacks-a70471. Accessed October 25, 2021.

Capabilities and operations have similarly evolved over the last 30 years to support the role of nuclear weapons in Russian military strategy. Russia's perceived conventional weakness vis-à-vis the United States was a consistent problem which needed to be addressed. Other challenges were also coming into focus: new U.S. capabilities such as conventional strike and missile defenses, emerging domains such as cyber and space, demonstrated U.S. operations in the Balkans and the Middle East, and concerns over U.S. sponsorship of destabilizing "color revolutions." As Russia adapted its military forces to meet these threats and conceived of new rungs in the escalatory ladder, nuclear weapons would continue to be always present as a possible tool.

As newer and more credible Russian conventional capabilities emerged, conventional-nuclear integration became a subject of increasing focus in Russian military journals. As Dave Johnson noted in his paper on Russian conventional strike capabilities, this integration is critical for understanding the Russian military's emerging approach to regional conflict, its creation of a single strategic toolkit, and the potential uses of conventional precision strike in regional crises and conflicts and their impact on nuclear thresholds.[23] Even as Russian conventional capabilities improved, however, the potential for nuclear use in a regional war or in response to conventional aggression remained firmly anchored in Russian thinking, ensuring a continual need for exploring and exercising the seams between conventional and nuclear domains to see whether new nuclear capabilities might be needed and developed.

Another major theme of the Russian military's approach to nuclear weapons is suffusion, seen in several different aspects. The first aspect is suffusion throughout the force structure. In addition to its strategic triad, Russia maintains a diverse array of nuclear capable non-strategic nuclear systems scattered through its ground, air, air defense, and naval forces.[24] Every service has nuclear options available to confront tactical, operational, and strategic challenges in the theater. The second aspect is suffusion across the spectrum of modern conflict. For Western audiences accustomed to a clean division between conventional and nuclear operations and crisis and conflict, the Russian approach to strategic deterrence is striking. As the following graphic demonstrates, nuclear weapons are in play throughout the maturation of a crisis and the various stages of conflict in the form of signaling, mobilization, and employment.

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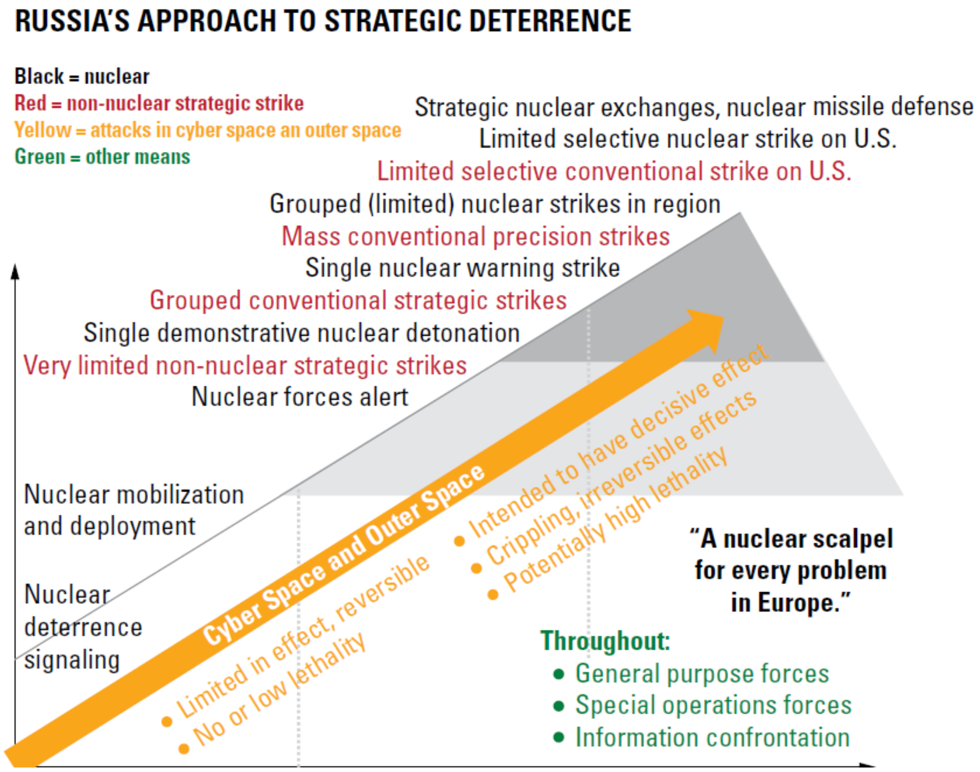
[23] For an excellent report on Russian conventional nuclear integration, see Dave Johnson, *Russia's Conventional Precision Strike Capabilities*, *Regional Crises, and Nuclear Thresholds*, Livermore Papers on Global Security No. 3 (Livermore, CA: Lawrence Livermore National Laboratory Center for Global Security Research, 2020). https://cgsr.llnl.gov/content/assets/docs/Precision-Strike-Capabilities-report-v3-7.pdf. Accessed October 25, 2021.

[24] Lt. Gen. Robert P. Ashley Jr., "Russian and Chinese Nuclear Modernization Trends," remarks as prepared for delivery at the Hudson Institute (May 29, 2019). https://www.dia.mil/Articles/Speeches-and-Testimonies/Article/1859890/russian-and-chinese-nuclear-modernization-trends/. Accessed October 25, 2021.



Source: Brad Roberts, On Theories of Victory: Red and Blue, Livermore Papers on Global Security No. 7. (Livermore, CA: Lawrence Livermore National Laboratory Center for Global Security Research, 2020), p52. https://cgsr.llnl.gov/content/assets/docs/CGSR-LivermorePaper7.pdf.

Suffusion is also seen with respect to time. Nuclear weapons are in play very early in a crisis, and options for their use are fully integrated with conventional operations as well as actions taking place in domains like space and cyber.

Taken as a whole, one can clearly see the predominance of nuclear weapons in Russian military strategy. Russia has a deep, active strategic culture of thinking about nuclear weapons. Unlike a U.S. Joint Staff comprised of officers from the various services on a short-term "joint" assignment, the Russian General Staff is a permanent staff with a clear career-long mission focus on looking holistically at the Russian military's capabilities and challenges. The Russian deterrence strategy has remained consistent in the post-Cold War era—the Russian political and military leadership should be prepared to use nuclear weapons first if Russia is losing a conventional war and the existence of the state is threatened.

The challenge Putin and his general staff faced was in making that strategy a credible one, transforming a crumbling conventional force and a legacy Soviet nuclear force into an integrated Russian military with numerous options up and down the ladder. What are the military objectives Russia needs to achieve? What types and amounts of nuclear and non-nuclear systems does Russia need to achieve them? How does Russia create the operations to use these capabilities effectively? How does Russia organize and restructure to perform these operations? How much does Russia need to exercise to test these operations? A great deal of sustained thought by military scholars, prioritization of allocations to nuclear forces in the defense budget, and senior military leadership took place in Russia over the last two decades to tailor the nuclear deterrence piece correctly. Setbacks were encountered. Certain programs were discarded. But the cumulative effect of a 20-30-year view is impressive, particularly how Russia has made hard choices in terms of prioritization, risk, and restructuring.

Russia's Changing Nuclear Arsenal

Russia's nuclear forces have made considerable progress in the last 20 years, as the clear and continued emphasis by President Putin on modernizing and replacing the Russian nuclear arsenal have borne fruit. Other resources are readily available to detail the various systems and force composition within the Russian arsenal.[25] This section instead will talk about the more macro trends in Russia's nuclear modernization and the key hallmarks of Russian nuclear forces.

Early in the 2000s, Russian military thinkers were concerned by the vulnerability of Russian nuclear forces to a U.S. first strike, that a potential "window of vulnerability" existed as several significant threat factors coalesced. The first was that Russia was just beginning the transformation of its Soviet legacy forces. The second was that the United States seemingly had a robust long-range conventional strike capability as well as the intention for rapid missile defense expansion following U.S. withdrawal from the ABM Treaty.[26] Moreover, the slow production of SS-27 Topol-M ICBMs (single-warhead silo-based and road-mobile) was not keeping pace with the dismantlement of the many legacy SS-18s, SS-19s, SS-24s, and SS-25s. Even further, the replacement Borey SSBN and its associated SLBM, the Bulava, were experiencing problems and delays in testing and development. At the same time, Delta III SSBNs were well past their intended service lives. And the Tu-160 BLACKJACK strategic bomber, Russia's most modern strategic bomber, was grounded for an extended period following a well-publicized crash, leaving Russia dependent on the turboprop driven Tu-95MS BEAR. For Russia, it was a total picture of known weaknesses and perceived rapidly advancing technological threats.

In such an environment, Russia needed a deterrence metric around which to base its new nuclear force structure, and the structure of the Russian forces today reflects a strong military intent to meet this deterrence objective under any conceivable circumstance. The metric, a familiar one in U.S. nuclear thinking, is "unacceptable damage." Usually defined by complex quantitative metrics of levels of destruction in

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[25] See, for example, Congressional Research Service, *Russia's Nuclear Weapons: Doctrine, Forces, and Modernization*, R45861 (September 13, 2021). https://crsreports.congress.gov/product/pdf/R/R45861#:~:text=Russia%E2%80%99s%20Euclear%20Weapons%3A%20Doctrine%2C%20Forces%2C%20and%20Modernization%20Russia%E2%80%99s,missiles%20%28ICBMs%29%2C%20submarine-launched%20ballistic%20missiles%20%28SLBMs%29%2C%20and%20heavy. Accessed October 25, 2021.

[26] The manifestation of Russian fears can be seen in Keir A. Lieber and Darryl G. Press, "The End of Mad? The Nuclear Dimension of U.S. Primacy," *International Security* 30, no. 4 (Spring 2006), pp7–44.

terms of population or industrial potential, the measure of success for the Russians was relatively simple: ensure that a certain number of strategic warheads—perhaps as many as 100, perhaps several hundred—was capable of reaching the United States homeland.[27] This would ensure both the proper level of material damage inflicted to deter an adversary, as well as achieve the appropriate psychological effect on the target to end or "win" the conflict on terms acceptable to Russia.

Developing the forces to meet these criteria in a complex and challenging geopolitical environment would prove, however, to be more challenging. Given the U.S. penchant for massed conventional strikes early in a conflict, Russian systems would need to survive long enough to be able to launch. This required either increased hardness against conventional attacks or increased mobility to get away from the base and avoid detection and targeting. Russian warheads would also need to be able to survive to hit targets within the homeland United States, surviving all the various effects of current and anticipated missile defenses. Russian solid rocket first stage motors would need to burn quickly to avoid being targeted in the boost and post-boost phase of flight before payload release. Russian warheads would need to be accompanied by penetration aids—balloons, jammers, chaff, and decoys—to avoid missile defense intercepting in the mid-course and terminal phases. U.S. missile defenses would need to be penetrated, overwhelmed, or bypassed. Targets in the U.S. homeland would need to be able to be reliably destroyed by various means, assuming one or more Russian systems suffered technical failures or were knocked out during a conflict. Emerging domains such as space and cyber would need to be understood and addressed to meet these objectives.

The Russian strategic forces of today are the result of this metric and these challenges in meeting this metric. They display several key hallmarks of survivability, flexibility, and redundancy that can be seen in the newly deployed weapons systems.[28] Heavy liquid-fueled ICBMs like the SARMAT ICBM have returned to the forefront of future Russian capabilities with their ability to deliver large numbers of hard-target, kill-capable warheads. While some in the West view the SARMAT as destabilizing, it is a practical way of dissuading a potential adversary first strike given the powerful incentives to launch out from under an incoming attack. The road-mobile RS-24 carries multiple warheads as well, providing more warheads in a survivable ICBM force to hedge against targeting the SSBNs. The Borey class SSBNs is a more capable replacement to the Delta III and Delta IV SSBNs they are replacing simply by having more reactor life and thus more ability to disperse away from base, just as modernized strategic bombers allow for more flight operations and forward deployment. Missile front sections can be configured in a variety of different ways to focus on maximum warhead loadouts or increased penetration aids for survivability. All

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[27] Michael Kofman and Anya Fink, "Escalation Management and Nuclear Employment in Russian Military Strategy," War on the Rocks (June 23, 2020). https://warontherocks.com/2020/06/escalation-management-and-nuclear-employment-in-russian-military-strategy/. Accessed October 25, 2021.

[28] Congressional Research Service, *Russia's Nuclear Weapons: Doctrine, Forces, and Modernization.*

of this provides redundancy as survivability can be achieved in each leg of the triad and warheads can be delivered in a variety of different packages and methods. As a result, the Russian military can meet targeting requirements in the face of uncertainty, as well as technical challenges in a crisis or conflict. Russia's theater nuclear forces, largely addressed in the previous chapter, have evolved along similar lines. Newer systems have been introduced into the force to likewise meet various unacceptable damage criteria set at the theater level. Russia has thus largely replaced its Soviet legacy force with a modernized mix of capabilities at both the tactical and strategic level.

There has been fierce expert debate about the implications of the so-called "novel" systems[29] announced by President Putin in his March 1, 2018 State of the Nation address to the Russian Federal Assembly.[30] Outside of arms control considerations and trade chips, some would argue Russia is pursuing a potential first strike capability or another form of coercive leverage by deploying new, larger, more dangerous strategic systems and expanding its triad. Others suggest their development shows deep seated fears about the vulnerability of Russia's current nuclear deterrent or reflect broader political goals in driving military and scientific innovation in the Russian defense industry.[31] The best approach is to examine each of the systems individually rather than lumping them together into a single category of new systems. Each has a different role. Each has a unique development history.

Their development makes perfect sense when placed into the larger context of the Russian metric of unacceptable damage and their modernization efforts focused on survivability, flexibility, and redundancy. Given the pace of technological change, and the uncertainties surrounding the long-term survivability of second-strike nuclear forces in the face of these changes,[32] it makes logical sense to hedge in these directions to ensure new ways of improving the survivability of warheads in order to meet unacceptable damage criteria. Ballistic and cruise missiles may become more vulnerable to interception. Mobile systems may become more locatable. Conventional strike systems may become more capable of hard target kills on missile silos.

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[29] The systems: 1) Avangard boost-glide system carried by an SS-19 or a Sarmat — reentry body carried atop a ballistic missile that can maneuver to evade air defenses and ballistic missile defenses to deliver a nuclear warhead to targets.
2) Poseidon Autonomous Underwater Vehicle — Carried by special-purpose submarines; intended as a second-strike, retaliatory weapon that can "generate a radioactive tsunami" to destroy cities along the U.S. coast.
3) Burevestnik Nuclear Powered Cruise Missile — "unlimited" range owing to its nuclear reactor; intended to overcome missile defense.
4) Kinzhal Air-Launched Ballistic Missile — intended to target naval vessels.
5) Tsirkon Hypersonic Cruise Missile — intended to attack ships and ground targets.

[30] President of Russia, "Presidential Address to the Federal Assembly" (March 1, 2018). http://en.kremlin.ru/events/ president/news/56957. Accessed October 25, 2021.

[31] The following piece provides a nice encapsulation of the various arguments concerning the systems. Matthew Kroenig et al., "Russia's exotic nuclear weapons and implications for the United States and NATO," The Atlantic Council (March 6, 2020). https://www.atlanticcouncil.org/in-depth-research-reports/issue-brief/russias-exotic-nuclear-weapons-and-implications-for-the-united-states-and-nato/. Accessed October 25, 2021.

[32] These arguments are explored in detail in Rose Gottemoeller, "The Standstill Conundrum: The Advent of Second-Strike Vulnerability and Options to Address It," *Texas National Security Review* 4, no. 4 (Fall 2021). https://tnsr.org/2021/10/the-standstill-conundrum-the-advent-of-second-strike-vulnerability-and-options-to-address-it/. Accessed October 25, 2021.

While Russian forces have come a long way in the last 20 years out of the shadow of a window of vulnerability, there is no breathing space. Russian military planners' fears of U.S. technological prowess and surprise (and now perhaps the growth of Chinese nuclear and non-nuclear capabilities) will continue to drive Moscow's force modernization in new qualitative and quantitative directions.

Russia's Nuclear Weapons Complex

Along with its delivery systems, Russia has prioritized the maintenance and modernization of a large and robust nuclear weapons complex inherited from the Soviet Union. The complex supporting the Russian nuclear weapons program is immense, with some similarities to that found in the United States in terms of overall footprint and types of facilities. There are the major nuclear weapons design centers, facilities responsible for the design and production of nuclear and non-nuclear components, sites for fissile material production, and facilities for warhead assembly and disassembly—all of which have analogues to some degree within the U.S. system. An illustrative list[33] can be found below:

Russian Minatom "closed cities" map[34]

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[33] Materials on the Russian nuclear weapons complex and its associated facilities are difficult to find in the open press, particularly at present in light of new Russian regulations against publishing information about "sensitive" military programs. As the nuclear weapons complex continues to consolidate and evolve, the roles of some of these facilities may have likewise been dropped or revised. This list should be seen as a useful starting point for discussion rather than a comprehensive and authoritative listing.

[34] Public Broadcasting Service, *Frontline*, "Russian Roulette," map of Russian Minatom closed cities, "Structure of Nuclear Facilities in Russia." https://www.pbs.org/wgbh/pages/frontline/shows/russia/arsenal/structure.html#:~:text=The%20major%20installations%20of%20the%20Russian%20nuclear%20weapons,weapons%20and%20produce%20fissile%20materials%20and%20weapon%20components. Accessed January14, 2022.

Russia's Nuclear Weapons Complex[35]

Closed Facility Name (Traditional, New Name)	Institution Name	Role
Arzamas-16, Sarov	Russian Federal Nuclear Center – All-Russian Scientific Research Institute of Experimental Physics (RFYaTs – VNIIEF), Nizhny Novgorod region	Nuclear Weapon Design, Nuclear Weapon Assembly/ Disassembly
Chelyabinsk-70, Snezhinsk	Russian Federal Nuclear Center – Academician E. I. Zababakhin All-Russian Scientific Research Institute of Technical Physics (RFYaTs – VNIITF), Snezhinsk, Chelyabinsk region	Nuclear Weapon Design
Chelyabinsk-65, Ozersk, Mayak	"Mayak" Production Association (PO "Mayak"), Ozersk, Chelyabinsk region	Plutonium Reprocessing, Tritium Production, Weapon Component Production
Krasnoyarsk-26, Zheleznogorsk	Mining and Chemical Combine (Gorno-Khimichesky Kombinat), Zheleznogorsk, Krasnoyarsk region	Weapons Grade Plutonium Production (ended in 2010)
Krasnoyarsk-45, Zelenogorsk	Urals Electrochemical Plant, Krasnoyarsk region	Uranium Enrichment
Penza-19, Zarachnyy	"Start" Production Association (PO "Start"), Penza Region	Nuclear Weapon Assembly/ Disassembly, Component Fabrication
Sverdlovsk-44, Novoural'sk	Urals Electrochemical Combine, Sverdlovsk region	Uranium Enrichment
Sverdlovsk-45, Lesnoy	"Elektrokhimpribor" Combine (Kombinat Elektrokhimpribor), Sverdlovsk region	Nuclear Weapon Assembly/ Disassembly, Weapon Component Fabrication
Tomsk-7, Seversk	Siberian Chemical Combine (Sibirsky Khimichesky Kombinat), Seversk, Tomsk region	Uranium Enrichment, Fabrication of HEU Weapon Components, Plutonium Production
Zlatoust-36, Trekhgornyy	Device-Building Plant (Proborostroitelny zavod), Trekhgorny, Chelyabinsk region	Nuclear Weapon Final Assembly/Disassembly

Table continued on next page

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[35] Thomas B. Cochran, Robert S. Norris, and Oleg A. Bukharin, "Russia's Nuclear Weapons Complex," table information derived from *Making the Russian Bomb: From Stalin to Yeltsin* (Boulder, CO: Westview Press, 1995), p94; Pavel Podvig, "Presidential decree lists Russia's military nuclear facilities," Russian strategic nuclear forces (July 10, 2007), https://russianforces.org/blog/2007/07/presidential_decree_lists_russ.shtml, accessed October 25, 2021; and Progretto Humus, "Russia's Nuclear Infrastructure," map in Tracking Nuclear Proliferation, Carnegie Endowment for International Peace (1998), https://www.progettohumus.it/wp-content/uploads/2018/05/ruinfrastrutture.pdf, accessed October 25, 2021.

No Special Closed Facility Designation	N. L. Dukhov All-Russian Scientific Research Institute of Automatics (N. L. Dukhov VNII Avtomatiki, VNIIA), Moscow	Nuclear Weapon Design
No Special Closed Facility Designation	Institute of Impulse Technologies (VNII Impulsnoi Tekhniki, VNII IT), Moscow	Nuclear Test Diagnostic Equipment
No Special Closed Facility Designation	Institute of Strategic Stability, Moscow	ROSATOM Think Tank
No Special Closed Facility Designation	Design Bureau of Road Equipment (KB Avtotransportnogo oborudivaniya, KB ATO), Mytyshchi, Moscow region	Nuclear Warhead Transportation and Handling Equipment
No Special Closed Facility Designation	Urals Electromechanical Plant (Uralsky electromekhanicheskiy zavod), Yekaterinburg	Production of Non-Nuclear Weapon Components
No Special Closed Facility Designation	“Sever” Production Association (PO Sever), Novosibirsk	Production of Non-Nuclear Weapon Components
No Special Closed Facility Designation	Federal Scientific Production Center “Yu. E. Sedakov Scientific Research Institute of Measurement Systems” (FNPTs “NII IS im. Yu. E. Sedakova,” NII IS), Nizhni Novgorod	Design of Non-Nuclear Components
No Special Closed Facility Designation	Bazalt, Raskovo settlement, Saratov region	Beryllium Production
No Special Closed Facility Designation	Expedition No. 2 (Ekspeditsiya No. 2), Novaya Zemlya Island, Arkhangelsk region	Nuclear Test Site
No Special Closed Facility Designation	Electromechanical Plant “Avangard” (Electromekhanichesky zavod “Avangard”), Sarov, Nizhni Novgorod region	Former Nuclear Weapon Assembly Facility
No Special Closed Facility Designation	Production Association “Molniya” (PO Molniya), Moscow	Production of Non-Nuclear Components
No Special Closed Facility Designation	Nizhnyaya Tura Machine-Building Plant (Nizhneturinsky mashinostroitelnyi zavod), Nizhnyaya Tura, Sverdlovsk region	Production of Support Equipment

There are a few major differences, however, between the U.S. and Russian nuclear complexes, which makes it problematic to directly compare the two complexes. The first is with regards to terminology. There is no single moniker in the Russian system for what its nuclear weapons complex is doing with regards to its warheads, which is something akin to the stockpile stewardship program in the United States. The term "stockpile stewardship" is occasionally applied to describe the Russian program,[36] primarily in the context of how budgetary increases in the Russian nuclear weapons complex in areas like supercomputing and simulations could allow Moscow to accomplish its tasks without resorting to nuclear testing.[37] But the Russian nuclear weapons complex is also seeking these advanced capabilities to remain at the state of the art in terms of technological capabilities, something independent of the nuclear testing issues which will be discussed in detail in the following section. As one Russian article stated, with these investments "our bomb makers will now become less jealous of their competitors from Los Alamos, Livermore, and Sandia [the primary nuclear weapons focused U.S. national laboratories]."[38] More frequent terms of what the Russian nuclear weapons complex is doing is that it does "assembly/disassembly of nuclear warheads" (in Russian descriptions) or that it maintains a "warm" or "hot" warhead production line (in U.S. descriptions). As Undersecretary of Defense Douglas Feith noted when briefing Congress about the 2001 Nuclear Posture Review: "Russia has a large [nuclear weapons] infrastructure. They have a warm production base capable of producing large numbers of new nuclear weapons annually."[39]

The second major difference is with regards to throughput in the complex, which is largely a function of Russian warhead design. The Director of the Defense Intelligence Agency stated in 2019 that "in contrast to the United States, during the past decade Russia has improved and expanded its production complex, which has the capacity to process thousands of warheads annually."[40] Part of this asymmetry is based on the long-standing requirements of the force, but the maintenance and modernization of a warm processing line was also needed to support the broader nuclear modernization effort undertaken by Putin. The other part of this is Russian warhead design. Russian warheads reportedly have a shelf life of approximately 10-15 years, due to the degradation of their conventional high explosive and fissile components. Their deployment cycle is reported to be three years long, after which they are removed from their delivery systems, shipped to a serial production facility for modernization and refurbishment, and then placed in storage prior to a new cycle of operational

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[36] See for example Siegfried Hecker, ed., *Doomed to Cooperate, Vol. II*, Section VI (Los Alamos, NM: Bathtub Press, 2016).

[37] Pavel Podvig, "Russian stockpile stewardship program," Russian strategic nuclear forces (June 9, 2010). https://russianforces.org/blog/2010/06/russian_stockpile_stewardship.shtml. Accessed October 27, 2021.

[38] Alexander Emelianenkov, "Sarov and Snezhinsk raised the bar," *Rossiskaya Gazeta* (June 10, 2010). https://rg.ru/2010/06/10/atom.html. Accessed October 27, 2021.

[39] Senate Armed Services Committee, Hearing on the Results of the Nuclear Posture Review (February 14, 2002). Available at https://www.armscontrol.org/act/2002-10/features/breakdown-breakout-us-russian-warhead-production-capabilities#1.

[40] The term "process" is chosen carefully in this statement. Processing is not the same as production. Instead, it is a combination of production, refurbishment, and dismantlement—with the total capacity of the production complex divided between these three efforts depending on force and stockpile requirements in any given year. Hudson Institute, "Transcript: The Arms Control Landscape ft. DIA Lt. Gen. Robert P. Ashley, Jr." (May 31, 2019). https://www.hudson.org/research/15063-transcript-the-arms-control-landscape-ft-dia-lt-gen-robert-p-ashley-jr. Accessed October 27, 2021.

deployment.[41] Thus warheads are always cycling through the complex as they move between production, deployment, refurbishment, and elimination. With a significant force of close to 6,000 estimated strategic and non-strategic nuclear warheads and a weapons design requiring constant refurbishment and replacement, the Russian nuclear weapons complex has been kept constantly in motion during the post-Cold War era handling, fixing, and improving nuclear weapons. This constant motion is expected to continue as new systems enter the force.[42]

The third major difference is with regards to the modernization of the nuclear weapons complex. Like with the Russian nuclear arsenal, its nuclear weapons complex has made significant strides over the last two decades because of sustained leadership attention, prioritization in the Russian defense budget, and a willingness to take short-term risks to achieve longer-term objectives. In the 1990s and early 2000s, the Russian nuclear weapons complex was largely seen as underfunded and crumbling, with its inability to retain scientists or perform its mission paralleling the qualitative and quantitative decline in the Russian strategic forces. Laboratory-to-laboratory efforts and programs like Cooperative Threat Reduction led by the United States were all designed to arrest the precipitous decline of the Russian nuclear laboratory infrastructure and secure both materials and scientific knowledge. To Russia, these unfortunately became a visible symbol of weakness—that its most important programs and sensitive facilities were dependent on American money and open to American visitors. Thus, when Putin assumed office, it became a clear priority for him to fix this known problem, one which lay at the heart of a broader modernization program for Russia's nuclear forces and its scientific future. Facilities were upgraded and consolidated. Technologies were modernized. Funding was sustained in the defense budget. The importance of nuclear weapons was highlighted frequently in major national security documents. While this time of evolution likely contributed to Russian fears of a window of vulnerability in the early 2000s, the overhaul of the complex is now complete, and Russia is in a much stronger position to deal with a more uncertain future.

Russia's Implementation of Test Constraints

Russia's record on testing constraints has been another subject of high-level interest, both in terms of compliance with U.S. interpretations of arms control obligations under the Comprehensive Test Ban Treaty (CTBT) as well as what it means

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[41] Russian warhead lifecycle details were taken from the statements of the former head of the 12th Main Directorate of the Russian Ministry of Defense; the organization is responsible for warhead security, maintenance, operations, and transportation. Oleg Bukharin, "A Breakdown of Breakout: U.S. and Russian Warhead Production Capabilities," Arms Control Association. https://www.armscontrol.org/act/2002-10/features/breakdown-breakout-us-russian-warhead-production-capabilities#notes. Accessed October 27, 2021.

[42] Alexander Bratersky, "Russian nuclear weapons stand out in defense budget request," Defense News (November 1, 2021). https://www.defensenews.com/global/europe/2021/11/01/russian-nuclear-weapons-stand-out-in-defense-budget-request/. Accessed November 3, 2021.

for Russia's ability to field new and better nuclear warheads. Consensus seems to have consolidated around the fact that Russia is likely performing low-yield tests, and that this testing is important to the development of Russian warheads. There is more debate about whether the sides have similar legal interpretations of whether such testing is allowed under the CTBT.[43] The 2009 *Final Report of the Congressional Commission on the Strategic Posture of the United State*s stated that "apparently Russia and possibly China are conducting low yield tests."[44] More recently, the Director of the Defense Intelligence Agency highlighted Russian testing and what it meant for Russia's nuclear weapons program:

> *Russia's development of new warhead designs and overall stockpile management efforts have been enhanced by its approach to nuclear testing. The United States believes that Russia probably is not adhering to its nuclear testing moratorium in a manner consistent with the "zero-yield" standard.*
>
> *Our understanding of nuclear weapon development leads us to believe Russia's testing activities would help it to improve its nuclear weapons capabilities. The United States, by contrast, has forgone such benefits by upholding a "zero-yield" standard.*[45]

The Russian decision on nuclear testing should not be surprising, however. It is by no means a new revelation, as the contours of the debate have long been visible in Russian statements. These Russian developments have long been known and long been judged as unlikely to upset the strategic balance between the United States and Russia. While the United States has also had an open debate about the moratorium and its impact on its nuclear weapons complex, with laboratory or military leadership speaking at the time in favor of renewed testing, the preponderance of U.S. views has been in favor of maintaining the current stockpile stewardship approach. In Russia, ever since the beginning of the testing moratorium, there have been prominent voices in favor of the necessity of testing to maintain a strong and viable nuclear deterrent. Sometimes the necessity is couched in terms of safety. Senior leadership of the 12th Main Directorate of the Ministry of Defense, the organization responsible for maintaining the security and safety of Russia's nuclear warheads, has periodically

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[43] Russian CTBT interpretations can be understood as follows: "According to an understanding reached at the talks, this does not prohibit experiments with nuclear pulse reactors, inertial-confinement fusion experiments (including research with military applications), or so-called hydrodynamic experiments that do not include fission chain reactions." Pavel Podvig, ed., *Russian Strategic Nuclear Forces* (Cambridge, MA: MIT Press, 2004), p457. For a useful primer on the CTBT, see Anna Péczeli and Bruce Goodwin, *Technical Issues in the Comprehensive Nuclear Test Ban Treaty (CTBT) Ratification Debate: A 20-Year Retrospective* (Livermore, CA: Lawrence Livermore National Laboratory Center for Global Security Research, 2021). https://cgsr.llnl.gov/content/assets/docs/CGSRctbtONLINE.pdf.

[44] William J. Perry and James R. Schlesinger, *America's Strategic Posture: The Final Report of the Congressional Commission on the Strategic Posture of the United States* (Washington, D.C.: U.S. Institute of Peace, 2009), p83. https://www.usip.org/strategic-posture-commission/view-the-report. Accessed January 14, 2022.

[45] Hudson Institute, "Transcript: The Arms Control Landscape ft. DIA Lt. Gen. Robert P. Ashley, Jr."

issued statements that testing was needed to ensure warhead safety.[46] Scientific articles highlight that the Russian inability to conduct tests would be problematic for ensuring the safety of non-nuclear components, as Russian warheads do not use insensitive high explosives like the United States.[47] Other times testing is emphasized as something needed for the very survival of Russia's nuclear deterrent. In April 1996, Russian leadership emphasized that while Russia would sign the CTBT, it would take measures to maintain the combat readiness, reliability, and safety of its nuclear weapons and that Russia might reconsider its attitude to the treaty if the test ban should jeopardize the readiness or safety of its arsenal.[48] At an April 2002 press conference, two former Russian Ministers of Atomic Energy, Viktor Mikhaylov (1992-1998) and Yevgeniy Adamov (1998-2001) both stated Russia faced a choice of resuming tests or forgoing nuclear weapons altogether.[49]

What is apparent is that despite the technological investments in the Russian nuclear weapons complex, Russia has never felt entirely comfortable moving to a technology-based, U.S.-style stockpile stewardship approach. There was simply too many unknowns and too much at stake, either in terms of advancing programs to guarantee Russian security requirements, maintaining safety and reliability on existing and future weapons, and maintaining and training a scientific technical base.

The Russian attitude on nuclear testing can best be seen in the comments of Rady I. Ilkaev, scientific director of the Russian Federal Nuclear Center (VNIIEF), the Russian equivalent of a combined Los Alamos National Laboratory and Sandia National Laboratory (given VNIIEF's responsibility for the complete weapons R&D cycle).[50] In a book chapter entitled "Nuclear Weapons of Russia: Their Value and Development Concept," Ilkaev outlined the challenges with a nuclear testing moratorium:

> *Let us consider what issues we were solving with nuclear tests and what we have lost by banning them. First, nuclear tests assured the reliability and safety of the existing nuclear arsenal. Second, they provided for the development of new nuclear weapons that met pressing defense requirements and new challenges, and they were able to determine the required level of durability of military equipment. It is obvious that the second set of issues cannot be solved without nuclear testing.*

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[46] Kirill Belyaninov, "The Administration of the US is ready to Resume Nuclear Explosions," Novyye izvestiya, (January 11, 2002), "Claim that Defense Ministry's 12th Main Directorate in Favor of Resuming Tests," FBIS Document CEP20020111000320. Cited in https://nonproliferation.org/renewed-us-russian-controversy-over-nuclear-testing/.

[47] "Nelzya isklyuchit vozmozhnost khishcheniya yadernykh materiyalov," *Yadernyy kontrol*, No. 34/1997, in Integrum Techno, http://www.integrum.ru/. Cited in https://nonproliferation.org/renewed-us-russian-controversy-over-nuclear-testing/.

[48] Pavel Podvig, ed., *Russian Strategic Nuclear Forces*, p457.

[49] "Yadernaya energetika i opasnost rasprostraneniya yadernogo oruzhiya. Strany 'yadernogo kluba'—garanty stabilizatsii ili vdokhnoviteli novykh yadernykh ispytaniy?,"Agentstvo informatsionnogo vzaimodeystviya (April 11, 2002). Cited in https://nonproliferation.org/renewed-us-russian-controversy-over-nuclear-testing/.

[50] Pavel Podvig, ed., *Russian Strategic Nuclear Forces*, p103.

> *With regard to the first set of issues, there are a number of debatable points. Since nuclear tests have always been used to create nuclear weapons and maintain their reliability, we need assurances when asked whether nuclear weapons can exist long-term in the absence of nuclear testing or whether a test ban is an intermediate step toward the ultimate degradation of nuclear weapons.*
>
> *An essential fact here is the realization that not being able to test our arsenal is a problem and that the problem exists as a result of a politically motivated decision, not supported by the nuclear weapons experts.*[51]

Having outlined the problems of the political decision, he notes other issues—an inevitable loss of skills; the necessity for expensive complex facilities and special programs to maintain, upgrade, and certify nuclear warheads; and the need for an even more ambitious and costly scientific base to advance the science of nuclear and thermonuclear weapons.[52] Having made a political decision, he points the finger at political leadership to realize and address the problem.

The Russia logic, at least from those most responsible for nuclear weapons, is fairly clear:

- nuclear warheads are integral to Russian deterrence and defense
- Russian warheads must reliably meet safety and security requirements
- new warheads need to be developed to meet military requirements
- testing is a proven way to accomplish these goals with certainty, while stockpile stewardship in contrast involves both increased costs and increased uncertainty with little perceived benefit

Russia's Nuclear Future

The conclusion to this chapter will make three broad points. First, nuclear weapons are important to Russia in a way that is almost unimaginable in the United States. They are instruments of Russia's great power status, evidence of the resurgence of Russia from a period of weakness in the 1990s, and a sign of national strength and technological prowess. They are fully embraced by Russian political leaders as a physical embodiment of all that is good and strong about the country. Moreover, as a visible demonstration of regime strength and success, Russian leadership goes out of its way to be publicly depicted with its nuclear arsenal in exercises and launches. In 2012, Putin directly pointed at nuclear weapons as the savior of Russian sovereignty:

> *We should not tempt anyone by allowing ourselves to be weak. It is for this reason that we will under no circumstances surrender our strategic deterrent capability, and indeed, will in fact strengthen it. It was this*

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[51] *Doomed to Cooperate*, pp375-376.

[52] Ibid., p376.

> *strength that enabled us to maintain our national sovereignty during the extremely difficult 1990s, when, let's be frank, we did not have anything else to argue with.*[53]

A popular Russian t-shirt printed in response to sanctions by the West following Russian aggression against Ukraine. The slogan reads "Topol [road-mobile ICBM]s aren't afraid of sanctions."[54]

Second, Russia's nuclear weapons are different than those of the United States in several respects. Not necessarily better, but simply different than would appear from a surface comparison of the doctrine, capabilities, and complexes of the two largest nuclear weapon states. Apples-to-apples comparisons, often to find common ground for strategic stability talks or trade space for future arms control agreements, miss many of the important nuances which make the complexes and capabilities different.

Finally, Russia has worked long and hard over the last two decades to transform its nuclear weapons complex from a position of weakness to one of strength. Analysts returning to study Russia after a long hiatus would be surprised to see a very robust capability and a very confident leadership, and they perhaps would have missed the risks that were taken and mistakes that were overcome over the last 20 years by Russian leadership to get to this point.

Do the asymmetries matter? They signal that the greatest advantage Russia has gained through the investments in its nuclear complex is that Russia has options.

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[53] Article by Prime Minister Vladimir Putin in *Rossiiskaya Gazeta* (February 20, 2012). http://archive.premier.gov.ru/eng/events/news/18185/. Accessed January 14, 2022. Reprinted in *Doomed to Cooperate*, p405.

[54] Photo featured in Mat Babikak, "In response to sanctions, Moscow goes nuclear," *Euromaidan Press* (September 24, 2014). https://euromaidanpress.com/2014/09/24/in-response-to-sanctions-moscow-goes-nuclear/. Accessed January 14, 2022.

It has more potential alterative future pathways. Political and military options are enormously valuable in a time of geopolitical uncertainty and technical advancement. Russia is now well prepared to negotiate from a position of strength at the arms control table. It has many cards in its hand, perhaps even some that could be traded away for its own set of longstanding demands. But Russia is equally well prepared to walk away from the table and enter a world of where strategic arms control does not exist. In short, Russia can cooperate and compete simultaneously to maximize its advantages and punch above its geopolitical weight. Russia also has technical options—that is, the ability to go in a number of different directions with its future warhead development efforts. Russia is prepared for the two most likely scenarios it will face in the next five years: a strategic competition constrained to some degree by arms control, and a strategic competition wholly unconstrained by arms control.

These options, however, have not granted Russia what it most desperately seeks: long-term security, regime stability, and a guarantee of safety. Russia has spent a great deal of time and money building its new modernized strategic force. It has a wide variety of delivery systems, thousands of warheads, and a robust nuclear complex stretching across Russia. However, its continued focus on better warheads and more exotic delivery systems demonstrates that Russian leadership cannot really pause to revel in successfully implementing a long-term vision. There is always the threat that technological advances will combine with adversary intentions to form an instrument that could nullify Russia's deterrent and leave it open to weakness, coercion, and dissolution. As with Tsar Nicholas I, the reign of a long and seemingly successful Russian leader can end quickly—with a demonstration of technological backwardness and military defeat.

China's Approach to the Long-Term Development of Its Nuclear Deterrent

Michael Anastasio

While the United States modernizes its legacy nuclear weapons under the principle of stockpile stewardship and while Russia aggressively modernizes and develops new types of nuclear weapons, how has China approached the long-term development of its nuclear arsenal? For many years, China's answer has been that it seeks only to maintain a "lean and effective" nuclear force in service of its no-first-use policy.[55] Doubts about this answer have increased in recent years as China's nuclear forces have grown rapidly.[56] Revelations in the summer and autumn of 2021 of a significant expansion of its silo-based force are one example of this growth that led Admiral Charles Richard, the commander of U.S. Strategic Command, to argue that China is engaged in "strategic breakout."[57] President Xi Jinping has amplified U.S. concerns about China's nuclear future in several statements, promising "a great rise in strategic capabilities" (2016), "breakthroughs…in strategic deterrence capability" (2017), and affirming his ambition that China secure "a dominant role…at the center of the world stage" (2019).[58]

This chapter examines China's approach to the long-term development of its nuclear arsenal. It begins with brief reviews of main themes in China's grand strategy and military strategy as they relate to nuclear weapons. It next examines key developments in China's rapidly evolving nuclear force. The chapter then turns to a review of available information on China's nuclear weapons complex and approach to stockpile modernization.

China's Political Strategy and Nuclear Weapons

The Chinese Communist Party (CCP) has put its primary focus on their vision of national rejuvenation, which involves modernization of social, economic, and military institutions and capabilities under tight political control by the party. CCP leaders aspire for China to restore the country's historically preeminent place in the world and to become a great modern socialist country. For a civilization that stretches back over thousands of years, this aspiration is deeply influenced by repeated violations of China's national sovereignty by foreign powers and by the lack of social, economic,

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[55] Eric Heginbotham et al. "Baseline: China's Evolving Strategic Nuclear Concepts," Chapter 2 in *China's Evolving Nuclear Deterrent* (Santa Monica, CA: RAND, 2015).

[56] Ibid.

[57] Adm. Charles A. Richard, "Statement of Charles A. Richard, Commander, United States Strategic Command Before the Senate Committee on Armed Services" (April 20, 2021).

[58] Brad Roberts, "China and the 2021 Nuclear Posture Review: Testimony before the U.S.-China Economic and Security Review Commission Hearing on China's Nuclear Forces" (June 10, 2021).

and even physical security of the Chinese people. The party is engaged in wide-ranging efforts to expand China’s national power, to perfect its governance systems, and to revise the international order seeking to achieve “the great rejuvenation of the Chinese nation” by 2049. This rejuvenation is intended to restore China to a position of strength, prosperity, and leadership on the world stage. China views itself as embroiled in major international competition with other states and that their socialist system with Chinese characteristics ultimately is a source of tension with the West.[59]

In its 2021 Annual Threat Assessment, the U.S. Intelligence Community judged that the CCP “will continue its whole-of-government efforts to spread China’s influence, undercut that of the United States, drive wedges between Washington and its allies and partners, and foster new international norms that favor the authoritarian Chinese system.”[60]

To successfully execute this strategy, the CCP is bringing together foreign policy, economic policy, military-civilian fusion (blurring the lines between military and civilian science and technology innovation and industry), and defense policy. In particular, China’s defense policy makes it an imperative to have a “world-class” military led by the CCP which can “fight and win” and “resolutely safeguard” the country’s sovereignty, security, and development interests.[61]

In support of this national strategy, the role of nuclear weapons is shifting. For decades, China downplayed its nuclear capabilities, as part of a strategy “to hide and bide”—that is, to keep out of sight China’s improving military capabilities until a future time when its new strength could be used to good benefit. In contrast, Xi Jinping has talked about nuclear weapons as important instruments of national power and great power status. But there has been no elaboration of what might be required to make China’s nuclear deterrent “world class.”[62]

Chinese Military Strategy and the Role of Nuclear Weapons

The People’s Liberation Army (PLA) is evolving and advancing its capabilities and concepts to continue strengthening China’s ability to counter an intervention by a third party in a conflict along its periphery, project power globally, and deter nuclear attack.[63] China is rapidly executing a comprehensive modernization program to build a robust military spanning all domains, including conventional, nuclear, cyber, space, and information.

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[59] Office of the Secretary of Defense, *Military and Security Developments Involving the People’s Republic of China 2020*, Annual Report to Congress (2020).

[60] Office of the Director of National Intelligence, *2021 Annual Threat Assessment of the U.S. Intelligence Community* (April 9, 2021).

[61] Office of the Secretary of Defense, *Military and Security Developments Involving the People’s Republic of China 2020*, Annual Report to Congress (2020).

[62] Ibid.

[63] Ibid.

The CCP desires to ultimately modernize the PLA through an indigenous, self-reliant, fused civilian-defense industrial sector. In the meantime, it continues to acquire foreign sensitive and dual-use technologies and equipment through both licit and illicit means. It seeks leadership in a number of key technology areas with military applications, such as artificial intelligence, autonomous systems, advanced computing, quantum information sciences, biotechnology, and advanced materials and manufacturing.[64]

The PLA's modernization program has significant implications for the size, capabilities, and readiness of its nuclear forces. Historically, the overall strategy for China's nuclear policy has been based around the concept of a limited function for nuclear weapons. Mao Zedong was heavily influenced by the implicit threat of nuclear weapons use against China during the Korean War and again in the Taiwan Straits Crisis of the mid-1950s. He viewed nuclear capability as critical to both deterring nuclear use against China and countering potential coercion by nuclear powers.[65] China's commitment to become a nuclear power became apparent when it conducted its first nuclear test in 1964.

China has seen nuclear weapons as critical to both deter nuclear use against China and to counter coercion by nuclear-armed powers. Key elements of its nuclear policy are to maintain an assured, but minimal, retaliatory capability through an arsenal that is "lean but effective," with a no-first-use doctrine. "Lean but effective" implies that China has chosen appropriate technology and deployment methods that allow its nuclear weapons to sufficiently deter nuclear attacks. As long as their retaliatory force is adequate, China believes it can avoid an arms race.[66] However, these concepts allow for a broad interpretation that also changes over time.

China's implementation of its policy for an assured, minimal retaliatory capability depends on leadership assessments of multiple factors, such as: the likelihood of a nuclear attack by an adversary, the vulnerability of China's retaliatory capability to nuclear and non-nuclear attack, their susceptibility to nuclear coercion, and the appropriate balance of these efforts with other developmental needs. As its perception of these factors has changed over time, China's force structure has evolved from a posture that imposes the risk of second strike against an adversary to a posture of assured retaliation.[67] This has resulted in a force evolving from a small number of atomic weapons to thermonuclear weapons, to more compact warheads and solid propellant missiles, and finally to the few hundred weapons and mobile delivery platforms of today (a more detailed discussion follows below).

China has maintained that its nuclear forces are intended for self defense. As part of this intent is a pledge of no-first-use of nuclear weapons: that China will not employ

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[64] Ibid.

[65] Eric Heginbotham et al., "Baseline: China's Evolving Strategic Nuclear Concepts," in *China's Evolving Nuclear Deterrent.*

[66] Ibid.

[67] Ibid.

nuclear weapons unless it has been the subject of nuclear attack. The efficacy of a no-first-use doctrine relies on the threat of a retaliatory second-strike capability. If that capability is in question, even by non-nuclear threats, the deterrent value of the nuclear force could be weakened or negated, driving a shift to a posture of assured retaliation. As Fiona Cunningham and Taylor Fravel have argued, these pressures may "... create strong pressures on China to expand its force structure to ensure survivability under its existing strategy or abandon assured retaliation for a first-use posture ..."[68] Moreover, the Department of Defense (DOD)'s 2021 assessment of China's strategy judges that "the PRC's nuclear weapons policy currently prioritizes the maintenance of a nuclear force able to survive a first strike and respond with sufficient strength to conduct multiple rounds of counterstrike, deterring an adversary with the threat of unacceptable damage to its military capability, population, and economy."[69] A 2015 RAND study concluded that "Although China is unlikely to abandon adherence to both its no-first-use policy and a 'lean and effective' nuclear force structure, it will likely acquire capabilities more relevant to warfighting doctrines and may begin to discuss or interpret its policies and practices in ways that could accommodate using nuclear weapons for a wider range of purposes."[70] In fact, some believe that it "... has become quite clear that the Chinese are signaling that a conventional strike on nuclear assets (and potentially nuclear command and control) would be grounds for nuclear retaliation."[71]

China's Rapidly Evolving Nuclear Force

China has been expanding and diversifying its nuclear weapons and forces through a modernization program that has been essentially continuous from the start, as its short-lived first-generation systems were replaced by newer and more capable versions beginning in the 1980s.[72] Over the past 30 years, China's forces have undergone a significant transformation. In recent years, the pace of change has rapidly accelerated.

China has moved to solid fuel rockets, which are very responsive and have the potential for launch under attack. They have been deployed as precision strike delivery systems such as the dual-use road mobile DF-26 intermediate-range ballistic missile (IRBM)—providing a regional threat that is capable of precision strikes in the Western Pacific, the Indian Ocean, and the South China Sea from mainland China. In addition, they have deployed survivable road-mobile ICBMs with the CSS-10 mod 2 (DF-31A)

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[68] Fiona S. Cunningham and M. Taylor Fravel, "Assuring Assured Retaliation: China's Nuclear Posture and U.S.-China Strategic Stability," *International Security* 40, no. 2 (2015).

[69] Office of the Secretary of Defense, *Military and Security Developments Involving the People's Republic of China 2021 – Annual Report to Congress* (November 2, 2021). https://media.defense.gov/2021/Nov/03/2002885874/-1/-1/0/2021-CMPR-FINAL.PDF. Accessed December 22, 2021.

[70] Eric Heginbotham et al., "Baseline: China's Evolving Strategic Nuclear Concepts," in *China's Evolving Nuclear Deterrent.*

[71] Christopher Twomey, "China's Nuclear Doctrine and Deterrence Concept," Chapter 3 in *China's Strategic Arsenal*, James M. Smith and Paul J. Bolt, eds. (Washington, DC: Georgetown University Press, 2021).

[72] Eric Heginbotham et al., "Baseline: China's Evolving Strategic Nuclear Concepts," in *China's Evolving Nuclear Deterrent.*

class missile capable of striking locations within the continental United States. The CSS-20 (DF-41), also a road-mobile ICBM, became operational in 2020 and "is thought to be capable of carrying multiple independently targetable reentry vehicles" which can allow multiple warheads, decoys, and/or penetration aids.[73] It is also possible that the DF-41 could be rail-mobile or launched from silos.[74]

The summer of 2021 brought revelations, via commercial satellite imagery, about the construction of several nuclear missile fields in western China with about 250 new ICBM silos.[75] These silos dramatically augment the approximately 20 CSS-4 Mod 2 and Mod 3 MIRV equipped, liquid fuel silo-based missiles with ranges of up to 13,000 kilometers.[76]

China has constructed 12 nuclear submarines. Six of these are second generation Jin-class (Type 094) nuclear-powered ballistic missile submarines (SSBNs). Each of these carry up to 12 JL-2 submarine launched ballistic missiles (SLBMs) and provide China with its first credible sea-based nuclear deterrent (i.e., a survivable second strike capability and a missile that can reach the continental United States from a protected bastion in the South China Sea). China's next-generation SSBN, expected later in the decade, will reportedly carry a new type of SLBM with extended range.[77] It is expected to operate concurrently with the Type 094 with up to eight SSBNs by 2030.[78]

The PLA's dormant air-delivered capability is being revitalized. This follows a decision to assign a nuclear mission to the PLA Air Force (PLAAF). The H-6N bomber features a modified fuselage that allows it to carry externally either a drone or a nuclear capable air-launched ballistic missile (ALBM). The H-6N's air-to-air refueling capability also provides it with greater range over other H-6 variants that are not refuelable in air. In addition, the PLAAF is seeking to further extend its power projection capability with the development of a new stealth strategic bomber.[79]

Chinese President Xi Jinping's 14th Five-Year Plan (2021-2025) follows his call to "strengthen strategic forces" and "accelerate the creation of high-level strategic deterrence."[80] The PLA nuclear force, in the very near-term, will possess a credible nuclear triad, supported by its growing stockpile and weapon systems. It is continuing to develop a range of technologies for its nuclear forces, including MARV, MIRVs,

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[73] Office of the Secretary of Defense, *Military and Security Developments Involving the People's Republic of China 2020.*

[74] Hans Kristensen and Matt Korda, "Chinese nuclear forces, 2020," *Bulletin of the Atomic Scientists* 76, no. 6 (2020), pp443-457.

[75] Adm. Charles A. Richard, Space and Missile Defense Symposium (August 2021).

[76] Eric Heginbotham et al., "Baseline: China's Evolving Strategic Nuclear Concepts," in *China's Evolving Nuclear Deterrent.*

[77] Office of the Secretary of Defense, *Military and Security Developments Involving the People's Republic of China 2020.*

[78] Hans Kristensen and Matt Korda, "Chinese nuclear forces, 2020," *Bulletin of the Atomic Scientists.*

[79] Ibid. See also Adm. Charles A. Richard, Space and Missile Defense Symposium (August 2021).

[80] Georgetown University Center for Security and Emerging Technology, Translation of the Outline of the People's Repubic of China 14th Five-Year Plan for National Economic and Social Development and Long-Range Objectives for 2035 (May 12, 2021; original Five-Year Plan published in Chinese on Xinhua News Agency March 12, 2021). https://cset.georgetown.edu/wp-content/uploads/t0284_14th_Five_Year_Plan_EN.pdf. Accessed January 5, 2022.

decoys, chaff, jamming, thermal shielding, and hypersonic glide vehicles, which it justifies as necessary to counter the BMD, ISR, and precision strike systems deployed by the United States and other countries. China is also working to field nuclear theater-range, precision-strike systems.[81]

Looking to the future, the U.S. Intelligence Community predicts that China "will continue the most rapid expansion and platform diversification of its nuclear arsenal in its history, intending to at least double the size of its nuclear stockpile during the next decade and to field a nuclear triad. Beijing is not interested in arms control agreements that restrict its modernization plans and will not agree to substantive negotiations that lock in U.S. or Russian nuclear advantages." It judges further that China seeks "a larger and increasingly capable nuclear missile force that is more survivable, more diverse, and on higher alert than in the past, including nuclear missile systems designed to manage regional escalation and ensure an intercontinental second-strike capability."[82] The 2021 DOD assessment states that "… Beijing has accelerated its nuclear expansion, which may enable the PRC to have up to 700 deliverable nuclear warheads by 2027 and likely intends to have at least 1,000 warheads by 2030."[83]

The Chinese nuclear force expansion is not constrained in any way by any international treaties, as is the United States. China can develop and deploy whatever they choose. In addition, of concern for the United States, Admiral Charles Richard, commander of U.S. Strategic Command, expressed in summer 2021 that China's missile defense system is now undergoing "tremendous capability and capacity improvements" and "continues its pursuit of advanced weapons systems with novel attributes and capabilities" such as hypersonic weapons technology with dual-use capability that is "designed to evade detection through atypical trajectory geometries and changes the traditional ballistic missile warning timelines."[84] In fact, according to the 2021 DOD assessment, the DF-17 "passed several tests successfully and is deployed operationally. While the DF-17 is primarily a conventional platform, it may be equipped with nuclear warheads."[85]

Surveying this entire landscape of force development, Adm. Richard also argued that "we are witnessing a strategic breakout by China" and that "China's explosive growth and modernization of its nuclear and conventional forces can only be what I describe as breathtaking."[86] In testimony to the Senate Armed Services Committee,

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[81] Office of the Secretary of Defense, *Military and Security Developments Involving the People's Republic of China 2020.*

[82] Office of the Director of National Intelligence, *2021 Annual Threat Assessment of the U.S. Intelligence Community* (April 9, 2021).

[83] Office of the Secretary of Defense, *Military and Security Developments Involving the People's Republic of China 2021 – Annual Report to Congress.*

[84] Adm. Charles A. Richard, Space and Missile Defense Symposium (August 2021).

[85] Office of the Secretary of Defense, *Military and Security Developments Involving the People's Republic of China 2021 – Annual Report to Congress.*

[86] Ibid.

he argued further that “it is also necessary to consider the command and control, readiness, posture, doctrine, and training. By these measures, China is already capable of executing any plausible nuclear employment strategy within their region and will soon be able to do so at intercontinental ranges as well.”[87]

He continued by stating that “while China keeps the majority of its forces in a peacetime status, increasing evidence suggests China has moved a portion of its nuclear force to a Launch on Warning (LOW) posture and are adopting a limited ‘high alert duty’ strategy. To support this, China continues to prioritize improved space-based strategic early warning, and command and control as specific nuclear force modernization goals.”[88]

Nuclear Weapon Complex

The planned rapid expansion of China’s ICBMs and SLBMs requires a concomitant increase in the nuclear warhead stockpile. This requires an acceleration of the rate of production. It requires also technical and military confidence in any design innovations that may be made as part of the modernization process. In 2020, DOD estimated that China’s stockpile was in the low-200s and that China probably has enough nuclear materials to at least double that number without additional fissile material production.[89] Adm. Richard has written that it is expected to double if not triple or quadruple over the next decade.[90]

Information about China’s nuclear weapons activities is tightly controlled. Its nuclear weapon complex is concealed from view. But some informed conjecture is possible. To understand whether or when new nuclear material production might become necessary, a number of questions must be answered, such as: how much material has already been produced, whether any production capability is operating today, what type of nuclear weapon designs are used, and what material could be available from future military or civilian reactors.[91] Any estimate of the number of nuclear weapons that China’s current and/or future nuclear material can support will require a set of assumptions and significant ensuing uncertainties.

For its original weapons production program, China set up two industrial complexes in the 1960s to produce weapon grade plutonium (WGPu), each with a production reactor and a reprocessing plant. Both complexes were closed in the 1980s. The amount of plutonium produced before these facilities closed is not publicly known, but estimates from open source information indicate that “China might be able to produce

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[87] Adm. Charles A. Richard, Statement Before the Senate Committee on Armed Services (April 20, 2021).

[88] Ibid.

[89] Office of the Secretary of Defense, *Military and Security Developments Involving the People’s Republic of China 2020.*

[90] Adm. Charles A. Richard, “Forging 21st Century Strategic Deterrence,” *US Naval Institute Proceedings* (February 2021).

[91] For a discussion of the basic elements of a nuclear weapons program, see Bruce Goodwin, *Nuclear Weapons Technology 101 for Policy Wonks* (Livermore, CA: Lawrence Livermore National Laboratory, Center for Global Security Research, 2021).

between 400 and 800 nuclear weapons using this material."[92] This is consistent with DOD's estimate.[93]

Concurrently, China was enriching uranium to weapons-grade based on gaseous diffusion technology starting in the 1960s, a project which ceased in the 1980s. Again, from open source information, the amount produced during these operations is estimated to be sufficient to produce perhaps at least 500 nuclear weapons.[94]

If China uses tritium in its weapons, a steady supply is necessary to maintain these weapons (tritium decades rapidly, with a half-life of 12.3 years). Typically, nuclear weapon states produce tritium by irradiating lithium in a nuclear reactor. There is no public information available on where and how China currently may produce tritium for weapons.

All these estimates only consider existing "military" fissile material. The accelerating expansion of China's nuclear arsenal will require additional material. Assuming that the availability of WGPu is the key material that limits the rate of increase in production, China's path forward would depend on two basic options. One would be to build and operate a new plutonium production reactor; this is clearly feasible technically, given China's accumulated experience in reactor design, construction and operations.[95] The other would be to take advantage of existing civilian nuclear capabilities. Thomas Cochran and Henry Sokolski estimate that China is capable of producing roughly 1,440 kilograms (kgs) of WGPu from the two breeder reactors it has under construction. They also estimate that China could recover 110 kgs of WGPu by processing blanket material from its small experimental fast breeder reactor. In this way, China could have enough nuclear material by 2030 to build at least 1,270 nuclear warheads.[96] This is consistent with the 2021 DOD assessment that Beijing's accelerated nuclear expansion

> *"… may enable the PRC to have up to 700 deliverable nuclear warheads by 2027 and likely intends to have at least 1,000 warheads by 2030. The PRC is constructing the infrastructure necessary to support this force expansion, including increasing its capacity to produce and separate plutonium by constructing fast breeder reactors and reprocessing facilities. Though this is consistent with the PRC goal of closing the nuclear fuel cycle, the PRC*

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[92] Mark Hibbs, "China's Nuclear Forces," testimony before the US-China Economic and Security Review Commission (June 10, 2021).

[93] Office of the Secretary of Defense, *Military and Security Developments Involving the People's Republic of China 2020.*

[94] Mark Hibbs, "China's Nuclear Forces."

[95] Ibid.

[96] Thomas B. Cochran and Henry D. Sokolski, *How Many Nuclear Warheads Might China Acquire by 2030?*, Nonproliferation Policy Education Center Occasional Paper 2102 (March 2021).

> *likely intends to use some of this infrastructure to produce plutonium for its expanding nuclear weapons program."*[97]

China's Implementation of Test Constraints

To enable its projected buildup, China must also have the means to provide technical and military confidence in the designs and weaponization of these warheads for deployment on the variety of different delivery platforms that are being developed. Just as the nuclear weapons complex requires certain capabilities and capacities to meet future military requirements, the certification of new weapons also requires certain capabilities and capacities. How has China approached this part of the project? Here too, the veil of secrecy cast by China over its nuclear activities obstructs a clear view.

This confidence has many potential sources: the quality of the workforce, the sophistication of the technical means, and a robust science base, among others. Validation through testing also plays an essential role. Before the nuclear testing moratorium was agreed in 1996, nuclear weapon states relied on yield-producing explosive tests at full and then reduced yield (first atmospheric, then underground). Various non-nuclear tests, flight tests, and computer simulations played an important supporting role. Both the United States and China are also signatories of the Comprehensive Test Ban Treaty (CTBT) and are constrained by its terms even though it has not entered into force. In the absence of such underground testing, how has China sustained adequate confidence in its current stockpile and how will it establish and sustain sufficient confidence for the new deployments coming in the future?

As described elsewhere in this Occasional Paper, the United States and Russia have charted different courses on this matter. As Michael Albertson has noted, Russia has added capabilities and capacities to maintain confidence in its changing nuclear arsenal and relies on a particular interpretation of the CTBT to undertake test activities not seen by the United States as consistent with CTBT requirements. As George Miller has reported, the United States created the Science-Based Stockpile Stewardship Program (SBSS) to bring together the results of past nuclear tests with enhanced capabilities for non-nuclear testing of many kinds and advanced computer simulations. Although China has not described a program equivalent to SBSS, it is apparently tackling many of the issues that are addressed by SBSS.

A central question is whether China had acquired sufficient data to characterize the functioning of its deployed warheads when full-scale nuclear testing ended in 1996. A closely related question is whether newer warhead designs reflect only incremental or more fundamental changes from the tested versions. The veil of secrecy again obstructs the search for sound answers to these questions.

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[97] Office of the Secretary of Defense, *Military and Security Developments Involving the People's Republic of China 2021 – Annual Report to Congress.*

The question is how will China provide confidence in—and how much progress has China made in developing—the advanced scientific tools it deems necessary. Here there are a few useful data points in the form of reports of advances in the development of science-based capabilities that bear on stockpile confidence.

For example, a report of the China Academy of Engineering Physics (CAEP) states that between September 2014 and December 2017 China has carried out about 200 laboratory experiments to simulate the extreme physics of a nuclear blast. These tests were typically executed using high-power gas guns that fire projectiles at materials of interest in the laboratory. Such experiments provide data on material properties and shock response of components in a nuclear warhead such as weapons-grade plutonium, other metals, plastics, or foams.[98] The experiments on plutonium are similar to those in the United States on the Joint Actinide Shock Physics Experimental Research Facility (JASPER) gas gun.[99]

Another report discusses the development of the Shen Guang-III (SG-III) laser facility at China's laser fusion research center to study inertial confinement fusion. It operates with 48 beams at 200 kilojoules (kJ) and is being used to study the many phenomena controlling integrated implosions that could lead to laboratory-based fusion, with applications to thermonuclear weapons and civilian energy. Over 80 diagnostics have been installed at the SG-III laser facility, including optical diagnostics, X-ray imaging diagnostics, X-ray spectrum diagnostics, fusion product diagnostics, and general diagnostics assistant systems.[100] China is also planning a SG-IV laser which would be comparable to the National Ignition Facility in the United States and the Laser Mégajoule in France.

These and related capabilities, and the associated scientific advances, can be used to improve the models used in computer simulations of nuclear weapon performance. The higher the fidelity of the simulations, the more powerful the supercomputer that is needed. China has been aggressively developing supercomputer capabilities over the last two decades. For example, Mark Anderson quotes J. Dongarra of the University of Tennessee that "Back in 2001, the Top 500 list had no Chinese machines. Today they're dominant."[101] As of June 2019, China had 219 of the world's 500 fastest supercomputers, whereas the United States had 116.[102]

Chinese scientists are also developing the simulation tools that utilize such computers that are relevant to nuclear weapon performance. For example, He et al. cite the development and use of the JASMIN adaptive structure mesh application

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[98] Stephen Chen, "China steps up pace in new nuclear arms race with US and Russia as experts warn of rising risk of conflict," *South China Morning Post* (May 28, 2018).

[99] National Nuclear Security Administration fact sheet, "Joint Actinide Shock Physics Experimental Research Facility (JASPER)," NNSS-JASP-U-0016-Rev01 (October 2020).

[100] Shaoen Jiang et al., "Experimental progress of inertial confinement fusion based at the Shen Guang-III laser facility in China," *Nuclear Fusion* 59 (2019).

[101] Mark Anderson, "*Will China Attain Exascale Supercomputing in 2020?*", *IEEE Spectrum* (January 7, 2020).

[102] Ibid.

infrastructure and the LARED-integrated code (involving 2D hydrodynamics, radiation transport and multi-group diffusion, thermal conductivities for electrons and ions, and plasma burning) in their study of inertial fusion.[103]

In addition, despite its status as a signatory of the CTBT, there are also indications that China has been conducting yield-producing tests at its Lop Nur nuclear weapons test site. The U.S. Department of State, in its 2020 report on treaty compliance, reports that

> *China maintained a high level of activity at its Lop Nur nuclear weapons test site throughout 2019. China's possible preparation to operate its Lop Nur test site year-round, its use of explosive containment chambers, extensive excavation activities at Lop Nur, and lack of transparency on its nuclear testing activities—which has included frequently blocking the flow of data from its International Monitoring System (IMS) stations to the International Data Center operated by the Preparatory Commission for the Comprehensive Nuclear Test-Ban Treaty Organization—raise concerns regarding its adherence to the "zero yield" standard adhered to by the United States, the United Kingdom, and France in their respective nuclear weapons testing moratoria.*[104]

Commercial satellite imagery has also recently revealed an additional tunnel under construction, expanding the complex at Lop Nur used in the past for underground nuclear testing. Adm. Richard pointed out that the projected expansion served as a reminder that China has an active nuclear testing program.[105]

Conclusions and Implications

China has charted a unique nuclear course—different from that of the United States or Russia—towards its nuclear future. It might be thought of as nuclear modernization with Chinese characteristics. Those characteristics include a great deal of opacity (and thus uncertainty) among outside observers about China's intentions and capabilities.

While the United States has sought for decades to reduce the role of nuclear weapons and their international salience, China has moved in the opposite direction away from its traditions of nuclear minimalism. Nuclear weapons play a more important role than ever in underwriting China's national rejuvenation and development of a modern military. And as China increases, modernizes, and adapts its force to new military goals and challenges, its nuclear force is rapidly evolving. Its capabilities and capacities to grow the force substantially over the coming decade or two are clear. What

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[103] X.T. He et al., "Advances in the national inertial fusion program of China," *EPJ Web of Conferences* 59, no. 01009 (2013).

[104] U.S. Department of State, *Adherence to and Compliance with Arms Control, Nonproliferation, and Disarmament Commitment* (June 2020).

[105] Adm. Charles A. Richard, "Forging 21st-Century Strategic Deterrence."

is less clear is its capabilities and capacities to provide the necessary technical and military confidence in new warheads. There is some evidence that China is pursuing a science-based approach to warhead certification not unlike that of the United States (and as has been observed with Russia, may include test activities not seen by the United States as consistent with CTBT requirements). Taken together, the available data points strongly suggest that China has the capabilities to support the projected nuclear weapons buildup. It also reflects that China's leaders are seriously pursuing an ensured and effective nuclear deterrent for the foreseeable future.

Do the Differences in National Approach Matter?

Brad Roberts

The preceding chapters sketch out the basic approaches the United States, Russia, and China have taken to maintain their nuclear deterrents. This chapter provides a high-level comparison of these approaches. It also assesses whether and how the asymmetries in approach matter. It closes with a brief assessment of the competitiveness of the U.S. approach.

Where do Approaches Align and Differ?[106]

The approaches of the three differ significantly in strategy and policy. They are more closely aligned on their approaches to sustaining and modernizing their nuclear forces, albeit not fully aligned. In contrast, their technical capacities vary significantly.

On strategy and policy, the three have set out different objectives and frameworks. In support of national strategy, each has articulated a particular role for nuclear weapons. The United States emphasizes their role in safeguarding global and regional orders from challengers, while Russia emphasizes their role in reasserting Russia's claim to great power status and China emphasizes their role in restoring "resolutely safeguarding" its sovereignty and security.

Each has also articulated a particular role for nuclear weapons in military strategy. The United States identifies a limited role for nuclear weapons, for possible employment only in extreme circumstances when vital interests are at risk. Russia identifies a more expansive role, with deep and broad integration of nuclear weapons at the tactical, operational, and strategic levels. China frames the role as limited to retaliation.

Each has also set out its own parameters of nuclear modernization. The United States focuses on stockpile stewardship—that is, preservation of a down-sized legacy force through life extension—while also foreswearing new nuclear capabilities for new military purposes. Russia "keeps its nuclear powder dry" through continuous warhead processing while also developing, producing, and deploying new weapons. China is modernizing, building up, and diversifying its nuclear arsenal—rapidly so.

In contrast to these areas of divergence, the three are largely aligned in their approaches to sustaining and modernizing their nuclear forces within the context of agreed test limitations, including the Limited Test Ban Treaty, the nuclear test moratorium, and the Comprehensive Test Ban Treaty. The technical parameters of their programs are largely similar, as they have put together the methods and tools to

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[106] The following summary statements are derivative of the country-specific chapters in this volume, which include supporting citations. Supplemental information is available in *Russia Military Power: Building a Military to Support Great Power Aspirations* (Defense Intelligence Agency, 2017) and *Military and Security Developments Involving the People's Republic of China, 2021* (Office of the Secretary of Defense, 2021).

support national objectives within the context of those limitations (as they interpret them—an area of potentially significant divergence, as they appear not to agree on what constitutes a nuclear test).[107] All three rely on a variety of nuclear and non-nuclear experiments and advanced diagnostic methods to generate new data to improve computational models and methods. All three also rely on advanced simulation capabilities to guide certification decisions about warheads. To be sure, discrete program elements differ in numerous ways, reflecting different technical approaches and different levels of sophistication and ambition in specific technical areas.

One important area where the technical capabilities clearly do not align is the design, engineering, and proof-of-concept production of new weapons. These skills are exercised as a matter of course in Russia's modernization program. China's build-up suggests a similar result. U.S. stockpile stewardship does not exercise those design, engineering, and production skills to the same degree and extent, given its primary focus on life extension of legacy capabilities. The Stockpile Responsiveness Plan has served as a partial corrective in this regard.

Another important area where the three are not aligned is in the technical capacity for large-scale production. Russia has put in place and exercised the capacity to design and produce weapons at scale. China is putting in place the capacity to grow its force substantially over the decade. In the meantime, the United States continues to struggle to put in place the capacity sufficient to its stewardship mission, with strong doubts today about whether it will be possible to deliver the current program of record.

Do the Asymmetries Matter?

The asymmetries in national and military strategy, in the approach to the development of the future force, and in capacities are numerous. From the perspective of the United States and its allies, do they matter? If so, how?

Within the U.S. expert community, there are at least three contending views. One view is that the asymmetries do not matter so long as the commander of U.S. Strategic Command is able to certify that he or she has available all of the capabilities needed to successfully execute presidential nuclear employment guidance. A second view is that the asymmetries do not matter today but might matter in the future when and if there is a strategic surprise for the United States and the United States finds itself incapable of developing, certifying, and/or fielding a needed capability in a timely manner. The third view is that the asymmetries matter here and now because adversaries are gaining militarily-useful new capabilities while the United States is not.

These different answers reflect different ideas about the nature of competition in the nuclear domain. Those who believe that the asymmetries do not matter generally argue that the United States is not competing with Russia or China to

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[107] *2021 Adherence to and Compliance with Arms Control, Nonproliferation, and Disarmament Agreements and Commitments*, Report of the Bureau of Arms Control, Verification, and Compliance, Department of State (April 15, 2021).

maintain comparable capabilities or capacities; rather, it is competing to ensure that its deterrent remains safe, secure, and effective and conveys an impression of strength and resolve. Those who believe that the asymmetries might matter in the future generally argue that the United States is competing now largely as a hedge against future strategic surprise. Those who believe that the asymmetries matter here and now generally argue that an arms race is underway—and Russia and China are winning because the United States has chosen not to compete.

To test these competing hypotheses, it is necessary to probe a bit more deeply. Towards that end, this analysis considers the impact of these asymmetries on different bilateral relationships (U.S.-Russia and U.S.-China) and on the core functions of U.S. nuclear strategy. For purposes of this analysis, those core functions include deterrence (and the impact on the calculus of benefits, costs, and risks of different courses of action), assurance (and the impact on allied confidence in U.S. security guarantees even under nuclear threat), and dissuasion (and the impact on a potential adversary's calculus of the benefits, costs, and risks of an attempt to seize and hold some advantage through long-term competition).

In the U.S.-Russia strategic relationship, the stark differences of approach have important consequences. In Russian military thought and strategy, nuclear weapons have a central role, given their contributions to the effort to exert psychological pressure on the United States and NATO when and if they contemplate military action and escalatory acts against Russia.[108] Russian leaders clearly have the political will to innovate in the nuclear realm and face no domestic deterrence skeptics. They are developing new nuclear solutions to new military problems (e.g., the "novel" strategic weapons to penetrate or circumvent U.S. missile defenses). Their nuclear adaptations at the regional level of war are intended to directly undermine U.S. extended nuclear deterrence and the assurance of U.S. allies and thus earn them freedom of action.

In the U.S.-China strategic relationship, the asymmetries are strategically less consequential, at least for now. The nuclear factor in the bilateral relationship is vastly less prominent, even in the bilateral military relationship, given China's much smaller nuclear force and no-first-use (NFU) doctrine. This is changing, however, given the build-up and diversification of China's nuclear forces and pressures on NFU. China too is developing new nuclear solutions to new military problems (e.g., dual-capable regional missiles as part of anti-access, area-denial strategy). Given China's lack of transparency on all matters nuclear, a great deal of uncertainty attaches to considerations of China's nuclear future.

The asymmetries in technical capability and capacity and in overall national approach to deterrence can be expected to have a negative effect (from a U.S. perspective) on the calculus of deterrence of both Russia and China. Both have put their focus on tailoring their strategic toolkits for regional wars on their peripheries and are developing new capabilities in support of new strategies for nuclear

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[108] Dave Johnson, "Russia's Deceptive Nuclear Policy," *Survival* (2021), pp123-142.

deterrence, coercion, and employment at the regional level of war. Moreover, if their increased risk taking is indicative, they appear to be gaining confidence in those capabilities and strategies. In this context, the asymmetries may embolden them further to embrace the idea that such regional wars can be fought and won because the nuclear dimension can be both decisive and kept limited. Put differently, they may come to believe that the benefits of nuclear-backed action are significant while the costs are bearable and the risks are calculable because the Alliance's will to employ its nuclear forces can be broken.

These asymmetries can also be expected to have a negative effect on the assurance of U.S. allies. Allies count on the military posture of the United States to remain effective even in an eroding security environment. They also count on the United States to fix whatever needs fixing in its deterrent to get the job done. From their perspective, the fundamental issue here is in the difference of national approaches to deterrence, not the difference of technical capability or capacity. The allies most anxious about the credibility of the U.S. extended nuclear deterrent are also the allies most anxious about the intention of the United States to compete effectively, militarily and otherwise, and to do so over a long period of time. These allies are not deeply knowledgeable about the technical parameters of the weapons programs of Russia, China, or even the United States, but they are close observers of U.S. nuclear posture reviews, Congressional debates on force modernization, and disagreements within the expert community.

These asymmetries can also be expected to have a negative effect (again, from a U.S. perspective) on the adversary's calculus of competition. The long-term objectives guiding the approaches of Russia and China to nuclear deterrence are unclear. They may also be unformed, as yet. Their leaders state that their intent is essentially to preserve the nuclear status quo and an overall balance of strategic power with a United States that they see as hellbent on gaining strategic advantage. The coming decade will put this proposition to the test, as their modernization programs come to a culminating point—or simply continue in pursuit of some new advantage. Here, the asymmetrically vastly smaller production capacity of the United States may come to be seen as a window of opportunity by Russia or China or both to seize that advantage and act upon it.

What does this analysis imply for the three views set out above? The first view (that the asymmetries do not matter so long as STRATCOM's military requirements are met) misses the point that the requirements for the nuclear assurance of allies and for success in long-term competition are not well elaborated and have no clear military advocate. The second view (that the asymmetries don't matter today but might in the future) misses the point that speed of response is itself a strategic asset in today's security environment. Moreover, the uncompetitive nature of the U.S. weapons program may be reinforcing the perception of leaders in Moscow and Beijing that the United States is a power in decline, too divided politically to compete effectively or to defend its interests in crisis. The third view (that the asymmetries matter here and now because adversaries are gaining new military capabilities while the United States is not) misses the point that the United States does not face the same military problems as Russia and China and does not seek to solve the new problems it does face with nuclear means. But it is also the case that Russia has substantially improved its overall posture vis-à-vis NATO over the last decade, in part through adaptations to its theater nuclear capabilities.

How Competitive is the U.S. Approach?

The answer to this question must begin by recognizing that the U.S. approach is not designed to be competitive. That is, stockpile stewardship was conceived and begun in a very different strategic context—a largely benign security environment in which the United States enjoyed unrivaled power, military and otherwise. It was endorsed by many as an alternative to the competitive pursuit of new nuclear capabilities of the Cold War. In this sense, stockpile stewardship is inherently conservative. While it is innovative in its approach to sustainment without testing, it is not innovative in the sense that new military capabilities are essentially outside its scope. The competitive aspect is intended to be designed in—that is, latent—in the physical infrastructure and human capital necessary to the stockpile stewardship mission.

U.S. policymakers have regularly praised the virtues of a responsive infrastructure as part of a national hedge against unwelcome developments in an unpredictable, volatile, and dangerous security environment. But they have been reluctant to accept some of the risks that come with innovation and to invest to create the desired agility and flexibility. The reality today is that the U.S. nuclear complex is neither robust nor particularly agile or responsive. A decade from now, the U.S. hedge posture will be stronger, as a result of interim modernization activities. But it will likely still be constrained in various ways, with design capabilities under-exercised and production capacities scaled for life extension, not competition.

This gap between political aspiration and technical reality will come into sharp focus as stockpile modernization accelerates. Where might the U.S. deterrent stand in 2030? Let’s consider three alternative outcomes: plausible best case, plausible worst case, and plausible middle case.

The plausible best case is that the program of record is delivered on time and no new requirements emerge. From a U.S. perspective, this would be sufficient to maintain strategic stability so long as the efforts of Russia and China to increase and adapt their respective strategic postures do not result in new U.S. nuclear requirements.

The plausible worst case is that the program of record falters while the erosion of the security environment accelerates. In this case, existing force requirements could not be supported, resulting in a dramatic stand down of elements of the deterrent. Hedge forces would not be available and capacity to field additional forces would be focused instead on repairing the existing force. Military commanders would report that targeting requirements were not being met. Extended deterrence commitments would be in growing doubt. In this context, the strategic balance could shift decisively and dangerously from the perspective of the United States and its allies and partners.

The plausible middle case is that the program of record proceeds but U.S. leaders also seek qualitative or quantitative changes to U.S. nuclear forces requiring new capabilities. As this would take more than a decade to deliver, deterrence and assurance would erode.

Given these potential consequences, why has this gap been tolerated? For the most part, the risk in the U.S. posture has been tacitly accepted, not explicitly. The barrier to progress in narrowing the gap is not fundamentally fiscal or technical. The problem is cultural. U.S. political and military leaders apparently remain largely content with the conservative approach to preserving the U.S. nuclear deterrent. The sense in national security strategy that significant changes are afoot in the security environment hasn't called into question confidence that the legacy arsenal provides the right strategic answers for the moment. The sense in the Department of Defense (DOD) that "speed matters" in responding to a dynamic security environment has not yet percolated through a Department of Energy (DOE) procurement culture that seems content with 10- to 15-year cycles of work. DOD is breaking old business models, while the U.S. nuclear complex remains hamstrung by a governance structure and management process that stifles innovation and punishes risk taking.[109] All the while, risk accumulates.

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[109] Terri Moon Cronk, "Speed Must Be Put Back Into DOD, Hyten Says," DOD News (January 17, 2020).

Toward a More Competitive U.S. Approach

Kimberly Budil, Thom Mason, James Peery

In the new era of strategic competition with Russia and China continuing risks associated with emergent nuclear powers, U.S. policymakers face new questions about whether and how such competition should shape the U.S. approach to stewardship of the nuclear deterrent. Is the current approach to Stockpile Stewardship fit for purpose in this environment? What, if anything, should be done to ensure that it remains fit for purpose? Reflecting on the analysis in this volume, the following key points stand out for us.

First, Russia and China are pursuing ambitious projects to ensure that their nuclear deterrents remain effective in security environments they deem dangerous and unpredictable. Their efforts have some common attributes. For both, nuclear modernization and adaptation are clear leadership priorities. The nuclear complexes benefit from sustained leadership focus and long-term funding. They are rapidly adapting their approach to new technologies and an understanding of the ways those technologies can challenge a largely static U.S. deterrent.

Second, while the United States has a robust Stockpile Stewardship program for preserving legacy capabilities, it has not created the agile and responsive infrastructure its leaders have regularly pointed to as a hedge in a world they too see as dangerous and unpredictable. Stockpile Stewardship, as practiced since the end of nuclear explosive testing 30 years ago, has been focused on sustaining, modernizing, and slowly evolving the deterrent, leveraging the robustness and demonstrated ability to remain effective beyond the original design lifetime of systems first deployed in the 1980s.

Third, this imbalance involves substantial risk to U.S. deterrence and assurance objectives. It is not clear to us that this risk is knowingly accepted. In a world where scientific and technological advancement is not a monopoly of any country, new options have emerged that, without a response, can erode the effectiveness of deterrence. Similarly, Russia and China have sought to erode the U.S.'s longstanding preeminence in many strategic scientific disciplines, demonstrating their determination to seek technological advantage.

Finally, the United States should adapt its approach to meet the challenges we face. It need not compete on Russian and Chinese terms, seeking both quantitative and qualitative improvements. It should compete on its own terms recognizing the inherent strengths and weaknesses of our position.

In this short closing chapter, we offer a vision of what it could mean to compete more effectively on our own terms. We also describe the pathway from here to there with the goal of informing national debate about what approach to stewardship of the nuclear deterrent best serves the interests of the United States and its allies and partners.

Understanding the Current Trajectory

Let's consider the plausible state of play in 2030 in the U.S. nuclear enterprise. Between now and then, the modernization of the nuclear complex will have advanced significantly, given the infrastructure investments now underway to implement the full planned stockpile modernization program. The complex of 2030 will be more robust than that of today, not least because it will have warm production lines and a new generation of experienced practitioners. We will have made substantial progress in updating all three legs of the triad, although that task will not be complete.

But the complex and deployed weapons of 2030 will bear a striking resemblance to what existed in 1985, albeit with more modest production capacity and incremental improvements in safety, security, and delivery systems. It will have largely similar facilities, given the standard conservative approach to extend warhead service life with nearly identical processes to those utilized in their original manufacture. Many of those facilities were designed for serial large-scale throughput and are expensive to construct and operate, while others have limited capacity based on past expectations of fewer concurrent programs.

This 2030 complex will have limited resilience. It will still include single points of failure and choke points and will be partially dependent on a fragile and potentially vulnerable external supply chain, although these will be better understood. It will continue to be constrained from readily and continuously incorporating lessons learned from the commercial sector and the associated new technologies and techniques. It could be scalable with the addition of costly new facilities or more efficient practices. While the refreshed infrastructure and human capacity along with renewed weapons systems will provide a basis on which to build, it will not have the capacity to take on additional projects without compromising the schedules for ongoing life extension.

An Alternate 2030 Vision

We can imagine an alternate outcome in 2030 that would be more fit for purpose in an era of strategic competition and are engaged in an active dialogue with leaders at NNSA and DOD to reshape our current trajectory. We imagine a nuclear security enterprise that has the innovative acumen, technological adaptiveness, production efficiency, and manufacturing scalability of America's world-leading private sector manufacturers. We imagine an end-to-end acquisition process that enables responses to technical or geopolitical surprise rapidly enough to be strategically relevant. These would be measured in months or a few years and not a decade or longer. We imagine a production infrastructure capable of (1) delivering both small-scale spiral block improvements and large-scale surges without requiring add-on infrastructure and (2) robust, continuous operation, eliminating single point failures and choke points by designing in resiliency, not redundancy. We imagine an enterprise focused on continuous improvement, with production approaches that regularly incorporate new commercial technologies and techniques. We imagine a more balanced supply chain, with internal sources for critical technologies that can compensate for weaknesses in the external supply chain.

This alternate vision is of an enduring approach to stewardship of the U.S. nuclear deterrent that also enables tailoring for the needs of the moment.

Enabling this Vision

This vision is within our reach. The recent example of the W76-2 is indicative of a more rapid response to an emergent military requirement. There are lessons to be learned from that example, which was a targeted, smaller-scale response that leveraged the ongoing modernization program, stockpile, and infrastructure. Within the bounds of existing authorities and guidance, there is much that our three laboratories can do now to help realize this 2030 vision. Working in close partnership, we have settled on some useful first steps. For example, we are working to selectively re-engineer various business practices to shorten production timelines. We have forged novel partnerships with the production sites to enable shorter development timelines and faster introduction of modern manufacturing technologies and approaches. We have utilized the Stockpile Responsiveness Program to develop the next generation of experts and leaders. We have used internal resources to lay the foundations for improved competitiveness. We have also worked to change laboratory culture by renewing our focus on mission, conveying a sense of urgency, rewarding risk taking, and holding ourselves and others accountable for results.

But the three nuclear weapons laboratories cannot realize the 2030 vision by working alone. To do so we will need support, including the following:

- A clear national commitment to a 2030 vision, hopefully informed by that sketched out above.
- A sense of urgency about the need to improve U.S. competitiveness, with an emphasis on competing on U.S. terms and across a range of scientific and technological activities.
- Actions to enable an agile and responsive infrastructure to support campaigns for deterrence and assurance as a signal of U.S. resolve to respond effectively to future negative developments in the security environment.
- Action to accelerate the effort to fundamentally re-engineer business practices across the complex.
- Action to adapt procurement processes to enable more rapid adoption of new technologies and techniques and continuous acceptance and certification.
- Investments to enhance production capacity and agility and enable selective rejuvenation of the defense industrial base.

We realize that these recommendations may be controversial. Some commentators are content with the status quo in the nuclear complex and worry that a more competitive U.S. approach puts us on a pathway to renewed arms racing. We do not see it that way and believe strongly that future arms control should be part of the framework for competing on our terms.

The status quo approach is based on a more slowly evolving and geopolitically benign environment than we find ourselves in today. The danger derives primarily from the risk that the United States may lack the capabilities and capacities to respond to further unwelcome changes in the nuclear security environment.

A more competitive approach need not lead to arms racing. We do not see a need to compete with Russia and China on their terms. A more competitive approach promises to put the United States in a stronger position to sustain existing capabilities, respond to future requirements, and improve effectiveness, while also reducing timelines and costs. A more competitive U.S. approach should in fact serve to disincentivize arms racing, by signaling to leaders in Moscow and Beijing the incontrovertible political resolve of U.S. leaders to ensure that U.S. nuclear forces remain safe, secure, and effective over time.

Stockpile stewardship must evolve with the changing security environment. In a more competitive environment, the legacy approach is ever less fit for purpose. The time for innovation is now.

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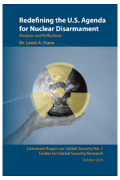

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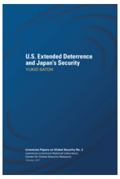

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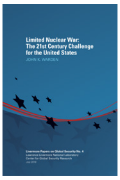

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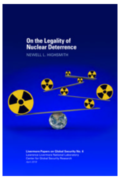

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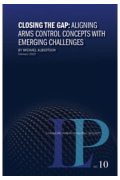

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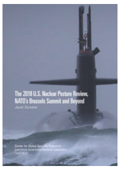

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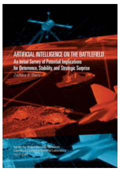

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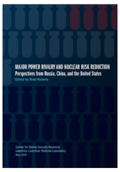

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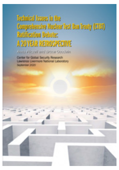

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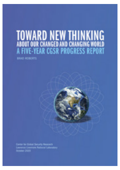

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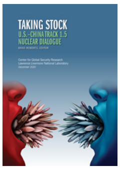

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> “The increasing complexity of the security environment has brought a new sense of urgency about ensuring the effectiveness of nuclear deterrence. This urgency must drive accelerated innovation and timely delivery in the U.S. nuclear enterprise. It is the right time to evaluate our vision for the enterprise. This important and timely new study of stockpile stewardship and its fit with our changing world is a great example of the new thinking needed.”

Jill Hruby
Administrator, National Nuclear Security Administration

Lawrence Livermore
National Laboratory

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