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ASSESSMENT OF U.S. READINESS TO DESIGN, DEVELOP AND PRODUCE NUCLEAR WARHEADS:

Current Status and Some Remedial Steps

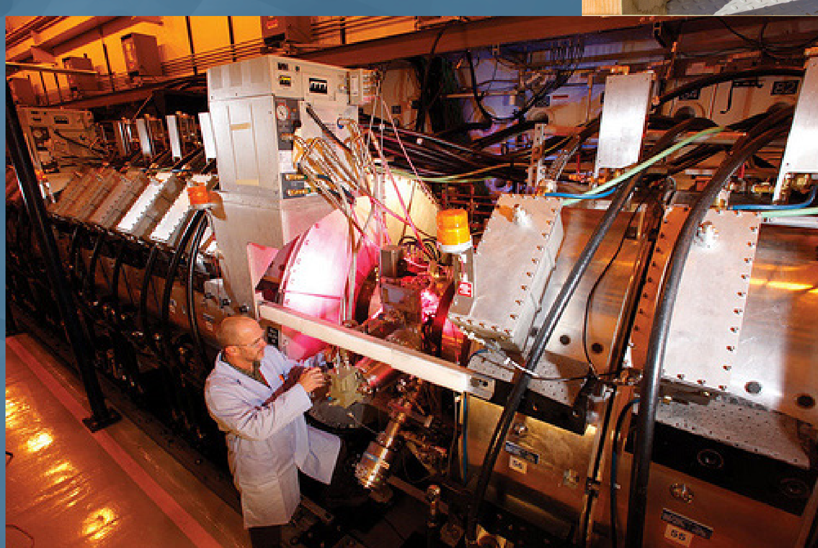

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Table of Contents

Foreword

This report should be a wake-up call for U.S. leaders in the executive branch and in Congress. Given the dynamic, uncertain security environment of today, the U.S. nuclear infrastructure—in particular the intellectual nuclear infrastructure—should expect to be surprised, perhaps even shocked, sometime in the future by unforeseeable events that demand a U.S. response. Prompt action could be needed to develop and produce nuclear warheads in a timely manner to strengthen U.S. deterrence and assurance missions. Currently, the U.S. nuclear infrastructure is not ready to respond effectively to such surprise.

This situation has developed over several administrations. U.S. leaders, while aware of the need to sustain U.S. nuclear warhead development capabilities, have not assigned sufficient priority to this task. In the early 1990s, in the wake of the collapse of the Soviet Union, this was viewed as an important but not urgent task. That is no longer the case.

As this report documents, the need for the United States to improve, maintain, and periodically exercise the full set of nuclear warhead design, engineering, and production capabilities has been a consistent conclusion from studies conducted over the past two decades. This task demands more than just modernizing the production infrastructure—it requires revitalizing the intellectual infrastructure and developing critical skills and expert judgment in the next generation of nuclear-skilled personnel.

It is time for U.S. leaders to address this long-standing capability shortfall with the urgency demanded by the complex threat environment facing the United States and its allies. The report calls for specific actions and a bipartisan, long-term commitment to this goal. I heartily endorse that goal.

Dr. John S. Foster, Jr.

Preface

This assessment was initiated out of deeply held concerns that the U.S. nuclear weapons enterprise has not achieved the proper balance between ensuring the safety and reliability of today's nuclear stockpile, and providing the capabilities, personnel skills, and production infrastructure needed to respond to future adverse contingencies. Of particular concern is the atrophy in readiness to design, develop, and produce new nuclear warheads if required in the future. Numerous studies over the past two decades have documented this atrophy but their recommendations have not received priority attention from national leadership. This report identifies important capability shortfalls of the current U.S. nuclear enterprise—in particular, the intellectual capital on which the health of the current and future U.S. nuclear deterrent depends—and offers recommendations to address these shortfalls. Our goal is to stimulate debate on this critical national security issue and provide a foundation for follow-on assessments.

The authors are indebted to Dr. John S. Foster, Jr. and Dr. Keith B. Payne who served as senior reviewers for this report. In addition, Mr. Kurt Guthe, Director of Strategic Studies at National Institute, reviewed earlier drafts of this work and provided valuable suggestions on the presentation of assessment findings and recommendations. The authors are fully responsible for the content of this final report.

The authors also wish to thank the Sarah Scaife Foundation for its generous support, without which this assessment would not have been possible.

Tom Scheber and John Harvey

Executive Summary

This report provides an assessment of the U.S. readiness posture to be able to design, develop, and produce new nuclear weapons, in particular the nuclear warheads. The first part of the report focuses primarily on policy-related issues, including the benefits of a healthy nuclear readiness posture, discusses the relevant nuclear weapon policies of three post-Cold War administrations, addresses lessons from an attempt to constrain U.S. nuclear warhead development activities, and summarizes findings of numerous studies of security issues relevant to this topic over the past two decades. The second part of the report addresses technical issues; it characterizes the current state of readiness to develop and produce new nuclear capabilities, identifies existing limitations, and provides recommendations to improve the U.S. nuclear readiness posture.

This report does not advocate any specific new nuclear capability. The focus is on a *readiness capability* to respond to adverse contingencies and the steps needed to remediate an aspect of the U.S. security posture that, over the past two decades, has been documented repeatedly as being deficient. A healthy nuclear readiness capability would enable the United States to respond to a reliability failure in a nuclear warhead or weapon system type, to an emerging vulnerability as the result of new adversary capabilities, or to presidential direction calling for an increase in the U.S. inventory of weapons.

Why is Sustaining a Nuclear Weapon Development Capability Important?

With multiple and diverse security challenges for the United States and its allies, Department of Defense (DoD) officials have recently expressed alarm at the narrowing U.S. margin of technological superiority in military capabilities vis-à-vis potential adversaries. Former Secretary of Defense Chuck Hagel and current Secretary of Defense Ashton Carter have both called for greater innovation and creativity for defense technologies. Arguably, a military capability sector that clearly demonstrates a shrinking U.S. margin of capability is that of nuclear weapons—the National Nuclear Security Administration (NNSA) capabilities to develop and produce nuclear warheads and the DoD-developed delivery systems that carry those warheads.

Maintaining a readiness capability to develop new weapons or replacements for existing nuclear weapons is fundamentally about reducing risk in the future. Indeed, the 2009 report of the bipartisan Strategic Posture Commission cited the "unpredictable nature of the security environment" as one of the emerging challenges for the United States. Of significant concern was the "profound uncertainty about the future international roles of Russia and China" as well as uncertainty about the future roles of various rising powers. The Commission concluded that the United States needs "to hedge against the possibility that ... these factors might not turn out for the best and that new challenges for the U.S. nuclear strategy might emerge and, indeed, suddenly so."[1]

Currently, shortfalls in the U.S. nuclear infrastructure—especially the intellectual infrastructure for warhead research and development—significantly degrade the ability of the United States to respond to challenges that could undermine the deterrence of adversaries and the assurance of allies. Establishing a nuclear weapon readiness program should be a national priority in order to provide resilience for new and unforeseen challenges ahead. The nuclear infrastructure and personnel could be called upon to diagnose and fix an unexpected reliability problem in a warhead type, replace older warheads with similar or different warhead types, increase the number of deployed warheads, or design with different military capabilities. Currently, it is not ready to respond.

A fully functioning and responsive development infrastructure would:

- Improve the credibility of U.S. nuclear capabilities in support of deterrence and assurance;
- Provide enhanced adaptability and resilience for the nuclear force to be able to respond to emerging challenges in a timely manner; and
- Enable the United States to reduce the overall size of the nuclear stockpile. Instead of relying on a large inventory of non-deployed warheads to manage risk and hedge against reliability problems, U.S. leaders would rely more heavily on the infrastructure and skilled workforce to be able to fix warhead problems quickly and, when needed, respond to new security challenges.

Summary of U.S. Post-Cold War Nuclear Weapon Policies and Readiness Posture

The administrations of President William J. Clinton and President George W. Bush agreed on the *explicit* policy of maintaining the ability to design and produce new nuclear warheads and weapons, when required. For example, in February 1997, the Clinton administration Under Secretary of Defense for Policy, Walter B. Slocombe, testified before a Senate subcommittee on “The Future of Nuclear Deterrence.” When asked about the administration’s policy regarding development of new types of nuclear weapons, Slocombe replied,

> To be clear, we maintain the capacity to design new weapons. We do some design of potential backups and replacements. Under current circumstances, we do not foresee a requirement to design new weapons from the ground up, but we will retain that capacity, the capacity to do so.[2]

During the George W. Bush administration, at a February 2002 congressional hearing on the 2001 Nuclear Posture Review (NPR), NNSA Administrator, General John Gordon testified on the continuing need for a responsive infrastructure and skilled personnel. Gordon stated,

> If the U.S. is to have a flexible deterrent, it must be able to adapt its nuclear forces to changing strategic conditions. Adaptation and modernization of forces, including implementation of new technologies, will enable us to continue to achieve deterrence objectives more efficiently even as we move to significantly lower force levels. ... In certain cases, it may be appropriate to design, develop and produce a small build of prototype weapons both to exercise key capabilities and to serve as a “hedge,” to be produced in quantity when deemed necessary.[3]

Maintaining a resilient nuclear capability was characterized by both administrations as a “hedge” against future uncertainties. Both administrations stated this requirement periodically and reflected this priority in their programmatic initiatives.

In its 2010 NPR, the Obama administration assigned highest priority to nuclear nonproliferation and reducing the role of nuclear weapons in U.S. national security strategy. The administration also promoted the vision of a nuclear-free world. At the same time, President Obama committed to sustain the reliability of nuclear warheads as long as those weapons are needed and to enhance safety and security features for nuclear weapons. The requirement to maintain a capability to develop and field modern warheads, or modify warheads to provide new military capabilities is *implicit* in President Obama's commitment to sustain the nuclear stockpile. In a 24 May 2010 letter from Vice President Joseph Biden to Senators Kyl and Lieberman, Biden stated:

> Admiral Mullen and General Kevin Chilton, Commander, U.S. Strategic Command, have stated that the current deterrence requirements are met with existing weapons systems capabilities. They have made clear that there is no military requirement for new warheads or new military capabilities—*and equally clear that they and their successors would be obligated to state if they believed such a requirement arises in the future*.[4]

Bottom line: Notwithstanding the fact that programmatic goals for nuclear capabilities have from time to time been scaled back to conform to fiscal limits and extant congressional support, the long-term goal of a healthy nuclear weapon development and production posture has been supported—explicitly or implicitly—by the current and previous two administrations. Over the past two decades, however, U.S. capabilities to design, develop, and field modern nuclear warheads have not been exercised and, as a result, have deteriorated.

Numerous Studies over the Past Two Decades Cite the Need for Improved U.S. Readiness Capabilities for Nuclear Weapons

Over the past two decades, many studies of the U.S. nuclear readiness posture confirm the atrophy of nuclear skills in the United States. These studies include assessments conducted by the bipartisan Strategic Posture Commission, other congressionally-mandated studies and commissions, the National Research Council, and the Defense Science Board. The consistency of the findings on capability limitations is striking and includes the following:

- Important NNSA nuclear warhead development skills are not being exercised;
- DoD nuclear expertise is declining;
- Improvement is needed in NNSA-DoD coordination and integration; and
- Nuclear warhead production facilities are outdated and inefficient; some are decrepit.

Studies and reports over the past 20 years also provide consistent recommendations to remediate this situation.

Limitations of the Current U.S. Nuclear Weapons Enterprise

The finding that significant limitations exist in the current nuclear readiness posture is reaffirmed by recent interviews with former senior officials who served in the DoD, NNSA, or at national laboratories. Specific limitations include:

- **No Comprehensive Approach Exists to Sustaining Nuclear Readiness**. The current approach to sustaining critical nuclear skills is piecemeal. A comprehensive approach to improving and sustaining a nuclear warhead readiness and response capability is needed.

- **Not All Critical Skills and Capabilities Are Being Exercised**. Currently, the approach for life-extending warheads calls for options to either *refurbish* existing warheads, to *reuse* nuclear components from warhead designs previously in the stockpile, or to *replace* warheads or the nuclear components with previously tested designs. However, most warhead life extension programs (LEPs) today are of limited scope—primarily *refurbishment* LEPs—which exercise only a limited set of critical skills for nuclear warhead development and production. One study called the current approach "unsustainable."

- **Lack of Balance between Computation and Experiments**. Currently, the nuclear warhead development community is overly dependent on computer simulation. As one designer has 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 computer codes break down and why. This over-dependence on computer simulation impedes the development of professional judgment that will be needed in the future when facing complex design challenges.

- **Infrastructure Modernization Delayed Repeatedly**. Modernization of critical nuclear facilities has been delayed. The U.S. nuclear infrastructure has not been fully operational for a quarter century. A September 2008 white paper signed jointly by Secretary of Defense Robert Gates and Secretary of Energy Samuel Bodman states, "...the United States is now the only nuclear weapon state party to the NPT that does not have the capability to produce a new nuclear warhead."[5] In its 2009 report, the bipartisan Strategic Posture Commission stated that some facilities are "genuinely decrepit" and much still remains to be done to put in place a modern nuclear weapon infrastructure to serve national security goals for the long term.[6] In addition, infrastructure modernization plans may not adequately address the need for reserve capacity to respond to unforeseen needs. Nearly all of the planned capacity to produce warheads over the next 25 years will be tied up with the life extension programs needed to sustain the existing stockpile. There is little, if any, margin left for unplanned tasks. As a result, the United States plans to maintain a larger stockpile of reserve warheads than desired in order to manage risk and provide options to respond to contingencies.

Recommendations to Improve the Readiness Posture of the Current Nuclear Enterprise

This report identifies several near-term actions that would help the United States to strengthen and maintain nuclear warhead development capabilities, including scientific and technical personnel, experimental capabilities, and manufacturing infrastructure needed to—if directed by the president—develop and field new or modified warheads.

A Bipartisan, Long-Term Commitment to a Resilient Nuclear Readiness Posture is Needed. Above all else, it is essential to restore a bipartisan consensus that supports maintaining a resilient nuclear weapons development and production capability, and routinely demonstrating that capability. Periodically communicating continued U.S. nuclear competency and the message that this is important to our nation is a critical component of deterrence and assurance. Bipartisan support in Congress and a dedicated partnership between the executive branch and Congress will be imperative to achieve this long-term goal.

Recommendation: Make explicit, as national policy, the national security goal of maintaining a resilient nuclear weapon development and production capability and exercising that capability periodically. This would demonstrate continued U.S. nuclear competency for both potential adversaries and allies. Bipartisan support in Congress will be imperative for this to succeed.

The People: Ensuring Weapons Design and Engineering Development Skills for the Long Term. It is fundamental in nuclear weapons work, as it is in other highly technical activities, that the skilled people—the scientists, designers, and engineers—will be unable to maintain critical capabilities absent opportunities to exercise them routinely on complex warhead design and development challenges. Over the past two decades, such opportunities have been few and far between.

At present, there are no military requirements for new warheads or for warheads with new military capabilities. How then can all critical skills be exercised? A more comprehensive approach is needed—one that exercises the entire design, development and manufacturing enterprise and advances a modern warhead design from initial concept through prototype development and flight testing to the point where one or a few are built, but not fielded.

In generating modern warhead designs, weapons scientists, working with their military counterparts, have traditionally conducted a Phase 1 warhead concept study leading to a Phase 2 feasibility and cost study. These are generally paper studies and, while important, do not fully exercise critical skills.

To maximize benefit for skill development, work must include at least parts of Phase 3 engineering development and Phase 4 production engineering associated with building and integrating actual hardware. The benefits of training young weapons scientists on innovative design problems would be compounded in value when the designer must iterate his/her work with systems engineers—in both NNSA and DoD—to weaponize a warhead design and with the production personnel who would actually have to build the prototype warhead.

One near-term action to more fully exercise skills involves restoring the original schedule for a LEP for one “common” warhead which would replace two aging warheads—one carried on intercontinental ballistic missiles, the other on submarine-launched ballistic missiles. (The proposed common-use warhead is referred to as the Interoperable Warhead-1 or IW1). Compared to other LEPs underway, the IW1 LEP presents a much more formidable design and development challenge for training a new generation of developers and would exercise a broader range of skills.

Recommendations: Actions that would help retain and advance needed skills and capabilities into the future for nuclear warhead design and engineering personnel include the following.

- Reverse the recent five-year delay to the IW1 LEP program in order to begin providing young weapons scientists and engineers a timely, important and complex design and development challenge.

- Accelerate activities, already underway, to certify, without nuclear testing, the safety and reliability of an older warhead primary that is modified with insensitive high explosives.

- Explore opportunities to introduce into future LEPs warhead features that facilitate ease of maintenance, enhanced surety, and certification without nuclear testing.

- Increase opportunities to train nuclear designers via the design and manufacture of a few prototype warheads, including warhead designs in ongoing programs to assess foreign nuclear weapon designs as called for in the 2015 National Defense Authorization Act (NDAA).[7] Here, a modern warhead design would be taken from initial concept and paper studies through prototype development and flight testing. One or a few would be built, but not fielded.

- As part of nuclear counterterrorism efforts, increase opportunities for young designers to explore potential improvised nuclear device designs and means to render them safe.

- Fund a small program to enable designers to spend part of their time in "blue sky" thinking about what might be achievable in nuclear weapon technology. To help motivate innovation, this should be competitive in nature and challenge young designers and engineers at the two U.S. nuclear design laboratories to propose creative concepts.

Increase Use of Experiments with Advanced Diagnostics to Complement Computer Simulation. The challenge of training weapons designers and engineers has evolved due to the absence of nuclear testing and availability of new, extraordinarily powerful computing capabilities. More so than their predecessors, young designers rely more heavily on computer simulation, modeling, and calculations and tend toward overconfidence in the quality of the weapon physics embedded in the codes. One senior designer noted that "the codes always lie" and the job of the designer is to figure out where they can be wrong and when. A more balanced Stockpile Stewardship Program would include computer simulations and modeling backed up by a more comprehensive experimental program. The weapon physics models in the computer codes would be compared to experimental results in various warhead design configurations.

Indeed, the United States has developed modern experimental facilities with advanced diagnostics to conduct experiments that not only greatly advance the state of our knowledge about weapons physics and chemistry but can be used to test designer judgment as well. However, other priorities and, to a lesser extent, funding shortfalls have prevented young scientists from fully exploiting these facilities to conduct experiments to test their calculations. These facilities are not being fully utilized.

Recommendations: Actions to expand the use of experimental programs for training a new generation of stockpile stewards include the following.

- More fully utilize existing experimental facilities. Given that tight budgets are a fact of life, seek "more bang for the experimental buck" by: (1) assigning a higher priority to experiments; (2) operating more efficiently by reducing bureaucratic overhead and micromanagement that increases costs; and (3) *managing safety risks* rather than fruitlessly (and at high cost) seeking to eliminate them.

- Provide young weapon designers at Los Alamos National Laboratory more opportunities to exploit experiments at high energy density facilities in their training and later warhead design work. (Note: Such facilities are not located at Los Alamos.)

- Challenge young designers with "out of the stockpile box" problems and the opportunity for innovative experiments to test judgment. Challenge young weapons scientists to brief their predictions—perhaps in a lab-to-lab competitive environment—on the expected results of experiments before they are carried out. This so-called "pre-mortem" process would offer the potential for failure and, thus, would be valuable for building judgment.

Accelerate Infrastructure Modernization. A functioning and responsive nuclear warhead manufacturing infrastructure is essential to any plausible strategy to respond to unforeseen contingencies and is also an important component of efforts to train the next generation of warhead development personnel. The infrastructure problem (along with the deterioration of skills) has existed for more than two decades. This is not a problem caused solely by this administration or this Congress, but also by administrations and congresses before them.

The aging, inefficient infrastructure has caused stockpile LEPs to be more expensive and to take longer than would have been otherwise possible. For example, the W87 LEP, carried out in the late 1990's and early 2000's, was more expensive and took 15 years—much longer than anticipated—because of the need to restore capabilities for warhead secondary work at the Y-12 plant in Oak Ridge, Tennessee. Also, difficulty in restoring a lost capability to produce a special material called Fogbank delayed completion of the W76-1 LEP by several years.

Recommendations: Steps for modernizing the physical infrastructure are straightforward.

- Accelerate efforts to provide a capability to produce plutonium pits at a capacity of 50-80 pits per year at Los Alamos, New Mexico.

- Implement the revised approach identified by NNSA's Red Team[8] to restore safe and environmentally sound highly-enriched uranium component manufacturing capabilities at the Y-12 plant in Oak Ridge, Tennessee.

What follows is an unclassified assessment of the existing U.S. nuclear warhead development readiness posture. In brief, this assessment identifies some serious shortfalls in readiness to design, develop, and produce nuclear warheads, presents near-term actions for remediation, and provides a foundation for follow-on work.

Introduction

This report provides an assessment of the U.S. readiness posture to be able to design, develop, and produce new nuclear warheads or warheads with new military capabilities. Such a readiness posture is important to reduce risk over the long term for the United States and its allies. This report does not advocate any specific new nuclear capability. The focus is on a *readiness capability* and the steps needed to remediate a critical element of the U.S. security posture that, over the past two decades, has been documented repeatedly as being deficient. A healthy nuclear readiness capability would enable the United States to respond to a reliability failure in a nuclear warhead or weapon system type, to an emerging vulnerability as the result of new adversary capabilities, or to presidential direction calling for an increase in the U.S. inventory of weapons.

The first part of this report deals primarily with policy-related issues relevant to nuclear readiness capabilities. The report discusses the importance of maintaining the readiness of nuclear development capabilities and the relevant nuclear weapon policies of the three most recent post-Cold War administrations. In addition, the policy-oriented section of this report summarizes the findings relevant to this topic from numerous studies of security issues over the past two decades. The findings and recommendations from these studies are striking in the consistency of conclusions calling for an improved nuclear readiness posture and the need to exercise routinely the full range of critical nuclear design and development skills. Moreover, the review of studies highlights that insufficient priority devoted to this need have led to the atrophy of critical skills.

The second part of this report focuses primarily on technical issues. It characterizes the current state of readiness to design, develop, and produce new nuclear warhead capabilities, identifies current shortcomings in capability, and provides recommendations to improve the U.S. nuclear development readiness posture. In particular, corrective action is needed to improve and sustain the intellectual capital that supports nuclear warhead design and development as well as the manufacturing infrastructure that would be necessary for the United States to respond in a timely manner to changing security needs.

This report is intended for those who currently have, or in the future will have, responsibility for setting goals, priorities, and funding levels for U.S. nuclear capabilities. This includes current and future officials in the Department of Defense (DoD), National Nuclear Security Administration (NNSA), and Congress.

The Importance of Sustaining a Nuclear Weapon Development Capability

With multiple and diverse security challenges for the United States and its allies, DoD officials have recently expressed alarm at the narrowing U.S. margin of technological superiority in military capabilities vis-à-vis potential adversaries. For example, in November 2014, then-Secretary of Defense Chuck Hagel announced a Defense Innovation Initiative. In his implementation directive, Hagel stated, "We are entering an era where American dominance in key warfighting domains is eroding, and we must find new and creative ways to sustain, and in some cases expand, our advantages."[9] Similarly, in February 2015, Deputy Secretary of Defense Robert Work announced to an audience at a U.S. Naval Institute seminar that U.S. military "technology superiority is eroding."[10] And, in March 2015, Secretary of Defense Ashton Carter testified before Congress on the DoD budget for Fiscal Year 2016. Carter warned,

> Today that [U.S.] superiority is being challenged in unprecedented ways. ... Russia, China, Iran, and North Korea ... have been pursuing long-term, comprehensive military modernization programs to close the technology gap that has long existed between them and the United States. These modernization programs are developing and fielding advanced aircraft, submarines, and both longer-range and more accurate ballistic and cruise missiles. ... In some areas, we see levels of new weapons development that we haven't seen since the mid-1980s, near the peak of the Soviet Union's surge in Cold War defense spending.[11]

Arguably, a military capability sector that clearly demonstrates a shrinking U.S. margin of superiority is that of nuclear weapons—the NNSA capabilities to develop and produce nuclear warheads and the DoD-developed delivery systems that carry those warheads. In a written statement submitted for its March 2015 testimony to Congress, the members of the Nuclear Weapons Council warned, "Limited opportunities exist to exercise the full range of weapon design and production skills, including materials handling, code development, and design and engineering. Exacerbated by an aging workforce, the pressure and risk to sustain critical skills is increasing." They stressed the challenge of sustaining a skilled nuclear workforce for the indefinite future.[12]

When the Cold War-era ended a quarter-century ago, the United States was by far the most technologically-advanced nuclear power in the world. However, over the past two decades, U.S. nuclear development skills and capabilities have atrophied, primarily as the result of inactivity. Over that timeframe, the United States had not exercised the skills and capabilities to design, develop, and produce nuclear warheads, and the physical infrastructure for manufacturing nuclear warhead components has undergone a lengthy, drawn-out reconfiguration process. After over two decades of reconfiguration and modernization, the completion of this process is not yet in sight, and the physical infrastructure is not fully functional. In fact, in 2008, Secretary of Defense Robert Gates and Secretary of Energy Samuel Bodman reported to Congress that, "the United States does <u>not</u> have the ability to produce new nuclear weapons."[13]

According to numerous reports, Russia and China, two nuclear-armed competitors of the United States and its allies, reportedly have continued to develop and produce new types of nuclear warheads and have maintained fully operational industrial capabilities for the development and production of nuclear warheads.[14] These developments have caused U.S. defense commentators, as well as key allies, to question whether the United States is still "second to none" regarding its nuclear capabilities to deter adversaries and assure allies.[15]

Maintaining a readiness capability to develop replacements for existing nuclear weapons and, if required, new nuclear capabilities is fundamentally about reducing risk in the future. Indeed, the 2009 report of the bipartisan Strategic Posture Commission cited the "unpredictable nature of the security environment" as one of three emerging challenges for the United States. Of significant concern was the "profound uncertainty about the future international roles of Russia and China" as well as uncertainty about the future roles of various "rising powers." The Commission concluded that the United States needs "to hedge against the possibility that ... these factors might not turn out for the best and that new challenges for the U.S. nuclear strategy might emerge and, indeed, suddenly so."[16]

Although the United States is embarking on an intensive program to modernize nuclear delivery platforms and associated command and control, today's nuclear stockpile is essentially composed of warheads left over from the Cold War. Indeed, today's stockpile is probably not what the United States would have fielded if U.S. leaders had envisioned the cessation of nuclear testing in the early 1990s or today's more complex security environment. No other important U.S. military capability has been "frozen" for over two decades and not been adapted to the emerging security environment. For the United States, an improved nuclear readiness posture would provide benefits which include demonstrating nuclear competence to help strengthen the credibility of the U.S. nuclear force for deterrence and assurance, providing adaptability and resilience for an uncertain future, and reducing the total size of the stockpile.

Credibility of Deterrence and Assurance. A nuclear readiness capability can enhance the credibility of the U.S. nuclear deterrent in the face of adverse trends, including the deterioration of relations with Russia or China, arms control violations, an arms buildup by a hostile power, improvements in opposing offensive or defensive capabilities, and defects in warhead types. Sustaining a healthy nuclear design and development capability would provide tangible evidence that U.S. leaders place high value on the nuclear deterrent, thereby increasing the credibility of U.S. nuclear declaratory policy. Improving the credibility of the U.S. deterrent also supports extended deterrence, which is closely related to, if distinct from, the assurance of allies. A nuclear weapons enterprise of the first rank is important for the leadership role the United States plays in its alliances and other security arrangements in Europe, Asia, and the Middle East. In short, a healthy nuclear readiness capability would increase the credibility of the U.S. nuclear posture to support important U.S. policy goals—the deterrence of adversaries and assurance of allies.

Adaptability and Resilience.[17] Given the potential dangers and uncertainties of the future, constraints on budgets, and lengthy time needed to develop new military capabilities, the DoD has stressed the importance of innovation and adaptability for its general purpose military capabilities. In August 2014, Under Secretary of Defense for Acquisition, Technology, and Logistics Frank Kendall told an audience, "We've become complacent. ... Our technological superiority is very much at risk, there are people designing systems [specifically] to defeat us in a very thoughtful and strategic way, and we've got to wake up."[18] Adaptability and resilience should also be among the design criteria for the twenty first-century nuclear posture of the United States. In order to provide adaptability and resilience for the nuclear force, the modernization of infrastructure facilities must be completed and capabilities to design, develop, and field new nuclear warheads need to be exercised routinely.

Reduced Stockpile Size*.* A fully functioning and responsive nuclear infrastructure would enable the United States to reduce the overall size of the nuclear stockpile. Instead of relying on a significant inventory of non-deployed warheads to manage risk and hedge against reliability problems, U.S. leaders would rely on the infrastructure and skilled workforce to be able to diagnose and fix warhead problems quickly or respond to new security challenges. The goal of relying more on a revitalized nuclear infrastructure instead of a large non-deployed stockpile has been endorsed by the three most recent administrations.

In summary, improving the readiness of U.S. nuclear warhead development capabilities would increase the credibility of the nuclear force in support of deterrence and assurance, help provide adaptability and resilience for the nuclear force to respond to future challenges, and facilitate a reduction in the total size of the nuclear stockpile. A healthy warhead design and development capability would enable the United States to respond to a reliability failure in a nuclear warhead or weapon system type, to an emerging vulnerability as the result of new adversary capabilities, or to presidential direction calling for an increase in the U.S. inventory of weapons.

U.S. Post-Cold War Nuclear Weapon Policies and Readiness Posture

It is important to understand the nuclear weapon policies of the Clinton, Bush, and Obama administrations as these policies relate to a readiness posture for the development of nuclear warheads. The policies of the Clinton and Bush administrations were outwardly similar and both stated publicly the goal of maintaining a national capability to develop new nuclear weapons, if needed. The Obama administration, more so than the previous two, has advocated policies intended to reduce the role of nuclear weapons while, at the same time, maintaining high reliability and enhancing the safety and security of nuclear warheads. Sustaining nuclear development capabilities was an *explicit* goal for the Clinton and Bush administrations, but has been *implicit* for the Obama administration. Whether sustainment of nuclear development capabilities has been an explicit or implicit goal, the trend over the past three administrations has been a continuing decline in U.S. nuclear weapon design, engineering, and production capabilities. Summarized below is a discussion of lessons learned from an effort, early in the post-Cold War environment, to constrain certain nuclear development activities and the unintended consequences resulting from that policy.

Clinton Administration (1993-2001). In the early-to-mid 1990s, with the Soviet Union broken into its constituent republics and the Russian economy and military only shadows of what they had been, the Clinton administration turned its attention to nuclear arms control and nuclear reductions. In 1994, the Clinton administration's Defense Department, at its own initiative, conducted an internal review of the U.S. nuclear posture. This Nuclear Posture Review (NPR) was intended to provide guidelines and some initial steps to transition the U.S. nuclear force from its Cold War size, composition, and posture to a force more appropriate for the emerging security environment. The review provided the rationale for a "lead but hedge" strategy and followed through on decisions of the George H. W. Bush administration to retire many types of nuclear weapons, especially weapons designated as nonstrategic—those weapons with delivery systems with less than intercontinental range. However, even in the generally benign security environment of the early-to-mid 1990s, the DoD-led NPR required the Department of Energy (DOE) to "[m]aintain capability to design, fabricate, and certify new warheads" and to "[d]emonstrate capability to refabricate and certify weapons types in [the] enduring stockpile."[19] This was to provide a "hedge" to protect against "a return to an authoritarian regime in Russia hostile to the United States."[20]

In February 1997, the Clinton administration's Under Secretary of Defense for Policy, Walter Slocombe, testified on "The Future of Nuclear Deterrence" before a Senate subcommittee. Slocombe's unclassified testimony provides a comprehensive articulation of the Clinton administration's integrated policies for arms control, nuclear nonproliferation initiatives, and nuclear force employment and posture issues. When asked about the administration's policy regarding development of new types of nuclear weapons, Slocombe replied,

> To be clear, we maintain the capacity to design new weapons. We do some design of potential backups and replacements. Under current circumstances, we do not foresee a

> requirement to design new weapons from the ground up, but we will retain that capacity, the capacity to do so.[21]

In the late 1990s, the Clinton administration initiated modifications to the nuclear stockpile. A nuclear gravity bomb, the B61 Mod 7, was repackaged in a hardened case for use as an earth-penetrating weapon (EPW). The modified weapon was given the new designation, B61 Mod 11. This modification was to be a near-term, interim solution to respond to reports that potential adversaries, such as Russia, North Korea, and China, were locating command centers, weapons, and other high-value assets in hardened and buried facilities. The Clinton administration continued DoD-led follow-on studies on concepts for more effective nuclear weapons for the long term, including an improved nuclear EPW which, during the Bush administration, was later referred to as the Robust Nuclear Earth Penetrator (RNEP).[22]

Bush Administration (2001-2009). At the onset of the Bush administration, Secretary of Defense Donald Rumsfeld pursued "defense transformation" to restructure DoD capabilities for the new century. The first capabilities to be examined were those deemed to be "strategic." The findings of this assessment were reported in the 2001 Nuclear Posture Review Report to Congress. This NPR broadened the scope of strategic capabilities beyond just nuclear, to include offensive strike capabilities (both nuclear and conventional), strategic defenses, and a responsive defense-industrial infrastructure. These capabilities were referred to as the "New Triad." Much of the strategy behind this new approach was to reduce risk to the United States and its allies and to support U.S. defense policy goals, including deterrence and assurance. In February 2002, the Under Secretary of Defense for Policy, Douglas Feith, testified on the sweeping policy changes regarding U.S. nuclear forces and said that the new policies approved by the president included preserving "the flexibility and capability for reconstitution necessary to adapt to any adverse changes in the new security environment. "[23] This reconstitution capability or hedge was intended as "insurance against the re-emergence of a hostile peer competitor."[24]

During the deliberations of the 2001 NPR, one working group focused on the need to sustain critical nuclear skills in the DoD and the NNSA. Concern about the deterioration of skills and the need to sustain skills and expert judgment within the nuclear development community led to the recommendation for an Advanced Concepts Initiative (ACI). The ACI was a small program (approximately $15 million per year) to exercise, and thereby strengthen, nuclear design skills at the national laboratories by providing design teams with opportunities to explore and assess innovative nuclear weapon concepts.

At the February 2002 congressional hearing on the new NPR, NNSA Administrator, General John Gordon testified on the continuing need for a responsive infrastructure and skilled personnel. Gordon stated,

> Perhaps more so than in any previous defense review, this concept of a New Triad reflects a broad recognition of the importance of a robust and responsive defense R&D [research and development] and industrial base in achieving our overall defense strategy. The ability of our modern defense industrial base to bring advanced defense technology rapidly to the field is well respected internationally among both friend and foe.
>
> ... If the U.S. is to have a flexible deterrent, it must be able to adapt its nuclear forces to changing strategic conditions. Adaptation and modernization of forces, including

> implementation of new technologies, will enable us to continue to achieve deterrence objectives more efficiently even as we move to significantly lower force levels. Our goal is to maintain sufficient R&D and production capability to be able to design, develop, and begin production on the order of five years from a decision to enter full-scale development of a new warhead. To achieve this goal, we must work with DoD to determine and prioritize potential weapons needs over the long term. In certain cases, it may be appropriate to design, develop and produce a small build of prototype weapons both to exercise key capabilities and to serve as a "hedge," to be produced in quantity when deemed necessary.[25]

During the Bush administration, DoD proposed to carry forward the development of RNEP to provide earth-penetrating capabilities originally envisioned for the B61-11, and to explore a modern replacement warhead referred to as the Reliable Replacement Warhead (RRW). The RRW program was intended to explore a promising approach to develop replacement warheads with military capabilities comparable to the warheads in the existing stockpile. RRW-type warheads would replace more complex Cold War-era warheads, while also enhancing warhead safety, security, reliability, and manufacturability.[26]

After the 9-11 attacks, the attention of senior DoD leaders was devoted primarily to combating terrorism; many aspects of the nuclear agenda and related interactions with Congress were not given adequate attention. Although largely unjustified, the perception existed among some members of Congress and the public that the Bush administration was pursuing an aggressive program to develop and field new warheads, including warheads with new military capabilities. Poor communications and, in some cases, distrust between DoD leaders and congressional committees on the intent and need for the ACI and RNEP led to the cancellation of both. The funding from ACI was transferred to start up the RRW program which, for a short period of time, received reasonable congressional support. Among the reasons RNEP did not gain congressional support was DoD's failure to communicate effectively how this system would strengthen deterrence and assurance as well as the strong opposition from a powerful member of an appropriations committee.[27]

Eventually, the RRW program was also terminated by Congress. As DoD and NNSA enthusiasm for the RRW program grew, a few members of Congress apparently became concerned that the program was moving too fast and that the initial goal to demonstrate the capability to develop one RRW system was expanding prematurely to transition the entire stockpile to RRWs. Funding for RRW was denied by the Energy and Water Appropriations Committees during the last two years of the Bush administration. In response, in September 2008, Secretary of Defense Robert Gates and Secretary of Energy Samuel Bodman sent a joint report to Congress stating the case for the RRW and asking that funding for this program be provided.[28] In the executive summary of this report, the two cabinet secretaries state,

> While the service lives of existing warhead types are being extended through refurbishment, at present the United States does <u>not</u> have the ability to produce new nuclear weapons . . . We seek replacement of existing warheads with Reliable Replacement Warheads (RRW) of comparable capability that would have advanced safety and security features, be less sensitive to manufacturing tolerances or to aging of materials, and be certifiable without nuclear testing.[29]

Even so, the Bush administration left office without restoration of RRW funds, and the Obama administration did not seek to restart the program.

For both the Clinton and Bush administrations, maintaining the ability to design and produce new types of nuclear weapons, if needed, was an *explicit* requirement and this requirement was stated publicly multiple times. For both, the motivation was to manage risk over the long term and hedge against the uncertainties of the future. However, the goal of restoring a competent and resilient nuclear readiness posture for the United States remained an unfulfilled goal.

Obama Administration (2009-Present). During Barack Obama's presidential campaign and in the very early stages of his first term, there were questions about his commitment to the nuclear deterrence mission. As a candidate for president, then-Senator Obama campaigned to stop the development of new types of nuclear weapons and, specifically, to shut down the development of the RRW. On the first day of the new administration in January 2009, the White House web site listed the new president's objectives for various agendas including to "stop development of new nuclear weapons." This was listed under the Foreign Policy objective, "Move Toward a Nuclear Free World."[30] One reporter noted that, this prohibition was stated, "with no equivocation, asterisks or caveats."[31]

Just a month into the new administration, the Obama administration unveiled its budget proposal for the coming year. This proposed budget did not add funds for RRW (making good on the president's campaign promise). Of course, the new administration was just gearing up to conduct its own review of nuclear policy and there was much confusion over the scope and objectives of the RRW program, despite the fact that Robert Gates, a strong supporter of RRW, was asked to stay on as Secretary of Defense.

In early April 2009, only three months after taking office, President Obama gave a speech in Prague that: (1) laid out his long-term vision for a nuclear-free world; and (2) stated his commitment, until no longer needed for U.S. national security, to take needed steps to ensure that the U.S. nuclear stockpile remained safe, secure and effective.[32] The Obama administration's Nuclear Posture Review (NPR), issued in April 2010, placed highest priority on preventing nuclear proliferation and nuclear terrorism and on reducing the role of U.S. nuclear weapons in U.S. national security strategy. That same review affirmed a commitment to the sustainment and modernization of U.S. nuclear forces.[33] At the same time, the 2010 NPR included general policy constraints regarding warhead life extension programs (LEPs) and "new" nuclear warheads.

2010 Nuclear Posture Review: "Replacement LEPs." In the 2010 NPR report to Congress, the Obama administration stated that its priorities for the nuclear force would be on modernization and warhead life extension programs. The new NPR articulated the president's strategy for warhead life extension:

> The U.S. will study options for ensuring the safety, security, and reliability of nuclear warheads on a case-by-case basis, consistent with the congressionally-mandated Stockpile Management Program. The full range of LEP approaches will be considered: refurbishment of existing weapons, reuse of nuclear components from different warheads, and replacement of nuclear components.

And,

> In any decision to proceed to engineering development for warhead LEPs, the United States will give strong preference to options for refurbishment or reuse. Replacement of nuclear components would be undertaken only if critical Stockpile Management Program goals could not otherwise be met, and if specifically authorized by the President and approved by Congress.[34]

This direction to the nuclear weapons laboratories was further elaborated in the administration's May 2010 Section 1251 Report to Congress and in the Fiscal Year 2011 Stockpile Stewardship and Management Plan:

> The Laboratory Directors will ensure that the full range of LEP approaches, including refurbishment, reuse, and replacement of nuclear components are studied for warheads on a case-by-case basis. While the NPR expresses a policy preference for refurbishment and reuse in decisions to proceed from study to engineering development, the Laboratory Directors will be expected to provide findings associated with the full range of LEP approaches, and to make a set of recommendations based solely on their best technical assessment of the ability of each LEP to meet critical stockpile management goals (increased warhead safety, security, and reliability).[35]

Thus, the national labs were to consider three possible approaches—warhead refurbishment, component reuse, and warhead replacement—in their concept and feasibility studies for warhead life extension, and laboratory directors were to make their recommendations solely on the technical merits of each option. The government, however, would give policy preference to warhead refurbishment and reuse as opposed to the more ambitious option—replacement. As will be discussed later, replacement LEPs provide weapon designers and engineers with unique opportunities to exercise, and thereby sustain, certain critical skills. The president's decision begs an important question: Why apply such an additional policy hurdle to replacement LEPs? In answering this question, one must first understand the context.

There was misunderstanding, even among some in the Obama administration, that a replacement LEP approach was RRW by another name and would necessarily involve new nuclear component designs or could lead to new military capabilities. Such views were apparently held by some who believed that "new" warhead development would have a negative impact on the president's nonproliferation agenda. Unfortunately, as is often the case in Washington, misperceptions and misunderstandings can morph into a false reality. More importantly, the debate over "new" and "replacement" diverted attention from the urgent need to extend the service lives of warheads in the existing stockpile and modernize NNSA's degraded infrastructure. This was the critical problem that confronted the Obama administration when it took office.

In engaging this issue in the 2010 NPR, some in the administration argued against singling out the warhead replacement option for special review because it would certainly impose an additional policy hurdle and would also discourage exploratory work on concepts that could provide potential benefits for the future. However, a renewed emphasis on nonproliferation and nuclear reductions was a critical part of the president's national security agenda. The administration decided to respond to the concerns of the nonproliferation community by ensuring that the president's personal attention was given to any decision to proceed with an LEP which involved the replacement of nuclear components.

2010 Nuclear Posture Review: "New Warheads." During the 2010 NPR deliberation process, the administration also studied whether new warheads or warheads with new military capabilities were needed in light of the existing security environment and that expected over the next decade. According to administration officials, the views of the Commander of Strategic Command were sought on this specific question and it was his judgment that nuclear deterrence would be sufficient for the current environment with the existing stockpile, and with existing military capabilities, so long as the LEPs and infrastructure modernization programs were kept on track.[36] His response reflected a near-term priority to ensure that the current stockpile remained safe, secure and effective, coupled with the recognition that, whether or not new capabilities were desired, the intensive LEP effort would have to be carried out with a severely degraded manufacturing infrastructure and would not provide much excess capacity over the next two decades to field new designs. In part, based on the Commander's judgment, the 2010 NPR directed that,

> The U.S. will not develop new nuclear warheads. Life Extension Programs will use only nuclear components based on previously tested designs, and will not support new military missions or provide for new military capabilities.[37]

The decision to forgo, in principle, fielding new warheads and warheads with new military capabilities is noteworthy because it is one that separates Obama's policy from those of his two predecessors. To be clear, however, it was not a decision to forgo such warheads for all time or forgo maintenance of the capabilities to develop and field them, if required, in the future. In the 6 April 2010 NPR rollout briefing, Gen. James Cartwright, the Vice Chairman of the Joint Chiefs, was asked to clarify the administration's views on nuclear testing and "new" warheads:

> . . . nobody has ever removed from the commander or anyone else in that chain the ability to stand up and say, 'I'm uncomfortable; I believe that we're going to have to test, or I believe that we're going to have to build something new.' That's not been removed here. What has been done, though, is to say, in the realities of what we know today, we see no requirement for any additional testing . . . and we see no need for additional nuclear weapons of a new type, either in capability or in capacity. So this is a reflection of where we are now, looking forward.[38]

This conclusion is reinforced in the 24 May 2010 letter from Vice President Joseph Biden to Senators Jon Kyl and Joseph Lieberman in which Biden states:

> Admiral [Michael] Mullen [Chairman of the Joint Chiefs of Staff] and General Kevin Chilton, Commander, U.S. Strategic Command, have stated that the current deterrence requirements are met with existing weapons systems capabilities. They have made clear that there is no military requirement for new warheads or new military capabilities—*and equally clear that they and their successors would be obligated to state if they believed such a requirement arises in the future*.[39]

To preserve this option, therefore, the nuclear weapons enterprise must maintain personnel and infrastructure with capabilities to design, develop and field new warheads or to provide existing warheads with new military capabilities, if the president so directs. This has been the policy not only of the Obama administration but of the two administrations preceding it. How successful they have all been in implementation is another matter to be addressed shortly.

The 2010 NPR decisions on "replacement LEPs" and "new" warheads were controversial even within the Obama administration. On reflection, however, the 2010 NPR and administration policies helped to advance, at least for a while, a relatively broad consensus across the political spectrum in support of the president's nuclear modernization program and warhead life extension programs that emphasized limited changes based on warhead refurbishment and component reuse. Arguably, this consensus was achieved in part by how these two issues were dealt with in the administration's NPR report to Congress, helping to garner support in Congress for authorizations and appropriations for stockpile and infrastructure modernization.

Upload Hedge. President Obama's policy on the so-called "upload hedge" was clarified in a follow-on study to the NPR and documented in the president's unclassified Nuclear Weapons Employment Policy issued in June 2013.[40] Specifically, the United States will maintain additional warheads in the nuclear stockpile, and the ability to upload those warheads on existing delivery systems to: (1) restore existing force levels in the event of a technical problem with a warhead or delivery system; or (2) field a larger deployed force, if required, in the event of a geopolitical reversal. The Obama hedge approach was a slightly modified version of the Bush upload strategy—the goal was to provide an adequate hedge, but with fewer total warheads. This hedge strategy was intended to provide response options against "a change in the international landscape" or "a geopolitical surprise" that would "alter the U.S. calculus about the necessary composition of the deployed force."[41]

Of course, the preference, reflected in the 2010 NPR, as well as in previous NPRs, is to be able to "hedge" with a modern, responsive nuclear weapons infrastructure that can repair or manufacture warheads in a timely way in response to unplanned contingencies. But that infrastructure does not yet exist, and will not exist for more than a decade. In the interim, the United States will need to maintain additional reserve warheads in the stockpile.

Lessons from an Effort to Constrain Nuclear Weapon Development Capabilities. Past experience has demonstrated that *even the perception* of a policy against the design and production of nuclear weapons can undercut the pertinent creativity, skills and innovation at the U.S. nuclear weapons design laboratories. Since the end of the Cold War, arms control advocacy groups and some factions in Congress have tried to curtail the development of certain types of nuclear weapons. One past example illustrates the harmful effects from such actions. The National Defense Authorization Act (NDAA) for Fiscal Year (FY) 1994 included a provision (Section 3136) that prohibited the Secretary of Energy from conducting or providing for the conduct of "research and development which could lead to the production by the United States of a new low-yield nuclear weapon, including a precision low-yield warhead."[42] This became known as the "PLYWD (precision low-yield warhead development) law." Enactment of this law resulted in a dilemma for nuclear designers and engineers at the national laboratories. How were they to carry out their responsibilities to understand potential nuclear developments for the United States and assess what capabilities were under development by adversaries without breaking this law? Many seemingly benign areas of research and engineering could reasonably be interpreted as "leading to" the production of precision, low-yield warheads. A 2004 report to Congress submitted jointly by the Secretaries of State, Defense, and Energy described the harmful effects resulting from this law.

> [This prohibition] has had a "chilling effect" on advanced concepts work. It has impeded our scientists and engineers from exploring the full range of technical options. It did not simply prohibit research on new, low-yield warheads, but prohibited activities "which could lead to production by the United States" of such a warhead. The fact is that most nuclear weapons research could be characterized as fitting that criterion. The result has been, quite literally, that our design teams have had to check with lawyers before starting computer calculations exploring certain concepts ... simply because such calculations "*could lead to*" production of lower-yield systems.[43]

Furthermore, the 2004 report stated that continuing to examine advanced nuclear concepts is important to our ability to "understand possible military applications of atomic energy before anyone else does."[44] In 2004, after a decade of confusion at the national laboratories over how to comply with this law while sustaining the nuclear stockpile, Congress repealed the PLYWD law. Part of the rationale for repeal was the damaging effect on research at the nuclear weapon laboratories and the observation, "to our knowledge, no other nuclear weapons possessing state has imposed upon itself a comparable restriction on basic exploratory research on nuclear weapons."[45]

Linkage between U.S. Nuclear Weapon Development Capabilities and Nuclear Nonproliferation Goals. In considering the Bush administration's request to repeal the PLYWD law, some in Congress expressed concern that some U.S. nuclear weapon development activities could be at odds with nuclear nonproliferation objectives. Therefore, the legislation repealing the PLYWD law[46] required the administration to submit a report to Congress on the impact of repeal on the ability of the United States to achieve its nuclear nonproliferation objectives. In response, the administration's 2004 report to Congress briefly addressed the rationale for repeal and stated that maintaining and periodically exercising a nuclear development capability will not, in itself, stimulate nuclear proliferation; nor will U.S. restraint and nuclear reductions ensure that others follow our lead. Indeed, over the past quarter century the United States has not developed any new type of nuclear warhead and has reduced its stockpile of nuclear warheads by over eighty percent.[47] Yet, over this same period, nuclear warhead and weapon development has continued, and in some cases even accelerated, in Russia, China, North Korea, Pakistan, India, and presumably, Iran. In the 2004 report the three secretaries stated:

> … the Administration does not expect that repeal of PLYWD, in itself, would have any effect on vertical proliferation among nuclear weapon possessing states. First, no such state other than the U.S. has a self-imposed restraint on nuclear weapon exploratory research. Russia, for example, has a very active (and unrestrained) exploratory nuclear research program that has accelerated over the past several years. The repeal of PLYWD by the U.S. literally cannot motivate others to remove similar restraints because no other state has a comparable restraint. Second, even if the repeal of PLYWD led to concepts that the Administration would seek to develop and field, and for which the Congress would authorize and appropriate funds, any presumed nonproliferation implications would depend on the specific nature of the concept under consideration.[48]

Summary Findings from U.S. Nuclear Weapon Policies in the Post-Cold War Era. Each presidential administration has sought to distinguish its nuclear weapon policies from its predecessors. The Clinton administration initiated steps to transform the nuclear force and infrastructure from its Cold War footing. The Bush administration developed an approach for strategic forces and nuclear force sizing that better fit twenty-first century policy goals than the Cold War-era approach based mainly on targeting goals. The Obama administration's two-track approach elevated the priority of nuclear nonproliferation and sought broad support for near-term steps on a long-term goal of nuclear elimination. At the same time, with bipartisan support, the Obama administration advanced essential programs to sustain and modernize nuclear forces.

Notwithstanding the fact that programmatic goals for nuclear capabilities have from time to time been scaled back to conform to fiscal limits and extant congressional support, the long-term goal of a healthy nuclear weapon development and production posture has been supported—explicitly or implicitly—by the current and previous two administrations. The administrations of President Clinton and President Bush agreed on the *explicit* policy of maintaining the ability to design and produce new nuclear warheads and weapons, independent of the need for new capabilities at the time. Both administrations stated this requirement periodically and reflected this priority in their programmatic initiatives. However, both administrations achieved only limited success in garnering the necessary support from Congress. For the Obama administration, the primary emphasis has been on maintaining the nuclear stockpile with life extension programs of limited scope while modernizing the aging infrastructure. At the same time, the intent to sustain a development capability for new warheads is *implicit* in the maintenance of a Stockpile Stewardship and Management Program.

Since the end of the Cold War, presidential administrations have supported goals to modernize the nuclear infrastructure and sustain key nuclear weapon skills. Maintaining such a capability has been characterized by all three administrations as a "hedge" against future uncertainties and preferable to maintaining a large number of non-deployed warheads in the stockpile. As discussed later, this goal remains unfulfilled and lacks a bipartisan approach for a sustained, long-term plan to redress existing shortfalls.

Numerous Studies Over the Past Two Decades Cite the Need for and Shortcomings of U.S. Nuclear Weapon Readiness Capabilities

Over the past two decades, myriad studies and reports have documented persistent concerns over the deterioration of U.S. nuclear weapon development capabilities and the need for a more resilient U.S nuclear capability. Consistent recommendations to remediate the situation include:

- Revitalizing the intellectual infrastructure by instituting programs that provide the necessary training and development of technical skills and judgment for future generations of nuclear weapon and warhead scientists, designers, engineers, and production specialists;

- Exercising warhead-to-weapon integration activities between NNSA and DoD regarding the development of nuclear weapon delivery systems; and

- Modernizing outdated, inefficient nuclear facilities.

Appendix A provides a bibliography of noteworthy studies and other documents from the past two decades that are relevant. Excerpts from key documents are quoted in Appendix B, with pertinent findings underlined for emphasis to illustrate the consistent identification of certain deficiencies and recommendations for remedial actions. Findings and recommendations relevant to U.S. nuclear readiness capabilities are discussed briefly below.

Revitalize the Intellectual Infrastructure. The intellectual nuclear infrastructure includes activities to develop and sustain critical skills, transfer skills and expert judgment to the next generation of NNSA and DoD personnel, and integrate NNSA and DoD capabilities into modern weapon systems. The Strategic Posture Commission concluded that the intellectual infrastructure is "in serious trouble—perhaps more so than the physical complex."[49] The decline in intellectual infrastructure skills includes those at NNSA/DOE laboratories and plants, in the DoD and its contractor base, and in NNSA/DoD integration activities.

NNSA/DOE Nuclear Warhead Development Skills are Not Being Exercised. One frequent conclusion from the studies examined has been the observation that, with infrequent nuclear warhead development activity, many critical nuclear skills are not being exercised. A 1999 report by a congressionally-mandated commission (the Chiles Commission) responded to tasking in the National Defense Authorization Acts of 1997 and 1998. This was the first comprehensive study to examine the challenges of sustaining DOE nuclear development skills in an environment without nuclear testing and with few new warhead/weapon development programs. Significant findings from this commission include the following:

- Concern exists over the "centrality of on-the-job training" and the "drastic change affecting knowledge transfer to the nuclear design groups" in an environment of few development activities and the absence of testing which can validate the results of computer simulations with experimental data.[50]

- "Throughout the nuclear weapon complex, there are positions which require years of training to master requisite skills and develop technical judgment. These positions range from nuclear weapon designer, to the machinist of materials unique to nuclear weapons, to the nuclear test engineer who supervises the emplacement of the nuclear explosive."[51]

- The difficulties of sustaining skills, transferring knowledge, and developing technical judgment will be exacerbated in the future due to further personnel retirements, turnover, and downsizing of the stockpile and infrastructure.[52]

- "Training the workforce and validating the effectiveness of training must be among the highest priorities of the nuclear weapon complex." In an environment of limited new development and production, the Commission recommended that "system and engineering design and skills be exercised to maintain competence and train new employees."[53]

The Chiles Commission report recommended 12 comprehensive actions to strengthen, track, and sustain nuclear development skills. Number one on the list of recommendations was to "reinforce the national commitment [to the nuclear mission] and fortify the sense of mission."[54]

However, from reviewing the assessments of U.S. nuclear capabilities since the 1999 Chiles Commission report, it is clear that the goal of halting and reversing the atrophy of nuclear development skills has not received sufficient priority. For example, in 2009, the director of a nuclear design laboratory reported: "Design capabilities at the laboratories have atrophied because most of the SSP [Stockpile Stewardship Program] work at the laboratories has focused on analysis of the existing stockpile instead of design."[55] And, a March 2012 study by the National Research Council (NRC) on Comprehensive Nuclear Test Ban Treaty issues stated, "Significant gaps in critical skills exist [in NNSA] due to a combination of workforce demographics and/or reduced level of stockpile work."[56]

DoD Nuclear Expertise is Declining. The lack of new nuclear development activities has reportedly also negatively affected nuclear skill sustainment in DoD. A 2001 DoD report concluded that DoD had been living "off the fat of the land of Cold War-experienced personnel."[57] The report also stated that the quality and quantity of nuclear expertise was viewed as being in a state of decline, and some expertise shortfalls already existed in certain areas, such as munitions and stockpile management, nuclear effects modeling, and safety and security.[58] A 2006 Defense Science Board (DSB) Task Force led by Dr. John Foster and Gen. Larry Welch, USAF (ret.), concluded: The current approach of life extending an aging stockpile of warheads "is not sustainable."[59]

And, a 2008 Defense Science Board report on nuclear deterrence skills concluded: "The task force is concerned that adequate nuclear deterrence competency will not be sustained to meet future challenges."[60] One reason for this pessimism was the lack of activity to maintain unique skills. The report stated,

> Development of new systems (of any kind) requires certain skills that are different from those needed to sustain existing systems. A program of exploration of follow-on nuclear weapon and weapon system design should be reestablished at some level ... The full range of real and engaging work is the only validated mechanism for sustainment of unique skills.[61]
>
> Management and the work force in the defense industry and in nuclear weapon contractors believe that 'sustainment' programs (e.g. life extension programs) will not retain the skills necessary to competently solve major problems with existing systems or to initiate new programs should the need arise. Pessimism exists about follow-on nuclear deterrence systems becoming a reality, thereby leading to loss of opportunity to train the next generation of nuclear weapon experts.[62]

Improvement is Needed in NNSA-DoD Coordination and Integration. Coordination between NNSA and DoD is required to establish the criteria for weapon delivery parameters for nuclear weapons; set standards for the nuclear effects environment for each weapon system; integrate each warhead—designed by NNSA—into the weapon delivery system—designed by DoD; and define the command-and-control interface for each warhead/weapon combination. Some unique skills are exercised only during such integration activities. It is the integration of NNSA and DoD capabilities and technologies that results in an effective, modern weapon system which meets specified military characteristics. However, few opportunities have existed over the past two decades to exercise these skills.

Nuclear Facilities are Outdated and Need Modernization. This issue has been the focus of various high-visibility reports and has received significant attention, in part because it is a costly undertaking.[63] As noted by the 2009 report of the bipartisan Strategic Posture Commission, some facilities are "genuinely decrepit" and much still remains to be done to put in place a modern nuclear weapon infrastructure to serve national security goals for the long term.[64] Similarly, a 2012 report by the National Research Council (NRC) cited actions needed to maintain technical nuclear expertise in the United States. Among the actions needed was modernization of nuclear production facilities. The NRC report stated, "Most of the nuclear weapon production facilities are old (50 years in some cases) and are both difficult and costly to operate in accordance with modern standards of safety and security."[65] As this important issue has received widespread attention and documentation elsewhere, the need for modernizing the physical infrastructure for the nuclear weapon complex will not be examined in depth in this report. The need has been well established.

Conclusions from Two Decades of Studies. This review of two decades of studies has found that the need to exercise all critical nuclear skills in order to sustain and transfer critical skills to the next generation of nuclear warhead personnel has been a persistent and well documented conclusion of numerous studies. To date, however, this assessed need has not received sufficient priority, relative to other national security needs, for this goal to be attained. Of particular concern from this assessment is that U.S. nuclear warhead development skills—the intellectual infrastructure—are continuing to atrophy and a dedicated effort will be needed to strengthen, exercise, sustain, and transfer unique skills to future personnel. This need was recently communicated in a January 2015 report to Congress from the Commander of the U.S. Strategic Command. He stated, "Overall, the nuclear enterprise requires relevant and challenging design work to assure an ongoing capability in science and engineering to certify and sustain the stockpile."[66]

Of course, the intellectual infrastructure is but one of several elements needed for a resilient nuclear posture. It is the subject of this report because it is the most at risk and, given the potential security challenges to the United States, its remediation should be a priority. A bipartisan consensus in support of this national need is long overdue. For completeness, Appendix C lists major elements of a near- and long-term strategy to achieve and maintain a resilient nuclear warhead development posture and the status of each.

The remainder of this report addresses issues which are more technical in nature: (1) the current state of the U.S. nuclear enterprise and ongoing modernization activities, including the "3+2" vision for the long-term stockpile and the current approach to stockpile life extension; (2) shortfalls in maintaining critical capabilities of weapon designers and engineers and in restoring manufacturing infrastructure; and (3) recommendations to redress shortfalls. The characterization of the current state of the nuclear readiness capability, as well as identification of current shortfalls and recommended actions, was informed by interviews of current and former senior officials who held positions of authority in the DoD, in NNSA, and at the national laboratories. Summaries of several interviews are included in Appendix D.

Current State of the U.S. Nuclear Weapons Enterprise

U.S. nuclear forces must remain safe, secure, and effective for as long as they are needed in service to the nation's security. The near-term challenge is to sustain and modernize nuclear forces and supporting infrastructure in a period of fiscal austerity, using a nuclear enterprise that will not be fully modernized for a decade or more. The longer-term challenge is to ensure that the nuclear enterprise is resilient to respond to changing needs.

As noted, today, the U.S. nuclear weapon stockpile is the smallest in size since the Eisenhower administration, yet its role in deterring the most grievous of threats to the United States and its allies remains central. The nation is on the cusp of a modernization cycle for nuclear delivery platforms and the warheads they carry. The last such cycle—the Carter-Reagan strategic modernization program—occurred during the late 1970s and early 1980s, and led to deployment of B-1B and B-2 bombers, the Peacekeeper intercontinental ballistic missile (ICBM), the Trident D5 SLBM, and air-, ground- and sea-launched cruise missiles. Many of the nuclear warheads and associated delivery platforms that are fielded today—including the Minuteman III ICBM, the B-52 bomber, and the B61 bomb—evolved from the modernization cycle that took place two decades before that one. These forces and warheads need to be life-extended or otherwise modernized.

The DoD develops and fields nuclear delivery platforms and generates military requirements for the warheads carried on those platforms. The NNSA oversees the research, development, test, and acquisition programs that respond to DoD's warhead needs. Specifically, NNSA funds and oversees work carried out at eight government-owned, contractor-operated facilities—three national laboratories (Los Alamos [LANL], Lawrence Livermore [LLNL], and Sandia [SNL]), four production plants (Pantex, Y-12 Plant, Kansas City Plant, and Savannah River), and the Nevada National Security Site. This enterprise supports the U.S. nuclear weapon stockpile from cradle to grave. NNSA must ensure a research and development and manufacturing infrastructure with sufficient highly qualified personnel to advance four key objectives:

- Sustain today's nuclear stockpile and ensure that it is safe, secure and reliable;
- Provide scientific and technical capabilities to assess and certify the future stockpile so that it is safe, secure, and reliable;
- Carry out warhead life extension programs and other modernization to extend stockpile life and provide needed military capabilities as determined by the president; and,
- Enable a rapid, effective response to technical surprises or geopolitical reversals.

In addition, the enterprise is expected to leverage nuclear capabilities and infrastructure to support national security needs beyond U.S. nuclear weapons, including R&D that supports the work of DOE, DoD, the intelligence community, and other agencies in such areas as nuclear arms control, threat reduction, naval nuclear propulsion, non- and counter-proliferation, assessment of foreign nuclear weapon programs, nuclear counterterrorism, and emergency response.

In coming years, many systems will need to be replaced or their service lives extended. Every warhead type in the stockpile must either undergo a life extension or be retired over the next two decades.[67] At the same time, the U.S. government faces an increasingly austere fiscal environment. The 2011 Budget Control Act, coupled with cost growth in key programs, has forced a tightening of belts. In addition, continuing budget resolutions have further complicated the efforts of DoD and NNSA to maintain and modernize U.S. nuclear forces.

On balance, the NNSA enterprise has done a commendable job of developing the tools, the scientific facilities, and the expertise to certify a safe and reliable stockpile absent nuclear testing. It has also been effective in leveraging core capabilities in support of the national security missions of other government agencies. Indeed, the NNSA's weapon labs, plants, and the Nevada site are crown jewels of U.S. science, technology, and engineering. That said, the NNSA has, in large part, been unable to plan, manage, oversee, and hold accountable a nuclear enterprise responsible for delivering, on time and cost, warhead life-extension programs to sustain today's stockpile and large infrastructure projects that provide capabilities to respond to future stockpile needs.[68]

A key issue is maintaining the skills of the weapon scientists and engineers who are not today being provided with challenging design and development problems, or the modern manufacturing infrastructure necessary to exercise and thereby sustain those skills. Concern in this area has grown in recent years because of decisions to delay key programs, which limit the responsiveness of the nuclear posture. Specifically:

- A five-year delay for a life extension program for an interoperable warhead to replace aging W78 ICBM and W88 SLBM warheads;

- A five-year delay in an alternate program designed to replace a failed program to recapitalize the aging facility at Los Alamos that supports the production of pits for the cores of nuclear weapons; and,

- A slowdown of efforts to recapitalize another aging facility—the Uranium Processing Facility at Y-12—due to mismanagement and cost overruns; based on a 2014 independent review, the entire concept is being rethought.

Recent Problems. Recent examples of the failure to sustain critical nuclear-related skills are well documented. In one instance, the NNSA schedule for refurbishment of the W76 warhead carried on Trident II/D5 submarine-launched ballistic missiles (SLBMs) was delayed and costs increased due to an unexpected production problem. Specifically, as described in a 2009 Government Accountability Office (GAO) report, "NNSA did not effectively manage a high risk [task] associated with manufacturing an essential material, known as Fogbank, needed to refurbish the W76 warhead." This resulted in $69 million in cost overruns and a schedule delay of at least one year.[69]

DoD has also experienced unfortunate incidents that reveal the loss of technical skills associated with nuclear design and operations. For example, in 2008 Secretary of Defense Robert Gates fired the Air Force Secretary and Chief of Staff after two embarrassing, high profile incidents involving mishandling of warheads or warhead components.[70] Another example involves the development of a replacement fuze for the W87 warhead carried on Minuteman ICBMs; this fuze has a 10-year design life and must be replaced periodically as part of life-extension activities. However, as documented in a 2012 report by the National Research Council, "Failure to maintain the technical knowledge base for this remanufacture has resulted in a problem. Addressing this problem has imposed cost and delays that could have been avoided with investment in maintaining the nuclear workforce."[71]

The "3+2" Vision for the Nuclear Stockpile. In 2012, under the auspices of the joint DoD-DOE Nuclear Weapons Council (NWC), the two departments advanced a 25-year baseline plan, updated annually, to align schedules for warhead LEPs with the modern delivery platforms that carry those warheads and with the limited capabilities of the uranium and plutonium component manufacturing infrastructure. The 25-year plan identifies a path toward a long-term stockpile end state, endorsed by the NWC, that has been characterized as "3+2." Beyond aligning schedules and leveling the NNSA workload, the plan provides opportunities to reduce the number of warhead types as well as the number of reserve warheads required to hedge technical or geopolitical contingencies.

Today, there are four types of ballistic missile warheads—two each for ICBMs and SLBMs. The life-extended W76 SLBM warhead is in production today. The W78 ICBM and W88 SLBM warheads continue to age and will require life extension with initial production scheduled to begin late in the next decade. The W87 ICBM warhead completed an LEP during the middle of the past decade.

In addition, there are three types of air-delivered warheads—two bombs (the B61, having multiple variants, and the B83 bomb) and one cruise missile warhead. The B61 LEP is currently in engineering development; the LEP for the ALCM replacement warhead is to begin later this decade. No LEP is currently planned for the B83 bomb. Plans call for it to be retired at some undetermined future time.

The 3+2 vision is, over the long term, to consolidate these seven warhead types to five: three interoperable ballistic missile warheads and two air-delivered weapons—one bomb and one cruise missile (hence 3+2!). Nuclear warheads are interoperable if they can be adapted to multiple delivery systems. For example, each of the three interoperable ballistic missile warheads could "swing" between ICBMs and SLBMs.[72]

Before the five-year delay, studies had been underway on the W78/88-1 LEP (potentially the first interoperable warhead or IW1) to determine whether a single nuclear explosive package could be adapted to both the Mk21 and Mk5 reentry bodies for, respectively, ICBM and SLBM delivery. If feasible, this could offer several advantages including:

- Increased resilience to reliability failures or other challenges by reducing today's heavy reliance on a single SLBM warhead—the W76;
- Enhanced warhead safety and security;
- Potentially reduced NNSA costs if one warhead development program could meet the life extension objectives of two existing warheads; more study is needed, however, to assess

whether substantial total cost savings—including both DoD and NNSA costs—could be realized;

- Maintenance of nuclear design and development competence by challenging designers and engineers with a more complex life-extension program than is typical in refurbishment LEPs;

- Exercising NNSA-DoD integration skills; and

- Reduction in the number of warhead types to maintain and reduced total stockpile size; fewer reserve warheads would be required to hedge against unforeseen contingencies.

An essential first step down the path to "3+2" is establishing whether an interoperable warhead is feasible and affordable and, if it is, to develop and field it. Unfortunately, the president's recent budget requests impose a five-year delay in the W78/88-1 LEP. This has broader implications than merely a delay in fielding life-extended warheads; it defers challenging nuclear warhead design and development work that would exercise key skills that are now largely dormant.

The United States ceased nuclear testing more than 20 years ago and subsequently signed (but did not ratify) the Comprehensive Test Ban Treaty (CTBT). A critical safeguard associated with forgoing nuclear testing was retention of a robust program of stockpile stewardship, involving peer review and independent assessment, to ensure warhead safety and reliability absent underground nuclear tests. This is best achieved with two independent and competing nuclear warhead design laboratories—Los Alamos and Lawrence Livermore.

At present, design and development work on the B61-12 LEP is being carried out mostly at Sandia and Los Alamos laboratories. Los Alamos is also the lead on the ongoing LEP for the W76. In the past, a Lawrence Livermore design team was the lead on life extension of the W87 ICBM warhead, and Livermore designers were heavily engaged in the Reliable Replacement Warhead competition, both completed in the middle of the past decade. Since then, Livermore has had little "real" warhead design and development work.

A five-year delay in the IW1 LEP would impede Lawrence Livermore's efforts to maintain critical capabilities to provide independent assessments. As documented in the review of two decades of studies discussed earlier, the government must ensure that the nuclear complex exercises the full set of required capabilities on a stable, year-to-year basis in order to build competence and confidence at all labs and plants. Therefore, it would be prudent to restore the IW1 LEP to its original schedule, not only to mitigate the risks of aging degradation to two warheads essential to the nation's deterrent but, as importantly, to provide an opportunity for the nuclear enterprise, especially Lawrence Livermore lab, to exercise and thereby sustain critical skills.

Warhead Life Extension Options. Life extension programs are designed to assure that existing nuclear warheads to be retained in the stockpile continue to meet military effectiveness and reliability requirements, and include where appropriate, options for enhanced safety and security features. They involve efforts to understand and predict aging processes within warheads that degrade performance, and to repair or replace aging components including those in the warhead nuclear explosive package (NEP); the warhead electrical system; arming, firing and fusing subsystems; and use control components.[73]

Warhead LEPs are characterized according to how two major components of the NEP—the plutonium pit and uranium secondary stage—are addressed.

A *refurbishment LEP* employs pits and secondary stages originally designed for the warhead undergoing life extension. The LEP may involve use of existing components or new manufacture of those same designs. The three most recent LEPs—the W87 LEP, the W76-1 LEP and the B61-12 LEP—are all refurbishment LEPs. The LEP for the W80-2 cruise missile warhead (in planning) will also very likely be a refurbishment LEP.

A *reuse LEP* employs pit and secondary designs currently or previously in the stockpile but from different warhead types. As with refurbishment, this could include use of existing components or new manufacture of those designs. The IW1 LEP, based on preliminary studies, may employ nuclear component reuse.

A *replacement LEP* would employ pit and/or secondary component designs that have not been previously produced for the stockpile, but are based on previously (nuclear) tested designs. This LEP option presents the most challenging design and development program and would exercise the largest set of critical skills. Currently, the United States has no replacement LEPs on the planning horizon.

All three approaches can provide essentially the same military capabilities as the original warhead, and require initial warhead certification and subsequent annual safety and reliability assessments (see Appendix E). They differ in the degree to which they can provide: (1) increased performance margins for assured long-term reliability; (2) enhanced safety and security features; (3) opportunities for warhead interoperability; (4) increased warhead maintainability and manufacturability; and (5) opportunities to exercise critical skills and capabilities of our people and infrastructure.

Warhead refurbishment, coupled with a robust warhead surveillance program, remains key to the nation's life extension strategy. A refurbishment-only strategy, however, is insufficient to manage long-term risks. Reuse and replacement LEPs could significantly increase performance margins, provide enhanced safety and security features, facilitate maintenance and manufacture, provide opportunities for warhead interoperability and, in doing so, advance the commitment of the last three presidents to deploy the smallest stockpile consistent with the nation's security and that of its allies.

Replacement LEPs allow the greatest design flexibility to achieve reliability, safety and security improvements within the NEP, but this approach is more dependent on an adequate production capacity, particularly for uranium and plutonium components. Given the current limitations in production infrastructure, a modernization strategy based on replacement alone would take decades to fully implement. Refurbishment and reuse help manage near-term risk by decreasing the time to modernize certain systems and, thereby, provide a "bridge" to the time when a fully functioning and responsive production infrastructure is in place. They also provide near-term insurance if higher production throughput is needed to augment forces as part of a hedge strategy.

Very importantly, the full range of critical nuclear weapon design, engineering, and production skills and personnel capabilities cannot be developed and sustained unless these capabilities are exercised. Refurbishment alone is insufficient. Reuse and replacement options will exercise and maintain critical skills across the complex; both require strong stockpile stewardship tools. Replacement, more so than reuse, exercises the full range of needed skills and capabilities to design, engineer, certify, and produce modern warheads.

For all these reasons, a mixed life extension strategy which employs all three LEP options, including replacement, is most desirable in seeking to achieve a nuclear enterprise that can be responsive to future needs and resilient to unanticipated events.

Assessing the Current Readiness Posture of the Nuclear Enterprise

This focus of this paper is to assess whether the U.S. nuclear weapons enterprise and the security it provides is resilient to unforeseen adverse contingencies. In order to meet that need, the United States must maintain scientific and technical capabilities and personnel, the experimental tools, and manufacturing infrastructure to develop and field new warheads or warheads with new or different military capabilities, if so directed by the president. Improvements are needed in each of these areas in order to achieve a readiness posture that can respond to such contingencies.

Ensuring Weapons Design and Engineering Development Skills for the Long Term. It is fundamental in nuclear weapons work, as it is in other highly technical activities, that the people—designers, engineers, production, and test personnel—will not be able to maintain critical capabilities absent opportunities to exercise them routinely on complex warhead design and development challenges. Over the past decade and more, such opportunities have been few and far between. Most work today involves refurbishment LEPs that do not, in general, present sufficiently complex design and development challenges to fully exercise skills. For example, the B61-12 bomb LEP presents a significant challenge to the Sandia teams working to develop non-nuclear warhead components—e.g., a modern warhead electrical system—but not to the design and engineering teams at Los Alamos because the so-called "physics package" (i.e., consisting of the warhead primary, secondary, inter-stage region and radiation case) is essentially the same as for the original bomb. For this LEP, the Los Alamos job is not "to design and develop" but to assess whether components of the original warhead have aged out or are otherwise in need of repair. This is an important (and interesting) technical problem, but primarily for the materials scientists and high-explosives experts.

What more is needed? In generating warhead design solutions to meet a potential new military requirement, weapon scientists, working with their military counterparts, typically conduct a Phase 1 warhead concept study leading to a Phase 2 feasibility and cost study. These are generally paper studies and, while important, are insufficient to fully exercise many critical skills. To maximize benefit, this work would need to include experiments to validate computer simulations. In addition, to sustain development skills activity must include engineering development (Phase 3) and production engineering (Phase 4) associated with building and integrating actual hardware. This needs to be conducted in a competitive, lab-to-lab environment to encourage innovation. Within NNSA, this approach would ensure the integration of the design labs and production plants. Very importantly, it would also connect NNSA and DoD in close collaboration involving integration of the warhead with the delivery vehicle and flight testing of the integrated weapon system to assess control and performance. The benefits of training young weapon scientists on innovative design problems are multiplied when the designer must iterate his/her work with systems engineers—in both NNSA and DoD—to weaponize a design, and with the people who would actually build and possibly flight test the prototypes.

Today, there are no military requirements for new warheads or for warheads with new military capabilities. How then can critical skills be exercised? Part of the answer, addressed earlier, involves restoring the original schedule for the IW1 LEP which, compared to other LEPs underway, presents a more formidable design and development challenge for training a new generation. A more comprehensive approach—exercising the entire design, development and manufacturing enterprise—would advance a modern warhead design from initial concept through prototype development and flight testing to the point where one or a few were built, but not fielded.

Language in the FY 2015 National Defense Authorization Act (NDAA) reflects an implicit recognition of some of these issues. Section 3111, entitled "Design and Use of Prototypes for Intelligence Purposes," authorizes the national labs to "design and build prototypes of nuclear weapons to further intelligence estimates with respect to foreign nuclear weapon activities and capabilities." The basic idea is to broaden U.S. understanding of foreign nuclear weapon programs while, at the same time, providing an opportunity to train a new generation of weapon designers and engineers. In May 2015, draft language was introduced in the House version of the FY2016 NDAA (not passed by Congress at the time of this writing) in part to address concerns about training the next generation. The draft legislation—Section 3115, "Nuclear Weapons Design Responsiveness Program"—states:

> The Secretary of Energy . . . in consultation with the Secretary of Defense, shall carry out a program along with the stockpile stewardship program ... and stockpile management program ... to sustain, enhance, and continually exercise all capabilities required to conceptualize, study, design, develop, engineer, certify, produce, and deploy nuclear weapons.

In its version of the FY 2016 NDAA, the Senate Armed Services Committee authorized $20 million in initial funding for a "responsive capabilities program" for activities to reduce the time and cost required to develop, fix, or modify warheads in the future.

The FY 2015 NDAA and FY 2016 draft bill reflect growing concerns that the nuclear weapons enterprise is at risk of losing capabilities that the nation will need in the future. With constrained budgets, innovative approaches will be needed to achieve the benefits of development and manufacturing activities without the high costs typical of full-scale engineering development.[74] Absent this effort, the downside risk is that, possibly within a decade, the nuclear enterprise could be unable to provide a timely response, for example, to ensure continued strategic deterrence in a significantly more dangerous international security environment.

Recommendations to Retain Needed Future Capabilities for Nuclear Weapon Design and Engineering. Actions which would help sustain critical skills include the following:

- Reverse the recent five-year delay to the IW1 LEP program in order to begin providing young weapons scientists and engineers a timely, important, and complex design and development challenge.

- Accelerate activities, already underway, to certify the safety and reliability of a warhead primary with insensitive high explosive that employs a pit originally designed to be used with conventional high explosive.

- Explore opportunities to introduce into future LEPs warhead features that facilitate ease of maintenance and certification without nuclear testing.

- Increase opportunities to train nuclear designers via the design and manufacture of a few prototype warheads. including (as noted in Section 3111 of the 2015 NDAA, referenced above) ongoing programs to assess foreign nuclear weapon designs. Here, a modern warhead design would be taken from initial concept and paper studies through prototype development and flight tested. One or a few would be built, but not fielded.

- As part of nuclear counterterrorism efforts, increase opportunities for young designers to expand understanding of improvised nuclear device designs and means to render them safe.

- Fund a small program for young designers to spend part of their time in "blue sky" thinking about what might be achievable in nuclear weapon technology.

- Develop novel approaches to ensure that these activities are useful in mentoring the next generation, yet are affordable.

It's the people. For two decades U.S. officials have wrestled with the problem of how best to ensure that the next generation of nuclear weapon designers and engineers is ready to take over from those who honed their skills during nearly five decades of nuclear testing. As time passes, loss of knowledge resulting from the departure of the older generation, and the need to transfer critical skills based on that knowledge, heighten the urgency of this effort. Lab directors have expressed concerns about the "shifting to the right" of the age distribution of working-level weapon scientists and engineers. This relates not just to the ability to develop a new warhead or field a new military capability, but to the judgment to ensure that the existing stockpile remains safe and reliable. Bringing highly-capable young scientists and engineers to the laboratories has been and will continue to be driven by access to world-class scientific facilities producing path-breaking research, and the ability to work on complex technical problems involving the security of the nation and the importance of which is communicated clearly by its leaders in words and actions.

Importance of Experiments with Advanced Diagnostics. The challenge of training weapon designers and engineers is evolving due to the absence of nuclear testing and the availability of new, extraordinarily powerful computing capabilities. More so than their predecessors, young designers rely heavily on computer simulation, modeling and calculations, tending towards overconfidence in the quality of the weapon physics embedded in the codes. Excerpts from a recent dialog among four Los Alamos weapon scientists express this concern with great clarity (see Appendix G). One senior designer noted that "the codes always lie" and the job of the designer is to figure out where and when they can be erroneous. This limitation highlights the need for a balanced program of computer simulations and modeling backed up by experiments.

Succeeding or failing to predict the results of an experiment, whether a nuclear test in Nevada or a hydrotest at the Los Alamos DARHT facility, can be an important learning experience for a young designer. Finding out why the codes do not work in certain instances advances knowledge that builds judgment. Indeed, the nuclear enterprise has modern experimental facilities with advanced diagnostics to conduct the types of experiments that not only greatly advance the state of our knowledge about weapon physics and chemistry, but that test designer judgment as well. These experimental facilities include:

- *Dual Axis Radiographic Hydrodynamic Test Facility (DARHT) (at Los Alamos)*: Facility that creates high-resolution 3-D images of dynamic warhead implosion experiments by combining two views. DARHT also can capture images at multiple times during the implosion.

- *Big Explosives Experimental Facility (BEEF) (at Nevada National Security Site (NNSS)), High Explosive Applications Facility (HEAF) (at LLNL), Contained Firing Facility (CFF) (at LLNL), Los Alamos High Explosive Facilities*: Facilities for experiments to study, among other things, fundamental shock physics, properties and reactions of chemical explosives, detonator development and testing, materials studies, and moving (non-nuclear) weapons assemblies.

- *National Ignition Facility (NIF) (at LLNL), Omega Laser Facility (at University of Rochester) and Z Machine (at Sandia)*: Explore physics at high temperatures and pressures characteristic of nuclear explosions generated by lasers (NIF, Omega) or pulsed power (Z).

- *Joint Actinide Shock Physics Experimental Research Facility (JASPER) (at NNSS)*: A gas gun used to generate high shock pressures, temperatures and strain rates for studies of materials properties, including the plutonium equation of state.[75]

- *Los Alamos Neutron Science Center (LANSCE)*: Linear accelerator that produces neutrons for study of fundamental materials properties. Proton radiography, an advanced diagnostic, produces high-resolution images of static or dynamic materials and is used in some experiments.

- *U1A Facility (at NNSS)*: Underground facility for subcritical experiments using plutonium, including scaled weapon experiments with advanced diagnostics such as Photon Doppler Velocimetry. Adding improved X-ray imaging and neutron diagnostics would provide higher-resolution data from scaled, subcritical experiments involving plutonium in weapon configurations.

These are an extraordinarily valuable set of modern experimental facilities, the use of which could be further improved, as noted in the above discussion of the U1A Facility. Funding shortfalls and other priorities, however, prevent our young scientists from fully exploiting these facilities to conduct the experiments that generate the data to test their calculations. These facilities were built at great expense, but some are not fully utilized.

Each quarter the NNSA produces a summary of experiments conducted in support of the stockpile stewardship program.[76] In FY2013, only four hydrodynamic experiments (hydrotests) were conducted at DARHT. In FY2014, the number of tests increased to seven experiments. This rate of experiments may not be sufficient to exercise the skills needed to maintain a competent nuclear design community. One shot per month at DARHT is seen by at least one designer as the minimum rate necessary to carry out needed weapons diagnostic work and at the same time challenge young designers and engineers.[77]

The subcritical experimental program at U1A over the years has greatly expanded knowledge of weapons physics and behavior of plutonium in weapons and non-weapon configurations. In the past two years, however, only two subcritical experiments were carried out. Only one of these experiments was with plutonium.[78] In contrast, during the latter years of underground nuclear testing (late 1980s-early 1990s) the test rate was roughly one per month. This observation raises at least two questions. Are there not valid scientific reasons to conduct experiments more frequently? Or has the highly risk-adverse behavior characteristic of officials who authorize such experiments made them overly expensive? The latter is suspected.

The inertial confinement fusion (ICF) and high energy density physics (HED) experimental programs at NIF, Omega, and Z are absolutely critical. In a letter to NNSA Administrator Frank Klotz, the three weapon lab directors jointly stated:

> The overwhelming majority of the yield of the Nation's nuclear weapons is generated when the conditions within the nuclear explosive package are in the high energy density (HED) state. This requires that proficiency in HED science remains a core technical competency for the Nation's Stockpile Stewardship Program (SSP) for the foreseeable future.

The letter goes on to identify specific goals for the ICF and HED scientific programs:

> In the absence of new nuclear tests and the attrition of nuclear test experience, looking forward the nuclear weapon laboratories will need the ability to (1) test nuclear designers in high energy density (HED) experimental design, (2) access material pressure and density regimes that are presently inaccessible to other experimental techniques, (3) generate and utilize thermonuclear burning plasmas, (4) develop commensurate high-fidelity diagnostics and experimental platforms that help to assure our weapons are safe, secure, and effective, and ultimately, (5) create and apply multi-megajoule fusion yields to enable enduring stockpile stewardship.[79]

In recent years, NIF weapon physics experiments, supplemented with related work carried out at Omega and Z, have resolved some of the scientific puzzles (e.g., the so-called "energy balance" enigma) discovered, but never explained, during the days of underground nuclear testing. Other contributions to weapon physics include furthering understanding of primary boost, secondary performance, and warhead radiation output and associated weapon effects (relevant to qualification, for example, of W76 and B61-12 non-nuclear components).

NIF, Omega and Z also provide opportunities for young weapon designers to build skills and judgment via the understanding gained when the results of their calculations are—or are not—confirmed by Mother Nature. Because Los Alamos does not have an HED facility on site, LANL secondary designers, in order to access temperature and pressure regimes unique to secondaries, must conduct experiments at a remote facility. All three facilities are open to outside users, but young LANL designers tend to rely less on HED experiments in honing skills than do those at LLNL. LANL's leadership recognizes the problem, and is working to address it by, for example, creating additional opportunities for LANL scientists to conduct experiments at NIF, Omega, and Z.

Since 2012, and the conclusion of the scientific campaign to produce fusion ignition at NIF, the trend has been to increase the proportion of NIF shots devoted to weapon physics experiments. This provides an opportunity to increase the number of shots that can be allocated to training young designers, an important development because much can be learned about weapon physics at NIF without ignition. At the same time, pursuit of ignition remains important to stockpile stewardship for three reasons. First, both weapon physics and hardening/vulnerability experiments will benefit in the intense neutron environment produced during ignition. Second, achieving ignition in the laboratory—arguably one of the preeminent scientific challenges of our time—would represent an extraordinary demonstration of U.S. excellence in science and technology related to nuclear weapons and, as such, would augment capabilities provided by U.S. operational nuclear forces in assuring allies and deterring potential adversaries. Third, some of the excellent young scientists and engineers who are drawn to state-of-the-art HED facilities to work on ignition will, at some point in their careers, move to nuclear weapon design work at the labs, thereby bolstering the knowledge base with young talent.

Recommendations to Bolster Experimental Programs for Training a New Generation of Stockpile Stewards. Actions for the Stockpile Stewardship Program which would provide better balance between computer simulation and experimentation include:

- More fully utilize existing experimental facilities. Given that tight budgets are a fact of life, seek “more bang for the experimental buck” by: (1) assigning a higher priority to experiments; (2) operating more efficiently by reducing bureaucratic overhead and micromanagement; and (3) *managing safety risks* rather than fruitlessly (and at high cost) seeking to eliminate them.

- Provide young weapon designers at Los Alamos National Laboratory more opportunities to exploit experiments at high energy density facilities in their training and later warhead design work. (Note: Such facilities are not located at Los Alamos.)

- Challenge young designers with “out of the stockpile box” problems and the opportunity for innovative experiments to test judgment. Challenge young weapons scientists to brief their predictions—perhaps in a lab-to-lab competitive environment—on the expected results of experiments before they are carried out. This so-called “pre-mortem” process would offer the potential for failure (i.e., inaccurate predictions). Such a process would be valuable for building judgment in young designers.

Infrastructure Recapitalization. A functioning and responsive nuclear warhead manufacturing infrastructure is essential to any plausible strategy to respond to unforeseen contingencies and is also an important component of efforts to train the next generation of weapon scientists. The infrastructure problem has existed for more than two decades. An inability to do secondary work at the Y-12 plant in the late 1990s and early 2000s, for example, caused the W87 LEP to take 15 years to complete. (A comparable warhead repair a few years earlier had taken only five years.) Difficulty in restoring a lost capability to produce a special material delayed completion of the W76-1 LEP by several years. At present, the United States cannot produce more than a few plutonium pits per year. This is a sharp contrast to the Cold War when the United States produced up to a thousand annually. Generally speaking, efforts to restore capabilities are not making anywhere near the progress they should be making. This is not a problem caused solely by this administration or Congress, but also by others before it. There is enough blame to go around.

With regard to plutonium, the government’s plan had been to ramp up pit production capacity to 50-80 pits per year at LANL’s PF-4 facility by 2023. The centerpiece was to be a new Chemical and Metallurgy Research Replacement (CMRR) facility at Los Alamos. This facility was to provide analytical support enabling increased pit production at the PF-4 facility. Because of austere budgets and cost escalation, however, the administration's FY2014 budget request deferred start-up of full operations at CMRR by several years. This deferral meant that the acquisition timeline for CMRR would now overlap the timeline to recapitalize the PF-4 facility, also in need of modernization. Consequently, the delay provided an opportunity to explore an integrated and potentially more responsive approach to managing long-term pit manufacturing and associated infrastructure. This approach is a "modular concept" that involves construction of a series of smaller, single-purpose modules (e.g., plutonium casting) linked together through secure tunnels with PF-4 and the existing plutonium analytical lab. By removing some hazardous operations from PF-4, the operational life of that facility could be extended and production capacity increased.

With regard to uranium, NNSA's "Red Team" has concluded its examination of design shortfalls and the associated cost escalation for the proposed Y-12 Uranium Processing Facility (UPF) and has developed alternatives for ensuring long-term capability to carry out enriched uranium operations for the weapons program.[80] In 2014, the Red Team issued its report that recommended stopping work on the current UPF in order to advance a strategy to exploit existing Y-12 facilities coupled with building new smaller facilities with separate hazard and security requirements. This is akin to the modular strategy for the plutonium infrastructure. The report highlighted the need for prompt action so that aging and unsupportable facilities carrying out high-risk operations could be shut down by 2025. The Red Team report suggests a plausible way ahead, and the president's FY16 budget request has allocated funding to this end.

Recommendations Regarding the Manufacturing Infrastructure. Actions needed to restore key elements of the manufacturing infrastructure include:

- Accelerate efforts to provide a capability to produce plutonium pits at a capacity of 50-80 pits per year at Los Alamos.

- Implement the revised approach identified by NNSA's Red Team[81] to restore safe and environmentally sound highly-enriched uranium component manufacture capabilities at the Y-12 plant in Oak Ridge, Tennessee.

Summary of Findings and Conclusions

This report provides an unclassified assessment of the existing state of the U.S. nuclear weapon development readiness posture and identifies some near-term remedial steps to improve readiness to design, develop, and produce new nuclear warheads or warheads with new military capabilities, if required by the president. The main points of this paper are summarized below:

- The Clinton, Bush, and Obama administrations have all supported the goals of modernizing the nuclear infrastructure and sustaining key nuclear weapon development skills. Maintaining these skills has been seen as a hedge against technical and geopolitical uncertainties.

- A future president may determine that the nation's security requires design, development, and production of a new type of nuclear warhead or modification of an existing warhead to provide new military capabilities in support of deterrence and assurance. The nuclear weapons enterprise must be prepared to respond.

- The current program of refurbishment LEPs does not exercise all of the design and engineering skills and judgment that would be needed to field new warheads. Additional efforts (described in this paper), beyond what are underway today, are needed to retain critical skills and build expert judgment for the future.

- Broadening design and development challenges for young designers, including potential development of prototype warheads, is a necessary component of training. To be an effective training tool, prototype development must include two important development challenges:
    - Collaboration of laboratory warhead design teams with production plants to actually build prototype warhead components; and
    - Close NNSA-DoD collaboration at both the policy level and in the integration of the warhead (developed by NNSA) with the delivery system (developed by DoD), to include flight testing.

- The new generation of nuclear weapon designers and engineers needs increased opportunities to carry out complex experiments and, thereby, build the technical judgment that in the past was provided through the underground nuclear test program. Advanced computer modeling and simulation is an important tool for stockpile stewardship; the ultimate challenge, however, is to reconcile computer simulation with empirical data generated in experiments.

- As documented in numerous other reports, continuing and persistent delay in modernizing the nuclear weapon manufacturing infrastructure and atrophy of skills in the workforce will impede the ability of the United States to respond to unplanned challenges that call for changes to U.S. nuclear forces and posture.

Follow-on assessments are warranted to examine more deeply nuclear weapon design, development, and production issues. Such assessments should be conducted in a classified setting and be led by an appropriate team, such as the Defense Science Board or U.S. Strategic Command's Stockpile Assessment Team.

Appendix A. Bibliography

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Appendix B. Excerpts on Nuclear Readiness from Relevant Studies over the Past Two Decades

Excerpts with pertinent findings from key documents are underlined for emphasis to illustrate the consistent identification of certain deficiencies and recommendations for remedial actions.

Report of the Chiles Commission on Maintaining United States Nuclear Weapons Expertise (March 1999).[82] In the National Defense Authorization Act of FY 1997, Congress mandated a commission to examine the ability of the United States to attract, train, and sustain scientific, engineering and technical personnel needed for nuclear weapon design, development, and production in an environment without nuclear testing and with few, if any, new warhead development programs. The report highlighted the challenge of sustaining and transferring knowledge in this environment and identified perceived weaknesses in the nuclear weapons complex at that time. The commission was led by a former head of U.S. Strategic Command, ADM Henry Chiles, USN (ret.).

The Chiles Commission was especially concerned about the retention and transfer of knowledge regarding nuclear weapons design, development, and production. Concerns about knowledge transfer included understanding the data and baselines upon which each warhead in the current stockpile was based and training new recruits on the technical aspects of the nuclear weapons program. During the 1998-1999 timeframe, the Commission noted the "centrality of on-the-job training" and the "drastic change affecting knowledge transfer to the nuclear design groups" in an environment of few development activities and the absence of testing which can validate the results of computer simulations with experimental data.[83]

The Commission found that "[t]hroughout the nuclear weapons complex, there are positions which require years of training to master requisite skills and develop technical judgment. These positions range from nuclear weapons designer, to the machinist of materials unique to nuclear weapons, to the nuclear test engineer who supervises the emplacement of the nuclear explosive." Furthermore, the Commission stated that the difficulties of transferring knowledge and developing technical judgment will be exacerbated in the future due to further personnel retirements, turnover, and downsizing of the stockpile and infrastructure.[84]
The Commission concluded that "[t]raining the workforce and validating the effectiveness of training must be among the highest priorities of the nuclear weapons complex." In an environment of limited new development and production, the Commission recommended that "system and engineering design and skills be exercised to maintain competence and train new employees."[85]
The commission report called for expediting improvements to the production complex and establishing effective programs to replenish "the essential scientific, engineering, and technical nuclear weapons workforce."[86]

One further note is the Chiles Commission's finding regarding the "perceived weaknesses in the DOE-DoD relationship and that there is a perceived, and often real, disconnect between DOE [NNSA] and DoD understanding of program needs." The Commission called for a variety of measures to strengthen the DOE-DoD relationship to help deal with the inherent uncertainties of the future.[87]

DoD Nuclear Deterrence Issues and Options Study (December 2001).[88] This study was initiated to examine potential gaps in DoD's nuclear capabilities, personnel, and expertise to support deterrence in the twenty-first century. Among the major findings were that the DoD had been living "off the fat of the land of Cold War-experienced personnel." Among other key findings were:

- The quality and quantity of nuclear expertise was viewed as being in a state of decline; and,

- Some expertise shortfalls already existed in certain areas, such as munitions and stockpile management, nuclear effects modeling, and safety and security.[89]

The study concluded that without hands-on programs to develop, sustain, and transfer specialized nuclear expertise to the next generation, there would be limited opportunity to correct identified shortfalls.

Report of the Defense Science Board Task Force on Nuclear Capabilities: Report Summary (December 2006).[90] In 2005, the Undersecretary of Defense for Acquisition, Technology, and Logistics tasked the Defense Science Board (DSB) to assess current and future capabilities to sustain the nuclear stockpile for national security needs for the twenty-first century. The task force assembled for this study was led by Dr. John Foster and Gen. Larry Welch, USAF (ret.). The Task Force report described significant problems in the nuclear weapons complex and an approach to sustaining a reliable, safe, secure and credible set of nuclear weapons, as well as problems in the management of the nuclear enterprise in DoD and DOE.

Of most concern, the Task Force concluded that the approach at that time (and almost identical to the current approach) of life extending an aging stockpile of warheads "is not sustainable." The report included recommendations to develop warheads that were simpler, safer, more secure and would support defense policy goals of deterrence, assurance, dissuasion, and defeat. In addition, the report recommended a variety of reforms to help improve coordination and integration of efforts between DoD and DOE. The RRW [Reliable Replacement Warhead] concept was strongly endorsed as a vehicle to help improve stockpile reliability, stimulate DoD-DOE integration and planning, and be a catalyst for innovation at the nuclear weapon design laboratories and production facilities. The task force report stressed the urgency of corrective action given the identified deficiencies.[91]

Schlesinger Task Force on DoD Nuclear Weapons Management: Phase II Report (December 2008).[92] This task force, led by former Secretary of Defense James Schlesinger, was commissioned by the Secretary of Defense in the wake of two Air Force incidents involving the mishandling of nuclear weapons and components. The task force Phase I report dealt exclusively with the Air Force and its nuclear-related training and procedures. The Phase II report expanded the scope to the "stewardship of the nuclear mission more broadly throughout the…DoD." The task force report addressed the need to prepare for changing nuclear weapon capabilities needed to deter and dissuade adversaries and assure allies. Specifically, the report expressed concern about the state of design and production capabilities and personnel skills. For example:

> The scientific base supporting strategic nuclear deterrence capabilities, a key enabler for the design and sustainment of nuclear weapons and delivery vehicles, has substantially eroded. There is legitimate near-term concern about the nation's ability to design and build nuclear warheads, given the past and prospective loss of intellectual capital and critical skills.[93]

DSB Report on Nuclear Deterrence Skills (September 2008).[94] In 2007, ADM Henry Chiles, USN (ret.) was asked to chair a DSB study on the status of a wide range of DoD personnel skills—government, military, and contractor—for nuclear capabilities in support of deterrence through 2020. One motivation for the task was to assess the trends in nuclear skills since the Chiles Commission report of 1999. Among the task force's principal observations were that:

- "Adequate nuclear deterrence competency will not be sustained to meet future challenges."
- "Management and the work force in the defense industry and in nuclear weapon contractors believe that 'sustainment' programs (e.g. life extension programs) will not retain the skills necessary to competently solve major problems with existing systems or to initiate new programs should the need arise. Pessimism exists about follow-on nuclear deterrence systems becoming a reality, thereby leading to loss of opportunity to train the next generation of nuclear weapon experts."
- "Today's nuclear weapons expertise generally is of high quality, although we are unable to assess the capability to design, develop, and produce new weapons or weapon systems through the entire cycle, as the nation has not done so for over 15 years."[95]

Among the specific recommendations of this DSB task force was the following: "Development of new systems (of any kind) requires certain skills that are different from those needed to sustain existing systems. A program of exploration of follow-on nuclear weapon and weapon system design should be reestablished at some level. ... The full range of real and engaging work is the only validated mechanism for sustainment of unique skills."[96]

Report of the Bipartisan Congressional Commission on the Strategic Posture of the United States of America (May 2009). In its Fiscal Year 2008 NDAA, Congress included a requirement for a bipartisan commission to conduct an assessment of U.S. strategic capabilities, with an emphasis on nuclear weapon capabilities. One purpose of this initiative was to generate a bipartisan consensus on nuclear policy for the twenty-first century to guide future administrations. The bipartisan Strategic Posture Commission issued its consensus report in May 2009, providing detailed findings and recommendations for policy and program issues for U.S. strategic capabilities, with emphasis on nuclear weapons. The report discussed the confusion resulting from general reluctance to initiate any change to the nuclear stockpile which might be deemed "new" as well as differing views of how *new* can be defined. The commissioners agreed that no new nuclear weapon capabilities were required at that time, but stopped short of recommending a comprehensive U.S. policy prohibiting any new weapon capabilities or curtailment of readiness to be able to develop a new nuclear weapon capability if such a requirement emerged. The report from the commission recommended that each warhead refurbishment and modernization program should be examined on a case-by-case basis. For some warheads, the simple remanufacturing and replacement of several components may be adequate; for others, the complete redesign and new production of all or most system components may be needed.[97]

In addition, the Strategic Posture Commission concluded that the "physical infrastructure is in serious need of transformation" and recommended that NNSA "conduct a study on the core competencies needed in the nuclear weapons complex." The commission also agreed on detailed recommendations for improving the nuclear weapons complex and infrastructure. [98]

As noted in the report of the bipartisan Strategic Posture Commission, the nature of the security environment has grown "more complex and fluid, the United States faces a diverse set of potential opponents, circumstances, and threats for which nuclear deterrence might be relevant."[99] Unlike the United States, potential U.S. adversaries, including Russia and China, maintain very active nuclear weapons design and production programs. To prepare for the uncertainties of this complex world, the 2009 commission report stated, "Resilience and flexibility of the [nuclear] triad have proven valuable as the number of operationally deployed strategic nuclear weapons has declined. They promise to become even more important" in the future.[100] This finding underscores this report's focus on enhancing resilience by maintaining a readiness capability to be able to design, develop, and produce nuclear weapons.

Responses by Directors of Nuclear Design Laboratories to Written Questions from then-Sen. Kyl (September 2009). In August 2009, then-Sen. Jon Kyl sent a list of specific questions to the directors of the two U.S. nuclear weapon design laboratories regarding the status of capabilities at the laboratories. He requested written replies. Replies from the laboratory directors provide a snapshot in late 2009 of their judgments of capabilities relevant to this assessment. A few excerpts from these responses are quoted below:

> *Regarding the infrastructure*: "Funding levels for all three pillars of the nuclear weapons enterprise (science and engineering, stockpile maintenance/modernization, and infrastructure) have been inadequate." "The U.S. nuclear weapons production complex is unable to respond to needs in a timely manner."[101]
>
> *Regarding nuclear weapon design and development skills*: "Design capabilities at the laboratories have atrophied because most of the SSP [Stockpile Stewardship Program] work at the laboratories has focused on analysis of the existing stockpile instead of design."[102]
>
> "Since the moratorium on nuclear testing began in 1992, the complete portfolio of traditional skills has not been exercised. The nuclear weapons enterprise has not been given the opportunity to demonstrate the design-certify-build process since the fielding of the W88 [warhead] in 1989. Actually performing all these steps, from initial concept through actual stockpile entry, is necessary to verifiably demonstrate that these capabilities exist. Instead, the complex has developed a generation of excellent analysts who are proficient in assessing small deviation from the tested conditions in the stockpile. This is … not sufficient to sustain the intellectual competency to implement new safety and security features in the stockpile of the future."[103]
>
> "Maintaining intellectual competency is a challenging priority for the national laboratories. … A compelling SSP ST&E [science, technology, and experimentation] effort is needed

> to have a pipeline of skilled personnel to address today's work as well as ensuring our deterrent remains second to none in the future. Of equal importance … is providing adequate opportunity to exercise skills in the complete design through production cycle, which is essential for training of laboratory and production plant personnel. The complex has not exercised the complete cycle of design through production since the mid to late 1980s."[104]

These responses to questions posed by Sen. Kyl provide a glimpse into the perspectives of the directors of the nuclear design laboratories in late 2009.

National Research Council (NRC) Report on *The Comprehensive Nuclear Test Ban Treaty: Technical Issues for the United States* (March 2012).[105] This report was initiated to update the findings of a 1998 report on issues related to the Comprehensive Nuclear Test Ban Treaty. One aspect of the 2012 report deals with maintaining an effective and reliable nuclear stockpile without nuclear testing and includes findings relevant to this study on readiness capabilities. In particular, the NRC report notes increasing concern with the nuclear intellectual infrastructure resulting from several negative developments (e.g., an aging work force, increasing workload for nontechnical tasks, and aging stockpile) since the 1998 report. The NRC report states, "Significant gaps in critical skills exist due to a combination of workforce demographics and/or reduced level of stockpile work."[106]

Appendix C. Critical Elements of a Resilient Nuclear Warhead Posture

Based on the studies and reports reviewed for this assessment, a prudent strategy to provide resilience and hedge against an uncertain future for the near term and transition to the long term would include the following:

- Until an adequate manufacturing infrastructure is restored, retain sufficient numbers and types of reserve warheads to support timely force augmentation, if necessary, and provide options to replace failed warhead types.
- Similarly, until the manufacturing infrastructure is restored, retain sufficient numbers of reserve warhead pits to support planned life extension programs and contingencies.
- Modernize the nuclear infrastructure; build in sufficient reserve capacity to be able to respond to unforeseen contingencies in addition to planned stockpile needs.
- Ensure a sufficient reserve of tritium for warheads and warhead transportation assets.
- Strengthen and maintain the intellectual infrastructure—laboratory capabilities, production capabilities, and NNSA/DoD integration skills—to design and develop warheads, including warheads with new or different military capabilities.
- Maintain underground nuclear test readiness.

The first two bullets above provide some resilience for the near term. However, as pointed out in a number of studies, this approach is not sustainable over the long term. For a resilient nuclear development capability that is sustainable over the long term, the last four bullets are necessary. Based on an examination of official policy documents and the latest Stockpile Stewardship and Management Plan, the current status of each item is shown in Table C-1 below.

	Goal	Current Status
Near-term Goal	Retain reserve warheads for augmentation and reliability replacements.	Current policy; implementation plans exist.
Near-term Goal	Retain reserve of warhead “pits.”	Current policy; implementation plans exist.
Long-term Goal	Modernize the nuclear infrastructure and build in reserve capacity of expansion options.	Modernization planned, but important projects delayed. No plans for reserve capacity for unexpected contingencies.
Long-term Goal	Ensure sufficient reserve of tritium and transportation assets.	Plans exist; implementation is underway.[107]
Long-term Goal	Strengthen, exercise, and sustain the intellectual capital—personnel skills to design, develop, and produce nuclear warheads.	Skill sustainment activities are piecemeal and inadequate. A more comprehensive, dedicated, long-term effort is required to redress current shortfalls.
Long-term Goal	Maintain underground nuclear test readiness capability.	NNSA required to maintain 24 to 36 month test readiness posture. Some skills exercised.[108]

Table C-1. Near-term and Long-term Goals Needed to Sustain a Resilient Nuclear Warhead Development Capability

Appendix D. Notes From Interviews with Current and Former Senior Officials

For this assessment, interviews were conducted with a select group of current and former senior officials at the weapons laboratories and at STRATCOM. The following question was posed to each person:

> *What more must be done to ensure maintenance of the capabilities and skills of our people (i.e., the intellectual capital of our nuclear warhead designers and engineers) should a future president decide that the nation's security requires fielding of a new nuclear warhead or modification of an existing warhead to provide a new military capability?*

The notes from these interviews have been summarized to reflect key points in the discussions. Any errors (or possible misinterpretations) are solely the responsibility of the interviewer.

Bob Webster, Los Alamos, Principal Associate Director for Weapons Programs (Interviewed on 12 May 2015). Los Alamos has some flexibility in concept study-like efforts, and like LLNL, they are largely computational. We have worked a few primary designs aimed at pit reuse concepts, some for which we have built hardware and performed hydrotests, but these are not full system designs. The ability to do "clean sheet" conceptual and engineering designs working with the Services is currently lacking. Present day LEPs are primarily engineering activities at LANL, which do not exercise the design skills of the entire set of folks including physics designers, engineers, code developers, material scientists, and test personnel. Because existing LEPs, and resulting pressures on RDT&E (research, development, test and evaluation), consume almost the entirety of the LANL weapons budget and support in this area, our flexibility to go beyond computational efforts is relatively limited.

The ability to expand beyond Phase 1 conceptual studies (i.e., of prototype warheads not intended to be fielded) into Phase 2 (feasibility and cost)- and Phase 3 (engineering development)-like activities would add significantly to training, not only designers but weapons engineers and material scientists as well. It would provide additional opportunities to engage and coordinate with the DoD and the IC (intelligence community) to help establish the importance and priority of this type of effort within the portfolio of efforts taking place within the SSP. Finally, if taken into Phase 3-like activities, it would provide important opportunities to potentially participate with the DoD in weapons development.

George Miller, former Director, Lawrence Livermore National Laboratory (Interviewed on 14 May 2015). The answer is straightforward with one exception addressed below. Generally, the Stockpile Stewardship Program, with all its attendant parts, is designed to maintain and exercise to the extent possible the requisite skills. I am concerned, however, that it has become overly bureaucratic, stove-piped, budget-constrained and politically influenced. As a result, the SSP is currently at some risk in my view. The one conceptual shortcoming in the program: One can only exercise the ability to design, or even understand how to design, by doing. Nuclear design and development, like any other complex activity, requires practice. This work is perhaps closer to art and athletic performance than it is to science, but it is a "discipline" that has to be learned. Making decisions about complex nuclear explosive systems with many possible trade-offs and constraints is difficult. Today, we have a group of very talented analysts—they are not designers. We need design activities both to understand what is possible for the United States should world circumstances change as well as to understand what our adversaries are actually doing. Programs like the Reliable Replacement Warhead, or the Navy's Strategic Warhead Protection Program (a prototype development effort, such as that led by Vice Admiral G. Peter Nanos when he was the director of the Navy's Strategic Systems Program), is what is needed. This needs to include experiments and the engineering associated with building and integrating hardware—both within the DOE complex and with the DoD. In my view, there is significant risk that we will shortly be found lacking. Innovative design work, in my opinion, must be carried out first in the context of what is doable/advisable/certifiable with no nuclear testing, and secondly, if that fails, to understand what other avenues that opens up.

Gen. Larry Welch, USAF (ret.), former Commander, Strategic Command and Air Force Chief of Staff (Interviewed on 4 June 2015). In nuclear weapons science there are three categories of knowledge: things we know, things we don't know but can know, and things we don't know and don't know how to know. Unraveling the Coronet Factor,[109] based on a series of experiments over the past decade at NIF and Z, took us from the second to the first category. Important topics remaining in the second category include ignition, boost and secondary burn. Some issues may be in the third category which means we just have to continue to design with tested limits.

Maintaining the current stockpile involves probing knowable weapons science to understand (and predict), among other things, component aging. The current LEPs (W76-1, B61-12) are mostly engineering problems and do not require significant scientific advances. In preparing for the future, we certainly do not want to be constrained by lack of knowledge. Exploring knowable weapons science increases understanding in ways that may permit design innovations without nuclear testing to enable future choices regarding needed nuclear capabilities. A key challenge is to develop the knowledge—i.e., from a first-principles understanding of the physics and chemistry—to ensure that the design and production of a new pit could be achieved without additional nuclear tests.

Young designers must be provided regular opportunities to develop skills in innovative prototype design and development. The RRW competition was the perfect example of fostering design innovations and out-of-the-box thinking about safety and security. Even though the development "rug" was pulled out from under the design teams who thought they were going to produce something of value for the country and that's what was important.

Development programs are not cheap. The challenge is to understand how far one needs to proceed to get the benefits of prototype development without absorbing the high costs. One approach would be to engineer a few, but not all, of the key warhead components.

While the two nuclear physics laboratories share expertise in science and nuclear component engineering, Lawrence Livermore has focused more intensely on nuclear weapons science while Los Alamos has led the focus on nuclear component engineering. It benefits the country that the two labs demonstrate both cooperative and competitive strengths in advancing nuclear weapons work.

One concept for the first interoperable warhead (aka IW1)—employing an IHE (insensitive high explosive) system in the Mk21 and Mk5 aeroshells—is more an engineering problem than it is a design challenge for young physicists. The proposed IW2—which could involve adapting a CHE (conventional high explosive) pit for IHE—is a much more challenging design effort.

Admiral Richard Mies, USN (Ret.), former Commander, U.S. Strategic Command (Interviewed on 10 June 2015): We must take a holistic view of the problem. Some concerns are structural and cut across both DOE and DoD's responsibilities in assuring an effective deterrent. For example, overall weapons system reliability is more often than not driven by the reliability of the delivery platform than it is by that of the warhead. The Triad modernization program now underway can provide opportunities for improved system reliability. Achieving this could provide opportunities to strengthen deterrence, to make deterrence more credible, and to avoid being self-deterred. For example, we could choose to field lower yield warheads with more accurate delivery systems to achieve comparable military effectiveness with lower collateral damage on critical targets.

Young designers must be provided opportunities to develop and maintain skill sets. But this must be done in the context of our overall strategy. For example, the risk and benefit tradeoffs of employing IHE warheads in SLBMs must be fully understood in all of its safety, security, system reliability and cost aspects before proceeding down that road. It is important to explore such an approach for training, and for ICBM systems that traditionally employ IHE, but decisions to proceed to a fielded SLBM design must be carefully weighed.

The DOE rightly objects to characterizing the DoD-DOE relationship as one between the DoD "customer" and its DOE "supplier". Perhaps a better characterization is between "supported" and "supporting" agencies. In the case of nuclear weapons programs, DoD is the "supported" agency. Regarding certain threat reduction programs, DoD may be the "supporting" agency.

The two nuclear design labs—Los Alamos and Lawrence Livermore—have vigorous programs of peer review and independent assessment of each other's activities that provides an element of challenge as well as a "competition of ideas" that benefits the nation. There is less of a proven peer review process for Sandia in connection with warhead non-nuclear components. Moreover, there is nowhere near as intense a scrutiny for delivery platforms than for the nuclear explosive packages carried by those platforms. This applies to ballistic missile systems and even more so for bombers and tankers, e.g., in regard to secure, survivable communications with these platforms or for operating in intense threat environments. As an example, the Advanced Cruise Missile was removed from service not because of a problem with the nuclear warhead, but due to delivery system unreliability.

Robert Selden, former Associate Director and Nuclear Design Leader at Los Alamos Laboratory; currently, a member of the U.S. Strategic Command Strategic Advisory Group (SAG) and Chairman of the SAG Stockpile Assessment Team (Interviewed on 11 June 2015). It is important to achieve the right balance of resources among the three components of stockpile stewardship: (1) to certify and maintain today's stockpile; (2) to extend the life of warheads in that stockpile; and (3) to prepare to respond to future uncertainties. Moreover, to maintain the skills of stockpile stewardship, we must provide relevant and challenging design work for our young people, including prototype development, and provide the necessary resources to support this work. There are many interesting questions to challenge our young people: How much linkage is required to the existing underground nuclear test data base to certify the safety and reliability of a new warhead design? How do you prove that the linkage is adequate? Can we understand how primaries work from (known and still to be known) first principles of materials science, chemistry, and physics? This last question, by the way, is the current great challenge for weapons science. Many of these questions convey the strong connection between “science” and “stockpile.”

In prototype development, it is important to include all three nuclear labs—and the Services—in a design competition, and tie that competition to building something. It is insufficient to limit design activities to simulation and modeling. The thing (or parts of the thing) being built does not have to meet all of the stringent standards of an LEP and therefore does not have to be as expensive. One way of making this work affordable is perhaps to provide the labs some flexibility to refocus some of the ongoing efforts in the science and engineering campaigns.

The most important shortfall addressed by involving our young people in challenging design and development work is to advance an evolution from good “analyst” to seasoned “designer” having the necessary judgment (and “feel”) for the complex tradeoffs inherent in weapons development. The current ongoing LEPs mostly challenge Sandia and its capabilities to design and develop non-nuclear components for nuclear warheads, not Los Alamos or Lawrence Livermore. The planned IW1 program represents a step up in physics design sophistication, and the IW2 would go substantially further.

The ICF program and HED physics are very important both for training designers and for advancing nuclear weapons science. The ICF program has demonstrated that our codes are unable to predict what we observe in ICF capsule performance. Since these capsules are intended to work at the temperatures, pressures and densities characteristic of nuclear weapons operation, the experimental programs at NIF and Z are important for the weapon designers to understand. In addition, the discipline of creating designs, predicting their performance, then conducting experiments that show the real performance, can be very helpful in providing designers new ways to think about weapons work where full-scale testing can no longer be done.

Appendix E. Technical Issues in Warhead Life Extension and Certification

Quantification of Margins and Uncertainties. Warhead life extension begins with the warhead surveillance program that employs tools having a strong scientific foundation. Each year a few warheads are taken apart to look for potential problems ranging from "birth defects" to degradation due to aging. Once a problem is identified, a Significant Findings Investigation (SFI) is initiated. Assessment of SFIs relies heavily on the scientific capabilities developed over two decades of stockpile stewardship. The basic question is: Does the SFI require action to fix the warhead? A program known as Quantification of Margins and Uncertainties (QMU) has become the generally accepted framework in which science and technology is applied to assess a safe and reliable stockpile.

Here is how it works. In very simple terms "margin," measured in kilotons, is the difference between the expected primary yield and the minimum yield required to ignite the warhead secondary. In general, more margin is considered better because the aim is for the secondary to go off even if there is some degradation in primary yield due to aging. Each of these measured (or assessed) yields has an associated uncertainty which, when applied conservatively, reduces available margin. Ideally, the uncertainties, when combined, are a relatively small fraction of the margin itself. This is often the case but not always. Under QMU, the scientific work is carried out to provide a more comprehensive understanding of how physical and chemical changes to a warhead affect margin, and uncertainties in margin, and hence overall performance. The job of the LEPs is to restore margin if QMU assessments indicate that the warhead is drifting (or is about to drift) into a region of risk.

Warhead Certification Without Additional Nuclear Tests. To date, the directors at the national labs have expressed confidence that certification of the safety and reliability of all three life extension options can be accomplished using data from past underground nuclear tests coupled with use of modern stockpile stewardship tools. These include advanced modeling and simulation with high-performance computers, materials research to improve the codes (e.g., better characterization of aged plutonium equation of state), and integrated experiments with modern facilities and advanced diagnostics to reconcile calculations with physical reality.

Warhead designs based on any of the LEP options will draw from a rich underground nuclear test data base to underwrite certification. For pit and secondary designs used in refurbishment and reuse LEPs, data from past nuclear tests that directly examined these designs is available to establish an LEP "test pedigree." For replacement "clean sheet" designs, certification would be based on data from several "near neighbor" nuclear tests. A decision to employ any LEP option would, of course, depend on ease of certification without requiring additional nuclear tests. This in turn would depend on (1) final design configuration and its relationship to the nuclear test data base, (2) increased performance margin incorporated in the design, and (3) the degree to which performance margin is "eaten up" by needed safety and security improvements. Such a decision would be determined on a case-by-case basis for each warhead.

Along these lines, experts believe that the potential for significantly increased margin from reuse and replacement LEPs, facilitated in part by relaxed warhead size and weight constraints (e.g., fewer warheads per missile), will strengthen their ability to ensure a safe, secure and reliable stockpile into the future absent nuclear testing.

Appendix F. Nuclear Weapons Designer Commentary on Warhead Design Skills

The following excerpts are drawn from a longer, published interview with four Los Alamos weapons scientists involved in nuclear design and weapons physics: Gary Wall, Jas Mercer-Smith, John Pedicini and Bob Webster. All developed their skills during the period of nuclear testing and are in the latter stages of their careers. Part of their job now is to nurture the next generation of designers who will replace them. Their comments center on the imperative—in a world without nuclear testing—of ensuring that the next generation is provided with tools and opportunities to acquire the necessary skills and, most importantly, sound judgment to assure a continued safe and reliable nuclear stockpile. The entire interview can be found in "Passing Good Judgment," *Los Alamos National Laboratory National Security Science*, February 2014.

Nuclear Testing as a Means to Develop Designer Judgment

> **Wall:** Eventually, if warranted, the developing designer got to be the lead in the design of a new weapon, and the test at NTS [Nevada Test Site] was the tangible feedback mechanism for developing and demonstrating judgment. Post-shot analyses of the test data allowed you to see which of your predictions were right, which were wrong, and why they were wrong. The test data also helped you evaluate the computer simulations that led to your predictions and learn which parts of the simulations you could trust and which you couldn't. Learning from these tests is what built credibility and judgment.
>
> **Pedicini:** A nuclear test challenged the accuracy of your judgments. Weighing the results of the test against your predictions—what you thought was going to happen—was how you developed better judgment. In the absence of testing, that's the kind of judgment we're failing to develop today in our young designers.

Life Extension Programs

> **Mercer-Smith:** It's up to the weapons designers to assess whether a defect we find during surveillance needs to be addressed and if so, how. That takes judgment. Even small defects or changes in a system like a weapon or a rocket can lead to catastrophic results. Judging how an aged weapon with a defect will or won't perform is even more difficult than designing a brand-new weapon, where you work with known quantities and qualities.

Being Misled by Computer Calculations

> **Webster:** Are we giving the new designers the training and experience needed to qualify them for certifying a stockpile 20 years from now? I'm worried that because we're doing very few experiments, we're becoming much too dependent on computation alone. So when a new question comes up, I might hear the new designers say, "Well, let's just compute it." If that's the only tool they have, I don't think that's good enough.

Mercer-Smith: New designers sometimes expect too much from a computer code. When I joined the Lab, it was pounded into our heads over and over that the *codes always lie* and that the job of a designer is to know when, where, and how much. The key challenge for the future is to train the next generation so they have that kind of judgment. But today we're forgetting—or ignoring—that the codes can lie, and we don't always have the experimental data we need—the reality check we need—to prove or disprove our conjectures. Experimental data are essential for developing our ability to judge when, where, and how much the codes are lying.

The Importance of Experiments

Webster: We're not doing enough experiments to replace the loss of full-scale testing. What we're talking about here is the need for more *integrated* experiments, which are experiments on weapon subsystems. Integrated experiments are the hydrotests we do at DARHT [Dual-Axis Radiographic Hydrodynamic Test facility] and the subcritical experiments we do at the Nevada National Security Site. Subcritical experiments, by definition, use plutonium, but not enough to ever produce a critical mass. Integrated experiments also give us the data needed to validate the predictions of our computer codes and help us improve the codes. Then we can validate or refine the improved codes with further experiments. It's a constant cycle. First, the designer runs a simulation that predicts the results of an integrated experiment. The experimental results then either validate the simulation and the prediction or not. The order, prediction first and integrated experiment second, is crucial because human beings can rationalize things faster than we'd like to believe. If the experiments came first, they would color how we read the results of a simulation. We'd always correctly predict the results of an experiment after the fact. Peer review also has its limitations because people can get into groupthink and be fooled by it. The only protection against rationalization and groupthink is doing experiments, new ones where the answer isn't already known.

Wall: Today, there's so little experimental feedback to validate or contradict their predictive work that the new designers have a hard time maintaining interest. Some want to either become managers or drop out of the program. Sadly, that makes sense, but it's not what the nation's national security needs.

Wall: That's one of the benefits of doing more experiments that's often overlooked. Maintaining the stockpile is a long-term effort extending decades into the future. It would definitely be easier to recruit people to be designers if we were doing more experiments. I know this from my own experience and from conversations with the younger designers. You can do computer simulations over and over again, but without having the excitement of anchoring your results in reality, what's the point? Having the data from experiments, having that feedback, creates excitement. Those experiments could be new designs, but they also could be old designs analyzed with new diagnostics that give you more information than you had in the past. That's exciting too.

Wall: A successful experiment proves what you already know; it validates your knowledge. In contrast, a failure, a missed prediction or a bad judgment call, lets you know where you need to seek more knowledge, where you need to go in order to expand your understanding. There was fear of failure during the nuclear testing era too, but it was different. There wasn't *time* to explore riskier approaches that might have resulted in better weapons. The military wanted to put things into the stockpile as quickly as possible during the Cold War. We had a blank check to do that as long as we delivered the product on time.

Appendix G. About the Authors

Mr. Thomas Scheber. Mr. Thomas (Tom) Scheber is Vice President, National Institute for Public Policy. Before joining the staff of National Institute in October 2006, he was the Director of Strike Policy and Integration in the Office of the Secretary of Defense. At National Institute, he specializes in deterrence strategies, extended deterrence and assurance of allies, and analyses of strategic force issues.

From September 2000 to September 2006, Mr. Scheber served in the Office of the Secretary of Defense (OSD) for Policy. In the Office of Forces Policy, he played a central role in the conduct of the DoD Nuclear Posture Review (NPR) and was the principal author of the DoD implementation plan for the NPR. In May 2003, he was selected as the Director for Strike Policy and Integration. In that role he was responsible for developing the policies necessary to implement the President's and Secretary of Defense's guidance for strategic forces in the new geopolitical environment. In addition, he transformed the OSD offices responsible for strategic strike from a Cold War orientation to one better suited to meet the challenges of the twenty-first century.

While in OSD, Mr. Scheber frequently represented the United States during consultations with officials from other countries. For example, he represented the U.S. at meetings of the NATO High Level Group and was a member of the U.S. delegation to the U.S.-Russia Consultative Group on Strategic Security (Offensive Transparency Subgroup) from 2002 through 2005. In that role he routinely briefed Russian officials on U.S. plans for strategic forces and U.S. views on issues related to strategic forces.

In 2008 and 2009, Mr. Scheber supported the Congressional Commission on the Strategic Force Posture of the United States. He served as a member and chairman of the Deterrent Force Posture Expert Working Group for the Commission.

From 1989 to 2000, Mr. Scheber was a member of the professional staff at the Los Alamos National Laboratory where he served as the Director of the Military Applications Group and Project Leader for Weapon Studies. Mr. Scheber is a former Naval Officer and Naval Aviator.

His awards include the Secretary of Defense Medal for Meritorious Public Service.

Dr. John R. Harvey. From July 2009 until retiring in August 2013, Dr. Harvey served as Principal Deputy Assistant Secretary of Defense for Nuclear, Chemical, and Biological Defense Programs where he advised on plans, policy and oversight of the U.S. nuclear weapons program, programs for combating weapons of mass destruction, chemical weapons demilitarization, treaty management and the work of the Defense Threat Reduction Agency. Among other things, he was lead in the Department's AT&L organization for the 2010 Nuclear Posture Review.

From March 2001 to July 2009, Dr. Harvey was Director, Policy Planning Staff of the National Nuclear Security Administration where he advised the NNSA Administrator on major policy and program decisions. He was responsible for studies and analyses relating to NSC-directed policy reviews, the work of the Nuclear Weapons Council, external advisory boards, and interagency working groups. He led development of the Strategic Planning Guidance that each year informs NNSA's program, planning, budgeting and execution process. Dr. Harvey was "point" for NNSA on the 2001 Nuclear Posture Review and its implementation, the drafting of Presidential Directive NSPD-28 addressing the command, control, safety and security of U.S. nuclear forces, and the work of the Congressional Commission on the Strategic Posture of the United States.

From March 1995 to January 2001, Dr. Harvey served as Deputy Assistant Secretary of Defense for Nuclear Forces and Missile Defense Policy where he developed and oversaw implementation of U.S. policy governing strategic and theater nuclear forces and ballistic missile defense. From 1989 to 1995, Dr. Harvey directed the Science Program at Stanford University's Center for International Security and Arms Control where he led research efforts on the proliferation of mass destruction weapons and delivery systems, the safety and security of U.S. nuclear forces, the role of export controls on advanced dual-use technologies in national security, and the implications of advanced conventional weapons for regional security. He has lectured on arms control and national security policy in the academic program at Stanford University.

Dr. Harvey has served on several senior advisory panels. For his service in DoD, he was awarded, in September 1985 and in January 1997, the Secretary of Defense Medal for Outstanding Public Service. Dr. Harvey received his BA in physics from Rutgers University and his MS and PhD degrees in experimental elementary particle physics from the University of Rochester. He is the author or co-author of numerous scientific and technical papers.

Dr. John S. Foster, Jr. Dr. Foster began his career at the Radio Research Laboratory of Harvard University in 1942. He spent 1943 and 1944 as an advisor to the 15th Army Air Force on radar and radar countermeasures in the Mediterranean Theater of Operations, and the summers of 1946 and 1947 with the National Research Council of Chalk River, Ontario.

In 1952, Dr. Foster joined the Lawrence Livermore National Laboratory and was promoted to Associate Director in 1958, and served as Director of the Livermore Laboratory and Associate Director of the Lawrence Berkeley National Laboratory from 1961 to 1965. He currently serves as a consultant to the Lawrence Livermore National Lab. and an Advisor to STRATCOM SAG Panel.

Dr. Foster was Director of Defense Research and Engineering for the Department of Defense, serving for eight years (1965-1973) under both Democratic and Republication administrations.
In 1973, Dr. Foster joined TRW and retired as Vice President, Science & Technology in 1988 and served on the Board of Directors of TRW from 1988 to 1994.

Dr. Foster served on the Air Force Scientific Advisory Board until 1956. He then served on the Army Scientific Advisory Panel until 1958 and was a member of the Ballistic Missile Defense Advisory Committee, Advanced Research Projects Agency in 1965. From 1973 until 1990, he was a member of the President's Foreign Intelligence Advisory Board. He is a Senior Fellow of the Defense Science Board and served as Chairman of the DSB from January 1990 to June 1993. He served on the Congressional Commission on the Strategic Posture of the United States and on the Advisory Committee to the Director of DARPA.

Dr. Foster served as Chairman of the Board of GKN Aerospace Transparency Systems, Co-Chairman Nuclear Strategy Forum, member of the board of Wackenhut Services, Inc., and consultant to Northrop Grumman Corp, Sikorsky Aircraft Corp, Intellectual ventures, and Defense Group Inc.

Among his numerous honors are the Nuclear Deterrence Summit-Exchange Monitor Johnny Foster Lifetime Achievement Award (2013), Marshall Institute Founders Award (2009), Department of Defense Eugene Fubini Award (1998), the Founders Award from the National Academy of Engineering (1989) and the 1992 Enrico Fermi Award. In 1979, he received an honorary Doctor of Science from the University of Missouri. Other awards include: The Ernest Orlando Lawrence Memorial Award of the Atomic Energy Commission (1960), the Defense Department's Distinguished Public Service Medals (1969, 1973, 1993), election of the National Academy of Engineering (1969), the James Forrestal Memorial Award (1969), the HH Arnold Trophy (1971), the Crowell Medal (1972), the WEMA Award (1973) and the Knight Commander's Cross (Badge and Star) of the Order of Merit of the Federal Republic of German (1974). Dr. Foster is a commander, Legion of Honor, Republic of France.

Dr. Foster was born September 18, 1922, in New Haven, Connecticut. He received his bachelor's of science degree from McGill University, Montreal in 1948. He received his doctorate in physics from the University of California, Berkeley, in 1952.

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[41] Ibid., pp. 5-7.

[42] The Secretary of State, the Secretary of Defense, and the Secretary of Energy, *Report to Congress on: An Assessment of the Impact of Repeal of the Prohibition on Low Yield Warhead Development on the Ability of the United States to Achieve Its Nonproliferation Objectives,* March 2004, p. 1.

[43] Ibid., p. 2. (Emphasis as in the original.)

[44] Ibid.

[45] Ibid., p. 3.

[46] Section 3116 of the National Defense Authorization Act for Fiscal Year 2004, Public Law 108-136.

[47] Department of State, "Transparency in the U.S. Nuclear Weapons Stockpile," fact sheet, April 29, 2014, available at http://www.state.gov/t/avc/rls/225343.htm.

[48] *Report to Congress on: An Assessment of the Impact of Repeal of the Prohibition on Low Yield Warhead Development*, op. cit., p. 4.

[49] 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 and 51.

[50] ADM Henry G. Chiles, Jr., USN (ret.), Chairman, *Report of the Commission on Maintaining United States Nuclear Weapons Expertise,* Report to the Congress and the Secretary of Energy, March 1, 1999, pp. 20-21.

[51] Ibid., p. 22.

[52] Ibid.

[53] Ibid., pp. 30-32.

[54] Ibid., p. iii.

[55] Ibid.

[56] *The Comprehensive Nuclear Test Ban Treaty—Technical Issues for the United States* (Washington, DC: The National Academies Press, 2012) p. 79.

[57] *Nuclear Deterrence Issues and Options Study: A Baseline Assessment of DoD Staff Nuclear Expertise*, Advanced Systems and Concepts Office, Defense Threat Reduction Agency, December 21, 2001, p. 5.

[58] Ibid.

[59] Report of the Defense Science Board Task Force on Nuclear Capabilities: Report Summary, Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, December 2006, pp. 5-9.

[60] Report of the Defense Science Board Task Force on Nuclear Deterrence Skills, Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, September 2008, p. xii.

[61] Ibid., p. x.

[62] Ibid.

[63] For example, "Recommendations for the Nuclear Weapons Complex of the Future," Report of the Nuclear Weapons Complex Infrastructure Task Force, Secretary of Energy Advisory Board, U.S. Department of Energy, July 13, 2005.

[64] 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.

[65] *The Comprehensive Nuclear Test Ban Treaty—Technical Issues for the United States,* op. cit., p. 119.

[66] ADM C. D. Haney, U.S. Navy, Commander, United States Strategic Command, *Report to Congressional Committees: Report on Balance in Nuclear Weapons Program*, United States Strategic Command, January 2015.

[67] "Fiscal Year 2016 Stockpile Stewardship and Management Plan: Report to Congress," National Nuclear Security Administration, March 2015.

[68] See, *A New Foundation for the Nuclear Enterprise: Report of the Congressional Advisory Panel on the Governance of the Nuclear Security Enterprise*, Norm Augustine and Richard Mies, co-chairs, November 2014. Management and

governance problems within the nuclear weapons enterprise are complex and involve cross-jurisdictional boundaries both in the executive branch and with Congress. These studies have been the subject of a series of studies that agree on many of the steps that must be taken to reform the U.S. nuclear weapons complex. For reform to succeed, it will require senior government leaders with the determination and drive to implement the necessary changes within the DOE, NNSA, and its labs and plants. This report does not further address this problem.

[69] "NNSA and DoD Need to More Effectively Manage the Stockpile Life Extension Program," Government Accountability Office Report GAO-09-385, March 2009.

[70] Ann Scott Tyson and Josh White, "Top Two Air Force Officials Ousted," *Washington Post*, June 6, 2008.

[71] *The Comprehensive Nuclear Test Ban Treaty - Technical Issues for the United States*, op. cit., p. 33.

[72] "Fiscal Year 2016 Stockpile Stewardship and Management Plan," op. cit., pp. 1-6.

[73] A warhead LEP does not produce a "new" warhead. Consider the automobile analogy. Changing the spark plugs of a '63 Chevy BelAir, replacing parts in the engine or even replacing the engine, removing worn out fan belts, and adding seatbelts and airbags doesn't turn it into a Corvette; it's still a '63 Chevy BelAir.

[74] Because only a few prototype warheads would be built but not fielded, there may be cost savings compared to developing and fielding a warhead intended for operational deployment.

[75] JASPER was developed by LLNL at the former Nevada Test Site to conduct shock physics experiments to explore the fundamental properties of plutonium, including its equation of state. JASPER is a two-stage, light-gas gun that shoots projectiles at plutonium targets at a velocity of 1-8 km/sec, inducing very high pressures in the material. JASPER supports the stockpile stewardship program by providing important physics data relevant to the safety and reliability of a nuclear warhead primary, dynamic materials properties, and plutonium pit lifetime studies. Experiments at JASPER typically employ targets using a few tens of grams of plutonium. The target is enclosed in a Primary Target Chamber (PTC) that is designed to entomb the expended material while surviving the resulting stresses so that receipt of data from the experiment is assured. The Secondary Confinement Chamber (SCC) provides a redundant, engineered passive safety feature to preclude the release of radioactive material should the PTC fail to contain radioactive debris.

[76] Summary of Experiments Conducted in Support of Stockpile Stewardship (for FY2013, FY2014, and 1st Quarter of FY2015), Quarterly Reports from the National Nuclear Security Administration.

[77] Communication between John Harvey and Brad Beck, Los Alamos National Laboratory, April 27, 2015.

[78] Summary of Experiments in Support of Stockpile Stewardship, op.cit.

[79] Letter to Frank Klotz, NNSA Administrator, from William Goldstein (LLNL), Charles McMillan (LANL) and Paul Hommert (Sandia), January 20, 2015.

[80] "Final Report of the Committee to Recommend Alternatives to the Uranium Processing Facility Plan in Meeting the Nation's Enriched Uranium Strategy," op. cit.

[81] Ibid.

[82] ADM Henry G. Chiles, Jr., USN (ret.), Chairman, *Report of the Commission On Maintaining United States Nuclear Weapons Expertise,* Report to the Congress and the Secretary of Energy, March 1, 1999.

[83] Ibid., pp. 20-21.

[84] Ibid., p. 22.

[85] Ibid., pp. 30-32.

[86] Ibid., pp. iv-v.

[87] Ibid., pp. 23, 26.

[88] *Nuclear Deterrence Issues and Options Study: A Baseline Assessment of DoD Staff Nuclear Expertise*, Advanced Systems and Concepts Office, Defense Threat Reduction Agency, December 21, 2001.

[89] Ibid., p. 5.

[90] Report of the Defense Science Board Task Force on Nuclear Capabilities: Report Summary, Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, December 2006.

[91] Ibid., pp. 5-9, 37.

[92] Hon. James Schlesinger, Chairman, *Report of the Secretary of Defense Task Force on DoD Nuclear Weapons Management: Phase II Review of the DoD Mission*, December 2008.

[93] Ibid., pp. iii-vi.

[94] "Report of the Defense Science Board Task Force on Nuclear Deterrence Skills," Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, September 2008.

[95] Ibid., p. xii.

[96] Ibid., p. x.

[97] 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. 40-45.

[98] Ibid., pp. 62-64.

[99] Ibid., p. 23.

[100] Ibid., p. 26.

[101] Michael R. Anastasio, Director, Los Alamos National Laboratory, Los Alamos National Laboratory Response to Stockpile Questions, 10 September, 2009, p. 2.

[102] Ibid.

[103] Ibid., p. 12.

[104] George H. Miller, Director, Lawrence Livermore National Laboratory, written memorandum to Sen. Jon Kyl, September 19, 2009, p. 8.

[105] *The Comprehensive Nuclear Test Ban Treaty—Technical Issues for the United States*, op. cit.

[106] Ibid., p. 79.

[107] Department of Energy Fiscal Year 2016 Stockpile Stewardship and Management Plan: Report to Congress, March 2015. For tritium programs and plans, see pp. 1-10, 2-34 through 2-36, 4-13, 4-22, 8-4, and D-60 and -61; for secure transportation programs, see pp. 1-10, and 5-1 through 5-7.

[108] Ibid., pp. 1-6, 4-1, Appendix C. Also see recommendations in *The Comprehensive Nuclear Test Ban Treaty—Technical Issues for the United States*, op. cit., pp. 120-121.

[109] The Coronet Factor refers to the relative loss of energy as radiation, produced by the primary in a nuclear weapon, travels to the secondary. During underground nuclear tests, scientists measured less radiation arriving at the secondary than predicted. Until recently, the science associated with the relative loss of energy was not fully understood, but could be approximated by applying what became known as the Coronet Factor.