FROM STEWARDSHIP TO TRANSFORMATION: TOWARD A NUCLEAR ENTERPRISE FOR THE 21ST CENTURY

BRAD ROBERTS, EDITOR

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Summary

The erosion of the global security environment over the last two decades has been rapid and dramatic. It appears also to be accelerating. There are deep and widening concerns in the United States and among its allies and partners that deterrence too has eroded at both the conventional and nuclear levels. The Strategic Posture Commission captured the essence of the problem in its October 2023 report: the United States seeks to meet the challenges of complex multipolar nuclear rivalry in the 21st century with a slimmed-down version of a nuclear deterrent designed in the middle of the 20th century. With great urgency, the Commission recommended that something more and/or different is needed than simply the replacement of legacy systems with modern variants. But the U.S. nuclear security enterprise was reshaped after the Cold War to support the stockpile stewardship mission; it was not renewed to enable the design, engineering, and production of new capabilities at scale. It has long fallen short of the agility, flexibility, and adaptiveness periodically asked of it by national leaders.

In recent years, however, the message of urgency has been clearly received in the enterprise. Its culture has begun to shift. It has also been received by those in Washington DC responsible for funding and guiding the enterprise. The result is an enterprise in transition. Stockpile stewardship has given way to stockpile transformation. Risk aversion is giving way to risk management. Innovation and adaptation have been embraced.

Experience to date has yielded some important lessons about what works and what doesn't in terms of accelerating and delivering the needed innovation and adaptation. It has revealed the enduring character of some challenges. But it has also revealed that a much more agile and effective enterprise is within the national reach—something that will pay important dividends for deterrence, assurance, strategic stability, and peace.

Preface

Brad Roberts

Surveying our “extraordinarily dangerous world” in 2017, President Donald Trump called for urgent action. His secretary of defense, James Mattis, responded with a call for change “at the speed of relevance.” Four years later, President Joe Biden described a world “at an inflection point.” His secretary of defense, Lloyd Austin, followed with a rejection of “business as usual” in the pursuit of new military solutions. In the years since, the changes that worried them have only accelerated. And the call for urgent action remains strong—the Strategic Posture Commission used the word “urgent” nearly 50 times in its 2023 report.

The call to urgent action has not been lost on the U.S. nuclear security enterprise. Nor has the need to move on from business as usual to something more transformative. Moreover, the enterprise is acutely aware that the long-standing strategy to maintain legacy deterrence capabilities through stewardship programs has been found wanting in a world of new, different, and more numerous deterrence challenges. The enterprise has had to pick up its game. And, with leadership focus and support in Washington DC, it has made some important progress in doing so. While ongoing stewardship work continues, the focus is shifting increasingly to innovation and transformation.

This volume captures the state of an enterprise in transition.[1] Many big challenges lie ahead for the enterprise. But much has already been accomplished. Innovation is deepening and accelerating. Culture has changed. The enterprise is much more competitive than before. Only time will tell if it has become competitive enough.

1 An earlier volume captured the thinking of enterprise leadership about how to align enterprise activities with the inflection point. See Brad Roberts and William Tobey, co-editors, *The Inflection Point and the U.S. Nuclear Security Enterprise* (Lawrence Livermore and Los Alamos National Laboratories, 2023).

Agile Innovation: Enabling a 21st Century Nuclear Deterrent

Kim Budil

The United States today faces an unprecedented environment characterized by rapidly evolving threats, disruptive technologies, and intense strategic and economic competition. Strategic competitors are modernizing and expanding their nuclear capabilities, space and cyber are increasingly contested domains, and technologies such as artificial intelligence are accelerating the pace of change. A transformational approach is needed to meet this moment. The technologies, processes, and infrastructure that underpin America's nuclear capabilities were largely developed during the Cold War and are now undergoing modernization. In this environment, this modernization should be accelerated with a focus on the ability to rapidly innovate, develop, and deploy new technologies and systems for maintaining strategic stability. This paper examines how an agile and adaptable science, technology, and manufacturing enterprise can position the U.S. to lead and enable the development and sustainment of a credible nuclear deterrent for the 21st century.

The Changing Requirements of Nuclear Deterrence

The fundamental purpose of nuclear deterrence remains unchanged: to prevent adversaries from conducting strategic attacks against the United States and its allies by ensuring that the costs of such actions would far outweigh any potential benefits. However, the technical requirements for achieving this objective have evolved significantly. In particular, the dramatic expansion of China's nuclear capabilities means that we must now contend with a tri-polar world and an increasing priority to extend a credible U.S. deterrent umbrella to allies in Asia.

Today's nuclear deterrent must be effective, adaptable, and resilient, operating where space, cyber, and electromagnetic capabilities may degrade or disrupt traditional command, control, and communications systems. Adversaries are developing increasingly sophisticated capabilities to target the U.S. nuclear enterprise across all of these domains, necessitating more resilient and adaptable systems. This environment demands deterrent systems that can operate effectively even when facing advanced countermeasures and disruption attempts.

Simultaneously, the global diffusion of advanced technologies has accelerated, with potential adversaries gaining access to capabilities that can challenge aspects of the U.S. deterrent. To further complicate this situation, the U.S. nuclear enterprise is undergoing a generational modernization effort across platforms, warheads, and manufacturing infrastructure, an immense undertaking. Maintaining technological superiority requires not just periodic modernization, but continuous innovation across the nuclear enterprise. Where once the United States held clear technological advantages in most domains relevant to strategic systems, today the landscape is more competitive, requiring greater agility in how we develop and field new capabilities. Indeed, barriers to entry in many strategic areas of technology have been lowered or eliminated and the space and cyber domains are increasingly the purview of the private sector.

Unlike during the Cold War, the nuclear deterrent must now compete with numerous other national priorities for resources and attention. This reality demands greater efficiency and effectiveness in how systems are designed, produced, and sustained. The days of virtually unlimited resources flowing to nuclear systems development are long past, requiring new approaches that deliver capabilities more cost-effectively and with enhanced agility.

The nuclear security enterprise has begun to lay the foundations needed to meet these demands, but there remains much work to be done. To date, key capabilities such as plutonium pit production have been restarted, although production rates and scale must still be expanded significantly. Legacy processes have been restarted for manufacture of important alloys and other materials, but there has been limited progress toward implementation of new technologies. An enterprise-wide approach to fully embracing digital engineering and creation of a digital thread has begun but essential hardware, networking, and software decisions and investments lay ahead. Finally, the large resource needs for critical manufacturing infrastructure have made it more difficult to invest in important S&T capabilities, both for sustaining existing facilities and developing more advanced capabilities. Balancing the needs of today versus the opportunities to position the enterprise for the future is challenging and requires significant collaboration between the NNSA federal team, labs, plants, and sites.

The Role of an Agile S&T and Manufacturing Enterprise

An agile and adaptable S&T and manufacturing enterprise provides the foundation for meeting these challenges through several key capabilities that transform how we approach the development and sustainment of nuclear deterrent systems.

Rapid Development and Prototyping

Traditional development cycles for nuclear systems span decades, making it difficult to respond to emerging threats or incorporate new technologies. An agile enterprise fundamentally transforms this approach through innovative organizational and technical capabilities that enable much shorter development timelines while maintaining the rigorous standards required for nuclear systems.

Production development enclaves represent a particularly promising innovation in this domain. These specialized facilities focus on production R&D but are available as limited surge capacity for production when needed, creating a unique middle ground between pure research and full-scale manufacturing. By housing both development and production capabilities under one roof, these enclaves eliminate many of the transition challenges that traditionally delay the implementation of new technologies. During normal operations, they serve as innovation centers where new designs, materials, and processes can be developed and refined and partnerships between the design agency and production agency can be fostered. When increased production capacity is needed, they can rapidly transition to manufacturing roles, providing surge capacity without the delays and costs associated for standing up new production lines and without the added cost of building and sustaining excess production capacity that is likely to often be idle.

One early example of success on this front is the Polymer Production Development Enclave at Lawrence Livermore National Laboratory (LLNL). LLNL and the Kansas City National Security Campus (KCNSC) partnered to create this facility to speed the maturation of direct-ink-write additive manufacturing of polymers and its integration into KCNSC for near-term stockpile modernization program needs. This team has worked together to troubleshoot production issues, develop processes and procedures for the production environment, and prototype new approaches such as on-machine inspection and the integration of AI-driven control systems.

Advanced simulation and modeling capabilities further accelerate the innovation cycle by enabling simulation-based design approaches. Rather than relying entirely on physical prototyping and testing—which is particularly challenging for nuclear systems—an agile enterprise leverages high-performance computing resources to create virtual environments where designs can be tested and refined. These digital capabilities allow engineers to explore innovative concepts more rapidly and thoroughly than would be possible with physical prototyping alone, significantly compressing development timelines.

An example of how this approach can support faster and more agile development is the work being done at LLNL and SNL on alternate approaches to flight and environment qualification for the W87-1. The Sentinel missile is the delivery platform for this warhead and has been impacted by significant cost and schedule challenges, delaying the flight test program. The development teams have applied advanced simulations of flight environments, alternate experimental platforms for ground and flight test, and radiation environment data from new platforms enabled by fusion experiments at the National Ignition Facility to create an alternative strategy that will keep the warhead on track and delay the need for full scale flight testing several years.

The concept of spiral development further enhances agility by enabling incremental capability improvements that allow for continuous integration of new technologies rather than waiting for comprehensive system replacements. Instead of the traditional approach of designing and deploying entirely new systems every few decades, spiral development allows for regular updates to existing platforms, incorporating new technologies and capabilities as they mature. This also ensures that critical production capabilities are not idled for long periods of time, maintaining proficiency in the specialized skills required and mitigating the potential loss of critical supply chains. This approach maintains the deterrent's technological edge while avoiding the costs and risks associated with infrequent, disruptive modernization cycles.

NNSA is working with the labs, plants, and sites to move toward a more agile approach to development by exploring the establishment of a rapid capability prototyping effort. This program will pilot new approaches to rapidly designing, prototyping, and fielding capabilities to address deterrence needs on relevant timescales. Two new concepts are being explored as first candidates for this innovative approach.

Together, these approaches enable the deterrent to evolve continuously rather than through infrequent, disruptive modernization cycles. This continuous evolution is essential in a security environment where threats and technologies are changing more rapidly than traditional development cycles can accommodate.

Advanced Manufacturing Capabilities

The manufacturing base supporting the nuclear enterprise must be transformed from traditional approaches to more flexible and responsive production systems that can adapt to changing requirements and technological opportunities.

Additive manufacturing stands at the forefront of this transformation. Far beyond simply "3D printing" parts, advanced additive techniques enable entirely new design approaches that would be impossible with traditional manufacturing methods. Complex geometries, integrated structures, and gradient materials can now be produced as single components, eliminating assembly steps and potential failure points. For nuclear systems, where reliability is paramount and production volumes are often low, additive manufacturing offers particular advantages. It enables on-demand production of specialized components, reducing supply chain vulnerabilities, and allowing for design optimization that enhances system performance. While specific examples like the production of polymer parts highlighted above show the promise, there is much more opportunity across all of the materials and component systems NNSA must manufacture.

Digital manufacturing represents another critical capability, integrating design, simulation, and production systems to create a seamless workflow from concept to component. This digital thread ensures that manufacturing processes precisely implement design intent, capturing and preserving the knowledge embodied in each component. In the nuclear enterprise, where the consequences of manufacturing defects can be severe, this digital integration provides unprecedented quality assurance while accelerating production cycles. The integration of advanced computational approaches and artificial intelligence also enables more rapid iteration and better control of the manufacturing process with the goal of high confidence component production and certification.

Here again, the nuclear security enterprise is building a strong vision for this digital future, but a wide range of investments and challenges still remain, including: building the digital backbone across all of the sites, establishing the digital infrastructure to manage the many complex data sets required and ensuring adequate cyber and need-to-know controls, deploying the critical hardware and software, and working with our teams to embrace this new approach and toolkit. One recent example at LLNL showed the promise of creating a digital twin during the manufacturing process using on-machine sensors to gather data and create a detailed digital representation of the "as-built" part, rather than relying on "as-designed" specifications for design, assessment, and certification simulations.

The development of flexible production lines complements these capabilities by enabling rapid reconfiguration to produce different components as needs change. Unlike traditional manufacturing lines optimized for high-volume production of identical parts, these reconfigurable systems can efficiently produce both legacy and new components, sometimes within the same facility. This flexibility is particularly valuable in the nuclear enterprise, where the need to sustain legacy systems often competes with the production of modernized replacements and production volumes are low relative to standard industries.

Together, these manufacturing capabilities have the potential to reduce dependence on specialized suppliers, mitigate obsolescence issues, and enable cost-effective production of both legacy and new systems. By embracing new technologies and methodologies, the manufacturing base can move from being a potential bottleneck in the modernization process to an enabler of innovation and responsiveness.

Digital Transformation and Knowledge Management

The nuclear enterprise faces significant challenges in knowledge retention as the workforce that designed and built the current stockpile retires. An agile enterprise can address this through comprehensive digital transformation and knowledge management strategies that preserve critical expertise while enabling new approaches to system development and certification.

The concept of a digital thread represents a fundamental shift in how knowledge is captured and preserved throughout a system's lifecycle. Rather than relying on paper documentation and the expertise of individual scientists and engineers, the digital thread will create a comprehensive digital representation of systems from initial concept through design, production, deployment, and eventually retirement. This digital continuity serves to preserve design knowledge and enables future modifications by ensuring that the rationale behind design decisions is captured alongside the technical specifications. Today's process is still dominated by paper-based processes and limited access to needed digital tools. The Digital Transformation Senior Steering Group comprises leaders from the NNSA, labs, plants, and sites and has put forward a strategy and spun up working groups to begin the process of implementing this new approach.

Artificial intelligence and machine learning can further enhance knowledge management by developing systems that can capture and organize institutional knowledge, making it accessible to new generations of scientists and engineers. These tools can identify patterns in vast repositories of technical data, surface relevant precedents when engineers face design challenges, and even suggest approaches based on historical solutions. While human expertise remains essential, these AI-enhanced knowledge systems help bridge the generational gap as experienced personnel retire, potentially providing a new staff member with a "digital expert" to help them learn. For more experienced staff, this "digital coworker" could make the process of researching past approaches, gathering extant data, and postulating approaches much faster and more efficient. Early efforts are underway to take advantage of the large stores of digital information that have been developed in recent years through significant investments in knowledge management to preserve historical archives.

Virtual testing and verification capabilities reduce reliance on physical testing while maintaining confidence in system performance. For nuclear systems, where full-system testing is no longer conducted, the ability to convincingly demonstrate performance through simulation has proven to be highly successful. Advanced computational models, validated against historical test data and high precision experiments, provide assurance that systems will perform as designed even without full-scale testing. This was the fundamental premise of the Stockpile Stewardship Program and has proven exceptionally effective, leading to continued sustainment and modernization of the stockpile without the need for further underground nuclear tests. Indeed, this approach has also enabled a great deal of learning by applying advanced tools and methodologies to this archival data.

These approaches preserve critical knowledge while enabling more efficient design, production, and certification processes. They ensure that the nuclear enterprise can maintain and enhance capabilities even as the generations that originally developed these systems retire, creating a sustainable foundation for long-term deterrence.

Implementation Priorities

Transforming the nuclear enterprise requires focused investment in several priority areas that collectively enable the agility and adaptability required for 21st century deterrence.

Computational Infrastructure

Advanced simulation and modeling form the backbone of our enterprise, providing the capabilities needed to design, test, and certify nuclear systems without relying solely on physical prototyping and testing. Continued investments in high-performance computing, artificial intelligence, and digital engineering environments create the foundation for transformative approaches to system development.

Physics-based models with sufficient fidelity to credibly predict the performance of nuclear systems represent a particularly important capability. These models integrate multiple physical domains—from engineering through physics—to create comprehensive simulations of system behavior under various conditions. When informed by and validated against experimental data and historical tests, these models enable confident predictions about system performance even for configurations that have never been physically tested.

Design optimization tools that leverage this computational infrastructure have been shown to enable rapid exploration of solution spaces to identify optimal configurations, accelerating innovation while improving system performance. Rather than relying on incremental improvements to existing designs, these tools can evaluate thousands of potential configurations to find solutions that might not have been identified through traditional approaches. New computational tools and hardware are beginning to enable large-scale parameter studies that should add fidelity to our understanding of uncertainties. Further work will focus on developing computational pipelines to enable a thorough exploration of uncertainties in the models via large ensembles of calculations and parameter variations.

Digital twins of production processes can ensure that manufacturing outcomes match design intent by simulating the production process before physical manufacturing begins. These detailed models identify potential manufacturing challenges early in the design process, enabling adjustments that improve producibility without compromising performance. For nuclear components, where quality requirements are exceptionally stringent, these digital twins help ensure that designs can be manufactured consistently and reliably. Several early examples of the application of high-fidelity modeling and simulation to production challenges have led to optimizations of processes ranging from manufacture of polymers to pit production.

Advanced Manufacturing Ecosystem

Creating a responsive manufacturing base requires a comprehensive ecosystem of capabilities, processes, and expertise focused on advanced manufacturing technologies suitable for nuclear applications and there are many lessons we can learn from the private sector.

The strategic deployment of additive and other advanced manufacturing capabilities across the nuclear security enterprise should be a core element of this ecosystem. Rather than concentrating these capabilities in a single facility, distributing them throughout the enterprise will support resilience while enabling specialized facilities to develop expertise in particular materials, processes, or component types. This distributed approach would also support surge production by providing multiple facilities capable of producing critical components if needed. As noted earlier, the polymer enclave at LLNL is one such example.

Qualification and certification protocols specifically designed for components produced using advanced manufacturing techniques are essential for incorporating these technologies into nuclear systems. Traditional qualification approaches often assume conventional manufacturing methods and may not adequately address the unique characteristics of additively manufactured components. Developing science-based qualification protocols—including generating "as-built" digital representations of components—can account for these differences while maintaining rigorous standards, which are critical for leveraging advanced manufacturing in nuclear applications.

Another important effort is enhanced focus on supply chain visibility and management tools to enable the identification and mitigation of vulnerabilities before they impact system development or production. In an era of global supply chains and increased competition for specialized materials and components, the ability to monitor supply chain health, identify potential disruptions, and rapidly implement alternative sourcing strategies is essential for maintaining program schedules and system availability.

Workforce Development

The human dimension is perhaps the most critical element of an agile enterprise, requiring comprehensive approaches to recruiting, developing, and retaining the specialized talent needed for nuclear system development and production.

Cross-disciplinary training prepares scientists and engineers to work across traditional boundaries, enabling the integrated approaches essential for addressing complex challenges. Rather than organizing work strictly by discipline—mechanical engineering, electrical engineering, and materials science, for example—an agile enterprise should develop professionals who understand multiple domains and can collaborate effectively across disciplinary boundaries. This cross-disciplinary capability is particularly important for nuclear systems, where performance depends on the integration of multiple technical domains. It is also essential to ensure this workforce has the opportunity to pursue relevant and challenging scientific research, such as studies of fusion ignition at the National Ignition Facility, to test their judgment and hone their skills. Direct contact with complex experimental data is an important part of maintaining the scientific humility so important for this high-consequence work and establishing the credentials of this expert cadre.

Knowledge transfer programs are an important part of capturing expertise from retiring personnel, ensuring that critical knowledge is preserved as the workforce evolves. These programs need to go beyond traditional documentation to capture the tacit knowledge—the judgment, experience, and intuition—that often proves most valuable in addressing complex challenges. Through mentoring relationships, recorded interviews, case studies of past programs, and other approaches, these programs seek to preserve insights that might otherwise be lost as experienced personnel retire.

Partnerships with universities and industry develop specialized talent pipelines that ensure a continuous flow of qualified personnel into the nuclear enterprise. These partnerships can include specialized academic programs, internship opportunities, research collaborations, and other mechanisms that expose students and early-career professionals to the unique challenges and opportunities of the nuclear security field. Given the specialized nature of many roles within the nuclear enterprise, these focused talent development efforts are essential for maintaining the workforce needed for long-term success.

Secure Collaboration Environment

Effective innovation requires the ability to share information and collaborate while protecting sensitive data, necessitating specialized environments and tools that balance security and collaboration needs.

Information-sharing platforms enable collaboration while protecting sensitive information through technical and procedural controls that limit access to authorized users while facilitating necessary communication. For the nuclear enterprise, where security requirements are particularly stringent, these specialized platforms will be essential for enabling the collaboration needed for innovation while maintaining appropriate information protection. New approaches to data curation and management, including use of secure cloud capabilities, will also be essential to an enterprise increasingly powered by advanced AI tools. Given the distributed nature of the nuclear enterprise, with capabilities spread across national laboratories, production facilities, and contractor organizations, these common environments are particularly important for enabling integrated development efforts.

Strategic Benefits

An agile S&T and manufacturing enterprise can deliver a number of strategic benefits that enhance nuclear deterrence in the 21st century security environment.

The maintenance and demonstration of a technological edge represents perhaps the most direct benefit. By accelerating innovation cycles, the United States can maintain clear technological advantages over competitors, even as technology diffusion accelerates globally. This technological edge includes both advanced deterrent capabilities as well as S&T leadership in strategic areas. Together these enhance the credibility of the deterrent and ensure that U.S. systems remain superior to potential adversary capabilities. Speed and innovation are the surest path to ensure that the United States maintains qualitative advantages that complicate adversary planning and reinforce deterrence.

Enhanced deterrence flexibility will enable more rapid adaptation to changing strategic conditions, allowing the U.S. to adjust its deterrent posture as threats evolve. This responsiveness should strengthen extended deterrence commitments to allies by demonstrating the ability to counter emerging threats before they can undermine security guarantees. It can also support strategic stability by ensuring that the United States can respond to technological surprises or strategic shifts without resorting to destabilizing crash programs or accepting periods of vulnerability while new capabilities are developed through traditional processes. By leading in strategic areas of S&T, it also affords the opportunity to create technological surprise and demonstrate the credibility of the U.S. deterrent.

The improved resource efficiency that these approaches would allow will deliver more capability per dollar invested, a critical consideration in an era of competing national priorities. By reducing development times, enabling more efficient production, and extending system lifespans through continuous modernization, an agile enterprise maximizes the impact of limited resources. This efficiency will allow for the maintenance of a credible deterrent even when resources are constrained, ensuring that budget limitations do not compromise national security.

Effective strategic signaling sends powerful messages to adversaries about U.S. resolve and capability without necessarily deploying new systems. The demonstrated ability to rapidly develop, test, and field new capabilities when needed will enhance uncertainty for potential adversaries, reinforcing deterrence by making aggression appear both risky and unlikely to succeed. This signaling value extends beyond deployed systems to encompass the enterprise capabilities themselves, which become strategic assets that influence adversary calculations.

Conclusions

The credibility of the U.S. nuclear deterrent in the 21st century depends not just on the systems deployed today, but on the enterprise that will develop, produce, and sustain future capabilities. Transforming this enterprise to become more agile and adaptable is not merely a technical or organizational challenge, but a strategic imperative essential for maintaining effective deterrence in an evolving security environment.

By investing in production development enclaves, advanced manufacturing, computational capabilities, strategic S&T, and workforce development, the United States can ensure that its nuclear deterrent remains effective against evolving threats while maintaining strategic stability. This transformation will require sustained commitment and investment, but the alternative—a deterrent that cannot adapt to changing conditions—poses an unacceptable risk to national security. By making this transformation a priority, the United States can ensure that its nuclear deterrent continues to provide the foundation for national security and global stability in the 21st century.

Rapid Response to Urgent and Emerging Requirements: From the Era of Stockpile Sustainment to Weapons Modernization

Thom Mason

> "The view that it is possible to sustain, in the 21st century, an element of national security completely unchanged from its Cold War origins is applied uniquely to nuclear capabilities. In no other aspect of national security do we assume an unchanging constant in a rapidly changing world."
>
> —*Report of the Defense Science Board Task Force on Nuclear Capabilities, 2006*

The United States faces a rapidly evolving national security environment, a global landscape marked by strategic competition and the increasing salience of nuclear deterrence.[2] The New START Treaty, limiting both United States and Russian nuclear warhead numbers, is set to expire in February 2026, with Russia already suspending it. Meanwhile China, unconstrainted by strategic nuclear treaties, continues to engage in a massive nuclear force build-out. In both the Indo-Pacific and European theaters, the United States faces theater nuclear force imbalances favoring its adversaries. The October 2023 report on America's Strategic Posture specifically called out the 2027 to 2035 timeframe as a critical period to address threats from two nuclear-armed adversaries.[3] To meet these quickly evolving challenges effectively, the United States—and particularly its Nuclear Security Enterprise (NSE)—must also become more rapid and agile.

Over the past several years, Russia has persistently supported its aggressive actions in Ukraine with nuclear threats. Moscow recently upgraded and expanded its nuclear capabilities, and its continued possession of a substantial theater nuclear weapons arsenal remains a source of concern for United States and allied strategists. In the Indo-Pacific region, China is undergoing a nuclear expansion which appears at odds with its stated no-first-use policy. If China maintains its current pace, it is projected to possess 500 warheads sometime in 2025 and over 1,000 operational warheads by 2030.[4] Despite previously being considered a lesser nuclear power, China's ongoing nuclear buildup and investments in related capabilities will likely

2 Originally released by Los Alamos National Laboratory as LA-UR-25-27884.

3 *America's Strategic Posture – The Final Report of the Congressional Commission on the Strategic Posture of the United States,* Madelyn Creedon, Chair and Jon Kyl, Vice Chair (October 2023), p. vii.

4 *Military and Security Developments Involving the People's Republic of China, 2024, DOD Annual Report to Congress,* Department of Defense (2024), p. ix.

make it a nuclear near-peer of the United States in the coming decade and China may not stop at parity. How the United States confronts these substantial challenges today will affect our security far into the future. All of this requires the United States to urgently address emerging nuclear weapons requirements. However, these requirements come at a time that is far different from the Cold War when the NSE was larger and could rapidly design and produce nuclear weapons.

The current U.S. nuclear triad modernization—the program of record (POR)—was established in 2010. But as described above, today's security environment is vastly different from 15 years ago. The 2023 Congressional Strategic Posture Commission (SPC) recommended an overhaul and expansion of the capacity of the United States nuclear weapons defense-industrial base and Department of Energy's National Nuclear Security Administration (NNSA) nuclear security enterprise to meet some of these challenges, including: stable, year-to-year funding for warhead modernization; reestablishing pit production; advancing the science and technology for warhead certification; and ongoing investment in the NSE's pit and other weapons production facilities.[5] All of these recommendations, however, might take a decade or more to implement, and the nature of China's projected nuclear weapons expansion—as well as the ongoing and very real threat posed by Russia—may require faster solutions. The SPC concluded, therefore, that given the increasingly aggressive behaviors of Russia, China, and North Korea, it might be necessary to change U.S. nuclear forces levels, posture, capabilities and possibly develop increased missile defenses.[6] It is, therefore, crucial to identify mechanisms for harnessing the NSE technologies and capabilities within the next 10 years as the SPC recommended.

Accordingly, a new approach is needed. While the "*stockpile sustainment*" era may have been sufficient for a time, the 2023 bipartisan SPC concluded that the current POR is "necessary but not sufficient" to meet near-future threats from China and Russia. Considering this, the NNSA subsequently tasked the NSE with studies that provide recommendations and improvements to respond more swiftly to evolving and emerging threats. These studies looked at both the current nuclear modernization (the POR) and potentially new capabilities that might be developed concurrent with the POR.

The studies contemplated several questions: Could the NSE design, develop, and produce a new or modified warhead for new or different military capabilities to bolster deterrence and assurance given the necessary mandates to do so? What innovative approaches to development, certification, test programs, and manufacturing could be taken to respond rapidly to an urgent and emerging requirement? What changes to the existing regulatory environment and the acquisition process would be needed? How might efforts to develop a new capability impact the POR? Fundamental to any change in current DOE/NNSA – DOD processes would be the ability of the NNSA to receive

5 *America's Strategic Posture,* p. ix.

6 Ibid., pp. viii - x.

military requirements earlier in the process and have an identified Service partner to work with in order to move forward rapidly on innovation solutions.

From these studies, some common concepts emerged, including creating conditions for continuous weapons modernization; identifying weapons requirements and Service partners much earlier than is currently done; reforming acquisition and funding processes; standardizing technology, engineering, and manufacturing processes and embracing emerging technologies/processes; and streamlining authorities and decision communications. To implement these concepts, a new organizational model that leverages best practices from previous rapid integration and rapid development efforts is also necessary. While these organizational approaches may not be completely transferable to NSE needs, they still provide valuable guidance.

The United States must find ways to leverage and reorganize the existing knowledge base present in NNSA's laboratories, production plants, and related sites—not merely with the aim of expediting the production of already planned capabilities, but rather to find new ways to develop new capabilities urgently.

In fact, there are examples of rapidly fielding solutions to the most pressing problems, both within the NNSA enterprise and the DOD at large. In the nuclear realm, the W76-2 reentry body and the B61-13 bomb represent relatively inexpensive, short-term solutions to quickly and meaningfully enhance the nuclear deterrent. Both were implemented in a way that leveraged the ongoing modernization programs rather than displacing them. Elsewhere in DOD, offices like the USAF Rapid Capabilities Office and the DOD Defense Innovation Unit developed novel approaches to field priority conventional capabilities by leveraging nontraditional approaches to move fast. These offices (and there are other examples) may serve as process models that NNSA could adopt to meet future challenges.

This chapter is organized in three parts: first a description of the threat environment with a specific focus on the role of the U.S. nuclear deterrent in meeting the challenges posed by Russia, China, and North Korea; next, a short historical discussion on nuclear weapons development and the NSE infrastructure during the Cold War and its aftermath (the *era of stockpile sustainment)*; and finally, a description of the NSE today and tomorrow with thoughts on how the NSE can develop capabilities to respond rapidly to urgent and emerging requirements in an *era of weapons modernization*. Undoubtedly hard decisions will have to be made in a budget- and bandwidth-constrained environment. Nevertheless, given the formidable current and emerging threats, the time to act expeditiously is now.

The Threat Environment

China, Russia, North Korea, and Iran are making policies, executing plans, and aligning and synchronizing actions across the entire range of instruments of national power toward the common goal of refashioning the international order, which for nearly a century has been led by the United States and its allies. This aligned action is neither perfect nor complete. Nevertheless, where interests and/or instruments overlap, competitive and/or hostile world powers are increasingly cooperating to undermine the interests of the United States. This cooperation, particularly between Russia and China, has sharpened the focus on the role of nuclear forces along the competition-conflict continuum.

The highest level in the spectrum of conflict is dominated by strategic nuclear forces, i.e. nuclear weapons that are deliverable on an intercontinental basis. For a half century, since the Strategic Arms Limitation Treaty (SALT I), the United States and Russia have engaged in limitations on strategic nuclear forces. But the latest in this sequence of bilateral strategic arms treaties—the New Strategic Arms Reduction Treaty (New START)—will expire in February 2026. Russia and the United States would then be free from the current numerical constraint of 1,550 deployed warheads.

Additionally, China—unconstrained by any strategic nuclear treaties—has been engaged in a massive nuclear force build-out, which former Strategic Command (USSTRATCOM) commander, Admiral Charles Richard, described as "breathtaking."[7] The People's Liberation Army (PLA) rapidly constructed three new large missile silo fields, bringing the total number of active ICBM silos to somewhere around 320.[8] In fact, the current USSTRATCOM Commander, General Anthony Cotton, recently was required to inform Congress that the PLA now operates more strategic launchers than

Rapid Response Organizations –
Air Force Rapid Capabilities Office

Air Force Rapid Capabilities Office (AFRCO) expedites development and fielding of select DOD combat support and weapon systems at the speed of emerging threats. This leverages defense-wide technology development efforts and existing operational capabilities. AFRCO, known for the very few high-profile systems such as development of the B-21 Raider, is a model for rapid prototyping and operational deployment. AFRCO programs follow these tenets to execute their programs.

- Short, narrow chain of command
- Overarching programmatic insight
- Early, prominent warfighter involvement
- Small integrated team operating within a single office
- High DOD, Air Force, and Industrial priority rating
- Funding stability
- Waivers and deviations from any encumbering practices, procedures, policies, directives or regulations.

The U.S. Space Force established a Space RCO office in 2018 to meet the needs of U.S. Space Command. This new organization has achieved some recent successes, including multiple payloads on the USSF-67 mission in January 2023.

7 David Vergun, "China, Russia Pose Strategic Challenges for UNITED STATES, Allies, Admiral Says," DOD News (August 12, 2021). https://www.defense.gov/News/News-Stories/Article/Article/2729519/china-russia-pose-strategic-challenges-for-us-allies-admiral-says/.

8 S*ee Military and Security Developments Involving the People's Republic of China, 2024,* DOD Annual Report to Congress, p. 101.

the United States.[9] More concerning, though, is that China is only at the beginning of its build-out, which over the next decade is slated to include new road-mobile and silo-based variants, some with multiple independently targeted vehicles (MIRVs).

At the theater level in both Europe and the Indo-Pacific, the United States faces a severe theater nuclear force imbalance relative to its adversaries. Russia confronts Europe with thousands of theater nuclear weapons, while the United States and its allies field hundreds. In the Indo-Pacific, the United States deploys zero theater nuclear forces relative to China's many hundreds of nuclear-capable theater weapons. In Europe, one particularly concerning event regarding theater nuclear weapons is Russia's recent Oreshnik intermediate range ballistic missile (IRBM) "combat test," which demonstrated a novel theater delivery system that is MIRV'd and capable of penetrating defenses with a high degree of probability.[10] The United States has no capability comparable to the Oreshnik. The United States' relative disadvantages at the theater nuclear level are what former USSTRATCOM Admiral Richard referred to as a "deterrence gap" that our adversaries could exploit.[11]

While these strategic- and theater-level discontinuities certainly affect strategic deterrence, they could have an outsized impact on assurance. If our allies see an unmanageable strategic force ratio, they might surmise that our extended deterrent lacks credibility, which could induce them to build their own nuclear forces. Thus, addressing these deterrence gaps is crucial to nonproliferation.

A rapidly increasing deficit at the strategic nuclear level, coupled with a widening theater nuclear weapon gap relative to our adversaries, puts the United States in the position of urgently needing to address nuclear warhead-centric emerging requirements.

Yesterday: From the Cold War to the Stockpile Sustainment Era

During the Cold War, the NSE could design and produce weapons at a much higher pace than today—described as "breathtaking," to again quote Admiral Richard. Of course, this was in an era when the NSE infrastructure was much larger than it is today. From World War II to the late 1960s, the stockpile grew to a peak of more than 30,000 weapons and remained above 20,000 until the end of the Cold War.

9 Bryant Harris, "China surpasses US in number of ICBM launchers," Defense News (February 7 2023). https://www.defensenews.com/congress/2023/02/07/china-surpasses-us-in-number-of-icbm-launchers/.

10 For more information on the Oreshnik, see RUSI's " The Oreshnik Ballistic Missile: From Russia with Love?," (December 10, 2024), https://www.rusi.org/explore-our-research/publications/commentary/oreshnik-ballistic-missile-russia-love and Real Clear Defense, "Military and Arms Control Implications of the New Russian Orsehnik Missile" (December 17, 2024). In particular, note Putin's public statement in referring to the Oreshnik: "Air defense systems currently available in the world and missile defense systems being created by the Americans in Europe cannot intercept such missiles. It is impossible." As quoted in https://www.realcleardefense.com/articles/2024/12/17/military_and_arms_control_implications_of_the_new_russian_oreshnik_missile_1079036.html.

11 Admiral Charles Richard in testimony before the Senate Armed Services Committee, Subcommittee on Strategic Forces, Hearing to Receive Testimony on the Nuclear Weapons Council (May 4, 2022). https://www.armed-services.senate.gov/imo/media/doc/22-37_05-04-2022.pdf.

Likewise, a wide range of delivery systems were quickly fielded during the Cold War. These consisted of everything from a recoilless gun and land mine to field artillery; short-, medium-, and intermediate-range missiles; and a variety of air-delivered weapons. Many of these delivery systems were "dual-capable," meaning they could deliver nuclear or conventional munitions.

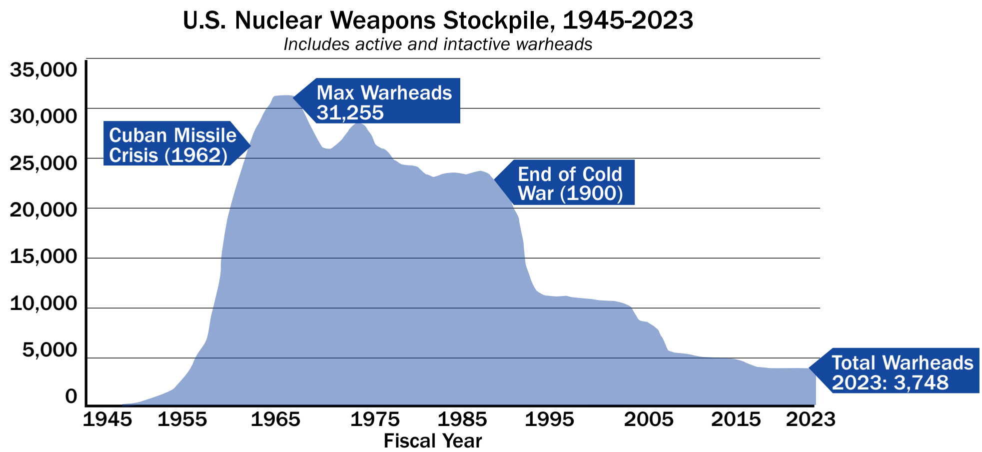

Figure 1. United States Nuclear Weapons Stockpile, 1945-2023[12]

Rapid Development During the Cold War[13]

In each year of the Cold War, the United States produced more than 1,000 warheads and delivered them to the stockpile. The stockpile consisted of as many as 50 weapon types, and between 1950 and 1989, an average of two systems were introduced to the stockpile per year.[14]

The rapid development of nuclear warheads and their delivery systems during the Cold War was evolutionary. In 1945, the Manhattan Project and the NSE that produced the Trinity test device and the Fat Man and Little Boy bombs dropped on Japan consisted of three principal sites: Los Alamos, Hanford, and Oak Ridge.

By 1975, the United States had opened 50 sites across the country—25 plants, three laboratories, 15 nuclear test sites and seven non-nuclear test sites. The NSE had a large capacity. For example, in 1959 and 1960, the production rate exceeded 7,000 weapons per year.[15]

12 Ibid.

13 The National Reconnaissance Program (text box) information is drawn from: https://www.nro.gov/About-NRO/history/.

14 *Extrapolated from Nuclear Matters Handbook 2020* (Revised), Office of the Secretary of Defense (2020).

15 "Brief History of the Nuclear Weapons Complex," Presentation for the University of California, Dwight Jaeger, Officer of Military Applications, Weapons Engineering and Manufacturing, Los Alamos National Laboratory, LA-UR-03-3556 (July 10, 2003).

Along with the production and manufacturing capability in the NSE was the ability to conduct nuclear testing. From July 1945 to September 1992, the United States conducted 1,054 nuclear tests. Atmospheric testing ended in 1962, but the United States (and other countries) continued to conduct underground nuclear testing.[16]

During this period, the enterprise averaged more than six concurrent development and engineering phases (phase 3) and production engineering phases (phase 4), with an average of eight systems in production at a time. The average time from the start of full-scale engineering development to first production was about three years. While this is not a 1:1 comparison given the post-Cold War reduction in infrastructure and capability across the NSE, today it takes the enterprise between 10-12 years to execute a life extension program—double the average during the Cold War.[17]

After the Cold War, from 1994 through 2023, the United States dismantled 12,088 nuclear warheads. Approximately 2,000 additional nuclear warheads are currently retired and awaiting dismantlement.[18]

From 1955 to 1993, the NSE used the Nuclear Weapons Development Guidance (NWDG) Program to ensure that DOD elements maintained awareness of innovative concepts being explored by the NSE, and conversely, that the NSE was aware of current and emerging DOD needs. There was close coordination between DOD and NSE to ensure that both organizations were aware of possible requirements and potential solutions.

Emergency Capabilities and the Cold War

There were several occasions in which, to advance the deterrence mission, emergency operational capabilities were developed and even fielded prior to the arrival of more permanent solutions. This discussion is not meant to advocate against fielding such capabilities, but rather to demonstrate that rapidly fielding new systems is possible. For example, in the early 1950s, as it became clear that the Soviets were racing toward multi-megaton warhead designs, the United States fielded several large thermonuclear bombs as emergency capabilities within less than two years. These were rapidly replaced within a matter of months by “permanent” warhead solutions.

In the mid-1950s, United States policy shifted more strongly toward Eisenhower’s “New Look” approach, in which nuclear weapons should be employed across the entire area of conflict. This called for a nuclearized artillery round—the artillery fired atomic projectile (AFAP)—for the nation’s ubiquitous 8” artillery units, resulting in the W33 being fielded on an expedited basis.

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16 “United States Nuclear Weapons Tests,” Congressional Research Service (Updated January 23, 2025).

17 *Accelerating Product Realization: Aligning the NNSA NSE with Industry Best Practices*, Office of Defense Programs Science Council, NNSA (April 2022), p. 1.

18 “Transparency in the United States Nuclear Weapons Stockpile,” Fact Sheet, Department of Energy, NNSA (2024). Available at: https://www.energy.gov/nnsa/transparency-us-nuclear-weapons-stockpile.

Another initiative during the New Look period was the development of air-defense weapons to address what was in part attributed to a belief that the Soviets had gained some advantage in their strategic bomber capability. Based on what later proved to be faulty intelligence, the United States deemed it necessary to field credible air defense weapons as soon as possible, and the result was the EC-25 for integration with the unguided MB-1 Genie air-to-air defensive rocket. In the later 1950s, with the rise of more compact nuclear designs, guided air-to-air missiles with nuclear payloads became possibilities. The first of these was the GAR-11 Falcon air-to-air missile carrying the versatile W54 warhead, originally fielded on an emergency basis. The W54 was adapted from use in the Davy Crocket recoilless smoothbore gun.

Finally, in the late 1960s, with the rise of potent Soviet air defenses following the shootdown of a U-2 high-altitude reconnaissance aircraft, it became necessary for bombers like the B-52 to "shoot their way in" to deep targets. To quickly address this emerging requirement, the NSE employed expedited development processes to deliver a short-range attack missile (SRAM) and its W69 warhead. From concept to fielding, the entire process took about five years. Other emergency capabilities took less than five years. Today the average time to produce or refurbish a warhead is approximately 25 years.[19]

The Era of Stockpile Sustainment

Cold War tension began to ease with the fall of the Berlin Wall in 1989 and the breakup of the Soviet Union in 1991. Landmark arms reduction treaties like the Intermediate-range Nuclear Forces (INF) Treaty (1987) and the Strategic Arms Reduction Treaty (START) (1991) ushered in a period of nuclear arms reduction by the United States and Russia. Nuclear warhead numbers dropped from their Cold War peak of about 30,000 and 40,000 warheads on the U.S. and Russian sides respectively to less than 5,000 strategic warheads as the START treaty entered into force in 1994.[20] Underground nuclear testing ended in 1992, and "science-based stockpile stewardship" became the methodology used by the United States to assess the safety, reliability, and performance of current and future nuclear weapons without underground nuclear explosive testing. The focus of the next two decades became maintaining core capabilities while reducing the size of the overall NSE complex. Thus, the United States entered the era of "*stockpile sustainment,*" i.e., conducting activities focused on the health of the stockpile; this included surveillance, annual assessments, investigations, and routine maintenance to include updating components of weapons through modernization programs.[21]

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19 Apart from the systems currently in the stockpile, systems were fielded for an average of less than 15 years.

20 "START I at a Glance," Arms Control Association Fact Sheet. https://www.armscontrol.org/factsheets/start-i-glance.

21 For details, see the "Fiscal year 2025 Stockpile Stewardship and Management Plan—Biennial Plan summary," DOE/NNSA (September 2024). Available at: https://www.energy.gov/nnsa/articles/stockpile-stewardship-and-management-plan-ssmp.

During this time period, a once tight coupling between the DOD and the NSE began to drift. As the focus of warfare shifted from preventing nuclear wars to executing conventional conflicts, programs like the NWDG were abandoned. With the end of the NWDG, a critical communication and planning tool was gone—a key tool that had informed Service and NSE Research and Development (R&D).

While the stockpile sustainment approach was prudent considering the international security environment, it levied some unanticipated costs on the NSE, many of which are now starting to be fully understood. The enterprise's ability to field new and modern systems was handicapped. Likewise, the timelines to complete life extension and modernization programs to maintain the aging stockpile extended to an average of 10-12 years to execute—double that of the Cold War.[22] This was coupled with a shift to drive system lifetimes out to 20 and then 30 years. Nevertheless, given the geostrategic conditions during this timeframe, the stockpile continued to provide an effective deterrent, and the organizations and processes of the era were fit for purpose.

In an era in which the goal was a static nuclear arsenal and weapons complex, an inability to move rapidly was not seen as a disadvantage. A slowly evolving stockpile was matched by a slowly evolving strategic environment.

Today: Strategic Competition and Weapons Modernization

By 2010, it was clear that B-52 bombers (from the 1960s), Minuteman missiles (fielded in the 1970s), and Ohio-class ballistic missile submarines (first put out to sea in the 1980s) needed to be modernized. Just a few years earlier, Russian President Vladimir Putin had made a surprising speech at the 2007 Munich Security Conference, accusing the United States of creating a unipolar world "…in which there is one master, one sovereign." He added "… at the end of the day, this is pernicious."[23] Concurrently, China had embarked on "… a new phase of military development by articulating roles and missions for the People's Liberation Army (PLA) that go beyond China's immediate territorial interests," as noted in the 2010 annual DOD report to Congress titled *Military and Security Developments Involving the People's Republic of China.*[24] The report observed that China was modernizing its nuclear forces by adding more survivable delivery systems, including a road-mobile ICBM "which were possibly capable of carrying multiple independently targeted re-entry vehicles (MIRV)."[25]

22 *Accelerating Product Realization: Aligning the NNSA Nuclear Security Enterprise with Industry Best Practices*, Office of Defense Programs Science Council, NNSA (April 2022).

23 Daniel Fried and Kurt Volker, "Opinion: The Speech in which Putin Told Us Who He Was," *POLITICO Magazine* (February 18, 2022).

24 *DOD Annual Report to Congress on Military Developments Involving the People's Republic of China*, Office of the Secretary of Defense (2010).

25 Ibid., p. 2.

However, "strategic competition" and the idea of not one but two nuclear peers had not yet entered the United States national security lexicon. In fact, excerpts from the 2010 *Nuclear Posture Review* illustrate the threat assessment at the time.

> Today's most immediate and extreme danger is nuclear terrorism … today's other pressing threat is nuclear proliferation. … While policy differences continue to arise between the two countries and Russia continues to modernize its still-formidable nuclear forces, Russia and the United States are no longer adversaries, and prospects for military confrontation have declined dramatically … The United States and China are increasingly interdependent and their shared responsibilities for addressing global security threats, such as WMD proliferation and terrorism, are growing.

Thus, the rational for U.S. strategic modernization was a one-for-one replacement of old systems. Additionally, the 2010 NPR pointed out the need to improve the state of the NSE, stating the following: "Increased investments in the nuclear weapons complex of facilities and personnel are required to ensure the long-term safety, security, and effectiveness of our nuclear arsenal. New facilities will be sized to support the requirements of the stockpile stewardship and management plan being developed by the National Nuclear Security Administration." Furthermore, it had been made clear that the NNSA workforce needed recapitalization.[26]

New START was also being negotiated to replace the expired 1991 START I Treaty. So, while the administration's focus was on reducing the role and numbers of nuclear weapons (i.e., the Moscow Treaty), the United States would embark on a modernization of all three legs—a new stealth strategic bomber, a new air-launched cruise missile (ALCM), a new ballistic missile submarine, and a new ICBM. A bipartisan consensus in Congress supported both arms control and strategic modernization, and there was a linkage between the two that solidified Senate ratification of New START.

By 2017 it had become apparent that the hopes of 2010 had not come to fruition. In fact, the threat environment was assessed in much bleaker fashion by the 2018 *Nuclear Posture Review*:

> Global threat conditions have worsened markedly since the most recent 2010 NPR. …While the United States has continued to reduce the number and salience of nuclear weapons, others, including Russia and China, have moved in the opposite direction. They have added new types of nuclear capabilities to their arsenals, increased the

26 *Nuclear Posture Review Report 2010*, Department of Defense (April 2010).

salience of nuclear forces in their strategies and plans, and engaged in increasingly aggressive behavior.

This assessment spurred a re-energizing of the NNSA infrastructure modernization program. It also resulted in the recommendations that the United States retain the B83 strategic gravity bomb, rapidly field the W76-2 low-yield SLBM warhead, and pursue a nuclear sea-launched cruise missile—the SLCM-N—for theater nuclear deterrence.

Today, the NSE has several POR-related warhead efforts underway simultaneously. In the near-term (2025-2030), the NSE has delivered the B61-12 and the first production units of B61-13 (2025) and is slated to accomplish the following: deliver the W80-4 weapon and achieve the capability to produce 30 pits/year at LANL, deliver the first production units of the W87-1 and W93 warheads (due in years 2031-2040), and reach initial operational capability in the SLCM-N. Meanwhile, DOD is progressing with delivery systems to eventually replace Cold War legacy platforms—the B-21 to replace the B-2, the Sentinel ICBM to replace the Minuteman III, the Long-Range Standoff (LRSO) Weapon to replace the ALCM, and the Columbia class nuclear ballistic missile submarine (SSBN) to replace the Ohio class SSBNs.

The Strategic Posture Commission Report

In October 2023, the bipartisan commission on America's strategic posture released its report.[27] The bottom line was that the current modernization POR (B-21 nuclear-capable bomber, Sentinel ICBM, Columbia class SSBN, and Long Range Stand Off weapon and associated nuclear explosive packages) remains "necessary but is not sufficient to meet the threat challenges posed by Russia and China in the 2027-2035 timeframe."[28]

The Strategic Posture Commission (SPC) made clear that the United States needs to *fully and urgently execute the POR* while supplementing it to ensure effectiveness in a two-peer environment. The Commission recommended three actions:

- First, to fully execute the current POR and accelerate timing and completion where possible while determining what additional requirements are needed to meet threats that have emerged since 2010.
- Second, identify risk-mitigating actions across the Triad to ensure program modernization delays and/or deployed system early age-outs do not result in militarily significant shortfalls in deployed nuclear capability.

27 The Commission consisted of 12 individuals from both sides of the aisle: Jon Kyl, Madelyn Creedon, Marshall Billingslea, Gloria Duffy, Rose Gottemoeller, Lisa Gordan-Hagerty, Rebecca Heinrichs, Leonore Tomero, Matt Kroenig, John Hyten, Frank Miller, and Robert Scher.

28 The Commission concluded that while the current POR was necessary to modernize an aging U.S. nuclear Triad, it alone was not sufficient to deter and if necessary, achieve national security objectives should deterrence fail, given the emerging threats posed by China, Russia, and other nuclear capable states.

- Third, the president must have a U.S. theater nuclear force posture with a significant range of effective options to counter adversary limited nuclear use in theater.

Regarding actions to mitigate the legacy-to-modern transition risk, the SPC recommended the following be pursued with urgency:[29]

1. prepare to / exercise upload ICBM and SLBM warheads;
2. develop plans to reconvert some SLBM launchers and B-52s to the nuclear role;[30]
3. provide sufficient funding to extend the service life of some deployed systems where technically feasible (e.g., Ohio-class SSBNs);[31]
4. plan to deploy Sentinel ICBM in a MIRV'd configuration;
5. increase the planned numbers of LRSO weapons and B-21 bombers;
6. pursue feasibility of a future road-mobile ICBM force;
7. develop advanced integrated air and missile defense (IAMD) countermeasures.

Finally, concerning theater nuclear forces, the SPC called for urgent modification. Specifically, to develop and deploy theater nuclear-delivery systems that have some/ all of the following attributes:[32]

- Forward deployed or deployable to European or Asia-Pacific theaters
- Survivable against pre-emptive attack without daily force generation
- Range of yield options including low yield
- High confidence IAMD penetration
- Operationally relevant weapon delivery timeline (promptness)

The SPC also identified several major challenges in both the DOD and DOE/ NNSA industrial base that will require policy, budgetary, and organizational solutions on an accelerated schedule to execute the current POR and expand capability as identified in the report. Three areas are identified by the SPC with recommendations: infrastructure, manufacturing supply chain, and workforce.

- *Infrastructure:* The SPC recommends funding NNSA's recapitalization efforts both for new facilities to replace those beyond repair and those that extend the life of

29 *America's Strategic Posture*, pp. 45-48.

30 See June 18, 2024 Defense News article: "Congress wants to restore nukes on conventional B-52 bombers," available at: https://www.defensenews.com/air/2024/06/18/congress-wants-to-restore-nukes-on-conventional-b-52-bombers/.

31 SSBN service life extensions require an 18-month overhaul called a Pre-Inactivation Restricted Availability (PIRA). This decision will be made during the FY25 Program Objective Memorandum (POM) build.

32 *America's Strategic Posture*, p. 49.

maintainable facilities.

- *Manufacturing supply chain:* The SPC recommends DOE/NNSA (and DOD) continue to reform acquisition and project management processes to better reward on-time product delivery.
- *Workforce:* The SPC recommends the following actions.
  1. Establish a workplace culture in the NSE reinforcing the strategic importance of the work.
  2. Grow effective leaders.
  3. Reward experimentation and appropriate risk-taking.
  4. Adjust to new workplace expectations.
  5. Recognize failure as part of the development process.
  6. Delegate responsibility to those program experts at the lowest level who are most knowledgeable of that program's characteristics.

Regarding streamlined requirements for development and rapid and more agile acquisitions, the SPC recommended both DOD and DOE further expand processes to do so. Specifically:

> This would enable insertion of innovative technologies to accelerate applications of new capabilities and have an impact on the 2027-2035 strategic landscape and beyond. To this end, the Departments of Defense and Energy should establish agile acquisition pathways and set aside specific budget lines and funding to rapidly acquire and leverage innovative commercial technologies for applications to strategic deterrence.[33]

Following the Strategic Posture Commission's (SPC) report release, NNSA's Office of Defense Programs tasked various elements in the NSE with studies to explore accelerated production and better enable the NSE to respond more swiftly to the evolving national security environment and DOD requirements for future systems. Some of the studies and their recommendations focused on meeting the modernization demands of the current POR and actions in some cases extend out to 2050. Other studies emphasized addressing near-term, urgent, and emerging requirements, particularly the 2027-2035 threat window.

33 Ibid., p. 74.

Tomorrow: Emergent Needs Demand a Rapid Response

The NNSA studies, SPC recommendations, and a range of public statements and papers all aver that *the time to act is now*, and the action must be rapid.[34] The United States can no longer continue to manage the NSE using framework and structures developed for the *stockpile sustainment era* of the 1990s.[35] In today's multifaceted threat environment—with two strategic competitors equipped with sophisticated nuclear arsenals and regional nuclear-armed actors that threaten United States and allied interests—"delay is the enemy." As stated by the Strategic Posture Commission, "The United States faces a strategic challenge requiring urgent action."[36]

While the NSE need not return to the size of production and R&D capacities and capabilities supported during the Cold War, some increase with intentional design for reconfigurability of facilities is essential. Starting in the 1990s, the NSE complex was intentionally downsized to support the nuclear weapon Life Extension Programs for 1 to 1.5 systems at a time. Even with this focus, not all capabilities were maintained in warm standby.[37]

Infrastructure upgrades that began in the last 10 years must continue with additional investment to ensure that both capacity and capabilities are ready for the burgeoning *era of weapons modernization*. This will require acting on the SPC recommendations to maintain NNSA's recapitalization efforts and partner where able with the United States industrial base. At the same time, critical aspects of the NSE should be "right sized" to meet urgent and emerging requirements. For example, if more frequent refreshes and updates to weapons are pursued, this will increase the demand on transportation, logistics, and storage and warehousing for materials and components, especially for special nuclear materials.

Managing Risk – Parallel vs. Serial

Evolving from the current *stockpile sustainment* paradigm to *weapons modernization* as described in this paper will entail risk. Every NNSA study pointed out the risks involved in taking a particular approach. The faster the NSE needs to move, the more parallel collaboration across areas of expertise and organizations must occur. Organizational stove piping needs to be minimized.

Serializing processes are a risk reduction strategy, but a heavily serialized process can extend a program's schedule. For example, the documented safety analysis for nuclear explosive operations currently depends on a (1) successful engineering evaluation, followed by (2) a nuclear explosive safety study, then (3) a contractor

34 The SPC report mentions the words "urgent" and "urgently" over 40 times.

35 DRAFT NNSA,"90x Day Continuous Improvement Study" (August 2024), p. 9.

36 *America's Strategic Posture*, p. vii.

37 DRAFT NNSA, "90x Day Continuous Improvement Study," p. 26.

readiness assessment, and then finally (4) a readiness assessment. Serialized processes like these need to be examined and where possible, needs should be met in parallel. Making mission delivery the priority requirement for all support organizations and asking questions like “what would it take to authorize safety basis in six months?” can help clarify essential requirements and eliminate redundant “check box” exercises that waste time and do not add value.[38]

The combination of policy and risk-averse culture has slowed the pace of adopting modern and integrated science, engineering, and manufacturing concepts (demonstrated by commercial industries) that are critical to delivering weapon components and systems in an effective and efficient manner.[39] Further, the adaptation and adoption of new processes and technologies such as AI coupled with risk management can start the evolution toward over-the-horizon predictive analytics to help identify as-of-yet unrecognized threats.

With any action, risk (threats and opportunities) is always present. What is important is an ability to gauge risk against the potential benefit and efficiently make decisions using the fail-fast and fail-forward concept.

A New Organizational Model

It may be that a new organizational model is necessary to meet the demands of the new *weapons modernization era*. This is not to suggest a complete overhaul of the existing

38 NNSA, Enhanced Mission Delivery Initiative (EMDI) Clean Sheet Study (July 2024), p. 24.

39 Office of Defense Programs Science Council, “Accelerating Product Realization: Aligning the NNSA Nuclear Security Enterprise with Industry Best Practices” (April 2022), p. 4.

Rapid Response Organizations – Big Safari

Big Safari rapidly fields new capabilities to meet urgent warfighter demands. This usually involves integrating a mature technology with a mature/fielded platform—e.g., rapidly modifying an aircraft with a sensor for a specialized mission. Big Safari, known for its rapid adaptation of aircraft for specialized missions, stands as a model for rapid prototyping and operational deployment. Big Safari programs follow five tenets to execute their programs:

- Projects must have sufficient importance and priority to warrant streamlined acquisition.
- They will produce relatively small numbers of vehicles or equipment.
- They will leverage in-service engineering modification in Air Force Life Cycle. Management Center (AFLCMC) control.
- They will require continuing unique logistics support due to non-standard technology, subsystems, and/or equipment.
- The importance of these projects will justify using extraordinary methods and practices to protect sensitive and classified aspects.

More recently, the U.S. Space Force recognized the utility of the Big Safari model and established a Space Safari office in 2021. Following the Big Safari model, this new organization has achieved some recent successes including developing a common satellite ground system and launching rapid turn “responsive” space capabilities such as the Victus series of spacecraft.

NSE structure, but rather implementing change in certain processes and adopting and adapting organizational models to existing structures.

NNSA is in the process of establishing a “rapid advanced integration program.” This initiative is intended to focus on quickly developing and deploying solutions to urgent and high-priority challenges.

This program will undoubtedly address many of the same issues that NNSA’s sister offices in DOD have had to resolve. Following is a brief sketch of two approaches taken within DOD that might provide NNSA with examples of how those issues could be addressed.

Rapid capability organizations fall into two broad categories. One is *rapid fielding,* which involves integrating high technology readiness level (mature) solutions into/onto existing systems. The emphasis here is on integration and normally results in fielding within two years. The second category is *rapid development* aimed at developing new technologies (but also integrating existing technologies) for unique purposes and often into/onto new systems. This usually takes longer than two years and involves unique authorities and streamlined organizational lines of communication.

Rapid capability development necessitates rapid acquisition authorities. These include Other Transaction Authorities (OTA), Middle Tier Acquisition (MTA), DOD FAR Rapid Acquisition Authority, and in the unique case of SOCOM, a Title 10 Special Acquisition Authority.

Some common traits of successful, fast-paced organizational models include:

- *Empowered Leadership:* Programs like Big Safari and the services of Rapid Capabilities Offices (described below) benefit from decentralized decisionmaking and streamlined chains-of-command. Talent density is key.

- *Highly Integrated Teams*: Lean, multi-disciplinary teams working closely together through co-location (rotational or fixed) and enabled by digital engineering.

- *Use of Commercial Off-the-shelf (COTS) Technology:* Leveraging commercial solutions allowed programs to avoid lengthy R&D timelines.

- *Streamlined Processes:* Programs bypassed traditional procurement regulations to meet urgent needs—use of Other Transaction Authority (OTA) is an example.

- *Operator Input:* Direct feedback from end-users was prioritized, ensuring relevance and effectiveness.

Both rapid integration (Safari) and rapid development [Rapid Capabilities Office (RCO)] constructs offer potential options for the NSE to consider if it chooses to establish a rapid development organization (RDO).[40] These models emphasize a distinct charter which enables reduced bureaucracy. Key elements would include:

- Short chain of command—usually directly to agency head
- Funding stability and reduced funding reporting through normal agency channels
- Priority for personnel, associated support, procurements, range time, for example.
- Standing waivers to agency policies, and ability to get additional waivers
- Long-term sustainment and full-rate production transitions to standing activities

There are pros and cons to both approaches. In both cases, the unique functions of the NNSA and the Labs, Plants, and Sites (LPS) will require a degree of customization when dealing with nuclear weapons. In both cases, the normal role of service acquisition agencies in acquiring, integrating, fielding, and sustaining nuclear weapon delivery systems will also need to be considered in a way that is not completely parallel with the service Safari and RCO constructs.

Conclusions

Taken as a whole, the history of the NSE—from the eras of the Cold War (1945-1992), *stockpile sustainment* (1992-2010), and *weapons modernization* (2010 to today) is one of evolution, adaptation, and transformation. During the Cold War, the Enterprise demonstrated the ability to rapidly develop new deterrent systems in the face of major challenges posed by adversaries. As the Cold War ended and landmark arms control treaties saw a massive drawdown in the nuclear stockpiles of the two superpowers, again, the NSE quickly adapted and embarked on stockpile stewardship and sustainment, extending the service lives of aging systems while ensuring a safe, secure, and effective nuclear deterrent.

As the Enterprise enters the second decade of the *era of weapons modernization*, three things are clear:

Urgent change is needed: A consistent concern across the NSE is the need to rapidly modernize nuclear weapons systems in the stockpile and be prepared to deliver new capabilities if tasked on shorter timelines. Change to current processes and organizational structures will be required. Growing uncertainty regarding 2027-

40 Big Safari and Air Force RCO information are drawn from: http://www.ndiagulfcoast.com/events/archive/38th_symposium/RutledgeSymp12.pdf and https://www.af.mil/About-Us/Fact-Sheets/Display/Article/2424302/rapid-capabilities-office/ respectively.

2035 threat environment demands urgent action. This uncertainty requires an increased focus on risk management and risk acceptance versus risk avoidance where the identification and realization of opportunities is viewed as important as the mitigation of threats.

Closer Department of Defense (DOD) collaboration is critical: As the NSE transitions from the era of stockpile sustainment to one of weapons modernization, it is essential to minimize organizational and cognitive impediments that impede developing and delivering the United States nuclear deterrent capability. Key to this will be creating mechanisms to improve DOD – NSE collaboration on requirements processes, supporting mixed populations in the stockpile, and developing other communication and coordination pathways. Closer DOD collaboration will better enable action in the areas of improved systems integration and the development of modular architectures, and block upgrades for weapons systems.

Restructure some NSE and related DOD processes to accelerate product realization: Implementing recommendations to improve NSE and associated DOD processes supporting the development of joint requirements can accelerate production, increase responsiveness, and better ensure the weapons acquisition process prioritizes schedule and capabilities. Changes in acquisition requirements and strategies and a realignment of joint planning, requirements, and funding can enable earlier technology maturation and shorter program acquisition periods. New organizational models like a "rapid capabilities office" and emerging technologies and processes (e.g., AI-enabled risk management, over-the-horizon predictive analytics, for example) can be critical enablers.

The Strategic Posture Commission noted that the current POR is necessary both to reestablish a backbone of modern strategic deterrence as well as the infrastructure to build weapons that will be called on to meet emergent needs. In seeking to address the sufficiency question, particularly regarding theater capabilities, deterrence gaps may be addressed, at least in the near term, with relatively small numbers of weapons that might not need to anticipate the long service life of the core strategic systems. Tailoring requirements that reflect this along with the very particular characteristics of the military needs creates the opportunity to implement a more nimble process.

As stated in the 2024 Commission on the National Defense Strategy report, "Production is deterrence."[41] Taking the necessary concrete steps to realize the recommendations put forth in the 2023 Strategic Posture Commission report and elsewhere will send a strong deterrent signal to our adversaries. The United States

41 *Commission on the National Defense Strategy 2024,* p. 51.

Nuclear Security Enterprise has successfully met significant challenges before and will do so again.

Beyond Stewardship: NSE Adaptations to Meet Today's Threats

Laura J. McGill

As the Strategic Posture Commission's (SPC) Final Report concluded in October 2023, "The current multi-program, multi-decade U.S. nuclear modernization program is necessary, but not sufficient to enable the nuclear strategy recommended by the Commission to address an unprecedented two-nuclear-peer threat environment."[42] To do its part in acting on the recommendations of the Commission with the urgency that this moment demands, the Nuclear Security Enterprise (NSE) must dramatically change its operating posture and infrastructure.

One of the report's findings is that "the two-nuclear-peer threat requires a U.S. nuclear force that is either larger in size, different in composition, or both." However, the Program of Record (POR) is already pushing the capacity constraints of the enterprise that was not sized for the current surge of stockpile modernization programs. Over the years, process creep has increased the burden of executing these programs, driving increased staffing and extending the durations to achieve each milestone. At the same time, manufacturing capabilities that were previously dismantled are being re-established, but rate production will not be achieved for several years. In spite of this, however, the amount of hardware demanded by engineering development teams has increased, competing for manufacturing capacity with programs that are already in production. Each of these conditions contribute to the saturation of resources that limits the ability to increase the stockpile or introduce additional systems. Therefore, the operating model must change. To deliver on the recommendations of the SPC, the National Nuclear Security Administration (NNSA) and the NSE are compelled to reduce the resource demands made by the POR. Modernization processes need to be streamlined to reduce labor and accelerate progress, while also decreasing the amount of development hardware that is required to verify performance and complete qualification prior to entering production.

This is achievable through the establishment of more efficient and effective practices that leverage commercial capabilities and enhance program execution to better leverage the strengths of the NSE workforce that wants to deliver on our mission. Furthermore, changes to product development approaches and operating models would also serve to accelerate programs. Many of the changes proposed require relief from the current Defense Programs Business Process System (DPBPS), but these are all within the control of the NSE. The following sections lay out specific

42 Strategic Posture Commission, U.S. Congress, *America's Strategic Posture* (2023).

changes that are required to fundamentally change the pace of the NSE to meet the needs of the nation.

Application of Commercial Technologies and Methods

To remain competitive, commercial companies have been quick to embrace new technologies, engineering advancements, and operational practices that increase the speed of design development and drive more affordable production. In the meantime, the NSE has leveraged the extensive national investment in the DOE labs and NNSA infrastructure to innovate and develop world class, leading-edge science and engineering. However, without the same pressure of competition which is exacerbated by the complexity of the NSE, the enterprise has been relatively slow to focus on accelerating programs and delivering more affordable solutions. Concerted efforts to adopt commercial best practices offer extensive opportunities for the complex to advance and meet the requirements identified in the SPC Report through the use of digital transformation, artificial intelligence, advanced manufacturing, agile execution methods, and other capabilities.

Digital Transformation

The NSE is already on a trajectory to establish an enterprise-wide digital thread that will support all eight Labs, Plants, and Sites (LPS) and the NNSA to access a single authoritative source of truth for Model-Based Definitions (MBDs) and the associated digital artifacts to support the entire lifecycle for each system. As designed, this will significantly increase enterprise efficiency through a phased approach that builds maturity into key elements of the digital thread over time.

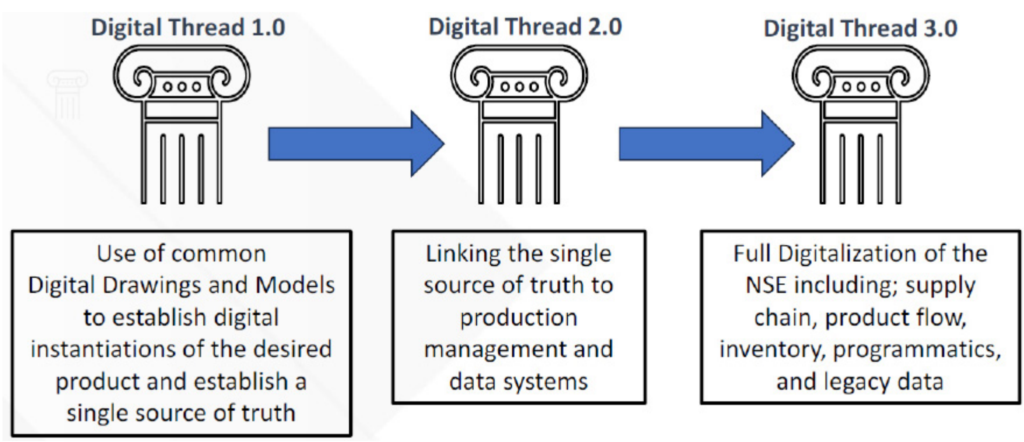

Figure 1. NSE Phased Approach for Digital Transformation

Benefits of this transformation include:

- Accelerated product development
  - » Faster and more predictable movement through workflows
  - » Elimination of manual translations of data to cross organizational boundaries
  - » Manufacturing constraints of production agencies are embedded in mechanical and electrical design tools to identify producibility issues prior to build
  - » Disciplined review and approval flows
- Increased technical insight
  - » Linkage of requirements, design MBDs, models, and simulations that predict component and system performance, factory process data, and test data produced from integration and system verification will provide for more data-driven decisions
  - » Application of artificial intelligence (AI) and machine learning (ML) to optimize designs against balanced requirements, and identify subtle discrepancies in component and system response that are not easily identified through human inspection
- Increased execution accuracy
  - » Elimination of errors in requirements allocation and data conflicts
  - » Elimination of errors from manual translations of data to fit site-unique tools and formats
- Increased efficiency across system lifecycle
  - » Single, designed repository for system digital artifacts maintains organization and accessibility from development through deployment, sustainment, and dismantlement
  - » Elimination of need to recreate historical data with pedigree of digital information embedded in meta data, linked to design and test configurations
  - » Engineer's time increasingly focused on technical, value-added tasks

- Increased organizational alignment
  - » Changes to work scope, schedule, cost, and margin ripple immediately through all affected NSE organizations
  - » More effective engagement of production agencies during design development

Progress on NSE's Digital Transformation requires significant effort to enhance the IT infrastructure, standardize on a common suite of commercial tools, integrate these with other capabilities across the NSE, develop digital engineering workflows, release compatible policies, and train the workforce to conduct their activities more effectively and efficiently through the digital enablers. Although typically reluctant to cite specific numbers, commercial companies indicate productivity improvements on the order of 25% or higher for applying digital engineering,"using advanced technologies to capture data and craft design in a digitized environment."[43] In a report released by the National Nuclear Security Administration's (NNSA) Science Council in April of 2022, the length of acquisition programs could be potentially reduced by 1.6 to 4.3 years.[44]

Artificial Intelligence (AI)

As it is a growing enabler in all business sectors globally, AI is increasingly being used within the NSE to enhance and accelerate work. Organizations have established AI toolsets, policies, and training to facilitate the use of AI. One example is from early 2024, when Sandia National Laboratories released SandiAI Chat, a fire-walled version of the Large Language Model that pulls from curated information and does not feed public data collections. While NSE AI experts develop exquisite algorithms and capabilities, all members of the workforce have access to basic tools and aids. Co-pilots are also now commonly used as digital partners to aid or perform numerous administrative and analysis tasks that save time and resources.

As the technology matures, more advanced uses include design optimization of complex subsystems to increase overall performance. This will be increasingly enabled as the enterprise converts masses of legacy data that is not currently digitized or organized to easily support AI applications. Under the umbrella of digital transformation, a project has been proposed to apply AI techniques to convert historical records to an AI-ready state that will be used for multiple purposes. In the meantime, the associated tools are being enhanced to cite the sources from which

43 Digital Engineering: Controlling Costs for Mega Projects; Paul Menser, Nuclear Newswire (July 2, 2020). https://www.ans.org/news/article-215/digital-engineering-controlling-costs-for-megaprojects/.

44 "Accelerating Product Realization: Aligning the NNSA Nuclear Security Enterprise with Industry Best Practices," Office of Defense Programs Science Council (April 2022). Science Council Members included: Kevin Greenaugh (chair) and members Shawn Dirk (Sandia National Laboratories), Linda Stuart (Lawrence Livermore National Laboratory), James Lynn (Kansas City National Security Campus), Greg Schaaff (Pantex Plant / Y-12 National Security Complex), Jeffrey Paisner (Los Alamos National Laboratory), and Katie Heroux (Savannah River National Laboratory / Savannah River Site).

data is pulled, so that AI results can be validated. Going forward, all information will be digital and formatted for efficient AI applications. This provides significant opportunity to correlate data sets from design models, performance analyses, system integration, production test records, subsystem and system level tests, and full flight telemetry data to verify performance predictions and identify any anomalies that could be extremely subtle and buried in the masses of data that are recorded through the life of the system. This capability will serve as a significant enabler to head off potential issues well in advance of them being manifested in a failure, and will also accelerate the conduct of significant findings investigations, when failures occur.

Modular Design

Modernization programs over the last decade were established to make targeted upgrades that extend the life of aging systems and increase their safety, security, reliability, and effectiveness. Although there are examples of design re-use and some common subsystems, generally each system is uniquely designed for the given requirements. **The NSE can benefit by adopting the same** modular design principles that are now prevalent in the automotive industry, where different vehicles use the same standardized, interchangeable components to significantly reduce development time, as well as development and production costs.

As the NSE is shifting to new weapon designs, we can go even further to establish reference architectures that provide an initial configuration baseline that minimizes the detailed design effort. Although design **concepts have evolved over the years and tech**nologies have advanced, the basic functionality that is provided by most subsystems is relatively unchanged. A general architecture would serve as the baseline for common subsystems, which could be further refined into reference architectures for each leg of the triad to provide the unique performance characteristics that are required for those systems. This would significantly reduce the duration of development by limiting design activities to just those features that are unique to meet new requirements. To the extent that it does not conflict with surety and cybersecurity requirements, the principles of Open Systems Architecture and subsystem modularity should be applied within the reference architectures to provide for future upgrades and extensibility that do not ripple through **the entire configuration.**

Advanced Manufacturing (AM)

NSE design and production agencies are increasingly making use of AM—especially additive manufacturing—to obtain early prototypes for feasibility studies and to refine designs, shortcutting the historical lead times of two years or more that have increased significantly since the global pandemic due to challenges in the industrial supply base. Although these prototypes may not be fully representative of production, this is manageable in early development where the designs are changing rapidly. With these AM capabilities, it is still critical to have the production agencies engaged to assess and account for producibility features, before the trade space narrows to a selected configuration that could preclude later design adjustments.

Beyond fast prototyping, AM is also revolutionizing production for the final product. Additive manufacturing, combining AM and robotic operations, and introducing advanced materials and equipment capabilities that provide tighter tolerances in all aspects of manufacturing and assembly are all expanding the features and component performance that can be designed into our systems. Leveraging these technologies will contribute to the NSE's ability to deliver increased performance to meet adversarial threats. This also requires the design agencies to tap into the deep manufacturing expertise of the production agencies to best incorporate AM into system designs.

Further benefits of AM will be realized when manufacturing becomes embedded in the digital thread through the NSE's digital transformation. Production equipment will provide automated, real-time monitoring of AM mechanisms to identify any deviations (e.g., a material void or variation in surface finish) from the qualified process, which can then be compared to design models and analyzed in real-time to determine if the resulting performance is acceptable, prior to disrupting production operations or scrapping potentially discrepant hardware. This same real-time equipment data will also build the digital twins for each component, assembly, and system that will be used throughout the system lifecycle to assess the effects of the environment and aging. Having individual systems fully characterized will aid operational deployment with the ability to identify exact units that could be more suitable for specific mission scenarios, or susceptible to identified failure modes over time.

Agile Methods

The NSE's current product realization process is driven by increasingly prescriptive methods and processes. Its pace is set by the slowest components to achieve each milestone. Program planning is bottom-up, focused on following those processes and a set number of design iterations for all components rather than on achieving key program objectives and adapting the design activities to do only what is needed for each element. However, as commercial industry and numerous defense companies have demonstrated, agile methods—and specifically the Scaled Agile Framework (SAFe)—offers a much more streamlined and robust approach to product development. It is based on proven integrated principles, practices, and competencies that accelerate programs, with further benefits. In the SAFe construct, planning and work execution are focused on meeting program goals and customer requirements. Greater agility is achieved through empowered teams with the ability to bring innovative solutions and optimize resources across projects and mature each subsystem at its fastest effective rate. SAFe also provides artifacts that increase situational awareness for improved program management.

Agile methods represent a significant change in work processes, but a number of defense companies and programs have efficiently made this shift, converting large, cross-organizational teams to the new methodologies in a matter of weeks, which has resulted in both reduced schedules and costs for product development. Although this would be a significant change to the planning and execution of our programs, there are Agile/SAFe experts that currently reside within the NSE organizations, and additional specialist resources are easily contracted. Agile methods on modernization programs could also leverage the "clean sheet" approach that has been developed by a cross-enterprise team to incorporate a minimum set of requirements from DPBPS, under the umbrella of the NNSA's Enhanced Mission Delivery Initiative. The SAFe methodology is already structured to accommodate "clean sheet" process requirements.

Agile techniques are especially well-suited to support the activities of a new NNSA office organization that is under consideration for the primary purpose of demonstrating "integrated technology solutions of significant deterrence value." Such an organizational construct would focus efforts on a high pace of exercises that would demonstrate emergent deterrent capabilities through high-consequence tests and assessments. Cross-NSE teams are already effectively applying agile methods and have demonstrated the ability to rapidly iterate prototypes that—in addition to supporting demonstration programs—could likely serve as the basis for future capabilities.

Changes to Product Development Approaches and Operating Models

In addition to adopting best industry practices, the enterprise needs to modify long-standing operating models and cultural elements that hamper the streamlining of our programs. The criticality of the NSE mission reinforced with a very low tolerance for failure has increasingly driven a workforce culture that strives for perfection, even in intermediate steps towards the overall goal. This condition has contributed to the growth in bureaucratic processes and a reluctance to declare tasks "done" and close out activities. The adoption of more tactical business approaches would significantly free up capacity and accelerate delivery of needed capabilities. Although these are relatively simple principles, a number of them go against long-standing enterprise practices and habits. It will take a significant change management activity to align the workforce and embed these approaches into the NSE operating model.

Minimum Viable Product (MVP) – Trade Low Value Requirements for Schedule

System performance requirements in the form of Military Characteristics are generally accepted at face value and the NSE design agencies apply the full extent of their design expertise and ingenuity to meet them all. The occasional exception is when design features create conflicts between competing requirements, in which case the sponsors are consulted to clarify priorities. In the pursuit of excellence, there is also a predilection to pursue opportunities for exceeding the stated requirements, often at the cost of additional design iterations and/or design complexity that is likely to extend the development schedule.

What is rarely considered is a design that does not fully meet the requirements but comes close with respect to the key performance parameters and could be achieved within a considerably reduced schedule, or with significantly less risk to the target schedule. It is not part of the DNA of the enterprise to consider anything less than meeting the full scope of requirements. Although the decision to pursue such an MVP alternative would be up to the sponsor, these opportunities should be intentionally considered and proposed to meet the need for accelerated delivery. It should be noted that system safety, security, and reliability are “hard” requirements for which the opportunity for any compromise is extremely limited.

Consideration of trades to achieve the MVP require close collaboration with the program sponsor to fully understand the basis of the stated requirements in the context of the mission. The opportunity lies in understanding the difference between objective and threshold requirements, and the criticality of development timelines relative to those of complementary capabilities. When supported by the sponsor, the NSE should be open to requirements trades that achieve accelerated delivery and proactively pursue these as valid design alternatives.

Knowledge Point Planning

NSE design agencies have decades of experience in planning and executing programs that follow a standard cadence of typically three to five design iterations and review milestones at system levels that ripple down through lower level components. The configuration is incrementally matured through these iterations up until the point that the system is verified to meet requirements. Although the Product Realization Teams (PRTs) understand the more detailed work that needs to be conducted, the integrated baseline plans tend to reflect the set number of iterations for every component, with cost estimates developed accordingly, informed by previous programs that followed the same method.

A different approach is for each PRT to start by evaluating their previous component designs against the requirements of the new system (potentially the MVP) to determine what will be unique about the new component design. From this, they can identify knowledge gaps that will have to be addressed during the design process, which leads to identification of the specific activities (exercising models/simulations, testing prototypes, assessing production processes, etc.) that will close those gaps according to established criteria. Once the activities to close the knowledge gaps are laid out in a schedule with their associated durations, they are linked to establish the critical path, with knowledge point milestones to mark when each knowledge gap is closed. This approach offers several advantages:

- As the program is executed, the increasing technical maturity of each component, subsystem, and the system can be tracked through the closure of knowledge points.

- Instead of top-level iterations that drive every subsystem and component, only those activities that are required to close knowledge gaps are incorporated. If an activity in the plan does not support a knowledge point, then why are we doing it?

- Understanding the knowledge gaps being addressed can inform the fidelity of hardware that is required for prototyping testing, often resulting in faster acquisition of the development hardware test assets.

- Links across organizational boundaries are more evident when they are associated with specific activities.

- With a visible critical path, it can be assessed for opportunity to reduce it, likely by identifying more expedient approaches to close knowledge gaps (e.g., exercising models of appropriate fidelity, as opposed to waiting for prototype hardware).

- Tasking for technical support organizations (engineering analyses, test facilities, for example) can be planned and estimated.

- This approach will drive increased critical thinking and engineering discipline into the planning process that should result in a shorter duration program with higher fidelity cost estimates.

Drive Ultimate Success Over Short-Term Perfection

Current NSE processes are established to drive perfection at every level. Multiple design iterations, pre-design reviews, and design reviews are conducted in attempts to ensure that no "mistakes" are carried forward that could result in test failures, which are to be avoided at all costs in a culture that is intolerant of failure. This mindset drives increasing analyses and hardware assessments that consume more schedule and further capacity in the production agencies. To the contrary, complex engineering development is inherently a journey of discovery as designs are matured and characterized, and opportunities for improvements are identified. Attempts to prevent test failures result in increasingly longer durations before tests are conducted, when unanticipated failures will drive even more detrimental program delays. A low-risk posture for test failure may be appropriate for very complex tests that require time-consuming setups and expensive facilities where critical hardware assets could be damaged. However, early testing in a development program with lower-fidelity test assets can be the most efficient and effective way to identify the need for design changes when failures occur or when the results do not match performance predictions.

The current product realization process also requires that testing during development be conducted with production-representative hardware that may take years to acquire, since as defined, it exercises the entire value stream that would be invoked during rate production, but years before that production line is in place. This level of hardware fidelity is not always required to close knowledge gaps, especially early in development. Critical thinking to make these determinations should be encouraged over process-driven inflexibility. Faster iterations of design-test-fail can drastically reduce development times.

Faster Response to Issues

When issues inevitably arise on complexities, it is critical that they be characterized and addressed as efficiently as practical. Whether it is a development program, construction project, or a production program with the manufacturing line stopped, the entire project can experience day-for-day slips that rapidly impact key milestones and run up costs as the "marching army" is paused but still charging costs. The enterprise is knowledgeable and adept at applying standard industry practices—such as fault trees to guide anomaly investigations—but they are often constructed to cover a broader scope than the problem at hand requires. The problem statement should be as narrow as the issue, failure, or observation supports. Ideally, for an observed failure, this would be based on the specific failure mechanism that is identifiable. For example, instead of stating a failure as "component X did not function," it is desirable to state that "X trace on card Y experienced a fatigue break that resulted in component failure to respond to Z signal." The resulting fault tree should also be logic-based, focused on the most specific definition of the failure mechanism, such that branches of the tree are also specific regarding the ability to cause the known failure. Broad causal categories such as "environments," "aging," and "handling" should be strictly avoided and only included in the context of specific fault mechanisms. When fault trees are established based on failure mechanisms, entire branches can be eliminated at a high level once it can be determined that the specific mechanism did not occur, saving significant time and resources compared to independently closing out every box on an extensive fault tree.

Similar to establishing a baseline program plan as described above, once a logic-based fault tree is established, the investigation plan should also be based on knowledge gaps, and the most expedient methods and activities for closing those can be put into a project plan and scheduled. Long lead-time activities should be prioritized and the investigation team should be charged with providing a regular status report on progress per the investigation plan to maintain focus on efficient and effective resolution. The more specifically an issue can be identified, the more narrow the scope of the investigation will be, and the quicker the root cause can be determined and corrected.

Effective Decisionmaking

The NSE and the current product realization process is paced by decisions that are often made by consensus of large committees. A more efficient and effective mode of operating is to appoint knowledgeable and experienced individuals to serve in the key roles of program manager, chief engineer, PRT lead, and production lead, for example, and then confer the authority and accountability to make decisions within their clearly defined scope of responsibility. NSE programs typically define two types of authority:

- *Programmatic Authority:* The authority, responsibility, and accountability to oversee schedule, cost, program performance, and program integration within the nuclear security enterprise.

- *Technical Authority:* The authority, responsibility, and accountability to make technical decisions for the system or component, to ensure it meets all performance and lifecycle requirements (including safety, security, reliability, and effectiveness) within schedule and cost and is producible with high yields at rate production.

Clear levels and scope of authority to be held by designated individuals should be defined and consistently applied across NSE programs. Decisions by those individuals should be informed by appropriate experts, who are also knowledgeable and experienced in their identified domains. Peer reviews staffed by these experts should be regularly conducted to review documentation, analyses, and test results. They should also be conducted to identify potential implications and risks and make recommendations to the designated decision authority. Major project technical review milestones (e.g., system requirements review, concept design review, baseline design review, product definition design review, final design review, and production readiness review) and program gate review milestones (project feasibility study, product cost study, product conceptual design, product pre-production engineering, product pre-pilot production, and product production steady-state) and the associated decisions should still be subject to broad stakeholder review to ensure NSE-wide alignment, but the vast majority of technical decisions leading up to these reviews should be executed by designated individuals and not committees.

In complex development and sustainment programs there is regular opportunity for disagreement that needs to be vetted, but these conflicts should be resolved as rapidly as practical and revisited only when substantive new information indicates that need. Disagreements are most likely to occur between designated decision authorities at different labs, plants, and sites (LPS), for which conflicts should be resolved at the lowest level practical (e.g., PRT level). When resolution cannot be reached within a reasonable timeframe with respect to impact and program deadlines, disagreements should be escalated quickly to the next level of authorities within the two conflicted organizations. To maintain program schedules, it is imperative that decisions are made when needed to continue progress and not delayed due to disagreements that will not improve with time.

Systems Integration

In the development and sustainment of complex systems for which eight LPS each have significant and specific responsibilities, it is critical that systems integration is conducted effectively to ensure that interfaces are identified and managed, so that the overall system works seamlessly across subsystems and with the delivery platform. This applies to each weapons system, as well as the enterprise itself, especially in an environment where resources are strained to deliver new capabilities and the numbers of units that it was sized for.

Sandia National Laboratories (SNL) serves as the Lead System Integrator for the nuclear weapons program with overall responsibility to ensure that each system meets their military characteristics, including the standards for safety, security, reliability, and effectiveness. Ensuring that nuclear weapon systems meet DOD needs and military characteristic requirements is a joint responsibility between SNL and the respective NEP design laboratory (Lawrence Livermore National Laboratory or Los Alamos National Laboratory) for a given weapon system. As the system integrator, SNL does not have design authority or responsibility to make decisions regarding allocation of requirements to—or management of interfaces for—the NEP design laboratories. However, SNL is responsible for ensuring decisions are made,documenting mutual decisions, managing the documents which define DOD to NNSA interfaces, and when decisions must be made that cannot be agreed to by the weapon system teams, ensuring those decisions are elevated to the laboratory senior management leaders. These activities are critical to continued progress and maintaining program schedules, leveraging SNL's unique system-level models, analyses, and test capabilities—including those that replicate delivery platform interfaces.

In addition to integrating each nuclear weapons program, the limited capacity and resources of the entire NSE need to be accommodated. Increasingly, this requires that design decisions, test procedures, test programs, and the associated hardware assets (in development and production) be scrutinized and limited to what is strictly required and what can be supported within the context of the larger enterprise program portfolio. Only when carefully managed will the NSE be prepared to deliver on the SPC recommendations.

Conclusions

As identified and characterized by the SPC Report, the NSE has great demands being placed on it to meet the current threat environment and to ensure that the nuclear deterrent continues to serve as the foundation of the U.S. National Defense Strategy. However, there are also numerous opportunities to enhance enterprise capabilities and practices to significantly advance and accelerate the ability to deliver an effective nuclear deterrent.

No single capability or practice presented herein will achieve the necessary efficiencies. It will require that all, or at least many, of these capabilities are invoked to meet the moment. The best opportunity to deliver more and/or different systems for U.S. nuclear forces will result from the synergistic effect of applying proven commercial technologies in concert with changes to product development approaches and operating models. It is imperative that the NSE make the required changes to realize these benefits and meet the needs of our nation.

Peace through Strength in the Nuclear Enterprise

Austin Long

"Peace Through Strength" has been a key component of America's defense and foreign policy from the beginning. In the first-ever State of the Union address, President Washington stated that "To be prepared for war is one of the most effective means of preserving peace." Washington's remarks were echoed during the Cold War, when U.S. nuclear deterrence was the linchpin of the U.S. alliance structure that ultimately prevailed in the struggle with the Soviet Union. The U.S. nuclear enterprise was the core of peace through strength in this period, providing innovative capabilities at a rapid pace.

At the end of the Cold War, the enterprise shifted—while still pursuing leading-edge science, it became far less focused on manufacturing and delivering innovative nuclear capabilities. With peace seemingly assured, strength seemed less important. Instead, the enterprise (and the nation) prioritized sustainment, refurbishment, and life extensions of existing nuclear platforms, delivery systems, and weapons. During this "peace dividend" era, the U.S. nuclear enterprise institutionalized many processes and habits that have become detrimental to achieving its primary purpose. It institutionalized the drive to eliminate risk, not manage it. It developed the habit that every problem could be studied at length until all risk of action was eliminated—while discounting or simply ignoring risk associated with inaction. It forgot the need to deliver rapidly, outpacing threats. In a time of limited threat, this was perhaps acceptable if not optimal.

Yet the international security environment has dramatically worsened in the past decade, and the need to assure peace through strength is once again front and center. As with the Cold War, nuclear deterrence will be a critical element of peace through strength. The nuclear enterprise must once again rapidly deliver innovative capabilities to outpace threats.

Delivering peace through strength in the 21st century will require fundamental transformation in the nuclear enterprise's components, in both the Department of Energy (DOE) and the Department of War (DOW). This essay outlines the need for change and then takes stock of the incremental progress the enterprise has made over the past decade. It then turns to recommendations for more fundamental changes needed to ensure the rapid delivery of innovative capabilities.

The Imperative of the Security Environment

The challenge confronting the nuclear enterprise begins with the security environment, which has worsened at a dizzying speed. China is rapidly expanding its military capabilities quantitatively and qualitatively, and in all domains including nuclear forces. China's nuclear breakout is in both long-range and strategic force, and regional nuclear capabilities that seek advantage in the Indo-Pacific. China's leaders are also investing in the underpinning nuclear infrastructure and to carry out an expansion that will enable it to achieve rough parity with the United States in the 2030s.

In addition, Russia has spent the past two decades modernizing its nuclear arsenal while illegally invading Ukraine. It has used nuclear coercion to discourage international military responses to its aggression. The growing alignment of Russia and China and the emergence of a de facto axis between them, North Korea, and Iran exacerbates the challenge.

In contrast, as described by the 2023 Strategic Posture Commission, the nuclear capabilities currently being developed by the U.S. nuclear enterprise remain rooted in the geopolitical environment of the peace dividend and through the lens of arms control initiatives. Nuclear modernization plans still being executed today were largely established in the early 2010s, providing essentially like-for-like replacement of core nuclear triad capability, but with less overall capacity and quantity. While U.S. nuclear forces remain effective for deterring strategic attack today, the Strategic Posture Commission rightfully points out that they lack the flexibility that ensured both strategic and regional deterrence throughout the Cold War. Put simply, U.S. nuclear deterrence—the core of peace through strength—is eroding. Successfully deterring current and future adversaries will require the United States to complete the necessary but not sufficient program of modernization of the nuclear deterrent. At the same time, the leaders of the nuclear enterprise must make hard decisions to address the challenge of the emerging security environment and be willing to take risks in a culture that prioritizes risk aversion above all else.

Incremental Progress in the Nuclear Enterprise, 2015-2025

Over the past decade there has been some progress in adjusting the nuclear enterprise to the challenge of peace through strength in the 21st century. At the top of the list is investment in the infrastructure needed to design and produce nuclear weapons, which has been neglected since the end of the Cold War. This investment is slowly beginning to yield dividends. Most notably, after roughly 35 years of not making new plutonium pits, apart from a limited production run for research purposes, Los Alamos produced the first new U.S. war reserve pit in 2024.[45]

In addition to investments, the laboratories, plants, and sites under the purview of the National Nuclear Security Administration (NNSA) have also begun to adapt, both individually and in concert with one another. For example, working with NNSA, the

45 Whitney Spivey, "We have commenced war-reserve pit production," Los Alamos National Laboratory (December 9, 2024). https://www.lanl.gov/media/publications/national-security-science/1224-we-have-commenced-war-reserve-pit-production.

Kansas City National Security Complex (KCNSC) has taken creative short-term and long-term measures to expand its capacity to build non-nuclear components for the nuclear enterprise.[46] In 2022, KCNSC and Lawrence Livermore National Laboratory jointly opened a Polymer Production Enclave to enable concurrent engineering and accelerated development of advanced materials.[47]

Promisingly, NNSA and Congress have begun exploring an alternative framework for rapid capability development. The draft Fiscal Year 2026 National Defense Authorization Act directs the creation of a Rapid Capabilities Office within NNSA, modeled on similar entities in the military services. One of the key missions of the office is to "identify and pursue opportunities to accelerate operationally-focused capabilities through advanced prototyping."[48] NNSA had already begun to work along these lines in advance of the Congressional direction.

The enterprise has successfully demonstrated the ability to make incremental progress in responding to the security environment. It first accomplished this in 2019 with the execution of the W76-2 low-yield submarine-launched ballistic missile warhead. Pursuant to direction in the 2018 ***Nuclear Posture Review***, the nuclear enterprise smartly leveraged an existing production line to offer a new capability to the stockpile rapidly. Second, perhaps paramount and utilizing the lesson of the open production line, is the B61-13 gravity bomb. A variant of the B61-12, the first B61-13 was completed in May 2025—less than two years after the announcement of the program and almost one year ahead of schedule. Secretary of Energy Chris Wright noted at the time that "[m]odernizing America's nuclear stockpile is essential to delivering President Trump's peace through strength agenda. The remarkable speed of the B61-13's production is a testament to the ingenuity of our scientists and engineers and the urgency we face to fortify deterrence in a volatile new age."[49]

Accelerating a Return to Peace Through Strength

These green shoots of change in the nuclear enterprise are welcome, but more fundamental changes are required to meet the challenge. At present, the enterprise is struggling to deliver on the basic requirements of modernization (e.g., Minuteman III to Sentinel transition) along with very modest additional/different capabilities (e.g. SLCM-N) with anything like speed. Accelerating a return to peace through nuclear strength, which will require delivering more and different nuclear capabilities at

46 Government Accountability Office, "National Nuclear Security Administration: Update on Actions to Manage Production Challenges at the Kansas City Site" (November 16, 2023). https://www.gao.gov/assets/d24105858.pdf.

47 "Polymer Production Enclave fully operational," Lawrence Livermore National Laboratory (May 11, 2022). https://www.llnl.gov/article/48646/polymer-production-enclave-fully-operational.

48 S.2296, "FY26 National Defense Authorization Act" (July 15, 2025). https://www.congress.gov/119/bills/s2296/BILLS-119s2296rs.pdf#page=1366.

49 "NNSA completes assembly of the first B61-13 nuclear gravity bomb ahead of schedule," Department of Energy (May 19, 2025). https://www.energy.gov/nnsa/articles/nnsa-completes-assembly-first-b61-13-nuclear-gravity-bomb-ahead-schedule.

speed and scale to match the emerging security environment, is simply beyond the nuclear enterprise as currently constituted. Fundamental changes are a must to break out of the past three decades of slightly less than benign neglect. Three of these fundamental changes extend to entirety of the enterprise, while others are specific to DOD and especially to NNSA.

Enterprise-Wide Changes

Providing a Sense of Urgency to Deliver Nuclear Capabilities

The most fundamental thing senior leaders of the nuclear enterprise can do to accelerate a return to peace through strength is to provide a real sense of urgency that the nuclear enterprise has an opportunity and imperative to act *today*. For too long the U.S. government has acted as if it always has more time to develop modern nuclear capabilities. For example, the fiscal year 2013 budget delayed the procurement of the first COLUMBIA-class submarine by two years in order to free up resources at the time. Now, delivery of the first submarine faces a delay of up to 18 months, and there is no time to spare as the OHIO-class submarine approaches the end of its lifecycle. In a similar vein, over the last 20 years, the United States has attempted no less than four strategies to achieve new plutonium pit production at scale. This time and financial investment finally yielded its first war reserve pits in 2024.

While the acting NNSA administrator has recently and admirably tried to impart a sense of urgency in NNSA, it must truly begin with the secretaries of War and Energy, who must personally engage on these issues. A requirement that the Nuclear Weapons Council brief them jointly at least twice a year on progress and problems in the nuclear enterprise would do much to advance this urgency. Similar briefings to then-Secretary of Defense Esper as part of the implementation of the National Defense Strategy were very useful in ensuring senior attention inside the Department of Defense (and it would have been all the more effective had it included the Energy Secretary as well). At the same time these briefings would enable the responsible Cabinet officials to work together to address problems, and as discussed below, to manage risk strategically and cumulatively.

Balancing and Managing Risk Strategically and Cumulatively

When weighing options and actions within the U.S. nuclear enterprise, decisionmakers must balance and manage many types of risk. Toward one end of the spectrum of risks are risks associated with individual organizations, projects, or programs. For example, the U.S. Air Force must manage programmatic or acquisition risk to develop the Sentinel ICBM or the B-21 bomber, and the NNSA must consider environmental risk when modernizing a nuclear facility. These risks are important to delivery of particular capabilities or capacities, and often involve balancing among cost, schedule, and performance tradeoffs.

At the other end of the spectrum is the risk of deterrence failure. Deterring strategic attack on the United States and its allies is *the* driving risk and underlying rationale for the U.S. nuclear arsenal. However, since the end of the Cold War, these kinds of existential risks have faded from view and risk of deterrence failure has rarely been included or considered when weighing localized risks. With this focus on individual organizational tasks, projects, and programs, the nuclear enterprise took actions that did not consider the impact of those actions to the highest-order geopolitical risks. While the risk to deterrence failure has unquestionably risen in recent years, the nuclear enterprise has been slow to react. If the U.S. nuclear deterrent is to focus again on its fundamental purpose this must change, and the risk of deterrence failure must again drive decisionmaking.

This will potentially entail assuming more risk at the individual program level. For example, in the era of the peace dividend, reducing risks of unauthorized nuclear use was a very high priority, and was prioritized higher than timely delivery of capability. In the future, this prioritization deserves scrutiny—while preventing unauthorized use will always remain a high priority, marginal reduction of that risk may not be as important as reducing the risk of deterrence failure.

Ruthlessly Prioritizing and Trading Requirements to Move at Speed

Nuclear weapons are produced to meet requirements while being constrained by regulations, which are a form of imposed requirements. Well-scoped requirements and regulations are crucial to programmatic success but must remain flexible, particularly when fulfilling a requirement or regulation that is in tension with other objectives, such as speed of delivery. For the purposes of the U.S. nuclear enterprise, requirements could be considered to fall into three broad categories: national nuclear deterrent requirements, program and project requirements, and weapon system requirements.

- *National nuclear deterrent requirements* are developed to ensure a safe, secure, effective, and credible nuclear deterrent that also provides the president options to achieve national objectives should deterrence fail. At the national level, the Joint Requirements Oversight Council (JROC) and Nuclear Weapons Council (NWC) are two organizations that promulgate such requirements derived from guidance such as the president's nuclear employment strategy, the *National Defense Strategy*, the *Nuclear Posture Review*, and other national policy direction. These requirements are based on the global threat environment, the roles and desired attributes of U.S. nuclear forces, and integrated assessments of how individual capabilities come together within the broader nuclear deterrent. An example of national nuclear deterrent requirements is contained in the NWC's Requirements and Planning Document (RPD), which considers enterprise-wide constraints, opportunities, and risks to develop overarching near- to long-term plans for the U.S. nuclear stockpile that subsequently inform the detailed execution plans of NNSA and the military services. Ultimately, the considerations that drive national nuclear deterrent requirements stem primarily from national policy and current and projected threats to U.S. vital interests, including existential risks to the nation.

- *Program and project requirements* govern and influence how organizations within the enterprise execute programs or projects, such as nuclear weapon programs, infrastructure projects, or advanced scientific exploration. These requirements directly impact the cost and schedule associated with executing a project or program and are often directly balanced and traded by program or project managers. Considerations that drive requirements in programs and projects may be technical (scientific, engineering, manufacturing), regulatory, or administrative in nature and could constrain or enable the ability of a performer to effectively execute the program or project on schedule and within budget.

- *Weapon system requirements* specify the characteristics necessary for a weapon to achieve the desired military effect, should it be employed. Weapon system requirements can include system physical characteristics (e.g., size and weight), functional aspects of delivery (e.g., survival of stockpile-to-target sequence environments or ability to overcome adversary defenses), desired effect on target (e.g., yield or accuracy), and desired reliability of the system. The detailed requirements for components, subassemblies, and various technologies are derived from higher-level weapon system requirements. Weapon system requirements can be derived from a combination of national and program requirements, and ultimately from considerations for how the weapon would be employed should deterrence fail.

These three broad categories of requirements inextricably link to one another, with various enterprise stakeholders and organizations owning them. How these requirements are managed and traded directly impacts the success or failure of a program. Ever-changing requirements that never solidify or requirements that are too high level are common root causes in failed programs. However, a program with requirements that are fully and completely sacrosanct and cannot be changed, or are overly prescriptive and disallow flexibility, can also lead to failure.

Ruthless assessments and hard decisions regarding requirements and regulations are needed. For example, is achieving 100% of a JROC-validated military requirement worth a two-year schedule slip and another billion dollars? Or is achieving only 80% of the requirement—but on-schedule and on-cost—the better course of action for the nuclear deterrent writ large? Senior leaders of the nuclear enterprise, including at the Cabinet level, must demand opportunities to make these hard decisions.

Changes Specific to the Department of Defense/War

DOD's part of nuclear modernization is at present mixed in terms of success. While some programs such as the Long-Range Stand-Off (LRSO) cruise missile and B-21 bomber are proceeding reasonably well, others such as the Sentinel ICBM and Columbia SSBN are doing less well. Sentinel in particular has experienced a massive slip in cost and schedule.

A major change directed by Congress is the establishment of an assistant secretary of defense (now war) for Nuclear Deterrence, Chemical, and Biological Defense Policy and Programs. This position is intended to provide a single point of senior attention to the Department's nuclear deterrence mission. While a potential positive change, the position does not have direct ability to accelerate the deployment of capabilities. That is the responsibility of the Services and Congress has not yet directed fundamental change there. In essence, this ASD has responsibility and accountability, but no authority to direct resourcing priorities within the Services to ensure that the nuclear mission remains untouchable.

In contrast, when Congress established a new assistant secretary of defense (war) for Space Policy, it also directed change in the Department of the Air Force. It created a new assistant secretary of the Air Force for Space Acquisition and Integration (SAF/SQ) to focus specifically on space issues, relieving the existing assistant secretary of the Air Force for Acquisition, Technology & Logistics (SAF/AQ) of that responsibility. This change ensured that there is a Senate-confirmed Service Acquisition executive solely responsible for the crucial space mission.

A similar change is needed within the Department of the Air Force for the nuclear mission. The Department of the Air Force has responsibility for two-thirds of the nuclear triad, the only existing theater capability (dual capable fighter aircraft), and the bulk of nuclear command, control, and communications. An assistant secretary of the Air Force for Nuclear Deterrence Acquisition and Integration (SAF/NQ) would ensure a Service Acquisition executive fully focused on the demands of delivering peace through nuclear strength. This could be done a fairly resource neutral way by reorganizing and absorbing staff from both SAF/AQ and the deputy chief of staff for Strategic Deterrence and Nuclear Integration on the Air Staff (HAF/A10) into the new office. The existing HAF/A10 three-star general could then become the military deputy to the new assistant secretary.

This is a better long-term solution than the creation of program manager for some of these programs reporting directly to the deputy secretary of war, which is apparently under consideration.[50] It would both be more permanent and would align better with existing service responsibilities and organization. There would be no barrier to having the SAF/NQ routinely provide progress reports to the secretary of the Air Force as well

50 Justin Katz, Valerie Insinna, and Aaron Mehta, "DOD considering 'czar' roles for key Navy, Air Force programs," Breaking Defense (August 7, 2025). https://breakingdefense.com/2025/08/exclusive-dod-considering-czar-roles-for-key-navy-air-force-programs/.

as the secretary and deputy secretary of war, which would achieve the same effect as a direct report program manager.

Changes Specific to NNSA

The most significant change that is needed is at NNSA. As noted, the acting administrator is trying to instill a sense of urgency in the organization, but I believe structural change is needed to truly enable peace through strength. NNSA was created at a time and in a context that is in many ways antithetical to the current environment. Congress wanted to ensure greater oversight and accountability in the nuclear enterprise following, among other things, the Wen Ho Lee furor.[51] Initial focus for assessing the new organization was on security practices, financial management, and program management.[52]

The culture of a professional organization is established in its formative years and, once established, becomes highly resistant to change.[53] NNSA was created to ensure the laboratories, plants, and sites it oversaw upheld the highest standards of security and that taxpayer dollars were well and wisely spent. At a time when the role of the enterprise was stockpile stewardship, this was sensible. A core focus of the agency was to invest money and manpower to ensure weapons that were safe and secure were more safe and secure, with no upper bound on safety and security. Yet this has become ingrained in NNSA culture as its organizational essence—its reason to be.[54] In this view, NNSA structure and process, while important, is a reflection of a culture of caution and scrutiny, rather than cause, though structure and culture are mutually reinforcing. Changing a well-established organizational culture generally requires radical change to the organization—even then it can be painful and often laborious.[55]

It is perhaps unsurprising then that multiple reviews by outsiders over the past two decades have concluded that NNSA is too slow and cautious in its approach to the nuclear mission. The 2020 final consensus report of a multi-year review of NNSA by a National Academies panel concluded, among other things:

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51 Asian/Pacific/American Institute, "Wen Ho Lee Media Collection," New York University. https://apa.nyu.edu/collection/wen-ho-lee-media-collection/.

52 Government Accountability Office, "National Nuclear Security Administration: Additional Actions Needed to Improve Management of the Nation's Nuclear Programs" (January 31, 2007). https://www.gao.gov/assets/a255324.html.

53 Austin Long, *The Soul of Armies: Counterinsurgency Doctrine and Military Culture in the US and UK* (Ithaca, NY: Cornell University Press, 2016), Chapter 2.

54 On organizational essence, see Morton Halperin, *Bureaucratic Politics and Foreign Policy* (Washington, DC: Brookings Institution, 1974).

55 On the challenge of changing established culture, see Donald Abenheim, *Reforging the Iron Cross: The Search for Tradition in the West German Armed Forces* (Princeton, NJ: Princeton University Press,1989). This is an account of the transformation of West German military culture during post-World War II rearmament following extensive demilitarization.

> While NNSA has made substantial progress, the panel believes that the agency still has some organizational characteristics—such as lengthy decisionmaking processes, burdensome regulations, and risk aversion—that hamper its ability to meet its ambitious mission. For example, while most people the panel interviewed indicated that they or their office have the authority to make the decisions necessary to do their work, the panel also heard complaints about decisions at the headquarters level taking too long (e.g., in the pit production case study discussed in this chapter). This comes across as a lack of urgency and can impact schedules. In addition, leadership commitment, measuring and communicating success, and institutionalizing change will be necessary to maintain momentum and sustain progress. Most importantly, NNSA needs to continue to make specific changes, such as those discussed in this chapter, as it continues its journey toward a workplace culture that emphasizes performance, credibility, and accountability.[56]

These attributes of "lengthy decisionmaking processes, burdensome regulations, and risk aversion" appear evergreen in assessments of NNSA. Indeed, even recent success stories like the B61-13 are, in this author's view, as much in spite of as because of NNSA process—the labs, plants, and sites deserve the lion's share of credit.[57] This is not to denigrate many of the excellent federal employees of NNSA, but merely to note they are embedded in an organization that is culturally and structurally intended to scrutinize and assess without urgency.

In this author's view, delivering peace through nuclear strength will require more than the incremental changes recommended by the National Academies study. More than a decade ago the Augustine-Mies review laid out one blueprint for a fundamental transformation of NNSA and DOE, including recommended statutory language for change. Without recapitulating in its entirety, the proposed change places much more of the onus of the nuclear security mission on the Secretary of Energy (including renaming the department to the "Department of Energy and Nuclear Security"), with a presidentially-appointed, Senate-confirmed director of an Office of Nuclear Security carrying out the current NNSA mission—yet with a fixed term. This director would have significant ability to reshape the workforce by making all non-administrative federal personnel either Senior Executive Service or Excepted Service.[58]

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56 Panel to Track and Assess Governance and Management Reform in the Nuclear Security Enterprise, *Governance and Management of the Nuclear Security Enterprise* (Washington, DC: National Academies Press, 2020), p. 28.

57 This is a personal view, but in his previous job the author was involved in virtually every step of the Nuclear Weapons Council process that culminated in the fielding of the B61-13.

58 "A New Foundation for the Nuclear Enterprise," Report of the Congressional Advisory Panel on the Governance of the Nuclear Security Enterprise (November 2014). http://cdn.knoxblogs.com/atomiccity/wp-content/uploads/sites/11/2014/12/Governance.pdf.

One might quibble with some of the specifics of this proposed change, but it is of the right magnitude to drive real cultural change. One could also devise equally effective alternative solutions of similar magnitude. For example, one could pull NNSA in to the Department of War, creating a single undersecretary level position to oversee the entire nuclear deterrence mission. Yet whatever the change, it must be fundamental rather than incremental. Nothing less will empower the federal civilians in the current structure who want to do more, faster. However sensible NNSA culture and structure was in the era of stockpile stewardship, it is inappropriate for an era of peace through nuclear strength.

Conclusion

It has been almost 35 years since the fall of the Soviet Union and the end of the Cold War. Today, nearly everyone working within the U.S. nuclear enterprise grew up in a post-Cold War environment. For some, this has been a foundation to their whole professional career, while for others it is the only geopolitical environment they know. Only a very few senior professionals working in the nuclear enterprise of 2025 experienced the urgency and delivery-based enterprise that underpinned Peace Through Strength prior to 1991. While no one desires a return to the frightening heights of Cold War nuclear tensions, the U.S. nuclear enterprise must urgently regain its focus on delivering nuclear weapon capabilities to the warfighter to deter and prevent exactly these circumstances.

Changing the culture and approach within the whole of the enterprise will require leadership from above and below. Difficult choices will be required at all levels, including between maintaining programs, projects, and lines of effort associated with a sustainment-focused enterprise and a new business model that focuses on innovation and product delivery. Established and engrained ways of doing business must be challenged and risk must be managed strategically, with an eye towards managing and mitigating the ultimate risk of deterrence failure. To move quickly, requirements must be scrutinized for their impacts on timely delivery of capability. Ultimately, the U.S. nuclear enterprise must regain the sense of urgency that it lost with the end of the Cold War and refocus on delivering nuclear capabilities to the warfighter.

From the Manhattan Project through the Cold War, the American innovators and patriots in the U.S. nuclear enterprise were the backbone of U.S. nuclear deterrence. They were giants and accomplished huge things. The innovators and patriots within U.S. nuclear enterprise of today stand on the shoulders of these giants, but must realize that they are giants themselves and capable of rising and meeting this new, equally awesome challenge.

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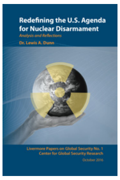

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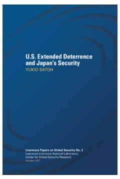

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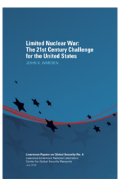

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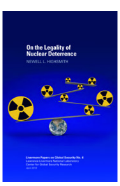

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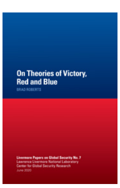

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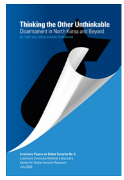

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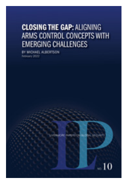

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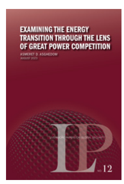

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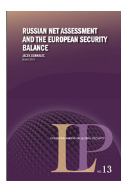

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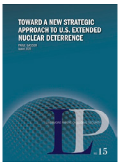

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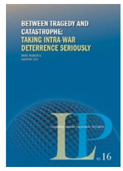

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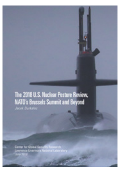

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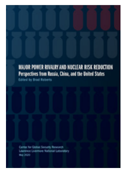

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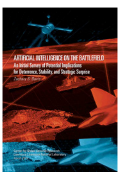

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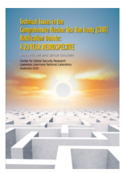

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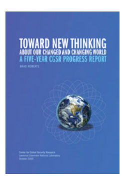

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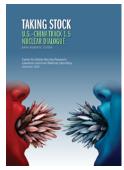

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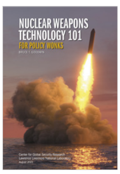

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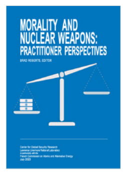

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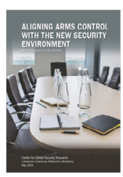

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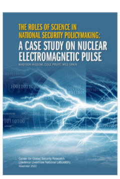

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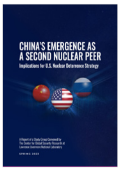

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