ANALYSIS

Responsive Infrastructure

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Executive Summary

Beginning in 1989, after over four decades of continuous operation, the nuclear warhead infrastructure of the United States was shutdown, missions transferred to other sites, aging warheads were life-extended instead of replaced with new warheads, and nuclear testing ceased. The infrastructure has not been fully operational since 1989. Now, over thirty years later, the infrastructure is still not fully operational. The infrastructure is tasked with being ready to assess the reliability of the U.S. nuclear warheads, to evaluate the nuclear arsenals of adversaries, and to respond with warhead life extension programs, other modifications, or new designs in a timely manner. However, the responsive infrastructure needed for that role is still years—perhaps a decade—away. Significant improvements are needed if it is to be capable of that mission.

First, the national laboratories responsible for nuclear warhead designs and reliability assessments will need to restore a more complete skill set for warhead design and development. The current approach for life-extending warheads exercises only a limited set of critical skills for warhead development and production at a time. Prototype or new warhead development programs will be needed to more fully exercise critical skills that have atrophied in order to train a new generation of warhead developers. Also, there exists a lack of balance between computational analysis and experiments at the laboratories. Today, the nuclear warhead development community is overly dependent on computer simulation. Greater emphasis needs to be placed on experimental activities so that inexperienced warhead designers and engineers can push the limits of design, explore concepts, and develop judgment skills that will be critical in the years ahead.

Second, the facilities for warhead component production have yet to be fully modernized and the overall complex is not fully operational. Several actions are needed in the near term to help achieve a responsive and resilient infrastructure. All are important. Several require urgent attention.

Recommendations requiring urgent action include the following: For plutonium processing and fabrication, proceed with greater urgency to achieve an operational pit fabrication capability at Los Alamos, accelerate the second fabrication site at the Savannah River Site (SRS), and develop plans for each site to be able to scale up plutonium pit production quantities in a timely manner.

For nuclear test readiness, survey test readiness capabilities and take immediate corrective action to restore a readiness capability to conduct a fully instrumented nuclear test within two years; also, appropriate funds for test readiness and keep the funding in an "escrow" account to be used, when needed, to begin test preparations.

For the Department of Defense (DoD) and the National Nuclear Security Administration (NNSA) program integration, proceed apace on W93 warhead development and give high-level attention to DoD/NNSA integration activities for the W93 program.

Other important recommended actions include accelerating the construction of the replacement uranium and lithium fabrication facilities at Oak Ridge, expanding capacity for non-nuclear component production at the Kansas City Plant and at Sandia, and accelerating the completion of the Tritium Finishing Facility and other modernization projects at SRS.

Introduction: Responsive Infrastructure

The government-owned infrastructure needed to build, sustain, and modify nuclear warheads is of particular concern. A capability that is responsive to changing national security needs and resilient to technical and geopolitical surprises is a necessary part of a risk management approach for the United States and its allies.

The lack of an operational nuclear warhead infrastructure has been discussed as a concern for the past thirty years. For example, a September 2008 white paper signed jointly by Secretary of Defense Robert Gates and Secretary of Energy Samual Bodman states: "The United States is now the only nuclear weapon state party to the NPT (Nuclear Nonproliferation Treaty) that does not have the capability to produce a new nuclear warhead."[1] That statement remains true today. The 2009 report of the Perry-Schlesinger Strategic Posture Commission stated that some facilities to produce nuclear components are "genuinely decrepit" and much remains to be done to put in place a modern nuclear infrastructure to serve national security goals for the long term.[2] In the more than fifteen years since these two reports were published, some significant progress has been made toward a responsive infrastructure, but the overall goal of an operational and responsive infrastructure remains elusive with completion projected well into the future.

Background

To fully understand the challenge of reestablishing a responsive infrastructure for the United States, some background is helpful. The U.S. nuclear warhead infrastructure operated continuously from its inception in the 1940's until 1989. The business model for this enterprise involved three design laboratories and numerous large-capacity plants which operated continuously for over four decades. The manufacturing plants were geographically dispersed with a final assembly plant in Texas. Deployed warheads were typically replaced with newer warhead designs before the end of service life. Nuclear testing was used to

[1] Robert M. Gates and Samuel W. Bodman, "National Security and Nuclear Weapons in the 21st Century," September 2008, p. 19, available at https://www.bits.de/NRANEU/docs/NucPol21Century_092308.pdf. (This unclassified report was an edited and redacted version of a classified report on the same subject sent to Congress in February 2008.)

[2] William J. Perry and James R. Schlesinger, et al., *America's Strategic Posture: The Final Report of the Congressional Commission on the Strategic Posture of the United States* (Washington, D.C.: United States Institute of Peace Press, 2009), p. 8.

determine the proper function of warheads in development and in the stockpile. Since 1989, four major changes, perhaps better described as *shocks*, have transformed the operation, location, and planning regarding the business model for this enterprise.

- **Shutdown**. The first major shock was the sudden, unplanned break in serial warhead production. In 1989, the Rocky Flats plutonium pit production plant was closed abruptly because of regulatory noncompliance. At that time, plutonium pits for W88 warheads were in production at Rocky Flats and the overall nuclear weapons complex was operating to complete the planned build of W88 warheads for Trident II missiles. In 1991, then-President George H. W. Bush announced that the plant would not be reopened and the planned build of W88 warheads would be truncated with only about a third of the planned number of W88 warheads completed. (This was one element of the second Presidential Nuclear Initiative intended to respond to the new, more cooperative relationship between the United States and the Soviet Union, later Russia.) After more than forty years of continuous operation, production lines for warhead components fell silent.
- **Reconfiguration**. The second major shock was the plan to reconfigure the nuclear complex. This plan was initiated by the Department of Energy (DOE) in 1991. With warhead production lines idle and no prospect of resumed production in the near term, DOE sought to reduce future costs and improve efficiency by permanently closing some sites and consolidating the functions at other, larger sites. For example, the Rocky Flats pit production plant in Colorado was to be permanently closed and the functions moved to New Mexico and reconstituted as part of Los Alamos National Laboratory; the functions then performed at the Mound Facility in Ohio that produced nonnuclear parts for arming, fusing, and firing devices would be moved to the DOE plant at Kansas City, Los Alamos, and Sandia laboratories.[3]
- **Mission Change**. The third major shock to the system was the change in strategy to sustain the nuclear stockpile for the future. Instead of replacing older nuclear warheads with newly produced warheads when they reached the end of service life, warheads would be "modified" to extend the service life. The national laboratories would be responsible for determining the components to be replaced and designing and certifying the life extension programs. At the same time, the laboratories were to maintain the capability to design, develop, and certify new types of nuclear weapons, if required.
- **Cessation of Nuclear Testing.** Finally, a variety of factors led to the abrupt cessation of testing in 1993. The cessation of testing was mandated by the new Clinton Administration without any period of final preparation for a no-testing environment. As of this report, the most recent underground nuclear test performed by the United

[3] Department of Energy, *Nuclear Weapons Complex Reconfiguration Study*, January 1991, p. 15, available at https://www.osti.gov/servlets/purl/6077838.

> States was conducted in the fall of 1992. Prior to the cessation of testing and pursuit of a Comprehensive Test Ban Treaty, the United States had tested nuclear warhead designs under development as well as those in the stockpile in order to assess functionality throughout the stockpile-to-target environment and understand physics concepts.

After over four decades of continuous operation, the nuclear warhead infrastructure of the United States was shutdown, missions transferred to other sites, replacement was changed to life extension, and testing ceased. The infrastructure has not been fully operational since 1989. Now, over thirty years later, the infrastructure is still not fully operational. At the same time, the infrastructure is tasked with being ready to assess the reliability of the U.S. stockpile, to evaluate the nuclear arsenals of adversaries, and to respond with life extension programs, other modifications, or new designs in a timely manner.

Response Role for the Infrastructure

The 2001 *Nuclear Posture Review* (NPR) report from DoD called for deep reductions in the number of operationally deployed nuclear warheads and a significant reduction in the total stockpile of nuclear warheads. In order to respond to potential vulnerabilities from arms buildups or advances by adversaries, the 2001 NPR called for a responsive infrastructure that would be able to resume design and production of nuclear warheads, if needed, in the future.[4] This new posture was to be in place within a decade. Similarly, the 2018 NPR noted that the necessary responsiveness of the infrastructure was far from being a reality and called for "an effective, responsive, and resilient nuclear weapons infrastructure."[5] More recently, the 2023 report bipartisan Strategic Posture Commission (SPC) listed a functioning infrastructure as a necessary component of a "hedge against risk, geopolitical, technical, operational, and programmatic risks that could render U.S. nuclear forces insufficient …"[6]

What follows is a discussion of the status of, and plans for, several important elements of a responsive and resilient infrastructure.

National Laboratories

The national laboratories that designed nuclear warheads in the extant stockpile must be capable of surveilling and assessing the status of each type of warhead, designing

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[4] Department of Defense, *Nuclear Posture Review Report*, December 2001, p. 14, available at https://www.esd.whs.mil/Portals/54/Documents/FOID/Reading%20Room/NCB/06-F-1586_Nuclear_Posture_Review.pdf.

[5] Department of Defense, *Nuclear Posture Review Report*, 2018, p. XIV, available at https://fas.org/wp-content/uploads/media/2018-Nuclear-Posture-Review-Version-2.pdf.

[6] Madelyn Creedon and Jon Kyl, et al., Congressional Commission on the Strategic Posture of the United States, *America's Strategic Posture*, *The Final Report of the Congressional Commission on the Strategic Posture of the United States* (Alexandria, VA: Institute for Defense Analysis, 2023), p. 27, available at https://www.ida.org/-/media/feature/publications/a/am/americas-strategic-posture/strategic-posture-commission-report.ashx.

modifications, as needed, for life extension and upgrades, and developing new, different, or modified warheads as national security needs dictate.

In the early 1990's, after warhead production lines were idled and advanced warhead development was suspended, funding for the nuclear infrastructure was slashed. DOE developed a strategy for infrastructure sustainment that would give priority to maintaining a healthy scientific community at the national laboratories at the expense of modernizing aging production facilities. Senior leaders at DOE defended this strategy by noting that "the body will die without a head."[7]

With new design and development activities suspended at the laboratories, DOE initiated the development of unique scientific facilities at each of the labs. Research at each of these facilities was to be relevant to the science of nuclear weapons and designed to attract and retain scientists and engineers. Toward this goal, the National Ignition Facility (NIF) was constructed at Lawrence Livermore National Laboratory, the Dual-Axis Radiographic Hydrotest Facility (DARHT) at Los Alamos, and the Microsystems Engineering Science and Applications (MESA) Facility at Sandia. Each of these facilities is a world-class scientific facility; all are currently operational, and upgrades continue to be pursued. In addition, each of the laboratories was included in a supercomputing initiative that has produced some of the most advanced computer systems in the world. These accomplishments are to be applauded for their contributions to science and the ability to attract talented scientists to the laboratories.

In general, the plan to maintain healthy design laboratories is considered to be a success story. For example, the labs have developed enhanced stockpile surveillance capabilities to better understand warhead aging and to propose timely life extension programs (LEPs). The initial LEPs have been completed or are currently in-work for almost all the warheads in the stockpile. However, one former laboratory director cautioned that, to date, the life extension programs completed have been "modest" in complexity, have required "very long timelines," and "often encountered significant difficulties."[8]

In 2015, National Institute for Public Policy (NIPP) commissioned an assessment of U.S. readiness to Design, Develop and Produce Nuclear Warheads—essentially the potential responsiveness of the nuclear infrastructure.[9] Among the key findings of that assessment (Scheber-Harvey Report) were the following:

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[7] George Miller, "Stockpile Stewardship: What Were We Thinking? How Did It Work Out?," in Brad Roberts (eds.), *Stockpile Stewardship in an Era of Renewed Strategic Competition* (Livermore, CA: Center for Global Security Research, April 2022), p. 7, available at https://cgsr.llnl.gov/sites/cgsr/files/2024-08/CGSR_Occasional_Stockpile-Stewardship-Era-Renewed-Competition.pdf.

[8] Ibid, pp. 12, 18.

[9] Thomas Scheber and John R. Harvey, *Assessment of U.S. Readiness to Design, Develop and Produce Nuclear Warheads: Current Status and Some Remedial Steps* (Fairfax, VA: National Institute Press, 2015), available at https://nipp.org/monographs_cpt/assessment-of-u-s-readiness-to-design-develop-and-produce-nuclear-warheads-current-status-and-some-remedial-steps/.

- Not all critical nuclear skills at the laboratories and plants are being exercised. The approach for life-extending warheads exercises only a limited set of critical skills for warhead development and production at a time.[10]
- There exists a lack of balance between computational analysis and experiments at the laboratories. The nuclear warhead development community is overly dependent on computer simulation. As one experienced warhead designer stated, "The codes always lie." Without sufficient experimental activities against which to test the results of computer simulations, new designers and engineers may not recognize where the codes are unreliable and why. This imbalance between computation and experiments impedes the development of professional judgment to train the next generation of warhead designers and engineers that will be needed in the future.[11]
- Infrastructure modernization has been delayed repeatedly, and completion remains elusive.[12]

Concerns about test readiness are long-standing, have not abated over the course of years. A 2002 high-level review panel concluded that a much more responsive test readiness posture is needed. In its final report to Congress in March 2002, the Panel to Assess the Reliability, Safety, and Security of the United States Nuclear Stockpile (The Foster Panel) wrote:

> The President should have the latitude for a timely and effective response to unexpected events, whether due to problems in the stockpile or an international situation. Current test readiness of two to three years does not provide a viable option for a timely response. The Panel's assessment is that test readiness should be no more than three months to a year, depending on the type of test.[13]

Current Assessment of Readiness to Respond

Now, a decade after the 2015 Scheber-Harvey assessment briefly summarized above, not much has changed. For example:

- Critical skills. Warhead life extension programs still dominate the workload at the laboratories. No complete, end-to-end exercise of critical design and development skills has been undertaken for decades. This would involve developing a new, or at least different, warhead design and taking it through development to production (at least prototyping) and, perhaps even flight testing. This type of activity would tell senior managers a lot about the real state of readiness to respond in a timely manner to technical or geopolitical surprise. To its credit, Congress has done its part to ensure

[10] Ibid., p. xiv.

[11] Ibid.

[12] Ibid.

[13] John S. Foster, et al., *Final Report of the Panel to Assess the Reliability, Safety, and Security of the United States Nuclear Stockpile*, March 15, 2002, p. ES-2, available at https://nuke.fas.org/control/ctbt/text/foster99.pdf.

that the laboratories have explicit authorization to undertake such comprehensive activities as needed to train the next generation of weapon scientists. For example, the FY 2016 National Defense Authorization Act established the Stockpile Responsiveness Program. This legislation states,

> It is the policy of the United States to identify, sustain, enhance, integrate, and continually exercise all capabilities required to conceptualize, study, design, develop, engineer, certify, produce, and deploy nuclear weapons to ensure the nuclear deterrent of the United States remains safe, secure, reliable, credible, and responsive.

Unfortunately, the NNSA annual reports on stockpile stewardship and management have not reported any specific actions toward this goal except to acknowledge the legislative tasking.

- **Lack of balance between computation and experiments.** The imbalance between computational assessments and complex experiments at the laboratories has not been corrected. The laboratories remain overly reliant on computer simulations and in need of more confirmatory experiments. For example, the 2015 assessment noted that one experienced designer had opined that the number of hydrodynamic experiments conducted in support of the stockpile stewardship program should be about one per month: twelve per year. The 2015 assessment noted that only four hydrotest experiments had been conducted in FY2013 and seven in 2014.[14] Another complex experimental capability exists in the form of subcritical experiments in Nevada. The 2015 assessment noted that only one subcritical nuclear experiment per year had been carried out in the previous few years. The FY 2024 Stockpile Stewardship and Management Plan (SSMP) states that during 2023, only four hydrodynamic tests were conducted at DARHT[15] Similarly, only one subcritical test was conducted in 2024. The imbalance between computation and experiments appears to persist.
- **Infrastructure modernization.** The 2015 assessment noted that infrastructure modernization had been delayed repeatedly. In 2015 the NNSA plan was to develop the capability to produce 50-80 plutonium pits per year at Los Alamos. That goal was to have been accomplished by 2023.[16] As will be discussed more fully later, there is currently no operational capability for the production of plutonium pits. The estimate for a production capacity meeting the congressionally mandated minimum capacity

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[14] Scheber and Harvey, *Assessment of U.S. Readiness to Design, Develop and Produce Nuclear Warheads: Current Status and Some Remedial Steps*, op. cit., p. 30.

[15] Department of Energy, *Fiscal Year 2024 Stockpile Stewardship and Management Plan*, November 2023, p. F-21, available at https://www.energy.gov/sites/default/files/2023-11/FY24SSMP_FINAL_NOVEMBER_2023_0.pdf.

[16] Scheber and Harvey, *Assessment of U.S. Readiness to Design, Develop and Produce Nuclear Warheads: Current Status and Some Remedial Steps*, op. cit., p. 32.

of eighty pits per year[17] by 2030 has slipped to about 2035. The 2015 assessment noted that the replacement facility for uranium and lithium processing had not yet begun construction. The assessment called for a new facility and the shutdown of the existing Uranium Processing Facility (UPF) by 2025.[18] NNSA has been making progress toward these goals, but the eighty-year-old UPF is still in operation and the two new construction facilities to process highly enriched uranium and lithium components are estimated by NNSA to be complete by 2029 and 2031 respectfully, barring further delays.

In sum, not much has changed since the 2015 assessment. Next, this report will discuss the status of several key components of a responsive infrastructure.

Plutonium Pit Production Capabilities

One of the key capabilities needed in a responsive infrastructure is a facility capable of manufacturing plutonium pits for weapon primaries. During the height of the Cold War, the United States produced between one thousand and two thousand pits per year. However, the United States has not had the capability for serial production of plutonium pits since 1989. The relocation of pit fabrication capabilities from Rocky Flats in Colorado to Los Alamos, New Mexico, seemed relatively straightforward when it was proposed in the early 1990s. Equipment would be moved from Rocky Flats and installed at the Los Alamos plutonium facility that was already operational. This facility, known as PF-4, was primarily for scientific research on pits and the fabrication of plutonium heat sources for applications such as long-duration space probes.

However, soon after some of the equipment was installed and tested at Los Alamos, some problems were encountered. Specifically, the welding machine for plutonium parts did not perform correctly. The same machines, doing the same tasks, and operated by some of the same operators as at Rocky Flats, did not create acceptable welds for the assembly of plutonium parts. Eventually, this problem was traced to the difference in pressure altitude between central Colorado and the mountains of New Mexico. The determination of cause led to a successful fix. This unexpected sensitivity of plutonium welding underscores the complexity of plutonium metal in its various forms. A 2021 article on the history of working with plutonium referred to "the incredible, confounding complexity of plutonium …"[19]

Over the past 30+ years, DOE has proposed several different plans for restoring a plutonium pit fabrication capability. The plans considered have included doing all of the pit fabrication at Los Alamos, moving this capability elsewhere because of earthquake concerns in New Mexico, and the current two-site strategy.

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[17] Department of Energy, *Fiscal Year 2025 Stockpile Stewardship and Management Plan*, op. cit., pp. 3-28.

[18] Scheber and Harvey, *Assessment of U.S. Readiness to Design, Develop and Produce Nuclear Warheads: Current Status and Some Remedial Steps*, op. cit., p. 33.

[19] Joseph C. Martz, Franz J. Freibert, and David L. Clark, "The Taming of Plutonium: Pu Metallurgy and the Manhattan Project," *Nuclear Technology*, Vol. 207 (2021), p. S267, available at https://www.tandfonline.com/doi/epdf/10.1080/00295450.2021.1913035?needAccess=true.

The effort to restore this capability has had some notable successes through the years. One such success is demonstrating the production of pits of different stockpile warheads that could pass the rigorous certification inspection and be "diamond-stamped" which signifies acceptance as a stockpile component. In 2024, the plutonium facility at Los Alamos completed this demonstration goal when it produced a diamond-stamped W87 pit for the Minuteman III intercontinental-range ballistic missile.[20]

Other notable accomplishments include the production of thirty-one pits for W88 warheads for submarine-launched ballistic missiles (SLBMs) over a period of about five years (2007-2011). This supply of newly produced pits is important to replace older W88 warhead pits that are removed from service, one per year, and destructively tested to observe aging trends and estimate reliability.[21] Recall that the W88 warhead build was terminated abruptly in 1989 when Rocky Flats was closed and, therefore, many fewer W88 warheads were produced than planned. This build of thirty-one W88 pits allows for deployment of a constant number of W88 warheads for 31 years since the pits removed for reliability sampling can be replaced by these newly built pits.

In 2018, the DoD and NNSA released a joint statement that, instead of developing a single pit production facility at Los Alamos, a two-site option would be pursued. The second site is to be a modification of the Mixed-Oxide Fuel Fabrication Facility (MFFF) at the Savannah River Site (SRS) in South Carolina. The stated production goal at the SRS site is at least fifty pits per year. In response to language in the 2019 Senate Energy and Water Appropriations Bill, NNSA commissioned The Institute for Defense Analyses (IDA) to conduct an independent analysis of various pit production options including an expanded single site at Los Alamos and a two-site option. The IDA final report concluded that "None of the rejected alternatives is demonstrably superior to the two-site option announced by DOE/NNSA and certified by the NWC [Nuclear Weapons Council]." The two-site option provides resilience and redundancy for the Nuclear Security Enterprise. Additionally, the IDA report concluded that the goal of thirty pits per year at Los Alamos was "potentially achievable given sufficient time, resources, and management focus, although not on the schedules or budgets currently forecasted."[22] The assessment concluded that eventually achieving a production rate of eighty pits per year is possible but will be extremely challenging. None of the options can be expected to achieve the goal of eighty pits per year by 2030 as required by the law.[23] The IDA assessment cautioned that DoD would need to decide how to respond to this shortfall.[24]

When the IDA report was published in 2019, NNSA listed a goal of 2026 for achieving a thirty pit per year production capability at Los Alamos. The most recent SSMP states that

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[20] Department of Energy, *Fiscal Year 2025 Stockpile Stewardship and Management Plan*, op. cit., p. X.

[21] Arnie Heller, "Monitoring a nuclear weapon from the inside," *Science & Technology* (June 2008), pp. 13-14, available at https://str.llnl.gov/sites/str/files/2024-04/2008.07.pdf.

[22] David E. Hunter, et al., *Independent Assessment of the Two-Site Pit Production Decision: Executive Summary*, Institute for Defense Analyses, May 2019, p. 4, available at https://www.ida.org/-/media/feature/publications/i/in/independent-assessment-of-the-two-site-pit-production-decision-executive-summary/d-10711.ashx.

[23] War and National Defense, 50 U.S. C. § 2538a, available at https://www.law.cornell.edu/uscode/text/50/2538a.

[24] Hunter, et al., *Independent Assessment of the Two-Site Pit Production Decision: Executive Summary*, op. cit., p. 5.

the completion date has slipped to 2028 and the NNSA estimated timeframe for commencement of pit production at SRS is now 2035.[25] Clearly, the congressionally mandated goal of a plutonium pit production capacity of at least eighty pits per year by 2030 will not be met. The historical trend in tracking the progress of complex, one-of-a-kind facilities that are key for responsiveness and resilience for the nuclear complex indicates that these dates may well slip further unless significant resources and management focus are expended.

The lack of a plutonium pit production facility of sufficient capacity to provide responsiveness for the stockpile is arguably the most important shortfall to be corrected in the current complex. Eighty pits per year is unlikely to be sufficient for the long-term. The United States needs to plan for a pit production capacity that is greater than that just based on current stockpile levels as a hedge.

Recommendations for Plutonium Processing and Fabrication

- Proceed with greater urgency and purpose to achieve an operational capability at Los Alamos and accelerate the pit fabrication site at SRS.
- Develop plans and facility readiness to be able to scale-up plutonium pit production quantities beyond eighty pits per year in a timely manner.

Production Capabilities for Highly Enriched Uranium and Lithium Components for Warhead Secondaries

The following discussion of warhead capabilities to fabricate highly enriched uranium (HEU) and lithium parts for warhead secondaries is more straightforward than the preceding discussion on plutonium pits.

The secondary is where the lion's share of explosive yield is generated in a modern nuclear weapon. While the primary generates a few thousands of pounds of explosive yield, the secondaries of modern weapons generate tens or hundreds of thousands of pounds of yield.

For the past eighty years, HEU and lithium parts for secondaries have been fabricated at a plant at the Y12 site in Oak Ridge, Tennessee. One of the essential facilities for these parts at Y12 is the Uranium Processing Facility (UPF) which is over eighty years old. During the deliberations of the Perry-Schlesinger Strategic Posture Commission, commission members toured several locations in the nuclear weapons complex. One of the visits was to the UPF (building 9212) at Y12. This plant dates to the Manhattan Project and has been operated continuously to fabricate HEU parts. It is considered by many to be the poster child for decrepit and outdated facilities in the nuclear weapons complex.

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[25] Department of Energy, *Fiscal Year 2024 Stockpile Stewardship and Management Plan*, op. cit., pp. 5-10.

According to a 2020 NNSA fact sheet:

> Building 9212 is a large chemical processing facility that was completed in November 1945 as a chemical recovery operation to recycle uranium. It was the location of the first production of uranium metal at Y-12 and the earliest nuclear weapons production facility at Y-12. Since then, it has been modified many times to meet changing national security missions, but, generally speaking, is optimized for a large nuclear weapons production mission necessary during the buildup of U.S. thermonuclear forces in the 1950's and 1960's. It continues to serve as one of the primary chemical processing and enriched uranium production facilities at Y-12.[26]

This facility has been maintained with great effort and expense. In the Perry-Schlesinger commission's final report, commission members referred to this and other outdated facilities as "genuinely decrepit."[27] Touring the facility was compared to visiting a museum that displays technology from the 1940's and 50's—controlled by valves, dials, and manual controls instead of digital technology.

It is significant to note that this "decrepit" facility is still operating and in the 1990's it was key when Y-12 was called upon to build warhead secondaries as replacement components for a warhead type that remains in the modern stockpile.

Construction of modern replacement facilities for HEU and lithium parts is in work. The most recent SSMP calls for the new Uranium Processing Facility (UPF) to be completed and operational by 2029 and the lithium facility completed by 2031.[28]

Recommendations for Uranium Processing and Fabrication

- To the extent possible, accelerate the completion of the replacement UPF and lithium facilities at Y-12.

Production Capabilities for Warhead Arming, Fusing, and Firing Systems, Neutron Generators, and Other Non-nuclear Components

In addition to the facilities specializing in components with special nuclear materials, the weapons complex needs a variety of non-nuclear components that are critical for the safe, secure operation and control of nuclear warheads. These non-nuclear components include arming, fusing, and firing systems as well as neutron generators. Most of these components are manufactured at the Kansas City National Security Complex (KCNSC) and at Sandia National Laboratories.

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[26] "Y-12 Facility Descriptions," August 2020, available at https://www.energy.gov/nnsa/articles/y-12-facility-descriptions.

[27] Perry and Schlesinger, et al., *America's Strategic Posture: The Final Report of the Congressional Commission on the Strategic Posture of the United States*, op. cit., pp. 47-51.

[28] Department of Energy, *Fiscal Year 2025 Stockpile Stewardship and Management Plan*, op. cit., p. X.

In 2014, the activities at Kansas City were moved into a newly constructed site which is currently undergoing further expansion. Between Sandia and Kansas City, the non-nuclear needs for stockpile life extension programs have been successfully met by these facilities. However, capacity at both Kansas City and Sandia will need to be expanded to accommodate the future workload and to be able to respond to unplanned contingencies.

Recommendations for Non-nuclear Components

- Expand capacity at both the Kansas City Plant and at Sandia to enable greater capacity and, thereby, provide resilience.

Tritium Production and Handling Capabilities

Tritium is a radioactive isotope of hydrogen that is used in modern nuclear weapons to "boost" the explosive yield. Since tritium decays at a rate of about five percent per year, the supply of tritium must be replenished periodically. Until the late 1980s, the production of tritium and the filling/refilling of tritium reservoirs was done at the Savannah River Site (SRS). Tritium was produced in reactors and extracted in order to transfer the tritium produced into reservoirs and installation into nuclear weapons. Nuclear arms reduction agreements and the end of the Cold War resulted in dramatic reductions in the number of deployed nuclear weapons. This resulted in a glut of tritium extracted from retired warheads. As a result, the aged reactors at SRS were shut down in the late 1980's.

During the 1990's the DOE evaluated options for resuming the production of tritium. In late 1998, DOE announced that it had chosen as the primary means of producing tritium irradiating lithium rods in a light water reactor. In 2003, after several developmental experiments, the first batch of lithium fuel rods were loaded into a reactor at the Watts Bar Nuclear Plant in Tennessee. In 2005, the rods were removed and shipped to SRS for the extraction of tritium.[29]

Since the initial run in 2005, the process of irradiating lithium rods at Watts Bar and subsequent tritium extraction at SRS has been refined. However, one important tritium handling facility at SRS is over sixty-five years old and is badly in need of replacement. While construction of a new Tritium Finishing Facility (TFF) has been approved and initial funding appropriated, construction is not projected to be complete until about 2034.[30] The fundamental approach to tritium production for the future appears to be on track, but the construction of modern facilities for tritium handling needs to be accelerated.

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[29] United States Nuclear Regulatory Commission, "Tritium Production," *Backgrounder,* June 2005, available at https://www.nrc.gov/docs/ML0325/ML032521359.pdf.

[30] Department of Energy, *Fiscal Year 2024 Stockpile Stewardship and Management Plan*, November 2023, pp. 3-22, available at https://www.energy.gov/sites/default/files/2023-11/FY24SSMP_FINAL_NOVEMBER_2023_0.pdf.

Recommendations for Tritium

- Accelerate the completion of the TFF and other needed modernization projects at SRS.
- Ensure that tritium production can be scaled up to meet operational needs should the number of operationally deployed warheads be significantly increased.

Nuclear Test Readiness

As noted earlier, the United States ceased nuclear testing in late 1992. At that time, the near-term resumption of testing was anticipated with the goal of improving the safety and security of nuclear warheads. However, in early 1993, President Clinton extended the test moratorium indefinitely in pursuit of a global, "zero-yield" Comprehensive Test Ban Treaty (CTBT). Later, in August 1995, President Clinton signed a directive establishing "safeguards" to be maintained in a no-testing environment. Those safeguards included: the conduct of a Science-Based Stockpile Stewardship Program, the maintenance of the "basic capability to resume nuclear testing," and conditions under which the President would be prepared to withdraw from the CTBT under the "supreme national interests" clause to conduct whatever testing was required.[31] Clinton directed that after FY 1996, the United States readiness posture for resuming nuclear testing would be based on testing within two to three years following a decision to proceed.

Today, most of the nuclear testing safeguards remain relevant and have been adequately maintained. However, one of these safeguards has not been fully maintained and is of particular concern: the safeguard to maintain the readiness to conduct a nuclear test, which may become necessary. According to DOE/NNSA, there has been no funding specifically for nuclear test readiness since FY 2010. NNSA has maintained that the routine activities being conducted for subcritical nuclear experiments at the National Security Site in Nevada essentially fulfill this readiness requirement. DOE/NNSA asserts that the current "test readiness strategy is to reconstitute underground nuclear explosive testing if or when needed, rather than maintaining obsolete facilities and capabilities."[32] In 1997, a former director of Los Alamos supported this approach and stated that most of the key skills needed for test readiness are being exercised in the conduct of subcritical testing in Nevada.[33]

Currently, NNSA tasks its Nevada site with being "ready to perform an underground nuclear test using a test article drawn from the existing stockpile and limited diagnostics within 36 months." NNSA also assumes that a nuclear test would be conducted only when the President has declared a national emergency or other similar contingency.[34] A 36-month

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[31] U.S. Department of State, "Comprehensive Test Ban Treaty Safeguards," *Fact Sheet*, available at https://usinfo.org/usia/usinfo.state.gov/topical/pol/arms/ctbt/factsafe.htm.

[32] Department of Energy, *Fiscal Year 2024 Stockpile Stewardship and Management Plan*, op. cit., pp. 4-21.

[33] Siegfried S. Hecker, "Letter to Hon. Jon Kyl," September 24, 1997, available at https://www.govinfo.gov/content/pkg/CHRG-105shrg44720/html/CHRG-105shrg44720.htm .

[34] Department of Energy, *Fiscal Year 2024 Stockpile Stewardship and Management Plan*, op. cit., pp. 4-20.

readiness timeline for testing appears to be inconsistent with the assumption of a national emergency.

At least one high-level review panel agreed that a much more responsive test readiness posture is needed. In its final report to Congress in March 2002, the Panel to Assess the Reliability, Safety, and Security of the United States Nuclear Stockpile (The Foster Panel) wrote:

> The President should have the latitude for a timely and effective response to unexpected events, whether due to problems in the stockpile or an international situation. Current test readiness of two to three years does not provide a viable option for a timely response. The Panel's assessment is that test readiness should be no more than three months to a year, depending on the type of test.[35]

John Hopkins, a former associate director for nuclear weapons technology and former Director for Nuclear Testing at Los Alamos, has been an outspoken critic of the NNSA test readiness posture. For example, in 2017, Hopkins argued that:

- much, if not most, of the equipment and technology required for nuclear testing in the past has not been adequately maintained, is obsolete, or has been sold or salvaged;
- the knowledge needed to conduct a nuclear test, which comes only from testing experience, is all but gone; and
- the whole testing process—whether to conduct one test or several—would in essence have to be reinvented, not simply resumed.[36]

The potential funding for one or more nuclear tests is an important issue. There are at least two important aspects of this funding issue:

- First is the overall cost of conducting a nuclear test. No credible cost data exists to estimate the cost of a fully instrumented nuclear test in the current environment. The best estimate is to extrapolate from 1992 when a nuclear test cost around $100 million dollars. Of course, in 1992, all the necessary equipment was ready and operational. In short, a test would be expensive.
- Second is the uncertainty over whether the cost of a test would be taken from the annual budgets for the laboratories or funded by a separate appropriation. For more than thirty years, the nuclear weapon laboratory directors have certified that the stockpile of warheads meet reliability and performance standards and there is no immediate need to resume nuclear testing. That judgement call has likely been biased somewhat by the view that, if a nuclear test is requested, the funding for the test

[35] Foster, et al., *Final Report of the Panel to Assess the Reliability, Safety, and Security of the United States Nuclear Stockpile, Report to the Senate Armed Services Committee*, op. cit., p. ES-2.

[36] Bill Gertz, "Los Alamos Expert: U.S. Unable to Conduct Nuclear Tests," *Washington Free Beacon*, March 2, 2017, available at: https://freebeacon.com/national-security/los-alamos-expert-u-s-unable-conduct-nuclear-tests/.

would likely come at the expense of other laboratory programs. For example, a former lab director argued against testing by stating,

> data is not free … to get more data of one type, you have to sacrifice something else. … e.g., if you have to give up advanced computing or all laboratory experiments to afford full-scale nuclear testing, it is a poor bargain, in my opinion.[37]

How important is testing? Some test-experienced senior managers at the nuclear labs have argued that the scientific foundation for assessing the performance of warheads in the stockpile is eroding without nuclear testing. For example, in a 2019 article, one former associate laboratory director and a senior warhead designer listed several concerns about the health of warheads in the stockpile. Those concerns include the fact that:

> … the physical state of weapons in today's stockpile differs from what it was when their performance (e.g., yield) was tested, and second, the current nuclear test moratorium precludes a decisive determination of whether these changes in physical state adversely affect performance.[38]

If a confirmatory nuclear test was to be scheduled in the near term, a life-extended W76 warhead would be a good candidate for testing to determine whether the modifications have affected performance, and if so, in what way. Why the W76? The now-complete W76 life extension program for submarine-launched ballistic missiles was extensive. According to one description, it involved

> … changes to both the reentry body and the warhead package; replacing detonators; replacing chemical high explosives; refurbishing the secondary; adding a new arming, fusing and firing (AF&F) system; adding a new gas reservoir and transfer support system; and a new lightning arrestor connector.[39]

Finally, if the United States decides to conduct a nuclear test, the collection of as much test data as possible should be a priority to make the best use of this opportunity. It is unclear from the available documentation whether NNSA still maintains the required capability to build and deploy test sensors and radiochemical collection and analysis capabilities to support a fully instrumented nuclear test. Collection of this data would enable scientists at the labs to benchmark the latest computer codes for future use.
Recommendations for nuclear test readiness:

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[37] Miller, "Stockpile Stewardship: What Were We Thinking? How Did It Work Out?," op. cit., p. 16.

[38] John C. Hopkins and David Sharp, "The Scientific Foundation for Assessing the Nuclear Performance of Weapons in the US Stockpile is Eroding," *Issues in Science and Technology* Vol. XXXV, No. 2, (Winter 2019), p. 23, available at https://issues.org/the-scientific-foundation/.

[39] Pat Host, "W76-1 Life Extension Program Reaches Production Phase Halfway Point," *Defense Daily*, October 31, 2014, available at https://www.defensedaily.com/w76-1-life-extension-program-reaches-production-phase-halfway-point/navy-usmc/.

- Since nuclear testing may be needed, we need to survey test readiness capabilities and take immediate corrective action to restore a readiness capability to conduct a fully instrumented nuclear test; and
- Appropriate funds for test readiness improvements and keep the funding in an "escrow" account that could be immediately used to begin test preparations after concerns over one or more stockpile warheads results in decision to seek presidential approval to test. This escrow fund would help alleviate the concerns at the labs over having to immediately cut other nuclear weapon programs in order to begin preparations for a nuclear test.

DoD and NNSA Integration for Nuclear Weapons Development

No complex industrial process can be expected to restart without serious problems after having been shut down for decades, having had a huge turnover of the work force, and having had plants and processes moved to different locations. That is the challenge that will face the nuclear weapons complex as it develops new warheads and integrates them with modern DoD-developed weapon delivery systems.

The most recent warhead to successfully go from concept development to the deployed stockpile is the W88 warhead for Navy SLBMs. That development occurred about forty years ago during a time when the serial production of warheads in the complex was the norm. In the intervening forty years, a few new warhead acquisition programs have been proposed and some have begun development. However, senior government officials have, until now, found reasons to terminate these programs before completion.

NNSA integration with DoD program offices gets exercised within the project officer groups for each warhead type. Life extension programs have helped to exercise this integration activity to a limited degree. However, completely new warhead development is more complex and involves the creation of military characteristics and survivability criteria in nuclear environments which the new warheads design will have to meet. The initiative to develop and deploy the W93 warhead is likely to encounter numerous challenges. It is the first newly developed warhead planned for deployment in forty years and should not be delayed further.

Recommendations for DoD and NNSA Integration:

- Give high-level attention to DoD/NNSA integration activities for the development of the W93 warhead.

Contractor-based Infrastructure for Strategic Bombers, Intercontinental-Range and Submarine-Launched Ballistic Missiles, Cruise Missiles, and Maneuvering Hypersonic Delivery Vehicles

Discussion of a responsive infrastructure would not be complete without at least some observations about the commercial defense industry responsible for nuclear weapon delivery vehicles (e.g., heavy bombers, ballistic missiles, and cruise missiles).

DoD is deep into a generational modernization of its nuclear force. Already well underway are the development and production of the B21, a next-gen strategic bomber, and a Long-Range Standoff Missile (LRSM). The LRSM has undergone numerous flight tests and is slated to be operational by the end of the decade. The B21 is reported to be in low-rate initial production, however, the fleet of long-range bombers will need adequate tanker support in order to complete their missions. At present, the number of long-range aerial refueling aircraft to support bomber operations is insufficient and additional tankers and improved capabilities are needed.[40]

Less further along are programs to field the Sentinel ICBM to replace Minuteman III and the Columbia SSBN to replace Ohio-class SSBNs. Both acquisition programs have faced significant challenges. For example, in January 2024, DoD reported to Congress that the Sentinel program was in breach of Nunn-McCurdy due to significant cost overruns. To meet the Navy's goals for ballistic missile submarines and attack submarines, two U.S. shipbuilders, General Dynamics Electric Boat and Newport News, are executing the most significant increase in nuclear-powered submarine and ship construction in over 30 years.[41] Both programs, Sentinel and Columbia, are high priority programs, but are behind schedule and over cost.

Recommendations for DoD and the contractor-based infrastructure:

- Do not further delay funding for the recapitalization of any strategic nuclear force programs now underway;
- Increase the build of Columbia-class SSBNs. The planned number of these submarines which carry fewer missiles than Ohio-class submarines is insufficient to maintain the current level of SLBMs at sea; and
- Increase the fleet of tankers to better support long-range bombers.

[40] Caleb Egli, "Fueling a Superpower: Reprioritizing the US Air Refueling Fleet for Great Power Conflict," *Journal of Indio-Pacific Affairs*, May 8, 2024, available at https://www.airuniversity.af.edu/JIPA/Display/Article/3768313/fueling-a-superpower-reprioritizing-the-us-air-refueling-fleet-for-great-power/.

[41] United States Government Accountability Office, *Columbia Class Submarine: Overcoming Persistent Challenges Requires Yet Undemonstrated Performance and Better-Informed Supplier Investments*, GAO-24-107732 (Washington, D.C.: Government Accountability Office, September 30, 2024), p. 3.

Cautionary Lessons from Industry

The nuclear warhead complex is government-owned and unique in several ways. However, it is an industry that involves specialized manufacturing processes and, therefore, lessons learned from other industries may well apply. Significant problems have already been encountered when trying to restart production of components for warheads during life extension programs.

Industrial problems in the commercial sector reveal some parallels with that of the nuclear complex. Consider the recent example of problems involving Boeing 737 aircraft. Boeing for decades was an aerospace pioneer, but it's been 20 years since Boeing introduced a new airplane. Since then, the jet maker has instead made updates to its existing models.[42] Two aircraft crashes in 2018 and 2019 resulted in 346 fatalities. In 2024, a door blew off a 737 aircraft in flight. These incidents led to investigations into the Boeing corporate culture and industrial practices. One assessment of problems at Boeing cites a change in the previously engineering-centric corporate culture at Boeing following the 1997 merger of Boeing and McDonnell Douglas. One analysis stated,

> For most of its history, Boeing had what you might call an engineering-centric culture, with power in the company resting in the hands of engineering and design. … Executives from McDonnell Douglas ended up dominating and remaking Boeing. They turned it from a company that was relentlessly focused on product to one more focused on profit.[43]

A former CEO of Boeing who had formerly been CEO of McDonnel Douglas is quoted as saying, "I changed the culture of Boeing, that was the intent, so that it's run like a business rather than a great engineering firm."[44]

The change in the corporate culture at Boeing resulted in the outsourcing of some assembly procedures and the creation of "shadow factories" that were essentially production lines where engineers and mechanics work on fixing, maintaining or updating aircraft instead of new ones." One Boeing official reported, "It seems like 30% of everybody's job is fixing something that's bad quality or late product or something that shouldn't have happened."[45] The incident of the door of a 737 that had blown off in flight was traced to procedural errors at one of the shadow factories and work that had been outsourced.

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[42] Sharon Terlep and Andrew Tangel, "Can Boeing Be Fixed? Aerospace Leaders Offer a Repair Manual," *The Wall Street Journal*, January 6, 2025, available at https://www.wsj.com/business/airlines/boeing-plane-aerospace-leaders-advice-cb4c846c?gaa_at=eafs&gaa_n=ASWzDAgIKF0OZQX2POZH2RTETBgO52WOUCrPLpZ3wxAHWt5754I7XzgbCOu1&gaa_ts=687bdf02&gaa_sig=CpV_Hx27S7Xbq0Iis-_7Npn8yyrnxnpPlEa2TNuS02_Gdd4gxnSTDfi7RSbm9nc-n8INl6uWtXbNVEgdGk93fQ%3D%3D.

[43] James Surowiecki, "What's Gone Wrong at Boeing," *The Atlantic*, January 15, 2024, available at: https://www.theatlantic.com/ideas/archive/2024/01/boeing-737-max-corporate-culture/677120/.

[44] Ibid.

[45] Sharon Terlep, "Boeing's Push to Boost 737 Production Starts with Closing 'Shadow Factory'," *The Wall Street Journal*, February 14, 2025, available at https://www.wsj.com/business/airlines/boeing-shadow-factory-plane-repairs-fb80dfed?gaa_at=eafs&gaa_n=ASWzDAhagn-

The Boeing case study is one of many possible examples that appears to have parallels with the nuclear warhead complex. Has the corporate culture of the nuclear complex changed since it was shut down in 1989? You bet! In the past the nuclear complex was driven by designers, engineers, and production experts with years of experience in the nuclear industry. It is now driven primarily by analysts and computer simulation personnel that have never designed and produced a new nuclear warhead. Lessons from industry provide concerns that any attempted restart of serial warhead production is not likely to be a smooth process.

For the nuclear warhead enterprise to be successfully returned to functionality, competent leadership and accountability at the National Nuclear Security Administration (NNSA) will be essential. A November 2014 report of the Mies-Augustine Panel that examined the management of NNSA reported that:

> NNSA's Stockpile Stewardship Management Plan, which is intended to communicate long-range plans and cost estimates, has varied from year to year in the costs and schedules for the delivery of several major life extension programs and nuclear facilities. The panel concluded that the lack of a stable, executable plan for modernization is a fundamental weakness for NNSA.[46]

Furthermore, the panel concluded that "NNSA is on a trajectory toward crisis unless strong leadership arrests the current course and reorients its governance to better focus on mission priorities and deliverables."[47] Strong, competent leadership at NNSA and accountability for performance will be required to restore the nuclear enterprise to full operation.

How Do Nuclear Warheads Work? Are Concerns Regarding Reliability Warranted?

Modern nuclear warheads in the U.S. stockpile are much more complex than the chemical explosives found in conventional bombs and missile warheads. Each nuclear warhead in the U.S. inventory involves chemical explosives as well as exotic materials necessary for both nuclear fission and fusion. One warhead in the stockpile is made up of over 5,900 parts.[48]

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o7jpCBSiTfSwRZx1Xz5MUi6xINlCIL1uYvL7HZFUJYH4XrybO&gaa_ts=687bdf8c&gaa_sig=0kUpudR7dIiCpfnVYd8dj3pkBI5irjMcvhbyT51JUeT95o2wFhgTfIqcCO0PDlIS14UWgKdhGSD5zp1jidUgcw%3D%3D.

[46] Quoted in Government Accountability Office, "National Nuclear Security Administration: Observations on Management Challenges and Steps Taken to Address Them," GAO-15-532T (Washington, D.C.: Government Accountability Office, April 15, 2015), p. 4, available at https://www.gao.gov/products/gao-15-532t.

[47] Richard M. Jones, "Hearing Underscores Problems at the National Nuclear Security Administration," *American Institute of Physics*, April 24, 2014, available at https://www.aip.org/fyi/2014/hearing-underscores-problems-national-nuclear-security-administration.

[48] "B61 Nuclear Gravity Bomb," *Brookings*, available at https://www.brookings.edu/b61-nuclear-gravity-bomb/#:~:text=Three%20views%20of%20a%20B61,weapon's%205%2C919%20parts%20(foreground).

The warhead designs involve precise timing and multiple, reactive processes for proper operation.

Most U.S. nuclear warheads are two-stage devices. The first stage, or primary, includes a subcritical sphere-like shell made of an isotope of plutonium and/or highly enriched uranium. This shell is surrounded by chemical explosive materials, often called lenses. The term lens refers to the function of the explosive material. Just as glass lenses bend and redirect light to aid a vision-impaired individual, the high explosive lenses focus the explosive shock waves so that they compress the plutonium/uranium shell into a dense, somewhat spherical ball.

Some readers may be familiar with photos of early nuclear weapons. Movies such as "Oppenheimer" featured mock-ups of the earliest devices. The "Fat Man" nuclear device depicted in that movie was huge—about a five-foot diameter sphere with many explosive detonators attached to the explosive lenses. Modern primaries feature only a very small number of detonators and the size of the first stage has been greatly reduced and redesigned to enable the completed two-stage warhead to fit into a compact bomb case, missile compartment, or ballistic missile reentry cone.

The detonators have to be fired in a precise, coordinated manner to ignite the high explosives and create the focused shockwave that compresses the plutonium/uranium core into a smaller core that, as a result of its compact size and density, achieves criticality—a self-sustaining nuclear reaction. To enhance the energy release, at the optimal time determined by designers, a source of neutrons is introduced into the now super-critical assembly to initiate an exponentially increasing fission chain reaction and resultant nuclear explosion.[49]

Additionally, there is another important process involved in the detonation of the first stage of a modern nuclear warhead. A mixture of deuterium and tritium atoms are injected into the primary. Both deuterium and tritium are isotopes of hydrogen atoms. (The hydrogen atom is the lightest atom of the elements in the periodic table. Each hydrogen atom has only one neutron while deuterium and tritium have two and three neutrons, respectively.) The compression and ignition process creates pressure and heat sufficient to fuse deuterium and tritium atoms into helium atoms and the resulting process releases energy and expels a neutron which helps "boost" the growing fission process.

There are numerous ways in which this initial ignition process in the primary can go wrong. For example, the timing of the firing of the detonators can be off, the consistency of the high explosive material can be compromised and result in a shock wave that does not properly compress the plutonium/uranium material, or the introduction of the neutrons can be injected at a time that is slightly different from the precise timing required.

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[49] Bruce T. Goodwin, "Nuclear Weapons Technology 101 for Policy Wonks, Center for Global Security Research," (Livermore, CA: Center for Global Security Research, August 2021), pp. 18-21, available at https://cgsr.llnl.gov/sites/cgsr/files/2024-08/CGSR_NW101_Policy_Wonks_11-04-21_WEB_v5.pdf.

The process described above is just the beginning of the explosion process for a modern nuclear weapon. The explosive power of most primaries (first stages) is less than ten kilotons of yield. The high yield of modern weapons is generated in the second stage.

As the primary is imploding and creating an explosion to produce fission and fusion processes, it creates heat that is so hot that "it glows, not red hot or white hot, but glows in the X-ray spectrum." The challenge is to contain those X-rays for a very short time in a radiation case and direct them to "compress the secondary, resulting in a thermonuclear detonation" which produces the enormous yield of the H-bomb.[50]

For a modern nuclear warhead to operate as designed, all of these processes have to function in a precise manner while the warhead is literally blowing itself apart. In addition, this series of interactions must all be completed properly within one ten-thousandth of a second. What could go wrong?

One more thing. For the ignition process to send a properly coded signal to fire the detonators, that signal must pass through multiple logic circuits. These circuits are referred to as "use-control" devices and have two primary purposes. First, the use-control circuits are designed to ensure that a firing signal from a verifiably authorized source reaches the detonators. And second, use-controls are designed to ensure that if an adversary, such as a terrorist, gets control of a nuclear weapon and tries to bypass security logic circuits and detonate it, the logic circuit senses the deviation from proper protocols and prevents detonation.

Nuclear warhead designs are engineered to function properly after being subjected to harsh, often violent environments such as from the launch of a ballistic missile and reentry into the atmosphere. The materials must be able to withstand the intense cold of very high altitude and searing heat and G forces of reentry. Each warhead design may also include specialized materials to help the warhead survive and operate in an environment of intense nuclear effects (e.g., neutron flux, X-rays, thermal).

The purpose of this highly condensed description of the operation of a modern nuclear weapon is provided here to provide readers with a basic understanding of the complexity of these weapons and that their reliability and proper operation as they age and are modified should not be taken for granted. To date, most (but not all) warhead life extension programs have been modest in scope. As the existing warheads continue to age, more complex modifications will be required. Each modification represents a change in the certified design of these complex systems. Proper operation, if needed, should not be assumed, and eventually, these warheads will have to be replaced. In the meantime, it is not unreasonable to consider nuclear testing to verify the proper functioning of U.S. nuclear weapons that are years beyond their design life and that have been modified to replace or upgrade components deemed unreliable due to aging.

For readers who seek more details on the design and operation of nuclear warheads, Bruce Goodwin at Lawrence Livermore National Laboratory has published an excellent tutorial and history of nuclear weapons technology. Much of the description of warhead

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[50] Ibid, pp. 23-24.

operation in this paper is a highly condensed version of material from his publication.[51] Also, the Union of Concerned Scientists has a useful article on how nuclear weapons work on their website.[52]

What about Russia and China? Do They Have Similar Issues Regarding the Operation of Their Nuclear Warhead Infrastructures?

The serial production of nuclear warheads in the United States was abruptly halted in 1989. As the numerous changes, discussed earlier, to the U.S. business model for designing and producing nuclear warheads took effect in the early 1990s, the situation regarding the nuclear warhead complexes in Russia and China were very different from that of the United States. In the early 1990s, the nuclear complex of the United States was considered to be more capable than those in Russia and China, with the sole exception of the U.S. plutonium pit facility that had been closed but was planned to be relocated. What follows is a condensed description of changes to the nuclear infrastructures of Russia and China over the past three decades.

Russia

The breakup of the Soviet Union resulted in significant challenges for Russia's ability to sustain its huge nuclear force. Following the Soviet Union dissolution, large numbers of nuclear weapons were located in other former Soviet Republics. The physical security of those weapons was an international concern. The United States helped negotiate agreements to return strategic nuclear weapons from Ukraine, Belarus, and Kazakhstan and tactical nuclear weapons from a variety of eastern European countries to Russia. The Nunn-Lugar Program was initiated and funded by the United States to help decommission some of the former Soviet nuclear weapon deployment sites, dismantle warheads, and provide security for those weapons returned to Russia.

In the early 1990s, Russia deployed about ten thousand nuclear warheads on strategic weapons and had about twenty thousand tactical nuclear weapons of various types.[53] According to one Russian source,

> The disintegration of the Soviet Union also resulted in significant changes in the military industry, affecting Russia's ability to maintain and modernize its strategic forces. The missile production industry was affected the most, since many key research and production facilities were located in Ukraine. Other industries

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[51] Ibid.

[52] "How Do Nuclear Weapons Work?" *Union of Concerned Scientists*, August 23, 2023, available at https://www.ucsusa.org/resources/how-nuclear-weapons-work#:~:text=Modern%20nuclear%20weapons%20work%20by,pressure%20needed%20to%20ignite%20fusion.

[43] Pavel Podvig, "The Russian Nuclear Arsenal," *Center for International Security and Cooperation, Stanford University*, November 2005, available at https://ciaotest.cc.columbia.edu/casestudy/case003/case003.html.

> suffered major disruptions in their subcontractor chains. One notable exception was the nuclear weapons production complex, which historically had all its vital research and production facilities located in Russia.[54]

One exception to the exception above that was the Semipalatinsk Russian nuclear test complex which was in Kazakhstan and, therefore was no longer accessible by Russia and had been closed.

When the Strategic Arms Reduction Treaty (START) entered into force in 1994, the treaty permitted Russia to deploy up to six thousand accountable strategic nuclear warheads. Russia and the United States negotiated START II which would have capped the number of accountable strategic nuclear warheads at 3,000 to 3,500 and would have eliminated all multiple warhead ICBMs. Both START and START II included verifiable dismantlement provisions and deadlines. Russia complained that under the treaty provisions it would need to produce several hundred new single-warhead ICBMs to keep pace with the United States and this, along with the dismantlement provisions, were beyond its economic capability. START II was eventually eclipsed by the 2002 Strategic Offensive Reductions Treaty in May 2002 and a month later Russian President Putin announced that Russia was no longer bound by the provisions in START II.

Immediately after the so-called end-of-the-Cold-War, Russia had large numbers of existing nuclear weapons, a nuclear warhead complex that was in-tact within Russian borders, but was shackled by a weak economy. Under Russian President Yeltsin, government spending in Russia was shifted away from military readiness and priority was given to rebuilding the Russian economy. Throughout the 1990s, the United States and Russia explored opportunities for cooperation instead of military confrontation. It was in this environment that the Clinton Administration sharply cut funding for the U.S. nuclear complex and terminated all new nuclear warhead development and testing.

The improved relationship between the United States and Russia began to change after President Putin succeeded Yeltsin in 2000. Putin is famous for his April 2005 address to the nation in which he declared that "The collapse of the Soviet Union was the greatest geopolitical catastrophe of the [twenty-first] century."[55]

Over the past twenty years Russia has put highest priority on rebuilding and modernizing its nuclear forces and the production complex needed to support those forces. It has replaced the closed nuclear testing facility at Semipalatinsk with a revitalized and expanded facility, Novaya Zemlya, above the Artic Circle, and has conducted numerous experiments at this new test facility.

With a great deal of activity at this revitalized nuclear test facility, Russia's compliance with its CTBT commitments have been questioned. In fact, the Perry-Schlesinger Strategic Posture Commission report stated in 2009 that "Apparently Russia and possibly China are

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[54] Ibid.

[55] "Putin Address to Nation: Excerpts," *BBC*, April 25, 2005, available at http://news.bbc.co.uk/2/hi/europe/4481455.stm.

conducting low yield tests."[56] In May 2019, Lt. Gen. Robert P. Ashley, Jr., then-Director of the Defense Intelligence Agency, stated:

> Russia's development of new warhead designs and overall stockpile management efforts have been enhanced by its approach to nuclear testing. The United States believes that Russia probably is not adhering to its nuclear testing moratorium in a manner consistent with the "zero yield" standard.[57]

In late 2023, the Russian government announced that it was revoking its ratification of the CTBT. In September 2024, Andrei Sinitsyn, head of Russia's central nuclear test site at Novaya Zemlya, stated that,

> The test site is ready for the resumption of full-scale testing activities. It is fully ready. Laboratory and testing facilities are ready. The personnel are ready. If the order comes, we can start testing at any moment.[58]

While the United States, has been very cautious about any new nuclear warhead development over the past thirty years, Russia has designed and produced numerous new warheads for its deployed weapons systems.[59]

In 2019, Lt. Gen. Robert Ashley, the Director of the Defense Intelligence Agency, talked openly about Russian and Chinese nuclear developments. He stated,

> Russia's stockpile of nonstrategic nuclear weapons, already large and diverse, is being modernized with an eye towards greater accuracy, longer ranges and lower yields to suit their potential war-fighting role.[60]

He also stated that "during the past decade Russia has improved and expanded its [nuclear weapons] production complex, which has the capacity to process thousands of warheads annually."[61] He elaborated further,

> Russia claims to be developing new warhead designs for strategic systems such as a new high-yield, earth-penetrating warhead to attack hardened military targets, like the U.S., allied and Chinese command and control facilities. Russia's

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[56] Perry and Schlesinger, et al., *America's Strategic Posture: The Final Report of the Congressional Commission on the Strategic Posture of the United States*, op. cit., p. 83.

[57] Robert P. Ashley, Jr., "The Arms Control Landscape," *Transcript*, The Hudson Institute, May 31, 2019, available at https://www.hudson.org/national-security-defense/transcript-the-arms-control-landscape-ft-dia-lt-gen-robert-p-ashley-jr.

[58] Astri Edvardsen, "All Clear for Nuclear Testing at Novaya Zemlya, Says Russian Head of Test Site," *High North News*, September 23, 2024, available at https://www.highnorthnews.com/en/all-clear-nuclear-testing-novaya-zemlya-says-russian-head-test-site.

[59] Mark Schneider, "How Many Nuclear Weapons Does Russia Have? The Size and Characteristics of the Russian Nuclear Stockpile," *Occasional Paper* Vol. 3, No. 8 (Fairfax, VA: National Institute Press, August 2023), available at https://nipp.org/wp-content/uploads/2023/09/Vol.-3-No.-8.pdf.

[60] Ashley, Jr., "The Arms Control Landscape," op. cit.

[61] Ibid.

> development of these new warhead designs and overall stockpile management has been enhanced by its approach to nuclear testing.[62]

The 2025 DIA Worldwide Threat Assessment states:

> Russia is expanding its nuclear forces by adding new capabilities, including nuclear air-to air missiles and novel nuclear systems. Russia probably maintains a nuclear stockpile of about 1,550 deployed strategic warheads and up to 2,000 non-strategic warheads. Russia is expanding its nuclear posture to Belarus by establishing missile and nuclear-capable aircraft capabilities, renovating a nuclear weapons storage site, and training Belarusian crews to handle tactical nuclear weapons. Throughout the Russia-Ukraine conflict, Russia has used nuclear related rhetoric and military exercises to signal its resolve and deter Russia-perceived Western involvement in the conflict.[63]

In summary, Russia has revitalized its nuclear warhead infrastructure from its greatly weakened status in the early 1990s to that of a nuclear powerhouse today. It has designed and produced numerous new types of nuclear warheads, is capable of producing over a thousand new warheads each year, and has relocated and revitalized its nuclear testing site. The contrast with the United States, which has produced no nuclear warheads, new or otherwise, since 1989, and has no test readiness program, is stark.

China

In the early 1990s, China could be described as a regional nuclear power. Its nuclear force was estimated to include less than one hundred warheads on ballistic missiles of which only about seventeen had enough range to reach the far western coast of the United States. China also had only one rudimentary ballistic missile submarine which never deployed far from its home base.[64]

Even in the early twenty-first century, U.S. assessments of Chinese military developments dismissed any serious nuclear threat from the People's Republic of China (PRC) nuclear forces. For example, a DoD report to Congress confidently stated,

> The technological level of China's defense industrial complex is too far behind that of the West to produce weaponry that could challenge a technologically advanced foe such as the United States or Japan for an indefinite period of time.[65]

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[62] Ibid.

[63] Defense Intelligence Agency, *2025 Worldwide Threat Assessment*, 2025, p. 15, available at https://armedservices.house.gov/uploadedfiles/2025_dia_statement_for_the_record.pdf.

[64] Ron Montaperto, "China as a Military Power," National Defense University Strategic Forum, No. 56, December 1995, available at https://apps.dtic.mil/sti/pdfs/ADA394422.pdf.

[65] Department of Defense, *Annual Report on the Military Power of the People's Republic of China*, June 2000, p. 8, available at https://apps.dtic.mil/sti/pdfs/ADA381499.pdf.

That characterization of Chinese military technology has changed dramatically since it was published in June 2000. The most recent assessments by DoD of Chinese nuclear capabilities provide quite a different picture. The DoD assessment in 2024 was that China had about 400 ICBMs in its arsenal, all of which could reach the continental United States.[66] No longer were the Chinese missiles limited to carrying a single warhead. China has now deployed multiple-warhead missiles. China has also recently constructed three new silo fields for ballistic missiles and probably has begun loading missiles into the silos. The PRC nuclear arsenal also includes road-mobile ICBMs and intermediate-range ballistic missiles (IRBMs). It has fielded two types of ballistic missile submarines and is now capable of conducting near-continuous at-sea missile patrols and targeting the United States from its littoral waters. In addition, the PRC has joined the ranks of countries with a strategic nuclear triad by equipping its bombers with a refueling capability as well as the ability to carry air-launched ballistic missiles.[67]

The pace of nuclear developments in China appears to be accelerating. For example, the 2020 report on China's military developments estimated that China possessed an operational nuclear warhead stockpile of about 200 warheads and that by 2030 that number would at least double.[68] Just four years later, DoD estimates that the Chinese operational stockpile of nuclear warheads has surpassed 600 and will exceed one thousand by 2030—several years before the U.S. completes its planned infrastructure modernization.[69] The Defense Intelligence Agency estimates that:

> China will continue to increase the size of its force until at least 2035. This supports the PLA's objective to achieve a more diverse nuclear force, comprising systems including low-yield precision strike missiles and ICBMs with multi-megaton yields, to provide a broader range of nuclear response options.[70]

China continues to produce weapons-grade nuclear materials and is expanding its nuclear warhead production infrastructure. In addition, recent upgrades and possible preparation for testing at its Lop Nur nuclear test site have raised concerns about its testing plans.[71] The newly developed nuclear capabilities being fielded by China may well provide a compelling rationale for them to conduct nuclear tests to confirm proper functioning of those warheads.

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[66] Department of Defense, *Military and Security Developments Involving the People's Republic of China*, 2024, p. 65, available at https://media.defense.gov/2024/Dec/18/2003615520/-1/-1/0/MILITARY-AND-SECURITY-DEVELOPMENTS-INVOLVING-THE-PEOPLES-REPUBLIC-OF-CHINA-2024.PDF.

[67] Ibid, pp. 103-107.

[68] Department of Defense, *Military and Security Developments Involving the People's Republic of China*, 2020, p. xiv, available at https://media.defense.gov/2020/sep/01/2002488689/-1/-1/1/2020-dod-china-military-power-report-final.pdf.

[69] Department of Defense, *Military and Security Developments Involving the People's Republic of China*, 2024, op. cit., pp. 107, 109.

[70] Defense Intelligence Agency, *2025 Worldwide Threat Assessment*, op. cit., pp. 8-9.

[71] Ibid.

Russia-China Nuclear Cooperation. The rapid modernization of Russian and Chinese nuclear forces is a serious concern in itself. That concern is heightened further by the potential for cooperation by Russia and China against the United States and its allies. In May 2025, a DoD official with responsibilities for nuclear deterrence testified,

> Today, the United States faces one of the most unprecedented strategic environments in our Nation's history. China and Russia are modernizing and diversifying their nuclear forces at breathtaking pace, and the Democratic People's Republic of Korea (DPRK) continues to demonstrate its ability to execute a strategic attack. Additionally, our adversaries are increasing their level of coordination and cooperation, which also raises the possibility of simultaneous conflicts with multiple nuclear-armed adversaries.[72]

During the early part of the twenty-first century, U.S. officials may have felt comfortable with the slow pace of reconfiguring the U.S. nuclear warhead complex. However, the rapid modernization of nuclear forces in Russia and China and the dramatic gap in capability between Russian and Chinese nuclear infrastructures and the capability of the United States is now a valid cause for alarm.

In June 2025, one former DoD official warned that the possibility of a combined Sino-Russian nuclear attack is now a mandatory planning scenario for the United States. He states that his is not just a theoretical concern. As evidence, he cites recent joint Chinese-Russian strategic bomber patrols near Alaska.[73]

Summary Findings

The need to restore to operation the nuclear warhead design and industrial capabilities of the United States is an urgent concern. Restoring this capability is unlikely to be smooth and without further difficulties. Accomplishments in modernizing nuclear component production facilities initiated over the past two decades provide a useful base for pushing ahead. However, additional funding, high level attention, and acceleration of current infrastructure plans are required to provide the capability to discourage nuclear racing and brinksmanship by Russia and China. The recommended actions cited in this report are the minimum of what is necessary to help restore the nuclear warhead complex to functionality.

[72] Statement of Brandi Vann before the House Armed Services Committee, Subcommittee on Strategic Forces, May 7, 2025, p. 3, available at https://armedservices.house.gov/uploadedfiles/passback_bln-119-14d_defense_vann_hasc_nuclear_posture_hearing_statement.pdf.

[73] Eric S. Edelman, "America's Latest Problem: A Three-Way Race," *Foreign Policy*, June 2, 2025, available at https://foreignpolicy.com/2025/06/02/us-nuclear-weapons-deterrence-command-control-nc3-decapitation-strike-china-russia-strategy-geopolitics/.

Summary of Recommendations for
Responsive Infrastructure for Nuclear Warheads

Below are recommended actions needed in the near term to help achieve a responsive and resilient infrastructure. All are important. Several require urgent attention.
Recommendations requiring urgent action:

- ***Plutonium processing and fabrication***: proceed with greater urgency to achieve an operational pit fabrication capability at Los Alamos; accelerate the second fabrication site at SRS; and develop plans for each site to be able to scale-up plutonium pit production quantities in a timely manner.
- ***Nuclear test readiness***: survey test readiness capabilities and take immediate corrective action to restore a readiness capability to conduct a fully instrumented nuclear test within two years; also, appropriate funds for test readiness and keep the funding in an "escrow" account to be used, when needed, to begin test preparations.
- ***DoD and NNSA Integration***: proceed apace on W93 development and give high-level attention to the DoD/NNSA integration activities for the W93 warhead.

Other important recommended actions:

- ***Uranium processing and fabrication***: to the extent possible, accelerate the construction of the replacement UPF and lithium facilities at SRS.
- ***Non-nuclear components***: expand capacity at both the Kansas City Plant and at Sandia to provide resilience.

Tritium production and handling: accelerate the completion of the TFF facility and other needed modernization projects at SRS; and ensure that tritium production can be scaled up to meet operational needs should the number of operationally deployed warheads be significantly increased.

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