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EFFICIENCY VERSUS EFFECTIVENESS:

WHY DO NUCLEAR WEAPON PROGRAMS COST MORE AND TAKE LONGER THAN THEY DID DURING THE COLD WAR ERA?

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TERRY JOSSERAND
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EFFICIENCY VERSUS EFFECTIVENESS:

WHY DO NUCLEAR WEAPON PROGRAMS COST MORE AND TAKE LONGER THAN

THEY DID DURING THE COLD WAR ERA?

A DISSERTATION APPROVED FOR THE
DEPARTMENT OF POLITICAL SCIENCE

BY THE COMMITTEE CONSISTING OF

Dr. Hank C. Jenkins-Smith, Chair

Dr. Carol L. Silva, Co-Chair

Dr. Joseph Ripberger

Dr. Aimee Franklin

Dr. Charles Nicholson

Dedication

I dedicate this to my family— my wife and best friend, and our beautiful children who graciously gave up their time with dad.

Te iubesc cu toată inima.

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Edwin P. Chamberlin, Michael D. Green, Leone Z. Young, and Susan Zamora Gorman. Thanks for your guidance and motivation to make sure I finished.

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To my committee, thanks for your patience and positively shaping me.

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Abstract

United States nuclear weapons are high reliability engineered systems managed by high reliability organizations that make up what is collectively referred to as the Nuclear Security Enterprise. In the Post-Cold War era, there was a monumental shift in nuclear weapons policy from increasing effectiveness of underground system testing, new design, and innovation to sustainment and enhancing fiscal efficiency through management controls.

However, absent from high reliability systems and organizations literature are studies of effectiveness versus efficiency and the balance of management controls. Instead, the high reliability systems and organization literature describes intense concentrations in areas such as safety, security, reliability, error reporting, high functioning public-private partnerships, continuous organizational self-evaluation, mission-driven cultures, and specialized expertise as theoretical features leading to effective outcomes.

Thus, this dissertation integrates a management controls reforms-as-routines framework into a Black Box Model of Implementation on a high reliability organization responsible for nuclear weapons to generate and explore an observational measure of labor resources spanning a 21 fiscal year timeframe. The output is utilized to explore the primary empirical research question:

> *Over time, how have changes in reforms for management controls in the Post-Cold War Era impacted the distribution of resources across the Nuclear Security Enterprise?*

The empirical results illustrate a larger increase in the labor resources implementing management controls reforms than the technical resources responsible for the United States Nuclear Deterrence Mission. The results are useful to high reliability system and organization theorists as an empirical case study regarding the implications of shifting the balance between policy priorities of cost, schedule, and performance in a resource constrained environment. Furthermore, these results should inform policymakers and other high reliability organizations responsible for high reliability engineered systems in the United States that increasing management controls may *not* be the preferred mechanism to improving effectiveness of mission outcomes.

Chapter 1. Introduction

Why do nuclear weapon programs cost more and take longer than they did during the Cold War Era?

This has been a common question throughout the Post-Cold War Era as the United States Nuclear Security Enterprise responsible for the Nuclear Deterrence Mission has been characterized as being inefficient and ineffective (Augustine et al. 2014). The characterization is driven by recurrent Post-Cold War Nuclear Weapon program performance that is increasingly over budget and schedule. This has prompted requests from the United States government for independent investigative panels and audits to determine the underlying problems and recommend solutions to improve cost efficiency and schedule effectiveness.

The investigative panels and audits contain consistent findings that attempt to explain why the Nuclear Security Enterprise in the Post-Cold War Era is inefficient and ineffective. These select findings come from interviews with scientists and engineers from the three weapons laboratories—Sandia National Laboratories, Lawrence Livermore National Laboratories, and Los Alamos National Laboratories—and the National Nuclear Security Administration, the federal agency responsible for the management of the Nuclear Security Enterprise. The select findings include:

- Inadequate focus on budgets and schedules (United States Congress 2013)
- Lack of clear roles and responsibilities (Augustine et al. 2014)
- Culture focused on compliance and process over mission delivery (Augustine et al. 2014)
- Extreme oversight practices (Cohon et al. 2015)
- Unnecessary micromanagement (GAO-19-286R)
- Unwarranted audits and inspections, loss of trust (GAO-19-286R)
- Excessive budget controls (Breul et al. 2020)

These findings subsequently inform the policy making process with formal recommendations for management reform for implementation directed towards improving cost efficiency and schedule effectiveness. The formal recommendations for management reform call for the creation of new or the enhancement of existing management controls.

These findings have a recurrent feedback loop informed by the findings throughout the Post-Cold War Era with recommendations for implementation directed towards improving cost efficiency and schedule effectiveness. The Commission to Review the Effectiveness of the National Energy

Laboratories observed that “past recommendations for improvement have, for the most part, had limited impact, as demonstrated by the fact that the same problems recur in report after report (Cohon et al. 2015).” The recurrent recommendations thematically call for the creation of new or the enhancement of existing management controls.

Management controls described herein are concerned with the application of formal processes, policies, procedures, and tools for planning, monitoring, controlling, and reporting on budget and schedule. Formal management controls carry authority, incentives, and consequences that are typically from federal requirements, Congressional legislation, executive orders of the President, or accepted recommendations for implementation from government audits and investigative panels (Franklin 2001). Some of the recurrent Post-Cold War Era thematic areas identified for creating or enhancing reforms for increasing management controls include:

- Oversight management (GAO-07-36)
- Financial management (GAO-07-36, GAO-09-385)
- Risk management (GAO-11-387)
- Budget and cost management (GAO-16-218)
- Schedule management (GAO-16-218, GAO-23-106059)

These resulted in increased controls in the areas of financial, risk, budget, cost, and schedule management through mechanisms such as new and updated policies, legislation, requirements, contract incentives, guidance documents, governmental offices, etc. Mostly under the pretext that through the implementation of augmented management controls, the Nuclear Security Enterprise will realize improved cost efficiency and effective schedule outcomes. However, there are costs associated with the implementation of management controls that occur within a resource constrained environment.

Thus, the primary empirical research question is:

Over time, how have changes in reforms for management controls in the Post-Cold War Era impacted the distribution of resources across the Nuclear Security Enterprise?

The concept of controls has deep roots in how the United States Government has historically imagined realizing effective and efficient outcomes. Woodrow Wilson’s *The Study of Administration* initiated the call for the development of a science of administration (Wilson 1887). A science that would enable the United States to control, operate, and manage the constitution *like a business* with the primary value being efficiency. Frederick Taylor built on this concept through studies of time and motion in industrial settings. Taylor observed and measured how much time and effort was required to execute tasks such as brick laying and shoveling dirt in order to discover *the one best way* or most efficient path in order to develop expectations to control for time and cost (Taylor 1911). Together, the works of Wilson and Taylor makeup critical pieces of the foundation for the school of scientific management (Wilson 1987, Taylor 1911). Scientific management conceptualizes control mechanisms to guide organizational behavior through cost and activity-based performance measurement.

The works of Wilson and Taylor are engrained in the multitudes of movements to *run government like a business.* Implementing broad federal government reforms to measure and control for outcomes, i.e., performance, has been emphasized throughout the Cold War Era as cost efficient (Box 2015). However, as Osborne and Gaebler describe in *Reinventing Government*, the public and private sectors are very different. Private sector behaviors and interests are not always going to be effective and efficient to public sector needs. Policies and controls must be tailored (Osborne and Gaebler 1992, Franklin 2000). As Long and Franklin summarized from their analysis of the implementation of the Government Performance and Results Act, "the one-size-fits-all approach to implementation is not suitable (Long and Franklin 2004, p. 317)." Policies and the application of the various types of control mechanisms must be tailored to each organization towards desired outcomes aligned to each agency's mission. The challenge over time is that the underlying dynamics of the environment—and thus policies—change along with the desired outcomes. This is especially the case with the Nuclear Security Enterprise and the Nuclear Deterrence Mission of the United States.

Since the advent of the first Nuclear Weapon systems *Fat Man* and *Little Boy* in the 1940s, the policy priorities of the Nuclear Security Enterprise evolved over long periods of time throughout the Cold War Era, and substantively changed into the Post-Cold War Era. The policy priority changes over these long periods of time simultaneously impacted the engineering of the nuclear weapon system and the resources within the organizations responsible for them. However, the investigative panels and audits of the Nuclear Security Enterprise tend to focus on cross-sections of time for specific programs of interest that all occur within the policy priority environment of the Post-Cold War Era. As the late Senator Pete Domenici (New Mexico) stated as he was describing the challenging future of the Nuclear Security Enterprise in the 21st century, "it's hard to know where you're going if you don't know where you are and how you got there (Johnson 1997)."

The Cold War and Post-Cold War Eras of the Nuclear Security Enterprise occur over long periods of time. Thus, in order to examine the primary empirical question, it is critical to first understand to some extent, the extensive history of the Nuclear Security Enterprise and the driver of the shift in policy priorities from the Cold War Era to the Post-Cold War Era.

1.1. Nuclear Deterrence Policy Priority Shifts Cold War to Post-Cold War

In 1985, President Reagan signed Executive Order 12499 in accordance with Public Law 98-525, that established the President's Blue Ribbon Task Group on Nuclear Weapons Program Management. The task group was required to report to the President and the Committees on Armed Services of the Senate and the House of Representatives on recommendations for how nuclear weapons should be managed as the Cold War was coming to an end. The task group recommended that the United States nuclear weapons program shift from a focus on design innovation to sustainment of its current capabilities and cost efficiency (Clark et al. 1985).

The task group identified that the impressive accomplishments of the national laboratories responsible for nuclear weapons design innovation to meet national security requirements, had long standing traditions of autonomy unique to broader defense organizations. This autonomy included heightened discretion in defining research programs and managing critical technical resources within constrained environments (Clark et al. 1985, Greenwalt 2021). The national laboratories were charged with anticipating future threats throughout the Cold War and maintaining a level of expertise in science and engineering that "demanded intense, sophisticated, and sustained technical talent (Hruby et al. 2011)." Autonomy was foundational to the national laboratories history of delivering exceptionally effective outcomes on time.

Sustainment of capabilities in the Post-Cold War Era meant that the need to rapidly design and produce new nuclear weapon systems on urgent schedules to mitigate emerging threats would no longer be necessary. The nuclear weapons that already existed in the United States stockpile would meet the anticipated national security needs of the Post-Cold War Era. Reagan's task group identified that policies directed towards sustainment of capabilities would by design be very challenging to sustain over time without identifying an end to the Post-Cold War Era policy timeline (Clark et al. 1985).

The policy shift from design innovation to sustainment of capabilities was combined with the recommendation that the United States Nuclear Weapons Program Management focus on cost efficiency. Cost efficiency would be achieved through the implementation of management controls mechanisms directed to instill fiscal accountability and responsibility, cost discipline, budgeting, and cost management practices. The task group identified that this shift to cost efficiency through management controls would be difficult to implement "in a community where performance and reliability have been considered more important than cost or measures to control costs (Clark et al. 1985 p. vi)." The balance at the national laboratories between performance and schedule effectiveness and cost efficiency had historically lacked weight and attention to the latter.

In summary, the task group had two primary concerns with their policy shift recommendations as the Cold War was coming to an end:

1. Ensuring the preservation of capabilities of the Nuclear Security Enterprise and the national laboratories while simultaneously divesting in engineering innovation for new nuclear weapon systems.
2. Heightened trepidation that the introduction of management controls for cost efficiency may disrupt the delicate balance between competing concerns for performance and safety or inhibit innovation.

Fundamentally, Reagan's Blue Ribbon Task Group on Nuclear Weapons Program Management 1985 report set in motion the framework for post-Cold War Era nuclear weapons policy—a shift from innovation and schedule effectiveness to sustainment of capabilities and cost efficiency.

1.2. Nuclear Deterrence Policy Priority Shift Through Post-Cold War Era

Executive Order 12499 initiated the framework for Post-Cold War Era nuclear weapons policy (Clark et al. 1985). Beginning in 1989, the Secretary of Energy Admiral James D. Watkins─United States Navy retired─established Tiger Team Assessments of the Nuclear Security Enterprise to review adherence to national Environmental, Safety, and Health regulations, requirements, and guidelines that concluded in 1992. The Tiger Team Assessments outlined thousands of findings that described a broad array of deficiencies in management, oversight, training, and budgeting among others that led to a substantive increase in new Environmental, Safety, and Health regulations, requirements, and guidelines to be imposed on the operations across the Nuclear Security Enterprise (Department of Energy 1992).

Then, in 1992 under the Bush Administration, the United States unilaterally banned underground nuclear weapon testing with Public Law 102-377, §507[1]. Then in 1993, with the signing of Presidential Decision Directives 11 and 15 under the Clinton Administration (Clinton 1993), the United States continued the unilateral moratorium and officially entered the Science-Based Stockpile Stewardship Program (Nikitin and Woolf 2020).

The Science-Based Stockpile Stewardship Program was designed to enable the responsible organizations to maintain the safety, security ,and reliability of the nuclear weapons stockpile without underground nuclear weapons testing. The Science-Based Stockpile Program further enabled the shift from the innovation and production of new nuclear weapons systems to sustainment by providing confidence in the reliability and credibility of the nuclear deterrent (United States Congress 2000). This confidence led to the United States Department of Energy and the United States Department of Defense jointly approving the Phase 6.X Process (Department of Defense 1996). The Phase 6.X Process is a sub-process of new weapon system Phase 6 Quantity Production of the Cold War Era Phase X Process[2], the relationship of these processes is illustrated in Figure 1. The Phase X Process was the nuclear weapon acquisition process utilized during the Cold War Era for the acquisition of new designs, and subsequently the Phase 6.X Process was utilized throughout the Post-Cold War Era for sustainment.

The Phase 6.X Process takes nuclear weapons formerly produced, replaces obsolescence, and appropriately modernizes to extend their engineered lives. In summary, the actions taken subsequent to Executive Order 12499 ended the United States underground nuclear weapon test program and halted new weapon development and innovation in alignment with policies of sustainment of capabilities (Clark et al.1985).

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[1] United States Congress. 1990. "Hatfield-Exon-Mitchell Amendment to the Energy and Water Development Appropriations Act, Nuclear Weapons Activities." *Pub. L. No. 102-377, 106 Stat 1315*. Washington, DC: United States Congress.

[2] The Phase X Process contains eight phases related to the nuclear weapon acquisition life cycle utilized during the Cold War. These phases reflect the logical progression of activity for development, production, deployment, and retirement of a new weapon. In the Post-Cold War Era, the Phase 6.X Process enabled the sustainment of systems formerly produced in .

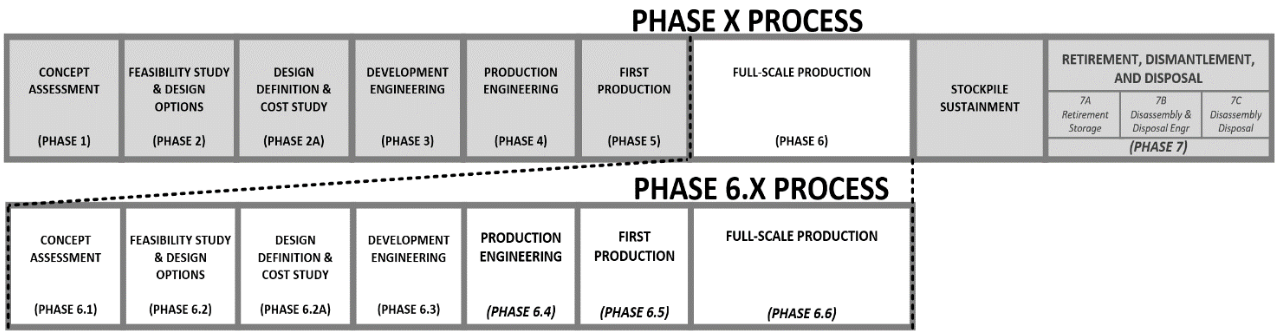


Figure 1. Phase X Process Correlation to Phase 6.X Process

The last new nuclear weapon program to be approved by the United States Government for development engineering in the Phase X Process was the W91 in August of 1990 and was subsequently canceled (Josserand 2017). The last underground nuclear weapon test was in September 1992 (DOE/NV 2000). Hence, it has been over 30 years since the United States authorized the start of a new nuclear weapon program and an underground nuclear weapons test.

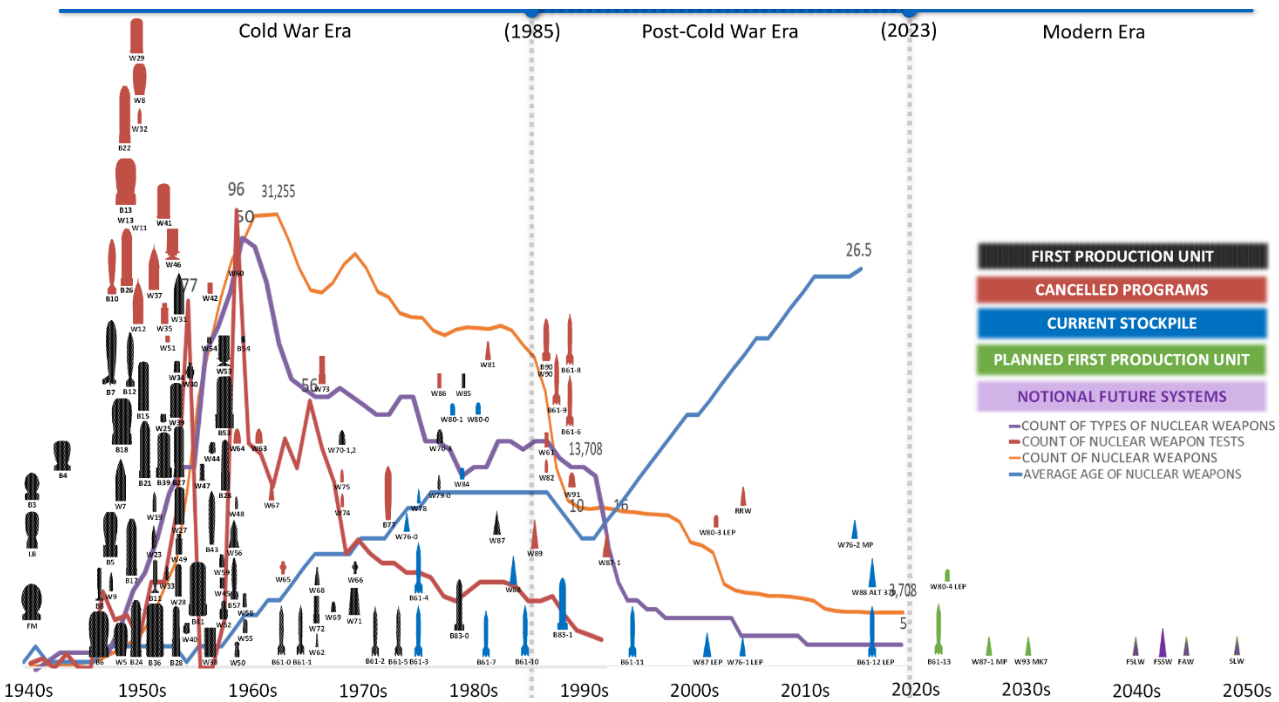
Other nuclear weapons policies and treaties—i.e., Intermediate-Range Nuclear Forces Treaty[3], Strategic Arms Reduction Treaty[4], etc.— of the post-Cold War Era were focused on nonproliferation imposing constraints and reductionist requirements on counts of nuclear weapons and types of delivery platforms. These efforts have cascaded throughout the Post-Cold War Era to a reduction in counts of delivery platforms from 26 in 1985, to 5 as of 2023 (Facini et al. 2023) and a reduction in counts of active and inactive nuclear weapons from 23,368 in 1985 to 3,748 as of 2023 (United States Department of Energy 2024).

Figure 2 illustrates the historic impact of the shift in nuclear weapons policy from the Cold War Era of design innovation through the Post-Cold War Era of sustainment of capabilities with projections into the Modern Era through FY2050. Within the window of the post-Cold War Era, Figure 2 illustrates:

- Increase in the mean average age of the United States nuclear weapons stockpile resulting from the Phase 6.X Process of life extension versus new weapon production
- Decline in counts of nuclear weapons in the stockpile
- Decline in counts of delivery platforms

[3] Signed in December 1987, abolished land-based missiles with ranges from 300-3,400 miles.
[4] Signed in July 1991, constrained the count of strategic nuclear warheads in the United States stockpile to 6,000.

- Cessation of a nuclear weapons testing program
- Cessation of authorizations for new nuclear weapon programs



Data Sources: United States Department of Energy 2016-2023, Nevada Operations Office 2000, Josserand 2017

Figure 2. Nuclear Security Policy Timeline

Throughout the Cold War Era, "policy could not keep up with technology (Martz 2014)." In the 1950s, engineers and physicists were able to reduce the mass of nuclear weapons by a factor of 30 and the diameter by a factor of three, this type of innovation continued throughout the Cold War Era (Josserand 2017). Nuclear weapon innovation coincided with innovation of delivery platforms producing nuclear tactical missiles, depth charges, land mines, artillery shells, and rifles—e.g., the W54 Davy Crocket. (Schwartz 1998, Martz 2014).

Table 1 summarizes the shift in nuclear weapons policy priorities from the Cold War Era through the Post-Cold War Era (Drewien et al. 2010). The policy priorities of the Cold War Era were characterized as having been executed with exceptionalism, while the Post-Cold War Era has been recurrently characterized as inefficient, ineffective, and dysfunctional, with programs continually over budget and over schedule (GAO-07-36, GAO-09-385, Cohon et al. 2015, Breul et al. 2020). However, a critical takeaway of the United States Nuclear Deterrent Mission, is there has always been an unwavering determination regarding the efficacy, safety, security, and reliability of the United States nuclear deterrent (Augustine et al. 2014).

Table 1. United States Nuclear Weapons Policy Priorities and Values

United States Nuclear Weapons Policy			
	Cold War Era 1940s – 1985	Post-Cold War Era 1985 – 2023	Modern Era 2023 –
Priorities	Build Up	Nonproliferation	NA
	Test	Test Moratorium	NA
	Innovation	Sustainment	NA
	Platform Diversity	Platform Reduction	NA
	Schedule Effectiveness	Cost Efficiency	NA
Values	Safe, secure, and reliable		

As United States nuclear weapons policy priorities are being shaped for the Modern Era, it is critical to evaluate the implementation and outcomes related to previous political inputs. It is especially important as the shift from the Post-Cold War Era to the Modern Era is occurring due to the recurrent findings of inefficiency and ineffectiveness in an era where sustainment and cost efficiency have been prioritized.

Why has there been a lack of attention to cost efficiency? As the President Reagan's Blue Ribbon Task Group identified in 1985, the balance at the national laboratories responsible for the engineering and physics of nuclear weapons between performance, schedule effectiveness and cost efficiency had historically lacked weight and attention to the latter. The Cold War Era Nuclear Security Enterprise was generally on schedule, and prioritized performance and reliability over controlling for cost. Thus, altering the delicate balance between cost, schedule, and performance related priorities was one of the primary concerns of the task group.

To describe and highlight the meaningfulness of the shift in policy priorities from the Cold War Era to the Post-Cold War Era, a focused set of literature on high reliability systems helps frame why and how nuclear weapons and the organizations responsible for them must be exceptionally different. Frederickson describes this invaluable literature on high reliability systems as a niche "tucked away in the recesses of Public Administration research and theory"(Frederickson et al. 2018). High reliability system and organization literature supplant a theoretical framework through which to view and think through the delicate balance between cost, schedule, and performance related priorities.

1.3. High Reliability Systems and Organizations

In response to a growing literature on crisis management and system safety theory, the High Reliability Organization Project at the University of California, Berkeley was launched in the mid-1980s (LaPorte 1996). The High Reliability Organization Project investigated organizations responsible for engineered systems that were required to perform at extremely high levels of safety and reliability due to the catastrophic implications of failure. Examples of high reliability systems can include nuclear power plants, air traffic control networks (La Porte 1988), nuclear command and control (Sagan 1993), aircraft carriers (Rochlin et al. 1987), manned spaced systems—Challenger and Columbia (Fuqua et al. 1986, Gehman et al. 2003), the electric grid, and nuclear weapons (Schlosser 2013).

High reliability systems described herein refers to a physical engineered system that "is created by and for people; has a purpose, with multiple views; satisfies key stakeholders' value propositions; has a life cycle and evolution dynamics; has a boundary and an external environment; and is part of a system-of-interest hierarchy (Systems Engineering Body of Knowledge 2015)." The high reliability system described refers to a United States nuclear weapon system.

In the Public Administration literature, the term *system* is often used interchangeably with *organization* from a socio-technical perspective (Bourrier 2011). A high reliability organization described herein refers to the institution responsible for the implementation and evaluation of policies related to the high reliability systems over their engineered lifecycle. There is a purpose to the distinction between the two—systems and organizations—which may be referred to in the literature as a singular sociotechnical system due to the complex mix of high functioning public-private partnerships, within a tight network of intricate horizontal and vertical linkages of high coordination and communication (LaPorte and Consolini 1991). It is the distinction between high reliability systems and organizations and their features where refinement of high reliability system and organization theory prospers.

Since most engineered systems do not result in catastrophic consequence in the event of failure, the literature on high reliability systems and high reliability organizations is highly limited, as most studies focus on error-tolerant lower reliability engineered systems and the institutions responsible for them (March and Olsen 1995). This section will further describe critical features of both high reliability systems and high reliability organizations and why they are important. An in-depth examination will be included regarding a specific United States high reliability system that is central to the nations National Security Strategy—a nuclear weapon—as well as a high reliability institution with substantive responsibility for aspects of the United States nuclear weapon stockpile—Sandia National Laboratories (Biden 2022). It is within the nexus of exploring United States Nuclear Weapons and Sandia National Laboratories, that this dissertation is able to explore the primary empirical question as well as contribute to high reliability system and organization theory.

In a high reliability system, the physical technologies and components are tightly and effectively integrated. A breakdown at any point in the system is not tolerable as the consequence of failure are catastrophic. Thus, a high reliability system design must be engineered with heightened priority on safety. Normal Accident Theory purports that tightly integrated structures, no matter how well attended, will ultimately fail because it is impossible to comprehend all possible system-wide failures (Perrow 1999, Shrivasta et al 2009). In his book *Normal Accidents*, Perrow asserts that adding additional safety features increases the complexity of an engineered system, thus decreasing the ability to understand the system, resulting in increased risk of an accident or system failure (Perrow 1984). Normal Accident Theory simply states that accidents are normal, and regardless of the safety theme deployed, which are unavoidable. Sagan warned against believing that any system can be made "perfectly reliable." Sagan's arguments stem from examples that integrate features of human behavior from the high reliability organization such as:

- Common-mode errors – an error caused because within a system there is always a probability that components not designed to interact with one another, can.
- Social shirking – an error caused when individuals of the high reliability organization have faith or believe that others will make up for their inaction.
- Diffusion of responsibility – an error caused when individuals of the high reliability organization know each other's roles, and thus, unilaterally augment their individual roles resulting in an overall reduction in reliability.
- Overcompensation – an error caused when individuals of the high reliability organization take risks because of their knowledge of redundant safety features (Sagan 2004, p. 945).

The High Reliability Organization Project acknowledged the improbability of achieving a perfectly reliable system. However, the High Reliability Organization Project noticed that organizations responsible for engineered systems and operations of heightened consequence in the event of failure appeared to avoid error and catastrophe at an above normal rate, and that this demanded attention (LaPorte 1996). The project members were driven by exploring the following question:

How are organizations responsible for high hazard systems able to avoid catastrophe at a greater than normal rate?

This question is especially pertinent to the Nuclear Security Enterprise. Since the advent of the nuclear weapon over 75 years ago, there have been 32 documented *broken arrows*[5], or near catastrophic accidents (Schlosser, 2015 p. 327). "No United States Nuclear Weapon accident has involved an inadvertent nuclear detonation of any yield (i.e., no *blinding white flash*) (Wolfgang 2012)." However, as a result of the near accidents in the 1950s and 1960s, the safety theme for nuclear weapons evolved into what is known today as the Walske Criteria. The Walske Criteria for nuclear weapons have been in place since 1968 and "set the following parameters for safety prior to launch in *normal* and *abnormal* environments. Those parameters being:

1. In normal storage and operational environments, the probability of nuclear yield greater than 4 pounds equivalent trinitrotoluene shall not exceed one in one billion per warhead lifetime.
2. In abnormal environments as described in the system Stockpile-to-Target sequence the probability of nuclear yield greater than four pounds equivalent trinitrotoluene shall not exceed one in one million per warhead exposure to the environment or accident (Wolfgang 2012)."

When the High Reliability Project group of researchers at the University of California, Berkeley noticed some high hazard organizations were successfully operating greater than normally expected, "they found absent from the literature any discussion on the idea that some organizations could not fail at all as an error would be so damaging that it would kill the industry altogether (Bourrier 2011)." As LaPorte and Consolini were challenged with the inability to theoretically explain how organizations responsible for high consequence engineered systems could operate with extraordinary levels of safety they posited the High Reliability Theory (LaPorte and Consolini 1991, LaPorte 1996). The High Reliability Organization Project came up with a High Reliability Theory as a means to examine in more depth the logic of Normal Accident Theory. High Reliability Theory does not contend that accidents will not occur but recognizes that organizations do exist that are responsible for exceptionally high hazard systems that must and are performing at levels greater than what is normally expected.

In order to continue meeting these extraordinary levels of safety, high reliability systems must be designed with significant redundancy. Redundancy theory purports that independent unreliable

[5] Schlosser defines a *broken arrow* as "an accident that caused the unauthorized launch or jettison of a weapon, a fire, an explosion, a release of radioactivity, or a full-scale detonation was a Broken Arrow."

components engineered in thematic sequences may improve overall system reliability. While it is improbable to account for all potential failures, parts of the system that are identified as at-risk are intentionally designed with redundant features. Thus, high reliability theorists have observed redundancy as a requirement in both the high reliability engineered system as well as in the roles and responsibilities of the high reliability organization. Redundancy is an inefficient feature of an engineered system and organization, however, in order to achieve high reliability redundancy is an intentional design decision. For high reliability systems an accident is not allowable; nuclear weapons are designed through a safety lens of intentional redundancy that ensures the system always works when authorized for use by the President and never otherwise (Sandia National Laboratories 2015). "Even a small nuclear weapons accident that involved nuclear yield would be catastrophic to the local community, the operation of the nuclear weapon complex, and the world's confidence in the United States' ability to safely maintain a sustainable deterrent (Wolfgang 2012)."

The high reliability organizations responsible for the high reliability systems are composed of a complex mix of high functioning interdependent public-private partnerships. This network is characterized by intricate horizontal and vertical linkages of high coordination and communication (LaPorte and Consolini 1991). In the 1940s, the United States Government innovated a "mechanism to focus scientific and engineering expertise on pressing national security challenges that demanded intense, sophisticated, and sustained technical talent (Hruby et al. 2011)." This mechanism is called a Federally Funded Research and Development Center. As of Fiscal Year 2024, there are 43 Federally Funded Research and Development Centers in the United States, of which four are for-profit industrial firms. Of these four, three are the design laboratories of the Nuclear Security Enterprise—Sandia National Laboratories, Los Alamos National Laboratory, Lawrence Livermore National Laboratory (National Center for Science and Engineering Statistics 2024). This group has been the design element of the Nuclear Security Enterprise since the 1940s as a strategy to integrate cutting edge industry capabilities and practices. On May 13, 1949, President Truman told the President of AT&T, Leroy Wilson, that "you have here an opportunity to render an exceptional service in the national interest" in reference to the request for AT&T to manage Sandia National Laboratories (Johnson 1997). To this day, the inspired motto of Sandia National Laboratories is "exceptional service in the national interest" accomplished through high functioning interdependent public-private partnerships.

High reliability organizations must have a culture that praises error reporting. This culture must actively anticipate and explore all potential pathways of failure, not accepting approaches to learning through trial and error that is characteristic of lower reliability organizations, but rather depending on lessons learned and a continuous base of expertise (Wildavsky 1988, Bourrier 2011). Examples of catastrophic accidents due to error include the nuclear reactor accident at Chernobyl, the Union Carbide plant at Bhopal, and the explosion of the National Aeronautical and Space Administration's space shuttles Challenger and Columbia (Roberts 1990). Both space shuttles Challenger (1986) and Columbia (2003) resulted from issues with the engineered system that were known by staff and management and were accepted risks. Investigations pointed the error on the culture of the high reliability organization, accepting technical risk on high consequence technology that ultimately resulted in catastrophe (Fuqua et al. 1986, Gehman et al. 2003). High reliability must be incorporated into the engineered system as well as within the culture of the organization and not just for safety, but for security and functional reliability as well.

Nuclear weapons like other high reliability systems, have incredible technical complexity requiring highly specialized expertise throughout the engineered lifecycle. The engineered lifecycle includes development engineering, production, operation and support, maintenance, transportation, storage, and disposal. This engineered lifecycle must ensure that the system is safe, but also secure and functionally reliable. If United States nuclear weapons can be reliably maintained, safeguarded, etc. into the future, there are debatable highly complex technical questions that exceed existing scientific knowledge (Herron and Jenkins-Smith 2005). High reliability systems operate every day, and society benefits from their existence. However, when an issue does arise on a high reliability system, it is the expert with technical know-how that is depended on to investigate and explain the cause (Shotts 1994). This cause is almost always from the unavoidable issue of human fallibility (Fuqua et al. 1986, Gehman et al. 2003, Roberts 1990).

The complex design of high reliability engineered systems results in highly restricted or closed settings or forums within which debate on policy and decision-making and evaluation of implementation takes place in the United States Government (e.g., Congress). This is especially true for nuclear weapons systems where the sensitivity to national security reduces the availability of policy-relevant data and the technical complexity create an especially large scientific knowledge gap leading to narrower participation by general members of the public as well as within Government settings (Herron and Jenkins-Smith 2005). "A successfully closed forum becomes, in a sense, its own analytic microcosm; its work cannot be critically debated and verified or rejected by the excluded members of the subsystem (Jenkins-Smith 1990, p. 102)."

In the case of nuclear weapons policy priorities, the evaluations of implementation of reforms are relegated to narrow sets of technical experts on closed teams that are almost entirely led by former elected officials, active and retired federal appointees, industry executives, as well as active and retired senior military officers funded and appointed by the President or Congress. Examples of closed nuclear weapon policy assessments include:

- Section 1632 of the United States Department of Defense Authorization Act, 1985 (Public Law 98-525) and Executive Order 12499 where President Reagan's Blue-Ribbon Task Group on Nuclear Weapons Program Management recommended a shift in policy priorities including a focus on cost efficiency. This team was led by Chairman William P. Clark the former Secretary of the Interior, former Assistant to the President for National Security Affairs, and former Deputy Secretary of State alongside Vice Chairman James R. Schlesinger, the former Secretary of Energy, former Secretary of Defense, former Chairman of the Atomic Energy Commission, and former Deputy Director of the Bureau of Budget (Clark et al. 1985).
- President Clinton's Foreign Intelligence Advisory Board assigned a special investigative panel in 1999 that investigated the adequacy of security at the United States Department of Energy. This team was led by the Honorable Warren B. Rudman, former United States Senator (New Hampshire), and Ms. Ann Z. Caracristi, former Deputy Director of the National Security Agency. The results of their investigation recommended and led to Public Law No. 106-65 NNSA Act Title 32 of the National Defense Authorization Act of 2000 leading to the creation of the semi-autonomous National Nuclear Security Administration.
- Section 3166 of the National Defense Authorization Act 2014, Congressional Advisory Panel on the Governance of the Nuclear Security Enterprise. The panel included Dr. Michael R. Anastasio, Director Emeritus of Los Alamos National Laboratory and Lawrence Livermore National Laboratory; Mr. Norman R. Augustine former Under Secretary and Acting Secretary of the Army and member of the United States Department of Energy Advisory Board; Retired United States Navy Admiral Kirkland H. Donald, and Retired United States Navy Admiral Richard W. Mies, among others.
- Section 319 of the Consolidated Appropriations Act, 2014. The United States Department of Energy Commission to Review the Effectiveness of the National Energy Laboratories. This commission was Co-Chaired by Dr. Jared L. Cohon, a former appointee to the Homeland Security Advisory Panel, former appointee to the Nuclear Waste Technical Review Board, former legislative assistant for energy and the environment, and distinguished academic; and Co-Chair T.J. Glauthier, a former appointed Associate Director of the Office of Management and Budget, former Deputy Secretary and Chief

Operations Officer of the United States Department of Energy, and former member of the Congressional Advisory Panel on the Governance of the Nuclear Security Enterprise.

Distinguishing between a high reliability system and organization is challenging due to their success relying on the tight interdependency of their individual features (Bourrier 2011). The ultimate point of interest of the High Reliability Project can be summarized with the following question:

> *"Would it be possible to deduce a number of principles that target not only the organizational design but also in a bolder manner the technological design itself?"*

Since the High Reliability Organization Project at Berkeley in the mid-1980s, the concept and theory of high reliability from engineering and social sciences perspectives have been challenged on the grounds that accidents are normal, and a perfectly reliable system is impossible to achieve (Sagan 2004). However, as the High Reliability Project initially identified, there are certain high consequence systems and organizations that appear to achieve substantively greater than normal reliability. The effectiveness of these systems and organizations are characterized by unique and critical features captured in the high reliability system and organization literature as listed in Table 2. It is important to note that the features of high reliability systems and organizations listed in Table 2 are highly interrelated and interdependent. It is the interaction of these features with one another that drives overall system and organization reliability.

Table 2. Features of High Reliability Systems and Organizations

Features of High Reliability Systems and Organizations
• Tightly integrated parts
• Closed policy and decision-making systems
• Design redundancy
• High functioning public-private partnerships
• Substantial reliance on expertise and lessons learned over trial and error
• A culture that praises error reporting and risk aversion
• Safety, security, and reliability, over economy
• Schedule effectiveness

The old adage "cost, schedule, and performance—pick two," relates to the incredible challenge organizations face with respect to balancing cost, schedule and performance requirements or standards. However, high reliability systems cannot fail and as such are associated with heightened design complexity, that is a known driver of both cost and time. Thus, when applying the logic of this adage to high reliability systems and organizations it becomes "cost, schedule, and performance—*pick one*" because performance is non-negotiable.

Cost, schedule, and performance can be seen as desired outcomes, that must be balanced within a framework of tradeoffs against each other as illustrated in Table 3. The boxes marked with an (X) are selected, and the boxes left blank are traded off with a described outcome.

Table 3. Product Acquisition Tradeoffs

Product Acquisition Tradeoffs			
Cost	**Schedule**	**Performance**	**Outcome**
X	X		Low cost and short schedule, lower performance
X		X	Low cost and high performance, longer schedule
	X	X	Short schedule and high performance, higher cost

This *balance* is at the center of the primary concerns of the President's Blue Ribbon Task Group in 1985 regarding the shifting policy priorities of the Nuclear Security Enterprise , as identified in *Chapter 1.1*:

1. Ensuring the preservation of capabilities of the Nuclear Security Enterprise and the national laboratories while simultaneously disinvesting in engineering innovation for new nuclear weapon systems.
2. Heightened trepidation that the introduction of management controls for cost efficiency may disrupt the delicate balance between competing concerns for performance and safety or inhibit innovation.

To the first concern, in 1985 it is not evident that any research was completed with respect to the enormous complexity inherent in the strategy of sustaining a nuclear weapon system as opposed to innovating new ones. Given that in 1985, such a strategy had not been implemented before on a comparable high reliability system, such research may not have been defensibly feasible. This coincides with the second concern and its interaction with the first. Conceptually, the strategy of sustainment of capabilities might have led this expert group in 1985 to believe that management controls for cost efficiency was feasible. As Browning identified through research on complex system development, simply maintaining a complex systems performance over time makes reducing time or cost problematic and would require an unprecedented level of sophisticated planning and control information (Browning 1998).

Coincidentally, The Congressional Advisory Panel on the Governance of the Nuclear Security Enterprise disclosed that the performance of the nuclear deterrent in the Post-Cold War Era is undiminished, safe, secure, reliable, and efficacious, yet governance for decades has been inefficient and ineffective (Augustine et. al 2014). Within this report, issues related to management controls described herein are cited over 300 times.

Thus, the primary theoretical research questions explore high reliability systems and organizations within the framework of tradeoffs of cost and schedule as they relate to non-negotiable performance features. These questions include:

- *How do the features of high reliability systems and organizations that enable heightened performance make trades between priorities of cost and schedule?*
- *How does the old adage of "cost, schedule, performance pick two" apply and not apply to high reliability organizations?*
- *Can an organization be considered high reliability if it cannot meet urgent schedules?*
- *Can an organization be considered high reliability if it is not on budget or cost efficient?*

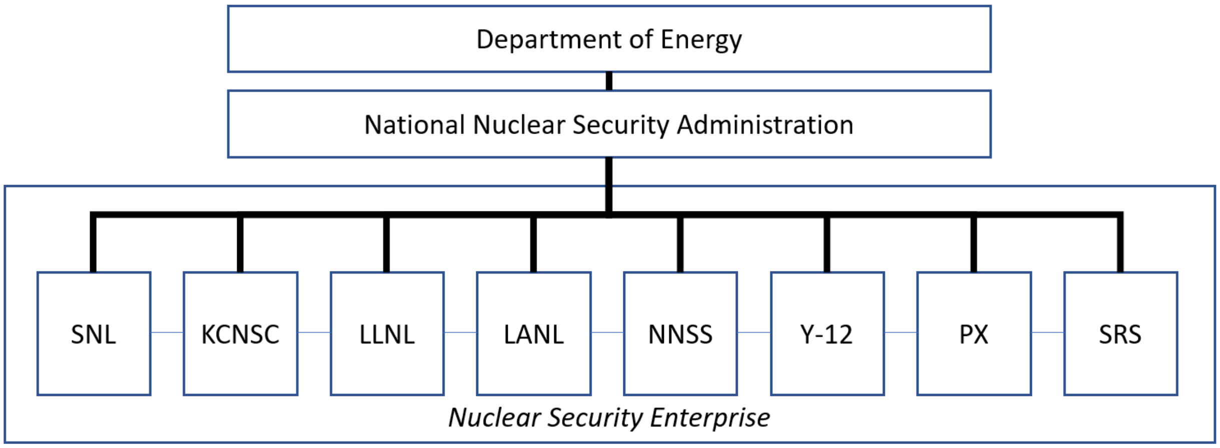
Browning's investigation of complex system development determined that there must be congruency between the policy priorities of the United States Government with respect to the engineered system and the balance of cost, schedule ,and performance (Browning 1998). The United States Government is unwavering it its values of safety, security, and reliability for the nuclear deterrent. It is within the exploration of the shift in policy priorities from innovation and schedule effectiveness to sustainment of capabilities and cost efficiency from the Cold War Era to the Post-Cold War Era that this dissertation provides a unique empirical approach and theoretical perspective to add to the body of knowledge.

To examine the empirical and theoretical research questions, a high reliability organization—Sandia National Laboratories—of the Nuclear Security Enterprise will be utilized to develop a unique approach to examine the implications of shifting priorities from the Cold War Era to the Post-Cold War Era.

1.4. Nuclear Security Enterprise and Sandia National Laboratories

The United States Nuclear Security Enterprise is one of the networks responsible for nuclear weapons. The Nuclear Security Enterprise is governed by the National Nuclear Security

Administration—a semiautonomous agency within the United States Department of Energy—responsible for maintaining the nuclear weapons stockpile, monitoring and promoting nonproliferation, powering the nuclear Navy, and responding to nuclear and radiological emergencies[6]. The Nuclear Security Enterprise is comprised of eight Management and Operating contractors[7] responsible for eight high reliability organizations, illustrated in Figure 3.



SNL	Sandia National Laboratories	NNSS	Nevada National Security Site
KCNSC	Kansas City National Security Campus	Y-12	Y-12 National Security Complex
LLNL	Lawrence Livermore National Laboratory	PX	Pantex Plant
LANL	Los Alamos National Laboratory	SRS	Savannah River Site

Figure 3. United States Nuclear Security Enterprise Governed by the National Nuclear Security Administration

One of the eight high reliability organizations is Sandia National Laboratories. Sandia National Laboratories is a Federally Funded Research and Development Center that collaborates broadly with government agencies, industry, and academic organizations in the strategic areas of nuclear weapons, energy, and national and global security. Within the Nuclear Security Enterprise, Sandia National Laboratories has some of the highest consequence responsibilities as the design agency for approximately 97% of the design of modern nuclear weapon components, weaponization of the

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[6] From DOE NNSA website https://www.energy.gov/nnsa/about-nnsa last accessed February 2021.

[7] Management & Operating contracts are agreements under which the government contracts for the operation, maintenance, or support, on its behalf, of a government-owned or -controlled research, development, special production, or testing establishment wholly or principally devoted to one or more of the major programs of the contracting agency. 48 C.F.R. § 17.601 (2018). The sites that comprise the Nuclear Security Enterprise are the Kansas City National Security Campus in Missouri, Lawrence Livermore National Laboratory in California, Los Alamos National Laboratory in New Mexico, Nevada National Security Site, Pantex Plant in Texas, Sandia National Laboratories primarily in New Mexico, Savannah River Site in South Carolina, and Y-12 National Security Complex in Tennessee.

physics package, and overall systems engineering and integration. Sandia National Laboratories is responsible for nuclear weapon systems and components over their entire lifecycle, from original design through final dismantlement and disposal. Nuclear weapon systems have some of the most rigorous technical requirements in defense as they sit dormant for decades, must be immediately available when needed, must always work when authorized by the President of the United States—and must never detonate otherwise.

This dissertation develops a unique approach to generate empirical data from Sandia National Laboratories to gain insight into how over extended periods of time, changes in reforms for management controls in the Post-Cold War Era impacted the distribution of resources and how they may relate to indicators of schedule effectiveness and cost efficiency of the Nuclear Security Enterprise.

1.5. Research Outline

Nuclear weapons are unique high reliability systems managed by high reliability organizations whose success depends on certain critical features enabling them to strive and sustain near error-free operations. Nuclear weapons policy and implementation depend on highly technical expertise due to the catastrophic implications of system failure—this results in a very closed policy system. This environment places more responsibility on the organizations responsible for policy implementation to maintain a continuous self-evaluation capability.

High reliability organizations must be self-evaluating, stiving to "clarify goals, relating them to different mechanisms of achievement, creating models (sometimes quantitative) of the relationships between inputs and outputs, seeking the best available combination (Wildavsky 1972)." The balance and tradeoffs between cost, schedule, and performance is enduring and nests itself differently within differing policy domains responsible for various national security systems. This balance had a notable change across the Nuclear Security Enterprise from the Cold War Era to the Post-Cold War Era as policy priorities shifted from innovation and schedule effectiveness to sustainment and cost efficiency.

While it is challenging to discover data from the Cold War Era, there is practical data available in the Post-Cold War Era to evaluate the implications of various government reforms over time as they relate to goals of policy priorities. During the Cold War Era, the "government never tried to track all nuclear weapon costs either annually or over time and as a result records in this regard are extremely spotty and in numerous instances non-existent (Schwartz 1998)." Further complicating efforts with data discovery from the Cold War Era, is the loss of the experts that operated in the historically closed system that had hands-on knowledge of how that system functioned (Shotts 1994, Holmes 2016). Given the length of the Post-Cold War Era, the same complication of the Cold War Era is beginning to manifest itself again as the Nuclear Security Enterprise is challenged with an aging workforce and increasing rates of retirement and attrition (National Nuclear Security Administration 2016).

While Nuclear Deterrence policy decision-making occurs within a markedly closed system of technical experts, the political inputs throughout the Post-Cold War Era align with recommendations of typical government-wide one-size-fits all applications and compliance with identified industry best practices. From the panel to Track and Assess Governance and Management Reform in the Nuclear Security Enterprise as their first major recommendation for success—"successful performance in the long run will always require disciplined compliance with best management practices and continued support from the Administrator and others in top management to offset any resistance that can naturally arise (2020)." However, compliance and best management practices must balance amongst goals related to cost, schedule, and performance as nuclear deterrence is the bedrock of United States national security, serving as the backstop and foundation of United States national defense, the defense of United States allies since 1945, and underwrites every United States military and diplomatic mission (Lopez 2019, United States Department of Defense 2008). Nuclear weapon systems serve as a deterrent that protects the United States homeland and allies abroad (United States Department of Defense 2018). The importance of the nuclear deterrent to United States national security is never understated. The nuclear deterrent gives the Unites States the ability to hedge against an uncertain future (United States Department of Defense 2018).

The framework for this research is established through the integration of existing concepts found in the implementation, project and organizational management, and high reliability system and organization literatures. While the concepts are operationalized uniquely, care is given to improve external validity discussed in Chapter 2 Methods. This research contributes to the literature by illustrating a unique quantitative approach to understanding how management controls reforms are experienced in practice. In addition, this research adds to the discussions regarding the need to customize policy directives particular to an agency based on their responsibilities as well as the critical necessity for continuous organizational self-evaluation especially in highly specialized closed policy systems.

Chapter 2. Methods

To evaluate the implications of the political inputs of reforms for management controls during the Post-Cold War Era of the Nuclear Security Enterprise, this dissertation explores the output behavior of labor resource allocation on the Nuclear Deterrence Mission at Sandia National Laboratories. The primary empirical data is collected from Sandia National Laboratories over a 21-year timeframe from Fiscal Years 2003 – 2023. The observational data for evaluation includes charged labor hours to the Nuclear Deterrence Mission by Technical Resources and Management Controls Resources responsible for Mission Execution and Mission Support respectively.

Through the Cold War Era, and until this time, the workforce at Sandia National Laboratories has been split amongst two primary groups—Member of Technical Staff and Member of Laboratory Staff (Johnson 1997). The former being the group responsible for the Mission Execution and the latter being associated with Mission Support. For the Members of Technical Staff, they are combined into a single job family called Research and Development and separated by discipline and degree (i.e., Mechanical Engineering, Electrical Engineering, Chemistry, etc.). Thus, throughout this research, Technical Resources refer to the individual labor resources responsible for Mission Execution made up of Members of Technical Staff classified within the Research and Development job family.

Members of Laboratory Staff are made up of multiple job families under an umbrella of Business & Operations (Sandia National Laboratories 2023). The Members of Laboratory Staff serve both indirect roles to maintain the operations of the organization as well as direct roles in serving as Mission Support to the Technical Resources on the various national security mission areas. Thus, throughout this research, Management Controls Resources refers to the individual labor resources that provide Mission Support to the Technical Resources responsible for Nuclear Deterrence Mission Execution.

Figure 4 illustrates the relationship of Mission Execution Technical Resources to Mission Support Management Controls Resources in the execution of the United States Nuclear Deterrence Mission at Sandia National Laboratories.

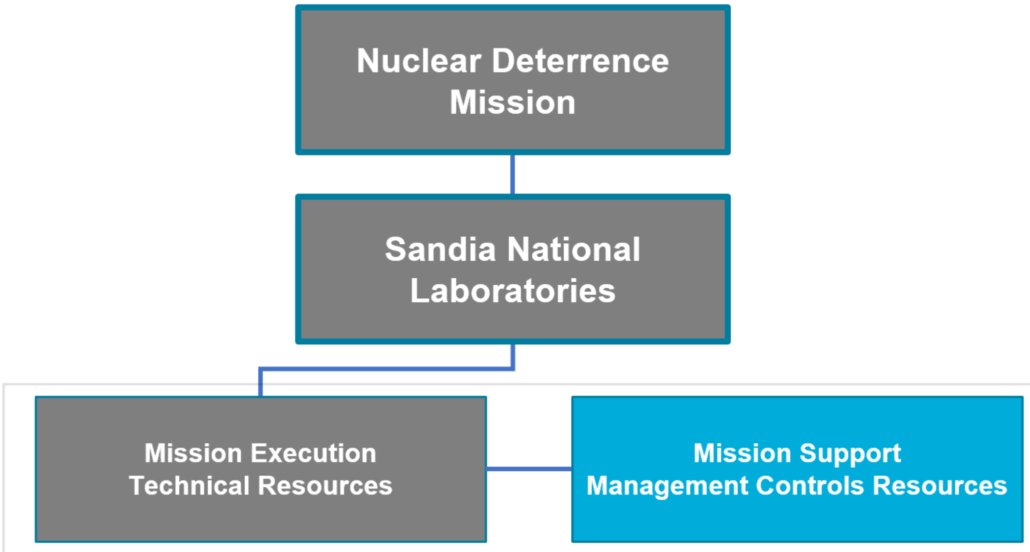


Figure 4. Management Controls Resources and Technical Resources Relationship Heuristic

The distinction at Sandia National Laboratories between Mission Execution Technical Resources and Mission Support Management Controls Resources is very clear due to the highly technical and consequential requirements of working on nuclear weapons. Delineating variables for these resources includes credential levels and types, as well as roles and responsibilities[8].

To work on nuclear weapon systems, emphasis at Sandia National Laboratories—and one of the prominent features of high reliability organizations discussed in *Chapter 1.3*—is placed on technical expertise as indicated by credential levels. In 1981, approximately 75% of Technical Resources at Sandia National Laboratories had a Master's or PhD (Johnson 1997). As of Fiscal Year 2023, 77% of Technical Resources working on the Nuclear Deterrence Mission at Sandia National Laboratories have achieved a Master's or PhD in Science, Technology, Engineering, and Mathematics[9] in disciplines such as Mechanical Engineering, Computing , Electrical Engineering, Physics, Chemical Engineering, Chemistry, Math, Nuclear Engineering, and Aerospace Engineering among others as illustrated in Table 4.

[8] In professional discussions with colleagues from several other Federally Funded Research and Development Centers, credential levels and types, as well as roles and responsibilities were identified as key critical characteristics that would be required to replicate the data for related research.

[9] The term science, technology, engineering or mathematics field means a field included in the United States Department of Education's Classification of Instructional Programs taxonomy within the two-digit series or successor series containing engineering, biological sciences, mathematics, and physical sciences, or a related field. In general, related fields will include fields of study involving research, innovation, or development of new technologies using engineering, mathematics, computer science, or natural sciences (including physical, biological, and agricultural sciences).

This research further delineates Nuclear Deterrence Mission Support Resources into the subcategory of Management Controls Resources—the resource of research interest—that work directly on the Nuclear Deterrence Mission, illustrated in Table 5. Management Controls Resources respond and directly implement management controls reforms. Management Controls Resources as described herein, are concerned with the coordination and application of formal processes, policies, procedures, and tools for planning, monitoring, controlling, and reporting on budget, schedule, risk, and other formal controls (Project Management Institute 2017, GAO-20-631, GAO-20-123, Construction Industry Institute 2023). Formal management controls carry authority, incentives, and consequences, that are typically from federal requirements, Congressional legislation, executive orders of the President, or accepted recommendations for implementation from government audits and investigative panels (Franklin 2001). Thus, Management Controls Resources are Mission Support to the Nuclear Deterrence Mission Technical Resources at Sandia National Laboratories.

Table 4 also includes a measure of *type of credential*, which measures terminal degrees that are either categorized or not categorized as Science, Technology, Engineering, and Mathematics for Technical Resources and Management Controls Resources working directly on the Nuclear Deterrence Mission at Sandia National Laboratories. *Type of credential* provides further distinction between Technical Resources and Management Controls Resources and serves as an indicator of the heightened focus on technical expertise required to work on high reliability systems.

Table 4. Sandia National Laboratories

Nuclear Deterrence Mission Credential Levels and Types as of Fiscal Year 2023

Sandia National Laboratories Nuclear Deterrence Credentials		
Credential Levels and Types	Mission Execution Technical Resources	Mission Support Management Controls Resources
<Bachelors	**3%**	**2%**
Bachelors	**20%**	**38%**
Masters	**59%**	**60%**
PhD	**18%**	**0%**
Type of Credential		
Non-STEM	**6%**	**84%**
STEM	**94%**	**16%**

Another distinction between Nuclear Deterrence Mission Technical Resources and Management Controls Resources at Sandia National Laboratories is demonstrated through the Responsible, Accountable, Supportive, Consulted, Informed Roles and Responsibilities Matrix in Table 5.

- **Responsible** – The organization (s) or person (s) who perform the action/task
- **Accountable** – The organization (s) or person (s) who is/are held accountable that the action/task is completed
- **Supportive** – The organization (s) or person (s)who provide support to those accountable that the action/task is completed
- **Consulted** – The organization (s) or person (s) who is/are consulted before performing the action/task
- **Informed** – The organization (s) or person (s) who is/are informed after performing the action/task

On nuclear weapons and other high reliability systems, the Technical Resources maintain responsibility and accountability for almost all tasks and activities of mission scope. The Management Controls Resources support the Technical Resources in meeting the intent of these tasks and activities as required per management controls reforms.

The following is an example narrative that aligns to the Roles and Responsibilities Matrix in Table 5 using a hypothetical Nuclear Deterrence Mission Radar Component Development effort at Sandia National Laboratories:

The Mission Support Management Controls Resources implement management controls reforms to support Mission Execution Technical Resources. In order to develop a radar cost estimate, a radar schedule, a radar risk register, etc. the Management Controls Resources must communicate with the responsible Technical Resources. This communication includes coordinating meetings, collecting technical inputs from the responsible Technical Resources, managing the data in the tools, maintaining processes and procedures, and generating mission execution reports.

Table 5. Sandia National Laboratories Nuclear Deterrence Mission Roles and Responsibilities Matrix

Sandia National Laboratories Nuclear Deterrence Roles and Responsibilities Matrix		
Radar Component Tasks	Technical Resources	Management Controls Resources
Design Definition	**Responsible/Accountable**	**Supportive**
Design Requirements	**Responsible/Accountable**	**Supportive**
Radar Schedule	**Responsible/Accountable**	**Supportive**
Radar Cost Estimate	**Responsible/Accountable**	**Supportive**
Radar Budget Estimate	**Responsible/Accountable**	**Supportive**
Radar Resourcing	**Responsible/Accountable**	**Supportive**
Radar Risk		
Identification	**Responsible/Accountable**	**Supportive**
Evaluation and Assessment	**Responsible/Accountable**	**Supportive**
Mitigation	**Responsible/Accountable**	**Supportive**
Monitoring and Controlling	**Responsible/Accountable**	**Supportive**
Closeout	**Responsible/Accountable**	**Supportive**

On this hypothetical Nuclear Deterrence Mission Radar Component Development effort, Management Controls Resources are not responsible, nor expected know how to design a radar. The Management Controls Resources are not responsible for identifying technical radar design and development risk, nor the identification of risk probability and consequence. The Management Controls Resources are expected to coordinate the meetings to collect the risk data from the Technical Resources, input the data into the appropriate tools, manage the tools, and generate required progress reports in support of the mission and in alignment with management controls reforms.

Figure 5 conceptualizes how the Nuclear Deterrence Roles and Responsibilities Matrix is operationalized into discrete activities in a schedule for the Nuclear Deterrence Mission Component Development effort to comply with management controls reforms. In Figure 5, Management Controls Resources are assigned to the Management Controls activity for the Radar Component. The Management Controls activity is not a discrete activity on the critical path[10], it is considered a Level of Effort task (Townsend et al. 2015). The Technical Resources are assigned to the Development

[10] The sequence of activities that determines the duration of the effort. Any delay in these activities will delay the delivery of the product or service.

Engineering activities—Design, Fabrication, and Test—that are on the critical path to the milestone COMPLETE on row 8 of Build 1.

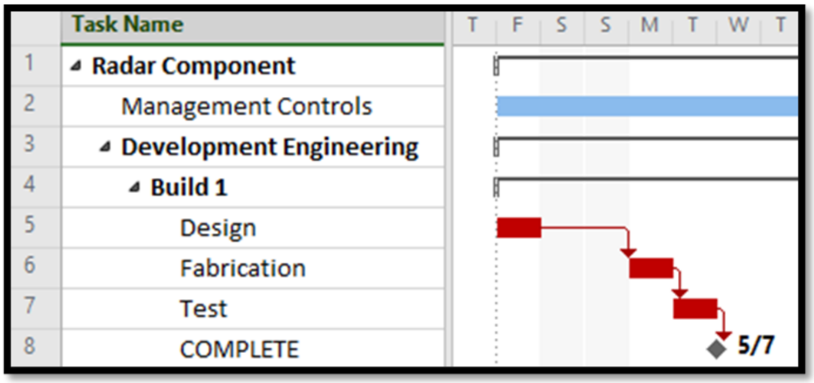


Figure 5. Nuclear Deterrence Mission Activities for Technical Resources and Management Controls Resources

Figure 5 illustrates the interdependent or *routine* relationship that Technical Resources have to Management Controls Resources through schedule activities or tasks. Thus, when management controls reforms are augmented, the implementation impacts this routine. Moynihan and Kroll (2015) define routines as "generative systems that produce recognizable, repetitive patterns of interdependent actions, carried out by multiple actors (Pentland and Feldman 2008, p. 235)." The challenge is developing an approach to meaningfully observe how reforms, and more specifically management controls reforms, impact this interdependent or routine relationship. This is not a unique challenge to Public Administration research. Moynihan and Kroll describe assessing government management reforms as a classical analytical problem in the field (Moynihan and Kroll 2015).

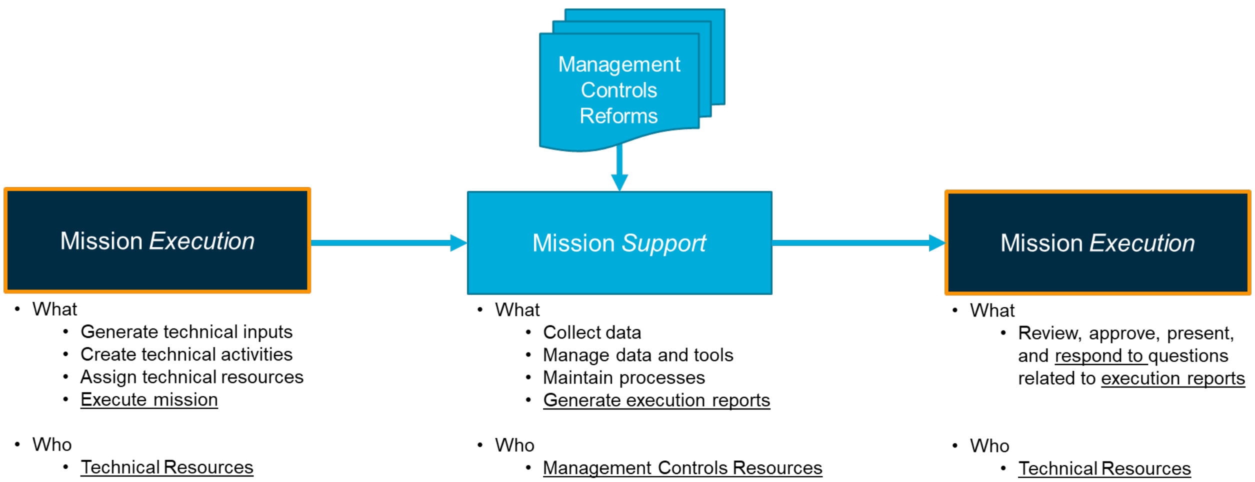
Figure 6 illustrates an operational application of how the reforms-as-routines concept of management controls reforms is experienced on the Sandia Nuclear Deterrence Mission (Josserand and Young 2019). As Management Controls Reforms are augmented, they directly impact the Mission Support Management Controls Resources. Throughout the Post-Cold War Era, Management Controls Reforms have included changes to but not limited to:

- Oversight management (GAO -07-36, GPRA Pub. L. No. 103-62[11])
- Financial management (GAO-07-36, GAO-09-385)
- Risk management (GAO-11-387)

[11] Government Performance and Results Act (GPRA) Modernization Act of 2010, Pub. L. No. 111-325, 124 Stat. 3866 (Jan. 4, 2011)

- Budget and cost management (FAR 2006[12], GAO-16-218)
- Schedule management (GAO-16-218, GAO-23-106059)

Since the Management Controls Resources depend on Technical Resources to generate the required technical inputs, it indirectly impacts the Technical Resources that are simultaneously responsible and accountable for the execution of critical path Nuclear Deterrence Mission activities as illustrated in Figure 6. On the back end, as outputs related to the Management Controls Reforms are completed, they must be reviewed prior to being released by Technical Resources, and any questions subsequent to release are also answerable by Technical Resources.



Source: Moynihan and Kroll 2015

Figure 6. Nuclear Deterrence Mission
Management Controls Reforms-to-Routines Conceptualization

The Technical Resources generating inputs and executing Nuclear Deterrence critical path activities are the same Technical Resources reviewing output reports and responding to subsequent inquiry. So, while the political inputs that augment Management Controls Reforms are not directed towards Technical Resources nor intended to disrupt the execution of Nuclear Deterrence Mission activities, it is important for policy and decision-makers as well as Public Administration scholars to understand the potential indirect implications of reforms-as-routines on the delicate balance of critical and constrained labor resources.

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[12] Federal Acquisition Regulation (FAR), Major Systems Acquisition, 48 C.F.R. part 32, subpart 34, Earned Value Management System

Government policy is often not written in a way that requires a well thought out approach to quantitatively assess and evaluate performance, especially one-size-fits all reforms (Pressman and Wildavsky 1984). The United States Government Accountability Office in their most recent assessment of agency reform across the Nuclear Security Enterprise, found that high risk reform areas "did not align with leading practices for setting goals, using data and evidence, monitoring, addressing longstanding management challenges, and engaging key stakeholders. Without establishing goals or processes to collect data and evidence, the National Nuclear Security Administration will not be able to monitor the effectiveness of implemented and ongoing reforms (GAO-25-106675, p. 44)." This assessment did not identify what effective implementation of reforms would look like, only that there was a lack of foundational processes to collect data for performance measurement purposes. According to the Commission to Review the Effectiveness of the National Energy Laboratories (Cohon et al. 2015), this is endemic throughout the Post-Cold War Era implementation of management controls reforms for the Nuclear Security Enterprise.

There exists substantive literature regarding the analytical challenge in Public Administration of assessing the performance of government reforms. To this end, the challenges identified across the Nuclear Security Enterprise are common across other enterprises, policy domains, and governments. A common expectation is that policy makers should clearly state goals and lay out detailed plans with comprehensive management controls aligned to desired outcomes prior to implementation. However, it may be that the policy priorities at the start were not feasibly implementable, or that during implementation—especially on policies whose implementation endures over several decades—events and learning occurred, and reform produced further reform (Brunsson 2006). "Many, perhaps most, constraints remain hidden in the planning stage, and are only discovered in the implementation process (Pressman and Wildavsky 1984, p. 166)." Thus, as discoveries, learning ,and change occur throughout the implementation process, there may be challenges with maintaining causal-tractable mechanisms by which to measure performance—this is especially the case with the Nuclear Security Enterprise. The Post-Cold War Era spans over several decades, and within this timeframe, there have been numerous-recurrent changes made to policies and political priorities related to management controls reforms.

Long and Franklin (2004) describe an overarching model from the policy literature based on the concept of the Black Box Model (Easton 1965) that can serve as a useful mechanism for understanding the implementation process. "Traditionally, this model has been used for analyzing the relationship between political system inputs, agency processing, and policy outputs (Long and Franklin 2004, p. 312-313)." Long and Franklin (2004) operationalized the Black Box Model to qualitatively investigate the related inputs, agency processing, and outputs of the Government and Performance Results Act. This research develops a unique approach that integrates the Moynihan and Kroll (2015) reforms-as-routines concept from Figure 6 as a heuristic for agency processing, into an overarching Long and Franklin (2004) Black Box Model of Implementation that enables the evaluation of the implications of political input changes in reforms related to management controls in the Post-Cold War Era, to the output distribution of Technical Resources and Management Controls Resources. This Black Box Model of Implementation is illustrated in Figure 7.

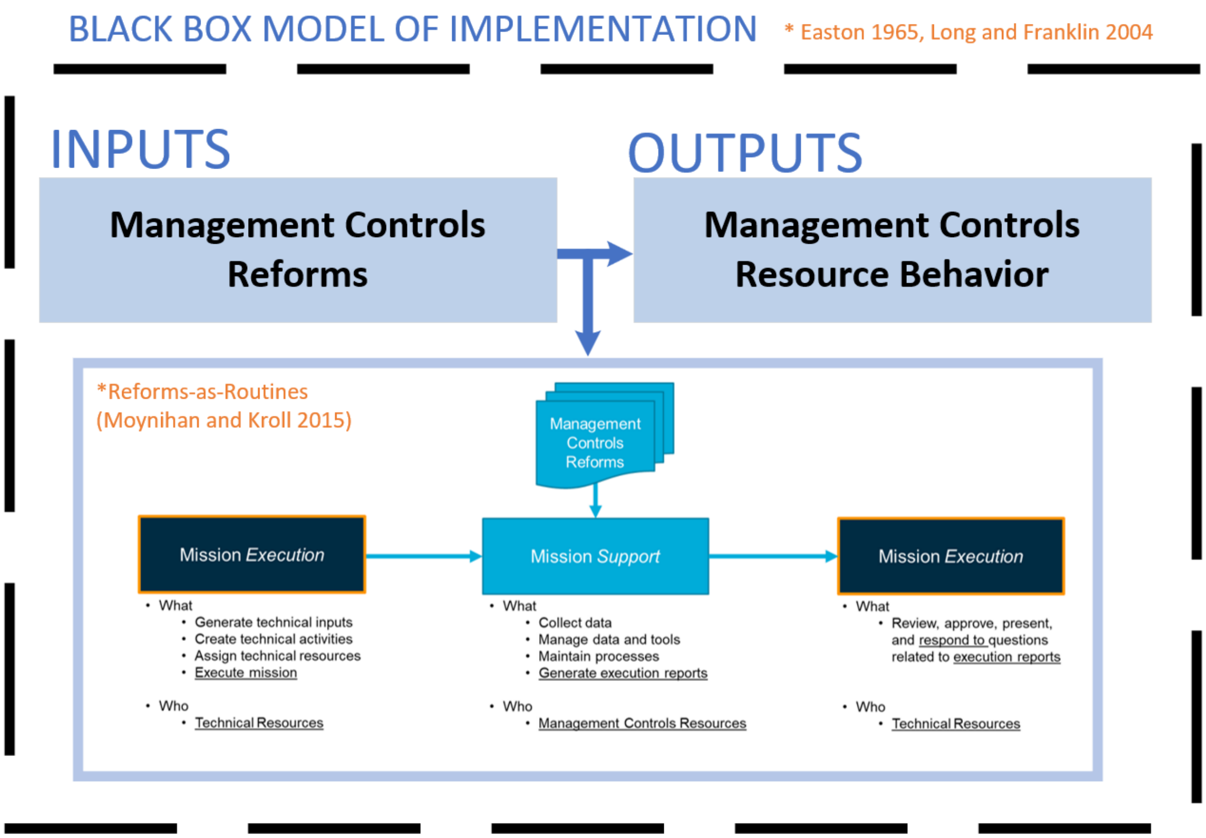

Figure 7. Black Box Model of Implementation

This dissertation develops a unique approach to analyze the relationship of management controls reforms to an empirical output behavior of defined labor resources on the Nuclear Deterrence Mission at Sandia National Laboratories over a 21-year timeframe utilizing the Black Box Model of Implementation illustrated in Figure 7. The primary empirical data is collected for Fiscal Years 2003 – 2023. The observational data for evaluation includes the growth in charged labor hours to the Nuclear Deterrence Mission by Technical Resources and Management Controls Resources responsible for Mission Execution and Mission Support respectively.

Finally, the model includes an observational table from Fiscal Year 2007 through Fiscal Year 2023 that illustrates changes to projected and actual schedule outcomes of Nuclear Deterrence Modernization Programs published by formal government sources—most prominently, a statutorily required document called the Stockpile Stewardship and Management Plan[13]. The schedule outcomes are based on two designated major milestones on Nuclear Deterrence Modernization Programs—First Production Unit, and Last Production Unit (Department of Defense 2020). The First Production Unit milestone occurs when the Military Department and/or the Nuclear Weapons Council accepts the design and the National Nuclear Security Administration verifies the first produced weapon meets the design requirements (Department of Defense 2020). The Last Production Unit is the successful delivery of the last produced weapon that meets design requirements. Together, the First Production Unit and the Last Production Unit major milestones are indicators the government utilizes to assess the effectiveness of Nuclear Security Enterprise schedule performance (GAO-23-104661).

Prior to Chapter 3. Data and Analysis, it is important to elaborate on some of the notable limitations of this research. First, the empirical labor resource data comes from a multi-mission national security organization—Sandia National Laboratories. Sandia National Laboratories is a matrix organization that shares resources across multiple national security mission areas to optimize effectiveness and efficiency of integrated deterrence[14] (Biden 2022, p. 22). The empirical data is generalized from Sandia National Laboratories Nuclear Deterrence Mission area whose scope includes parts of every phase of the engineering lifecycle and is shared across other organizations. This inhibits causal relationships and internal validity.

The data comes from a single organization. The small sample size may be challenged on the grounds of representativeness of the broader population. Furthermore, the small sample size inhibits statistical testing also further impacting internal validity.

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13 The National Nuclear Security Administration publishes the Stockpile Stewardship and Management Plan annually, either as a detailed report or summary, in response to statutory requirement 50 United States Code § 2523 to support the President's Budget Request to Congress for Weapons Activities (National Nuclear Security Administration 2025)."

14 Integrated deterrence is the seamless combination of capabilities to convince potential adversaries that the costs of their hostile activities outweigh their benefits. It entails integration across domains, regions, spectrum of conflict, the United States Government, and allies and partners.

The Black Box Model is specifically utilized to infer the relationship of the independent variables— management control reforms—over time to the quantitative output measure of the dependent variables—Management Controls and Technical Resources. However, the lack of a direct activity-based relationship and tracking mechanisms of management controls reforms to resources may contribute to errors in measurement and reduce confidence in internal validity.

The descriptions of roles, responsibilities, and scope-activities, as well as credential levels and types related to the dependent variables—Management Controls and Technical Resources—are intended to improve the ability of other organizations to replicate the dataset and increase external validity. As other high reliability organizations build upon this framework and contribute to a more comprehensive dataset, internal validity will improve.

The author of this dissertation has been employed at Sandia National Laboratories for over 15 years and is an expert in the data and execution of Nuclear Deterrence Mission scope. However, this affiliation to the organization from which the empirical data is acquired should be noted and taken into consideration for the potential impact selection bias may have on internal validity. However, given that the aims of this dissertation are not to test for causal relationships, but to illustrate an exploratory framework to enable inferential observations may alleviate the threats of selection bias and internal validity.

This dissertation is an exploratory form of case study research that seeks to probe the primary empirical research question:

> *Over time, how have changes in reforms for management controls in the Post-Cold War Era impacted the distribution of resources across the Nuclear Security Enterprise?*

This exploratory case study selection was driven by the extensive efforts from United States Government Panels to articulate or demonstrate a response to the primary empirical question. The purpose of this dissertation is to "probe for new—but as yet unspecified—explanations (Seawright and Gerring 2008, p. 302)" related to the primary research question. The hope is that by defining a unique case study with enough depth, other institutions may find it interesting and surprising enough to attempt replication.

Lastly, this research is based on a high reliability organization responsible for the purported highest reliability engineered system in the world—United States nuclear weapons. This is important to consider for organizations that do not share features congruent with those identified herein that are typical of institutions responsible for high consequence engineered systems. However, due to the unique operationalization of the routines-to-reforms approach in generating a quantitative resource measure, it is unknown if the replication of this research on non-high reliability organizations would have similar or different resource behaviors. Thus, the high reliability organization aspect of this research is not a threat to external validity, but a caution without further investigation in assumptions of general applicability.

Chapter 3. Data and Analysis

This dissertation is focused on exploring the impact of changes in management controls reforms from the Cold War Era to the Post-Cold War Era on labor resources of the Nuclear Security Enterprise. This chapter will describe the operationalization of the Black Box Model of Implementation (as shown in Figure 7) that generates output empirical data for analysis. Furthermore, this chapter includes an observational table for analysis from Fiscal Year 2007 through Fiscal Year 2025 that illustrates changes to projected and actual schedule outcomes over the 19-year timeframe of Nuclear Deterrence Modernization Programs published by the United States Government.

Management controls reforms are the independent variable that serve as the input into the Black Box Model of Implementation. Other approaches tend to focus on analysis of a single management reform, developing approaches to connect a reform as an input to an output. However, this connection of single reforms to outputs within organizations that are simultaneously implementing multiple reforms, is methodologically difficult. Additional challenges include connecting management reforms to their explicit goals. As an example, one of the goals of the Government Performance and Results Act was to enhance managerial use of performance data, with mixed results (Moynihan and Kroll 2015). Thus, this dissertation does not attempt to discern individual management controls reforms, but instead, aggregates them at the organizational level as an input into the Black Box Model of Implementation.

The input of the aggregate management controls reforms is experienced at the organizational level utilizing the defined reforms as routines approach to generate the empirical output. The empirical output is a measure of charged labor hours of the two types of resources defined in Chapter 2 Methods—Management Controls Resources and Technical Resources. The empirical data illustrates the change in the labor resource behavior over the 21-year timeframe with Fiscal year 2003 serving as the baseline against which the calculation of every subsequent Fiscal Year through 2023 is measured against. Thus, the measures of Management Controls Resources and Technical Resources change through Fiscal Year 2023 are calculated as follows:

Management Controls Resources = Management Controls Resources Hours Fiscal Year n/Management Controls Resources Hours Fiscal Year 2003 Baseline

Technical Resources = Technical Resources Hours Fiscal Year n/Technical Resources Hours Fiscal Year 2003 Baseline

The output empirical measures from the operationalization of the Black Box Model of Implementation for the dependent variables of Management Controls Resources and Technical Resources are illustrated in Table 6. Fiscal Year 2003 is the baseline for both resource types at 1.0. Each subsequent fiscal year utilizes Fiscal Year 2003 as the baseline in order to generate a measure illustrating 20 fiscal years of resource behavior.

Table 6. Sandia National Laboratories Nuclear Deterrence Mission Resource Changes from Fiscal Year 2003 – Fiscal Year 2023

Sandia National Laboratories Nuclear Deterrence Mission Resource Behavior from Fiscal Year 2003 Baseline																					
Fiscal Year	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
MANAGEMENT CONTROLS RESOURCES	1.0	1.0	1.2	1.3	1.5	1.7	2.0	2.1	2.5	2.7	3.1	2.9	2.8	3.2	3.1	3.1	4.3	5.2	5.0	5.4	5.7
TECHNICAL RESOURCES	1.0	1.1	1.2	1.3	1.4	1.4	1.5	1.4	1.2	1.1	1.1	1.1	1.1	1.2	1.1	1.1	1.2	1.3	1.3	1.4	1.4

The labor hours utilized in the calculation of Table 7 include hours allocated directly to the execution of Nuclear Deterrence Mission funded activities by Members of the Workforce at Sandia National Laboratories. Table 7 does not include purchased subcontract labor that was subcontracted by Sandia National Laboratories to work directly on the execution of Nuclear Deterrence Mission funded activities. Furthermore, the data in Table 7 does not include indirect labor resources that do not work directly on the execution of the Nuclear Deterrence Mission funded activities, but support operational needs of the organization such as Human Resources, Marketing, janitorial staff, security guards, environmental safety, etc. These data characteristics, in addition to those identified in Chapter 2, will support the replication of the dataset by other pertinent high reliability organizations.

The behavior of the data from Table 7 for Fiscal Year 2003 through Fiscal Year 2023 is illustrated in Figure 8. From Fiscal Year 2003 through Fiscal year 2023, the Management Controls Resources Hours allocated directly on Nuclear Deterrence Mission activities increased by a factor of 5.7, while the Technical Resources Hours saw a growth of 1.4. The initial exploration of the primary empirical research question is enabled by the data in Figure 8 which asks:

Over time, how have changes in reforms for management controls in the Post-Cold War Era impacted the distribution of resources across the Nuclear Security Enterprise?

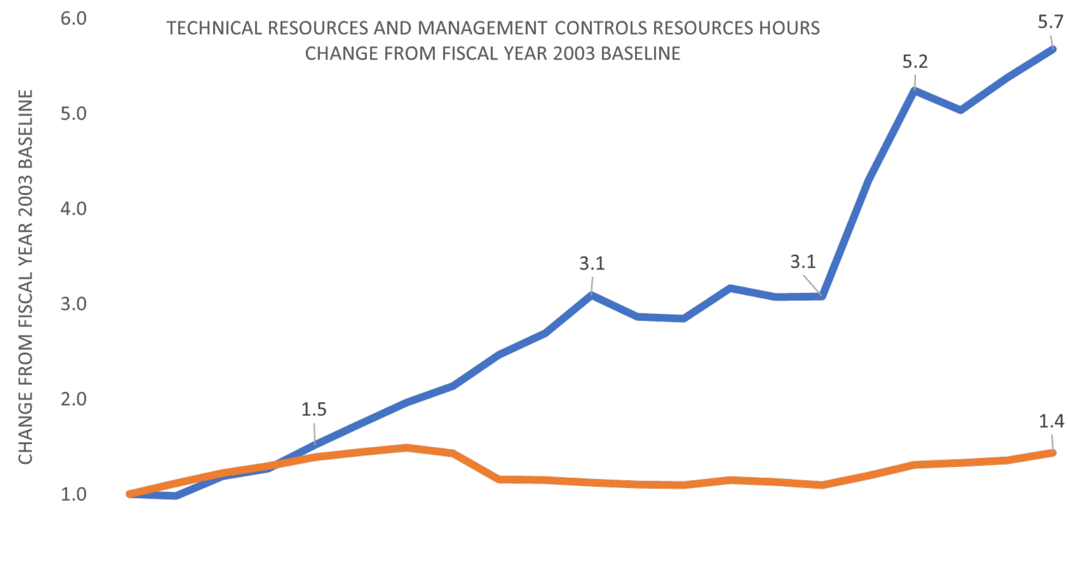
The data illustrates that both Management Controls Resources and Technical Resources increased on Nuclear Deterrence Mission activities at Sandia National Laboratories over time—serving as a proxy organization for the broader Nuclear Security Enterprise. This is not necessarily surprising as the risks and threats to the Nuclear Deterrence Mission and subsequently the scope and funding over this timeframe both increased (Nuclear Posture Review 2010-2018, National Nuclear Security Administration 2016-2025). "The United States now faces a more diverse and advanced nuclear-threat environment than ever before, with considerable dynamism in potential adversaries' development and deployment programs for nuclear weapons and delivery systems (Nuclear Posture Review 2018, p. 1)." Thus, it would be expected that both measures would increase.

However, Figure 8 illustrates what Abelson (1995) describes as surprising and important which are prerequisites leading to theoretical interest. The importance is the relationship to the United States Nuclear Deterrence Mission through a timeframe of rising global threats and reports of degrading performance—the surprise is in the large disparity between the behaviors of Management Controls Resources and Technical Resources (Hruby 2024).

> *What may help explain the disparity between the behaviors of Management Controls Resources and Technical Resources?*

Furthermore,

> *Why is the increase in Management Controls Resources substantively sharper than the increase in Technical Resources?*



	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
MANAGEMENT CONTROLS RESOURCES	1.0	1.0	1.2	1.3	1.5	1.7	2.0	2.1	2.5	2.7	3.1	2.9	2.8	3.2	3.1	3.1	4.3	5.2	5.0	5.4	5.7
TECHNICAL RESOURCES	1.0	1.1	1.2	1.3	1.4	1.4	1.5	1.4	1.2	1.1	1.1	1.1	1.1	1.2	1.1	1.1	1.2	1.3	1.3	1.4	1.4

Figure 8. Technical Resources and Management Controls Resources Behavior Change in Hours from Fiscal Year 2003 – Fiscal Year 2023

To explore these questions, it is important to frame a relationship of inputs, outputs, and outcomes. The Black Box Model of Implementation illustrated in Figure 7 can be augmented to include outcomes that may be pertinent to gaining insight into the behavior within the framework. One outcome of the Nuclear Security Enterprise that has been criticized throughout the Post-Cold War Era is schedule effectiveness. Thus, an observational table spanning 19 fiscal years from Fiscal Year 2007 through Fiscal Year 2023 is illustrated in Table 7 that measures changes to projected and actual schedule outcomes of Nuclear Deterrence Modernization Programs published by formal government sources

The schedule outcomes are based on two designated major milestones on Nuclear Deterrence Modernization Programs—First Production Unit and Last Production Unit (Department of Defense 2020). The First Production Unit milestone occurs when the Military Department and/or the Nuclear Weapons Council accepts the design, and the National Nuclear Security Administration verifies the first produced weapon meets the design requirements (Department of Defense 2020). The Last Production Unit is the successful delivery of the last produced weapon that meets design requirements. Together, the First Production Unit and the Last Production Unit major milestones are indicators the government utilizes to assess the effectiveness of Nuclear Security Enterprise schedule performance (GAO-23-104661). Each row identifies the Nuclear Weapon Modernization Program as it relates to the major milestone. Each column identifies the fiscal year that the Nuclear Security Enterprise communicated as the estimated completion date of the correlated program and milestone. The column CHANGE calculates the difference between the first estimated date and the actual completion or most recently estimated date as of Fiscal Year 2025.

Table 7. Nuclear Deterrence Modernization Program
First Production Unit and Last Production Unit Dates

Nuclear Deterrence Modernization Program First Production Unit and Last Production Unit Dates																				
Fiscal Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	CHANGE
W76-1 First Production Unit	2007	2008	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+1
W76-1 Last Production Unit	-	-	-	2017	2018	2018	-	2019	2019	2019	2019	2020	2019	2019	-	-	-	-	-	+2
B61-12 First Production Unit	-	-	-	2017	2017	2017	-	2019	2020	2020	2020	2020	2020	2020	2022	2022	-	-	-	+5
B61-12 Last Production Unit	-	-	-	-	-	-	-	-	2024	2024	2024	2025	2025	2024	2026	2025	2025	2025	2025	+1
W88 ALT 370 First Production Unit	-	-	-	-	-	2018	-	2019	2020	2020	2020	2020	2020	2020	2021	-	-	-	-	+3
W88 ALT 370 Last ProductionUnit	-	-	-	-	-	-	-	-	***2024***	***2024***	***2025***	***2025***	***2025***	***2024***	***2026***	***2026***	***2026***	***2026***	***2026***	***+2***
W80-4 First Production Unit	-	-	-	-	-	-	-	-	-	***2025***	***2025***	***2025***	***2025***	***2025***	***2025***	***2025***	***2027***	***2027***	***2027***	***+2***
W80-4 Last Production Unit	-	-	-	-	-	-	-	-	-	***2032***	***2032***	***2032***	***2032***	***2031***	***2031***	***2031***	***2031***	***2031***	***2033***	***+1***
W87-1 First Production Unit	-	-	-	-	-	-	-	-	-	-	-	-	-	***2030***	***2030***	***2030***	***Early 2030s***	***Early 2030s***	***2032***	***+2***
W87-1 Last Production Unit	-	-	-	-	-	-	-	-	-	-	-	-	-	***2036***	***2038***	***2037***	***2039***	***2039***	***2039***	***+3***

Completed

Projected

Data Sources: GAO-09-385, Nuclear Posture Review 2010, United States Department of Energy 2012-2025

The correlation of the schedule performance outcomes in Table 7 to the Technical Resources and Management Controls Resources behavior from Figure 8, does add some context that may provide insight for future causal research. In Fiscal Year 2007, the W76-1 First Production Unit missed its First Production Unit Milestone, which shifted to Fiscal Year 2008. This resulted in an audit that described a lack of effective cost and schedule management of the W76-1 by the National Nuclear Security Administration and the Department of Defense (GAO-09-385). Subsequently, in Fiscal Year 2010, the W76-1 missed its Last Production Unit. By Fiscal Year 2014 the following missed schedules occurred:

- The W76-1 Last Production Unit slipped schedule projections by two fiscal years
- The B61-12 First Production Unit slipped schedule projections by two fiscal years
- The W88 ALT 370 First Production Unit slipped by one fiscal year.

These schedule misses have contributed to the cascade of United States Government independent audits and panels that characterized the Nuclear Security Enterprise as being inefficient and ineffective in a persistent state of performance that is increasingly over budget and schedule, with excessive budget controls, and a culture that is focused on compliance over mission delivery (Augustine et al. 2014, Cohon et al. 2015, Breul et al. 2020).

As described in Chapter 2, this dissertation is an exploratory case study that is not designed to communicate causality. However, there is a notable systematic observation as the outcomes of

Nuclear Deterrence Mission Product Schedules are integrated with the Black Box Model of Implementation as illustrated in Figure 9. Over an extended period of time in the Post-Cold War Era of the Nuclear Security Enterprise, there have been a recurrence of increasing performance issues leading to a critically important question that summarizes the analysis of this dissertation:

> *Does degrading performance lead to increasing management controls reforms or is it that increasing management controls reforms are contributing to degrading performance?*

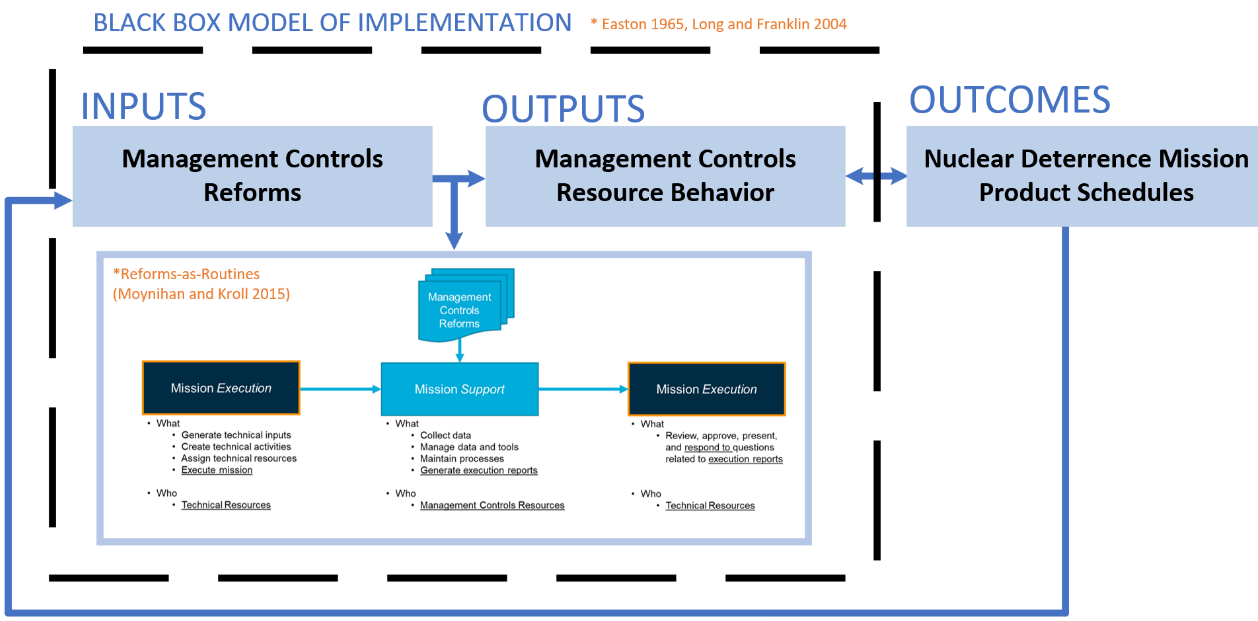


Figure 9. Black Box Model of Implementation with Outcomes

Chapter 4. Conclusions and Future Research

Why do nuclear weapon programs cost more and take longer than they did during the Cold War Era?

Though this dissertation does not directly answer this question, it does however consider the shift in political priorities from the Cold War Era of innovation and schedule effectiveness to the Post-Cold War Era of sustainment and cost efficiency to initiate a line of inquiry that should be useful for policy and decision makers as they United States Nuclear Security Enterprise enters the Modern Era.

This dissertation explored the variation in Management Controls Resources and Technical Resources resulting from the changes in management controls reforms during a 21-year timeframe of the Post-Cold War Era of the Nuclear Security Enterprise. To explore this variation, a Black Box Model of Implementation was utilized to aggregate management controls reforms (Long and Franklin 2004). This Black Box Model of Implementation was coupled with a reforms-as-routines model to specify how the sample high reliability organization—Sandia National Laboratories—experienced management controls reforms at the labor resource level.

The research illustrated that over the 21-year timeframe from Fiscal Year 2003 through Fiscal Year 2023, there was an increase in both Management Controls Resources and Technical Resources. However, the increase in Management Controls Resources during this timeframe was over four times larger than the Technical Resources. To gain insight into what might be driving the large disparity in variation of output Management Controls Resources and Technical Resources resulting from management controls reforms, nuclear weapon schedule performance data was added to the model to assess outputs to outcomes.

Over a 19-year timeframe from Fiscal Year 2007 through Fiscal Year 2025 of the Nuclear Security Enterprise, there has been uniformity in missing major schedule milestones. This schedule ineffectiveness along with cost inefficiency have been identified recurrently in the numerous Presidential and Congressional Panels and Government Audits cited within this dissertation. The recommendations consistently call for increasing management control reforms.

However, the fascinating question that summarizes Chapter 3 is:

> *Does degrading performance lead to increasing management controls reforms or is it that increasing management controls reforms are contributing to degrading performance?*

Future research would present two primary paths. First, future research should seek to improve upon the weaknesses identified in Chapter 2 to external and internal validity. This could be done through the replication of the dataset from other institutions to improve comprehensiveness. Furthermore, bringing this case study from a single unit to conclusions more representative and generalizable that may enable hypothesis testing and causal research (Gerring 2004). The second path is to expand upon high reliability organization and high reliability system theory.

Throughout the Cold War Era, the political inputs focused on effective schedules and the performance of the nuclear weapon systems. Reaching the goal of having a high performing system delivered on time during the Cold War Era ultimately contributed to its end (Norquist 2003, Loeber 2005). Of theoretical interest, during the Cold War Era, while the political inputs were on innovating high performing nuclear weapon systems and schedule effectiveness, the Nuclear Security Enterprise also achieved cost efficiency (Clark et al. 1985). This is in contrast to the Post-Cold War Era, where the political priorities and inputs shifted to performance sustainment of the nuclear weapon systems and cost efficiency, rendering the recurrent assessments identified in Chapter 1 that the Nuclear Security Enterprise is inefficient and ineffective, over budget and schedule. Thus, several questions for future research emerge that are pertinent to high reliability organization and high reliability system theory:

- *How do the features of high reliability systems and organizations that enable heightened performance make trades between priorities of cost and schedule?*
- *How does the old adage of "cost, schedule, performance pick two" apply and not apply to high reliability organizations?*
- *Can an organization be considered high reliability if it cannot meet urgent schedules?*
- *Can an organization be considered high reliability if it is not on budget or cost efficient?*

The importance of the future research identified has significant practical and theoretical implications in the Modern Era of the Nuclear Security Enterprise. Policy and decision-makers of nuclear security must look beyond small cross-sections of the Post-Cold War Era to inform direction and political inputs of the Modern Era. As of the writing of this dissertation, it has been 33 years since the last United States nuclear weapon test, and 35 years since the last new nuclear weapon system was authorized for development engineering. At Senate Hearing 106-262 in October 1999, the former United States Senator from Nebraska Robert Kerrey asked the Committee on Foreign Relations to consider the environment in 30 years without nuclear weapons testing and innovation. "We would then be dependent on the judgement of personnel with no personal experience either in designing or testing nuclear weapons (United States Congress 1999)."

Not only does the United States find itself in the Modern Era dependent on the judgement of personnel with no experience either in designing or testing nuclear weapons, the United States also finds itself in an era dependent on inexperienced policy and decision-makers. As the late Senator Pete Domenici of New Mexico stated in Johnson (1997) regarding the challenging future of the Nuclear Security Enterprise in the 21st century:

"It's hard to know where you're going if you don't know where you are and how you got there."

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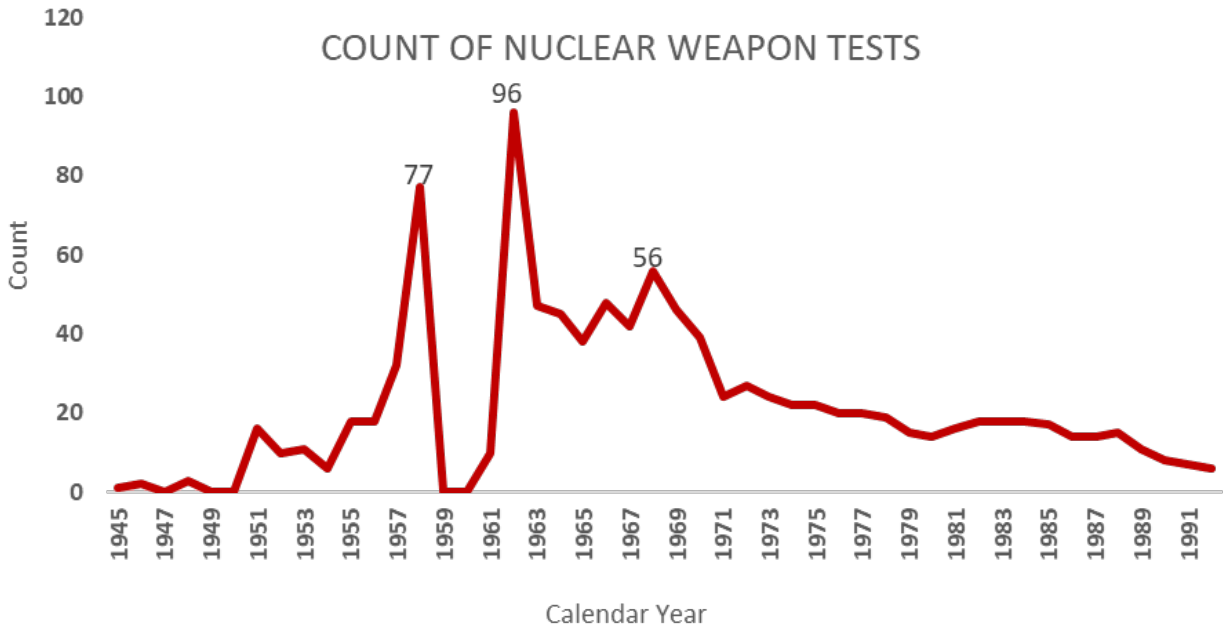
Appendix 1. United States Nuclear Weapon Data

The data contained in this appendix supports the United States Nuclear Security Enterprise narrative discussed throughout this dissertation and illustrated in Figure 2. Nuclear Security Policy Timeline.

1.1. United States Nuclear Weapon Test Counts



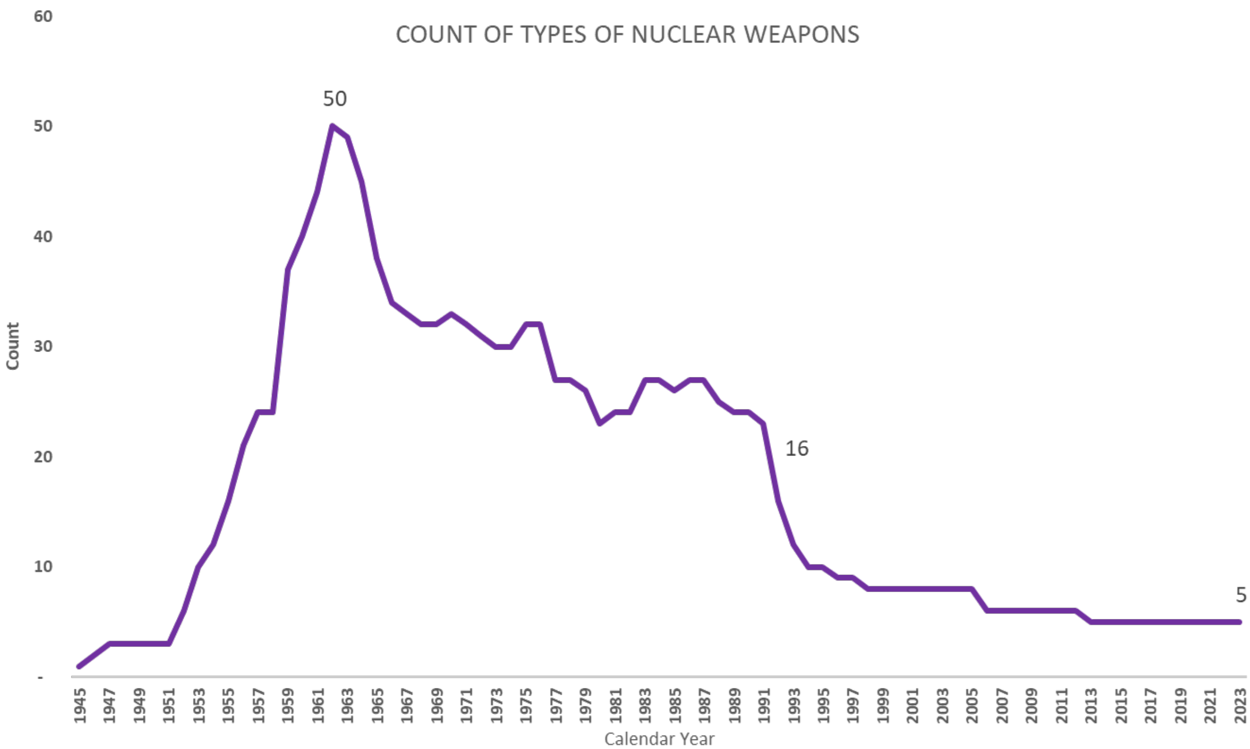
Source: United States Department of Energy, Nevada Operations Office. 2000.

Figure 1-1. United States Nuclear Weapon Test Counts

Table 1-1. United States Nuclear Weapon Test Counts

CALENDAR YEAR	TEST COUNT	CALENDAR YEAR	TEST COUNT
1945	1	1969	46
1946	2	1970	39
1947	0	1971	24
1948	3	1972	27
1949	0	1973	24
1950	0	1974	22
1951	16	1975	22
1952	10	1976	20
1953	11	1977	20
1954	6	1978	19
1955	18	1979	15
1956	18	1980	14
1957	32	1981	16
1958	77	1982	18
1959	0	1983	18
1960	0	1984	18
1961	10	1985	17
1962	96	1986	14
1963	47	1987	14
1964	45	1988	15
1965	38	1989	11
1966	48	1990	8
1967	42	1991	7
1968	56	1992	6

1.2. United States Nuclear Weapon Delivery Platform Type Count



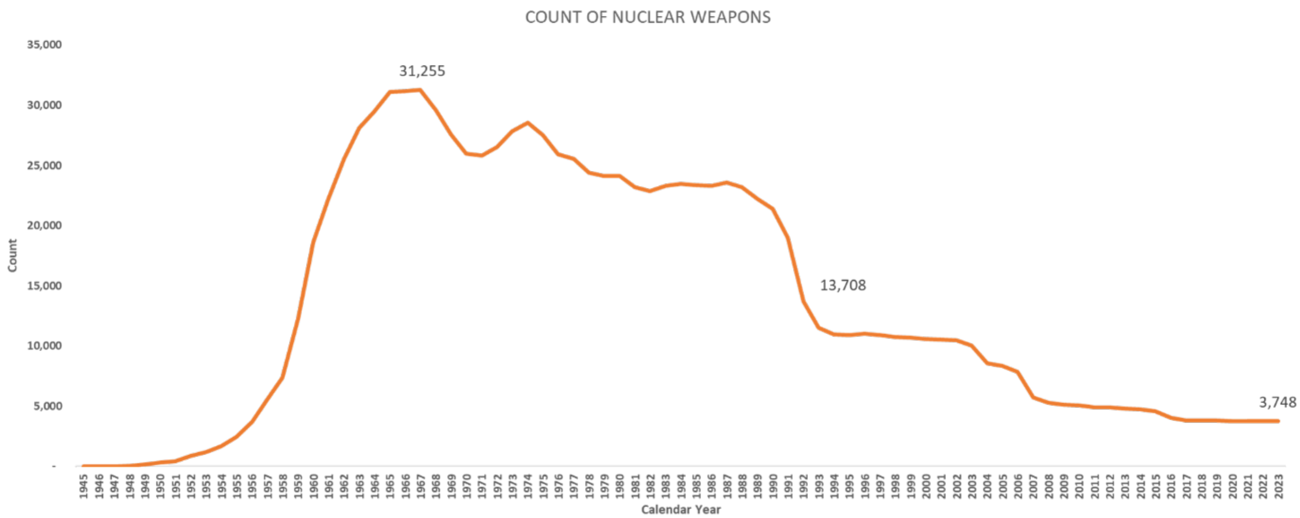
Source: Facini et al. 2023

Figure 1-2. United States Nuclear Weapon Delivery Platform Type Count

Table 1-2. United States Nuclear Weapon Delivery Platform Type Count

CALENDAR YEAR	COUNT	CALENDAR YEAR	COUNT	CALENDAR YEAR	COUNT
1945	1	1982	24	2019	5
1946	2	1983	27	2020	5
1947	3	1984	27	2021	5
1948	3	1985	26	2022	5
1949	3	1986	27	2023	5
1950	3	1987	27		
1951	3	1988	25		
1952	6	1989	24		
1953	10	1990	24		
1954	12	1991	23		
1955	16	1992	16		
1956	21	1993	12		
1957	24	1994	10		
1958	24	1995	10		
1959	37	1996	9		
1960	40	1997	9		
1961	44	1998	8		
1962	50	1999	8		
1963	49	2000	8		
1964	45	2001	8		
1965	38	2002	8		
1966	34	2003	8		
1967	33	2004	8		
1968	32	2005	8		
1969	32	2006	6		
1970	33	2007	6		
1971	32	2008	6		
1972	31	2009	6		
1973	30	2010	6		
1974	30	2011	6		
1975	32	2012	6		
1976	32	2013	5		
1977	27	2014	5		
1978	27	2015	5		
1979	26	2016	5		
1980	23	2017	5		
1981	24	2018	5		

1.3. United States Nuclear Weapon Systems Stockpile Count



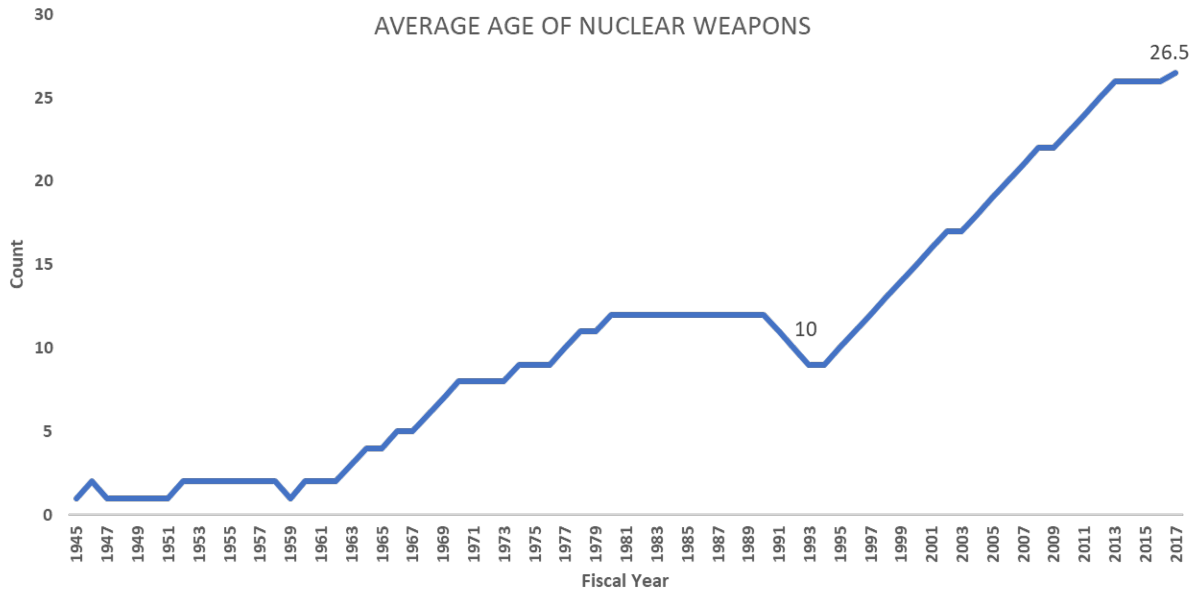
Source: United States Department of Energy/National Nuclear Security Administration

Figure 1-3. United States Nuclear Weapon Systems Stockpile Count

Table 1-3. United States Nuclear Weapon Systems Stockpile Count

CALENDAR YEAR	COUNT	CALENDAR YEAR	COUNT	CALENDAR YEAR	COUNT
1945	2	1982	22,886	2019	3,805
1946	9	1983	23,305	2020	3,750
1947	13	1984	23,459	2021	3,748
1948	50	1985	23,368	2022	3,748
1949	170	1986	23,317	2023	3,748
1950	299	1987	23,575		
1951	438	1988	23,205		
1952	841	1989	22,217		
1953	1,169	1990	21,392		
1954	1,703	1991	19,008		
1955	2,422	1992	13,708		
1956	3,692	1993	11,511		
1957	5,543	1994	10,979		
1958	7,345	1995	10,904		
1959	12,298	1996	11,011		
1960	18,638	1997	10,903		
1961	22,229	1998	10,732		
1962	25,540	1999	10,685		
1963	28,133	2000	10,577		
1964	29,463	2001	10,526		
1965	31,139	2002	10,457		
1966	31,175	2003	10,027		
1967	31,255	2004	8,570		
1968	29,561	2005	8,360		
1969	27,552	2006	7,853		
1970	26,008	2007	5,709		
1971	25,830	2008	5,273		
1972	26,516	2009	5,113		
1973	27,835	2010	5,066		
1974	28,537	2011	4,897		
1975	27,519	2012	4,881		
1976	25,914	2013	4,804		
1977	25,542	2014	4,717		
1978	24,418	2015	4,571		
1979	24,138	2016	4,018		
1980	24,104	2017	3,822		
1981	23,208	2018	3,785		

1.4. United States Nuclear Weapon Systems Average Age



Source: United States Department of Energy/National Nuclear Security Administration

Figure 1-4. Average Age of United States Nuclear Weapons

Table 1-4. Average Age of United States Nuclear Weapons

FISCAL YEAR	AVERAGE AGE	FISCAL YEAR	AVERAGE AGE
FY1945	1	FY1982	12
FY1946	2	FY1983	12
FY1947	1	FY1984	12
FY1948	1	FY1985	12
FY1949	1	FY1986	12
FY1950	1	FY1987	12
FY1951	1	FY1988	12
FY1952	2	FY1989	12
FY1953	2	FY1990	12
FY1954	2	FY1991	11
FY1955	2	FY1992	10
FY1956	2	FY1993	9
FY1957	2	FY1994	9
FY1958	2	FY1995	10
FY1959	1	FY1996	11
FY1960	2	FY1997	12
FY1961	2	FY1998	13
FY1962	2	FY1999	14
FY1963	3	FY2000	15
FY1964	4	FY2001	16
FY1965	4	FY2002	17
FY1966	5	FY2003	17
FY1967	5	FY2004	18
FY1968	6	FY2005	19
FY1969	7	FY2006	20
FY1970	8	FY2007	21
FY1971	8	FY2008	22
FY1972	8	FY2009	22
FY1973	8	FY2010	23
FY1974	9	FY2011	24
FY1975	9	FY2012	25
FY1976	9	FY2013	26
FY1977	10	FY2014	26
FY1978	11	FY2015	26
FY1979	11	FY2016	26
FY1980	12	FY2017	26.5
FY1981	12		