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Report to Congressional Requesters

September 2020

NUCLEAR WEAPONS

NNSA Should Further Develop Cost, Schedule, and Risk Information for the W87-1 Warhead Program

GAO-20-703

GAO Highlights

Highlights of GAO-20-703, a report to congressional requesters

September 2020

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Why GAO Did This Study

The Department of Defense (DOD) and NNSA restarted a program in fiscal year 2019 to replace the capabilities of the aging W78 nuclear warhead with the W87-1. NNSA made key design decisions for this weapon from 2010 until the program was paused in 2014. NNSA estimated in December 2018 that the W87-1 would cost $8.6 billion to $14.8 billion, which could make it the most expensive warhead modernization program to date. NNSA plans to newly manufacture the entire warhead, including the two major nuclear components, called the primary and secondary, using facilities it is modernizing or repurposing.

You asked us to examine plans for the W87-1 warhead. This report examines, among other things, the extent to which NNSA (1) considered cost estimates in prior design decisions for the W87-1 and the potential effects of remaining design decisions on program cost, and (2) will be able to produce sufficient numbers of key nuclear components to meet W87-1 production needs. GAO reviewed NNSA documentation on prior and remaining design decisions and preliminary cost estimates, reviewed warhead and component production schedules, and interviewed NNSA and DOD officials.

What GAO Recommends

GAO is making four recommendations, including that NNSA require programs such as the W87-1 to follow analysis of alternatives best practices when studying design options and that the plutonium program build an integrated schedule consistent with schedule best practices. NNSA generally agreed with the recommendations.

View GAO-20-703. For more information, contact Allison B. Bawden at (202) 512-3841 or bawdena@gao.gov.

What GAO Found

The National Nuclear Security Administration (NNSA) did not consider cost estimates in early major design decisions for the W87-1 warhead because it was not required to do so, but NNSA has since changed its guidance to require that cost be considered, according to a May 2019 NNSA review of program documentation. The design decisions that remain for features that would achieve either minimum or enhanced requirements for the W87-1 could affect cost, according to NNSA officials (see table). We found, however, that NNSA did not yet have study plans for assessing the costs and benefits of the remaining decisions consistent with best practices as detailed in NNSA's analysis of alternatives business procedure. NNSA does not require and only recommends that programs such as the W87-1 follow these best practices. By directing the W87-1 program and future weapons programs to follow best practices for design studies, or to justify and document deviations, NNSA would have better assurance that design studies apply consistent, reliable, and objective approaches.

NNSA Cost Estimates for W87-1 Warhead Design Variations That Meet Minimum and Enhanced Requirements, as of December 2018
(Dollars in billions)

W87-1 design variations	Cost estimate range [a]
Design includes features that meet minimum safety and security requirements	7.7 - 13.3
Design includes enhanced safety and security features	8.6 - 14.8
Difference between the above estimate ranges	0.9 - 1.5

Source: National Nuclear Security Administration (NNSA) documentation | GAO-20-703

[a]The cost ranges reflect low and high estimates for a single design variation. The ranges represent technical and production risk and uncertainty.

It is not clear that NNSA will be able to produce sufficient numbers of pits—the fissile cores of the primary—to meet the W87-1 warhead's planned production schedule. Recent NNSA and independent studies have cast doubt on NNSA's ability to ready its two planned pit production facilities in time. If one facility is not ready to produce pits in the early 2030s, for example, NNSA would likely produce fewer weapons than planned, according to GAO's analysis of NNSA plans.

We were unable to fully assess the extent to which the two pit production facilities will be ready to produce pits for the W87-1 because NNSA's plutonium program—which is managing the facility readiness efforts—has not yet completed an integrated schedule for the overall pit production effort. An integrated schedule is important, according to best practices, because it integrates the planned work, resources, and budget. An NNSA official stated that the program was building a schedule, but could not provide documentation that it would meet best practices. A schedule consistent with best practices would provide NNSA with better assurance that it will have adequate pits to meet planned W87-1 production.

This is a public version of a classified report that GAO issued in February 2020. Information that NNSA or DOD deemed classified or sensitive has been omitted.

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Abbreviations

AOA	Analysis of Alternatives
CEPE	Office of Cost Evaluation and Program Evaluation
DOD	Department of Defense
DOE	Department of Energy
DP	Office of Defense Programs
GBSD	Ground Based Strategic Deterrent
ICBM	intercontinental ballistic missile
LANL	Los Alamos National Laboratory
Lawrence Livermore	Lawrence Livermore National Laboratory
LEP	life extension program
NIMS	National Nuclear Security Administration integrated master schedule
NNSA	National Nuclear Security Administration
PF-4	Plutonium Facility 4
PPD	Presidential Policy Directive
RPD	Requirements and Planning Document
SLBM	submarine launched ballistic missile
SRS	Savannah River Site
SSMP	Stockpile Stewardship and Management Plan
UPF	Uranium Processing Facility
Y-12	Y-12 National Security Complex

U.S. GOVERNMENT ACCOUNTABILITY OFFICE
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September 9, 2020

The Honorable Adam Smith
Chairman
Committee on Armed Services
House of Representatives

The Honorable Marcy Kaptur
Chairwoman
Subcommittee on Energy, Water Development, and Related Agencies
Committee on Appropriations
House of Representatives

Since 2010, the Department of Defense (DOD) and the Department of Energy's (DOE) National Nuclear Security Administration (NNSA) have sought to replace the capabilities of the W78 nuclear warhead that is carried on the Air Force's intercontinental ballistic missiles (ICBM).[1] Introduced in 1979, the W78 is the oldest weapon in the U.S. nuclear stockpile that has not undergone a major life extension or replacement program, and components within the W78 are aging. As we reported in November 2018, a program to replace the W78 began in 2010 but was suspended in 2014, partly because of budget constraints.[2] The 2018 Nuclear Posture Review directed NNSA to restart the W78 replacement program in fiscal year 2019 so that it could be fielded on the Air Force's new ICBM system.[3] The W78 replacement program—now known as the

[1]NNSA is a separately organized agency within DOE responsible for the nation's nuclear weapons, nonproliferation, and naval reactor programs. The Air Force is undertaking a program to replace its aging ICBM system—the Minuteman III—with a new system called the Ground Based Strategic Deterrent (GBSD). The Minuteman III carries the W78 and another warhead—the W87-0. GBSD will carry the W87-0 and the W87-1.

[2]GAO, *Nuclear Weapons: NNSA Has Taken Steps to Prepare to Restart a Program to Replace the W78 Warhead Capability*, GAO-19-84 (Washington, D.C.: Nov. 28, 2018). During this period the warhead replacement program was also referred to as the Interoperable Warhead 1 program. The Interoperable Warhead 1 was to be the first of three "interoperable warheads" useable by both the Air Force and Navy that NNSA planned to develop and produce between about 2020 and 2050.

[3]The 2018 Nuclear Posture Review—which describes presidential policy on the role of nuclear weapons in national security—directed that the planned restart of the W78 replacement program be advanced by 1 year, from 2020 to 2019. The 2018 Nuclear Posture Review also directed NNSA and DOD to investigate the feasibility of fielding the W78 replacement system in a Navy submarine-launched ballistic missile (SLBM) system. In February 2020, a Navy official stated that such a system would not be feasible.

W87-1 Modification (W87-1) program—could be the most expensive warhead life extension or replacement program since the end of the Cold War, according to NNSA's December 2018 preliminary cost estimate.[4] Specifically, the projected cost of the W87-1 ranged from $8.6 billion to $14.8 billion from fiscal year 2020 through fiscal year 2037.[5]

When undertaking a warhead life extension program (LEP) or replacement program such as the W87-1 Modification, DOD, with input from NNSA, defines the warhead's military characteristics—the technical performance, safety, and security requirements for the warhead—which DOD, with regular NNSA input, refines over time and finalizes before NNSA begins full production.[6] NNSA defines technical requirements for the warhead based on its mission to improve the safety and security of the nuclear stockpile.[7] NNSA designs and produces warheads and bombs to meet these requirements and is responsible for ensuring and verifying weapon performance against those requirements.

Most weapons in the U.S. nuclear stockpile are two-stage nuclear weapons. The first stage, known as the primary, consists of a hollow pit

[4]Despite the name, the W87-1 is not a program to modify existing W87-0 warheads. The W87-0 first entered the stockpile in 1986 and underwent a life extension program from 1994 through 2004. A replacement program is planned in the mid 2030s.

[5]National Nuclear Security Administration (NNSA), *W78 Replacement Program (W87-1): Cost Estimates and Use of Insensitive High Explosives*, Report to Congress (Washington, D.C.: December 2018). According to NNSA's *Fiscal Year 2020 Stockpile Stewardship and Management Plan* and NNSA officials, the W87-1 program cost estimate is a preliminary estimate intended to support NNSA's early-stage program planning and alternatives analysis. In its report, NNSA increased the low range of its weapons cost estimates from a 15 percent probability to a 50 percent probability, which resulted in a cost estimate of $11.7 billion to $14.8 billion for the W87-1 program. See NNSA, *Fiscal Year 2020 Stockpile Stewardship and Management Plan* (Washington, D.C.: July 2019).

[6]For the purposes of this report, we refer to the military characteristics as "military requirements." DOD defines additional design criteria for the warhead's performance in the environments that the warhead is expected to encounter from its entry into the nuclear weapons stockpile through delivery to the target in the Stockpile-to-Target Sequence document.

[7]According to NNSA officials and an NNSA implementation guide, under Presidential Policy Directive (PPD)-35, NNSA should seek approaches to enhance safety and security of the stockpile when undertaking a program managed like an LEP, such as the W87-1. NNSA, *Defense Programs PPD-35 Implementation Guide: Use Control Requirements* (Washington, D.C.: June 2016). In addition, Department of Energy (DOE) Order 452.1E, *Nuclear Explosive and Weapon Surety Program* defines NNSA requirements such as safety and security standards to guide programs to develop new and refurbished nuclear weapons. See DOE, *Nuclear Explosive and Weapon Surety Program,* Order 452.1E (Washington, D.C.: January 26, 2015).

typically made of plutonium and other materials, surrounded by high explosives material. The second stage, known as the secondary, may consist of uranium, lithium, and other materials. The primary and the secondary together, within a radiation case, are referred to as the weapon's nuclear explosive package. When detonated, these nuclear components produce the weapon's explosive force, or "yield." The nuclear explosive package—plus an array of nonnuclear components that control and support the detonation sequence and help ensure its safety and security from human tampering and from environmental effects—are packaged within a reentry vehicle. Figure 1, below, shows a W87-0 within a Mk21 reentry vehicle; the future W87-1 is intended to be similar in size and shape.

Figure 1: W87-0 Nuclear Warhead within a Mk21 Reentry Vehicle

Source: U.S. Air Force photo by Senior Airman Jason Wiese. | GAO-20-703

At the time the program was suspended in 2014, NNSA had evaluated whether to refurbish, reuse, or replace the W78 warhead, ultimately choosing to replace the capability. Specifically, NNSA chose to replace the W78 capability with a warhead based on a W87 primary because it would meet military requirements and could be certified without underground nuclear testing.[8]

In restarting the program, NNSA plans to continue evaluating design options to meet DOD and NNSA requirements, with the goal of deciding on the system architecture design in fiscal year 2022. Remaining decisions cover a range of functional areas of the warhead including technologies for safety and security features, materials inside the nuclear explosive package, and production processes for nuclear and nonnuclear components. A key challenge in determining the baseline design for the W87-1, according to *NNSA's Fiscal Year 2020 Stockpile Stewardship Management Plan*, is the need to develop new technologies to replace legacy designs and obsolete materials, as well as to improve safety and security, manufacturing time, and maintainability, among other things.

The W87-1 will be the first weapon that NNSA has produced using entirely new or remanufactured nuclear and nonnuclear components since the end of the Cold War. However, as we have reported, many of the facilities that may be needed to provide components for the W87-1 are inadequate and are undergoing modernization to either build new facilities or repair existing facilities and capabilities, which represents a critical external risk to the program.[9] For example, the United States is limited currently to production of development pits; it has not manufactured a new pit for use in a weapon since 2012, and has not had the capability to produce more than 10 pits per year for over 2 decades.[10]

You asked us to examine the plans for the W87-1 warhead (under its former name of Interoperable Warhead 1). This report examines the extent to which NNSA (1) considered cost estimates in early design decisions for the W87-1 and the potential effects of remaining design decisions on program cost, and (2) will be able to produce sufficient numbers of key nuclear components to meet W87-1 production needs and has mitigation plans to address risks that production could be insufficient.

[8]The United States has observed a unilateral moratorium on the testing of nuclear weapons since 1992.

[9]GAO-19-84.

[10]DOE closed its last major pit production facility at Rocky Flats, Colorado, in 1992.

This report is a public version of a classified report that we issued in February 2020.[11] NNSA and DOD deemed some of the information in our February report to be classified, which must be protected from loss, compromise, or inadvertent disclosure. Therefore, this report omits classified information about planned warhead production and secondary production, additional warhead features under consideration, the effects of various reduced pit production scenarios on W87-1 production, information about pit reuse options, and information from pit reuse studies. In addition, NNSA determined some information related to pit production to be sensitive, and that information has been omitted. Although the information provided in this report is more limited, the report addresses the same objectives as the classified report and uses the same methodology.

To examine the extent to which NNSA considered cost estimates in early design decisions for the W87-1 and the potential effects of remaining design decisions on program cost, we focused on NNSA's design studies and decisions made from 2010 through 2014, before the program was suspended, and the remaining design decisions NNSA plans to make. Regarding decisions before the suspension, we reviewed the findings from an independent review of NNSA's initial analysis of alternatives (AOA) process for the W87-1 completed by NNSA's Office of Cost Evaluation and Program Evaluation (CEPE).[12] We also interviewed the CEPE review team to clarify its findings and reviewed NNSA documentation to confirm those findings. We reviewed the Air Force's August 2018 military requirements document and DOE and NNSA requirements documents, such as DOE Order 452.1E, *Nuclear Explosive and Weapon Surety Program*. For decisions made following the program's restart in January 2019, we reviewed early program plans and other documents for the W87-1 that described NNSA's approach to analyzing options for its remaining design decisions; however, due to the early stage of the program, some documentation was not available during the period of our review. We also reviewed documentation that described some of the technologies that NNSA is evaluating for these remaining

[11]GAO, *Nuclear Weapons: NNSA Should Further Develop Cost, Schedule, and Risk Information for the W87-1 Warhead Program*, GAO-20-207C (Washington, D.C.: Feb. 28, 2020).

[12]An AOA process entails identifying, analyzing, and selecting a preferred alternative to best meet the mission need by comparing the operational effectiveness, costs, and risks of potential alternatives. NNSA, *W78 Replacement Program (W87-1 Modification Program): Analyses of Alternatives and Requested Information*, Report to Congress (Washington, D.C.: May 2019).

decisions. In addition, we examined preliminary cost estimates that NNSA developed in December 2018 for design variations. We interviewed NNSA officials from the W87-1 federal program office within NNSA's Office of Defense Programs (DP) to clarify requirements, design study plans, and activities and cost information, as well as officials from the DP Office of Technology Maturation about new technologies that are potential options for the W87-1 and future warhead programs. We also interviewed officials in the DP Office of Systems Engineering and Integration about NNSA's requirements and guidance for managing the design phases of warhead life extension or replacement programs, such as the W87-1. We also interviewed DOD officials to clarify the military requirements for the W87-1.

To examine the extent to which NNSA will be able to produce sufficient numbers of key nuclear components to meet W87-1 production needs and has mitigation plans to address risks if production is insufficient, we reviewed NNSA's fiscal year 2019 Production and Planning Directive, which provides current and estimated nuclear weapons stockpile quantities for current and future years. It also defines the activities necessary—including pit and secondary production—to support the stockpile. In this report, we present pit and secondary production according to the plans noted in the 2019 Production and Planning Directive, which represented the best available information at the time of our review on the number of weapons and key components needed. At the time of our review, the Nuclear Weapons Council had not yet determined the number of W87-1 warheads that NNSA will produce; warhead production figures are based on preliminary information supplied by NNSA officials according to their knowledge of production plans.[13] We also interviewed NNSA officials from the W87-1 program office and plutonium and uranium program offices to obtain their views on the production needs and time frames for the W87-1 program, the W87-1 program's plan for developing a risk mitigation framework, and risk mitigation planning. To assess risk mitigation concepts, we reviewed studies from Lawrence Livermore National Laboratory (Lawrence Livermore) regarding the reuse of previously-manufactured pits and related reports by independent expert groups. We interviewed DOD officials to obtain their views on efforts to align production of the W87-1

[13]The Nuclear Weapons Council is the joint DOD and DOE activity responsible for matters related to executive-level management of the nuclear weapons stockpile. The Nuclear Weapons Council serves as the focal point for decisions to maintain and manage U.S. nuclear weapons, and reviews and approves proposed programs to extend the life or replace capabilities within the nuclear stockpile.

with the GBSD program, and their views on the risk of insufficient pits to sustain the W87-1 program.

To address both objectives, we conducted site visits to Lawrence Livermore and Sandia National Laboratories in California, as well as to Los Alamos National Laboratory (LANL) and to NNSA's Albuquerque Complex in New Mexico. During the visits, we interviewed NNSA officials and laboratory contractor representatives to obtain their views on planning, design, and production of the W87-1 and key components. We also visited Kirtland Air Force Base in New Mexico to interview Air Force officials regarding preliminary planning for the W87-1 program and alignment with GBSD, and we visited U.S. Strategic Command in Nebraska to interview DOD officials regarding their views on the W87-1 program. We also interviewed Navy officials in Washington, D.C., regarding the Navy's efforts to investigate the feasibility of fielding the W87-1 system in a Navy SLBM system.

The performance audit upon which this report is based was conducted from May 2018 to February 2020 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate, evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives. We subsequently worked with NNSA and DOD from March 2020 to September 2020 to prepare this unclassified version of the original classified report for public release. This public version was also prepared in accordance with these standards.

Background

Performance, Safety, and Security Requirements for the W87-1

The Nuclear Weapons Council approved the Air Force's most recent version of the military characteristics for the W87-1 in February 2019. As mentioned above, these define the military's performance, safety, and security requirements for the warhead. The military characteristics also define minimum, or "threshold," safety and security requirements that are intended to improve on the W78's safety and security features.[14] Key threshold requirements include a primary implosion system that is resistant to fire and detonation and improved security features to prevent unauthorized use of the warhead during normal road transportation environments.[15] In addition, the Air Force and NNSA identified optional "objective" enhanced safety and security requirements that NNSA should evaluate based on cost, benefits, and risk.

NNSA has reported that including insensitive high explosives in the W87-1 is a key threshold safety requirement that will also provide security benefits. Because of their greater insensitivity to shock, impact, or fire compared with the conventional high explosives that are used in the W78, including insensitive high explosives in the W87-1 will improve safety during the warhead's manufacturing, assembly, maintenance, and transport to and from NNSA and Air Force facilities, according to an NNSA report. In addition, use of insensitive high explosives is expected to allow a greater range of security tactics, techniques, and procedures to ensure secure transportation of the warhead. NNSA reported that it expects insensitive high explosives to help reduce one of the highest security risk environments identified by the Air Force for its ICBMs during an early study for the W87-1—transportation of ICBMs over long distances from Air Force bases to the approximately 450 geographically-dispersed ICBM launch facilities.

An additional key threshold military requirement for the W87-1 program is that the warhead can be certified for fielding without the need for new

[14]Safety features are intended to prevent unintended detonation and spread of nuclear material. Security features are intended to prevent unauthorized use of the warhead. DOE and DOD generally use the term "surety" to refer to safety, security, and use control of nuclear explosives and nuclear weapons. For the purposes of this report, we use the terms safety and security in place of surety.

[15]According to an NNSA report, high explosives are essential to the operation of all nuclear weapons. High explosives compress the plutonium pit in the primary and initiate the chain of events leading to nuclear yield. NNSA uses two types of high explosives for a weapon's main charge. Conventional high explosives detonate when given sufficient stimulus via a high-pressure shock. Stimuli from severe accident environments such as those involving impact, fire, or electrical discharge may also initiate the detonation or deflagration of conventional high explosives. Insensitive high explosives require a significantly higher shock stimulus than conventional high explosives to detonate or react violently. Stimuli from almost all credible accident environments will not initiate insensitive high explosives. In June 2019, we reported on NNSA's approach to managing its explosives activities, among other things. See GAO, *Nuclear Weapons: Additional Actions Could Help Improve Management of Activities Involving Explosive Materials*, GAO-19-449 (Washington, D.C.: June 17, 2019).

nuclear explosive testing. Specifically, the W87 primary was certified on the basis of several underground tests and many supporting tests for safety and security, and thus has a strong underground nuclear test base, according to NNSA documents. An independent expert group notes that the W87 primary system was a well-tested system that provides high confidence for its nuclear performance.[16] The W87 pit, as an integral part of the W87 primary, also satisfies several Air Force and NNSA requirements for a pit that features enhanced resistance to fire and that functions well within an implosion system driven by insensitive high explosives. The W87-1 primary system features two modifications from the W87-0 design to accommodate enhanced safety and security features. The W87 primary design provides high confidence that the weapon will work as intended without the need for underground testing, according to documentation and representatives from Lawrence Livermore.

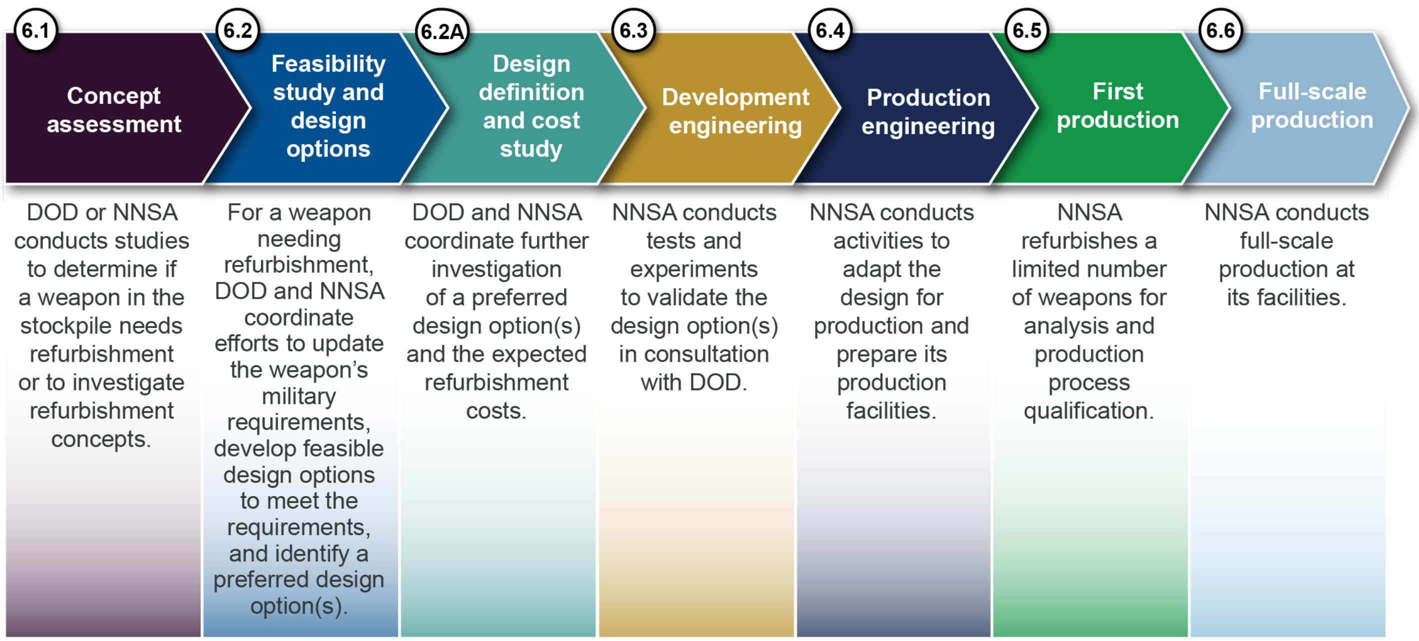
Phase 6.X Process for Managing Life Extension Programs and NNSA's Program Management Instruction

DOD and NNSA have established a process, known as the Phase 6.X process, to jointly manage warhead LEPs.[17] According to a Nuclear Weapons Council document, NNSA will follow this process to manage the W87-1 program. As shown in figure 2, this process includes key phases or milestones that a nuclear weapon LEP must undertake before proceeding to subsequent steps.

[16]JASON, *Technical Considerations for the Evolving U.S. Nuclear-Weapons Stockpile*, JSR-14-Task-006 (McLean, VA: June 2015).

[17]Department of Defense and NNSA, *Procedural Guideline for the Phase 6.X Process* (Washington, D.C.: December 2015).

Figure 2: Phase 6.X Process for Managing Warhead Life Extension Activities for Nuclear Weapons



Abbreviations

DOD Department of Defense

NNSA National Nuclear Security Administration

Source: Nuclear Weapons Council. | GAO-20-703

NNSA defines requirements as well as roles and responsibilities among NNSA offices for implementing the Phase 6.X process through a supplemental directive and DP business procedure documents. NNSA's DP is responsible for implementing most of the Phase 6.X activities for a warhead program—for example, by establishing the warhead program team led by a federal program manager and federal program office. In addition, under NNSA's supplemental directive, NNSA's CEPE is required to conduct independent reviews during certain phases. For example, CEPE is required to complete an independent cost estimate of the warhead during Phase 6.2A (Design Definition and Cost Study).

In addition to the Phase 6.X process, NNSA's DP established a program execution instruction that defines enhanced program management requirements for programs such as the W87-1 across a range of program management functions, including risk management, decision analysis, integrated scheduling, and interface management.[18] This instruction also describes the level of program management rigor that the W87-1 program must follow for each function.

NNSA's Preliminary Schedule for the W87-1

NNSA has developed a preliminary schedule for the W87-1 program under the Phase 6.X process that includes activities through fiscal year 2038. The schedule is intended to align at key points with the Air Force's schedule for acquiring GBSD. According to NNSA's preliminary schedule, the program will do the following:

- **Conduct remaining Phase 6.2 (Feasibility and Design Options)** activities, including, among other things, evaluating remaining feature and component design options for warhead components, selecting preferred design options, and developing cost estimates for them by the end of third quarter fiscal year 2021. NNSA previously completed Phase 6.1 and was authorized by the Nuclear Weapons Council to start Phase 6.2 in June 2012. NNSA did not complete Phase 6.2 before the program was suspended in 2014.
- **Conduct Phase 6.2A (Design Definition and Cost Study)** for 1 year beginning in the fourth quarter of fiscal year 2021. During this phase, for example, NNSA plans to develop a preliminary cost estimate for the program, called a weapons design and cost report, and NNSA's CEPE is to produce an independent cost estimate.
- **Start Phase 6.3 (Development Engineering)** in the fourth quarter of fiscal year 2022 and start to transition to Phase 6.4 (Production Engineering) in the fourth quarter of fiscal year 2024. During these phases, NNSA will develop the final design and cost baseline, as well as begin producing selected acquisition reports—which detail the total program cost, schedule, and performance, among other things.[19]
- **Achieve production of the first warhead—Phase 6.5**—by the second quarter of fiscal year 2030 so that it can be fielded on the Air Force's planned GBSD that same year.
- **Start Phase 6.6 (Full-scale Production)** by the second quarter of fiscal year 2031 and complete the last production unit in fiscal year 2038.

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[18]NNSA, *DP Program Execution Instruction: NA-10 Program Management Tools and Processes* (Washington, D.C.: June 2019).

[19]According to DOD documents and DOD officials, as of October 2019, DOD had not yet determined when the W87-1 will be flight tested on the GBSD.

NNSA Requirements and Guidance for Conducting Design Options Studies During Phase 6.2

NNSA has established the following procedural requirements and guidance for conducting design options studies during Phase 6.2:

- According to NNSA's Phase 6.X supplemental directive, during Phase 6.2, a warhead program is required to develop, analyze, and make choices among design options.[20] The Phase 6.2 study is to focus on components and technologies for design options and is to include analysis of design trade-offs and costs and benefits.[21]
- According to the DP program execution instruction, programs conduct AOAs or similar studies as needed during the Phase 6.X process.[22] In Phase 6.1, according to the instruction, the alternatives are focused on evaluating a life extension program or repair and maintenance. In Phases 6.2 and 6.2A, the instruction states that the alternatives relate to specific design or technology options. When performed by LEP or replacement programs, the only requirement under the program execution instruction is that such studies follow an established methodology to document the options considered and basis for conclusions. The program execution instruction recommends, but does not require, that programs executing an AOA or similar study produce a study plan to outline the goals, planned methodology, and schedule of the study. It also recommends, but does not require, a final report informing the decision-maker of key results and the study methodology.
- NNSA has established an AOA business operating procedure (AOA business procedure) for capital asset acquisitions that is considered optional guidance for LEPs and replacement programs.[23] Under the AOA business procedure, AOAs are required to be performed

[20]NNSA, *Phase 6.X Process*, Supplemental Directive, SD 452.3-2 (Washington, D.C.: Jan. 19, 2017).

[21]NNSA Supplemental Directive, 452.3-2.

[22]NNSA's Phase 6.X directive states that Phase 6.2 studies are AOA-like but that an LEP does not perform a "classical AOA." NNSA's directive does not define the term "classical AOA" and we could not find the term used or defined in any other NNSA or DOE policy, directive, or guidance. NNSA, Office of Cost Estimating and Program Evaluation, *Analysis of Alternatives,* Business Operating Procedure, BOP 413.6 (Washington, D.C.: March 14, 2016).

[23]Capital asset acquisition programs and projects in DOE and NNSA are governed by program management requirements defined in DOE Order 413.3B. DOE, *Program and Project Management for the Acquisition of Capital Assets*, Order 413.3B, Chg. 5 (Washington, D.C.: April 12, 2018).

consistent with GAO best practices for conducting an AOA.[24] As we have previously reported, these best practices can be applied to a wide range of activities in which an alternative must be selected from a set of possible options, as well as to a broad range of capability areas, projects, and programs.[25] They can provide a framework to help ensure that entities consistently and reliably select the alternative that best meets mission needs. The AOA business procedure provides more specific direction to programs about required AOA elements, such as a study plan and final report. For example, the study plan must specify the data and resources needed to complete the study, the selection and evaluation criteria that represent mission need and program requirements, and a sufficiently detailed description of the methodology the AOA team intends to pursue for each phase of analysis. When best practices cannot be followed, any deviations must be justified and documented in the study plan and final report. The AOA business procedure states that the requirements are intended to ensure that the AOAs provide decision-makers with reliable and objective assessments of options to best meet the mission need. For programs such as LEPs or replacement programs that are conducting AOAs or similar studies, the program execution instruction recommends, but does not require, that such programs employ the same analytic rigor and best practices as those found in the AOA business procedure.

NNSA Facilities Modernization to Meet Planned W87-1 Production Needs

Under DP programs separate from the W87-1 program, NNSA is undertaking a comprehensive effort to expand and modernize the facilities and infrastructure that make up the nuclear security enterprise. As part of this effort, NNSA is modernizing and repurposing the production facilities to produce the pits and secondaries needed for the W87-1, as described below:

Production facilities for pits: NNSA is developing the capability to produce and certify one pit in 2023, produce up to 30 pits in 2026, and to

[24]GAO, *Amphibious Combat Vehicle: Some Acquisition Activities Demonstrate Best Practices; Attainment of Amphibious Capability to be Determined*, GAO-16-22; (Washington, D.C.: Oct. 28 2015) app. I. GAO has identified 22 best practices for an AOA process. The practices are grouped under five phases: initialize the AOA process, identify alternatives, analyze alternatives, document the AOA process, and review the AOA process.

[25]GAO-16-22.

produce up to 80 pits during 2030.[26] In 2014, the Nuclear Weapons Council also affirmed to Congress that it needs NNSA to develop a capability to produce 50 to 80 pits per year. To achieve this production, in May 2018 the NNSA Administrator provided Congress with NNSA's plan to split pit production between facilities at two sites. According to NNSA, this dual approach is the best way to manage the cost, schedule, and risk of such an undertaking and provide increased resiliency, flexibility, and redundancy by not relying on a single production site. For the first prong of this plan, NNSA is modernizing its Plutonium Facility (PF-4) at LANL to produce 30 pits per year starting in fiscal year 2026. The second prong is to repurpose the partially constructed Mixed Oxide Fuel Fabrication Facility at the Savannah River Site (SRS) in South Carolina to produce 50 pits per year under an effort now called the Savannah River Plutonium Processing Facility. According to NNSA documentation, the agency preliminarily estimates that modernization of PF-4 will cost up to $3 billion over the next 5 years, and that converting and bringing the facility at SRS online will cost approximately $4.6 billion.[27] NNSA uses funds from the plutonium program for these projects.[28]

NNSA's plans call for ramping up its pit production capabilities to 30 pits per year at LANL by 2026 and 50 pits per year at SRS by 2030, according to NNSA documents (see table 1). This schedule is intended to support production through to final production of the last W87-1 in 2038.

[26]Federal law requires NNSA to produce no less than 10 war reserve pits during 2024, no less than 20 war reserve pits during 2025, no less than 30 war reserve pits during 2026, and to produce no less than 80 war reserve pits during 2030. 50 U.S.C. § 2538a.

[27]The SRS estimate is a rough-order-of-magnitude estimate not intended for budgeting purposes, according to NNSA documentation.

[28]The joint explanatory statement accompanying Pub. L. No. 116-94, one of the fiscal year 2020 consolidated appropriations acts, directed NNSA to manage LANL pit production and associated recapitalization, as well as the SRS pit production facility, under DOE Order 413.3B for managing capital asset acquisitions.

Table 1: GAO Analysis of Capabilities Needed to Meet National Nuclear Security Administration Pit Production Goals, Fiscal Years 2023 through 2035

	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
LANL pit production	1	10	20	30	30	30	30	30	30	30	30	30	30
SRS pit production								50	50	50	50	50	50
Cumulative pits produced	**1**	**11**	**31**	**61**	**91**	**121**	**151**	**231**	**311**	**391**	**471**	**551**	**631**

Legend: LANL=Los Alamos National Laboratory SRS=Savannah River Site

Source: GAO analysis of 50 U.S.C. § 2538a and NNSA's Fiscal Year 2020 Stockpile Stewardship Management Plan. | GAO-20-703

Note: A pit is the fissile core of a nuclear weapon.

Production facilities for secondaries: NNSA is constructing the Uranium Processing Facility (UPF) at its Y-12 National Security Complex (Y-12) in Tennessee to help produce secondaries for the W87-1 program, among other things.[29] NNSA plans to complete the facility for no more than $6.5 billion by the end of 2025—approximately 4 years before the scheduled delivery of the first production unit of the W87-1 warhead. This facility will in part replace an existing building, 9212, which contains the most hazardous enriched uranium operations and does not meet modern nuclear safety and security standards. In addition, NNSA is investing in modernization of other existing facilities at Y-12, including buildings 9215 and 9204-2E, which support and perform secondary production.

Coordination between NNSA's W87-1 Program and the Plutonium and Uranium Programs

NNSA's W87-1 program, plutonium program, and uranium program are separately funded and managed programs within NNSA DP. Under NNSA's Phase 6.X process directive, the W87-1 program must coordinate with these and other NNSA programs that are to produce the components, including the pits and secondaries needed for the warhead.

The W87-1 program intends to manage coordination with these other NNSA programs through interprogram agreements called "interface requirements agreements," according to W87-1 program documentation. These agreements describe the work to be provided by other NNSA programs needed to enable the W87-1 program to meet requirements on schedule, including milestone dates for completing the work; funding; and

[29]NNSA's Office of Acquisitions and Project Management manages the UPF project under DOE Order 413.3B with funding from NNSA's Office of Defense Programs through the uranium program.

any risks to cost, schedule, or performance. To help the W87-1 program ensure pits and secondaries are produced when needed, the program has developed interface requirements agreements signed by the W87-1 program manager and the program managers of both the plutonium program and the uranium program. The interface agreements between the programs provide the W87-1 program some confidence in obtaining the W87-1 pits and secondaries when needed, according to the W87-1 program manager. For example, under the agreement, the plutonium program office will have to report quarterly to the W87-1 program on the status of pit production; the uranium program would do the same for secondary production.

Best Practices for Schedule Estimating

In December 2015, we published a Schedule Assessment Guide (schedule guide) that identifies best practices for scheduling.[30] According to the schedule guide, a well-planned schedule is a fundamental management tool that can help government programs use funds effectively by specifying when work will be performed in the future and measuring program performance against an approved plan. Moreover, an integrated master schedule can show when major events are expected as well as the completion dates for all activities leading up to these events, which can help determine if the program's parameters are realistic and achievable. An integrated master schedule may be made up of several or several hundred individual schedules that represent portions of effort within a program. These individual schedules are "projects" within the larger program. An integrated master schedule integrates the planned work, the resources necessary to accomplish that work, and the associated budget, and it should be the focal point for program management. Furthermore, according to the schedule guide, an integrated master schedule constitutes a program schedule that includes the entire required scope of work, including the effort necessary from all government, contractor, and other key parties for a program's successful execution from start to finish.

Planning and scheduling are continual processes throughout the life of a project. Planning may be done in stages throughout the project as stakeholders learn more details. A comprehensive integrated master schedule should reflect all program activities and recognize that uncertainties and unknown factors in schedule estimates can stem from, among other things, limitations in data. Because the schedule is used for

[30]GAO, *Schedule Assessment Guide: Best Practices for Project Schedules*, GAO-16-89G (Washington, D.C.: December 2015).

coordination, the absence of necessary elements will hinder coordination, increasing the likelihood of disruption and delay. A process known as rolling wave planning incorporates levels of detail that depend on the information available at a point in time. Uncertainties regarding future activities are incorporated into the integrated master schedule in part by the rolling wave process and through schedule risk analysis.

NNSA Did Not Consider Cost Estimates in Early Design Decisions for the W87-1, but Has Required Later Warhead Programs to Do So

NNSA did not consider cost estimates in making early design decisions for the W87-1 warhead, according to a May 2019 independent review of the AOA process for the program. At the time, NNSA did not require warhead programs to examine cost estimates for early design decisions but has since required them to be considered. An independent review team from NNSA's CEPE found that NNSA's studies for the W87-1 during Phase 6.1 (Concept Assessment), and early Phase 6.2 (Feasibility and Design Options), were not informed by analysis of each potential option's affordability, schedule, or programmatic risk, although the review found that the studies generally followed the Phase 6.X procedural guidelines and practices in place at the time. The studies focused exclusively on the ability of each option to meet the military requirements, according to the CEPE review. In particular, the studies focused on requirements to (1) incorporate insensitive high explosives to improve the safety of the warhead and (2) provide an interoperable nuclear explosive package that could be used in Air Force and Navy ballistic missile systems.

According to the CEPE review, the requirements limited the analysis of design options. As a result, during Phase 6.1, NNSA screened out from further consideration a "status quo" option to refurbish the W78—before evaluating the costs and benefits of that option against those of all other options—because it did not meet the military requirements, particularly for safety.[31] In addition, in early Phase 6.2 before the program was suspended, NNSA chose the pit and secondary to include in the W87-1 without comparing costs and benefits of all options, according to CEPE's review. The CEPE review noted that NNSA, in its analysis to support the selection of the W87 type pit, had included limited cost and risk assessments for certification but that a basis of estimate for the costs and the risk assessment methodology was not included. According to AOA best practices—first published in December 2014, after the program's suspension—an analysis of alternatives study should evaluate all

[31]According to the CEPE review, the Phase 6.1 study examined a number of refurbishment, replacement, and reuse warhead concepts with a number of safety and security and yield capabilities.

alternative options, including a status quo option, by comparing costs and benefits.[32]

The CEPE review team told us that NNSA's implementation procedures for the Phase 6.X process at that time (2010 to 2014) did not require cost to be considered during Phase 6.1. Under the Phase 6.X process at that time, cost should have been considered in Phase 6.2, but NNSA had not done so before the program was suspended, according to the CEPE review. In the Phase 6.2 studies conducted before the program was suspended, NNSA completed an analysis of the technical scope and complexity of design options.[33] This analysis determined that, among other things, optional "objective" enhanced safety and security measures for the W87-1 design could be as much as 11 percent of the total cost. After the warhead program was suspended, NNSA revised its procedures for later LEPs and replacement programs implementing the Phase 6.X process to clearly require that cost be considered during Phase 6.1 and 6.2, including development of cost estimates, according to NNSA officials responsible for NNSA's Phase 6.X implementation procedures and our own review of the documents.[34]

NNSA's early decisions had a substantial impact on the agency's estimated cost of $8.6 billion to $14.8 billion for the program, according to

[32]GAO-16-22. CEPE noted in NNSA's report that the Phase 6.1 study was conducted from 2010 through 2012, prior to our initial publication in December 2014 of best practices for an AOA process. See GAO, *DOE and NNSA Project Management: Analysis of Alternatives Could Be Improved by Incorporating Best Practices*, GAO-15-37 (Washington, D.C.: Dec. 11, 2014).

[33]The report notes that complexity factors are directly proportional to costs.

[34]Specifically, according to the current requirements, during Phase 6.1, NNSA is to assess concepts and technological risks with potential cost ranges. In addition, as mentioned earlier, during Phase 6.2, NNSA is to develop preliminary cost estimates of potential design options. NNSA, *Implement Phase 6.X Process*, Defense Programs Business Process System R006 (Washington, D.C.: Jan. 01, 2018).

NNSA officials and reports.[35] For example, in presenting the W87-1 warhead cost range, NNSA's December 2018 report stated that NNSA had underestimated the complexity of addressing the challenges of newly manufactured warhead components, including development of new insensitive high explosives and new capability needed for secondary and nuclear explosive package work, among other things.

We found that the plan to newly manufacture all components of the warhead increased the estimated cost because it added substantial complexity to the work that will be required to engineer and qualify the W87-1. According to representatives from Sandia National Laboratories, this plan reflected the fact that many components are unavailable for refurbishment or reuse. In comparison, all of NNSA's prior LEPs have involved a mix of refurbished and newly manufactured components.[36] In addition, according to NNSA officials, the secondary planned for the W87-1 increased the estimated cost of the warhead because the materials for the secondary, including uranium, will need to be qualified. Further, NNSA plans to manufacture the secondaries in UPF when construction of that facility is completed. Manufacturing the secondaries in UPF would add complexity to the production because, among other things, the W87-1 secondaries would be the first secondaries produced in UPF, according to NNSA officials. Moreover, NNSA is building UPF to meet more restrictive criticality safety limits on the amount of uranium that can be used in the facility at one time, according to NNSA officials. The limit in UPF will be more restrictive than the limit to which NNSA's older production facilities were designed. Because of the amount of uranium in the W87-1 secondary's design, NNSA will need to use a new approach to manufacture the secondaries following the more restrictive safety limits in

[35]We examined NNSA's W87-1 cost estimate of $8.6 billion to $14.8 billion by comparing the estimate to GAO best practices to assess the extent to which it met the characteristics of a high-quality and reliable cost estimate. See app. I for the detailed results of our analysis. As mentioned above, the W87-1 program cost estimate is a preliminary estimate for NNSA to perform early-stage program planning and alternatives analysis. NNSA developed the W87-1 estimate using preliminary design assumptions, subject matter expert views on the technical complexity of the design, and program costs from recently completed and ongoing warhead and bomb LEPs such as the W76-1, B61-12, and W80-4. We found that the estimate substantially met three characteristics (comprehensive, accurate, and credible) and partially met one characteristic (well-documented). GAO, *GAO Cost Estimating and Assessment Guide: Best Practices for Developing and Managing Capital Program Costs*, GAO-09-3SP (Washington, D.C.: Mar. 2, 2009).

[36]NNSA could not provide us with data on how much these individual choices specifically contributed to the overall cost estimate because its cost-estimating methodology did not provide an estimate for each design element for the warhead.

UPF, thus adding complexity to the production, according to NNSA officials.

In fiscal year 2018, Congress directed NNSA to report on the estimated cost of a W78 refurbishment—or status quo option—compared to the estimated cost of the W87-1.[37] As discussed, NNSA had previously omitted the W78 refurbishment option from further study because a W78 refurbishment would not meet military requirements. Congress's direction followed the February 2018 Nuclear Posture Review direction to NNSA to restart the W87-1 program with a focus on providing a warhead for the Air Force's GBSD. NNSA reported that the Nuclear Posture Review direction removed the design constraint for an interoperable warhead. In its report to Congress, NNSA reported that the estimated cost for the concept of a W78 refurbishment would be close to the estimated cost of the W87-1, excluding the cost of producing the new pits for the W87-1; a W78 refurbishment would involve reusing existing W78 pits and not producing new pits.[38] NNSA estimated a W78 refurbishment could cost from $8.5 billion to $14.3 billion compared with NNSA's December 2018 estimate for the W87-1 of $8.6 billion to $14.8 billion. NNSA separately estimated that producing the new pits for the W87-1 could add $300 million to $750 million to the cost of the warhead, resulting in a cost range of from $8.9 billion to $15.6 billion.[39] (See table 2.) These costs are in addition to NNSA's estimate of up to approximately $3 billion to modernize LANL's PF-4 and approximately $4.6 billion to convert and bring the SRS facility online to produce pits. According to NNSA officials, these facilities would

[37]The conference report accompanying the Energy and Water, Legislative Branch, and Military Construction and Veterans Affairs Appropriations Act, 2019, Pub. L. No. 115-244, included a provision for NNSA to provide the Committees on Appropriations in both houses of Congress, not later than November 20, 2018, and prior to commencement of Phase 6.2, a report that provides, among other things, a rough-order-of-magnitude cost and schedule comparison of the differences between the requested interoperable warhead-1 (i.e., W87-1) and a W76 LEP-like refurbishment of the W78. H.R. Rep. No. 115-929 at 165 (2018).

[38]NNSA, *W78 Replacement Program (W87-1): Cost Estimates and Use of Insensitive High Explosives*, Report to Congress, (Washington, D.C.: December 2018).

[39]According to NNSA officials, they estimated the cost of producing the new W87-1 pits based on preliminary analysis of data from producing a small number of W88 pits from fiscal year 2007 through fiscal year 2012.

need to be modernized for future weapons programs in addition to the W87-1.[40]

Table 2: The National Nuclear Security Administration's (NNSA) Cost Estimates for the W87-1 Warhead Modification Compared with a W78 Warhead Refurbishment, as of December 2018
(Dollars in billions)

Warhead	Cost estimate range[a]
W87-1 Modification (i.e., W78 replacement), excluding new pit production	8.6 - 14.8
W87-1 Modification including cost of new pit [b] production	8.9 – 15.6
W78 Refurbishment[c]	8.5 - 14.3

Source: NNSA, *W78 Replacement Program (W87-1): Cost Estimates and Use of Insensitive High Explosives*, Report to Congress, (Washington, D.C. December 2018). | GAO-20-703

[a]The cost ranges reflect low and high estimates for a single design concept or variation. The ranges represent technical and production risk and uncertainty.

[b]NNSA separately estimated that producing new pits for the W87-1 may add about $300 million to $750 million to the total cost of the warhead. These pit costs are in addition to NNSA's preliminary estimates of up to approximately $3 billion to modernize the Plutonium Facility at Los Alamos National Laboratory in New Mexico and approximately $4.6 billion to repurpose the Mixed Oxide Fuel Fabrication Facility at the Savannah River Site in South Carolina to produce pits.

[c]The W78 refurbishment would reuse the existing W78 pits and not produce new pits.

According to NNSA's report, the cost of a W78 refurbishment would still be close to the cost of the W87-1 because a W78 refurbishment would still require substantial remanufacturing of components. NNSA also emphasized in its report to Congress that a W78 refurbishment, among other concerns, would not improve the safety and security of the W78 and would not meet threshold military requirements because it would not use insensitive high explosives. Under a W78 refurbishment option, NNSA would reuse the existing W78 pit, which uses conventional high explosives.

[40]As mentioned earlier, the costs to reestablish the facilities and infrastructure to produce new pits at LANL and SRS are to be funded through DP's plutonium program and not the W87-1 warhead program.

NNSA's Remaining Decisions for the W87-1 Could Affect the Program's Cost, and the Agency Does Not Yet Have Study Plans for Assessing All Remaining Design Decisions

NNSA's remaining design decisions for the W87-1 in Phase 6.2 could affect the program's cost, according to preliminary cost estimates and NNSA officials, and the agency does not yet have study plans that would help ensure that the program employs consistent, reliable, and objective approaches for assessing costs and benefits of the remaining design decisions.

The remaining decision expected to have the largest cost impact is whether to include certain safety and security features in the W87-1 design to meet the military's and NNSA's enhanced requirements. These features would provide enhanced capabilities above those that would meet the military's threshold requirements, according to NNSA's W87-1 program manager and lead engineer. NNSA's W87-1 cost range estimate of $8.6 billion to $14.8 billion incorporates the estimated costs of these enhanced safety and security features, according to preliminary estimates that NNSA developed in December 2018. Alternately, NNSA's cost range estimate for a W87-1 design with only the threshold safety and security features was approximately $7.7 billion to $13.3 billion, according to internal information that NNSA developed in December 2018. Therefore, the estimated cost of including the enhanced safety and security features in the W87-1 could account for approximately $900 million to $1.5 billion of NNSA's total estimated cost for the warhead. Table 3 illustrates the difference in estimated cost ranges between the threshold and enhanced cost estimates based on information NNSA developed in December 2018.

Table 3: The National Nuclear Security Administration's (NNSA) Cost Estimates for W87-1 Warhead Design Variations That Meet Threshold and Enhanced Requirements, as of December 2018
(Dollars in billions)

W87-1 design variations	Cost estimate range[a]
Design includes features that meet threshold (i.e. minimum) safety and security requirements	7.7 - 13.3
Design includes enhanced safety and security features	8.6 - 14.8
Difference between the above estimate ranges	0.9 - 1.5

Source: NNSA documentation | GAO-20-703

[a]The cost ranges reflect low and high estimates for a single design variation. The ranges represent technical and production risk and uncertainty.

The safety and security features that would meet the military's threshold requirements—and which NNSA projected could result in a high-end warhead cost of about $13.3 billion, according to NNSA's preliminary estimates—would provide the W87-1 with capabilities that already exist in other weapons in the stockpile but not in the W78. Among other things, the features include the following:

- **Explosive material performance.** The use of insensitive high explosives is not required, but the explosive material selected must perform at least as well as insensitive high explosives in resisting burning and detonation. As mentioned above, insensitive high explosives are designed to prevent explosive detonation and dispersal of nuclear material from the most severe impacts and fires that might occur from potential accidents, such as an airplane crash.
- **Fire-resistant pit material.** In the event of an accident, plutonium in the weapon’s pit can be dispersed as a result of intense heat. The pit can be designed with a shell material that is resistant to intense heat and can contain molten plutonium.
- **Detonator safety device.** Mechanisms can be located at the main detonators in the warhead’s primary to prevent accidental detonation of the high explosives by requiring separate unique and independent signals for each detonator to operate.

The safety and security features that NNSA was evaluating at the time of our review that would meet the military and NNSA’s objective requirements to provide enhanced capabilities above the military’s threshold requirements could result in the high-end warhead cost of about $14.8 billion if they were all incorporated in the design, according to NNSA’s preliminary estimates. These features would be new to the current stockpile or to ballistic missile warheads and could involve technical risk and certification challenges. For example, NNSA is evaluating inclusion of a mechanism called multipoint safety.[41] According to NNSA officials and NNSA documents, NNSA is required to consider multipoint safety when undertaking warhead refurbishment or replacements. According to an NNSA document and NNSA officials, incorporating multipoint safety into the W87-1 without underground testing will involve technical and certification challenges.

According to NNSA documentation and officials, the agency also has remaining design decisions for other features or components of the warhead that may also have a cost impact, but NNSA did not yet have

[41]Multipoint safety is not a military requirement in the Air Force’s military characteristics; rather, it is an NNSA requirement, according to DOD officials and the W87-1 program manager.

documented estimates of the impact of these decisions on the program's cost. For example:

- **Digital architecture technologies.** NNSA officials said they are evaluating technology options for including digital architecture, instead of conventional electrical wiring, for managing data or power for the warhead's components and subsystems. NNSA is considering such technology because it could, among other potential benefits, facilitate removing individual components from the warhead without impacting other components, according to NNSA officials. They indicated that the extent to which the warhead includes digital architecture could have a substantial impact on the cost of the program.
- **Neutron generators.** NNSA is evaluating three options for the neutron generator in the W87-1, according to a report by NNSA and officials. This nonnuclear component provides additional neutrons at specific timing and rates to initiate the weapon. One option is a new and early-stage technology called a radiation-hardened electronic neutron generator that can reduce life-cycle costs and increase reliability because it can be reused after testing, according to NNSA's report and officials. NNSA officials told us that a non-radiation-hardened version of this neutron generator is used in nuclear bombs. The radiation-hardened type, however, has never been used in a ballistic system. As a result, including this type of neutron generator in the W87-1 would require greater testing and certification, according to NNSA officials. The radiation hardening would be needed because of the environmental conditions in which the ballistic missile would operate. NNSA is also evaluating options for two other similar neutron generators called small and large ferroelectric neutron generators. These options are already in development or production for current LEPs, according to representatives from Sandia National Laboratories.[42] Therefore, these neutron generators would be developed based on reuse designs and would be simpler for testing and qualification. These neutron generators, however, would likely have higher production costs because they cannot be reused after testing. Therefore, NNSA would need to produce greater quantities compared to the radiation-hardened electronic neutron generator, according to NNSA officials.

[42]According to representatives from Sandia National Laboratories, electronic neutron generators are planned for use in the W80-4. Small ferroelectric neutron generators are used in the W87, W80-1, and W88. They are also under production for the W88-Alt 370. Large ferroelectronic neutron generators are used in the W78, W76-0, and W76-1.

- **New production process for radiation case.** According to officials and documents, NNSA is evaluating use of a new production process for manufacturing the radiation case that contains the nuclear explosive package components for the W87-1. The new process would reduce the number of production steps and reduce operating costs and would be more efficient, thus producing less waste, according to the officials. However, NNSA officials also told us that the new process would be expensive to fully mature and achieve readiness for the W87-1. As an alternative, these officials said the agency may decide to manufacture portions of the radiation case using another production process.

The W87-1 program management plan noted that NNSA intended to produce a final report at the end of Phase 6.2—by the fourth quarter of fiscal year 2021—that will present the agency's assessment of the major design options for the W87-1 and NNSA's recommendations for final design choices. To assess these feature and component design options, the W87-1 program intends to conduct studies similar to AOAs to understand their costs, benefits, and risks. As mentioned above, the DP program execution instruction recommends, but does not require, that design studies similar to AOAs for LEPs and replacement programs employ the analytic rigor and best practices of NNSA's AOA procedure for capital asset acquisitions. Instead, such programs may tailor their approach and deviate from the best practices in the AOA procedure to meet program needs. We found that, at the time of our review, the W87-1 program did not follow the best practices guidelines in the AOA procedure to have study plans that describe approaches for assessing the costs and benefits of the remaining feature and component design options, or to justify and document any deviations from best practices.[43] Specifically:

- We found that for the most costly remaining design decision—that of the additional enhanced safety and security features—NNSA did not follow all of the AOA procedure's best practices. In particular, we found that the W87-1 program had a tailored and informal study plan that provided minimal information compared with the guidelines for such a plan in the AOA procedure. For example, the plan did not provide the selection and evaluation criteria that represent mission need and program requirements, a detailed description of the methodology for the evaluation, or a description of deviations from best practices. According to senior NNSA officials and documents, the

[43]NNSA, *Analysis of Alternatives*, BOP 413.6.

study—initiated in January 2019—needed to provide meaningful insights about surety benefits and potential costs by the end of September 2019 to inform fiscal year 2021 budget planning. The evaluation team planned the study in meetings and site visits over several weeks but did not develop a written study plan before beginning the process, according to W87-1 officials. Under best practices, developing a study plan before the analysis begins ensures that bias does not influence study results and that poor methodologies are not applied. In December 2019, after reviewing a draft of our report, NNSA provided us with a predecisional draft study report of its evaluation of six combinations of safety and security features for the W87-1 design.[44]

- For other remaining significant feature and component design decisions, such as for the W87-1's digital architecture and neutron generators, NNSA did not yet have study plans that would help ensure that the teams leading these analyses plan to follow consistent, reliable, and objective approaches for assessing the costs and benefits of each of the remaining design decisions. According to W87-1 program officials, they intend to develop study plans for the remaining design decisions, but because the program had only restarted about a year earlier—in January 2019—the program was still establishing the teams to create them. The officials said that integrated teams made up of contractors from the national laboratories and production sites will be responsible for developing the approaches to guide specific decisions. In December 2019, after reviewing a draft of our report, NNSA provided two recent memorandums that provided some direction and guidance to the study teams in conducting the studies, but that did not cite best

[44]NNSA Office of Defense Programs, *W87-1 Modification Program Surety Risk/Benefits Analysis Final Report* (Washington, D.C.: Sept. 20, 2019). Because the predecisional study report was provided shortly before issuance of our final report, we were unable to fully assess this report against best practices. According to the report, W87-1 program officials and Lawrence Livermore contractor representatives evaluated design option cost estimates; quantitative measures of the expected benefit to safety and security; technical readiness of each option; producibility; schedule and integration complexity; and operational impact on the Air Force as assessed by the W87-1 program office. The report stated that the threshold requirement option had the greatest utility, or cost-benefit, followed by a threshold option with multipoint safety. In December 2019, NNSA senior officials told us that NNSA expected to recommend the option that met only threshold safety and security requirements to the Nuclear Weapons Council.

practices and did not require the development of study plans.[45]

NNSA currently estimates that the W87-1 will be the most expensive warhead program since the end of the Cold War, will be produced using entirely new or remanufactured nuclear and nonnuclear components, and will require the development of a range of new technologies. However, as previously discussed, the W87-1 program is not required to follow the rigor and best practices for analyzing alternatives that would provide assurance that the teams are applying consistent, reliable, and objective approaches to assessing design choices. Senior NNSA officials said that it was early in the process and that many of the plans for evaluating decisions and design trades were not yet in place. Nonetheless, senior NNSA officials within DP also said that the tailored AOA-like process to make early feature and component design decisions is adequate, and that the joint NNSA-DOD Phase 6.X process and supplemental W87-1 program memorandums provide sufficient rigor to oversee design decisions and ensure they are reliable and objective. By requiring, however, that the study plans for the remaining W87-1 feature and component design decisions are developed consistent with the AOA best practice guidelines for such plans as in NNSA's AOA procedure, including justifying and documenting deviations, NNSA would have better assurance that the evaluation teams are applying consistent, reliable, and objective approaches to assessing design choices.

More generally, NNSA has determined that the complexity and risks of LEPs and replacement programs do not require them to follow AOA best practices for their Phase 6.2 and Phase 6.2A design studies, or to justify and document deviations from those best practices, according to NNSA's program execution instruction. However, NNSA would have better assurance that LEPs and replacement programs are providing decision-makers with consistent, reliable, and objective assessments of design options under consideration by requiring that studies of significant and potentially costly early design decisions follow AOA best practices—such as by having a study plan as required in NNSA's AOA procedure—or justify and document any deviations from best practices.

[45]An August 2019 memorandum from the Deputy Administrator for Defense Programs stated that design option decisions and enhancements shall be implemented based on applicable performance, risk, cost, and schedule analysis. In addition, a November 2019 program memorandum to the national laboratories and production sites requested that risk-informed considerations of cost, technology readiness level, producibility, technical performance, and schedule integration complexity be considered and documented.

NNSA May Be Able to Produce Sufficient Numbers of Secondaries but Has Less Assurance That It Can Produce Sufficient Numbers of Pits to Sustain W87-1 Production

NNSA may be able to produce sufficient numbers of secondaries but has less assurance that it will be able to produce sufficient numbers of pits to sustain W87-1 production on its current schedule. NNSA has some assurance that it can produce sufficient numbers of secondaries to align with the W87-1 production schedule because it currently has secondary production capabilities that it can use if construction of the UPF or modernization of existing facilities is delayed and the UPF is meeting its current schedule baseline. Y-12 has been producing secondaries for many years and, according to the uranium program manager, could continue to use Y-12's functional but deteriorating facilities for several more years, if necessary, to compensate for a delay in UPF or the modernization of the other facilities. According to the uranium program manager, the capabilities and capacity of the UPF are aligned with the W87-1 program, and the program has sufficient time to prepare for production of the secondaries needed for the W87-1 program by fiscal year 2029—when they will be needed to support production of the first W87-1 warheads in fiscal year 2030.

However, NNSA has less assurance that it will be able to produce sufficient numbers of pits in time to sustain W87-1 production on its current schedule. NNSA has sought to reestablish a pit production capability for over 20 years. Achieving the capability to produce 80 pits per year by 2030 is NNSA's highest infrastructure priority, according to the NNSA Administrator. NNSA's planned production of W87-1 warheads depends entirely on NNSA's capability to produce up to 80 pits per year from the combined production of the two facilities at LANL (up to 30 pits per year) and SRS (up to 50 pits per year).

NNSA's past performance, agency documents, and an independent study suggest that achieving and sustaining production of sufficient pits per year may be challenging. Specifically:

- As we have previously reported, NNSA has been unable to plan for and complete major construction projects on time. It has spent billions of dollars designing and partially constructing several one-of-a-kind major capital asset projects (i.e., facilities with a cost greater than $750 million), only to reassess and, in some cases, ultimately cancel the projects.[46] We have reported on improvements in recent years in the execution of ongoing major construction projects, but few new major projects have been started recently.

- In the last 2 decades, LANL has twice had to suspend laboratory-wide operations after the discovery of significant safety issues. Specifically, from July 2004 through May 2005, LANL suspended operations to address pervasive safety issues.[47] From 2013 through 2016, LANL had to pause operations at PF-4 because of concerns with the criticality safety program. A recurrence of such issues prior to the SRS facility becoming operational could affect pit production.
- A 2018 LANL study found that LANL is “marginally capable” of meeting NNSA’s plan to ramp up pit production to 30 pits per year by 2026 and sustaining that rate thereafter.[48]
- NNSA’s October 2017 AOA to examine options for reestablishing a pit production capability stated that establishing pit production under any of the alternatives that NNSA considered, including using the facility at SRS, is unlikely to be achievable by 2030 even under the most optimistic circumstances.[49]
- An independent March 2019 study by the Institute for Defense Analyses found that repurposing the SRS facility to produce pits by 2030 would be unprecedented—and could not find an instance where

[46]For example, NNSA’s efforts to reestablish a pit production capability have undergone several iterations, all of which were ultimately canceled after schedule and cost increases. The Chemistry and Metallurgy Research Replacement project at LANL, approved by NNSA in 2005, was first intended to replace aging plutonium research capabilities with new facilities but was deferred in 2012 because of budget constraints. Subsequently, in January 2014, NNSA adopted a new strategy that entailed installation of new research equipment in PF-4 and construction of additional modular buildings. In 2018, NNSA chose to repurpose the facilities at SRS over pursuing the modular approach. Other projects that were reassessed after significant cost and schedule delays include the Mixed Oxide Fuel Fabrication project at SRS and the UPF at Y-12.

[47]Some plutonium-specific operations at LANL had already been suspended because of safety issues in August 2003; corrective measures had not been completely implemented by the time of the July 2004 suspension.

[48]Los Alamos National Laboratory, *Plutonium Sustainment Nuclear Facility and Equipment Configuration for Pit Manufacturing: Mid-2018 Update,* Technical Report LA-CP-18-20322 (Los Alamos, N.M: 2018) as cited in the Institute for Defense Analyses, *Independent Assessment of the Plutonium Strategy of the National Nuclear Security Administration*, P-10524 (Alexandria, VA: March 2019).

[49]NNSA, *Final Report for the Plutonium Pit Production Analysis of Alternatives* (Washington, D.C.: October 2017).

an NNSA project that cost over $700 million was completed in less than 16 years.[50] The study concluded that no available production option considered by NNSA—including its plan to split production between LANL and SRS—could be expected to provide 80 pits per year by 2030.

Based on our analysis of NNSA data, we found that if NNSA were unable to achieve and sustain its goals for pit production at both LANL and SRS, NNSA would not be able to sustain the W87-1 warhead production schedule. If SRS is not ready to produce pits by 2030 or within a few years of that date, the W87-1 program will need to rely solely on pits produced by LANL. Under this scenario, by 2033 the W87-1 program would not have sufficient W87-1 pits to meet its planned production. Instead, it would produce fewer W87-1 warheads with W87-1 pits. Through 2038—the last year of planned W87-1 production—the pit production shortfall would result in NNSA producing many fewer warheads than planned. Moreover, if SRS is not ready to produce pits and LANL can only sustain a capability to produce an average of 20 or 10 pits per year, rather than 30, then NNSA would produce significantly fewer W87-1 warheads.

We were unable to assess the extent to which NNSA is on track to ensure that LANL and SRS will be ready to meet its plans for pit production for the W87-1 warhead, however, because NNSA's plutonium program office has not completed an integrated master schedule for the pit production effort overall.[51] An integrated master schedule is the focal point of program management, according to GAO best practices for schedule

[50]Institute for Defense Analyses, March 2019. The Institute for Defense Analyses study was produced in response to a requirement in the National Defense Authorization Act for Fiscal Year 2019. In 2009, we reported that one of the main reasons NNSA met cost and schedule estimates for the B61 LEP was because it was able to reduce the number of weapons it had to refurbish by two-thirds. Even so, the cost of manufacturing each B61 almost doubled. The B61 is a gravity bomb carried by Air Force bomber aircraft. GAO, *Nuclear Weapons: NNSA and DOD Need to More Effectively Manage the Stockpile Life Extension Program*, GAO-09-385 (Washington, D.C.: Mar. 2, 2009).

[51]In response to a direction in the 2018 Nuclear Posture Review, NNSA completed a "road map" of modernization efforts that included some information on pit production. However, the road map did not contain the elements of an integrated schedule, and an NNSA official characterized it as a one-time demonstration effort.

development, because it integrates the planned work, the resources necessary to accomplish that work, and the associated budget.[52]

The plutonium program manager stated that the plutonium program has never had an integrated master schedule because—following the limited production of W88 pits from 2007 through 2012—there was not a clear demand for pit production for several years, and the program office had limited staff to implement such an undertaking.[53] The plutonium program manager also noted that the efforts to recapitalize LANL and repurpose SRS do not yet have their own schedule baselines. Specifically, at the project level, NNSA does not yet have an integrated master schedule for even the LANL recapitalization effort already under way because it had previously managed the project as sustainment operations, which do not require an integrated master schedule. A conference report accompanying a 2019 appropriations bill directed NNSA to manage further capital improvements at LANL as a construction project.[54] Such capital asset projects must be managed under DOE Order 413.3B—which requires an integrated master schedule. The pit program intends to implement management of further LANL capital improvements under DOE Order 413.3B by fiscal year 2021, according to NNSA's June 2019 report.[55]

The plutonium program office is developing an integrated master schedule and is in the process of internally reviewing a milestone-level schedule that it intends to use as the basis for developing an integrated master schedule for pit production, according to the plutonium program manager. However, the DP program execution instruction allows programs such as the plutonium program to tailor their approach to

[52]GAO-16-89G.

[53]As we have previously reported, recent NNSA and independent reviews have found that NNSA is understaffed across all functions and faces critical unmet staffing needs. GAO, *High Risk Series: Substantial Efforts Needed to Achieve Greater Progress on High-Risk Areas*, GAO-19-157SP (Washington, D.C.: Mar. 6, 2019). In particular, the plutonium program may need to hire 25 new federal staff to support plutonium sustainment and pit production, according to a 2018 NNSA review.

[54]H.R. Rep. No. 115-697, at 112 (2018).

[55]Specifically, NNSA's June 2019 report states that the program intends to manage the effort to ramp up to production of 10 pits per year under sustainment operations and manage the effort to ramp up from 10 to 30 pits by 2026 under DOE Order 413.3B. The plutonium program office also intends to manage the SRS project under 413.3B, according to this report. NNSA, *Plutonium Pit Production Scope, Cost, and Schedule: Report to Congress*. (Washington, D.C: June 2019).

development of an integrated master schedule and does not require that it be developed to one of the highest quality standards under the DP instruction—those used to manage warhead life extension or replacement programs, called an NNSA integrated master schedule (NIMS). For example, a program may choose whether to resource load the schedule to reflect resources required—such as labor, materials, facilities, and equipment—to do the work, whether they will be available when needed, and any funding or time constraints.

The plutonium program manager stated that the program intends to pursue elements of a NIMS approach but did not provide us with documentation—such as a work scope or order—demonstrating that it would do so, or when. As a result, there is little assurance that NNSA will develop a high-quality, reliable schedule consistent with best practices. The plutonium program manager stated in August 2019 that he anticipated it would take 18 months to create an integrated master schedule to coordinate significant pit production activities. However, during the course of our review, the anticipated completion date for the integrated master schedule slipped from approximately September 2020 to approximately January 2021. We note that it has taken NNSA over 2 years to implement our recommendation to establish time frames for developing an integrated master schedule for the UPF.[56] The plutonium program manager also noted that the effort to create an integrated master schedule for this effort was complex, requiring the integration of plutonium sustainment program activities, line-item construction projects, and federal activities needed to support pit production. Best practices for schedule development note that a comprehensive integrated master schedule should recognize that uncertainties can stem from limitations in data. In such cases, planning and incorporation of detail may be done in

[56]We reported in 2017 that NNSA had not set a time frame for developing an integrated master schedule for the overall uranium program—which is responsible for delivering secondaries to the W87-1 program—and recommended that NNSA do so. NNSA generally agreed with this recommendation and, according to program officials, is continuing its effort to develop an integrated master schedule for the overall uranium program. Specifically, NNSA has developed and approved a revised scope of work, cost, and schedule baseline estimates for four of the seven subprojects into which the UPF project is divided; it has since completed two more baseline estimates in fiscal years 2018 and 2019, and intends to complete the last subproject baseline estimate in fiscal year 2020. GAO, *Modernizing the Nuclear Security Enterprise: A Complete Scope of Work is Needed to Develop Timely Cost and Schedule Information for the Uranium Program*, GAO-17-577 (Washington, D.C: September 8, 2017). We have ongoing work assessing NNSA's implementation of this recommendation and the agency's progress toward construction of the UPF.

stages throughout the project as stakeholders learn more details. For example, one technique that could be used to account for uncertainty and data limitations is the "rolling wave" planning process, which incorporates levels of detail according to the information available at any point in time, according to best practices.[57]

As previously discussed, NNSA's effort to produce the W87-1 at planned quantities and consistent with NNSA's preliminary schedule—currently estimated to be the most expensive warhead program since the end of the Cold War—is dependent on NNSA's ability to produce up to 80 pits per year.[58] Given NNSA's track record of inadequate planning for large, integrated programs; its prior management of the LANL recapitalization activities as sustainment operations; and the importance of this program to warhead production, it is essential that the integrated master schedule being developed by the plutonium program for pit production meets NIMS standards, consistent with best practices for schedule development, to provide assurance of sufficient pits for the W87-1 program.

The W87-1 Program Has Not Developed Mitigation Plans for the Risk of Insufficient Pits, and Both the W87-1 and Plutonium Programs Have Only Notional Risk Mitigation Concepts

The W87-1 program has not yet developed formal risk mitigation plans to address the risk of insufficient pits to sustain W87-1 production, and both the W87-1 program and the plutonium program have only notional concepts to address this risk. If NNSA does not make sufficient W87-1 pits to sustain W87-1 production, the W87-1 program's initial notional concept for mitigating the risk to W87-1 production would not meet military requirements and would be costly. According to NNSA's May 2019 report to Congress, Lawrence Livermore documentation, and W87-1 program officials, NNSA's primary risk mitigation concept is to reuse some pits until new W87-1 pits are available. According to NNSA's May 2019 report and Lawrence Livermore documentation, when sufficient W87-1 pits are available later, NNSA could perform a second alteration to replace the reused pits with a W87-1 pit. This approach would increase the amount of work needed to complete a W87-1 warhead, likely delaying final production, and could have an impact on the availability of personnel and facilities for subsequent LEPs. W87-1 program officials stated that NNSA does not have estimates of the cost to test and qualify this concept

57 GAO-16-89G.

58 As noted previously, the preliminary cost estimate for the W87-1 program does not include estimated costs of $300 million to $750 million to produce new W87-1 pits.

or to perform the second alteration.[59] In December 2019, senior NNSA officials proposed a number of additional risk mitigation concepts that were not included in the May 2019 report to Congress. One such concept was that those W87-1 warheads with a reused pit remain in that configuration and be placed in the nuclear weapons stockpile hedge rather than deployed.[60] Additional concepts NNSA proposed included (1) extending W87-1 warhead production, which would not meet DOD's final production unit deadline and could increase costs; or (2) producing fewer W87-1 warheads, which would not meet U.S. nuclear stockpile weapons requirements. In February 2019, NNSA officials stated that the proposed concepts would be performed in coordination with DOD.

NNSA officials and Lawrence Livermore representatives told us that Lawrence Livermore has studied reuse of pits and is confident that the pits could be a technically viable backup option. Lawrence Livermore documented its evaluation of pit reuse in three studies dating from 2013 through 2015, each of which determined that pit reuse was a viable option for consideration. Specifically, in 2015, Lawrence Livermore documented its achievement of a significant milestone in its predictive capabilities for modeling pit reuse in support of the goal of certification of a pit reuse system without underground nuclear testing. An independent expert group has also stated that it would be technically feasible to reuse pits.[61]

However, there is some uncertainty about the desirability of the pit reuse strategy. Specifically, the May 2019 NNSA report noted that reusing pits was a suboptimal solution that does not enable the same safety and security improvements for the W87-1 that a newly-manufactured pit would enable. The report also noted that this concept would impair performance margins for the W87-1 and increase performance uncertainty because of

[59]In 2013, NNSA evaluated the costs of pit reuse and manufacturing a new W87 pit, among other options. NNSA concluded that pit reuse would be the cheapest option to obtain pits. Manufacturing a new W87 pit would be the most expensive option but it would support the need for a responsive pit production infrastructure, according to NNSA's evaluation. NNSA estimated that it would cost slightly more to certify the pit reuse options to meet threshold military requirements—about $180 million to $215 million for either pit reuse option, and $165 million for a new W87 pit. To meet objective requirements, NNSA estimated certification costs of about $270 million for either pit reuse option and $250 million for a new W87 pit.

[60]Since 1994, the United States has retained a stockpile of weapons to provide a "hedge" against unforeseen technical problems or changes in the international security environment.

[61]JASON, June 2015.

the age of the plutonium. A November 2019 letter to NNSA by an independent expert group stated that studies on plutonium aging have not been sufficiently prioritized over the past decade and recommended more work be done to mitigate potential risks posed by aging pits.[62] It also stated that the reuse of aged pits in rebuilt primary systems can address certain issues but cannot change the aged pits themselves.[63] The independent expert group also raised questions about the principles used to evaluate such systems; stated that it was unclear how such systems would be certified; and, in its November 2019 letter, urged caution against taking the stockpile away from the underground test base used to certify the weapons. In 2013, NNSA documented its evaluation of the reuse concept against a newly manufactured W87 pit in a pit selection decision presentation. This presentation noted that a key element behind the selection of the W87-1 pit was its strong nuclear test base and that certification of a reused pit system without underground testing would present unknown risks. However, in October 2019, Lawrence Livermore representatives stated that research performed since that time has given them a better understanding of the risks.

In recognition of the risk of producing insufficient pits, NNSA has presented notional strategies to increase pit production at LANL or to phase in efforts to bring pit production at SRS online. For example, one NNSA-proposed strategy reported by the Institute for Defense Analyses in March 2019 was to "surge" production to up to 80 pits per year at LANL.[64] Doing so would be technically possible, according to the study, but it could jeopardize LANL's capability to produce up to 30 pits per year by 2026, would be a challenge to execute by 2030, and would not be sustainable over the long term. According to our analysis of NNSA's pit production goals, as presented in table 1 above, even with a "head start" of up to 151 pits that could be produced at LANL from 2023 through 2029, LANL would have to greatly increase its pit production to complete W87-1 production by 2038, well beyond what could be considered a temporary surge. Alternately, the plutonium manager stated that SRS could focus on bringing production "lines" online in phases beginning in 2030, similar to the ramp-up at LANL, rather than all at once. According to our analysis, if

[62]JASON, *Letter Report to U.S. Department of Energy Defense Programs NA-11* (Nov. 23, 2019).

[63]JASON 2019.

[64]Institute for Defense Analyses, March 2019.

NNSA could execute such a strategy, pit production could be sufficient to sustain W87-1 production.

Notwithstanding these notional strategies, NNSA has not yet formally assessed them through a risk management framework for the W87-1 program. NNSA's DP program execution instruction directs programs such as the W87-1 to reduce program risk by identifying, assessing, and managing major risk events, such as through a risk and opportunity management plan. However, W87-1 program officials and senior DP officials noted that the program had only restarted in January 2019 and that it is too early in the Phase 6.X process to have a documented risk mitigation strategy for the W87-1 in the event that the pit program is unable to supply sufficient pits. W87-1 officials stated that a risk and opportunity management plan was under development and that the plan would create a framework to address the risk of late pit production. Senior NNSA officials further stated that identification of risks and detailed risk mitigation plans are not required until the end of Phase 6.2A, currently projected for the third quarter of fiscal year 2022.

W87-1 program officials also stated that to use limited resources to plan for an alternate strategy to meet pit needs for the new warhead would run counter to the program of record, which is to produce new W87-1 pits using both LANL and SRS. NNSA officials stated that the initial production milestone of one pit at LANL in fiscal year 2023—7 years before the first warhead production unit—will provide ample time for the W87-1 program to develop risk mitigation strategies if they are needed. However, by the end of fiscal year 2022, the W87-1 program will have already passed significant program milestones—for example, it will have already completed its baseline program cost estimate and had those figures independently reviewed by CEPE, according to the W87-1 preliminary schedule.

According to NNSA guidance, the ultimate goal of risk management is to improve the chances of activity success by focusing attention on problem areas early and reducing the amount of costly rework in the future.[65] As discussed previously, there is a risk that LANL may not be able to achieve or sustain a capability to produce up to 30 pits per year by 2026 and that SRS may not have a capability to produce up to 50 pits per year by 2030, which would hinder W87-1 warhead production. Alternate production

[65]NNSA, *Risk and Opportunity Management Methodology Guidance*, T057 (Washington, D.C.: June 30, 2012).

strategies, such as ramping up individual pit production lines at SRS or reevaluating the W87-1 production schedule, may present risk management opportunities. In addition, NNSA's current notional risk mitigation strategy for the W87-1 would not mitigate the risk of insufficient pits for the program and appears to present risks and costs to production. By prioritizing the development and documentation of a risk mitigation strategy, NNSA would be better positioned to respond to the risk that pit production will be not be sufficient to support W87-1 production under NNSA's preliminary production schedule.

Conclusions

The W87-1 program could be the most expensive modernization effort to extend the life of or replace a warhead since the end of the Cold War, according to preliminary NNSA estimates. The feature and component design decisions that remain could have an effect on program cost, but NNSA does not yet have study plans that would help ensure that the program employs consistent, reliable, and objective approaches for analyzing the costs and benefits of these remaining decisions. The DP program execution instruction recommends, but does not require, that design studies similar to AOAs for LEPs and replacement programs employ the analytic rigor and best practices of NNSA's AOA procedure for capital asset acquisitions. Instead, under the DP program execution instruction, NNSA allows programs such as the W87-1 to tailor their approach and deviate from the best practice guidelines in the NNSA business procedure to meet program needs. Requiring the W87-1 program to have study plans for the remaining feature and component design studies consistent with the best practice guidelines for such plans in NNSA's AOA procedure would provide assurance that the studies apply consistent, reliable, and objective approaches. More generally, revising the DP instruction to require that design studies for LEPs and replacement programs follow AOA best practices, such as by having a study plan, would provide NNSA with better assurance that such programs apply consistent, reliable, and objective approaches to assessing the best options to meet mission needs.

NNSA will need to produce newly manufactured pits and secondaries for the W87-1 warhead, which represents a critical external risk to the W87-1 program. NNSA's production schedule for the W87-1 warhead depends on NNSA's ability to meet its production goals for key nuclear components. In fact, achieving the capability to produce 80 pits per year by 2030 is NNSA's highest infrastructure priority, according to the NNSA Administrator. However, it is not clear whether NNSA will be able to produce sufficient numbers of pits to meet W87-1 production needs, which could significantly impact production of the W87-1 warhead. We were unable to assess whether NNSA's plutonium program was on track to produce sufficient pits because the program is developing but does not yet have an integrated master schedule for pit production. The plutonium program manager stated that the program intends to pursue elements of a NIMS approach but did not provide us with documentation demonstrating that it would do so, or when. An integrated master schedule is the focal point of program management, according to best practices, because it integrates the planned work, the resources necessary to accomplish that work, and the associated budget. NNSA's effort to produce the W87-1 depends on NNSA's ability to produce up to 80 pits per year. Given the importance of this program to warhead production, it is essential that the integrated master schedule being developed by the plutonium program for pit production meets NIMS standards, consistent with best practices for schedule development, to provide assurance of sufficient pits for the W87-1 program.

The W87-1 program also has not yet developed documented risk mitigation plans to address the risk of insufficient pits to sustain W87-1 production. W87-1 program officials stated that it was too early to do so, that NNSA had plenty of time to respond if that risk developed, and that to use scarce resources to plan for an alternate strategy would run counter to the agency's program of record. However, by prioritizing the development and documentation of a risk mitigation strategy, NNSA would be better positioned to respond to the clear risk that the plutonium program may not be able to supply sufficient pits to sustain W87-1 production.

Recommendations for Executive Action

We are making the following four recommendations to the NNSA Administrator:

The NNSA Administrator should direct the W87-1 program to ensure consistent, reliable, and objective assessments of remaining feature and component design decisions in Phase 6.2 by developing study plans for remaining design studies consistent with the guidelines for such plans in NNSA's AOA procedure, including documenting and justifying deviations from best practices. (Recommendation 1)

The NNSA Administrator should direct the Office of Defense Programs to revise its program execution instruction to require that design studies for warhead life extension and replacement programs follow AOA best practices, such as by having a study plan, or to justify and document deviations from best practices. (Recommendation 2)

The NNSA Administrator should direct the Office of Defense Programs' plutonium program office to ensure that the integrated master schedule in development for pit production meets NIMS standards, consistent with best practices for schedule development. (Recommendation 3)

The NNSA Administrator should direct the W87-1 program to prioritize the development and documentation of a risk mitigation strategy to address the risk that pit production may be insufficient to meet W87-1 production needs. (Recommendation 4)

Agency Comments and Our Evaluation

We provided a draft of the classified report to NNSA and DOD for review and comment. NNSA's comments on the classified report are reprinted in appendix II. In its comments, NNSA generally agreed with our recommendations. However, NNSA stated that it is not the exclusive decision making authority regarding design criteria and option selection for the W87-1 and that many of these decisions fall under the purview of the Nuclear Weapons Council. NNSA further stated that it is critical to explain the distribution of responsibilities between NNSA and the Nuclear Weapons Council to provide context on why specific best practices may or may not be a part of NNSA's role during the Phase 6.X process for the W87-1 program and certain other weapons modernization programs. We believe our report adequately reflects NNSA's role as the lead design agency for nuclear weapons. As noted in our report, NNSA evaluates the military requirements provided by DOD and designs and produces warheads and bombs to meet those requirements, while the Nuclear Weapons Council serves as the joint DOD and DOE focal point for executive-level management of weapons programs.

NNSA also stated that the report implied that there are still multiple design options being considered for the W87-1. NNSA stated that there was only one baseline design for the W87-1, with multiple features and components to be subsequently decided to meet objective safety and surety requirements. NNSA further stated that selecting those features and components did not require a formal AOA. We believe our report adequately noted those aspects of the design that have already been decided—such as the primary and secondary—and those features and components still under consideration, but we have added clarifying language, as appropriate. We note that by following best practices for conducting AOAs—including having study plans to ensure that the analyses for selecting certain designs, features, and components are consistent, reliable, and objective—NNSA would have better assurance that its recommendations to the Nuclear Weapons Council are the best options to meet mission needs.

In addition, NNSA provided us with technical comments and additional documentation, which we incorporated into our report, as appropriate. DOD provided technical comments, which we have incorporated, as appropriate.

As agreed with your offices, unless you publicly announce the contents of this report earlier, we plan no further distribution until 14 days from the report date. At that time, we will send copies to the appropriate congressional committees, the Secretaries of Defense and Energy, the Administrator of NNSA, and other interested parties. In addition, this report is available at no charge on the GAO website at http://www.gao.gov.

If you or your staff members have any questions about this report, please contact me at (202) 512-3841 or bawdena@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. GAO staff who made significant contributions to the report are listed in appendix III.

Allison B. Bawden
Director, Natural Resources and Environment

Appendix I: GAO Analysis of the National Nuclear Security Administration's (NNSA) W87-1 Preliminary Cost Estimate

NNSA's preliminary cost estimate for the W87-1 warhead of $8.6 billion to $14.8 billion, reported to Congress in December 2018, substantially met three of the characteristics of a high-quality and reliable cost estimate—comprehensive, accurate, and credible—and partially met the fourth characteristic—well-documented (see table 4 below).[1] NNSA's W87-1 estimate is a preliminary estimate intended to support NNSA's early-stage program planning and alternatives analysis, according to NNSA's *Fiscal Year 2020 Stockpile Stewardship Management Plan*.[2] We analyzed the cost-estimating practices used by NNSA against best practices in the GAO *Cost Estimating and Assessment Guide*. For this guide, GAO cost experts assessed measures consistently applied by cost-estimating organizations throughout the federal government and industry and considered best practices for the development of reliable cost estimates. For our reporting needs, we collapsed these best practices into four general characteristics for sound cost estimating: well documented, comprehensive, accurate, and credible, as applied to an early-stage preliminary cost estimate. To examine the extent to which NNSA followed best practices in producing the W87-1 estimate, we reviewed NNSA's documentation and data on the estimate. We also interviewed NNSA officials and contractors at Sandia National Laboratories responsible for producing the estimate to understand the methodologies, assumptions, information, and data used to produce the estimate. GAO cost estimation

[1]National Nuclear Security Administration, *W78 Replacement Program (W87-1): Cost Estimates and Use of Insensitive High Explosives*, Report to Congress (Washington, D.C.: December 2018).

[2]NNSA's W87-1 estimate did not include the estimated cost of producing new plutonium pits that are required for the W87-1. NNSA separately estimated that the costs of producing pits for the W87-1 could add an additional $300 million to $750 million to the cost of the warhead, resulting in a cost range of from $8.9 billion to $15.6 billion. These pit costs are in addition to NNSA's preliminary estimates of up to approximately $3 billion to modernize the Plutonium Facility (PF-4) at Los Alamos National Laboratory in New Mexico and approximately $4.6 billion to convert and bring the partially constructed Mixed Oxide Fuel Fabrication Facility at the Savannah River Site in South Carolina online to produce pits. According to NNSA officials, these facilities and infrastructure would need to be modernized for future weapons programs in addition to the W87-1.

specialists then assessed the information obtained against best practices for cost estimating found in GAO's cost-estimating guide.[3]

Table 4: GAO Observations on the Extent to Which the National Nuclear Security Administration's (NNSA) W87-1 Cost Estimate Met Best Practices for Cost Estimating

Best practice characteristic	Rating	Summary of assessment
Comprehensive • Includes all life cycle costs, completely defines the program, reflects the current schedule, and is technically reasonable. • Adopts a work breakdown structure (WBS) that is product-oriented, traceable, and at an appropriate level of detail to ensure cost elements are neither omitted nor double-counted. • Documents all cost-influencing ground rules, and assumptions are documented.	Substantially met	The overall estimate—which consisted of an estimate for the warhead's development and a separate estimate for its production— used a consistent WBS and identified ground rules and assumptions both from a methodological level and a technical level. The estimate also accounted for program management costs and different funding sources. However, the estimate did not include certain costs that NNSA officials said will be included in the cost of other programs. Specifically, W87-1 sustainment costs and pit production costs for the W87-1 are not included in the estimate but could have a significant impact on NNSA's costs associated with the W87-1.

[3]GAO, *GAO Cost Estimating and Assessment Guide: Best Practices for Developing and Managing Capital Program Costs*, GAO-09-3SP (Washington, D.C.: Mar. 2, 2009). For each of the four characteristics, we rated the best practices for the estimate on a five-tiered scale, determining that it (1) fully met, (2) substantially met, (3) partially met, (4) minimally met, or (5) did not meet the criteria for each characteristic. According to our scale, fully met means that the agency provided complete evidence that satisfies the entire criteria. Substantially met means that the agency provided evidence that satisfies a large portion of the criteria. Partially met means that the agency provided evidence that satisfies about half of the criteria. Minimally met means that the agency provided evidence that satisfies a small portion of the criteria. Not met means that the agency provided no evidence that satisfies any of the criteria.

Best practice characteristic	Rating	Summary of assessment
Well-documented • Captures the source data used, the reliability of the data, and how the data were normalized. • Describes, in sufficient detail, the calculations performed and the estimating methodology used to derive each element's cost. • Describes step by step how the estimate was developed so that an analyst unfamiliar with the program could reproduce the estimate. • Discusses the technical baseline description in a single document, and the data in the baseline are consistent with the estimate. • Provides evidence that the cost estimate was reviewed and accepted by management.	Partially met	The documentation provided discussed the W87-1 cost estimate and source data, NNSA's general methodologies for estimating warhead life-extension and replacement program costs for reporting in the annual Stockpile Stewardship and Management Plan (SSMP), and high-level technical assumptions. However, the documentation did not include programmatic assumptions—a key element of a technical baseline, clearly document the technical basis for the cost estimate in a single document traceable to the cost-estimating model, or provide enough specificity for an analyst unfamiliar with the program to reproduce the estimate. Documentation is essential for validating and defending a cost estimate. Poorly documented cost estimates can cause a program's credibility to suffer because the documentation cannot explain the rationale for the estimating methodology or the calculations underlying the cost estimate. Therefore, estimates that lack sufficient documentation are not useful for updates or information-sharing and can hinder understanding and proper use of the estimate.
Accurate • Based on an assessment of most likely costs, unbiased, and not overly conservative or optimistic. • Adjusted properly for inflation. • Contains few, if any, minor mistakes. • Updated regularly to reflect significant changes in the program. • Documents and explains variances between planned and actual costs. • Based on an historical record of cost estimating and actual experiences from other comparable programs.	Substantially met	The W87-1 estimate was primarily based on the actual costs for the W76-1 life extension program, which was the most recent and best data available. The formulas in the cost model were traceable, and the estimate was adjusted properly for inflation. For the portion of the estimate covering the warhead's development, subject matter expert inputs were used to address technical complexity, and all inputs were reviewed multiple times by different experts to minimize estimating bias. For the portion of the estimate covering the warhead's production, the cost model was based on historical data and provides the flexibility to test and evaluate variation in assumptions to minimize bias. The W87-1 estimate will be updated annually and reported in the SSMP; however, GAO was unable to trace the costs provided by NNSA to the costs in the SSMP because of the nature of the evolving estimate and when new information was used to drive changes to the model.

Best practice characteristic	Rating	Summary of assessment
Credible • Includes a sensitivity analysis that identifies a range of possible costs based on varying major assumptions, parameters, and data inputs. • Includes a risk and uncertainty analysis. • Cross-checks major cost elements to see whether results were similar. • Utilizes an independent cost estimate, conducted by a group outside the acquiring organization, to determine whether other estimating methods produce similar results.	Substantially met	NNSA varied design parameters to estimate and compare multiple W87-1 concepts. However, NNSA did not examine the cost drivers as part of these analyses. NNSA's SSMP estimating methodology addresses risk and provides bounds around the estimate to provide information to help management make decisions about the program. For the warhead's estimated development cost, ranges were developed based on subject matter expert inputs to establish triangular distributions of low, medium, and high complexities. This information was used to develop a quantifiable cost risk and uncertainty assessment using Monte Carlo analysis. However, the cost risk and uncertainty assessment does not account for correlation. For the warhead's estimated production cost, a range of one standard deviation is used to add contingency into the estimate. However, no probability distributions were developed for cost drivers, and no Monte Carlo analysis was developed.

Source: GAO-20-703

Appendix II: Comments from the Department of Energy National Nuclear Security Administration

Department of Energy
Under Secretary for Nuclear Security
Administrator, National Nuclear Security Administration
Washington, DC 20585

NNSA National Nuclear Security Administration

February 11, 2020

Ms. Allison B. Bawden
Director, Natural Resources
and Environment
U.S. Government Accountability Office
Washington, DC 20548

Dear Ms. Bawden:

Thank you for the opportunity to review the Government Accountability Office (GAO) draft report *Nuclear Weapons: NNSA Should Further Develop Cost, Schedule, and Risk Information for the W87-1 Warhead Program* (GAO-20-207C). The Department of Energy's National Nuclear Security Administration (DOE/NNSA) appreciates GAO's observations and recommendations for enhancing the W87-1 Modification Program, and other life extension and replacement programs. As we work towards implementation, we wanted to provide you with additional context on design criteria and the Phase 6.x process for the W87-1.

It is worth noting that NNSA is not the exclusive decision making authority regarding design criteria and option selection for the W87-1 Modification Program as may be interpreted from the report. In fact, many of these decisions fall under the purview of the Nuclear Weapons Council (NWC). We believe it is critical that the report clearly explain the distribution of responsibilities between NNSA and NWC to provide the proper context on why specific best practices may or may not be a part of NNSA's role during the Phase 6.x process for the W87-1 Modification Program and certain other weapon modernization programs.

Additionally, as drafted, the report implies there are still multiple designs to be considered for the W87-1. There was only one baseline design with multiple features and components subsequently decided in order to meet objective safety and security requirements. These decisions did not require a formal analysis of alternatives; and that fact impacts conclusions regarding design studies.

NNSA generally concurs with the recommendations in the report, and the enclosure to this letter identifies the detailed actions planned to address each. Subject matter experts have also separately provided technical and general comments for your consideration to enhance the report's clarity and accuracy.

If you have any questions, please contact Dean Childs, Director, Audits and Internal Affairs, at (301) 903-1341.

Sincerely,

Lisa E. Gordon-Hagerty

Enclosure

Enclosure

NATIONAL NUCLEAR SECURITY ADMINISTRATION

Response to Report Recommendations
"Nuclear Weapons: NNSA Should Further Develop Cost, Schedule, and Risk Information for the W87-1 Warhead Program" (GAO-20-207C)

The Government Accountability Office recommends the National Nuclear Security Administration (NNSA):

Recommendation 1: Ensure consistent, reliable, and objective assessments of remaining design decisions in Phase 6.2 by developing study plans for remaining design studies consistent with the guidelines for such plans in NNSA's Analysis of Alternatives (AoA) procedure, including documenting and justifying deviations from best practices.

Management Response: Concur, with comment. There are no remaining design decisions in Phase 6.2 for the W87-1 Modification Program. However, NNSA will ensure future weapon modernization programs conduct consistent, reliable, and objective assessments of design decisions in Phase 6.2 by developing design study plans consistent with the guidelines for such plans in NNSA's AoA procedure, including documenting and justifying deviations from best practices where appropriate.

Recommendation 2: Revise its program execution instruction to require that design studies for warhead life extension and replacement programs follow AoA best practices, such as by having a study plan, or to justify and document deviations from best practices.

Management Response: Concur. NNSA will revise its program execution instruction to require that design studies for warhead life extension and replacement programs follow AoA best practices, such as by having a study plan, or to justify and document deviations from best practices.

Recommendation 3: Ensure that the integrated master schedule in development for pit production meets NNSA Integrated Master Schedule standards, consistent with best practices for schedule development.

Management Response: Concur. NNSA will ensure that the integrated master schedule in development for pit production meets NNSA Integrated Master Schedule standards, consistent with best practices for schedule development.

Recommendation 4: Prioritize the development and documentation of a risk mitigation strategy to address the risk that pit production may be insufficient to meet W87-1 production needs.

Management Response: Concur. NNSA will prioritize the development and documentation of a risk mitigation strategy to address the risk that pit production may be insufficient to meet W87-1 production needs.

Appendix III: GAO Contact and Staff Acknowledgements

GAO Contact

Allison B. Bawden, (202) 512-3841 or bawdena@gao.gov.

Staff Acknowledgements

In addition to the individual named above, William Hoehn (Assistant Director), Julia T. Coulter (Analyst-in-Charge), and Brian M. Friedman (Analyst-in-Charge) made significant contributions to this report. Also contributing to this report were Antoinette Capaccio, Pamela Davidson, Penney Harwell Caramia, Anna Irvine, Jennie Leotta, Greg Marchand, Diana Moldafsky, Cynthia Norris, Katrina Pekar-Carpenter, and Dan Royer.

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