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October 2020

NUCLEAR WEAPONS

NNSA Plans to Modernize Critical Depleted Uranium Capabilities and Improve Program Management

Accessible Version

GAO-21-16

GAO Highlights

Highlights of GAO-21-16, a report to the Committee on Armed Services, U.S. Senate

Why GAO Did This Study

High-purity DU is an important strategic material for ongoing and planned modernizations of the nation's nuclear weapons stockpile. However, according to NNSA estimates, NNSA has a very limited supply of DU feedstock, and its current supply of DU metal will be exhausted in the late 2020s. NNSA also does not have the full range of capabilities needed to manufacture DU into weapon components needed for modernizing the stockpile. GAO has previously reported that NNSA has experienced challenges in restarting some technical manufacturing processes.

A Senate committee report accompanying a bill for the National Defense Authorization Act for Fiscal Year 2017 included a provision for GAO to examine NNSA's management of DU for nuclear stockpile modernization. GAO's report examines (1) the status of NNSA's efforts to obtain the necessary quantities of DU to meet stockpile modernization requirements; (2) the status of NNSA efforts to develop DU component manufacturing capabilities to meet stockpile modernization requirements; and (3) the extent to which NNSA is managing DU activities as a program, consistent with agency policy.

GAO reviewed relevant agency documents; interviewed NNSA officials and contractor representatives; and conducted site visits at headquarters and at research, development, and production locations.

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NNSA Plans to Modernize Critical Depleted Uranium Capabilities and Improve Program Management

What GAO Found

The Department of Energy's (DOE) National Nuclear Security Administration (NNSA) is taking steps to establish a new supply of high-purity depleted uranium (DU) to modernize the nuclear weapons stockpile. DU for fabrication of weapons components must be in high-purity metal form. Producing DU metal generally involves first converting a byproduct of uranium enrichment, known as "tails," into a salt "feedstock," which is then converted into metal. (See figure.) To reestablish a supply of feedstock, NNSA plans to install conversion equipment in an existing facility at DOE's Portsmouth site in Ohio. DOE initially estimated costs of $12 million to $18 million to design and install the equipment, with operations beginning in fiscal year 2022. However, in March 2020, NNSA requested an increase in conversion capacity, and an updated proposal in July 2020 estimated costs of $38 million to $48 million and a slight delay to the start of operations. NNSA plans to convert the feedstock into DU metal using a commercial vendor at a cost of about $27 million annually.

Conversion of a Byproduct of Uranium Enrichment into Metal

Source: Department of Energy. | GAO-21-16

NNSA is also taking steps to reestablish and modernize DU component manufacturing capabilities, but it risks delays that could affect the timelines of nuclear stockpile modernization programs, according to officials. NNSA has reestablished processes for manufacturing some DU components but not for components made with a DU-niobium alloy, a material for which NNSA has no alternative. Thus, restarting the alloying process—a complicated, resource-intensive process that has not been done in over a decade—is NNSA's top priority for DU and presents a very high risk to timely supply of components for certain nuclear stockpile modernization programs, according to NNSA documents and officials. NNSA is also developing more efficient manufacturing technologies, in part because the current alloyed component process wastes a very high percentage of the materials and NNSA cannot recycle the waste. For its DU activities, NNSA has requested an increase in funding from about $61 million in fiscal year 2020 to about $131 million in fiscal year 2021.

Until recently, NNSA had not managed DU activities as a coherent program in a manner fully consistent with NNSA program management policies. Since October 2019, however, NNSA has taken actions to improve program management. For example, NNSA has consolidated management and funding sources for DU activities under a new office and DU Modernization program with the goal of better coordinating across the nuclear security enterprise. Further, NNSA appointed two dedicated Federal Program Managers to gather and organize information for required program management and planning documents.

Contents

Abbreviations

CNS	Consolidated Nuclear Security, LLC
DOD	Department of Defense
DOE	Department of Energy
DU	Depleted uranium
DUF_6	Depleted uranium hexafluoride
DUF_4	Depleted uranium tetrafluoride
EM	Office of Environmental Management
LANL	Los Alamos National Laboratory
LLNL	Lawrence Livermore National Laboratory
LLNS	Lawrence Livermore National Security
MCS	Mid-America Conversion Services
MTU	metric tons of uranium
NAP	NNSA policy
NNSA	National Nuclear Security Administration
PPA	program, project, or activity
TRL	Technology Readiness Level
UPF	Uranium Processing Facility
UF_6	uranium hexafluoride
Y-12	Y-12 National Security Complex

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October 15, 2020

The Honorable James M. Inhofe
Chairman
The Honorable Jack Reed
Ranking Member
Committee on Armed Services
United States Senate

Depleted uranium (DU) is an important strategic material for ongoing and planned modernization of the nation's nuclear weapons stockpile.[1] Managing this stockpile is the responsibility of the National Nuclear Security Administration (NNSA), a separately organized agency within the Department of Energy (DOE). According to NNSA's 2020 *Stockpile Stewardship and Management Plan*, NNSA must ensure there is both (1) a sustainable supply of DU and other strategic materials critical to the nation's nuclear security missions, and (2) the manufacturing capabilities to effectively use these materials to make nuclear weapon components for stockpile modernization.[2] The DU for use in modernizing the stockpile must be in high-purity metal form. However, according to NNSA estimates, NNSA has a very limited supply of the DU feedstock it needs to produce new DU metal,[3] and its existing supply of DU metal will run out in the late 2020s. In addition, NNSA does not currently have the full range of capabilities it needs to manufacture nuclear weapon components from a DU alloy to the exacting specifications needed to modernize the stockpile, according to NNSA documents. As NNSA continues its stockpile modernization efforts, the needs for DU feedstock and metal are growing, and NNSA projects that these needs will persist beyond the late 2040s.

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[1]Depleted uranium is a byproduct of the uranium enrichment process after a significant fraction of fissile material has been removed from natural uranium.

[2]National Nuclear Security Administration, Department of Energy, *Fiscal Year 2020 Stockpile Stewardship and Management Plan* (Washington, D.C.: July 2019). The Stockpile Stewardship and Management Plan is NNSA's formal means for annually communicating to Congress the status of certain activities and its long-range plans and budget estimates for sustaining the stockpile and modernizing the nuclear security enterprise.

[3]The feedstock for DU metal production is depleted uranium tetrafluoride (DUF_4), also known as "green salt," which is converted into a metal form by a chemical process known as the Ames process.

Historically, NNSA has relied on its Y-12 National Security Complex (Y-12) in Oak Ridge, Tennessee, to maintain sources of DU metal and manufacture certain nuclear weapon components made using DU metal. However, some of Y-12's DU operations were shut down or consolidated in the early 2000s, and much of the existing DU manufacturing equipment and infrastructure at Y-12 is aging and needs to be upgraded or replaced, according to NNSA documents. Our previous work has found that NNSA has experienced challenges in restarting other strategic material procurement and technical manufacturing processes and in managing programs.[4] The scope and persistence of these challenges are attributable at least in part to the agency not having effectively followed key program management practices in the past, including having complete scopes of work, realistic schedules, and credible cost estimates. We have found that such challenges caused delays and cost overruns in nuclear stockpile modernization efforts. For example, we reported in March 2009 that challenges in restarting the manufacture of an important material called Fogbank delayed a warhead life extension program by a year, with a cost increase of nearly $70 million.[5] If NNSA cannot reestablish a steady supply of DU and the associated manufacturing capabilities in time, work could slow or halt on billions of dollars in planned nuclear stockpile modernization programs within the next decade.

A Senate committee report accompanying a bill for the National Defense Authorization Act for Fiscal Year 2017 included a provision for GAO to provide periodic updates on NNSA's efforts to restart DU operations for nuclear stockpile modernization.[6] GAO's report examines (1) the status of NNSA's efforts to obtain the necessary quantities of DU to meet stockpile modernization requirements; (2) the status of NNSA's efforts to develop DU component manufacturing capabilities to meet stockpile

[4]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); *Nuclear Weapons: Additional Actions Could Help Improve Management of Activities Involving Explosive Materials*, GAO-19-449 (Washington, D.C.: June 17, 2019); *DOE Project Management: NNSA Should Ensure Equal Consideration of Alternatives for Lithium Production*, GAO-15-525 (Washington, D.C.: July 13, 2015); *Nuclear Weapons: National Nuclear Security Administration Needs to Ensure Continued Availability of Tritium for the Weapons Stockpile*, GAO-11-100 (Washington, D.C.: Oct. 7, 2010).

[5]GAO-09-385.

[6]S. Rpt. No. 114-255, at 401 (2016).

modernization requirements; and (3) the extent to which NNSA is managing DU activities as a program consistent with agency policy.

To examine the status of NNSA's efforts to obtain the necessary quantities of DU to meet stockpile modernization requirements, we analyzed NNSA and contractor briefings, reports, and memoranda on existing DU stockpiles and plans to reestablish a supply of DU. We also reviewed a feasibility study and other planning documentation for DU conversion line projects and contracts. We interviewed NNSA and DOE Office of Environmental Management (EM) officials and contractor representatives. We also conducted site visits to facilities associated with research, development, and manufacturing operations at DOE's Portsmouth site in Ohio and Y-12 and a commercial vendor, both in Tennessee.[7]

To examine the status of NNSA's efforts to develop DU component manufacturing capabilities to meet stockpile modernization requirements, we analyzed NNSA and contractor briefings, reports, and memoranda on efforts to reestablish and extend these capabilities. We also reviewed reports, plans, and briefings on the development of new DU manufacturing technologies and potential replacement facilities. We interviewed NNSA officials and contractor representatives and conducted site visits to facilities associated with research, development, and manufacturing operations at Y-12 and a neighboring research and development site in Tennessee.

To examine the extent to which NNSA's management of DU efforts is consistent with agency policy, we compared NNSA's actions with NNSA's DU Strategy and with DOE and NNSA program and project management policies and requirements. In addition, we analyzed how DU activities are organized and funded in relation to other strategic material programs based on DOE/NNSA organization charts, budget, and schedule information. We also analyzed information about NNSA program management and its recent reorganization of the Office of Defense Programs (of which DU activities are a part). We obtained this information through site visits and interviews with NNSA officials responsible for DU activities and for managing DU-related offices, such as the Office of Secondary Stage Production Modernization, the office at the center of NNSA's efforts to reestablish its capabilities to obtain and manufacture

[7]The Portsmouth site in Piketon, Ohio, enriched uranium for both commercial reactor fuel and military applications from 1954 through 2001. It is now a cleanup site managed by DOE's EM but has a role in producing DU feedstock for NNSA.

DU and a DU alloy needed to meet nuclear stockpile modernization responsibilities.

We conducted this performance audit from March 2019 to October 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.

Background

Nuclear Stockpile Modernization

The United States is in the midst of a long-term and accelerating effort to modernize its nuclear security enterprise.[8] Following the Cold War, U.S. nuclear strategy shifted focus from designing, testing, and producing new nuclear weapons to extending the operational lives of these weapons indefinitely through refurbishment.[9] NNSA undertakes nuclear stockpile modernization programs, in coordination with the Department of Defense (DOD), to refurbish or replace nuclear weapons and their components, enhance their safety and security characteristics, and consolidate the stockpile into fewer weapon types to minimize maintenance and testing costs while preserving needed military capabilities.[10]

[8]NNSA's nuclear security enterprise is comprised of a nationwide network of government-owned, contractor-operated national security laboratories and nuclear weapons production facilities. These facilities provide the research, development, testing, and production capabilities needed to carry out stockpile stewardship.

[9]NNSA's fiscal year 2021 budget request seeks funding for a new submarine-launched ballistic missile warhead, the W93, which is not a life extension of an existing warhead.

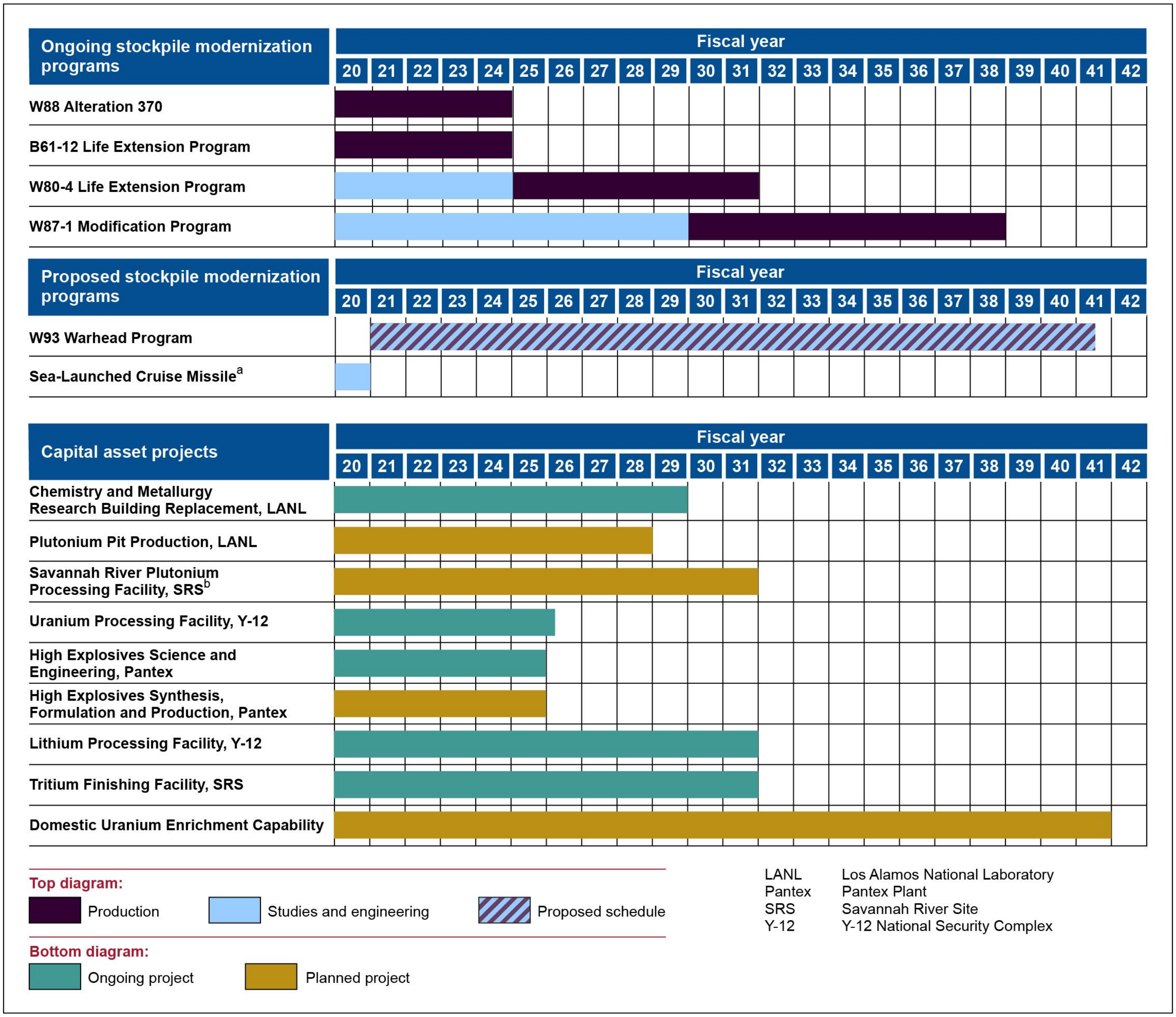
[10]Generally, "nuclear stockpile modernization programs" refers to life extension and modernization of existing weapons in the stockpile, which usually entail replacing older components with newer components, and other planned efforts intended to replace aging weapons with updated weapons capabilities.

NNSA is experiencing its busiest time since the Cold War era, according to NNSA's *Fiscal Year 2020 Stockpile Stewardship and Management Plan*. Over the next 2 decades, NNSA and DOD plan to spend hundreds of billions of dollars to simultaneously modernize the nation's nuclear stockpile and the supporting infrastructure on which nuclear stockpile modernization programs depend. In March 2020, we found that NNSA faced challenges in balancing ongoing and planned nuclear stockpile modernization programs with related capital asset projects at various production sites, such as Y-12.[11] We further stated that NNSA had made some progress in implementing our recommendations to improve the management of these programs and projects; however, we also found that any delays or technical challenges that affect NNSA's plans for its production facilities could result in delays and challenges to the stockpile modernization programs. Figure 1 shows the overlapping timelines of these various efforts.

[11]See GAO, *Nuclear Weapons: NNSA's Modernization Efforts Would Benefit from a Portfolio Management Approach,* GAO-20-443T (Washington, D.C.: Mar. 3, 2020), and *National Nuclear Security Administration: Action Needed to Address Affordability of Nuclear Modernization Programs*, GAO-17-341 (Washington, D.C.: Apr. 26, 2017).

Figure 1: Estimated Schedules of National Nuclear Security Administration (NNSA) Nuclear Stockpile Modernization Programs and Selected Enabling Capital Asset Projects

Timelines overlap for several NNSA nuclear stockpile modernization programs and for capital asset projects to provide the supporting infrastructure for these programs.



Sources: Department of Energy, *Fiscal Year 2021 Congressional Budget Request* and *Fiscal Year 2020 Stockpile Stewardship and Management Plan*. | GAO-21-16

[a]Under study, schedule to be determined.

[b]NNSA's fiscal year 2021 congressional budget justification provides a date range of fiscal years 2026 through 2031 for the start of operations, which will be updated as planning and design progress.

In addition to these efforts, NNSA is simultaneously undertaking an extensive set of supporting programmatic activities, such as reestablishing DU supply and manufacturing capabilities, to provide the materials and capabilities needed for nuclear stockpile modernization. Some of the programmatic activities require significant expenditures. For example, we reported in March 2020 that NNSA planned to spend $850 million from fiscal years 2016 through 2026 at Y-12 to support modernizing other enriched uranium processing capabilities that are not included in its $6.5 billion Uranium Processing Facility (UPF), which is under construction at Y-12.[12] We also found that NNSA had implemented our recommendation to set a time frame for developing a scope of work, schedule, and cost estimate to modernize these other uranium processing capabilities.[13] Likewise, in addition to funding plutonium capital asset projects at two sites, NNSA's 2021 congressional budget request identifies over $5 billion in planned programmatic funds from fiscal years 2021 through 2025 to reestablish plutonium pit production.

Depleted Uranium and Metal Production

Undertaking nuclear stockpile modernization programs involves production of some new weapon components, for which NNSA needs DU metal and a DU alloy made with niobium.[14] DU is uranium that has a lower concentration of uranium-235 than the 0.7 percent contained in natural uranium, a radioactive element.[15] Uranium-235 is the form, or isotope, of uranium that undergoes fission to release enormous amounts of energy in nuclear reactors and weapons. Natural uranium contains mostly uranium-238, an isotope that cannot sustain a nuclear chain reaction. To fuel nuclear power plants and meet certain national security requirements, natural uranium is enriched by separating uranium-235

[12]GAO, *Modernizing the Nuclear Security Enterprise: Uranium Processing Facility Is on Schedule and Budget, and NNSA Identified Additional Uranium Program Costs*, GAO-20-293 (Washington, D.C.: Mar. 11, 2020).

[13]GAO-20-293.

[14]Niobium (atomic number 41 on the periodic table of elements) is a transition metal used mostly in the production of high-strength steel alloys used in pipelines, transportation infrastructure, and structural applications due to its hardness, conductivity, and resistance to corrosion.

[15]DOE defines depleted uranium as having less than 0.707 or 0.711 percent uranium-235.

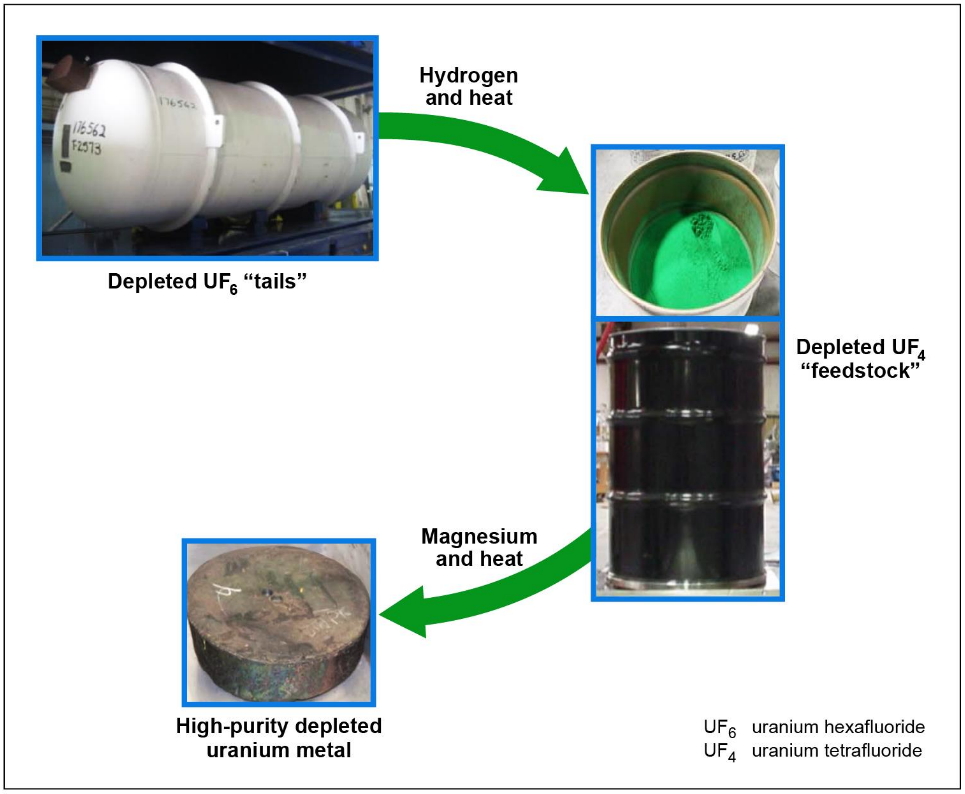
from uranium-238 to increase the concentration of uranium-235 in some material.[16] The rest of the material—DU—is left with a lower concentration of uranium-235 and a higher concentration of uranium-238.

Turning the DU byproducts of enrichment into the DU metal needed for the production of weapon components involves processing the material through several forms.[17] These byproducts—depleted uranium hexafluoride (DUF_6)—are known as “tails.” Historically, DOE or contractors have converted the tails, via a chemical process involving hydrogen, into depleted uranium tetrafluoride (DUF_4), the feedstock for DU metal production, also known as “green salt.” To then create the metal form of DU, another chemical process involving magnesium has been used to convert the feedstock into DU metal. Figure 2 shows these basic phases of DU metal production.

[16]Beginning in the 1940s and 1950s, the federal government, through DOE and its predecessor agencies, enriched uranium for both commercial reactor fuel and military applications at three large gaseous diffusion plants near Oak Ridge, Tennessee; Paducah, Kentucky; and Portsmouth, Ohio. In 1998, Congress privatized enrichment services, and the last gaseous diffusion plant, Paducah, ceased operations in 2013.

[17]The uranium enrichment process generally involves uranium in a gaseous form with fluorine called uranium hexafluoride (UF_6).

Figure 2: Basic Phases of Depleted Uranium (DU) Metal Production
DU metal needed for nuclear weapon components is produced from byproducts (tails) of uranium enrichment processes.



Source: Department of Energy. | GAO-21-16

DU for weapon components must be high-purity, without contamination from other elements such as plutonium or technetium. This purity requirement begins with the tails, which DOE has assessed for low levels of contaminants and the proper concentrations of uranium-235 and set aside for NNSA use.[18] Lower-purity DU metal is used in commercial and military applications such as radiation shielding, counterweights,[19] and munitions. For example, DOD uses lower-purity DU for several purposes, including munitions such as tank penetrators.

NNSA's manufacture of components from DU metal and DU-niobium alloy entails a variety of industrial metalworking processes, such as

[18]Unless otherwise noted, all further references to NNSA supplies of DU tails, feedstock, and metal refer to high-purity DU.

[19]A counterweight is an equivalent weight or force to counterbalance.

alloying, casting, wrought processing, machining, and welding, which are described below:

- **Alloying** is to melt at high temperature a mixture of multiple metals to a molten state that cools to form a new solid hybrid metal.
- **Casting** is a manufacturing process during which a solid material (such as metal or metal alloy) is melted to a molten form, heated to suitable temperature, and then poured into a mold or cavity, which keeps the molten material in a proper form during solidification. Casting is used to create complex or simple designs from any material that can be melted to a molten form. Casting can also be used to alloy multiple metals together at a high temperature to form a new solid hybrid metal.
- **Wrought processing** involves heating and then shaping or otherwise altering the contours of a pliable mass—typically metal, metalwork, or metal alloy—by hammering with mechanical or hand hammers. Wrought processing includes three main techniques:
  - **Rolling** is a metal-forming process in which metal stock is passed through one or more pairs of rolls to reduce and even out its thickness. The concept is similar to the rolling of dough.
  - **Pressing** involves changing the physical shape of solid metal or metal alloy by (1) preheating the shapes, (2) pressing the metal into a different shape in a press, and (3) providing a controlled period for cool down.
  - **Forming** is a manufacturing process during which material is stamped by a press around or onto a die or is otherwise stressed to deform the material into required shapes. During forming processes, no material is removed; instead, it is re-formed and displaced.
- **Machining** is any of various processes in which material is cut into a desired final shape and size by a controlled material-removal process. Machining processes that involve controlled removal of material are today collectively known as subtractive manufacturing, in distinction from processes of controlled material addition, which are known as additive manufacturing.[20]
- **Welding** is a process for joining materials by heating them to the welding temperature while potentially applying pressure or by applying pressure alone. Welding may also use filler metal to help join the

[20]The "controlled" part of the definition almost always implies the use of machine tools.

materials.

Y-12 National Security Complex and the Portsmouth and Paducah Sites

NNSA's "uranium center of excellence" is Y-12, which dates from the Manhattan Project. Many of Y-12's buildings and infrastructure are old, in some cases dating from the 1940s. Y-12's primary role in supporting the modernization of the nuclear weapons stockpile is the refurbishment and manufacture of secondary stages of nuclear weapons and related components.[21] These components may include DU, enriched uranium, and lithium compounds. Some of Y-12's DU operations were shut down or consolidated in the early 2000s, and, like much of the rest of Y-12, the DU manufacturing equipment and infrastructure there is generally decades old.

DOE has a large supply of DU tails (approximately 60,400 cylinders as of January 2020, each containing about 8 to 9 metric tons of DU) at two sites: the Portsmouth site, near Piketon, Ohio, and a site in Paducah, Kentucky. However, only a certain number of these cylinders are suitable for conversion into high-purity DU metal and have been set aside.

The two sites are former gaseous diffusion plants that were used for enriching uranium and are now primarily EM cleanup sites.[22] Both sites have facilities that are converting the tails (DUF_6) to a more stable uranium oxide for storage until final disposition as waste or for commercial reuse (see fig. 3). The Portsmouth and Paducah DUF_6 Conversion Facilities are similar in size and design; however, the Paducah facility has four process lines, while only three lines were installed at Portsmouth, leaving space at Portsmouth for a potential fourth line for NNSA purposes. The Portsmouth facility began operating in 2010 and experienced several safety and reliability issues during early operations. In 2015, after two safety incidents, EM shut down the facility until January 2018. According to EM officials, after bringing on a new

[21]Modern nuclear weapons have two stages: the primary, which is the initial source of energy, and the secondary, which is driven by the primary and provides additional explosive energy.

[22]GAO, *Nuclear Cleanup: Actions Needed to Improve Cleanup Efforts at DOE's Three Former Gaseous Diffusion Plants*, GAO-20-63 (Washington, D.C.: Dec. 17, 2019).

contractor in February 2017, safety improved significantly and preventative maintenance and reliability increased.

Figure 3: Portsmouth Depleted Uranium Hexafluoride (DUF_6) Conversion Facility with Tails Cylinders in Foreground

The facility at DOE's Portsmouth site near Piketon, OH, converts byproducts ("tails") of uranium enrichment processes into a more stable uranium oxide for storage; some tails are suitable for producing depleted uranium metal used in the nuclear stockpile modernization program.

Source: Department of Energy. | GAO-21-16

NNSA Funding for DU Activities

In recent years and through fiscal year 2020, DU activities have been carried out with appropriated funds available to various programs within NNSA's Office of Defense Programs, including but not limited to the following:

- **Uranium Sustainment** provides funding to modernize uranium operations to ensure delivery of secondary components needed to sustain the stockpile. This program focuses on replacing enriched uranium operations in a building at Y-12—known as 9212—that is beyond its useful life. These operations are being replaced with the new UPF and related projects.
- **Material Recycle and Recovery** provides vital quantities of strategic materials feedstock by purifying the materials (e.g., plutonium, uranium, and tritium) and recovering the intrinsic value of each

(usable quantities of the material without impurities) to sustain the nation's nuclear deterrent.

- The **Storage program** manages strategic materials storage and staging by sustaining capabilities, managing inventory logistics, conducting component and container surveillance activities, and storing dismantled warhead components and materials.
- **Stockpile Services** provides the logistical, mechanical, and support foundation for all Directed Stockpile Work operations that are applicable to multiple weapon systems in the nuclear weapons stockpile.
- **Component Manufacturing Development** seeks to accelerate the development of new manufacturing science and engineering capabilities that will replace hazardous, inefficient, and obsolete processes for future weapon systems.
- **Individual stockpile modernization programs** fund production costs of their specific components once a capability is established, as well as other specialized needs.

In addition to Defense Programs, the NNSA Office of Infrastructure provides funding that supports DU activities by maintaining, operating, and modernizing facilities. For example, this office provides funding for water and electrical utilities; safety systems; preventative and corrective maintenance; and recapitalization efforts to improve the condition and extend the life of structures, capabilities, and systems.

NNSA Program Management Challenges

Since 1990, we have designated DOE's contract and project management as at high risk of waste, fraud, abuse, and mismanagement.[23] In addition, NNSA has a history of program management problems that have resulted in significant cost overruns and schedule delays. NNSA has also encountered difficulties in restarting strategic material procurement programs and technical manufacturing processes after long periods of inactivity. For example, in March 2009 and June 2019, respectively, we reported on the management challenges NNSA faced in its efforts to resume production of two important stockpile materials—Fogbank and high explosives—after many years of not producing these weapons materials.[24] Regarding Fogbank, NNSA had ceased production for several years and had difficulties in resuming production after this multiple-year hiatus. Fogbank production challenges led to a year-long delay and $69 million in cost increases for a life extension program. In our report, we made several recommendations to improve the weapons modernization process and related issues, and NNSA has implemented some, but not all, of them.[25] Regarding restarting the production of certain high explosives, NNSA officials and contractor representatives identified several challenges, such as the agency's dwindling supply of explosive materials, aging and deteriorating infrastructure, and difficulty recruiting and training qualified staff. For example, only a single container of one specialized material remained. We made several recommendations in our report to improve management and planning of high explosives activities—all of which

[23]GAO, *High-Risk Series: Substantial Efforts Needed to Achieve Greater Progress on High-Risk Areas,* GAO-19-157SP (Washington, D.C.: Mar. 6, 2019). We designated DOE's contract management—which includes both contract administration and project management—as a high-risk area in 1990 because DOE's record of inadequate management and oversight of contractors had left the department vulnerable to fraud, waste, abuse, and mismanagement. In January 2009, to recognize progress made by DOE's Office of Science, we narrowed the focus of DOE's high-risk designation to two DOE program elements—EM and NNSA. In February 2013, we further narrowed the focus of the high-risk designation to NNSA's and EM's contracts, as well as major projects—those with an estimated cost of $750 million or greater—to acknowledge progress made in managing nonmajor projects.

[24]See GAO-09-385 and GAO-19-449

[25]With the completion of the W76-1 life extension program in December 2018, NNSA ceased production of Fogbank.

NNSA concurred with—and we are monitoring the agency's implementation of these recommendations.[26]

The scope and persistence of these challenges are attributable at least in part to the agency not completing or not effectively using key program management documents such as scopes of work, life-cycle cost estimates, and integrated master schedules[27] or not effectively implementing a risk mitigation strategy. In the case of Fogbank, we reported in March 2009 that NNSA had developed a risk mitigation strategy to avoid potential cost overruns and schedule delays related to the manufacture of this key material, but NNSA did not effectively implement this strategy. Regarding high explosives, we reported in June 2019 that NNSA's new strategic plan for explosives activities addressed some of the challenges agency officials and contractor representatives identified, and NNSA followed several key leading practices in developing its strategic plan. However, some of the plan's elements had not been fully developed consistent with selected leading practices.

Program Management Requirements

Under the National Nuclear Security Administration Act, the Secretary of Energy is responsible for establishing policy for NNSA.[28] The NNSA Administrator has authority to issue additional agency-specific NNSA policies and program execution instructions. In part because of past challenges and our recommendations to address them, NNSA and its

[26]In addition to these reports, GAO has an ongoing engagement examining the program and project management of NNSA's lithium activities per a provision in Senate Committee Report 116-48 accompanying the National Defense Authorization Act for Fiscal Year 2020.

[27]An integrated master schedule is a document that integrates the planned work, the resources necessary to accomplish that work, and the associated budget for a program, as called for in best practices. We discuss best practices concerning the development of scope of work, cost estimates, and schedules in two guides. In March 2009, we issued a cost estimating guide, a compilation of cost estimating best practices drawn from across industry and government, which we revised in March 2020: GAO, *GAO Cost Estimating and Assessment Guide: Best Practices for Developing and Managing Program Costs*, GAO-20-195G (Washington, D.C.: March 2020). In December 2015, we issued a schedule guide that develops the scheduling concepts introduced in our cost estimating guide and presents them as 10 best practices associated with developing and maintaining a reliable, high-quality schedule. GAO, *Schedule Assessment Guide: Best Practices for Project Schedules*, GAO-16-89G (Washington, D.C.: December 2015).

[28]Pub. L. No. 106-65, § 3203(a) (1999) (codified at 42 U.S.C. § 7144(a)).

Office of Defense Programs have established program management policies.[29]

NNSA's program management policies that pertain to DU are established in several documents—most significantly, in the information and requirements for managing programs in Defense Programs' *Program Execution Instruction.*[30] The purpose of the *Program Execution Instruction* is to implement NNSA's Program Management Policy (NAP 413.2) and to provide specific methods for conducting program management within Defense Programs. This instruction establishes program management categories and implementation requirements for those categories. There are four program management categories, which increase in rigor and formality as the program matures and becomes more complex; the DU Program is in the third-most rigorous category.[31] The *Program Execution Instruction* also provides a Program Management Category Determination Checklist, which establishes criteria for assessing and designating a program's management category. As the scope, cost, risk, and schedule of a program evolve, the program may be required to move to a more rigorous category. The *Program Execution Instruction* defines the role of the Federal Program Manager or her or his designee's activities to meet

[29]Defense Programs carries out NNSA's mission to maintain and modernize the nuclear stockpile through the Stockpile Stewardship and Management Plan.

[30]National Nuclear Security Administration, *Defense Programs' Program Execution Instruction,* Revision 2 (Washington, D.C.: June 2019). See also (1) *NNSA Program Management Policy, NAP 413.2* (Washington, D.C.: February 2019), which establishes NNSA's policy for conducting program management activities; (2) DOE Order 413.3B, which has detailed management policies and guidance for capital asset projects with an estimated cost of $50 million or greater; and (3) *NNSA Program Management Policy for Weapons and Strategic Materials Programs, Business Operating Procedure* (BOP) - 06.07 (Washington, D.C.: January 2017). The purpose of the BOP is to establish the roles and responsibilities of Federal Program Managers for (i) life extension programs; (ii) major alteration programs; and (iii) strategic materials across the nuclear security enterprise.

[31]The program management categories are Capital Acquisition Management, Enhanced Management A, Enhanced Management B, and Standard Management. According to NNSA officials, the DU Program will be in Enhanced Management B. Factors that cause an activity to be considered for this category include external commitments, increased emphasis on meeting cost and schedule deadlines, frequent interface with external stakeholders and partners, and the complexity and risk associated with the program.

the requirements for program management. It also lays out the roles and responsibilities of other Defense Programs senior management.[32]

The *Program Execution Instruction* provides tools and processes for the implementation of the program. Regardless of the program category, programs are expected to develop planning and program management documents that outline the scope, schedule, and cost of a program. GAO's schedule assessment and cost-estimating guides highlight similar program management tools as best practices.[33] Such documents include the following:

- **Program Plan**. The Program Plan is the governing document that establishes the means to define, execute, monitor, and control NNSA programs. It is the core document for the management of a program and identifies the plan and procedures to be used to manage and control program planning, initiation, definition, execution, and, ultimately, operations. The program plan must include planning and management documents that describe the efforts to address program needs and requirements and to fill any gaps in meeting them. It is to include an accurate depiction of how the program is to be accomplished. It is also to address the program performance parameters, resource requirements, technical considerations, risk management, roles and responsibilities, and other project elements. For example, under the *Program Execution Instruction*, the Federal Program Manager must document the management of risks and opportunities either in the Program Plan or in a separate Risk and Opportunity Management Plan. The Program Plan is to be updated throughout the duration of a program.
- **Integrated Master Schedule.** An Integrated Master Schedule integrates the planned work, the resources necessary to accomplish that work, and the associated budget for a program. It can also show when major events are expected as well as the completion dates for all activities leading up to these events, which can help managers determine if the program's parameters are realistic and achievable. Integrated Master Schedules are usually based on a work breakdown structure, also known as the complete scope of work, which is a

[32]Key NNSA positions for which the *Program Execution Instruction* defines roles and responsibilities include the Assistant Deputy Administrator, the Executive Officer for Future Warhead Systems, and Federal Program Managers. Also named are three NNSA Defense Programs organizations that support the program: Offices of Decision Support, Systems Engineering and Integration, and Chief Systems Engineer.

[33]GAO-16-89G and GAO-20-195G.

hierarchical code structure representing the entire scope of a project or program.

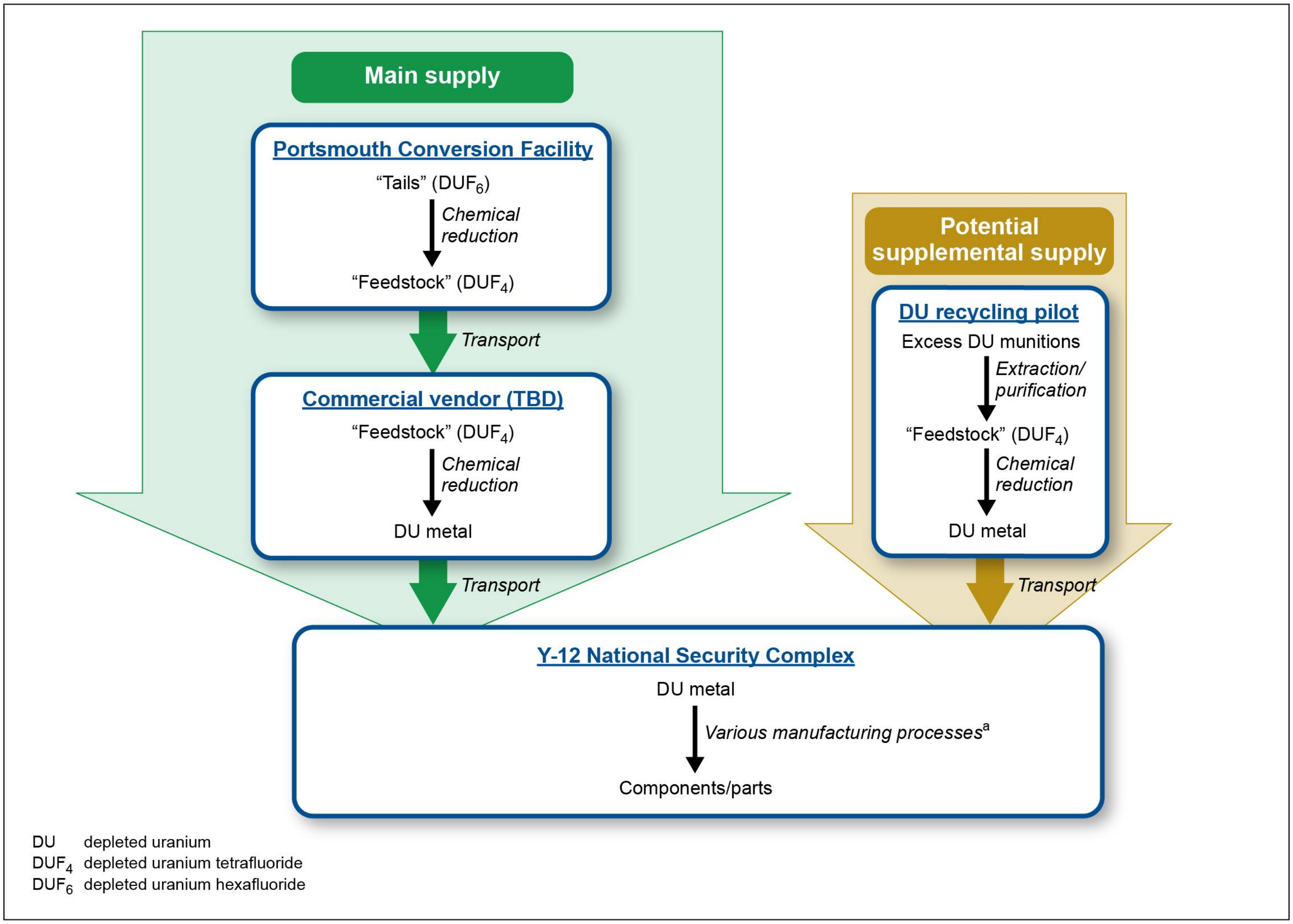
- **Life-Cycle Cost Estimate**. A life-cycle cost estimate provides an exhaustive and structured accounting of all resources and associated cost elements required to develop, produce, deploy, and sustain a particular program. A life-cycle cost estimate can be thought of as a “cradle to grave” approach to managing a program throughout its useful life. This entails identifying all cost elements that pertain to the program from initial concept all the way through operations, support, and the end of the program. A life-cycle cost estimate encompasses all past (or sunk), present, and future costs for every aspect of the program, regardless of funding source.

NNSA Is Taking Steps to Establish a New Supply of DU to Modernize the Nuclear Weapons Stockpile

According to agency officials, NNSA is taking several steps to obtain the necessary quantities of DU to meet stockpile modernization requirements.[34] These steps include establishing both a main supply of DU and a potential supplemental supply by (1) installing equipment at DOE EM’s Portsmouth DUF_6 Conversion Facility to reestablish a supply of DU feedstock; (2) contracting with a commercial vendor to convert DU feedstock into metal; and (3) conducting a pilot project to convert obsolete DU munitions to DU metal. (See fig. 4.)

[34]A 2017 analysis of supply and demand by Y-12’s management and operating contractor determined that NNSA’s high-purity DU supply would run out around fiscal year 2029.

Figure 4: Depleted Uranium Supply Chain for Nuclear Weapon Components
NNSA is seeking to establish a three-step supply chain to convert byproducts ("tails") of uranium enrichment processes into DU metal for weapons components; it is also exploring a recycling process that could provide a potential supplemental supply of DU metal.



Source: GAO analysis of Department of Energy information. | GAO-21-16

Note: Feedstock and metal in the illustration above are high-purity DU.

[a]These include casting and wrought processes with DU and a multi-step alloying and wrought process with a DU-niobium alloy.

NNSA Is Planning to Reestablish Its Supply of DU Feedstock at EM's Portsmouth Facility, Which Is Scheduled to Operate through 2036

To reestablish a supply of DU feedstock needed for DU metal production, NNSA plans to install a conversion line at EM's Portsmouth DUF_6 Conversion Facility, which is scheduled to operate through 2036. In September 2018, NNSA and EM agreed to install equipment in available space within the facility to convert approximately 1,200 cylinders (approximately 9,900 metric tons) of tails stored at the Portsmouth and Paducah sites into feedstock.[35] NNSA is funding this effort through its appropriation. According to agency officials, EM and NNSA are managing installation of the new conversion line as a project through EM's facility operations contract with Mid-America Conversion Services (MCS), and project design began in 2019. In January 2020, MCS provided EM with a full cost and schedule proposal for a conversion line with a designed annual throughput of 400 metric tons uranium (MTU) of feedstock per year. NNSA subsequently directed EM and MCS in March 2020 to provide an updated design, cost, and schedule proposal to increase the annual throughput to 800 MTU.

According to EM and NNSA officials, MCS plans to finalize design in late fall 2020 and begin construction in early winter 2021. EM and NNSA officials said that the 800 MTU design would meet NNSA's current and anticipated future demand through at least the early 2040s. EM and MCS officials said they expected design, engineering, installation, and commissioning of the original 400 MTU design to cost between $12 million and $18 million, with operations beginning in fiscal year 2022. On July 30, 2020, MCS submitted an updated certified cost proposal for the construction and commissioning of an 800 MTU design that increased the estimated cost range to between $38 million and $48 million. EM and NNSA officials are reviewing this updated cost and schedule proposal but still plan on completing construction in fiscal year 2022. EM and NNSA officials told us that this is an aggressive schedule driven by NNSA's need for new DU feedstock.

According to EM and NNSA officials, feedstock production will continue until the conversion facility's larger mission of converting cylinders to uranium oxide for disposition as waste or for commercial reuse is

[35]In May 2015, NNSA and EM signed a memorandum of agreement reserving those cylinders for future NNSA use.

complete; operations at the conversion facility will not be extended solely for NNSA feedstock production. Currently, EM estimates oxide conversion at Portsmouth will continue through 2036. Therefore, according to NNSA officials, starting operations as soon as possible will maximize the amount of tails converted to feedstock before conversion operations cease at the site. Likewise, according to officials, should the project's aggressive timeline slip, less feedstock would be produced, ultimately leading to lower supply of DU metal in the future.

According to EM officials, the estimated cost of the project to install the line does not meet the $50 million threshold that would require adherence to the detailed project management requirements of DOE Order 413.3B.[36] Nevertheless, according to EM officials, they still plan to use project management tools called for in the order, such as an Earned Value Management System.[37] In addition to the installation project cost, DOE anticipates operating expenses of about $13.5 million annually through fiscal year 2036.[38] Adding these operating expenses to the expected cost of the installation project brings estimated life-cycle costs for the conversion line to between $220 million and $250 million. To date, funds for this project to reestablish a supply of DU feedstock at Portsmouth have come from appropriations for NNSA's Material Recycle and Recovery program office, including $12 million in fiscal year 2019 appropriations across fiscal years 2019 and 2020 and $4.8 million in fiscal year 2020 appropriations, according to NNSA officials.

[36]DOE has detailed program and project management policies and guidance for large capital asset projects. In particular, DOE Order 413.3B requires projects to go through five management reviews and approvals, called "critical decisions," as the projects move from planning and design to construction and operation. The order also includes requirements for rigor in cost estimates and scheduling.

[37]Earned value management is a project management tool developed by DOD in the 1960s to help managers monitor project risks. Earned value management systems measure the value of work accomplished in a given period and compare the measured value with the planned value of work scheduled for that period and the actual cost of work accomplished. The purpose of earned value management is to integrate a project's cost, schedule, and technical efforts for management and provide reliable data to decision makers.

[38]Operating and life-cycle cost estimates presented on this page are in nominal dollars, unadjusted for inflation.

NNSA Is Planning to Contract for Conversion of DU Feedstock into DU Metal

NNSA plans to convert its feedstock supply to high-purity DU metal through a commercial vendor.[39] NNSA has not yet developed its acquisition strategy for procuring conversion services and has not decided whether it will subcontract through Y-12's management and operating contractor—currently Consolidated Nuclear Security, LLC (CNS)—or contract directly with a vendor. NNSA officials told us they began developing the acquisition strategy and initial procurement requisition after they received the initial cost and schedule proposal for the Portsmouth conversion project in March 2020. They also said that a sole-source contract is under consideration, given that market research indicates only one potential vendor currently has the capabilities to undertake high-purity metal conversion. According to these officials, NNSA would need a contract in place in fiscal year 2022, a year before production would start, subject to the final Portsmouth project schedule. NNSA estimates costs of $27 million per year for these metal conversion services, which would run for over a decade.

According to NNSA and EM officials, the transportation of tails from Paducah to Portsmouth and feedstock from Portsmouth to a commercial vendor for conversion to metal will be managed as either an NNSA contract or a CNS subcontract, depending on the structure of the metal conversion contract. CNS will handle delivery of metal from the vendor to Y-12. According to NNSA and EM officials, there are several potential storage options at different stages of the process, the details of which need to be worked out as NNSA establishes the contracts. Previous feedstock supplies were stored at the vendor. The current DU metal supply is stored at Y-12 at a cost of $1.7 million from funds available to the Storage program in fiscal year 2020.

NNSA Has Conducted a Pilot Project to Recycle Munitions into DU Metal

NNSA has also conducted a small-scale pilot project to assess the feasibility of recycling old, lower-purity DOD DU munitions into a supplemental source of high-purity DU metal. NNSA conducted this pilot project at a commercial vendor in Tennessee. The vendor produced its

[39]A commercial vendor in Tennessee performed such metal conversion for Y-12 from 2002 until 2017.

first full-size piece of DU metal from the recycled feedstock in November 2019. The pilot aims to prove the process at scale, assess its economic feasibility, and produce a report on feasibility and cost. According to officials, this report was originally due in January 2020 and then expected in June. Because of the effects of the ongoing COVID-19 pandemic on the vendor, NNSA officials stated they could not predict when they would receive the report; they hoped to receive the report and decide on whether to pursue this recycling process by the end of 2020. NNSA anticipates that only a small portion of its needed DU supply could be produced through this process. However, by creating a second, supplemental source of feedstock and metal, this process may offer such benefits as

- mitigating risk in the event of a disruption to the primary means of producing feedstock and metal;
- providing options for feedstock production past 2036, when Portsmouth's conversion operations are scheduled to cease; and
- reusing material that otherwise would require disposal.

The fiscal year 2020 budget for the recycling pilot was $600,000, from funds available to the Material Recycle and Recovery and Uranium/Molybdenum programs. According to NNSA officials, once the feasibility report is complete, NNSA will review and determine whether to go forward with further development of this recycled DU process.

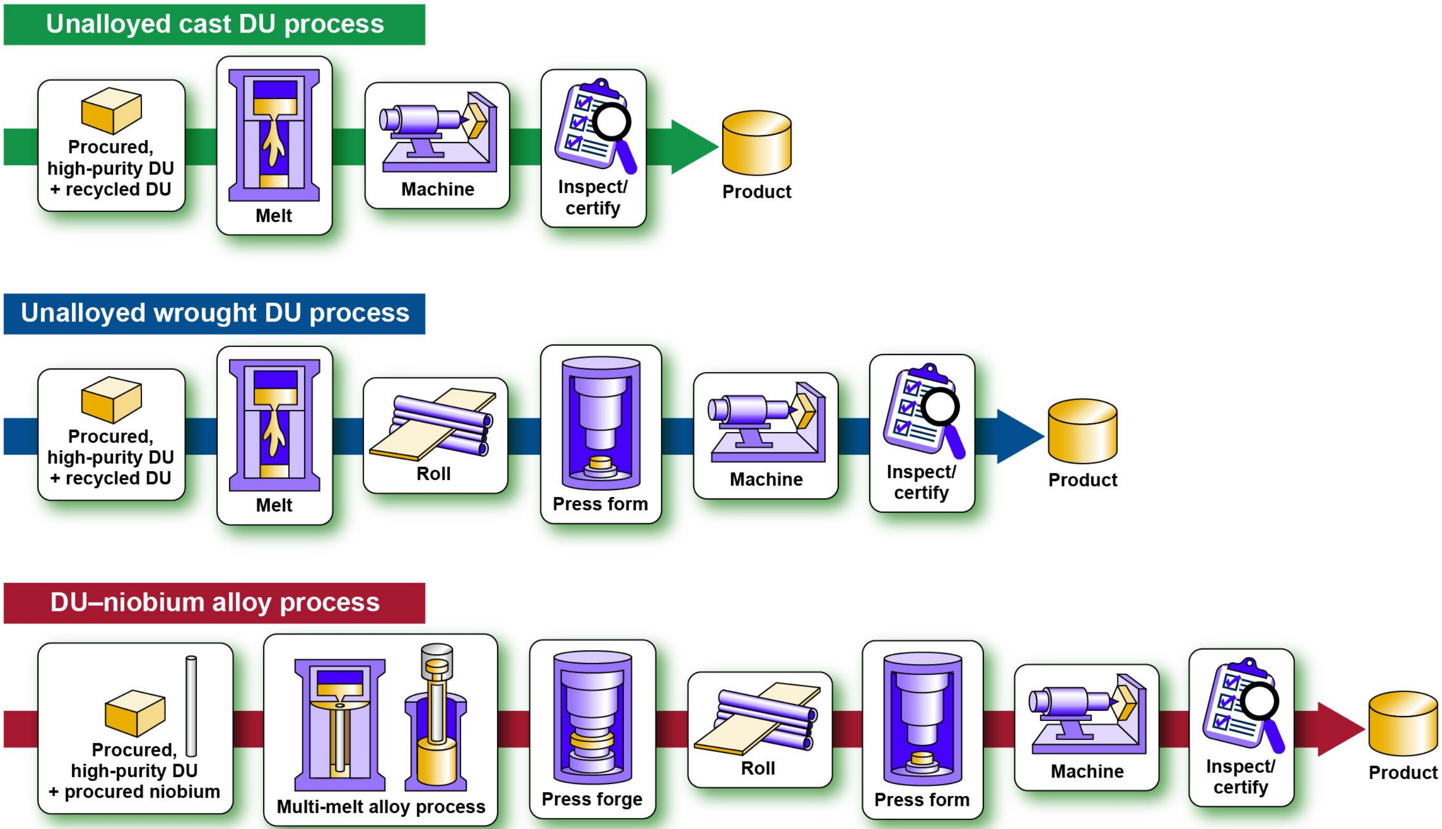
NNSA Is Taking Steps to Reestablish and Modernize Time-Sensitive DU Component Manufacturing Capabilities and Recognizes Risks of Delay

NNSA is taking steps to reestablish and modernize time-sensitive DU component manufacturing capabilities, but it risks delays that could affect the timelines of nuclear stockpile modernization programs, according to NNSA officials. NNSA's steps include (1) reestablishing critical DU component manufacturing processes that Y-12 previously used, (2) developing more efficient component manufacturing technologies to conserve DU supply, and (3) extending the life of and eventually replacing facilities that house DU component manufacturing capabilities. According to NNSA officials, all three elements need to be addressed in parallel, because the previously used processes are needed for near-term production and in case new technologies do not work as planned, the more efficient new technologies are needed to ensure sufficient supply of DU in the future, and current facilities are aging.

NNSA Is Reestablishing Previously Used DU Manufacturing Processes to Meet Certain Stockpile Modernization Schedules, but It Acknowledges High Risk of Delays

NNSA officials said that the agency is in the midst of reestablishing a full set of DU component manufacturing capabilities but that tightness in schedules and in material supplies creates a high risk of delays in certain nuclear stockpile modernization programs. According to NNSA officials, the agency has reestablished all needed processes for manufacturing unalloyed DU components. In particular, since 2011, Y-12 has restored certain equipment, such as melting furnaces and the rolling mill, for manufacturing unalloyed cast and wrought DU components; processes for both types of unalloyed DU components are operational. NNSA officials said that NNSA is also reestablishing its process for manufacturing alloyed DU-niobium components but cannot yet perform the full process. (See fig. 5 for diagrams of these manufacturing processes.)

Figure 5: Depleted Uranium (DU) Component Manufacturing Processes
To manufacture weapon components for nuclear stockpile modernization, NNSA must have capabilities to perform three processes; it has reestablished the first two and is working on the third—the DU–niobium alloy process.



DU = depleted uranium

Source: GAO adaptation of National Nuclear Security Administration (NNSA) graphic. | GAO-21-16

Restarting the DU–niobium alloy process—a complicated, resource-intensive process that has not been done in over a decade—is NNSA's number one priority for DU and presents a very high risk to timely supply of alloyed components for certain nuclear stockpile modernization programs, according to NNSA documents and officials. The DU–niobium alloy process is critical, as NNSA does not have an alternative material it can use. NNSA plans to produce qualified ingots of DU-niobium alloy by October 2023,[40] and any delays beyond that will affect the current schedules of these programs. As of June 2020, NNSA was taking steps

[40]Qualified ingots will be qualified by NNSA's national laboratories to the high-quality standards necessary for use in nuclear weapons.

to procure the necessary equipment and to develop and validate its manufacturing processes with that equipment.[41] For example, NNSA will need to restart existing furnaces or procure new furnaces, and it is performing test runs of a vacuum arc remelt furnace.[42] Once Y-12 fully develops and reestablishes the process, the site will undertake a couple years of evaluation and testing to ensure the alloy produced through this process meets the exacting requirements for weapon components.

In addition to procuring new equipment and validating its manufacturing processes, NNSA is working to maintain the functionality of its existing DU manufacturing equipment. NNSA and contractor officials said that several pieces of aging equipment represent potential single-point failures for the manufacturing processes for both unalloyed and alloyed DU components. For example, there is only a single rolling mill that, while refurbished with new parts, Y-12 acquired used in the 1950's. The risks and consequences of such aging equipment were demonstrated in May 2019, when a fire caused by a failed transformer shut down the rolling mill, stopping the manufacture of unalloyed wrought DU components for 6 months, until November 2019.

Several different NNSA offices and programs—such as Uranium Sustainment, Material Recycle and Recovery, Stockpile Services, and individual nuclear stockpile modernization programs—have funded efforts to restart the DU–niobium alloy process and to sustain and improve existing DU component manufacturing capabilities. These programs provided combined funding of about $5 million to $10 million per year in fiscal years 2011 through 2019, and $18.7 million in fiscal year 2020.

NNSA Is Developing More Efficient Component Manufacturing Technologies to Conserve DU Supply

NNSA is also developing some new DU component manufacturing technologies to improve the efficiency of the DU–niobium alloy process and avoid potential DU supply issues in future years. NNSA is pursuing

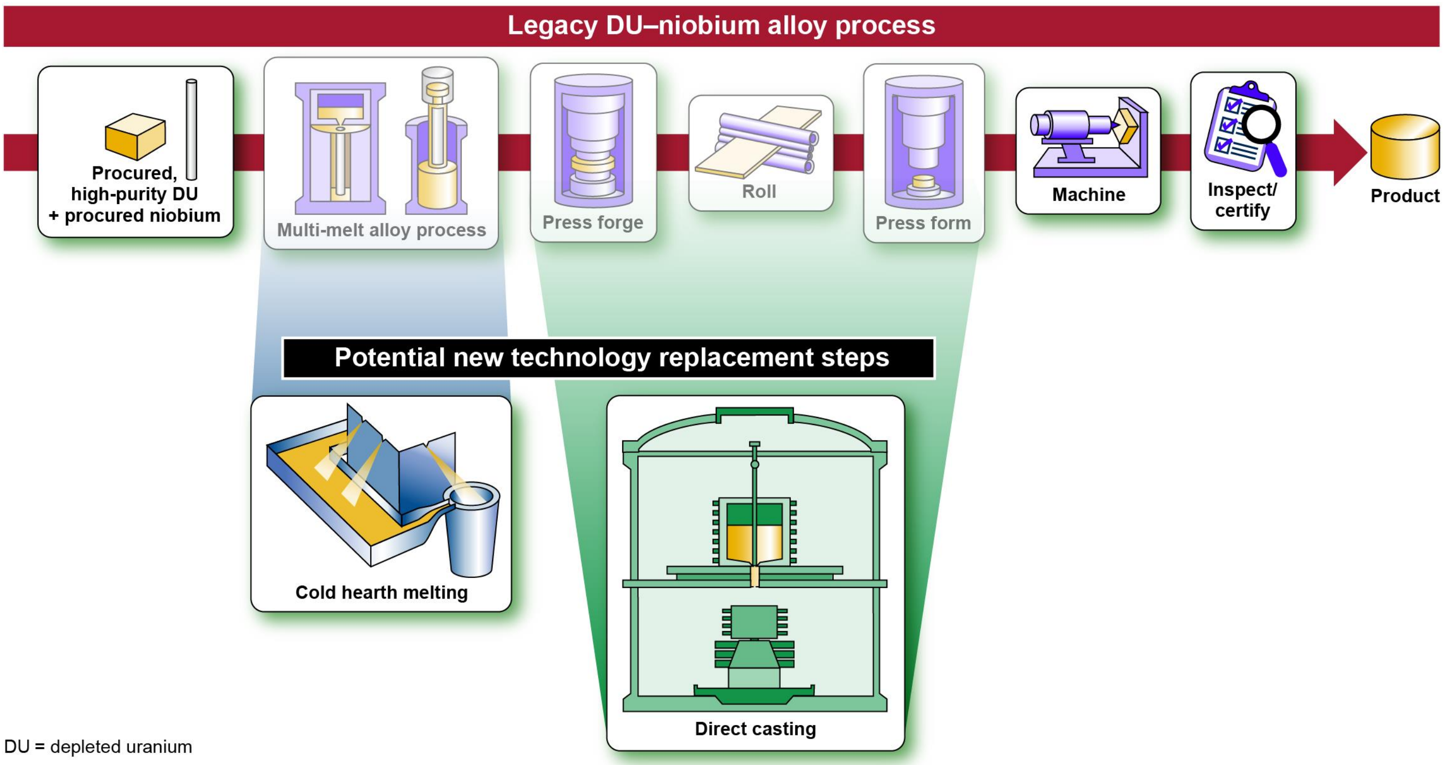
[41]According to NNSA officials, the COVID-19 pandemic did not have immediate effects on the scope or schedule of efforts to restart the DU–niobium alloy process because the work was deemed essential and continued at Y-12. However, the restart also relies on vendors for supplies and some development activities, and the pandemic's effects on those vendors could delay the restart in the coming months. NNSA is in the process of analyzing the potential effects.

[42]Vacuum arc remelting is a secondary melting process used in producing high-value and specialty alloys to improve the quality and homogeneity of the metal.

new manufacturing technologies for DU–niobium alloyed components because, according to NNSA's DU Strategy, these components "have some of the highest costs and longest lead times of any components in the nuclear stockpile." Also, according to NNSA documents, the current DU–niobium alloy component manufacturing process—including casting, forging, rolling, and forming—wastes a very high percentage of the materials involved, and NNSA currently cannot recycle this waste. Thus, enhanced manufacturing capabilities for these components could have a significant impact on efficiency and positively benefit supply of DU metal. Some new technologies are slated for insertion into NNSA's manufacturing processes within the next 3 to 10 years, and NNSA is taking steps to develop these technologies to sufficient maturity.

Of the new technologies, direct casting is the most mature and, according to officials, it must be ready in the next decade to conserve the limited supply of DU-niobium alloy and meet the needs of future modernization programs. Direct casting involves casting DU-niobium alloy directly into a component-shaped mold, and this technology would replace the multi-step forging, rolling, and forming of the wrought process (see fig. 6).

Figure 6: New Manufacturing Technologies for the Depleted Uranium–Niobium Alloy Process
New depleted uranium (DU) manufacturing technologies could make the process more efficient by replacing existing steps.



DU = depleted uranium

Source: GAO adaptation of National Nuclear Security Administration graphic. | GAO-21-16

According to NNSA's assessment, direct casting achieved Technology Readiness Level (TRL) 5 in February 2019. NNSA has a technology maturation plan and an implementation plan to bring the technology to sufficient maturity so that it can be relied upon for component production.

Technology Readiness Levels

The Department of Energy and the National Nuclear Security Administration (NNSA) use a systematic approach for assessing how far a technology has matured to evaluate the technology's readiness to be integrated into a system—Technology Readiness Levels (TRL). TRLs were pioneered by the National Aeronautics and Space Administration and have been used by the Department of Defense and other agencies in their research and development efforts.

NNSA adopted the use of TRLs for major projects, programs, and acquisition processes, particularly large capital asset projects and major atomic energy defense acquisition programs. This approach is intended to ensure that new technologies are sufficiently mature in time to be used successfully when a project or acquisition program is completed.

TRLs progress from the least mature level, in which the basic technology principles are observed (TRL 1), to the highest maturity level, in which the total system is used successfully in project operations (TRL 9). NNSA's phased process for managing nuclear weapon modernization programs requires that technological components be integrated with supporting elements so they can be tested in a simulated environment (TRL 5) before the development engineering phase and demonstrated as a prototype in an operational environment (TRL 7) by the production engineering phase. According to our guide on evaluating technology readiness, assessing technology readiness does not eliminate the risk of relying on new technology but can identify concerns and serve as the basis for realistic discussions on how to mitigate potential risks, such as those associated with the project's scope.

Source: NNSA, Defense Programs Technology Readiness Assessment Implementation Guide (Washington, D.C.: December 2018) and GAO, Technology Readiness Assessment Guide: Best Practices for Evaluating the Readiness of Technology for Use in Acquisition Programs and Projects, GAO-20-48G (Washington, D.C.: January 2020). | GAO-21-16

The implementation plan, prepared by CNS in January 2019, envisions the following schedule:

- achieve TRL 6 in the third quarter of fiscal year 2021;
- insert the first production furnace into the process in the fourth quarter of fiscal year 2022; and
- achieve TRL 7—a prototype demonstrated in an operational environment—in the first quarter of fiscal year 2023.[43]

[43]Consolidated Nuclear Security, LLC, *Direct Casting Technology Implementation Plan*, PLN YAREA-F-0086 000 00 (Oak Ridge, TN: January 2019).

However, the plan also notes that the schedule “is considered aggressive and does not appear to fully support the current notional schedule” for the requisite nuclear stockpile modernization program, indicating the risks of delays to stockpile modernization schedules.[44]

According to NNSA officials, while the increased demand for alloyed DU components could potentially be met by the current wrought process if sufficient supplies of alloy are available, the limited amounts of alloy currently available mean that if direct casting is not ready on schedule, shortages of alloy and delays in component production could occur in the near term. In the long term, the anticipated increased efficiency of direct casting could extend NNSA’s supply of alloy and high-purity DU. This improved efficiency takes on added importance given the potential limitation of new DU feedstock once the Portsmouth conversion facility ceases operations, currently planned for 2036.

NNSA’s implementation plan for this technology identifies the need for $141.25 million from fiscal year 2019 through fiscal year 2028 to develop the technology. According to the plan, this funding would draw on several sources such as Component Manufacturing Development, Uranium Sustainment, Laboratory-Directed Research & Development, and individual nuclear stockpile modernization programs.[45] Those sources combined provided about $16.9 million for direct casting in fiscal year 2020.

In addition to direct casting, NNSA is pursuing other technologies to enhance manufacturing capabilities for DU components. Cold hearth melting involves using electron beams or plasma torches to melt DU and niobium to create alloy ingots.[46] This technology would replace the current multi-step, multi-furnace alloying process and could allow recycling of DU

[44]NNSA officials noted in June 2020 that shutdowns and operational precautions due to the COVID-19 pandemic will have a potentially significant effect on direct casting development schedules; however, NNSA had not yet assessed those effects at the time of our report.

[45]Laboratory-Directed Research & Development are internally directed funding programs that NNSA sites can use to fund research and development projects of their own choosing.

[46]Cold hearth melting uses either a beam of high-energy electrons (electron beam) or a gas heated to high temperatures to make an ionized plasma (plasma torch) as a heat source for alloying metal or recycling scrap. When these high-energy electrons or plasma particles contact the feed material, they heat the bulk metal and cause it to melt. The temperature of the molten metal is closely controlled throughout the cooling process to achieve the desired purity.

and alloy scraps. According to NNSA officials, cold hearth melting is currently at TRL 3, and they hope to achieve TRL 5 in fiscal year 2023. These officials also noted that Lawrence Livermore National Laboratory and Y-12 will work to complete a Technology Maturation Plan and an Implementation Plan in fiscal year 2021. In addition, NNSA is researching other technologies, including several additive manufacturing techniques, which are further from being ready for deployment.

Similar to funding for direct casting, funding for developing these technologies comes from several sources such as NNSA's Component Manufacturing Development, Uranium Sustainment, Laboratory-Directed Research & Development, and individual nuclear stockpile modernization programs. Funding levels have varied by technology. In fiscal year 2020, NNSA had about $3.5 million in available funds for cold hearth melting activities and $2.3 million for DU additive manufacturing activities. According to NNSA officials, they will further develop the funding needs for those technologies as technology maturation and implementation plans are refined.

NNSA Plans to Extend the Life of and Later Replace Existing DU Manufacturing Facilities

According to agency officials, NNSA plans to continue DU component manufacturing operations in existing Y-12 facilities for 15 years or more, and then replace them. Some facilities in the 9215 complex, which dates from the 1950s, have already benefited from the extended life program for highly enriched uranium associated with the UPF project,[47] but others need upgrades to enable continued use. DU facilities outside the 9215 complex (dating from the 1940s–1970s) will also require ongoing maintenance and upgrades, according to officials at Y-12. According to NNSA officials, Y-12 manages DU facilities' extended lives as part of a

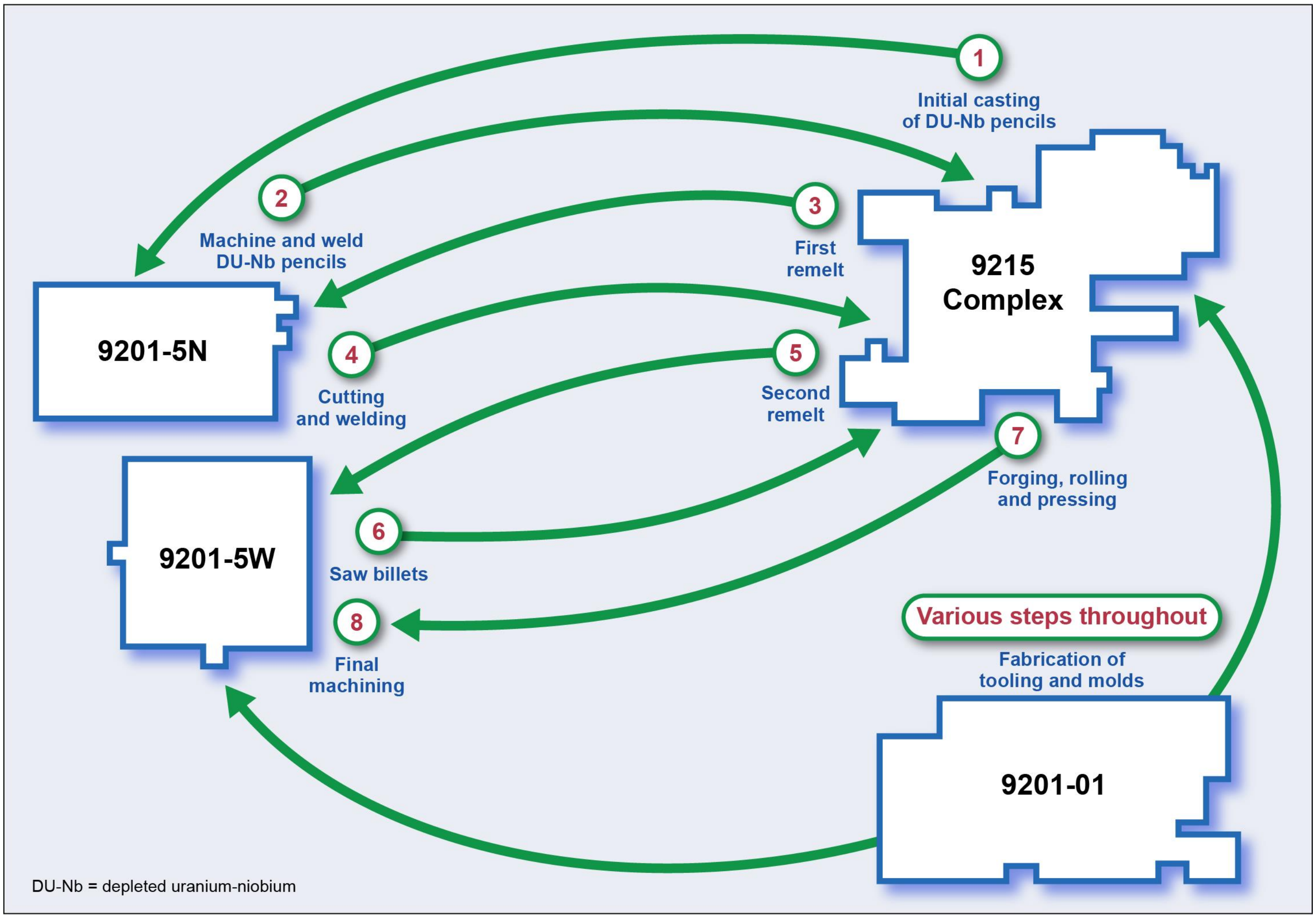
[47]NNSA's Uranium Processing Facility (UPF) project is constructing a new modern facility at Y-12 to replace Building 9212, which houses many key enriched uranium processing operations and dates to the 1940s. For more information on the UPF project, see GAO, *Modernizing the Nuclear Security Enterprise: A Complete Scope of Work Is Needed to Develop Timely Cost and Schedule Information for the Uranium Program,* GAO-17-577 (Washington, D.C.: Sept. 8, 2017), and GAO-20-293.

site-wide plant health effort with funding from the Office of Infrastructure.[48] NNSA will develop the time frames for the DU extended life program as part of the agency's planning for replacement facilities.

NNSA officials said that replacement facilities for DU manufacturing capabilities will be needed by 2040 or sooner, depending on requirements, given the age of current facilities. In addition, according to NNSA officials, the current workflow of DU manufacturing processes across facilities is inefficient, in particular for the DU–niobium alloy process, which requires shuttling material back and forth between buildings several times. DU metallurgical operations at Y-12, such as furnaces and the rolling mill, are currently housed in the 9215 complex; machining takes place in 9201-5N and 9201-5W; and support operations are located in 9201-1. See figure 7 for an example of the workflow at Y-12 for the DU–niobium alloy process.

[48]According to NNSA officials, CNS monitors plant health via the Aging Asset Management Program. This program integrates plant activities to ensure CNS is able to safely and reliably accomplish mission work with aging structures, systems, and equipment. The Aging Asset Management Program provides for the timely detection and mitigation of significant aging and degradation effects on structures, systems, and components important to safety and to operational reliability so as to ensure their integrity and functional capability. Additionally, the program provides prioritization of needed investments. While other programs provide many supporting elements, the Aging Asset Management Program is the overarching approach to managing aging physical assets.

Figure 7: Depleted Uranium–Niobium Alloy Component Process Workflow at Y-12 National Security Complex



Source: GAO analysis of Department of Energy information. | GAO-21-16

The replacement facilities could address the current inefficient layout of processes across facilities. According to NNSA documents, NNSA's concept to replace DU facilities—currently called the Consolidated Manufacturing Capability—could consist of one large central facility, a modular approach of several smaller facilities, or contracting with an off-site vendor. While NNSA and CNS have considered some potential options and alternatives for moving forward with replacement capabilities, they have not begun formal capital asset acquisition planning. According to officials, NNSA has funded a feasibility study in mid–calendar year

2020 to look at options and rough ideas for cost and schedule.[49] Whenever NNSA undertakes this facility replacement project, it will likely be a large capital asset project; the 2020 *Stockpile Stewardship and Management Plan* places the preliminary estimated cost of the project at more than $750 million.

NNSA Plans to Improve DU Program Management

Until recently, NNSA has not managed DU activities as a coherent program in a manner fully consistent with NNSA program management policies. Since October 2019, however, NNSA has taken actions to manage DU activities more consistently with these policies. These actions have included (1) consolidating management and funding of DU activities under a new secondary stage office and DU Modernization program and (2) appointing dedicated Federal Program Managers and increasing staff to work on required program management and planning documents. NNSA officials told us they believe these actions will allow the agency to better manage DU activities.

NNSA Has Not Managed DU Activities as a Coherent Program

Prior to October 2019, NNSA did not manage DU activities as a coherent program in a manner fully consistent with NNSA program management policies. Instead, from 2014 through 2019, NNSA included various DU activities as part of the much larger Uranium Program—a program that was, according to NNSA officials, more focused on the construction at Y-12 of the new $6.5 billion UPF and on related enriched uranium activities.[50] When DU activities were nominally under the Uranium Program, NNSA did not have a dedicated Federal Program Manager to coordinate the efforts of the multiple NNSA and DOE offices and several different contractors involved in DU activities at various locations. NNSA

[49]NNSA officials noted that this feasibility study will not be an Analysis of Alternatives as required by DOE Order 413.3B, but will be used to determine how they should go forward with such an analysis.

[50]In July 2014, NNSA included DU activities in the Uranium Program. The program also includes the construction of a new UPF, modernization of existing facilities for enriching uranium, and investments in related processing technologies.

also did not have a budget dedicated for these activities. For example, as discussed earlier, NNSA funding sources for DU activities in fiscal year 2020 included Uranium Sustainment, Material Recycle and Recovery, Component Manufacturing Development, Stockpile Services, individual nuclear stockpile modernization programs, and others. Although NNSA did develop key planning and program management documents for the Uranium Program—such as a scope of work, integrated master schedule, and life-cycle cost estimate—these key documents did not include a DU scope of work.[51]

Table 1 shows the various programs, offices, and contractors that have a current or planned role in managing, funding, or performing DU activities.

Table 1: Summary of Key Depleted Uranium (DU) Activities and Fiscal Year 2020 Funding

	Activity	Location	Contractor – DOE office	NNSA program and funding sources	Fiscal year 2020 funding (dollars in millions)
DU supply	DU feedstock production[a]	Portsmouth site, Y-12 National Security Complex (Y-12)	Mid-America Conversion Services – Office of Environmental Management (EM), Consolidated Nuclear Security (CNS) – National Nuclear Security Administration (NNSA)	• Material Recycle and Recovery • Uranium Sustainment	14.9
	DU feedstock to metal conversion	Vendor site (to be determined)	To be determined – NNSA contract or CNS subcontract	• NNSA funding planned to start in fiscal year 2022	0
	DU Material Recycle and Recovery operations	Y-12	CNS – NNSA	• Material Recycle and Recovery	0.7
	DU storage capability	Y-12	CNS –NNSA	• Storage	1.7
	DU recycling pilot	Jonesborough, TN	Commercial Vendor —NNSA	• Material Recycle and Recovery • Uranium/Molybdenum	0.6
	Niobium and graphite purchases	Y-12	CNS –NNSA	• Production Support	0.6

[51]Our two most recent reports on NNSA's Uranium Program have noted the importance of key planning and program management documents to effective program management and NNSA's improvement in developing such documents. See GAO-17-577 and GAO-20-293.

	Activity	Location	Contractor – DOE office	NNSA program and funding sources	Fiscal year 2020 funding (dollars in millions)
DU component manufacturing	Restoring/modernizing DU alloy component manufacturing capabilities	Y-12	CNS –NNSA	• Uranium Sustainment • Production Support • Stockpile Services • Material Recycle and Recovery • Plant Directed Research & Development • Individual nuclear stockpile modernization programs	18.7
	Direct casting	Los Alamos National Laboratory (LANL), Lawrence Livermore National Laboratory (LLNL), Y-12	Triad National Security, Lawrence Livermore National Security (LLNS), CNS – NNSA	• Component Manufacturing Development • Laboratory Directed Research & Development • Uranium Sustainment • Stockpile Services • Individual nuclear stockpile modernization Programs	16.9
	Cold hearth melting	LANL, LLNL, Y-12	Triad National Security, LLNS, CNS – NNSA	• Component Manufacturing Development • Laboratory Directed Research & Development • Stockpile Responsiveness Program • Uranium Sustainment	3.5
	Additive manufacturing	LANL, LLNL, Y-12	Triad National Security, LLNS, CNS – NNSA	• Component Manufacturing Development • Stockpile Responsiveness Program • Uranium Sustainment	2.3
	Facility extended life program	Y-12	CNS – NNSA	• Future needs to be determined by Office of Infrastructure	0
	Replacement manufacturing facilities	Y-12	CNS – NNSA	• Future needs to be determined – feasibility study planned for 2020[b]	0

	Activity	Location	Contractor – DOE office	NNSA program and funding sources	Fiscal year 2020 funding (dollars in millions)
DU program management	Staffing and other management activities	NNSA headquarters, Y-12	CNS– NNSA	• Uranium Sustainment • Material Recycle and Recovery	1.6
Total	--	--	--	--	**61.5**

Source: GAO analysis of Department of Energy information. | GAO-21-16

[a]This activity also includes a one-time purchase of DU metal.

[b]NNSA's 2020 Stockpile Stewardship and Management Plan listed the preliminary estimated cost of the project at more than $750 million.

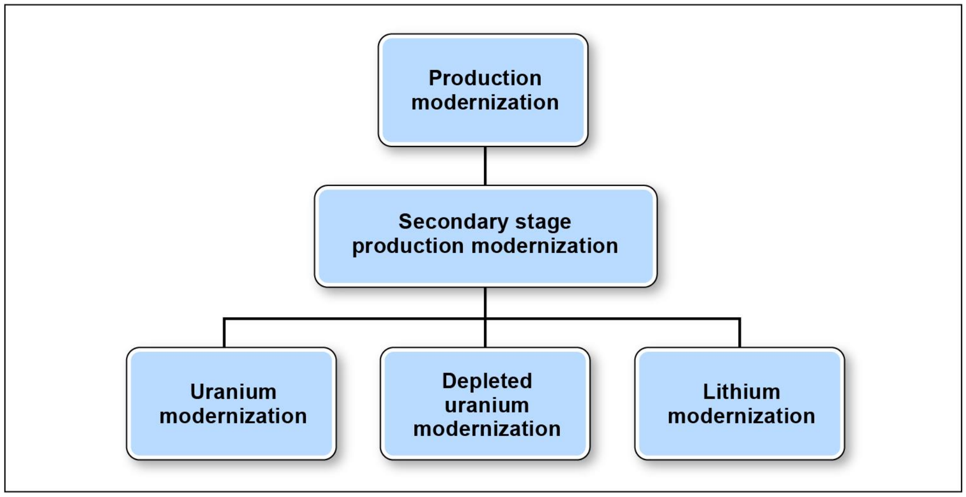
While NNSA spread its management of DU activities across various programs, it was spending millions of dollars, and committing to spend millions more, on DU activities without having the benefit of key program management and planning documents focused on these activities. These shortcomings in program management may have contributed to the DU supply and scheduling issues that present risks to certain current stockpile modernization timelines. NNSA officials told us that this decentralized management of DU activities limited the possibilities for comprehensive and effective oversight of this important program.

NNSA Is Consolidating Management and Funding under a DU Modernization Program with a Dedicated Program Office

NNSA is taking steps to improve the program management of DU activities by consolidating management and most Defense Programs funding under a DU Modernization program and office. The consolidation is part of a broader reorganization of all activities and strategic materials needed to produce the secondary stage of a nuclear weapon. These activities have been consolidated in the newly created Office of Secondary Stage Production Modernization within NNSA's Office of Production Modernization.[52] See figure 8 for the new organization chart.

[52]As noted above, modern nuclear weapons have two stages: the primary, which is the initial source of energy, and the secondary, which is driven by the primary and provides additional explosive energy. The Office of Production Modernization also includes offices for Plutonium, Tritium and Domestic Uranium Enrichment, High Explosives and Energetics, and Non-Nuclear Components.

Figure 8: Organization of NNSA's Office of Secondary Stage Production Modernization



Source: GAO analysis of Department of Energy information. | GAO-21-16

Note: In addition to Secondary Stage Production Modernization, the Office of Production Modernization also includes offices for Plutonium, Tritium and Domestic Uranium Enrichment, High Explosives and Energetics, and Non-Nuclear Components.

According to agency documents, the Office of Secondary Stage Production Modernization seeks to restore and increase manufacturing capabilities for the secondary stage of nuclear weapons by (1) ensuring the availability of strategic materials and subcomponents, (2) modernizing the facilities and operations required to process these materials, and (3) modernizing the facilities and operations required to fabricate and assemble the final components. As part of Secondary Stage Production Modernization,[53] the DU Modernization program consolidates management of DU activities previously performed under multiple programs noted above, such as Uranium Sustainment and Material Recycle and Recovery. With this reorganization, NNSA officials hope to better coordinate DU activities across the nuclear security enterprise and better integrate DU modernization with the related enriched uranium modernization and lithium modernization programs.

NNSA's fiscal year 2021 congressional budget justification includes a new program, project, or activity (PPA) budget element for DU Modernization to match the reorganized program structure and provide greater

[53]The Secondary Stage Production Modernization program is comprised of (1) Uranium Modernization, (2) DU Modernization, and (3) Lithium Modernization.

transparency regarding spending on DU activities.[54] This change consolidates most DU funding requested in fiscal year 2021 into one PPA from several previous PPAs, such as Uranium Sustainment, Stockpile Services, and Material Recycle and Recovery. The appropriations request for NNSA includes $110.9 million for DU Modernization in fiscal year 2021, a substantial increase over the $31.8 million in fiscal year 2020 appropriations provided for DU activities under the previous PPAs.

Even with the consolidation, additional funding for DU activities will continue to come from some research and development accounts and individual nuclear stockpile modernization programs, with NNSA requesting $19.9 million from those in fiscal year 2021, as well as future planned funding from NNSA's Office of Safety, Infrastructure, and Operations. This is in keeping with NNSA's typical approach of funding base capabilities through programs such as DU Modernization and then having individual weapons programs support their own specialized needs from a capability, while facility operations and maintenance remain under Infrastructure and Operations and sites control some research and development funding. Table 2 shows the consolidation and increase in planned funding for DU activities, with combined amounts from all sources more than doubling from about $61.5 million in fiscal year 2020 to $130.8 million in fiscal year 2021.

Table 2: Comparison of Funding for Depleted Uranium Activities, Fiscal Years 2020 and 2021

Dollars in millions

	Fiscal year 2020	Fiscal year 2021
Funding for DU activities consolidated into DU Modernization[a]	31.8	110.9
Funding for DU activities funded by other sources[b]	29.7	19.9
Total	**61.5**	**130.8**

Source: Department of Energy. | GAO-21-16

[a]NNSA's fiscal year 2021 congressional budget request consolidates most DU funding into one "DU Modernization" program, project, or activity (PPA) budget element from several previous PPAs, such as Uranium Sustainment, Stockpile Services, and Material Recycle and Recovery.

[54]A PPA is an element within a budget account. For annually appropriated accounts, such as those for NNSA, the Office of Management and Budget and agencies identify a PPA by reference to committee reports and budget justifications. Program activity structures are intended to provide a meaningful representation of the operations financed by a specific budget account—usually by a project, activity, or organization. GAO, *A Glossary of Terms Used in the Federal Budget Process,* GAO-05-734SP (Washington, D.C.: September 2005).

[b]The other funding sources include Component Manufacturing Development, individual nuclear stockpile modernization programs, Laboratory-Directed Research and Development, and Plant-Directed Research and Development.

According to senior NNSA officials, NNSA anticipates needing another $279.6 million in appropriations for DU Modernization and tens of millions of dollars from other sources for DU activities in fiscal years 2022 through 2025. The reorganization of DU modernization into a distinct, coherent program and the consolidation of Defense Programs funding sources in NNSA's fiscal year 2021 budget request are positive signs of the implementation of NNSA's plans for improved program management of DU activities in future years.

NNSA Has Appointed DU Program Managers and Begun Developing Program Management and Planning Documents

Another important step in improving the management of DU activities, according to agency officials, is the appointment of two dedicated, full-time Federal Program Managers for DU modernization. NNSA hired the managers in late 2019 and early 2020. With the support of contractors at headquarters and Y-12, the managers have begun gathering information to develop planning documents that outline the program's scope, schedule, and cost, including the following:

- **Program Plan**. NNSA documents and officials indicated that the Program Plan will serve as, among other things, a central repository for most of the documentary policy and planning information required by the *Program Execution Instruction*. According to NNSA officials, NNSA has outlined some elements of the Program Plan, such as a scope of work, in other internal documents such as the DU Strategy. The full Program Plan will be completed in 2021, according to NNSA officials.
- **Integrated Master Schedule**. The federal and CNS contractor program staff have begun developing an integrated master schedule, which NNSA officials noted will be their primary management tool because it captures management activities and the work breakdown structure. This schedule currently focuses on the operations needed to produce radiation cases used in the secondary stage of a nuclear weapon and in other production modernization efforts. Officials also said that the schedule will become increasingly comprehensive as the elements of the DU program mature. For example, officials said that the schedule will incorporate details from the conversion line project at the Portsmouth site as those plans develop. The DU Modernization

program plans to have a more comprehensive integrated master schedule by fiscal year 2021.

- **Life-cycle cost estimate**. NNSA officials said that they are gathering cost data from the piecemeal data NNSA has already collected from existing projects, but they do not yet have sufficiently comprehensive data to deploy a full–scale life-cycle cost estimate for the DU scope of work. According to NNSA officials, it is premature to develop a life-cycle cost estimate for the new DU modernization program; they intend to do so once the scope and schedule are further developed.

According to NNSA officials, as the DU program matures, NNSA intends to create other important program planning documents, such as the Risk and Opportunity Management Plan, and develop methods to manage, track, and report performance against scope, cost, and schedule baselines as required in the *Program Execution Instruction*. NNSA officials stated they also intend to address the other reporting requirements in the *Program Execution Instruction* but that, in many cases, it was too early to do so. NNSA officials told us they anticipate having a more complete set of program planning documents by 2021. We will continue to monitor NNSA's progress in developing program planning documents and methods to manage, track, and report performance against scope, cost, and schedule as a part of the reporting provisions directed to us in the Senate committee report accompanying a bill for the National Defense Authorization Act for Fiscal Year 2017.

Agency Comments

We provided a draft of this report to DOE and NNSA for comment. DOE and NNSA provided technical comments, which we incorporated as appropriate.

We are sending copies of this report to the appropriate congressional committees, the Secretary of Energy, the Administrator of the National Nuclear Security Administration, and other interested parties. In addition, the report is available at no charge on the GAO website at http://www.gao.gov.

If you or your staff 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 key contributions to this report are listed in appendix I.

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Appendix I: GAO Contact and Staff Acknowledgments

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In addition to the individual mentioned above, Jonathan Gill (Assistant Director), Ryan Gottschall (Analyst in Charge), Kevin Bray, William Bauder, Penney Harwell Caramia, Katrina Pekar-Carpenter, Juana Collymore, Cindy Gilbert, Cynthia Norris, Sophia Payind, William Reinsberg, Dan Royer, and Kevin Tarmann made key contributions to this report.

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