SANDIA REPORT
SAND2017-10660
Unlimited Release
September 2017

Building Foundations for Nuclear Security Enterprise Analysis Utilizing Nuclear Weapon Data

Terry Josserand, Leone Z. Young, Edwin P. Chamberlin

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Sandia National Laboratories

Issued by Sandia National Laboratories, operated for the United States Department of Energy by National Technology and Engineering Solutions of Sandia, LLC.

Printed in the United States of America. This report has been reproduced directly from the best available copy.

Available to DOE and DOE contractors from
U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831

Telephone:	(865) 576-8401
Facsimile:	(865) 576-5728
E-Mail:	reports@osti.gov
Online ordering:	http://www.osti.gov/scitech

Available to the public from
U.S. Department of Commerce
National Technical Information Service
5301 Shawnee Rd
Alexandria, VA 22312

Telephone:	(800) 553-6847
Facsimile:	(703) 605-6900
E-Mail:	orders@ntis.gov
Online order:	http://www.ntis.gov/search

SAND2017-10660
September 2017
Unlimited Release

Building Foundations for Nuclear Security Enterprise Analysis Utilizing Nuclear Weapon Data

Terry Josserand, Leone Z. Young, Edwin P. Chamberlin
00157 Nuclear Security Enterprise and Cost Analysis
Sandia National Laboratories
P. O. Box 5800
Albuquerque, New Mexico 87185-MS0413

Abstract

The Nuclear Security Enterprise , managed by the National Nuclear Security Administration – a semiautonomous agency within the Department of Energy – has been associated with numerous assessments with respect to the estimating, management capabilities, and practices pertaining to nuclear weapon modernization efforts. This report identifies challenges in estimating and analyzing the Nuclear Security Enterprise through an analysis of analogous timeframe conditions utilizing two types of nuclear weapon data – (1) a measure of effort and (2) a function of time. The analysis of analogous timeframe conditions that utilizes only two types of nuclear weapon data yields four summary observations that estimators and analysts of the Nuclear Security Enterprise will find useful.

This Page Intentionally Left Blank

Contents

Figures

Tables

Acronyms and Terms

AKA	Also Known As
CEAG	Cost Estimating and Analysis Group
CECOP	Cost Estimating Community of Practice
CER	Cost Estimating Relationship
CY	Calendar Year
DOE	Department of Energy
DOE/NV	Department of Energy/Nevada Operations
FM	Fat Man
FY	Fiscal Year
GAO	Government Accountability Office
Mk I	Little Boy
NCCA	Naval Center for Cost Analysis
NNSA	National Nuclear Security Administration
NSE	Nuclear Security Enterprise
SSMP	Stockpile Stewardship and Management Plan
US	United States

1 Introduction

The Nuclear Security Enterprise (NSE), managed by the National Nuclear Security Administration (NNSA) – a semiautonomous agency within the Department of Energy (DOE) – has been associated with numerous assessments with respect to the estimating, management capabilities, and practices pertaining to United States (US) nuclear weapon modernization efforts. [1] The Government Accountability Office (GAO), among others, have identified in their assessments that the DOE and the NNSA "cost estimating requirements and guidance for projects and programs do not fully reflect best practices for developing cost estimates." [1]

Governmental and Non-Governmental Organization assessments, along with US government imposed enhanced rigor on reporting requirements, are beneficial to the NSE. These assessments bring differing perspectives using a variety of data inputs, while the reporting requirements assist the NSE efforts in analyzing structures that impact cost. The growth in these assessments and reporting requirements are in part due to heightened scrutiny on federal spending at a time of record US national debt levels, and "because nearly every component of the triad is due for modernization." [5, 6] One assessment that has garnered alarming attention, published by the James Martin Center for Nonproliferation Studies titled *The Trillion Dollar Triad,* states that "a national discussion is needed about the future of the nuclear triad and deterrent, one that should include both the strategic and financial implications of these decisions." [7] These assessments serve as motivations to some of the nation's greatest minds within the NSE to collaborate and respond in the national interest. The impetus behind this manuscript is not to add to or refute completed assessments, but to offer insights that might support their efforts and to reinforce the focus on the foundation of a reliable cost estimate – data collection. [2]

Data is the foundation for good cost estimating and analysis. [3, 4] A common observable theme appears across the multitude of assessments of the NSE, that foundational data as a function of time and the characterization of the relationships are inconsistent. According to a Brookings Institution publication, "The Government has never tried to track all nuclear weapons costs either annually or over time and as a result records in this regard are extremely spotty and in numerous instances non-existent." [10]

Nevertheless, the NSE depends on historic nuclear weapon data to inform estimating and analysis. The rationale behind the dependence of utilizing historic nuclear weapon data is best summarized by the British science historian James Burke.

> ***"You can only know where you are going if you know where you have been."****[7]*
>
> *James Burke*

There is a sense of certainty with this idea of knowing "*where you have been.*" However, at any point in time there are numerous data point interactions that have materially influenced one another in the environment. The sheer number of inter-related data points that influence the NSE can be inundating when building an information basis to inform estimating or analysis. Furthermore, the protected national security environment that encompasses the NSE creates intentional ambiguity. What an estimator or analyst quickly discovers is that there are volumes of contextual data or tacit knowledge that are being lost as the minds that maintain that information leave the NSE and/or pass away. [22] In the present, one can only grasp that which one understands while being cognizant that historic data comes with uncertainty.

> ***"It ain't so much the things we don' know that get us into trouble. It's the things we know that just ain't so."****[8]*
>
> *Artemus Ward*

There are various types of historic nuclear weapon data. Table 1 lists several types of historic nuclear weapon data. This report utilizes two types of historic nuclear weapon data featured in Table 1:

1. A measure of effort by NSE Life Cycle Phase as defined by the New Weapon Development and Life Extension 6.X Process
2. Time by US government fiscal year (FY) which starts October 1st of a Calendar Year (CY). [25]

Table 1. Types of Nuclear Weapon Data

Type	Measurement
Effort	Phase Process
Time	Fiscal Year
Cost	Currency
Characteristics	Weight, Interfaces, Size, etc.
Performance	Yield, Speed, Range, etc.
Schedule	Time to Develop, Deploy, Test, etc.
Socio-political	Treaties, Legislation, Policy
Reliability	Failures, Issues, etc.
Production	Numbers, Processes, etc.
Systems Engineering Complexity	Phase Paradigm, Age, etc.
Staff	Experience, Training, etc.
Others	

There are limitations to this research study. The other nuclear weapon data types not defined in this report in Table 1 are important data types that have impact on the observations of this study and on estimates and analysis of the NSE. These other nuclear weapon data types therefore serve as caveats and as additional areas for future analysis. The analysis included in this study does not take into account, for example, the quantity of nuclear weapons produced each fiscal year, or the difference in the systems engineering complexity of the eras of New Weapon Development versus the Life Extension 6.X Process. Furthermore, this study does not account for the impact of the experience of the staff executing the mission of the NSE as a function of time, or treaties, policies, laws or cost implications, among other types of nuclear weapon data.

This research study follows a four-step framework illustrated in Figure 2 that will serve as the outline for this report.

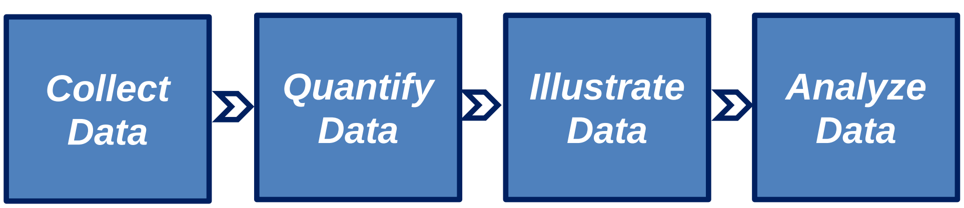

Figure 1. Research Study Framework

This Page Intentionally Left Blank

2 Collect Data

Data collection used in this study focused on one type of historic nuclear weapon data to derive a measure of effort. The definition of this nuclear weapon data is traceable, historic, and projected US nuclear weapon program entrance and exit dates by Phase. The historic nuclear weapon program entrance and exit dates come from traceable authorization letters. If an authorization letter was not available, the entrance and exit dates referenced the next available source with the most recent date of publication. Projected nuclear weapon program entrance and exit dates come from the FY2015-FY2017 NNSA Stockpile Stewardship and Management Plans (SSMP). [11, 12, 13] The lifecycle Phases associated with the entrance and exit dates are derived from two nuclear weapon eras (1) New Weapon Development and (2) the Life Extension 6.X Process. [16]

After the end of the Cold War and the passing of legislation US Public Law102-377 which halted underground nuclear testing in 1992, the NSE pivoted from New Weapon Development to the Life Extension 6.X Process era. [14] In the New Weapon Development era, new weapons were developed, tested (including nuclear tests), and produced. In contrast, the Life Extension 6.X Process enables the United States to "maintain a credible nuclear deterrent without producing new weapons or conducting new underground nuclear tests."[15] The Life Extension 6.X Process era executes as a function of the New Weapon Development era Phase 6 Production. [16] The Life Extension 6.X Process era utilizes the nuclear weapons previously produced in the New Weapon Development era and maintains them without nuclear testing. [15]

For this study, the phases of the two eras are combined and color-coded as follows:

- Conceptual Design – **Orange**
- Development Engineering – **Green**
- Production – **Blue**
- Dismantlement – **Grey**

This theme is present throughout the report's figures. For more information with respect to the general scope of the phases, see the NNSA's detailed definitions. [25]

Figure 2 illustrates the relationship between the New Weapon Development and the Life Extension 6.X Process eras in addition to the color-coding theme.

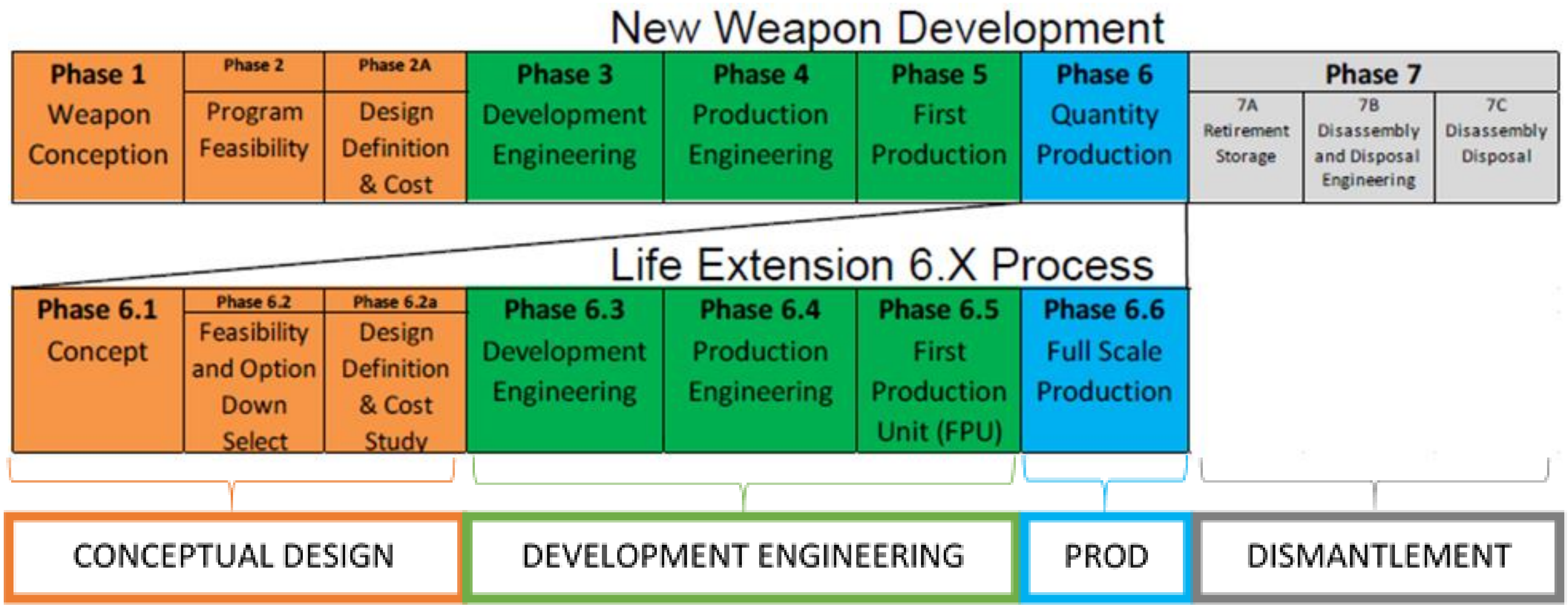

Figure 2. US Nuclear Warhead Lifecycle Phases [25]

Figure 3 represents the initial data illustration upon collection of the traceable historic and projected United States nuclear weapon program entrance and exit dates by phase.

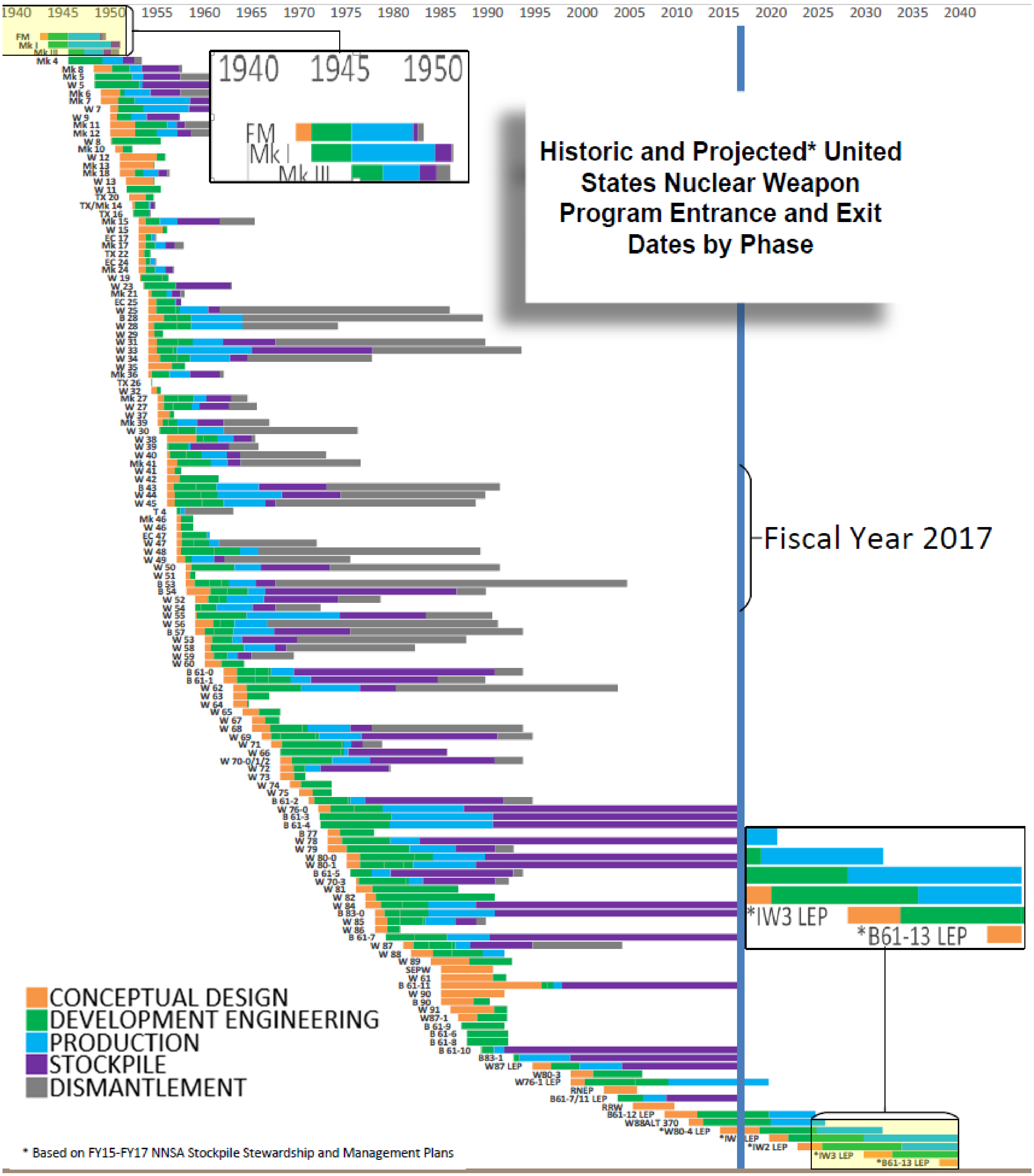

Figure 3. United States Nuclear Weapon Program Entrance and Exit Dates by Lifecycle Phases [25]

The color-coding theme in Figure 3 is consistent with Figure 2 with the exception of one new color. The color purple in Figure 3 was not included in the color-coding theme from Figure 2. This new purple color, represents Stockpile. Stockpile represents the measure of time after Production (blue) to the start of Dismantlement (grey). The dark blue vertical line represents FY2017. The zoom-in box at the top left identifies the first two nuclear weapon programs of the NSE: Fat Man and Little Boy (FM and Mk I).

In addition to being the first two nuclear weapon programs of the NSE, Fat Man and Little Boy, as shown in Figure 4 and Figure 5, remain the only two nuclear weapons to be used in warfare. [14] The enlarged box at the bottom right in Figure 3 identifies the two furthest out nuclear weapon programs according to the FY2017 NNSA's Stockpile Stewardship and Management Plan, the Interoperable Warhead 3 Life Extension Program and the B61-13 Life Extension Program. [13] Each horizontal purple Stockpile line that touches the dark blue FY2017 vertical line represents a nuclear weapon program that is currently in the United States Stockpile. Figure 3 renders numerous notable observations. Figure 3 represents almost a century of NSE history and projections by relative phase. From the NSE inception through the mid-1990s, it appears the NSE executed a steady state of parallel nuclear weapon programs. From the mid-1990s through the projections out to FY2040, the NSE execution plan illustrates a pivot towards non-parallel nuclear weapon program planning. It should be noted that historically, several nuclear weapon programs do not enter Production (blue), as a result of cancellation for varying reasons.

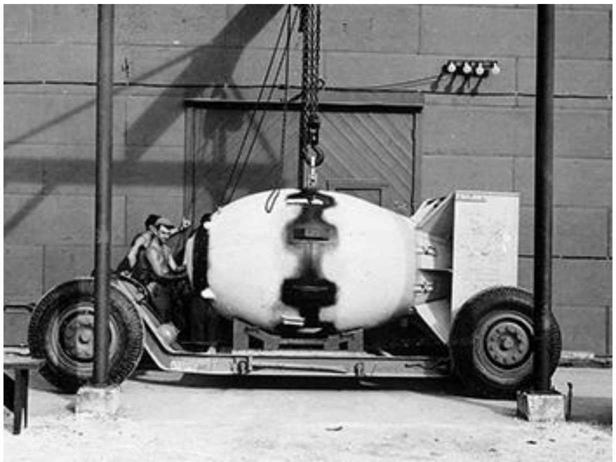

Figure 4. Fat Man [14]

Figure 5. Little Boy [14]

3 Quantify Data

Quantification of the Phase date nuclear weapon data provides a measure of effort to support the analogous timeframe identification analysis. There is one major framing assumption behind the method of quantifying the data, stated below:

A phase is a phase and a nuclear weapon program is a nuclear weapon program.

Meaning, there are no delineating factors with respect to the weight given to any nuclear weapon program or related nuclear weapon program Phase. The weight is equal to a count of 1 given to a nuclear weapon program in the corresponding fiscal year and Phase. Here are a few examples of the process to count traceable historic and projected United States nuclear weapon program entrance and exit dates:

- The W84 New Weapon Development Program was in Phase 3 Development Engineering in FY1979 [23]
    - In FY1979, the W84 New Weapon Development Program executed Phase 3 Development Engineering resulting in a count of 1 to the corresponding Phase (Phase 3 Development Engineering) and fiscal year (FY1979)

- The W88 New Weapon Development Program executed Phase 6 in FY1990 [23]
    - In FY1990, the W88 New Weapon Development Program executed Phase 6 Production resulting in a count of 1 to the corresponding Phase (Phase 6 Production) and fiscal year (FY1990)

- The W76-1 Life Extension Program executed Phase 6.3 Development Engineering in FY2001 [23]
    - In FY2001, the W76-1 Life Extension Program executed Phase 6.3 Development Engineering resulting in a count of 1 to the corresponding Phase (Phase 6.3 Development Engineering) and fiscal year (FY2001)

Caveats to this approach to quantifying the historic and projected United States nuclear weapon program entrance and exit dates:

- Nuclear weapon program Phases do not start and end with the fiscal year. So, transition years from one Phase to the next apply a count of 1 to each of the corresponding Phases:
    - For example, the W76-1 Life Extension Program received Phase 6.3 authorization in April of FY2000 [23]
        - In FY2000, the W76-1 Life Extension Program Phase 6.3 Development Engineering receives a count of 1
        - In FY2000, the W76-1 Life Extension Program Phase 6.2 Program Feasibility receives a count of 1
    - Most of the historic and projected United States nuclear weapon program entrance and exit Phase date documentation includes dates to the day, but not all of them. Some of the date documents are only to the month or the fiscal year. For example, the projections in the NNSA's Stockpile Stewardship and Management Plan in most cases are by fiscal year. [11, 12, 13] This supported the decision to maintain a count of 1 by fiscal year, in lieu of making the count a weighted function of 1/12th (month) or 1/365th (day).

4 Illustrate Data

Figure 6 illustrates the distributions of Phases by the color-coded theme resulting from the described process of quantifying the traceable historic and projected US nuclear weapon program entrance and exit dates by Phase. In Figure 6, the Y-axis is the count of the number of nuclear weapon programs in the correlated Phase and the X-axis is fiscal years from FY1942 to FY2040.

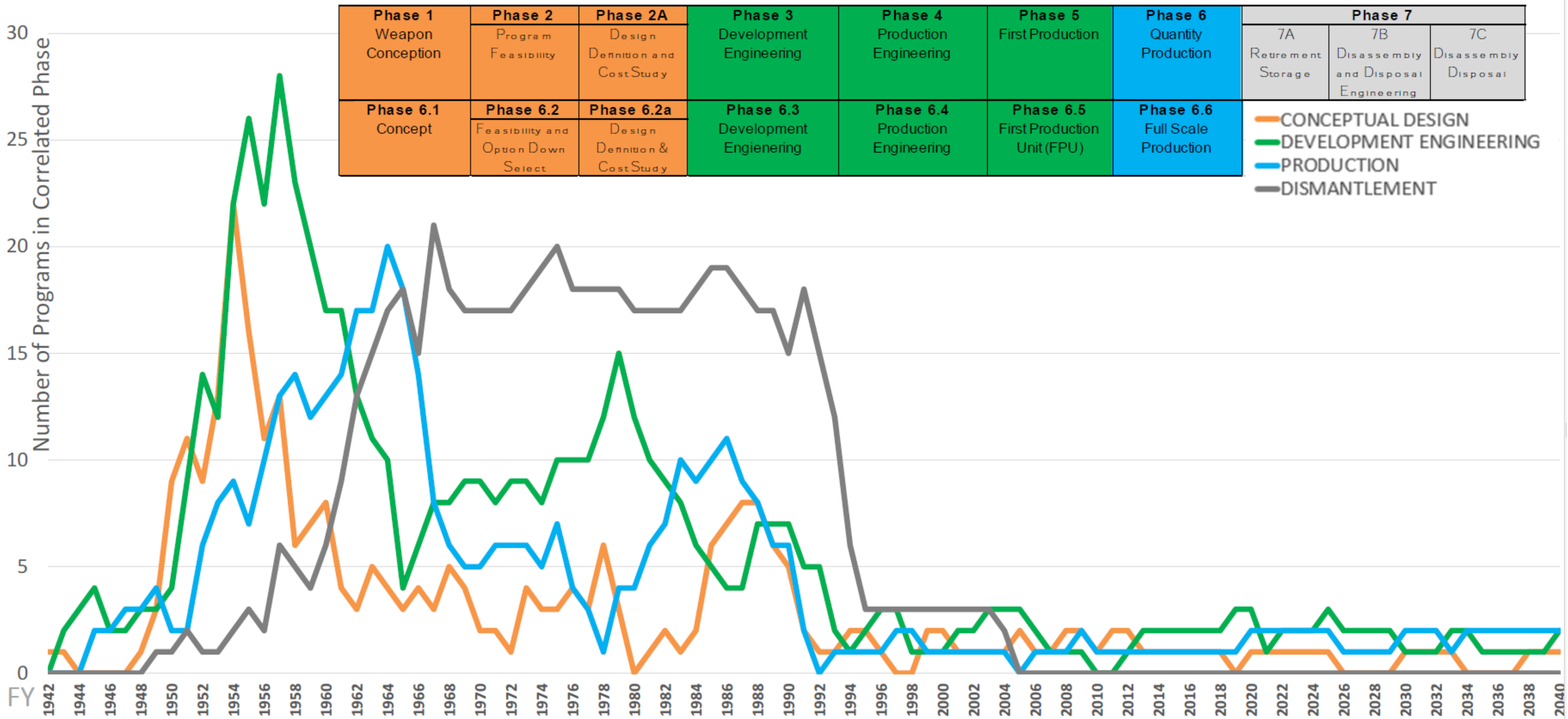

Figure 6. Count of Nuclear Weapon Programs by Phase by Fiscal Year

This Page Intentionally Left Blank

5 Analyze Data

The analysis of the data for this study focuses on identifying analogous timeframe conditions for nuclear weapon program Development Engineering (green) and Production (blue).

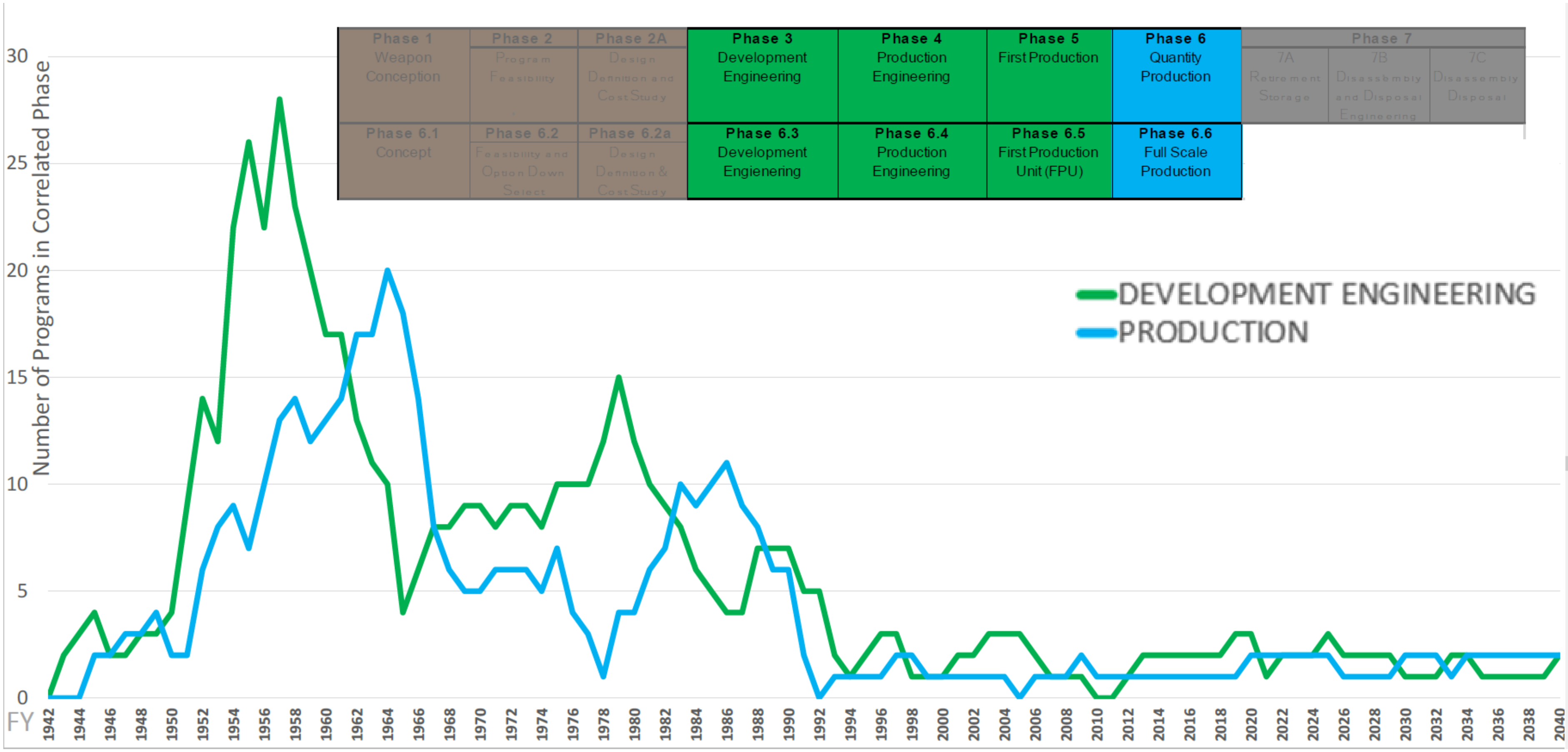

Figure 7. Count of Nuclear Weapon Programs in Development Engineering and Production by Phase by Fiscal Year

Figure 7 represents the distributions for nuclear weapon program Development Engineering (green) and Production (blue) with the other Phases removed. Prior to the analysis of analogous timeframe conditions, some historical context will be examined with respect to significant timeframes of Development Engineering and Production to be both informative and support the understanding of what the quantified nuclear weapon program data distribution in the illustration represents.

5.1 Development Engineering

From the start of calendar year 1951 to the end of calendar year 1957, the United States executed a total of 111 nuclear weapons tests across 13 nuclear weapon test series. [17, Appendix B] The NSE was flooded with new data leading to a rapid evolution of nuclear weapon program characteristics. For example, the information from these nuclear weapon program test series led to a reduction in the mass of nuclear weapons by a factor of 30 and a reduction in the diameter by a factor of 3. [18]

> ***"Policy could not keep up with Technology."*** *[18]*
> *Joseph Martz*

Nuclear weapon development expanded to multiple delivery platforms including tactical missiles, depth charges, land mines, artillery shells, and many more. [10] This resulted in nuclear weapon programs such as the W48, B54, and the W54, which were respectively a 155mm nuclear gun, a backpack nuke, and a nuclear rifle (aka the Davy Crocket). [18]

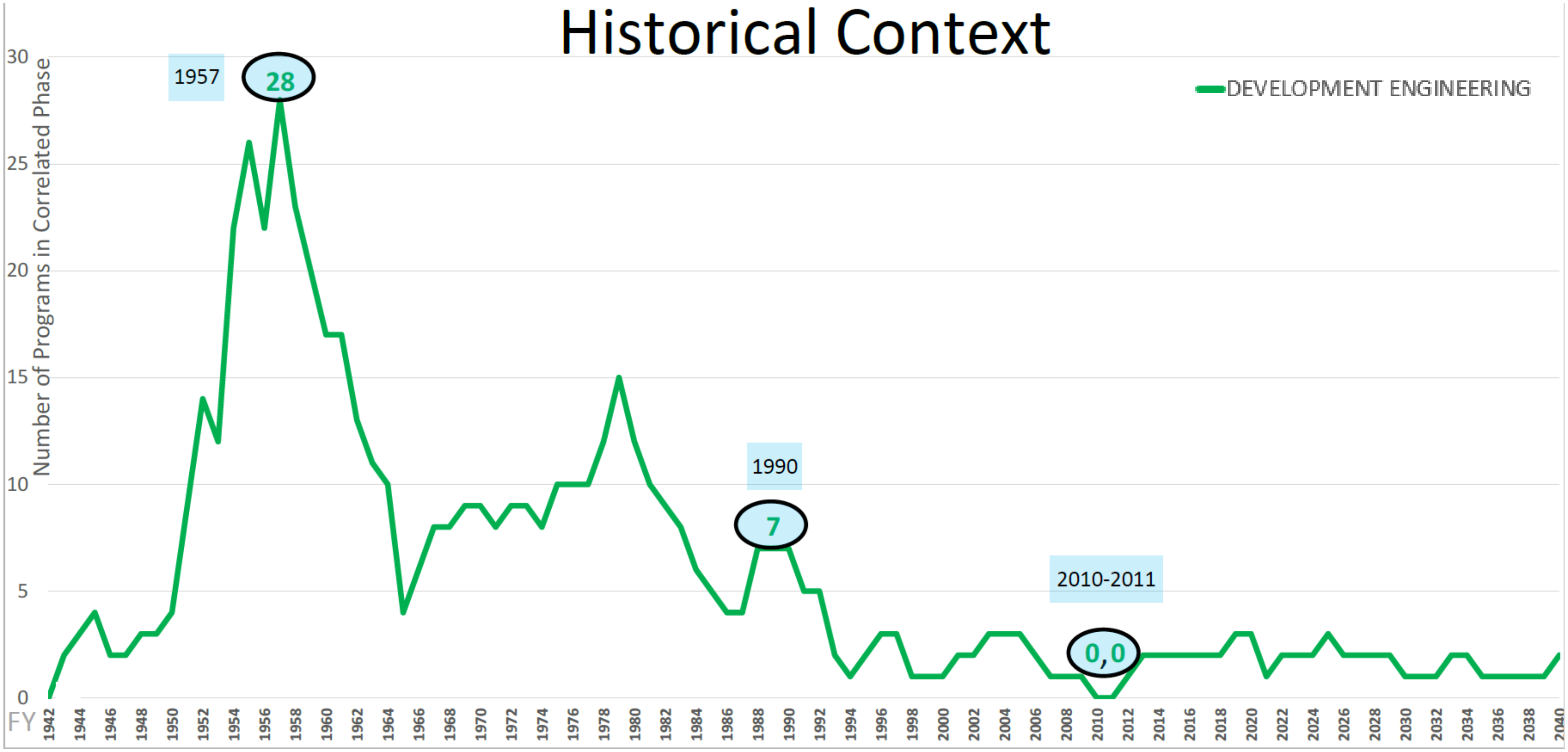

Figure 8. Important Historical Timeframe of Nuclear Weapon Program Development Engineering

Figure 8 highlights a few fiscal years of significance in a storied history of the NSE with respect to the count of nuclear weapon programs in Development Engineering by fiscal year.

- FY1957, the peak of the distribution, describes a fiscal year when the US was executing Development Engineering on 28 unique nuclear weapon programs.

- FY1990, specifically August of FY1990, represents the date that the last nuclear weapon program in New Weapon Development received authorization for entrance into Development Engineering – the W91. This means that in August of FY2020, it will be 30 years since the United States has executed Development Engineering on a new nuclear weapon program.
- FY2010-FY2011 represent the only two fiscal years in the history of the NSE that not a single nuclear weapon program was executing Development Engineering scope. This does not mean that the NSE was not executing *any* Development Engineering scope; it means that the NSE was not executing Development Engineering *on a program in New Weapon Development or the Life Extension 6.X Process.* Nevertheless, FY2010-FY2011 are two significant years in the history of the NSE.

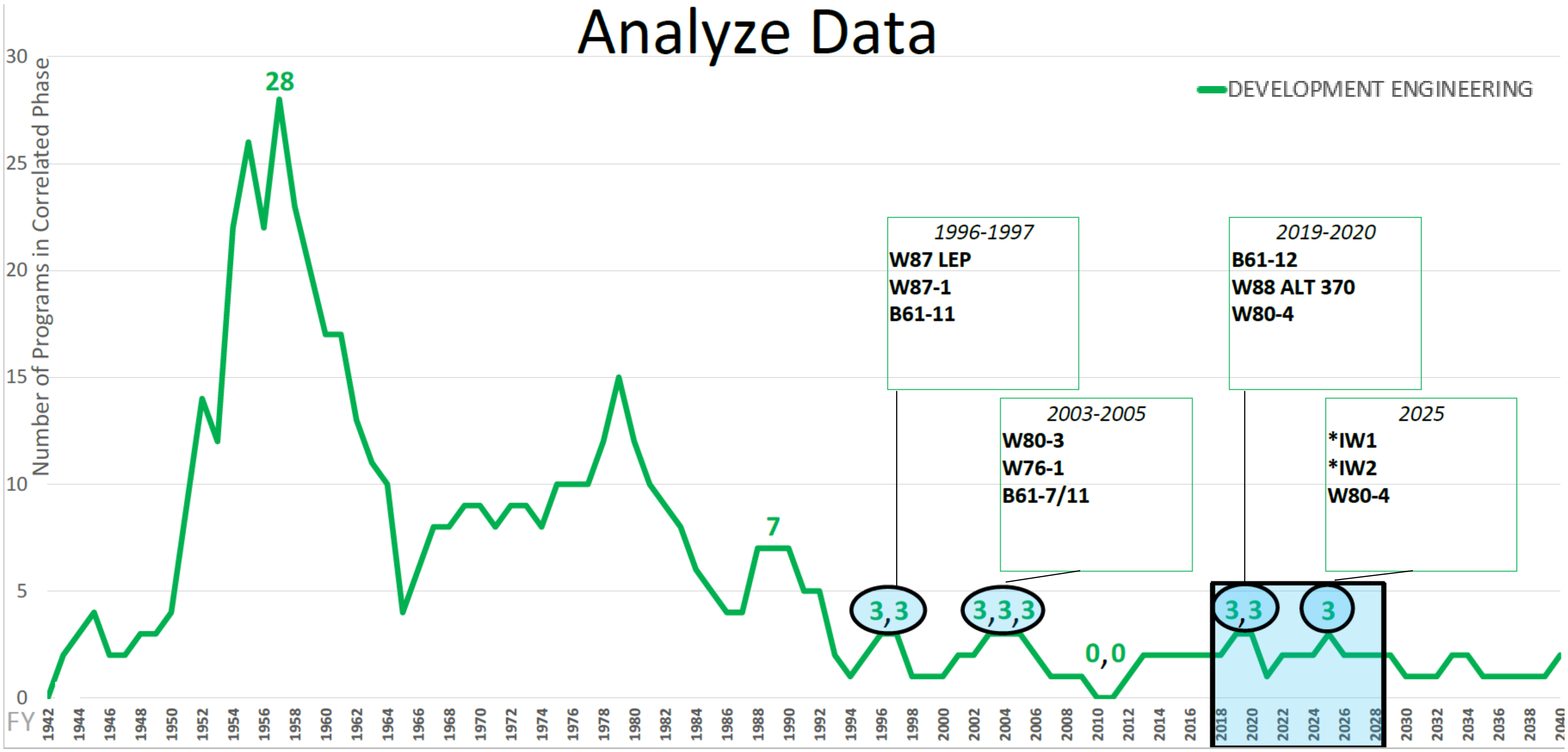

Figure 9. Comparative Timeframes of Nuclear Weapon Development Engineering

Figure 9 highlights the areas for analysis of analogous timeframe conditions. The blue box encompasses the quantification of the projected count of nuclear weapon programs that will be in Development Engineering from FY2018-FY2027 (10 fiscal years). [13] The two circles within the blue box highlight three fiscal years FY2019-FY2020 and FY2025. Each of these fiscal years has a count of three, representing that in each of these fiscal years, three different nuclear weapon programs will be executing Development Engineering scope. The green boxes above each of the highlighted counts identifies the correlated nuclear weapon programs; from

FY2019-FY2020 the B61-12 Life Extension Program, the W88 ALT 370*, and the W80-4 Life Extension Programs will be concurrently executing Development Engineering Scope. Additionally, in FY2025 the Interoperable Warhead 1 Life Extension Program, Interoperable Warhead 2 Life Extension Program, and the W80-4 Life Extension Program will be simultaneously executing Development Engineering scope. The identification of analogous timeframe conditions seeks to identify a timeframe in history that is analogous to the timeframe within the filled blued box representing FY2018-FY2027.

In order to satisfy the identification of analogous timeframe conditions, the historical reference fiscal year should have greater than or equal to a count of three nuclear weapons programs in Development Engineering to be analogous to the timeframes in the projections. Figure 9 illustrates two timeframes in the most recent history where the analogous timeframe condition is satisfied in FY1996-FY1997 and FY2003-FY2005. This indicates that starting in FY2019, the NSE will be executing a level of Development Engineering not seen in 14 fiscal years, or since FY2005. Moreover, within this window of 14 fiscal years (FY2005 to the start of FY2019), two of those fiscal years did not have a single nuclear weapon program executing Development Engineering scope (FY2010-FY2011).

* The W88 ALT 370 is the only Alteration program included in the dataset due to changes in the programs scope over time that make it similar in scope to a Life Extension Program.

5.2 Production

Moving on to the analysis of NSE Production, Figure 10 illustrates a few important historical timeframes with respect to the count of nuclear weapon programs in Production by fiscal year.

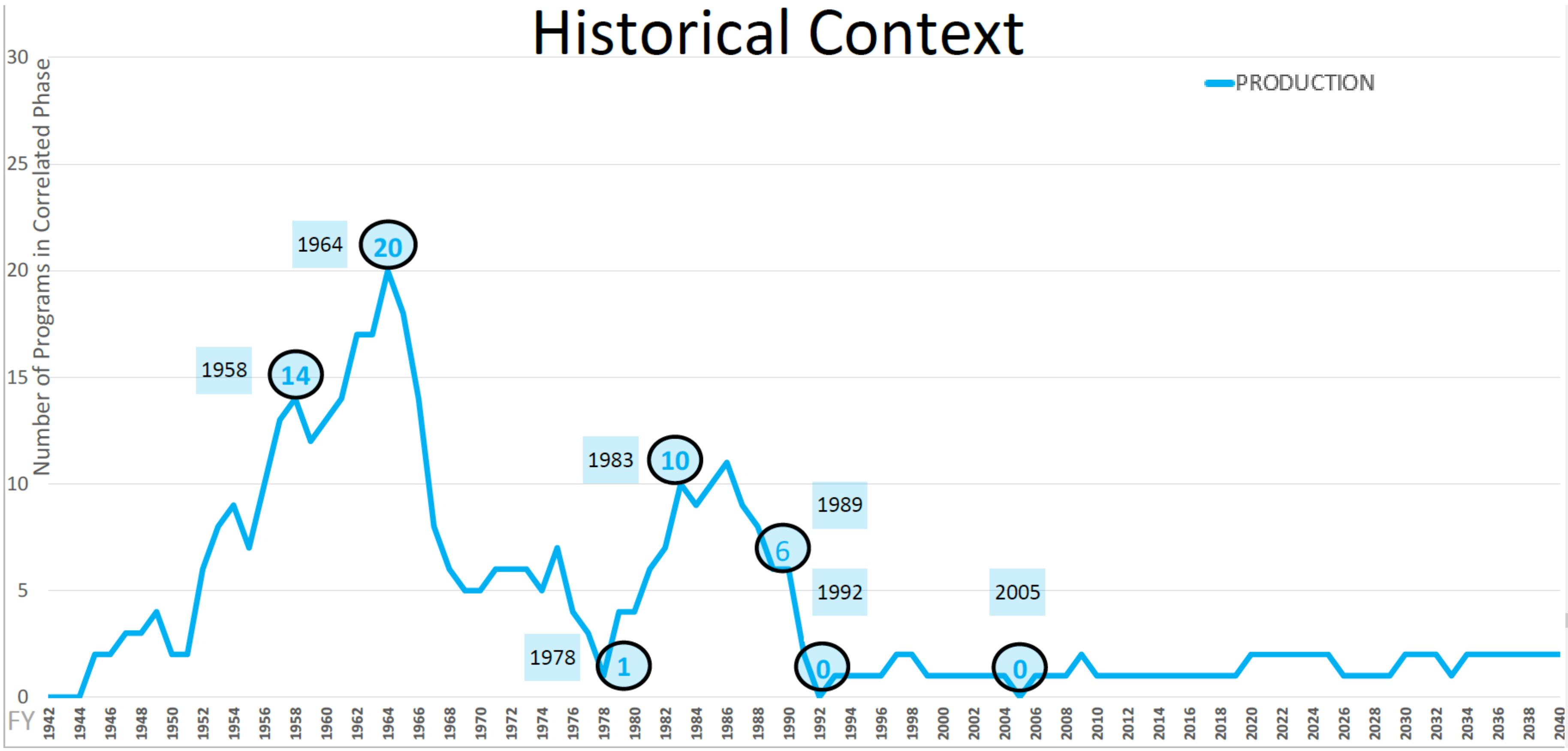

Figure 10. Important Historical Timeframes of Nuclear Weapon Program Production

- FY1958, unlike Development Engineering, the first fiscal year referenced is not the peak of the distribution. The significance of FY1958 is not that 14 different nuclear weapon programs executed Production that fiscal year, but that in FY1958 the NSE produced more nuclear weapons than any other fiscal year in history – approximately 8,300 – more than 20 nuclear weapons a day across 14 different nuclear weapon programs. [18]

- FY1964 represents the peak fiscal year for count of different nuclear weapon programs executing Production totaling 20. Following the peak in FY1964, Production count drops to 1 nuclear weapon program in FY1978 then back up to 10 in FY1983. These three dates and the correlated count of different nuclear weapon programs executing Production exhibits a wide range of Production flexibility in the history of the NSE.
- FY1989, specifically June of 1989, represents the date that the last nuclear weapon program in New Weapon Development received authorization for Production – the W88. This means that in June of FY2019, it will be 30 years since the United States has executed Production on a new nuclear weapon program.
- FY1992 and FY2005 represent two fiscal years where not a single nuclear weapon program in New Weapon Development or Life Extension 6.X executed Production. This does not mean that the NSE did *not* produce product, but it does mean that *not a single nuclear weapon program in New Weapon Development or Life Extension 6.X executed Production.*

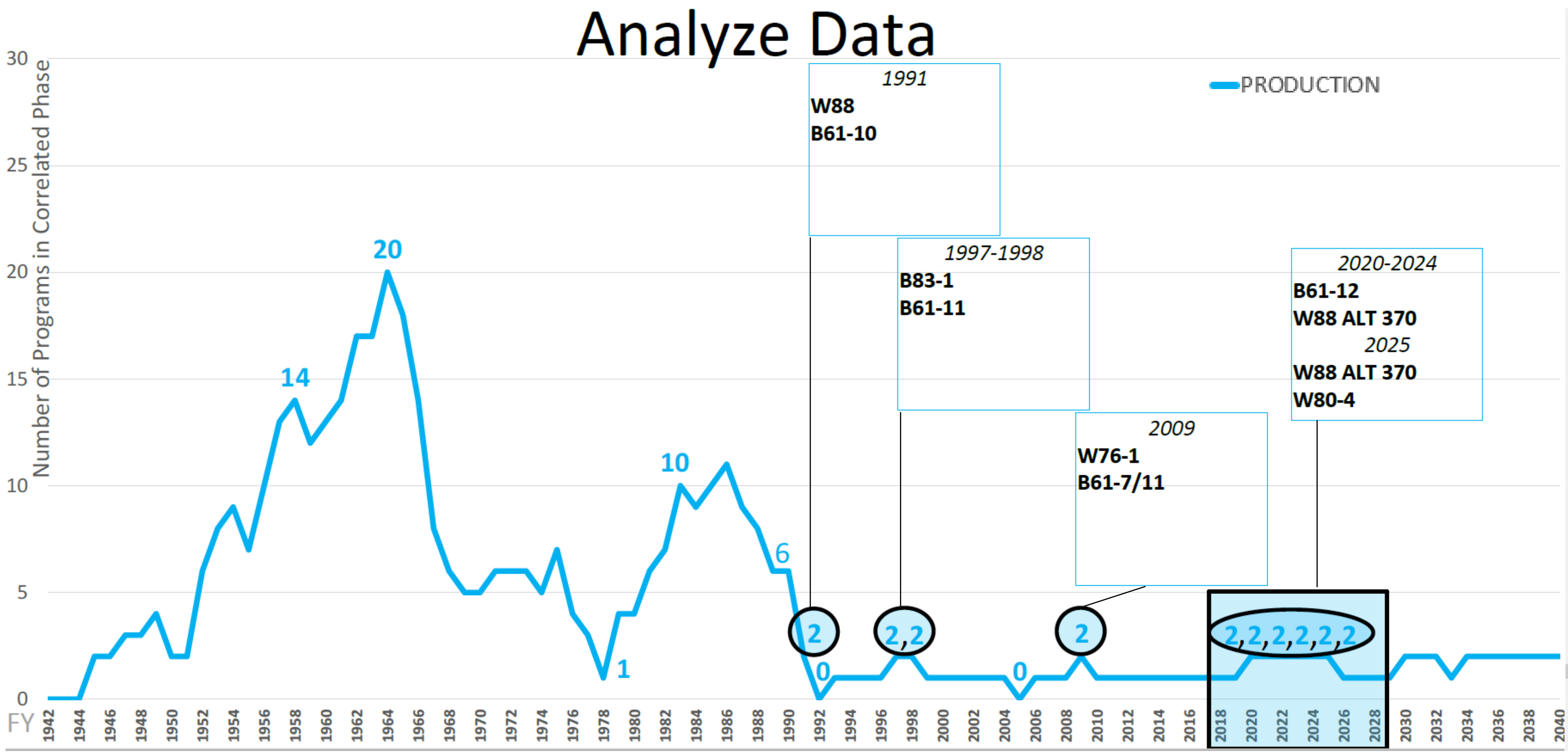

Figure 11. Comparative Timeframes of Nuclear Weapon Program Production

Figure 11 highlights the areas for analysis of analogous timeframe conditions. The filled blue box encompasses the quantification of the projected count of nuclear weapon programs that will be in Production from FY2018-FY2027. The circle within the filled blue box highlights six fiscal years FY2020-FY2025.

Each of these fiscal years has a count of two, representing that in each of these fiscal years two different nuclear weapon programs will be executing Production scope. The blue outlined boxes above each of the highlighted counts identify the correlated nuclear weapon programs. The identification of analogous timeframe conditions seeks to identify a timeframe in history that is analogous to the timeframe within the filled blued box representing FY2018-FY2027.

In order to satisfy the identification of analogous timeframe conditions, the historical reference fiscal year should have greater than or equal to a count of two nuclear weapons programs in Production to be analogous to the timeframe in the projection (blue-filled box). The count of the correlated programs in the blue-filled box projection window for Production differs from the projections for Development Engineering in that the count represents a level of *sustained* Production for six fiscal years across three different nuclear weapon programs the B61-12 Life Extension program, W88 ALT 3701, and the W80-4 Life Extension Program.

Figure 11 illustrates the three timeframes in the most recent history where the analogous timeframe condition of greater than or equal to a count of two nuclear weapon programs in Production is satisfied – FY2009 with the W76-1 and the B61-7/11 Life Extension Programs, FY1997-FY1998 with the B83-1 and the B61-11, and finally FY1991 with the W88 and the B61-10. While these timeframes meet the analogous timeframe condition of greater than or equal to two different nuclear weapon programs in Production, they do not meet the level of *sustained* Production represented in the projections in the blue-filled box. An analyst or estimator would have to go back prior to FY1991 to identify a timeframe where an analogous level of sustained nuclear weapon program Production could be identified.

This means that from FY2020-FY2024 the NSE will be executing a level of sustained Production not seen in over 29 fiscal years, or since before FY1991.

It is important to note that this analogous timeframe condition analysis does not take into account the complexity difference between Productions of a nuclear weapon program in New Weapon Development versus a nuclear weapon program in the Phase 6.X Life Extension Process. Furthermore, this analogous timeframe condition does not take into account other nuclear weapon data types as mentioned in Table 1 such as, count of nuclear weapons produced and technology, among others.

This Page Intentionally Left Blank

6 Summary

The NSE leans on historic nuclear weapon data to inform estimates and analysis. For "*you can only know where you are going if you know where you have been.*" [7] Yet historic nuclear weapon data and the relationships thereof, are complex and easily misrepresented. While a dataset that is valid, credible, repeatable, and traceable is foundational to a good estimate or analysis, the contextual understanding is important as well. For "*it ain't what you don't know that gets you into trouble, but what you know for sure that just ain't so.*" [8]

This study collected, quantified, illustrated, and analyzed one type of nuclear weapon data by US government fiscal year, traceable historic, and projected United States nuclear weapon program entrance and exit dates by Phase. Using this singular nuclear weapon data type and the FY2018-FY2027 timeframe from the 25-year plan of the NNSA's Stockpile Stewardship and Management Plan, this report highlights four major summary observations, which are:

1. The NSE is planning to execute a measure of Development Engineering starting in FY2019 – not seen in approximately 14 fiscal years.
2. The NSE is planning to execute a measure of Sustained Production starting in FY2020 – not seen in approximately 29 fiscal years.
3. The NSE, in August of FY2020, will reach 30 fiscal years since receiving authorization to enter Development Engineering on a new nuclear weapon program in New Weapon Development.
4. The NSE, in June of FY2019, will reach 30 fiscal years since receiving authorization to enter Production on a new nuclear weapon program in New Weapon Development.

The crucial role of nuclear weapons, with respect to the national security of the United States, makes the importance of improving the capabilities of nuclear weapon estimators and analysts imperative. A good place to start might be to follow the lead of Sandia National Laboratories, which has begun collection, and characterization of valid, credible, repeatable, traceable nuclear weapon data. [24]

To assert that nuclear weapons now are unimportant is to suggest that deterrence is no longer important, or that the future will be much more benign than the past, and that we will not again confront such opponents armed with dangerous weapons." *[19] John S. Foster, Jr.*

This Page Intentionally Left Blank

7 References

1. U.S. Government Accountability Office *15-29 Project and Program Management DOE.* [Last Accessed June 2017] https://www.gao.gov/products/GAO-15-29

2. Parker, Bruce. Naval Center for Cost Analysis (NCCA). *Cost Estimating Relationship* (CER)Development Handbook. 2016.

3. U.S. Government Accountability Office. *Cost Estimating and Assessment Guide*. Published March 2009. [Last Accessed June 2017] http://www.gao.gov/products/GAO-09-3SP

4. Department of the Navy. *Department of the Navy Cost-Estimating Guide*. 2017.

5. United States Department of the Treasury. *National Debt*. 2017.

6. Harrison, Todd and Evan Braden Montgomery. *Are U.S. Nuclear Forces Unaffordable?* Center for Strategic and Budgetary Assessments. June 23, 2015. [Last Accessed June 2017] http://csbaonline.org/research/publications/are-u-s-nuclear-forces-unaffordable

7. Burke, James. Connections. 1979. [Last Accessed June 2017] http://izquotes.com/author/james-burke

8. Gilovich, Thomas. *How We Know What Isn't So: The Fallibility of Human Reason in Everyday Life*. Free Press, March 5, 1993.

9. Wolfsthal, Jon. *Trillion Dollar Triad.* Middlebury Institute of International Studies at Monterey. January 7, 2014.

10. Schwartz, Stephen I. *The Hidden Costs of our Nuclear Arsenal: Overview of Project Findings.* Brookings Institute. June 30, 1998. [Last Accessed June 2017] https://www.brookings.edu/the-hidden-costs-of-our-nuclear-arsenal-overview-of-project-findings/

11. Department of Energy (DOE) National Nuclear Security Administration (NNSA). *(FY2015) Stockpile Stewardship and Management Plan (SSMP).*

12. Department of Energy (DOE) National Nuclear Security Administration (NNSA). *(FY2016) Stockpile Stewardship and Management Plan (SSMP).*

13. Department of Energy (DOE) National Nuclear Security Administration (NNSA). *(FY2017) Stockpile Stewardship and Management Plan (SSMP).*

14. Office of the Assistant Secretary of Defense for Nuclear, Chemical, and Biological Defense Programs. *(2011) Nuclear Matters Handbook Expanded Edition.*

15. Department of Energy. National Nuclear Security Administration. *Life Extension Programs*. [Last Accessed June 2017] https://nnsa.energy.gov/ourmission/managingthestockpile/lifeextensionprograms

16. Sandia National Laboratories. *Nuclear Weapons Product Realization Lifecycle.* [Last Accessed June 2017] https://webprod.sandia.gov/RPSS/index.xhtml

17. Department of Energy (DOE) Nevada Operations Office.*(2000) United States Nuclear Tests: July 1945 through September 1992 (DOE/NV—209-REV15).*

18. Martz, Joseph. Lecture on Nuclear Weapons, Testing, and the US Nuclear Arsenal. Stanford University. September 29, 2014.

19. Foster, John (Johnny) S. Jr. Excerpt from Article in *Forum Physics and Society of the American Physical Society* – Vol. 36, No. 4 (October 2007).

20. National Nuclear Security Administration. *2017 CECOP Symposium – About CECOP* [Last Accessed June 2017] https://nnsa.energy.gov/ourmission/maintainingthestockpile/2017-cecop-symposium/2017-cost-estimating-community-practice

21. National Nuclear Security Administration. *2017 CECOP Symposium – About CEAG* [Last Accessed June 2017] https://nnsa.energy.gov/node/13803

22. Holmes, Sue Major. *Cold War Warriors.* Sandia National Laboratories. [Last Accessed June 2017] http://www.sandia.gov/news/publications/labnews/articles/2016/29-04/cold_war.html

23. Josserand, Terry. Cost Estimating Community of Practice Symposium 2017. *Challenges with Historic Nuclear Weapon Data.* Sandia National Laboratories. [Last Accessed June 2017]. https://nnsa.energy.gov/node/13725

24. Sandia National Laboratories. *IT, Networks, & Facilities.* [Last Accessed June 2017] http://www.sandia.gov/news/publications/lab_accomplishments/articles/2016/it-networks-and-facilities.html

25. National Nuclear Security Administration. *Nuclear Weapons Life Cycle.* [Last Accessed June 2017] https://nnsa.energy.gov/ourmission/managingthestockpile/nwlifecycle

Distribution

1	MS0899	RIM-Reports Management	09532 (electronic copy)

This Page Intentionally Left Blank

Sandia National Laboratories