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August 2021

NUCLEAR WEAPONS

Actions Needed to Improve Management of NNSA's Lithium Activities

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GAO-21-244

GAO Highlights

Highlights of GAO-21-244, a report to the Committee on Armed Services, U.S. Senate

August 2021

NUCLEAR WEAPONS

Actions Needed to Improve Management of NNSA's Lithium Activities

Why GAO Did This Study

Since the 1940s, the nation's supply of lithium used in some nuclear weapons components has been processed at NNSA's Y-12 site. However, due to deteriorating facilities and equipment and the need to reestablish dormant processing capabilities, NNSA faces risks in meeting future lithium demand. To address these challenges, NNSA has developed a strategy to meet lithium demand until the 2030s, by which time it expects the new LPF will be fully operational.

The Senate committee report accompanying the National Defense Authorization Act for Fiscal Year 2020 includes a provision for GAO to examine NNSA's lithium programs and projects. GAO's report examines, among other things, (1) the status of current cost and schedule estimates and design activities for NNSA's LPF project and (2) the extent to which NNSA has developed management tools for the lithium program that are consistent with best practices.

GAO reviewed NNSA and contractor documentation, compared NNSA's efforts against agency requirements and best practices, and interviewed NNSA officials and Y-12 contractor representatives.

What GAO Recommends

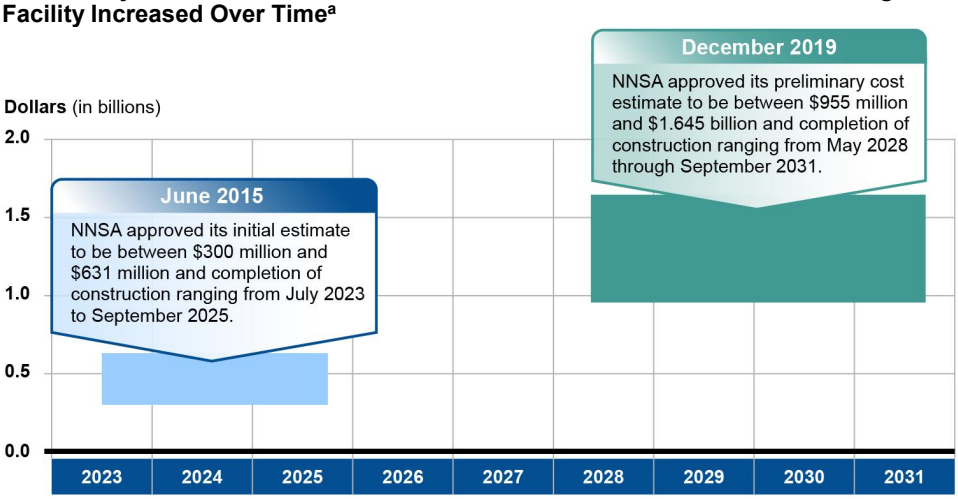
GAO is making seven recommendations, including that NNSA should ensure important data are collected for future technology assessments and align the program schedule with the scope of work. NNSA agreed with five and agreed in principle with two recommendations, noting actions taken. GAO believes NNSA needs to take additional actions, as discussed in the report.

View GAO-21-244. For more information, contact Allison Bawden at (202) 512-3841 or bawdena@gao.gov.

What GAO Found

In December 2019, the National Nuclear Security Administration (NNSA) preliminarily estimated construction would cost between $955 million and $1.645 billion for a new lithium processing facility (LPF) at the Y-12 National Security Complex (Y-12) in Tennessee and would be completed between May 2028 and September 2031. This is a substantial increase in cost and schedule; in 2015, NNSA initially estimated that a new facility would cost between $300 and $631 million and could be completed between 2023 and 2025. One reason for the cost and schedule changes is increased facility size, as reflected in a more mature design. GAO's evaluation of the LPF's preliminary cost estimate found it to be substantially comprehensive. NNSA also plans to include a new technology in the facility design based on its most recent technology assessment. In this assessment, NNSA did not collect certain data needed to fully evaluate the lithium produced with the technology. GAO best practices recommend agencies ensure all necessary evidence is collected when assessing the maturity of a new technology. Otherwise, NNSA faces some risks to ensuring the technology is ready to start construction in 2024 and could face future delays to the LPF if testing reveals unexpected problems with lithium produced with this technology.

Preliminary Cost and Schedule Estimates for NNSA's New Lithium Processing Facility Increased Over Time[a]



Source: GAO analysis of National Nuclear Security Administration (NNSA) documents. | GAO-21-244

Text of Preliminary Cost and Schedule Estimates for NNSA's New Lithium Processing Facility Increased Over Time[a]

- June 2015: NNSA approved its initial estimate to be between $300 million and $631 million and completion of construction ranging from July 2023 to September 2025.
- Dec. 2019: NNSA approved its preliminary cost estimate to be between $955 million and $1.645 billion and completion of construction ranging from May 2028 through September 2031.

[a]NNSA's estimates are reported as actual dollars and were not adjusted for inflation.

Source: GAO analysis of National Nuclear Security Administration (NNSA) documents. | GAO-21-244

Important program management tools that NNSA could use to help ensure that the agency meets lithium demand are under development and are not consistent with best practices. For example, the lithium program's current schedule and scope of work—as expressed in a work breakdown structure—do not track the same program activities. According to GAO best practices, a program's schedule should be aligned with its work breakdown structure to ensure that activities are completed on time. By aligning these management tools, NNSA could help ensure that the comprehensive scope of work for the program is reflected in the schedule and that NNSA is accomplishing all program activities on time.

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Abbreviations

CD	critical decision
COLEX	column exchange process
COVID-19	Coronavirus Disease 2019
CSA	canned subassemblies
DMM	direct materials manufacturing
DOE	Department of Energy
DOE-PM	DOE Office of Project Management
LPF	lithium processing facility
M&O	management and operating
NNSA	National Nuclear Security Administration
TRA	technology readiness assessment
TRL	Technology Readiness Level
Y-12	Y-12 National Security Complex

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August 12, 2021

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

The National Nuclear Security Administration (NNSA) is responsible for providing the nation's supply of lithium for use in some nuclear weapon components but its ongoing capability to do so currently depends on deteriorating infrastructure.[1] Since the 1940s, lithium needed for the nation's nuclear weapons stockpile has been processed at the Y-12 National Security Complex (Y-12) in Oak Ridge, Tennessee.[2] From 1954 through 1963, Y-12 used a process to enrich natural lithium for use in weapons that required large quantities of mercury, a toxic metal, which resulted in worker exposure and environmental contamination that is still being remediated. Since discontinuing this process, the site no longer has the capability to enrich natural lithium to the concentrations of lithium-6 needed for ongoing and planned life extension and modernization programs.[3] Instead, NNSA recovers lithium from retired, disassembled weapons and cleans it for reuse in nuclear weapons that NNSA is modernizing or replacing. This approach is possible because today's nuclear weapons stockpile is smaller than it was decades ago, making lithium and other strategic materials available for reuse.

[1]NNSA is a separately organized agency within the Department of Energy (DOE) and is responsible for enhancing national security through the military application of nuclear energy, maintaining and modernizing infrastructure for the U.S. nuclear weapons stockpile, and supporting the nation's nuclear nonproliferation efforts.

[2]Y-12 is a contractor-managed and -operated site that has been overseen by NNSA and its predecessor organizations.

[3]The isotope lithium-6 is a key element used in components of nuclear weapons and is therefore essential for the modernization of the nuclear weapons stockpile. Isotopes are varieties of a given chemical element with the same number of protons but different numbers of neutrons. Natural lithium consists of approximately 7.6 percent of the isotope lithium-6 and 92.4 percent of the isotope lithium-7. Hereafter, "lithium" refers to material with an enriched lithium-6 concentration, which makes it suitable for use in weapons. The forms of lithium used at Y-12 are different in isotopic and chemical composition from forms of lithium used more broadly in industry, such as lithium-ion batteries.

Currently, when NNSA recovers lithium from retired, disassembled weapons, NNSA processes it using a physical cleaning method known as direct materials manufacturing (DMM), which involves sanding the lithium to remove surface impurities. However, DMM cannot be used to clean the entirety of NNSA's existing inventory of lithium material taken from retired and disassembled weapons and meet weapons specifications. NNSA had also used a process to chemically purify recovered lithium, known as wet chemistry, which produces lithium chloride that is then converted into lithium hydride or lithium deuteride usable for weapons.[4] This wet chemistry process also allowed NNSA to reuse lithium from waste streams that cannot be processed for reuse using DMM.

However, in May 2013, NNSA decided to suspend the use of wet chemistry at Y-12 because of deteriorating conditions in the nearly 80-year-old lithium production facility where this process took place.[5] Specifically, the building has both internal and external deterioration of concrete in the roofs, walls, and ceilings—in part from exposure to corrosive liquids and processing fumes from the wet chemistry process—and is well beyond its expected lifespan. Since that time, Y-12 has relied solely on physically cleaning lithium from disassembled weapons using DMM, but this process cannot convert its existing inventory of lithium chloride into lithium usable for refurbished weapons.

NNSA determined in May 2017, through an analysis of alternatives process, that a new lithium processing facility (LPF) should be constructed at Y-12 to replace its deteriorated production facility and support the infrastructure and equipment for lithium production

[4]Hereafter, "wet chemistry" refers to a three-step process of lithium purification, lithium production using electrolysis, and then conversion into lithium hydride or lithium deuteride. Lithium components and parts for nuclear weapons are made from both lithium hydride and lithium deuteride, which are created by treating lithium material with hydrogen gas or deuterium gas, respectively. Nuclear weapons may contain parts with either lithium hydride or lithium deuteride.

[5]While wet chemistry operations have been suspended in the facility (building 9204-2), Y-12 continues to perform other operations in areas of that facility that are less deteriorated.

processes.[6] In December 2019, NNSA completed the project definition phase for acquiring the LPF. In doing so, it officially approved construction of a new facility as the preferred alternative, with the expectation that the new facility would start operations in the 2030s. NNSA's Office of Acquisition and Project Management will be responsible for managing construction of the LPF to meet long-term lithium demand.

Until NNSA can move lithium production to the new LPF, it must continue to provide lithium in the near term to meet increased demand from ongoing and planned nuclear weapons' life extension and modernization programs.[7] NNSA determined that DMM alone cannot provide enough lithium to meet demand beyond 2022 and, as a result, the agency will need to reestablish a small-scale wet chemistry capability at Y-12 to achieve lithium quantities consistent with its lithium supply and demand models.[8]

In 2019, NNSA established the Lithium Modernization program, which is responsible for planning and executing a strategy for meeting near-term lithium demand until the LPF is operational and ultimately for ensuring that the LPF will meet long-term programmatic requirements. As such, the Lithium Modernization program is responsible for coordinating with the Office of Acquisition and Project Management.

[6]We previously reported in July 2015 that NNSA did not develop a mission need statement—as required by DOE's Order for the Acquisition of Capital Assets (DOE Order 413.3B), that is fully independent of a particular solution—for developing a new lithium facility. We recommended that NNSA objectively consider all alternatives to meet its mission need, without preference for a particular solution, as it proceeded with its analysis of alternatives process. GAO*, DOE Project Management: NNSA Should Ensure Equal Consideration of Alternatives for Lithium Production,* GAO-15-525 (Washington, D.C.: July 13, 2015). In January 2017, NNSA addressed our recommendation and completed its analysis of alternatives. Based on the analysis, NNSA found that the most viable alternatives for lithium production were to build a new facility at Y-12 or buy and refurbish an off-site facility near Y-12. In May 2017, NNSA decided to move forward with planning for a new facility because there was not a suitable existing facility near Y-12 to refurbish.

[7]Ongoing stockpile modernization programs include the W88 Alteration 370, the B61-12 life extension program, the W80-4 life extension program, and the W87-1 modification program. A "W" at the beginning of these program names indicates that the program relates to a nuclear warhead, while a "B" indicates that the program relates to a nuclear bomb.

[8]NNSA produces lithium supply and demand models that are based on the existing program of record for stockpile modernization. These lithium supply and demand models are classified.

NNSA's efforts to meet future lithium demand come as the agency is experiencing its busiest time since the Cold War era. Over the next 2 decades, NNSA and the Department of Defense plan to spend hundreds of billions of dollars to simultaneously modernize the nation's nuclear weapons stockpile and the supporting infrastructure on which weapons programs depend. However, in March 2020 and May 2021, we stated that NNSA may face challenges in doing so because any delays or technical challenges that affect NNSA's plans for its production facilities, including the LPF, may result in delays and challenges for the weapons programs.[9]

The Senate committee report accompanying the National Defense Authorization Act for Fiscal Year 2020 included a provision for GAO to review NNSA's planning and assumptions for the Lithium Modernization program and the LPF project.[10] Our report examines (1) the current cost and schedule estimates for NNSA's LPF project and the status of design activities; (2) NNSA's near-term strategy to meet demand for lithium until the LPF is operational and address any risks NNSA faces in implementing the strategy; and (3) the extent to which NNSA has developed management tools for the Lithium Modernization program, consistent with best practices.

To examine the current cost and schedule estimates for NNSA's LPF project and the status of design activities, we reviewed documents, policies, and guides from NNSA and the Department of Energy (DOE) on the critical decision process, capital asset acquisition management, and technology readiness assessments.[11] We reviewed DOE's project status reports from fiscal years 2020 and 2021—the most recent available at the time of our review—for specific cost and schedule information for the LPF

[9]GAO, *Nuclear Weapons: NNSA's Modernization Efforts Would Benefit from a Portfolio Management Approach,* GAO-20-443T (Washington, D.C.: Mar. 3, 2020); and *Nuclear Triad: DOD and DOE Face Challenges Mitigating Risks to U.S. Deterrence Efforts*, GAO-21-210 (Washington, D.C.: May 6, 2021).

[10]S. Rep. No. 116-48, at 388 (2019). The Senate committee report provision was for GAO to review the planning and assumptions for the Lithium Sustainment program, which NNSA renamed the Lithium Modernization program, and the lithium production capability project, which NNSA renamed the LPF project.

[11]Department of Energy, *Program and Project Management for the Acquisition of Capital Assets*, DOE Order 413.3B (Washington, D.C.: Nov. 29, 2010; updated Apr. 12, 2018); and *Technology Readiness Assessment Guide,* DOE Guide 413.3-04A (Oct. 22, 2015); National Nuclear Security Administration, *Technology Readiness Assessments*, NAP-413.4 (Washington, D.C.: Dec. 22, 2016): and *Defense Programs Technology Readiness Assessment Implementation Guide, Revision 3.1*, (Washington, D.C.: Dec. 3, 2018).

project. We compared NNSA's preliminary LPF cost estimate (approved in December 2019) with best practices in our *Cost Estimating and Assessment Guide*.[12] We also reviewed documentation and interviewed DOE and NNSA officials regarding their independent reviews of the LPF cost and schedule estimates. We did not perform a similar assessment of NNSA's preliminary schedule estimate for the LPF project because of the maturity of the schedule at the time of our review.[13] We compared NNSA's April 2020 technology readiness assessment and its June 2020 technology maturation plan used to inform NNSA's LPF design with best practices in our *Technology Readiness Assessment Guide*.[14] We interviewed NNSA officials who oversee certain construction projects at Y-12 and representatives from the management and operating (M&O) contractor for the site to learn about the LPF project status and NNSA's plans for completing the facility design and maturing new technology for the LPF.

To examine NNSA's near-term strategy to meet demand for lithium until the LPF is operational and address any risks NNSA faces in implementing the strategy, we reviewed strategy documents, status reports, and implementation plans from NNSA and the M&O contractor for Y-12. We collected and reviewed photographs of infrastructure and equipment used to process lithium at Y-12.[15] We conducted interviews with Y-12 contractor representatives who manage lithium operations; with

[12]According to our *Cost Estimating and Assessment Guide,* a cost estimate is considered reliable if it meets all four characteristics of the best practices: comprehensive, well documented, accurate, and credible. Based on the maturity of the preliminary cost estimate approved in December 2019, we compared the estimate with one of the four characteristics: comprehensive. GAO, *Cost Estimating and Assessment Guide: Best Practices for Developing and Managing Program Costs*, GAO-20-195G (Washington, D.C.: Mar. 12, 2020). NNSA plans to produce an updated cost estimate for the LPF project when it approves the project's performance baseline at the next critical decision milestone.

[13]We reviewed the Lithium Modernization program's integrated master schedule, which includes high-level project milestones for the LPF.

[14]GAO, *Technology Readiness Assessment Guide: Best Practices for Evaluating the Readiness of Technology for Use in Acquisition Programs and Projects [Reissued with revisions on Feb. 11, 2020.],* GAO-20-48G (Washington, D.C.: Jan. 7, 2020).

[15] We planned to conduct a site visit to Y-12 to observe the condition of the existing lithium production facilities; however, we were unable to do so because of travel restrictions in place due to the effects of Coronavirus Disease 2019 (COVID-19). On March 11, 2020, the World Health Organization declared COVID-19 a pandemic. NNSA delayed some work on lithium operations due to limited availability of staff to work as a result of COVID-19 safety measures implemented at Y-12.

NNSA officials from the NNSA Production Office, including the federal field office co-located with Y-12, and the Lithium Modernization program; and officials from the NNSA offices that provide funding for lithium activities not directly funded by the program.

To examine the extent to which NNSA has developed management tools for the Lithium Modernization program, consistent with best practices, we reviewed the agency's program planning and management documents for the Lithium Modernization program. We compared the Defense Programs' *Program Execution Instruction* with common financial reporting requirements in the National Defense Authorization Act for Fiscal Year 2017.[16] We also reviewed the Lithium Modernization program's scope of work, including the first iteration of the work breakdown structure from April 2020 and the revised structure from November 2020. We reviewed NNSA's program planning and management documents for the newly created Lithium Modernization program and our *Schedule Assessment* and *Cost Estimating and Assessment* guides. We compared both of the work breakdown structures with the Lithium Modernization program's integrated master schedule to determine the extent to which the two tools aligned.[17] We interviewed NNSA officials responsible for lithium activities and program management regarding the development of key program management tools. See appendix I for additional information on our objectives, scope, and methodology.

We conducted this performance audit from January 2020 to August 2021 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.

[16]National Nuclear Security Administration, *Office of Defense Programs DP Program Execution Instruction*, (Washington, D.C.: June 19, 2019); Pub. L. No. 114-328, § 3113(b)(2), 130 Stat. 2000, 2757 (2016).

[17]GAO-16-89G and GAO-20-195G. As noted in those guides and previous GAO reporting, developing a proper scope of work, integrated master schedule, and life-cycle cost estimate increases the probability of program success.

Background

Nuclear Stockpile Modernization

The United States is in the midst of a long-term effort to modernize its nuclear security enterprise.[18] 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. As part of its responsibility to ensure a safe, secure, and reliable nuclear deterrent, NNSA undertakes nuclear stockpile modernization programs, in coordination with the Department of Defense. Over the next 2 decades, NNSA and the Department of Defense 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.[19]

NNSA relies on M&O contractors to carry out these modernization programs and to manage the day-to-day operations at eight sites.[20] NNSA's primary site with the capability to process lithium material is Y-12. Y-12's primary role in supporting the modernization of the nuclear weapons stockpile is the refurbishment and manufacture of secondary

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

[19]These programs 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. 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.

[20]M&O contracts are agreements under which the government contracts for the operation, maintenance, or support, on its behalf, of a government-owned or -controlled research, development, special production, or testing establishment wholly or principally devoted to one or more of the major programs of the contracting agency. 48 C.F.R. § 17.601. In addition to Y-12, the sites that comprise the nuclear security enterprise are the Kansas City National Security Campus in Missouri; the Pantex Plant in Texas; Lawrence Livermore National Laboratory in California; Los Alamos National Laboratory in New Mexico; Nevada National Security Site; Sandia National Laboratories in New Mexico and California; and the Savannah River Site in South Carolina.

stages of nuclear weapons and related components, generally known as canned subassemblies (CSA). These components may include enriched uranium, depleted uranium, and lithium materials. Y-12 is also responsible for taking apart CSAs from weapons dismantled at the Pantex Plant in Texas; these CSAs contain lithium material that is the source material to produce lithium for refurbished or modernized nuclear weapons.[21]

Information about Lithium and Methods for Its Production

The isotope lithium-6 is used to produce key components of nuclear weapons and is essential for the modernization of the nuclear weapons stockpile.[22] Natural lithium consists of approximately 7.6 percent of the isotope lithium-6 and 92.4 percent of the isotope lithium-7. From 1954 through 1963, Y-12 separated—or enriched—lithium-6 from lithium-7 using a column exchange (COLEX) process that required large quantities of mercury.[23] The COLEX process resulted in worker exposure to mercury and environmental contamination, which continues to be a significant issue at Y-12 and caused NNSA to discontinue its lithium enrichment efforts.[24]

[21]The Pantex Plant dismantles retired nuclear weapons and sends CSAs back to Y-12 for further dismantlement, material recovery, or refurbishment. The Pantex Plant also assembles modernized weapons, including new or refurbished components and CSAs produced at Y-12. The NNSA Production Office is the federal field office that oversees both sites.

[22]Isotopes are varieties of a given chemical element with the same number of protons but different numbers of neutrons. For example, the helium-3 isotope, which is used in research and to detect neutrons in radiation detection equipment, has one less neutron than the helium-4 isotope, which is the helium isotope commonly used in party balloons.

[23]The COLEX process separated the two lithium isotopes by using natural lithium dissolved in mercury and other chemicals. Lithium-6 is more attracted to the mercury than lithium-7, and lithium-7 is more attracted to the other chemicals, which separates the two isotopes. The result is a material with a greater percentage of lithium-6 than natural lithium—enriched ilithium-6—that can be used for weapons.

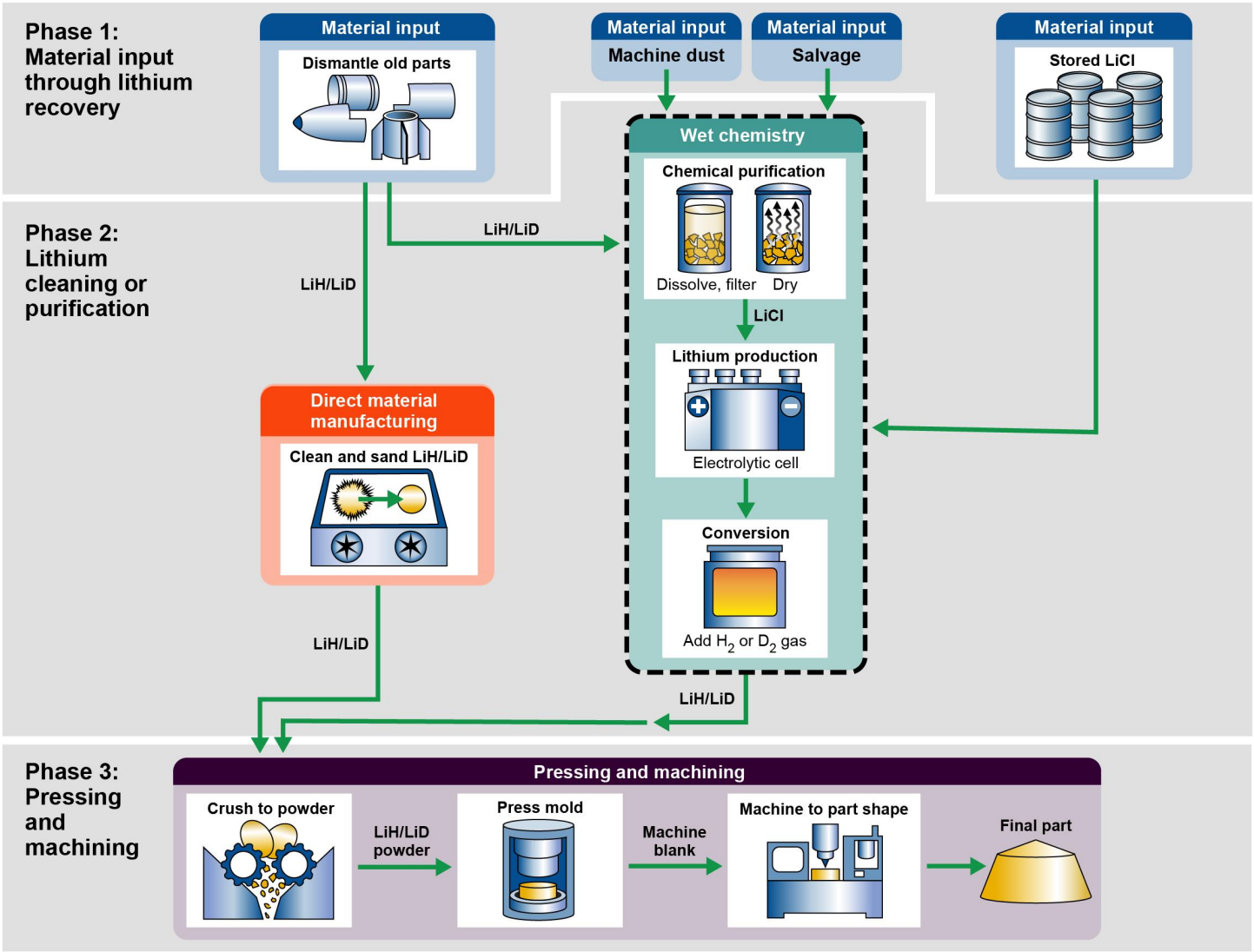
[24]DOE's Office of Environmental Management, along with the Tennessee Office of Environment and Conservation and the U.S. Environmental Protection Agency, identified mercury contamination at Y-12 as the greatest environmental risk on the Oak Ridge Reservation, which includes Y-12 and the Oak Ridge National Laboratory. DOE, *Strategic Plan for Mercury Remediation at the Y-12 National Security Complex,* DOE/OR/01-2605&D2/R1 (Oak Ridge, TN: September 2017).

Because NNSA no longer maintains the capability to enrich lithium, the agency's supply comes from recovering lithium from retired weapons that have been disassembled and, currently, cleaning it through DMM to remove surface impurities for reuse. As discussed above, NNSA has identified that it needs more lithium than it can supply through DMM alone to meet stockpile requirements. As a result, NNSA needs to reestablish a wet chemistry capability to increase lithium supply by chemically purifying and further converting recovered lithium that is not acceptable for use through the DMM process.[25] Together, we refer to these efforts—along with the ultimate production of lithium nuclear weapons parts—as the lithium production process. NNSA's lithium production process can be broken down into three phases, each of which has multiple steps that require specialized equipment and a humidity-controlled environment (see fig. 1 for a simplified depiction of the process). The process creates nuclear weapons parts from both lithium hydride and lithium deuteride.

[25]Wet chemistry allows NNSA to use recycled inputs such as lithium machine dust. DMM does not allow NNSA to recycle other material inputs, including machine dust, or to create other types of lithium.

Figure 1: Simplified Depiction of the National Nuclear Security Administration's (NNSA) Lithium Production Process

NNSA recovers lithium from retired, disassembled weapons for use in ongoing and planned weapons life extension and modernization programs.



NNSA suspended the use of wet chemistry in 2013 and is working to reestablish the capability in 2022

D_2 deuterium gas
H_2 hydrogen gas
LiCl lithium chloride
LiD lithium deuteride
LiH lithium hydride

Source: GAO adaptation of NNSA graphic. | GAO-21-244

Note: In May 2013, the Y-12 National Security Complex suspended the use of wet chemistry to purify lithium. NNSA plans to reestablish wet chemistry on a small scale in 2022 using the same historic process in a different facility.

- **Phase 1: Material input through lithium recovery.** Y-12 mainly recovers lithium hydride and lithium deuteride from disassembled CSAs it receives from the Pantex Plant. Other material inputs include machine dust, which is recovered during the machine to part shape step, and salvaged lithium, which is recovered throughout the lithium production process. NNSA also stored lithium chloride, created before wet chemistry was suspended in 2013, that may be processed once wet chemistry is reestablished.
- **Phase 2: Lithium cleaning or purification.** Y-12's current lithium cleaning process uses DMM, which involves physically sanding the lithium hydride and lithium deuteride removed from the disassembled weapons to remove surface impurities. Historically, Y-12's purification process relied on wet chemistry. Using wet chemistry, Y-12 purified the lithium hydride and lithium deuteride recovered from disassembled weapons using a combination of chemicals, including hydrochloric acid and stages of filtering. Wet chemistry can also be used to process other material inputs, including machine dust, salvage, and lithium chloride.[26] Once lithium material has been cleaned using DMM, or purified using wet chemistry, the material becomes feedstock for the pressing and machining steps of the process.
- **Phase 3: Pressing and machining.** To prepare the DMM-cleaned or wet chemistry-purified lithium material for use in weapons parts (see fig. 2 for an example of lithium material), the lithium hydride or lithium deuteride material is broken into pieces and fed into a crusher and grinder to pulverize it into a powder that is then blended and loaded into molds for pressing. The resulting blanks are machined into high-precision parts.

[26]Throughout the lithium production process, NNSA collects lithium machine dust and lithium salvage—chemically impure lithium material left behind in lithium processing equipment and tools. Without a wet chemistry capability, Y-12 stores machine dust and lithium salvage for future purification.

Figure 2: Lithium Feedstock Before Crushing into Powder and Machining to Produce Nuclear Weapons Parts

Source: National Nuclear Security Administration. | GAO-21-244

Lithium parts must be qualified for use in weapons through a process approved by the Los Alamos and Lawrence Livermore National Laboratories, as the design laboratories for nuclear weapons.[27] Both national laboratories coordinate to perform the qualification process based on jointly issued material specifications, according to representatives from Los Alamos and Lawrence Livermore National Laboratories, but each design laboratory is responsible for qualifying

[27]Wet chemistry produced a homogeneous feedstock that only had to be evaluated once for use in a given weapon system in production, regardless of the source material. DMM feedstock, however, is not necessarily homogeneous and the source material, which may contain impurities, must be evaluated separately for each weapon system in production.

lithium parts used for their respective weapon modernization programs.[28] Qualification of lithium parts involves testing for chemical and mechanical homogeneity, density, and tensile properties, among other things. Although only the final lithium weapon part must be qualified, Y-12 prepares for qualification by collecting data on the lithium material to verify it meets specifications throughout the production process.

Condition of Lithium Infrastructure at Y-12

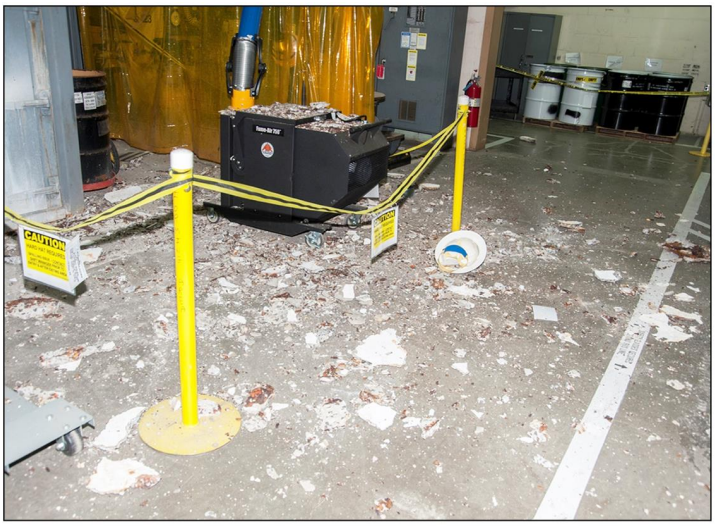
At Y-12, NNSA's lithium production process primarily occurs in two main buildings (buildings 9204-2 and 9202), both of which were constructed in the 1940s during the Manhattan Project. Building 9204-2 houses the equipment for the suspended wet chemistry process and the lithium pressing and machining (see fig. 3 for photographs of the building). Building 9202 supports lithium production in research and development and contains equipment for the lithium parts cleaning station used for DMM and the purification step of the small-scale wet chemistry process.[29] Thirteen other buildings provide support for NNSA's lithium production process, including for disassembling lithium components, and storing lithium materials and molds for weapons parts. For more information about the condition of these buildings and Y-12's plans to replace these capabilities in addition to the LPF project, see appendix II.

[28]Los Alamos National Laboratory is the design laboratory for the W88 alteration 370, scheduled to enter production in the 2021 and the B61-12 Life Extension Program that is scheduled to enter production in fiscal year 2022. Lawrence Livermore National Laboratory is the design laboratory for the W80-4 Life Extension Program that is scheduled to enter production in 2025 and the W87-1 modification program that is scheduled to enter production in fiscal year 2030. National Nuclear Security Administration, *Fiscal Year 2021 Stockpile Stewardship and Management Plan* (Washington, D.C.: Dec. 2020).

[29]Building 9202 is not solely used to support lithium operations.

Figure 3: Building 9204-2 at the Y-12 National Security Complex, Used for Lithium Processing

The National Nuclear Security Administration used to chemically purify lithium from retired, disassembled weapons here but discontinued that process because of deteriorating conditions in the building.



Interior view.

Sky view.

Source: National Nuclear Security Administration. | GAO-21-244

Note: Interior view shows where a 300 pound slab of concrete from the ceiling of the building collapsed in March 2014.

Lithium Project and Program Management

Two NNSA offices have primary responsibility for NNSA's lithium capability. First, NNSA's Office of Acquisition and Project Management, through its Y-12 Acquisition and Project Management Office, is responsible for managing the LPF construction project—a capital asset acquisition—under the direction of a federal project director.[30] The Y-12 Acquisition and Project Management Office is responsible for managing the project execution, developing and administering the acquisition strategy, and procurement to meet the mission requirements established by the Office of Defense Programs. The Office of Defense Programs is the second office with primary responsibility for NNSA's lithium capability.

[30]Under DOE Order 413.3B, NNSA's Office of Acquisition and Project Management is responsible for managing capital asset acquisition projects.

Second, the Office of Defense Programs established the Lithium Modernization program in fiscal year 2019.[31] According to NNSA documents and officials, the program's goal is to ensure a sufficient supply of lithium material is available by (1) establishing mission requirements for the new LPF (to be constructed by NNSA's Office of Acquisition and Project Management) to meet long-term demand, and ensuring the LPF meets mission requirements once construction is complete; (2) implementing plans to meet near-term lithium demand until the LPF is operational; and (3) coordinating with other NNSA offices—such as the Office of Safety, Infrastructure, and Operations—to sustain and recapitalize facilities and infrastructure needed to implement the near-term strategy and to maintain lithium support activities that are outside of the scope of the LPF project.[32] Since 2019, NNSA's Lithium Modernization program has been under the direction of a federal program manager.

For capital asset projects with a total project cost greater than $50 million, such as the LPF, NNSA is required to manage the construction in accordance with DOE Order 413.3B.[33] This order requires capital asset projects to go through five management reviews and approvals, called "critical decisions" (CD), as the projects move from planning and design

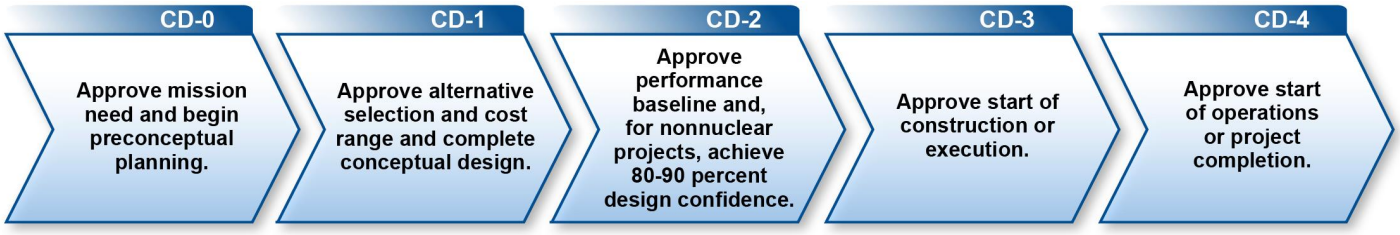
[31]The Lithium Modernization program is a sub office within NNSA's Office of Defense Programs' Office of Secondary Stage Production Modernization, which manages all materials associated with secondary capabilities and CSAs, and which may include lithium, enriched uranium, and depleted uranium. We previously reported on NNSA's programs for managing strategic materials, including lithium, in November 2017 and found that of the strategic materials programs, lithium had made the least amount of progress for implementing program requirements. Specifically, at the time of the report, NNSA had developed a mission strategy, a mission requirements matrix, and a technology development plan for its lithium activities but had not appointed a federal program manager. We made a recommendation to NNSA for it to identify the critical skills and competencies that will be needed for the strategic materials programs and use this determination to develop strategies for addressing challenges, if any, related to the number, deployment, and alignment of program staff. NNSA has since addressed this recommendation by increasing federal staff and appointing a lithium federal program manager. GAO, *Nuclear Weapons: NNSA Needs to Determine Critical Skills and Competencies for Its Strategic Materials Programs,* GAO-18-99 (Washington, D.C.: Nov. 14, 2017).

[32]NNSA's Office of Safety, Infrastructure, and Operations manages infrastructure sustainment efforts through recapitalization and conducts concrete deterioration monitoring activities, among other things. Infrastructure and equipment sustainment efforts are also supported through the maintenance and repair program, and other sources.

[33]Department of Energy*, Program and Project Management for the Acquisition of Capital Assets*.

to construction and operation (see fig. 4). In June 2015, NNSA approved its statement of mission need for providing new lithium production capabilities, the approval of which marks the end of the first phase—preconceptual planning (CD-0)—of its capital asset acquisition process.[34]

Figure 4: Summary of the Department of Energy's (DOE) Critical Decision (CD) Phases and Milestones



Source: GAO analysis of DOE Order 413.3B. | GAO-21-244

Text of Figure 4: Summary of the Department of Energy's (DOE) Critical Decision (CD) Phases and Milestones

- CD-O: Approve mission need and begin preconceptual planning.
- CD-1: Approve alternative selection and cost range and complete conceptual design.
- CD-2: Approve performance baseline and, for nonnuclear projects, achieve 80-90 percent design confidence.
- CD-3: Approve start of construction or execution.
- CD-4: Approve start of operations or project completion.

Note: The alternative selection process involves defining, analyzing, and refining project concepts and alternatives. At the end of CD-1, the project team selects, and DOE approves, the selected approach for the project. The cost range developed at CD-1 is the preliminary cost estimate for the selected approach and is refined through the other steps in the CD process.

Source: GAO analysis of DOE Order 413.3B. | GAO-21-244

[34]We reported in July 2015 on the status of NNSA's plans to construct a new lithium facility and found that NNSA did not develop for this proposed project a statement of mission need independent of a particular solution, contrary to the DOE Order on capital asset acquisition projects. We recommended that NNSA take steps to objectively consider all alternatives, without preference for a particular solution. GAO, *DOE Project Management: NNSA Should Ensure Equal Consideration of Alternatives for Lithium Production*, GAO-15-525 (Washington, D.C.: July 13, 2015). In 2017, NNSA addressed our recommendation to complete an analysis of alternatives and decided that building a new facility at Y-12 was the preferred alternative.

NNSA programs, including the Lithium Modernization program, are managed under NNSA's program management policy,[35] which provides specific requirements and controls for conducting program management. NNSA's programs are also managed under NNSA's financial integration policy,[36] which defines the policy for programs to follow for meeting enterprise-wide standards of cost collection and to improve transparency of financial information and consistent reporting.[37] NNSA's Office of Defense Programs has issued further guidance, the *Program Execution Instruction*, to implement DOE and NNSA policies for managing its programs. As a program within the Office of Defense Programs, the Lithium Modernization program is subject to this instruction.

While some capital asset acquisition projects are required to follow certain best practices for cost and schedule that are included in our *Cost Estimating and Assessment* and *Schedule Assessment* guides, NNSA programs may follow these best practices, tailoring them to programs' levels of risk.[38] For example, NNSA's program management policy states that programs must consider the use of GAO best practices. These guides and our previous reporting highlight the importance of outlining the scope, schedule, and cost of all programs.[39] Important program management tools highlighted by the guides include

- a **work breakdown structure**, a hierarchical structure that captures the complete scope of work and divides a program's end product into smaller elements suitable for management control;
- an **integrated master schedule**, integrating a complete scope of work reflected in the work breakdown structure, the resources

[35]National Nuclear Security Administration, *Program Management Policy*, NAP-413.2 (Washington, D.C.: Feb. 4, 2019).

[36]National Nuclear Security Administration, *Financial Integration*, NAP-412.1 (Washington, D.C.: Feb. 11, 2019).

[37]As part of its efforts to improve its enterprise-wide financial reporting and program management, NNSA established a common work breakdown structure, as required by the National Defense Authorization Act for Fiscal Year 2017. NNSA's Office of Management and Budget manages the common financial reporting effort.

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

[39]For examples of previous reports, see 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); and *Project and Program Management: DOE Needs to Revise Requirements and Guidance for Cost Estimating and Related Reviews,* GAO-15-29 (Washington, D.C.: Nov. 25, 2014).

necessary to accomplish that work, and the associated budget for a program, which may include capital asset projects. The schedule 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; and

- a **life-cycle cost estimate**—an exhaustive and structured accounting of all resources and associated cost elements required to develop and sustain a particular program that relies on a work breakdown structure that captures a complete scope of work. 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.

According to our *Cost Estimating and Assessment Guide*, a cost estimate is critical for government programs; having a realistic estimate of projected costs makes for effective resource allocation and increases the probability of a program's success.[40] According to the guide, to build an accurate life-cycle cost estimate, programs need to establish a full scope of work, represented by a complete work breakdown structure, and an integrated schedule of all program activities.

NNSA uses a systematic framework, called Technology Readiness Levels (TRL), for determining how far a technology has matured and to evaluate the technology's readiness to be integrated into a system for inclusion in a facility, such as the LPF.[41] This approach is intended to ensure that new technologies are sufficiently mature in time to be used successfully when a project becomes operational and to reduce the technical and cost risks associated with the introduction of new

[40]GAO-20-195G.

[41]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. DOE adopted the use of TRLs in response to our recommendation that DOE develop a consistent approach to assessing the extent to which new technologies have been demonstrated to work as intended in a project before starting construction. See DOE Order 413.3B; Department of Energy, *Technology Readiness Assessment Guide,* DOE Guide 413.3-04A (Oct. 22, 2015); and GAO, *Department of Energy: Major Construction Projects Need a Consistent Approach for Assessing Technology Readiness to Help Avoid Cost Increases and Delays*, GAO-07-336 (Washington, D.C.: Mar. 27, 2007).

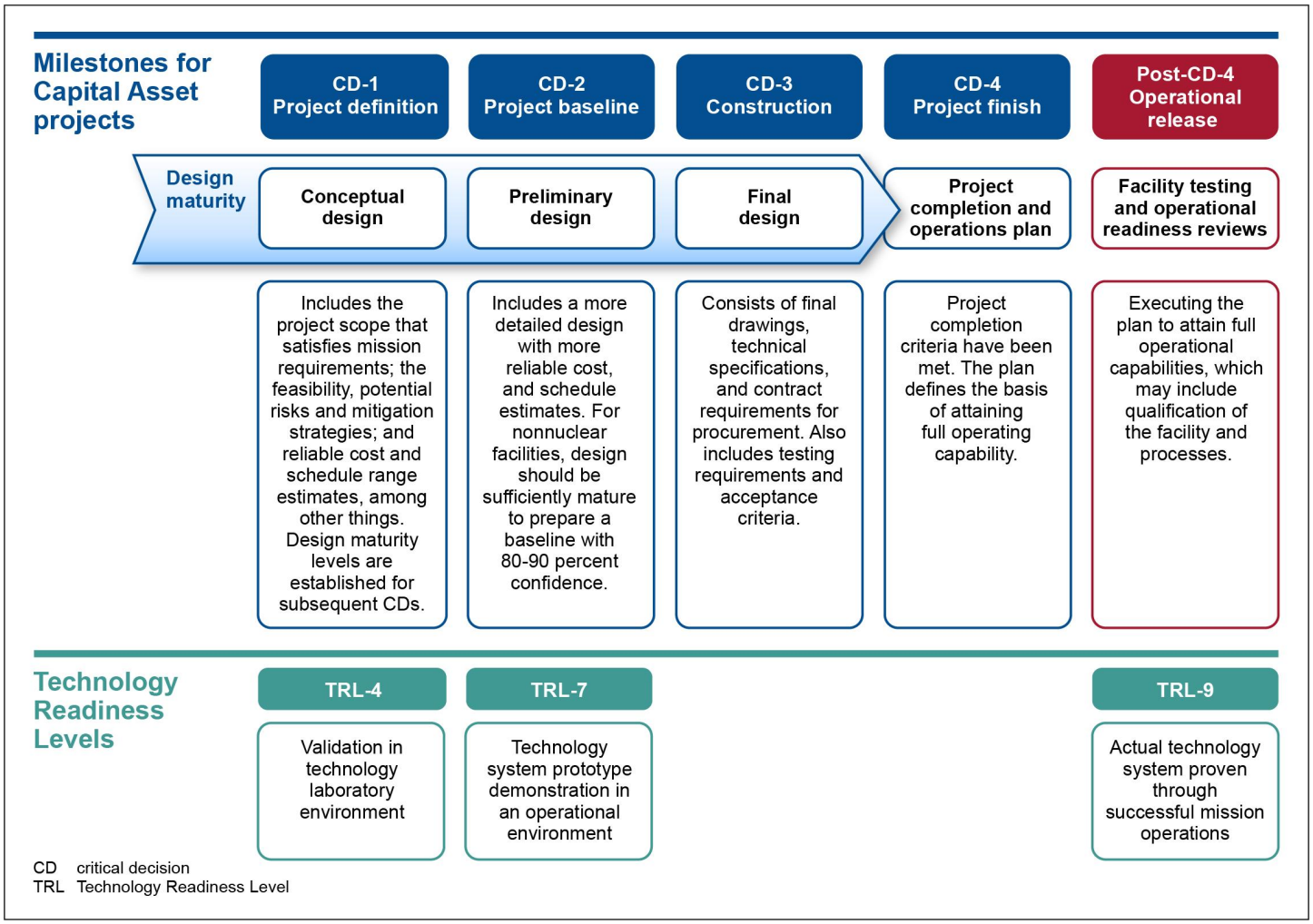
technologies. TRLs progress from the least mature level, in which the basic technology principles are observed (TRL 1), to the highest maturity level, in which the actual system is used successfully in project operations (TRL 9). It can take years to successfully mature a technology from TRL 1 to TRL 9.

NNSA assesses the maturity of a technology—its TRL—by conducting periodic technology readiness assessments (TRA). TRAs are used to inform program and project acquisition decisions and technology maturation planning by providing an objective assessment from subject matter experts of how successfully the technology is maturing. According to our TRA Guide, 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.[42] (For additional information on our TRA Guide, see app. V.) DOE Order 413.3B requires that each critical technology item or system on which a project depends must first be validated in a laboratory environment (TRL 4) before the project's alternative selection and cost range are approved (CD-1), and be demonstrated as a prototype in an operational environment (TRL 7) before the project's performance baselines are approved (CD-2) (see fig. 5).

[42]GAO-20-48G.

Figure 5: Milestones for Department of Energy (DOE) Capital Asset Projects and Associated Technology Readiness Level Requirements

The National Nuclear Security Administration's project for construction of a new lithium processing facility must meet DOE's requirements for capital asset projects and technology readiness.



Sources: GAO analysis of Department of Energy Order 413.3B; GAO's *Technology Readiness Assessment Guide* (GAO-20-48G). | GAO-21-244

Text of Figure 5: Milestones for Department of Energy (DOE) Capital Asset Projects and Associated Technology Readiness Level Requirements

Milestones for Capital Asset Projects

- CD-1Project definition. Conceptual design: Includes the project scope that satisfies mission requirements; the feasibility, potential risks and mitigation strategies; and reliable cost and schedule range estimates,

among other things. Design maturity levels are established for subsequent CDs.

  - Technological Readiness Level: TRL-4. Validation in technology laboratory environment

- CD-2 Project Baseline. Preliminary Design: Includes a more detailed design with more reliable cost, and schedule estimates. For nonnuclear facilities, design should be sufficiently mature to prepare a baseline with 80-90 percent confidence.
  - TRL-7: Technology system prototype demonstration in an operational environment
- CD-3 Construction. Final Design: Consists of final drawings, technical specifications, and contract requirements for procurement. Also includes testing requirements and acceptance criteria.
- CD-4 Project Finish. Project Completion and operations plan: Project completion criteria have been met. The plan defines the basis of attaining full operating capability.
- Post CD-4 Operational Release. Facility Testing and Operational Readiness Review: Executing the plan to attain full operational capabilities, which may include qualification of the facility and processes.
  - TRL-9: Actual technology system proven through successful mission operations

Notes: The first critical decision (CD-0) defined in DOE Order 413.3B, Program and Project Management for the Acquisition of Capital Assets, is not reflected in this graphic because there are no technology readiness level requirements associated with that milestone under the order.

Executing the operational release plan is not a critical decision described in CD-4, but planning for operational release does occur during CD-4. DOE released a memorandum describing an operational release milestone in 2016.

Sources: GAO analysis of Department of Energy Order 413.3B; GAO's Technology Readiness Assessment Guide (GAO-20-48G). | GAO-21-244

NNSA's Preliminary Cost and Schedule Estimates for the LPF Have Increased, and the Agency Faces Risks to Ensuring a New Technology Is Ready for Inclusion in the Design

In December 2019, NNSA substantially increased its preliminary cost estimate and schedule for constructing the new LPF compared with its estimate and schedule at completion of the first critical project milestone

(CD-0) in 2015, in part because the matured design for the facility increased its size. Given the cost increase, we analyzed NNSA's December 2019 cost estimate approved at CD-1 to establish whether it met the comprehensive characteristic of a reliable cost estimate. We found that the December 2019 cost estimate was comprehensive. NNSA's current cost and schedule estimates are based on a specific set of activities to be included in the LPF, and there are additional, related activities that NNSA plans to address through separate future efforts, at an additional cost. NNSA is in the early phases of designing the new LPF and has decided to incorporate a new technology to achieve greater efficiency and other benefits. However, NNSA faces some risks in ensuring the technology is sufficiently mature in time for the start of construction in November 2025.

NNSA's Preliminary Cost and Schedule Estimates for the LPF Have Substantially Increased since 2015, and the Cost Estimate Is Comprehensive

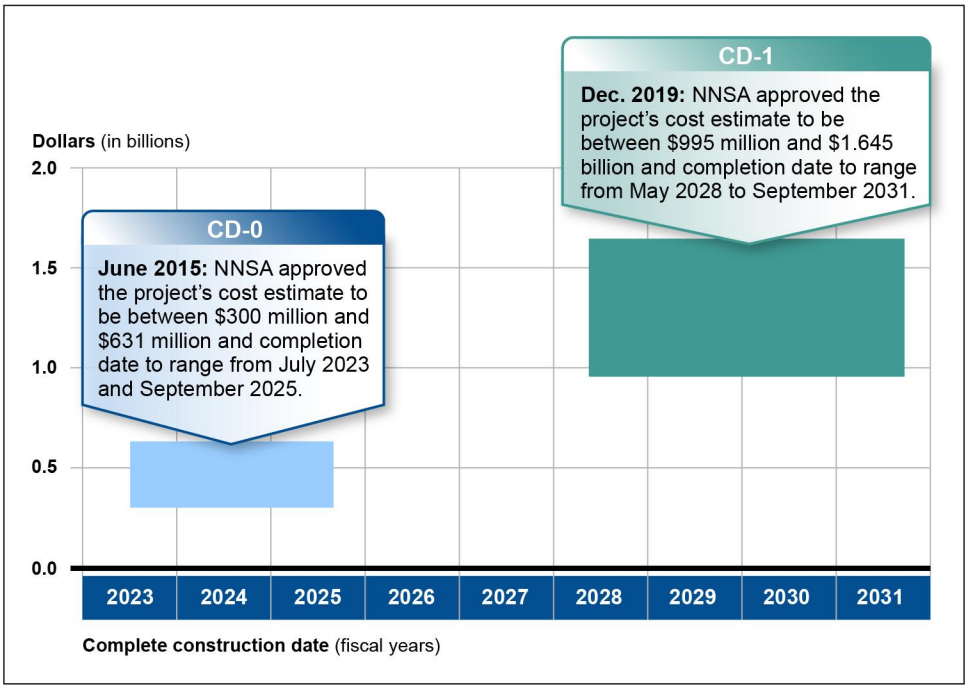
Since NNSA approved the first critical project milestone (CD-0) in 2015, its preliminary cost and schedule estimates for constructing the new LPF have substantially increased. Originally, NNSA estimated the new facility to cost between $300 million and $631 million. It increased these estimates to between $955 million and $1.645 billion in December 2019, when it approved the preferred alternative to build LPF and established its preliminary cost and schedule ranges (CD-1).[43] At the same time, NNSA also pushed back the preliminary estimated date for completing construction from between July 2023 to September 2025 to between May 2028 and September 2031, with plans to attain full operational capacity in the 2030s.

Figure 6 shows that the LPF cost estimate increased by between $655 million and $1.014 billion, and the schedule increased by about 5 to 6 years. According to NNSA documents, the increases occurred because (1) NNSA's preliminary cost and schedule estimates in 2015 did not

[43]NNSA is following the capital asset acquisition process as required by DOE Order 413.3B for projects over $50 million for nonnuclear facilities. Previously, the NNSA Deputy Administrator for Defense Programs approved the critical mission need for lithium capability (CD-0) in June 2015. According to DOE Order 413.3B, the conceptual design process must ensure that the chosen solution is responsive to the approved need, technically feasible, and affordable.

include the entire scope of work and (2) the planned size of the LPF increased as the design matured.

Figure 6: NNSA's Lithium Processing Facility Cost and Schedule Estimates Increased as the Project Matured



Source: GAO analysis of National Nuclear Security Administration (NNSA) documents. | GAO-21-244

Text of Figure 6: NNSA's Lithium Processing Facility Cost and Schedule Estimates Increased as the Project Matured

- June 2015: NNSA approved its initial estimate to be between $300 million and $631 million and completion of construction ranging from July 2023 to September 2025.
- Dec. 2019: NNSA approved its preliminary cost estimate to be between $955 million and $1.645 billion and completion of construction ranging from May 2028 through September 2031.

Note: NNSA's estimates are reported as actual dollars and were not adjusted for inflation.

Source: GAO analysis of National Nuclear Security Administration (NNSA) documents. | GAO-21-244

NNSA's preliminary cost and schedule estimates approved in December 2019 were based on the LPF conceptual design for a nonnuclear facility with a reinforced concrete structure of approximately 134,000 square feet.

The LPF conceptual design is based on the existing lithium production process—using DMM and wet chemistry—and includes the pressing and machining steps, among others. Before finalizing and approving the substantial increases to the preliminary cost and schedule estimates in December 2019, two offices within DOE and NNSA performed independent reviews of NNSA's preliminary estimates (see app. III for additional details about these reviews).

We performed an analysis of NNSA's December 2019 cost estimate approved at CD-1, to establish whether it met the "comprehensive" characteristic of a reliable cost estimate, given the substantial increase from CD-0. [44] We found that the LPF's preliminary cost estimate substantially met the "comprehensive" characteristic, based on the project's scope of work established by NNSA (see app. IV for additional details about our comparison). According to our *Cost Estimating and Assessment Guide*,[45] comprehensive cost estimates meet the following best practices:

- They are based on a technical baseline description that completely defines the project, reflects the current schedule and technical baseline, and are technically reasonable. This is the set of activities NNSA is including in its definition of the project.
- They are based on a statement of work that is product oriented and at an appropriate level of detail to ensure that cost elements are neither omitted nor double-counted.
- They include all life-cycle costs for the project.
- They document all cost-influencing ground rules and assumptions.

[44]Given the level of maturity of the estimate completed in December 2019 for CD-1, we compare the estimate to best practices of the "comprehensive" characteristic in our *Cost Estimating and Assessment Guide*. GAO-20-195G. The preliminary cost and schedule range could change when the project is fully baselined—currently planned to occur between May 2024 and November 2025.

[45]GAO-20-195G.

Demolition of the Biology Complex

The National Nuclear Security Administration selected the existing Biology Complex at the Y-12 National Security Complex (Y-12) as its preferred location for building the new lithium processing facility. The Biology Complex comprised five buildings and is no longer operational but still contains hazardous materials. In 2018, it was transferred to the Department of Energy's (DOE) Office of Environmental Management for demolition.

Removing the hazardous materials and demolishing the complex is expected to cost $101.3 million, according to DOE project information. According to Environmental Management officials, the demolition schedule has been delayed between 2 and 6 months because of the Coronavirus Disease 2019 pandemic, but officials believe they are still able to meet the time frames needed for the lithium processing facility construction to begin in November 2025.

Sources: DOE Office of Environmental Management (photo and text) and Y-12 contractor documents and officials. | GAO-21-244

According to the current project plan approved in December 2019, NNSA will continue to mature the design for the LPF while the DOE Office of Environmental Management completes the demolition of the Biology Complex at Y-12, which is the selected site for the new facility.[46] As of March 2021, NNSA officials anticipate the demolition to be complete and the site to be turned over to NNSA for preparation in June 2022.

According to NNSA documents, NNSA plans to approve and establish its performance cost and schedule baselines (CD-2) in November 2025, at which time it also plans to begin construction of the LPF (CD-3);[47] however, the approval to start operations (CD-4) may not occur until September 2031. After the approval to start operations, NNSA estimates it will take another 3 years to complete qualification of the facility—at which time the LPF will be considered fully operational. NNSA has included 3.5 years of schedule contingency in its estimates for completing future critical decision milestones.

For a summary of key project milestones, see table 1. To achieve these project milestones, congressional committees directed $109.4 million of NNSA's appropriations to the project in fiscal year 2021.[48] NNSA plans to request nearly $970 million from fiscal year 2022 through 2025, according to the agency's fiscal year 2021 budget request projections.

[46]According to DOE project information, demolition of the Biology Complex is expected to cost $101.3 million and is funded by the DOE Office of Environmental Management.

[47]NNSA decided to combine the next two project milestones for approving the performance baseline (CD-2) and starting construction of the LPF (CD-3). According to NNSA officials, the decision to combine the next two project milestones was made based on the agency's experience with managing capital asset acquisition projects. Once NNSA management has approved the project baseline, the Deputy Secretary of Energy or the NNSA Administrator must approve any deviations from the project scope, as required by DOE Order 413.3B.

[48]According to NNSA's fiscal year 2021 budget request, a total of $51 million was appropriated for the LPF in fiscal years 2019 and 2020.

Table 1: Project Milestones, Including Critical Decisions (CD), for the Lithium Processing Facility (LPF), as of March 2021

Project milestones	Actual/estimated start[a]	Estimated completion[b]
Biology Complex demolition and turnover to NNSA	October 2018	June 2022
Design maturation of the new LPF process and facility	February 2020	December 2023
Approve the performance baseline (CD-2) and start of construction (CD-3)	N/A	November 2025 [c]
Long-lead procurement and site preparation (CD-3a)	September 2023	November 2025
LPF construction	November 2025	September 2027
Approve start of operations (CD-4)	N/A	Between May 2028 and September 2031
LPF qualification	—[d]	Between October 2031 and September 2034

Legend:

N/A = not applicable[e]

— = to be determined

Source: National Nuclear Security Administration (NNSA) project documents. | GAO-21-244

[a]The date provided is the actual start date, if prior to March 2021.

[b]Dates include 3.5 years of schedule contingency.

[c]This date includes 18 months of schedule contingency. The earliest NNSA estimates approving CD-2 and CD-3 is May 2024.

[d]The estimated start date for LPF qualification is dependent on when NNSA approves the start of operations (CD-4).

[e]Approval of CD-2, CD-3 and CD-4 milestones occur at a point in time and do not have official start dates as the project is cumulative.

NNSA Intends to Address Lithium Support Activities That Are Not Included in LPF through Separate Future Efforts with Additional Costs

Some of the activities needed for a complete lithium production process are not planned for inclusion in the LPF conceptual design, and NNSA intends to develop separate future efforts to replace or recapitalize those activities. Specifically, NNSA's conceptual design for the LPF did not include certain necessary activities that support lithium production—such as rubber and foam operations, container refurbishment operations, oven room operations, deuterium gas production and recovery, and material

storage.[49] According to the Y-12 contractor's October 2020 infrastructure implementation plan, the buildings where some of these necessary

[49]There could be additional lithium-related activities that need to be replaced or recapitalized to ensure NNSA maintains its lithium capability, however, planning for those activities was not completed during our review. For example, according to the Y-12 infrastructure implementation plan from October 2020, the next update may include projects to replace or recapitalize activities that support lithium operations in buildings 9204-2E, 9201-01, and the analytical laboratory in building 9995. For additional information about these facilities, see appendix II.

Replacing Deuterium Gas Capability at the Y-12 National Security Complex (Y-12)

The National Nuclear Security Administration (NNSA) will need a supply of deuterium gas for producing lithium deuteride using wet chemistry at Y-12. Deuterium is also needed for NNSA customers, such as the International Thermonuclear Experimental Reactor, as fuel to create fusion in the reactor for energy.

Historically, NNSA extracted deuterium gas from heavy water—a chemical form of water where both hydrogen atoms are replaced with deuterium atoms—by separating the deuterium and oxygen atoms using electrolysis. To obtain this heavy water, NNSA recovered half heavy water generated during the wet chemistry process for lithium at Y-12 and converted it at a facility at its Savannah River Site in South Carolina. This facility closed in 1996.

NNSA currently has an inventory of heavy water stored at Y-12, according to NNSA officials. NNSA can continue to supply lithium deuteride for its nuclear weapons programs through 2039, based on its supply and demand estimates. As a result, NNSA does not plan to reestablish the capability to produce deuterium gas until 2038.

Deuterium Gas House in Building 9204-2 Complex at Y-12

Sources: NNSA and Y-12 contractor documents and interviews; Y-12 contractor (photo). | GAO-21-244

activities are currently performed have also deteriorated and pose a risk to achieving NNSA's lithium mission, while others need to be replaced because they will be affected by the planned demolition of the building 9204-2 complex.

NNSA officials said they intend to come up with separate efforts to replace those lithium activities at Y-12 and complete many of those projects before 2035—when Y-12 plans to start to transfer building 9204-2 to the DOE Office of Environmental Management for demolition.[50] The Y-12 contractor's October 2020 infrastructure implementation plan indicates that the total estimated cost for replacing or recapitalizing these

[50]Based on Y-12's infrastructure implementation plan from October 2020, its proposed efforts for replacing deuterium gas production and recovery are not needed until the 2030s and 2040s, and the proposed effort for material storage is not needed until fiscal year 2046.

lithium activities could be $472 million.[51] According to officials in NNSA's Lithium Modernization program, the program is aware that many of these efforts will need to be completed before the demolition of building 9204-2, but NNSA has not yet evaluated Y-12's proposals, and the agency's decision to fund these efforts will be based on the availability of funding in the future.

NNSA Plans to Include an Additional New Technology in the LPF Design and Faces Some Risks to Ensuring the Technology Is Sufficiently Mature

NNSA has decided to incorporate a new technology into the design of the lithium production process for the new LPF. Specifically, in May 2020, NNSA decided to modify the conversion step of the lithium cleaning and purification phase by incorporating an additional technology called homogenization, which involves using reactors at higher temperatures to remove the effects from pressing and machining lithium material.[52]

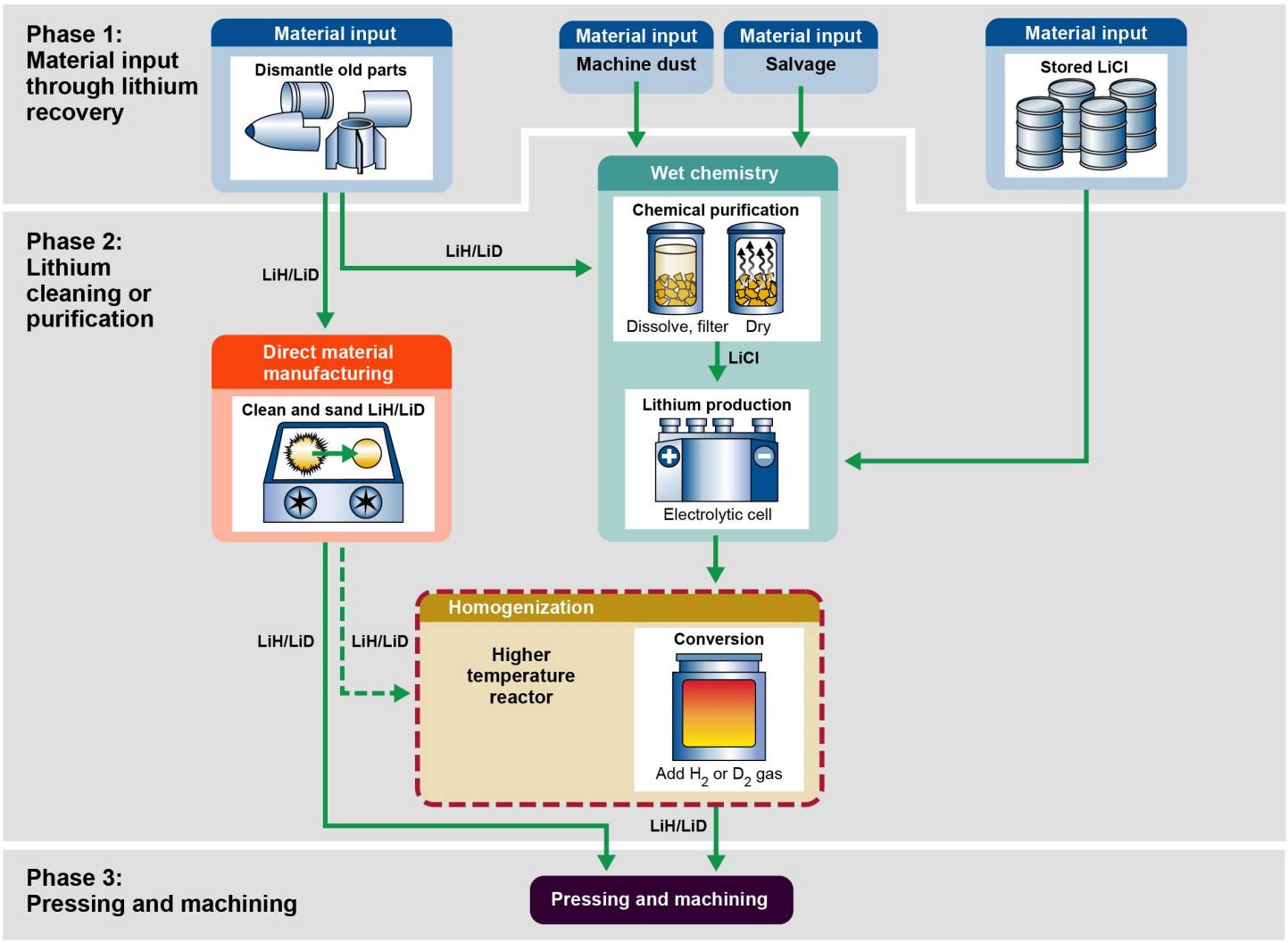
By doing so, NNSA may be able to reduce—but not eliminate—its use of wet chemistry to purify lithium material that cannot currently be cleaned using DMM, according to Y-12 contractor documents. DMM does not remove the effects of the original pressing of the material, but by using homogenization with a higher temperature reactor to remove those effects, NNSA could use DMM to clean lithium material multiple times. If NNSA were to reduce its use of wet chemistry, NNSA may benefit by reducing hazardous chlorine gas emissions from the electrolytic cell. NNSA may also make the lithium production process more efficient because it takes less time to process lithium material using DMM than

[51]This rough order of magnitude estimate is based on efforts identified in the Y-12 infrastructure and implementation plan from October 2020 for replacing or recapitalizing lithium-related activities to support production and does not include additional costs for demolition and disposition of the existing facilities. According to the 2020 plan, the M&O contractor for Y-12 has proposed that additional funding for these projects will come from outside the Lithium Modernization program and included three proposed line item construction projects: (1) a proposed replacement facility for lithium development activities; (2) a proposed replacement facility for nuclear material staging, and storage to replace an aging storage facility for lithium material, among other things; and (3) a proposed replacement facility for container refurbishment and the rubber and foam operations.

[52]NNSA considered another new technology, thermal distillation and decomposition, that could serve as an alternative or adjunct to wet chemistry but rejected it because it would increase the estimated cost of the LPF by $63 million and would add up to 15 months to the estimated schedule, according to NNSA documents.

wet chemistry. See figure 7 below for an illustration of how homogenization would be incorporated into the LPF design.

Figure 7: Incorporation of Homogenization into the Existing Lithium Production Process for the Lithium Processing Facility (LPF) Design



Source: GAO adaptation of NNSA graphic. | GAO-21-244

Note: The pressing and machining phase also includes a step to crush the lithium material into powder.

If the potential benefits of homogenization are achieved, a Y-12 contractor document estimates that NNSA may save nearly $1.3 billion over a 50-year life cycle for the new LPF.[53] NNSA may also realize these benefits, with low impact to project costs and schedule.[54]

According to DOE Order 413.3B, NNSA must mature the homogenization technology to TRL 7 by the time the LPF project obtains CD-2 approval, currently planned for between May 2024 and November 2025. To achieve TRL 7, NNSA requires prototype demonstrations of the technology in an operational environment. Based on the results of the April 2020 technology readiness assessment, NNSA determined that homogenization had matured to TRL 6.[55] NNSA plans to procure a production furnace and produce a full production batch of lithium material using homogenization to continue to mature the technology to TRL 7 before 2024, according to the June 2020 Technology Maturation Plan.[56] As part of its assessment, NNSA plans to then take the homogenized material through the remainder of the pressing and machining phase of the lithium production process and to perform chemical and physical analyses of the lithium material throughout the production process to ensure it meets weapons specifications.

NNSA, however, faces some potential risks to ensuring that homogenization is sufficiently mature in time for the approval of the final

[53]Based on the M&O contractor business case for homogenization, incorporating the technology also reduces the size of the new LPF by 1,000 square feet.

[54]To continue maturing homogenization, NNSA and the Y-12 contractor anticipated spending an estimated $19.5 million through October 2023, based on the June 2020 technology maturation plan. Previously, since fiscal year 2018, NNSA funded the technology development for homogenization through its Material Recycle and Recovery program and the Lithium Modernization program, according to NNSA officials, and the total combined cost from fiscal years 2018 through 2020 was just under $2 million.

[55]The LPF project within the Office of Acquisition and Project Management is taking over responsibility for maturing homogenization to TRL 7, according to NNSA officials. Previously, technology maturation for homogenization had been managed by the Lithium Modernization program through TRL 6.

[56]To continue to assess the maturity of homogenization and ensure the technology matures to TRL 7 before CD-2, NNSA plans to conduct annual technology readiness assessments. According to NNSA officials from the Office of Cost Estimating and Program Evaluation, the office is to be involved in reviewing TRA documents when a critical technology is approaching TRL 4 and TRL 7.

LPF design (CD-2) by November 2025, according to our analysis of the April 2020 TRA for homogenization.[57] Specifically:

- We found that NNSA did not prepare a documented TRA plan, as recommended by best practices and required by NNSA policy, for completing its April 2020 TRA.[58] According to the best practices in our TRA Guide, the agency should develop a TRA plan that ensures a comprehensive assessment is conducted with all key information for the TRA team to conduct the assessment. According to NNSA officials and Y-12 contractor representatives, they thought they had prepared a TRA plan as they had done for previous TRAs, but we found they had not done so. In the absence of a documented TRA plan, NNSA risks assessing the maturity level of homogenization without key information needed for the TRA team to ensure a homogenization is sufficiently mature to include in the final LPF design.
- We found, as part of its TRL 6 assessment, that NNSA did not obtain a complete analysis of the chemical properties of lithium material produced using homogenization and taken all the way through the crushing, grinding, and pressing steps of phase 3 of the lithium production process.[59] The April 2020 TRA identified steps to complete this analysis, but the report explained that testing was not completed in time for the results to be assessed for the April 2020 TRA. The results would have provided NNSA with data on whether lithium material processed with homogenization and input through the crusher and grinder would be likely to meet weapons qualification standards. According to NNSA officials and Y-12 contractor representatives, they decided to perform the TRA for homogenization earlier in 2020 to meet a key project decision milestone for including homogenization in the LPF design and, as a result, did not have time to complete the analysis and collect the data for the 2020 TRA.

[57]We performed an independent review of NNSA's April 2020 TRA and compared the process to best practices found in GAO's *TRA Guide* (GAO-20-48G). Appendix V provides greater detail on the results of our review.

[58]GAO-20-48G; and NAP-413.4.

[59]NNSA's technical evaluation called for it to homogenize material and then crush, grind, and press that material to compare homogenized material against historically acceptable material used in weapons. While NNSA performed chemical and physical analysis at earlier steps in the homogenization process, it did not produce and analyze these final pressed samples at the time of the TRA, which are essential to determine whether the homogenization can produce material acceptable for use in weapons.

According to our TRA best practices, the TRA should include all key evidence, and the TRA team should assign a TRL rating based on credible and verified evidence.[60] NNSA officials and M&O contractor representatives recognized the importance of this missing data and the potential risks introduced by not having the data. Furthermore, the TRA team reviewed the TRA for homogenization and decided the technology was mature enough to move forward without the testing being completed. However, given the importance of this TRA in deciding to incorporate homogenization into the LPF design, the absence of these data could undermine the objectivity of the TRA and cause delays if later data on homogenization reveal problems with the technology. Although NNSA would be able to complete the LPF design without homogenization technology, the agency would not achieve estimated cost savings and improve worker safety by reducing the use of wet chemistry. By taking steps to ensure that all key data are collected and assessed before completing future TRA assessments and achieving key project milestones, NNSA will have more assurance the LPF design will be completed prior to construction starting between May 2024 and November 2025.

- We found that NNSA did not complete or document management approval by the Lithium Modernization Program Manager or a written response to the April 2020 TRA completed by the Y-12 M&O contractor, as recommended by our *TRA Guide*. According to our *TRA Guide* and NNSA's *Defense Programs Technology Readiness Assessment Implementation Guide*, management should check the factual accuracy of the TRA, and the managers' response should be documented in writing, including any dissenting views.[61] Documenting the factual accuracy and response to the TRA is important because TRAs are iterative. They build on the knowledge of each previously conducted TRA over the years it can take to sufficiently develop and mature a technology. While NNSA officials said they reviewed the TRA, this review was not documented to know whether the TRA was reviewed for inaccuracies or whether there were any dissenting views regarding the April 2020 TRA.

  The omission of NNSA management approval for the April 2020 TRA completed by the Y-12 contractor is particularly relevant because (1)

[60]GAO-20-48G.

[61]GAO-20-48G; and National Nuclear Security Administration, *Defense Programs Technology Readiness Assessment Implementation Guide Revision 3.1* (Washington, D.C., December 2018).

the April 2020 TRA was missing key data on the analysis of chemical properties, as discussed above; (2) the results of the TRA were used to inform the key project decision to include homogenization in the LPF design; and (3) future TRAs will be built on the results of this TRA to inform the final LPF design. Without completing and documenting management review as part of the TRA process, NNSA has not demonstrated sufficient management oversight to give decision makers confidence in the reliability of the TRA results for the homogenization technology and future TRAs.

NNSA Has Taken Steps to Reestablish Wet Chemistry Capabilities to Meet Near-Term Lithium Demand but Has Identified Additional Risks to Sustaining Lithium Operations

NNSA's initial strategy to meet near-term, increased lithium demand involves reestablishing its wet chemistry capability on a small scale, and it is taking steps to do so and to mitigate additional risks it faces in meeting this demand. NNSA expects to reestablish small-scale wet chemistry operations in 2022, at an estimated cost of $53.3 million. However, even with wet chemistry reestablished, NNSA officials recognize the agency faces additional risks, primarily because of deteriorating and aging infrastructure and equipment, and NNSA and Y-12 are working to repair and upgrade infrastructure and equipment.

NNSA Is Reestablishing a Wet Chemistry Capability to Meet Near-Term Lithium Demand

NNSA's initial strategy to meet increased lithium demand before the LPF is operational relies primarily on reestablishing its wet chemistry capability on a small scale at Y-12 in buildings 9204-2 and 9202 by 2022.[62] Doing so would allow NNSA to make fuller use of the lithium material available than it can with DMM alone. Specifically, with wet chemistry reestablished, NNSA would be able to use its existing stored supply of lithium chloride and recycle material, such as lithium machine dust.

[62]According to the lithium program manager, the wet chemistry process that was suspended in May 2013 took up approximately 50,000 square feet of space, whereas small-scale wet chemistry will take up about 5,000 square feet.

Without reestablishing its wet chemistry capability, NNSA officials told us they risk not meeting the scheduled lithium demand until the LPF is operational—particularly for the B61-12 Life Extension Program based on the program's current production schedule starting in 2022.[63] According to

[63]The B61 gravity bomb is the oldest nuclear weapon in the stockpile. It was first fielded in 1968, with current modifications fielded between 1979 and 1991. The B61-12 Life Extension Program will consolidate and replace the B61-3, -4, -7, and -10 modifications of the bombs, according to the fiscal year 2021 Stockpile Stewardship Management Plan. We have previously reported on the B61-12 Life Extension Program's cost increases and schedule constraints. See GAO, *B61-12 Nuclear Bomb: Cost Estimate for Life Extension Incorporated Best Practices, and Steps Being Taken to Manage Remaining Program Risks,* GAO-18-456 (Washington, D.C.: May 31, 2018); and *Nuclear Weapons: NNSA Has a New Approach to Managing the B61-12 Life Extension, but a Constrained Schedule and Other Risks Remain,* GAO-16-218 (Washington, D.C.: Feb. 4, 2016).

NNSA Supplies Lithium Material to Other Customers

In addition to supplying lithium material for its own modernization and life extension programs, the National Nuclear Security Administration (NNSA) supplies lithium material to other customers. These customers include the Department of Energy (DOE) Office of Science Isotope Program, the National Aeronautics and Space Administration, the Department of Homeland Security, the Department of Defense, and private industry. According to Y-12 National Security Complex (Y-12) contractor representatives, such customers represent a very small demand for lithium and can be supplied with lithium that does not meet nuclear weapons program specifications.

NNSA plans to continue supplying these customers, in part, by using existing lithium material reserves, according to DOE officials and Y-12 contractor representatives. Specifically, those officials and contractor representatives said the agency has a reserve of lithium material that the DOE Office of Science, which manages the sales, established for this purpose in 2013. As of August 2020, the Office of Science has used over half of this reserve, according to these officials and contractor representatives. NNSA officials estimate they will need to produce additional lithium material to continue supplying other customers by between fiscal years 2022 and 2025 using the reestablished wet chemistry capability.

Sources: DOE and NNSA documents and interviews with NNSA officials and Y-12 contractor representatives. | GAO-21-244

NNSA's B61-12 program managers, if there are delays to the reestablishment of small-scale wet chemistry, the final phase of the B61-12 production—when NNSA would produce essential spare bombs — could be delayed, and additional costs to the program could be incurred.

NNSA has been aware of this risk for nearly a decade, and it began working in 2018 on efforts to reestablish a wet chemistry capability at Y-12, including replacing or refurbishing equipment for lithium purification, production, and conversion in aging facilities (see app. II). It also is aware of the needs to reestablish salvage operations. According to NNSA officials and documents, these efforts are expected to cost $53.3 million.[64] Some efforts have been completed, while others are planned for completion by July 2022.

According to NNSA officials, the agency anticipates having the small-scale wet chemistry process qualified and fully operational at Y-12 by July 2022. Before the capability is considered operational, Los Alamos and Lawrence Livermore National Laboratories need to qualify the equipment and processes to ensure that the lithium material produced meets weapons' specifications. As of October 2020, Los Alamos National Laboratory representatives said they had made progress qualifying some equipment, especially conversion furnaces for the B61-12 Life Extension Program.

As part of its overall strategy to meet increased lithium demand and in addition to reestablishing its wet chemistry capability, NNSA took steps to increase the amount of existing lithium material that could be processed using DMM. Specifically, the Y-12 contractor proposed changing the lithium material specification standards for use in weapons components. Los Alamos National Laboratory and Lawrence Livermore National Laboratory representatives said they reviewed the Y-12 contractor's proposal using advanced modeling and agreed with the Y-12 contractor's proposal. NNSA officials stated that this change increased the available lithium supply that met qualification standards and extended the time frames of available lithium for DMM by 3.5 years.

[64]This $53.3 million estimate includes actual and estimated costs for ongoing and completed efforts to reestablish small-scale wet chemistry.

NNSA Is Aware of and Taking Steps to Address Risks from Deteriorating Infrastructure, Aging Equipment, and Delays to Sustainment Efforts

Even with these measures and the reestablishment of wet chemistry capabilities at Y-12 by 2022, NNSA recognizes its ability to meet near-term lithium demand is at risk because these capabilities will continue to operate in deteriorating infrastructure with aging equipment, and there have been delays to sustainment efforts, according to NNSA and Y-12 contractor documents. NNSA's multiple offices involved in ensuring that near-term lithium demand is met are taking coordinated steps to address these risks. According to the Y-12 infrastructure implementation plan from October 2020, over $1 billion in additional funding will be needed to sustain lithium infrastructure until the LPF is operational and the older facilities are no longer needed.[65]

Deteriorating Infrastructure

NNSA's production requirements for nuclear weapons modernization are increasing and putting more demand on Y-12's lithium facilities at a time when they are already past their expected usable lives. NNSA officials and contractor representatives note that risks to lithium operations will remain until the LPF is fully operational, and some facilities will need to be maintained even longer to support lithium activities that are outside the scope of the LPF project. However, production disruptions caused by deteriorating infrastructure at Y-12 place NNSA's ability to meet lithium demand at risk. Most of NNSA's lithium operations are performed in two concrete buildings—9204-2 and 9202—that are over 70 years old, with known and serious structural deficiencies. As we reported in 2015, the deterioration of building 9204-2 has resulted in interruptions to lithium

[65]The Y-12 M&O contractor's October 2020 infrastructure implementation plan identified over $1 billion in additional actions to sustain, transition, and transfer lithium-related infrastructure to the DOE Office of Environmental Management for demolition over the next several decades. Some of these actions include efforts to replace and recapitalize lithium-related activities outside the scope of the LPF project, as previously discussed. This estimate is based on rough order of magnitude estimates and is not reflected in the NNSA's Lithium Modernization program budget request as of April 2021. NNSA and Y-12 will update the infrastructure implementation plan, and the next report will expand the scope to include the other facilities that support lithium operations, including buildings 9204-2E, 9201-01, and the analytical laboratory in building 9995.

operations and worker safety concerns.[66] For example, in March 2014, a 300-pound slab of concrete fell from the ceiling into an active work area, and the area was closed from further use. Building 9204-2 has experienced additional deterioration to structural steel, concrete, and rebar caused by the corrosive materials used in the lithium-production process.[67] According to NNSA officials and Y-12 contractor representatives, the integrity of building 9204-2 continues to be one of the top risks to the success of NNSA's lithium operations. In addition, building 9202—where NNSA recently installed new wet chemistry tanks—has significant issues with its electrical system; the roof; and the heating, ventilation, and air conditioning system. These issues have previously resulted in process disruptions at Y-12. NNSA officials and Y-12 contractor representatives said that without upgrades to the structures of buildings 9204-2 and 9202 and other facility infrastructure investments, these conditions will continue to deteriorate and will potentially affect NNSA's ability to meet lithium demand.

Infrastructure deterioration also poses a risk to efforts to sustain lithium operations through equipment upgrades. For example, the Y-12 contractor identified beryllium contamination in spring 2020 that resulted in delays to replacing equipment in building 9204-2, needed to meet lithium demand.[68] In 2020, Y-12 workers were unable to install other equipment because concrete deterioration prevented them from drilling into the floor, which resulted in further delays to reestablishing wet chemistry. The NNSA Lithium Modernization Program Manager said that these and other ongoing efforts to sustain lithium operations have taken longer than anticipated and experienced cost increases to address risks associated with deteriorating infrastructure.

NNSA and Y-12 have taken some steps to mitigate these infrastructure risks to ongoing lithium production through monitoring and improvement efforts. For example, NNSA's Office of Safety, Infrastructure, and Operations and the Y-12 contractor have conducted reviews of key lithium facilities to identify structural deterioration (see fig. 8 below for a

[66]GAO-15-525.

[67]The lithium production process contributes to concrete and structural deterioration because the process releases chlorides, including kathene used in the dehumidification system, and chlorine gas, as a byproduct of the electrolytic cell operations.

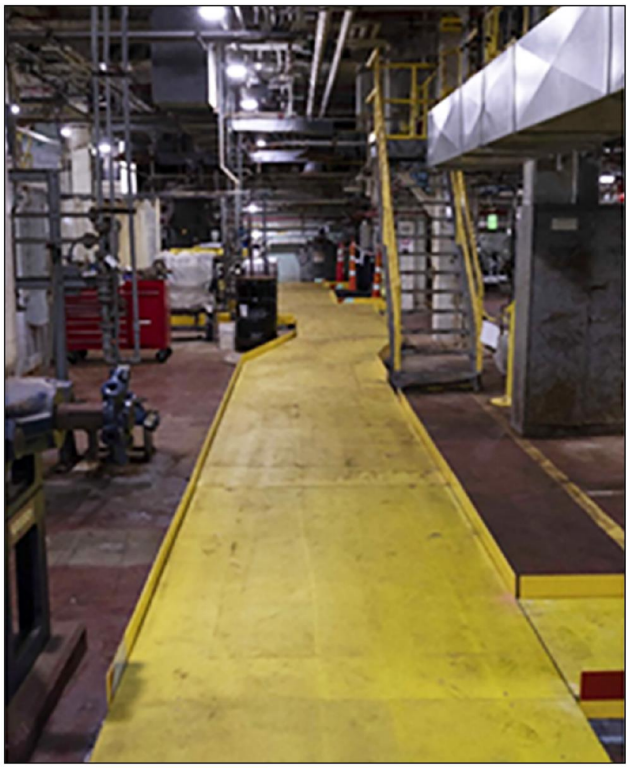
[68]Beryllium is a toxic, carcinogenic metal used in many industrial processes. Inhaling beryllium can cause respiratory symptoms (coughing, shortness of breath, or chemical pneumonia). Prolonged exposure to beryllium is known to cause lung cancer and, in high concentration, beryllium exposure can be fatal.

photograph of structural deterioration in building 9204-2). In October 2019, the Y-12 contractor completed a facility health oversight report for building 9204-2 to assess the health of the facility and identify any unacceptable risks to meeting lithium demand and worker safety. The report includes recommendations to sustain operations and mitigate risks in building 9204-2 until the LPF is operational. It also recommends that NNSA conduct annual reviews of the facility to identify structural deterioration of the concrete because their analysis cannot predict catastrophic failure of the building with certainty. By monitoring concrete for structural deterioration, NNSA likely prevented 100 pounds of concrete from falling in building 9204-2, according to the Lithium Modernization Program Manager. In addition to monitoring concrete, NNSA's infrastructure improvement efforts have included repairing failed concrete areas inside building 9204-2 and installing ramps for workers to avoid failed concrete flooring (see fig. 8 for photographs of the deteriorated concrete and the ramps used to cover the deteriorated concrete floor). As of July 2020, the Office of Safety, Infrastructure, and Operations has completed nine recapitalization projects to sustain lithium operations at Y-12 since fiscal year 2016.[69] Officials in the Lithium Modernization program and the M&O contractor for Y-12 plan to annually update their infrastructure implementation plan for lithium that includes a list of infrastructure improvement efforts, with rough order of magnitude cost estimates of what will be needed to sustain lithium operations through the next 5 years.

[69]NNSA's recapitalization projects are funded through its budget for Infrastructure and Operations to help the Office of Safety, Infrastructure, and Operations address ongoing issues with deferred maintenance and a need to replace aging infrastructure across the nuclear security enterprise. NNSA will continue to incur maintenance costs for sustaining building 9204-2 until the LPF is operational, when NNSA plans to transition operations out of the facility and transfer it for demolition to the DOE Office of Environmental Management..

Figure 8: Failed Concrete in Building 9204-2 and the National Nuclear Security Administration's Efforts to Make Repairs

Concrete failure from 2014 on the ceiling, resulting in collapse.



Walk ramps installed to cover deteriorated concrete floors.

Source: National Nuclear Security Administration. | GAO-21-244

Aging Equipment

NNSA's ability to meet lithium demand is at risk because equipment used for lithium operations at Y-12 is aging, and much of it is past its expected usable life. According to a Y-12 contractor document, 98 percent of the equipment in building 9204-2 is more than 40 years old, and 91 percent of that equipment is insufficient to meet current mission requirements. For example, the crusher and grinder operation relies on equipment that is more than 30 years old and, according to a Y-12 contractor document, is unreliable due to line blockages and mechanical failures, resulting in excessive downtime and unplanned maintenance costs. Y-12 is also experiencing increased crusher and grinder breakdowns due to processing harder lithium material that has gone through the DMM process. According to a Y-12 contractor document, due to age and current condition, the crusher and grinders are likely to experience catastrophic failures, which could take down the capability for an estimated 8 weeks or more each time. Y-12 contractor representatives

said that most of the equipment for the lithium production process does not have backup equipment, so Y-12 must rely on the ability to quickly replace or repair equipment to remain on schedule for production.

NNSA and Y-12 have taken steps to mitigate these risks by repairing or replacing deteriorated equipment and installing backup equipment. For example, NNSA has replaced several of the dehumidification units needed for maintaining a dry environment for much of the lithium production process and has planned efforts to replace others.[70] NNSA plans to install a backup crusher and grinder to mitigate risks from catastrophic failures. Officials in the Lithium Modernization program and the M&O contractor for Y-12 plan to annually update their infrastructure implementation plan for lithium that includes a list of its risk mitigation efforts needed to ensure that the aging equipment is able to process lithium material and to continue to meet lithium demand through the next 5 years.

Further, NNSA and Y-12 established rapid response plans to respond to high impact single-point-of-failure occurrences that could result from high risk and unpredictable catastrophic failure events and unreliable infrastructure. For example, in April 2016, NNSA and Y-12 established a plan for providing temporary humidity control in building 9204-2 in the event that the primary dehumidification systems failed, which would result in Y-12 suspending lithium production. NNSA and the Y-12 contractor have not yet had to use their existing rapid response plans and expect to establish additional plans in the future, according to NNSA officials and a Y-12 contractor document.

Delays to Sustainment Efforts

NNSA has faced additional delays to implementing its near-term sustainment efforts, according to NNSA officials and Y-12 contractor representatives, which could have an impact on their ability to meet

[70]A majority of the building 9204-2 lithium processes are conducted in a controlled, dry environment, due to the water-reactive nature of lithium materials and strict process quality specifications. As a result, operation of the dehumidification units is critical for meeting production safety and quality requirements. The dehumidification system uses kathene, which is highly corrosive and, as a result, is a significant contributor to deterioration of the infrastructure and equipment in certain areas of the building. In addition, the dehumidification units pull the water out of concrete, which causes it to crumble and exposes the rebar, which can then be corroded by kathene and chlorine gas produced during the wet chemistry process.

lithium demand.[71] For example, NNSA's efforts to procure and install an upgraded parts cleaning station for DMM were delayed and, as a result, the effort is not expected to be completed until September 2022. Specifically, NNSA procured gloveboxes from a vendor, and there were unexpected engineering deficiencies during their installation, resulting in delays to the effort. In addition, this effort has been delayed by the effects of COVID-19, design changes, and issues with the heating and air conditioning equipment. As a result, costs of efforts to procure and install an upgraded parts cleaning station have increased by over $10 million compared with the performance cost baseline, according to NNSA officials. Furthermore, if there are delays to completing the LPF and starting operations in the early 2030s, sustaining lithium operations using the existing facilities and equipment will become increasingly difficult, according to NNSA officials.

NNSA's Lithium Modernization Program Management Tools Are Under Development

NNSA is in the process of developing important management tools for the Lithium Modernization program encompassing both the LPF project and efforts to sustain near-term lithium operations. Important management tools include the Lithium Modernization program's current scope, as documented in the program's work breakdown structure, its integrated master schedule, and its life-cycle cost estimate. Currently, these tools are not complete or aligned with one another. Specifically, the Lithium Modernization program's work breakdown structure does not capture the complete scope of work needed to accomplish program goals. In addition, the Lithium Modernization program's work breakdown structure does not align with the program's integrated master schedule. Finally, NNSA does not have a life-cycle cost estimate for the Lithium Modernization program and does not expect to develop one until after 2025. This means that planning and implementation decisions for various ongoing and near-term activities—which NNSA estimates will exceed $200 million over the next 5 years—may be made without the benefits of this important information.

[71]Examples of other schedule delays include ongoing COVID-19 restrictions, competing production priorities at Y-12, funding shortfalls, and increases to the scope of the effort.

NNSA's Work Breakdown Structure for the Lithium Modernization Program Does Not Capture a Complete Scope of Work for Its Activities

NNSA has developed a work breakdown structure for the Lithium Modernization program since the program was established in 2019, but the structure does not capture the complete scope of work needed to meet the program's goals.[72] Specifically, we found the Lithium Modernization program's November 2020 work breakdown structure does not include all elements necessary to achieve the program's goal. Including all elements is also the basis for establishing the total cost of the program, which historically has been an issue for NNSA.[73]

NNSA officials said that the program's work breakdown structure does not include activities funded by other NNSA components, such as infrastructure recapitalization efforts funded by the Office of Safety, Infrastructure, and Operations. According to officials, this is because NNSA decided to include in its work breakdown structure only those activities funded under the specific budgetary control for the Lithium Modernization program.[74] In our analysis of the November 2020 work breakdown structure, we found that the scope of work does not clearly identify

- activities related to qualification of lithium materials to support weapons modernization and life extension programs;

[72]The Lithium Modernization program was the last of NNSA's original strategic materials programs to have a federal program manager appointed. See GAO-18-99.

[73]See, for example, GAO, *Nuclear Weapons: Actions Needed to Identify Total Costs of Weapons Complex Infrastructure and Research and Production Capabilities*, GAO-10-582 (Washington, D.C.: June 21, 2010); and *National Nuclear Security Administration: Additional Actions Needed to Collect Common Financial Data*, GAO-19-101 (Washington, D.C.: Jan. 31, 2019).

[74]For annually appropriated accounts, such as those for NNSA, the Office of Management and Budget and NNSA identify a program, project, or activity 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).

- some activities to sustain lithium facilities and equipment included in the lithium infrastructure implementation plan;[75]
- activities supported by the Office of Safety, Infrastructure, and Operations, such as concrete monitoring and replacement; and
- the demolition of the Biology Complex by the DOE Office of Environmental Management as the site of the LPF.

According to our *Cost Estimating and Assessment* and *Scheduling Assessment* guides, a properly constructed work breakdown structure captures a complete scope of work and should include every element of work necessary to support the program, regardless of funding source.[76] A complete scope of work is a building block for other program management tools, such as the integrated master schedule and a life-cycle cost estimate. A complete work breakdown structure can facilitate the tracking of resource allocations and expenditures, and it provides a basic framework for developing schedules and estimating costs. Therefore, a work breakdown structure should be complete enough to represent the entire program in detail sufficient to manage the size, complexity, and risk associated with the program.

Our *Cost Estimating and Assessment* and *Scheduling Assessment* guides further state that there should be one work breakdown structure for each program, and it should match the work breakdown structure used for the schedule and cost estimate so that actual costs can be fed back into the estimate with a correlation between the cost estimate and schedule.[77] In addition, the work breakdown structure should be updated as the program becomes better defined and to reflect changes as they occur. Without developing a work breakdown structure that captures the complete scope of work for the Lithium Modernization program, NNSA cannot build reliable cost estimates, and activities missing from the structure could be omitted from program planning, resulting in unanticipated delays and cost overruns.

[75]Funding sources for these activities included Capabilities Based Investments, Weapons Dismantlement and Disposition, and the maintenance and repair program.

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

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

NNSA's Common Financial Reporting Effort

Historically, the National Nuclear Security Administration (NNSA) and Congress have had difficulty determining the total costs of NNSA's programs and comparing costs across the management and operating contractors. NNSA implemented an agency-wide common work breakdown structure in response to financial reporting requirements in the National Defense Authorization Act for Fiscal Year 2017 and GAO recommendations. Section 3113 of the National Defense Authorization Act for Fiscal Year 2017 required the NNSA Administrator to implement a common financial reporting system for the nuclear security enterprise.

For fiscal years 2018 and 2019, the Office of Defense Programs, which includes the Lithium Modernization program, adopted a common work breakdown structure that was also used by several other NNSA program offices to demonstrate that a common structure could be used. In May 2020, NNSA expanded the common structure into the Offices of Safety, Infrastructure, and Operations and Defense Nuclear Nonproliferation.

According to GAO's *Cost Estimating and Assessment Guide,* establishing a common work breakdown structure is a best practice because it enables an organization to collect and share data among programs and across the agency, results in more consistent cost estimates, and leads to more efficient program execution.

Source(s): Pub. L. No. 114-328, § 3113, 130 Stat. 2000, 2757 (2016). For GAO reports on common financial reporting, see *National Nuclear Security Administration*: *Additional Actions Needed to Collect Common Financial* Data, GAO-19-101 (Washington, D.C.: Jan. 31, 2019); and *National Nuclear Security Administration: Additional Verification Checks Could Improve the Accuracy and Consistency of Reported Financial Data,* GAO-20-180 (Washington, D.C.: Jan. 16, 2020). | GAO-21-244

Further, the November 2020 lithium program work breakdown structure is a significant revision from a previous April 2020 version of the work breakdown structure., NNSA revised that version because it did not meet the requirement to use an NNSA-wide common work breakdown structure. According to NNSA officials, they were unaware of the requirement that would have helped them develop an April 2020 version of the work breakdown structure that was consistent with the agency-wide structure. The National Defense Authorization Act for Fiscal Year 2017 required NNSA to develop a common work breakdown structure as part of its efforts to implement common financial reporting.[78] This common structure allows NNSA to effectively analyze common financial data across its programs and sites.

We found that this requirement to use a NNSA-wide common structure is not included in the Office of Defense Programs' program management guidance, the *Program Execution Instruction*, which the Lithium Modernization program managers said they use to manage their program. By including common financial reporting requirements in Defense Programs' *Program Execution Instruction*, NNSA will be better positioned to avoid using structures that are not consistent with the agency-wide common work breakdown structure in the future and ensure that cost information is comparably collected across programs. Continuing to use a work breakdown structure that is not consistent with the common structure would require rework, as was done by the Lithium Modernization program to create the November 2020 work breakdown structure or, if not reworked, would result in NNSA collecting financial data in a structure that is inconsistent with other programs. Such inconsistent data collection could lead to inaccuracies, such as double-counting or undercounting costs.

NNSA's Lithium Modernization Integrated Master Schedule Does Not Align with Its Work Breakdown Structure

The Lithium Modernization program most recently revised its integrated master schedule in March 2021, but the structure of the schedule does not align with the November 2020 work breakdown structure. Specifically, NNSA officials said the March 2021 integrated master schedule includes additional activities that are funded through other NNSA programs and

[78]Pub. L. No. 114-328, § 3113(b)(2), 130 Stat. 2000, 2757 (2016).

activities because it is important for the Lithium Modernization program to maintain awareness of other NNSA activities that have an impact on their program. These activities were not included in NNSA's November 2020 work breakdown structure, as discussed above.

According to best practices identified in our *Schedule Assessment Guide*, the integrated master schedule should be based on the work breakdown structure, and every activity within the schedule should be traceable to an appropriate element of the work breakdown structure.[79] NNSA officials stated they were unaware that every activity in the schedule should track back to an element of the work breakdown structure. By aligning the integrated master schedule to the work breakdown structure, NNSA could help ensure that the entire scope of work is accounted for within the schedule and that NNSA is accomplishing important program activities on time to sustain the nuclear weapons stockpile until the LPF is fully operational. This further demonstrates why it is important for NNSA to develop a complete scope of work for the program and ensure that critical program management tools align with one another.

NNSA Does Not Have a Life-Cycle Cost Estimate for the Lithium Modernization Program

NNSA has not developed a life-cycle cost estimate—another important program management tool, which relies on a complete work breakdown structure and a corresponding integrated master schedule to inform its development—or any other overall cost estimate for the Lithium Modernization program. According to our *Cost Estimating and Assessment Guide*, a life-cycle cost estimate can be thought of as a "cradle to grave" approach that identifies all cost elements that pertain to a program from initial concept all the way through operations, support, and the end of the program.[80] According to NNSA officials, a life-cycle cost estimate for the Lithium Modernization program has not been completed and remains under development as planning continues for lithium modernization activities. Specifically, those officials said they do not plan to complete a program life-cycle cost estimate until after the LPF project's performance baselines are approved at CD-2, an event that is scheduled to occur by November 2025.

[79]GAO-16-89G.

[80]GAO-20-195G.

However, the main impediment to NNSA's ability to develop a life-cycle cost estimate is its incomplete understanding of the scope and estimated schedule and costs of the lithium activities outside of the LPF project, rather than information on the LPF project's costs. As previously discussed, there are lithium-related activities outside the scope of the LPF that will need to be replaced or recapitalized; infrastructure sustainment activities to continue to operate the lithium production process in buildings 9204-2 and 9202, among others; and activities to transition and transfer aging infrastructure and equipment to the DOE Office of Environmental Management. According to the Y-12 infrastructure implementation plan for October 2020, these efforts are expected to cost over $1 billion—with funding coming from the Lithium Modernization program and other programs. The plan acknowledged that the list of projects developed as of October 2020 is not a complete list and is likely to increase in the next iteration of the plan scheduled for release in 2021.

Our *Cost Estimating and Assessment Guide* states that cost estimates support decisions about funding one program over another and help agencies develop annual budget requests and evaluate resource requirements at key decision points.[81] Moreover, the guide says that having a realistic estimate of projected costs makes for effective resource allocation and increases the probability of a program's success. According to best practices, a credible cost estimate reflects all costs associated with a program—that is, it must be based on a complete scope of work—and that the estimate should be updated to reflect changes in requirements, which also affect the scope of work and the integrated master schedule.

Because NNSA has not completely captured its scope of work within its work breakdown structure or aligned its integrated master schedule with that work breakdown structure, NNSA does not have the basis for preparing a credible life-cycle cost estimate for the program. Having a life-cycle cost estimate can enhance decision-making, especially in early planning and concept formulation of acquisition, as well as support budget decisions, key decision points, milestone reviews, and investment decisions, according to our *Cost Estimating and Assessment Guide*.[82] For the Lithium Modernization program, a life-cycle cost estimate could better

[81]GAO-20-195G.

[82]GAO-20-195G.

inform decision-making regarding program management and funding, including by Congress.

NNSA officials said they intend to complete a life-cycle cost estimate sometime in fiscal year 2025 after approving the performance baseline for the LPF project. In the meantime, NNSA plans to request over $200 million for Lithium Modernization program costs over the next several years, according to the agency's fiscal year 2021 budget request. It also plans to support lithium activities using additional budget accounts. In addition, important activities, such as the reestablishment of wet chemistry to meet lithium demand, need to be completed before 2025. Not having a life-cycle cost estimate means decision makers at NNSA do not have important information that could inform planning and implementation decisions for these ongoing and near-term activities.

Conclusions

NNSA is planning to construct its new LPF at Y-12—the agency's only site for processing lithium for the nation's nuclear stockpile—over the next decade and expects to achieve full operational capacity for the facility by the early 2030s. The agency estimated in 2019 that the facility will cost between $955 million and $1.6 billion to construct. Until the LPF is fully operational, the agency must continue to meet near-term lithium demand using facilities and equipment that, because of their age and deteriorated condition, NNSA recognizes pose significant risks. Any delay to the LPF construction and operations would require that NNSA sustain lithium operations for even longer in these precarious facilities, and NNSA has identified additional risks to do so. To reduce these risks to the greatest extent possible, it is critical that NNSA take steps to effectively plan and manage its lithium activities consistent with best practices. Without following best practices for completing TRAs, NNSA risks delays to completing the LPF design in time to start construction by November 2025. This may, in turn, potentially jeopardize NNSA's nuclear weapons modernization plans. Although NNSA is taking steps to manage its lithium activities as a consolidated program, important program management tools are under development and currently are not consistent with best practices or statutory requirements for financial reporting. NNSA does not have a complete scope of work for the program that is aligned to its integrated master schedule, which may prevent the agency from developing a complete life-cycle cost estimate for the program and ensuring that NNSA is accomplishing all program activities on time and within budgets.

Recommendations for Executive Action

We are making the following seven recommendations to NNSA:

The Lithium Modernization Program Manager and the Federal Project Director for the LPF project should ensure that a TRA plan is documented, including a comprehensive assessment that ensures all key information is obtained by the TRA team to conduct future TRA assessments. (Recommendation 1)

The Lithium Modernization Program Manager and the Federal Project Director for the LPF project should take steps to ensure that all key data are collected and assessed before completing future TRA assessments and achieving key project milestones. (Recommendation 2)

The Lithium Modernization Program Manager and the Federal Project Director for the LPF project should complete and document management reviews of the TRA process following the completion of future TRAs. (Recommendation 3)

The Lithium Modernization Program Manager should ensure that the lithium modernization work breakdown structure captures the complete scope of work of lithium activities and should update the work breakdown structure in the event of future changes in scope. (Recommendation 4)

The Associate Administrator for Defense Programs should update its Defense Programs *Program Execution Instruction* to include the requirement that programs' work breakdown structures use the NNSA-wide common work breakdown structure. (Recommendation 5)

The Lithium Modernization Program Manager should align the program's integrated master schedule and work breakdown structure and do so continuously, following best practices for managing and integrating program scope, schedule, and cost. (Recommendation 6)

The Lithium Modernization Program Manager should develop a life-cycle cost estimate that aligns with the work breakdown structure and integrated master schedule, following best practices for managing and integrating program scope, schedule, and cost. (Recommendation 7)

Agency Comments and Our Evaluation

We provided a draft of this report to NNSA for review and comment. In its written comments, reproduced in Appendix VI, NNSA concurred with five recommendations and concurred in principle with two. Specifically, NNSA stated that it considers the fourth and sixth recommendations to be closed—that sufficient action has already been taken to address the recommendations—based on existing documentation and processes. We reviewed NNSA's existing documents and processes as part of our review and disagree that they fully address these two recommendations, as discussed below. NNSA also provided technical comments, which we incorporated as appropriate,

In its comments on recommendations four and six, NNSA reiterated that the current work breakdown structure contains only the scope of work for activities funded by the Lithium Modernization program and the agency does not plan to include activities funded by other components on the work breakdown structure to avoid double counting of funds. As a result, NNSA does not plan to fully align the work breakdown structure for the Lithium Modernization program with its integrated master schedule because the schedule does track activities that are funded by other NNSA components in support of the Lithium Modernization program.

We believe that by including activities not funded directly by the Lithium Modernization program in the integrated master schedule, NNSA has illustrated the importance of NNSA developing a complete scope of work, regardless of funding source, in its work breakdown structure for managing the Lithium Modernization program so that it fully aligns with the integrated master schedule.

Best practices outlined in our *Cost Estimating and Assessment* Guide are clear that the three program management tools build upon one another. According to the guide, to build an accurate life-cycle cost estimate, programs need to establish a full scope of work, represented by a complete work breakdown structure, and an integrated schedule of all program activities. Without a complete scope of work for the Lithium Modernization program that aligns with the integrated master schedule, we have concerns about NNSA's ability to produce an accurate life-cycle cost estimate, which would give Congress insight into the total costs for the Lithium Modernization program. A life-cycle cost estimate is not limited to identifying costs from a single funding source, but rather it should include the costs of all activities associated with the program.

NNSA does not anticipate having a life-cycle cost estimate for the Lithium Modernization program until May 2026 and officials stated that their reason for not developing a life-cycle cost estimate earlier is due to uncertainty around the costs of the LPF project. NNSA has already developed preliminary cost estimates for the LPF at CD-1. However, NNSA has not determined the cost of other lithium activities that will be necessary to continue to supply lithium materials for multiple weapons modernization programs while the new facility is constructed. Our review found these activities are likely to cost millions of dollars to sustain lithium infrastructure and develop plans to replace lithium support activities not included in the scope of the LPF. Without providing a life-cycle cost estimate for the entire Lithium Modernization program, Congress cannot make informed appropriations decisions.

We are sending copies of this report to the appropriate congressional committees, the Secretary of 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 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 this report are listed in appendix VII.

Allison Bawden
Director, Natural Resources and Environment

Appendix I: Objectives, Scope, and Methodology

The Senate committee report accompanying the National Defense Authorization Act for Fiscal Year 2020 included a provision for GAO to review the National Nuclear Security Administration's (NNSA) planning and assumptions for the Lithium Modernization program and the lithium processing facility (LPF) project.[1] This report examines (1) the current cost and schedule estimates for NNSA's LPF project and the status of design activities; (2) NNSA's near-term strategy to meet demand for lithium until the LPF is operational and to address any risks NNSA faces in implementing the strategy; and (3) the extent to which NNSA has developed management tools for the Lithium Modernization program, consistent with best practices.

To examine the current cost and schedule estimates for NNSA's LPF project and the status of design activities, we reviewed Department of Energy (DOE) and NNSA policies that NNSA is required to follow when managing capital asset acquisition projects such as the LPF project.[2] We also reviewed NNSA's documentation of the project's critical decisions, such as those approving alternative selection and the project's preliminary cost and schedule range.[3] We reviewed DOE's project status reports from fiscal years 2020 and 2021 and NNSA budget information from fiscal years 2019 to 2021—the most recent available at the time of our review—for specific cost and schedule information for the LPF project. We compared NNSA's preliminary LPF cost estimate that was approved in December 2019 with best practices included in GAO's *Cost*

[1]S. Rep. No. 116-48, at 388 (2019). The Senate committee report provision was for GAO to review the planning and assumptions for the Lithium Sustainment program, which NNSA renamed the Lithium Modernization program, and the lithium production capability project, which NNSA renamed the LPF project.

[2]Department of Energy, *Program and Project Management for the Acquisition of Capital Assets*, DOE Order 413.3B (Washington, D.C.: Nov. 29, 2010; updated Apr. 12, 2018).

[3]Under DOE Order 413.3B, DOE capital asset projects with an estimated or baselined total project cost of $50 million or more are to go through five management reviews and approvals, called "critical decisions," as the project moves forward from planning and design to construction and operation.

Estimating and Assessment Guide[4] related to the comprehensive characteristic to ensure that the December 2019 estimate includes all required costs and technical requirements.[5] We did not perform a similar assessment of NNSA's preliminary schedule estimate for the LPF project because of the maturity of the schedule at the time of our review.[6]

We reviewed DOE and NNSA policies and guides related to technology readiness assessments[7] (TRA) and our *TRA Guide*[8] to compare them with NNSA's documents evaluating critical technologies for potential inclusion in the LPF design. Specifically, we compared NNSA's most recent technology assessment completed in April 2020[9] and its June 2020 technology maturation plan to best practices that form the basis of a high-quality TRA.[10]

To discuss the LPF project's status and NNSA's plan for completing the facility design and ongoing efforts to mature new technology for the LPF project, we interviewed NNSA officials from the Office of Defense

[4]GAO, *Cost Estimating and Assessment Guide: Best Practices for Developing and Managing Program Costs*, GAO-20-195G (Washington, D.C.: Mar. 12, 2020).

[5]According to our *Cost Estimating and Assessment Guide,* a cost estimate is considered reliable if it meets all four characteristics of the best practices: comprehensive, well documented, accurate, and credible. GAO-20-195G. Using the maturity of the preliminary cost estimate approved in December 2019, we compared the estimate with only one of the four characteristics: comprehensive. NNSA plans to produce an updated cost estimate for the LPF project when it approves the project's performance baseline at the next critical decision milestone.

[6]We reviewed the Lithium Modernization program's integrated master schedule, which includes high-level project milestones for the LPF.

[7]Department of Energy, *Technology Readiness Assessment Guide,* DOE Guide 413.3-04A (Washington, D.C.: Oct. 22, 2015); National Nuclear Security Administration, *Technology Readiness Assessments*, NAP-413.4 (Washington, D.C.: Dec. 22, 2016); and *Defense Programs Technology Readiness Assessment Implementation Guide, Revision 3.1* (Washington, D.C.: Dec. 3, 2018).

[8]GAO, *Technology Readiness Assessment Guide: Best Practices for Evaluating the Readiness of Technology for Use in Acquisition Programs and Projects [Reissued with revisions on Feb. 11, 2020.],* GAO-20-48G (Washington, D.C.: Jan. 7, 2020).

[9]The April 2020 TRA was documented in June 2020. Consolidated Nuclear Security, *Lithium Homogenization and Thermal Decomposition and Distillation Technology Readiness Assessment Report* (Oak Ridge, TN: June 2020).

[10]According to our *TRA Guide*, a technology readiness assessment is high quality if it meets all four characteristics of the best practices: credible, objective, reliable, and useful. GAO-20-48G.

Programs' Lithium Modernization program, and the Office of Acquisition and Project Management, including the Y-12 National Security Complex (Y-12) Acquisition and Project Management Office, that oversee certain construction projects at Y-12. We also interviewed representatives from the management and operating (M&O) contractor for Y-12. We also analyzed documentation and interviewed officials from DOE's Office of Project Management (DOE-PM) and NNSA's Office of Cost Estimating and Program Evaluation regarding their independent reviews of NNSA's cost and schedule estimates that the Office of Acquisition and Project Management conducted.

To examine NNSA's near-term strategy to meet demand for lithium until the LPF is operational and to address any risks NNSA faces in implementing the strategy, we reviewed documents—which included information on risks and plans to address them—from NNSA and the M&O contractor for Y-12, including monthly status reports, annual implementation plans, and lithium strategy documents. We planned to conduct a site visit to Y-12 in Tennessee to observe the condition of the existing lithium production facilities; however, we were unable to do so because of travel restrictions in place due to the effects of Coronavirus Disease 2019 (COVID-19).[11] To gather similar evidence, we

- collected and reviewed photographs of infrastructure and equipment used to process lithium at Y-12;
- interviewed relevant Y-12 contractor representatives who manage lithium operations; and
- interviewed NNSA officials from the NNSA Production Office, the federal field office co-located with Y-12, and from the Lithium Modernization program.

We also interviewed NNSA officials from other offices that provide funding for lithium activities, including the Office of Defense Programs' Weapons Dismantlement and Disposition and Capabilities Based Investments programs and the Office of Safety, Infrastructure and Operations.

To examine the extent to which NNSA has developed management tools for the Lithium Modernization program, consistent with best practices, we

[11]On March 11, 2020, the World Health Organization declared COVID-19 a pandemic. NNSA delayed some work on lithium operations due to limited availability of staff to work as a result of COVID-19 safety measures implemented at Y-12.

reviewed NNSA's program planning and management documents for the newly created Lithium Modernization program and our *Schedule Assessment and Cost Estimating and Assessment* guides.[12] As noted in those guides and our previous reporting, developing a proper scope of work, an integrated master schedule, and a life-cycle cost estimate increases the probability of program success. Specifically, we reviewed NNSA's Lithium Modernization program's scope of work as presented in its work breakdown structure, including the first iteration from April 2020 and the revised structure from November 2020. We compared NNSA's work breakdown structure with the program's integrated master schedule to determine the extent to which the documents are aligned.

We also compared the Defense Programs' *Program Execution Instruction* with section 3113 of the National Defense Authorization Act for Fiscal Year 2017 to determine whether the statutory common financial reporting requirements were included in the document.[13] We also reviewed how lithium activities are organized and funded based on DOE and NNSA organization charts, budget and schedule information, and documents from the Y-12 contractor on the funding of lithium activities. We interviewed NNSA officials responsible for lithium activities and program management within the Office of Defense Programs, specifically officials from the Office of Secondary Stage Production Modernization and, within it, the Lithium Modernization program, and the Office of Systems Engineering and Integration, which provides support for programs using the Program Execution Instruction, about their development of key program management tools in line with DOE and NNSA policies and guidance.

We conducted this performance audit from January 2020 to August 2021 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.

[12]GAO, *Schedule Assessment Guide: Best Practices for Project Schedules*, GAO-16-89G (Washington, D.C.: Dec. 22, 2015); and GAO-20-195G.

[13]National Nuclear Security Administration, *Office of Defense Programs DP Program Execution Instruction* (Washington, D.C.: June 19, 2019); and Pub. L. No. 114-328, § 3113, 130 Stat. 2000, 2757 (2016).

Appendix II: Condition of Lithium Infrastructure at the Y-12 National Security Complex

Many of the buildings and infrastructure at the Y-12 National Security Complex (Y-12) are old, and in some cases date to the 1940s, when Y-12 was part of the Manhattan Project. This includes many of the facilities that house lithium processing equipment, and the condition of these facilities has placed the National Nuclear Security Administration's (NNSA) ability to meet lithium demand at risk. NNSA and the management and operating contractor for Y-12 are developing plans for maintaining operations until after the lithium processing facility (LPF) is fully operational. They expect that many of the buildings will be transferred to the Office of Environmental Management's excess facilities disposition program for demolition, according to the Y-12 October 2020 infrastructure implementation plan.

The following buildings constitute the main assets that house capabilities for producing lithium at Y-12:[1]

- **Building 9204-2.** Constructed in 1943, the building has been the primary location of Y-12's lithium production operations, including the suspended wet chemistry process for lithium purification and the equipment for lithium machining. According to the Y-12 contractor's July 2019 *Lithium Strategy*, the building is significantly oversized for the current mission, is well beyond its expected life, and is deteriorating rapidly. Much of the operating equipment was installed in the 1980s and has also exceeded its intended design life. The corrosive materials used in the production process, and the building's humidity control systems, have caused deterioration to the structural steel rebar and concrete. The Y-12 contractor has identified the building as a high-risk asset and developed a strategy to sustain operations and mitigate the risks of a catastrophic failure in building 9204-2 until after the new LPF is operational in the 2030s. Once the LPF is operational, NNSA plans to transition the facility to the excess facilities disposition program for demolition.

[1]When NNSA refers to a "building," it can include a facility, group of buildings, complex, or structure.

- **Building 9202.** Constructed in 1943, the building supports research and development for lithium operations and other NNSA programs and contains the lithium parts cleaning station used for the direct materials manufacturing process used to clean recycled lithium.[2] In addition, the building supports the Department of Energy's (DOE) Office of Science's processes to produce lithium material for other consumers. The building has significant structural issues and degradation to the heating, ventilating, and air conditioning system, electrical systems, and the roof, which have caused process interruptions. The Y-12 contractor has identified numerous efforts to sustain building 9202. Once the LPF is operational, NNSA plans to transition the facility to the excess facilities disposition program for demolition.
- **Building 9204-2E.** Constructed in the late 1960s and part of the Building 9204-2 Complex, the building—sometimes referred to as Beta-2E—supports lithium activities, including the dismantling of lithium components. NNSA plans to replace this facility in the 2050s, according to agency officials.
- **Building 9404-09.** Constructed in 1944, the building supports lithium activities by producing rubber inserts for containers and creates and stores molds for weapons parts, according to NNSA officials and a Y-12 contractor document. NNSA plans to prepare this facility for demolition but does not have a plan in place to replace its capability.
- **Buildings 9805 and 9805-1.** Constructed in 1956, these buildings provided deuterium gas for lithium deuteride production and are currently shut down, according to NNSA officials and a Y-12 contractor document.[3] NNSA plans to prepare these facilities for demolition but does not have a plan in place to replace this capability, which it estimates will be needed by 2039.
- **Building 9995.** Constructed in the mid-1950s, this building contains a laboratory with capabilities for analytical chemistry operations to support lithium production, among other things.[4] To continue operations in this building, NNSA will need to complete improvements to the heating, ventilating, and air conditioning system; the electrical system; plumbing; roofing; and the structure itself. The Y-12 contractor established an extended life program implementation plan

[2]Building 9202 supports other development activities, in addition to lithium production.

[3]According to a Y-12 contractor document, building 9805 is in use for hydrogen metering.

[4]Building 9995 is also used to support enriched uranium processing. GAO-20-293.

for this facility in 2019 and does not plan to replace the facility at this time.

- **Building 9201-01.** Constructed in 1969, this building is a support facility for general manufacturing production activities such as pressing, among other things.
- **Lithium Storage Complex.** The complex includes five buildings used to store lithium and other special materials. According to a Y-12 contractor document, the lithium container racks need reconfiguration to increase the storage capacity, which continues to be a concern at Y-12.

Appendix III: Summary of Independent Reviews of NNSA's Lithium Processing Facility Preliminary Cost and Schedule Estimates

Before finalizing and approving the substantial increases to the preliminary cost and schedule estimates in December 2019, two offices within the Department of Energy (DOE) and the National Nuclear Security Administration (NNSA) performed independent reviews of NNSA's preliminary estimates. In June 2019, DOE's Office of Project Management (DOE-PM) conducted an independent cost review and recommended adjustments to the cost and schedule estimates for the lithium processing facility (LPF) project.[1] DOE-PM recommended an adjusted cost range of $765 million to $1.625 billion and a schedule range for critical decision (CD)-4 of August 2027 to December 2031, according to recommended changes to the cost and schedule range and contingency. In September 2019, DOE-PM released a supplemental report to the independent cost review that recommended additional increases to the cost range from $805 million to $1.715 billion and an increase to the schedule range of July 2028 to November 2032. According to DOE-PM officials, NNSA is not required to address their recommendations; however, the officials said NNSA addressed their recommendations appropriately.

Separately, and at the request of the Office of Defense Programs, in August 2019, NNSA's Office of Cost Estimating and Program Evaluation performed a review to determine the drivers of the substantial increases to the cost and schedule of the LPF since 2017 and to find options for reducing them. According to the Office of Cost Estimating and Program Evaluation's review, the estimates had increased since 2017 because earlier estimates had not included costs for the entire scope of work based on NNSA's requirements at the time. As a result of better reflecting

[1]DOE-PM is required to conduct an independent cost estimate or independent cost review prior to CD-1 for capital asset projects when the estimated total project cost is greater than $100 million.

the scope of work, the review found that the square footage for the LPF had doubled in size in the conceptual design since the 2017 analysis of alternatives. The Office of Cost Estimating and Program Evaluation provided options to the Office of Defense Programs to reduce the cost and schedule of the LPF in part by removing certain lithium activities from the project scope. However, the Office of Defense Programs decided to continue the project without substantial changes because of concerns about the deteriorating conditions in building 9204-2.[2]

[2]Specifically, NNSA's Office of Cost Estimating and Program Evaluation made two recommendations to reduce the LPF project scope: (1) to continue the machining area in building 9204-2, which is less deteriorated than other areas of the building, and building the new LPF to replace the other steps in the production process; or (2) to refurbish an existing building at the Savannah River Site and continue to operate certain activities in building 9204-2.

Appendix IV: Summary of GAO's Analysis of NNSA's Preliminary Cost Estimate for the Lithium Processing Facility

Our research has found that a high-quality, reliable cost estimate is one that is comprehensive, well documented, accurate, and credible. Management minimizes the risk of cost overruns and unmet performance targets by ensuring that cost estimates reflect these four characteristics. We evaluated the National Nuclear Security Administration's (NNSA) preliminary cost estimate for the lithium processing facility (LPF) for critical decision (CD)-1 against the best practices for a comprehensive cost estimate to ensure that the preliminary estimates contain all required cost and technical requirements based on the maturity of the estimate. NNSA officials said they plan to complete a life-cycle cost estimate for the lithium modernization program in fiscal year 2025.

A comprehensive cost estimate completely defines the program and reflects the current schedule and technical baseline. The cost estimates are structured with sufficient detail to ensure that cost elements are neither omitted nor double-counted. Where information is limited and judgments must be made, assumptions and exclusions on which the estimate is based should be reasonable, clearly identified, explained, and documented. See table 3 for our assessment of NNSA's LPF cost estimate compared with best practices.

Table 2: Summary of GAO's Analysis of the National Nuclear Security Administration's (NNSA) Lithium Processing Facility (LPF) Preliminary Cost Estimate Compared with Best Practices for the Comprehensive Characteristic

Summary assessment	Best practices for comprehensiveness	Individual assessment	GAO assessment
Substantially met	The cost estimate includes all life-cycle costs.	Met	The cost estimate included all life-cycle costs for the project and costs associated with the government and the contractor.
	The cost estimate is based on a technical baseline description that completely defines the program, reflects the current schedule, and is technically reasonable.	Partially met	The technical baseline is partially met because it includes only high-level information, and assumptions were not documented for certain lower-level project cost elements.
	The cost estimate is based on a work breakdown structure that is product oriented, traceable to the statement of work, and at an appropriate level of detail to ensure that cost elements are neither omitted nor double-counted.	Substantially met	The work breakdown structure clearly defines the project and has an associated dictionary, but it does not align with NNSA's common work breakdown structure.
	The cost estimate documents all cost-influencing ground rules and assumptions.	Substantially met	The rationale or historical basis for the assumptions or the associated risk of the assumptions was not included in the documentation.

Legend:

Met=NNSA provided complete evidence that satisfies the entire criterion.

Substantially met=NNSA provided evidence that satisfies a large portion of the criterion.

Partially met=NNSA provided evidence that satisfies about half of the criterion.

Minimally met=NNSA provided evidence that satisfies a small portion of the criterion.

Not met=NNSA provided no evidence that satisfies any of the criterion.

Source: GAO analysis of NNSA's LPF cost estimate. | GAO-21-244

Note: We determined the overall assessment rating by assigning an individual rating to each best practice: Not met = 1; Minimally met = 2; Partially met =3; Substantially met = 4; and Met = 5. Then, we took the average of the individual assessment ratings to determine the overall rating for each of the four characteristics. The resulting average becomes a characteristic rating as follows: Not met = 1.0 to 1.4; Minimally met = 1.5 to 2.4; Partially met = 2.5 to 3.4; Substantially met = 3.5 to 4.4; and Met = 4.5 to 5.0.

Appendix V: Summary of GAO's Analysis of the NNSA's Technology Readiness Assessment of Homogenization

A technology readiness assessment (TRA) is a systematic, evidence-based process that evaluates the maturity of technologies that are critical to the performance of a larger system or the fulfillment of the key objectives of an acquisition project, including cost and schedule. TRAs, which evaluate the technical maturity of a technology at a specific point in time for inclusion into a larger system, do not eliminate technology risk. But when done well, they can illuminate concerns and serve as the basis for realistic discussions on how to address potential risks as programs move from the early research and technology development to system development and beyond.

Our *TRA Guide* describes five steps for conducting high-quality assessments that provide the framework for planning, assessing, and reporting the results (see fig. 9).[1] There are 29 best practices included within the five steps that form the basis of a high-quality TRA.

Figure 9: Five Steps for Conducting a High-Quality Technology Readiness Assessment (TRA)

Source: GAO. | GAO-21-244

[1]GAO, *Technology Readiness Assessment Guide: Best Practices for Evaluating the Readiness of Technology for Use in Acquisition Programs and Projects [Reissued with revisions on Feb. 11, 2020.]*, GAO-20-48G (Washington, D.C.: Jan. 7, 2020).

Text of Figure 9: Five Steps for Conducting a High-Quality Technology Readiness Assessment (TRA)

1. Step 1: Prepare the TRA plan and identify the TRA team
2. Step 2: Prepare the TRA Plan and Identify the TRA Team
3. Step 3: Assess the Critical Technologies
4. Step 4: Prepare the TRA report
5. Step 5: Use the TRA findings

Source: GAO. | GAO-21-244

In the *TRA Guide*, we established a methodology for evaluating technology maturity according to best practices that can be used across the federal government.[2] Our research and discussions with experts from government, industry, nonprofits, and academia has found that high-quality TRAs are credible, objective, reliable, and useful. A TRA is considered credible, objective, reliable, and useful if the overall assessment ratings for each of the four characteristics are substantially or fully met. If any of the characteristics are not met, minimally met, or partially met, then the TRA does not fully reflect the characteristics of a high-quality TRA. See table 2 for our assessment of the National Nuclear Security Administration's (NNSA) April 2020 TRA for homogenization compared with best practices.

Table 3: Summary of GAO's Analysis of the National Nuclear Security Administration's (NNSA) April 2020 Technology Readiness Assessment (TRA) for Lithium Homogenization Compared with Best Practices

Characteristic	Overall assessment	Summary of GAO's assessment
Credible TRAs are conducted with an understanding of the requirements that guide development of the critical technologies and system, the relevant or operational environment in which it will function, and its integration or interaction with other technologies.	Met	NNSA's January 2017 analysis of alternatives established factors for evaluating critical technologies, including tradeoffs and the impact of maturing the critical technology on the mission. NNSA laid out clear testing activities to appropriately evaluate homogenization at a testable level.

[2]GAO-20-48G.

Characteristic	Overall assessment	Summary of GAO's assessment
Objective TRAs are based on objective, relevant, and trustworthy data, analysis, and information, and the judgements, decisions, and actions for planning and executing the assessment are free from internal and external bias or influence.	Substantially met	NNSA's April 2020 TRA for homogenization clearly described the technology and the testing needed for achieving technology readiness level (TRL) 6. However, NNSA did not complete testing to collect important data on chemical, physical, and mechanical properties of the lithium material. The TRA team included team members selected from both NNSA national laboratories—Lawrence Livermore and Los Alamos—as well as the Pacific Northwest National Laboratory. However, the TRA could have included additional documentation to establish their expertise, qualifications, and independence. NNSA did not fully document the criteria it used to narrow down its selection of critical technologies.
Reliable TRAs follow a disciplined process that facilitates repeatability, consistency, and regularity in planning, executing, and reporting the assessment.	Partially met	NNSA documented its TRA process, including templates for preparing key documents, but did not provide complete documentation for the April 2020 TRA on homogenization. • NNSA did not document a TRA review plan for completing the April 2020 TRA. • NNSA did not document management review, including any dissenting views or lessons learned from the TRA.
Useful TRAs provide information that has sufficient detail and is timely and can be acted upon.	Met	The TRA identified as one of its primary objectives to inform a business case decision on the inclusion of new technologies into the lithium processing facility design. NNSA completed the TRA in time to inform the decision.

Legend:

Met=NNSA provided complete evidence that satisfies the entire criterion.

Substantially met=NNSA provided evidence that satisfies a large portion of the criterion.

Partially met=NNSA provided evidence that satisfies about half of the criterion.

Minimally met=NNSA provided evidence that satisfies a small portion of the criterion.

Not met=NNSA provided no evidence that satisfies any of the criterion.

Source: GAO analysis of NNSA and Department of Energy documents. | GAO-21-244

Note: We determined the overall assessment rating by assigning an individual rating to each best practice: Not met = 1; Minimally met = 2; Partially met =3; Substantially met = 4; and Met = 5. Then, we took the average of the individual assessment ratings to determine the overall rating for each of the four characteristics. The resulting average becomes a characteristic rating as follows: Not met = 1.0 to 1.4; Minimally met = 1.5 to 2.4; Partially met = 2.5 to 3.4; Substantially met = 3.5 to 4.4; and Met = 4.5 to 5.0.

Appendix VI: Comments from the National Nuclear Security Administration

NNSA-2020-006902

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

July 26, 2021

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: Actions Needed to Improve Management of NNSA's Lithium Activities" (GAO-21-244). The Department of Energy's National Nuclear Security Administration (NNSA) appreciates GAO's review of the Lithium Modernization program and the planned lithium processing facility. The report highlights areas where best practices and NNSA's current practices intersect. NNSA incorporates best practices using a tailored approach as appropriate, providing flexibility and agility to manage programs in the most efficient and effective manner.

We agree with the recommendations, noting some of the tailored applications within the Defense Program Execution Instructions. The attached Management Decision outlines the specific actions taken and planned to address each recommendation. Our subject matter experts have also provided technical and general comments under separate cover for your consideration to enhance the clarity and accuracy of the report. If you have any questions about this response, please contact Dean Childs, Director, Audits and Internal Affairs, at (301) 903-1341.

Sincerely,

Charles P. Verdon

Charles P. Verdon
Acting Under Secretary for Nuclear Security
and Administrator, NNSA

Enclosure

Enclosure

NATIONAL NUCLEAR SECURITY ADMINISTRATION
Management Decision

"Nuclear Weapons: Actions Needed to Improve Management of NNSA's Lithium Activities" (GAO-21-244)

The Government Accountability Office recommends the Department of Energy's National Nuclear Security Administration (DOE/NNSA):

Recommendation 1: Ensure that a technology readiness assessment (TRA) plan is documented, including a comprehensive assessment that ensures all key information is obtained by the TRA team to conduct future TRA assessments.

Management Response: Concur. A detailed TRA plan will be developed as a part of the technology readiness level (TRL) 7 testing of the Homogenization technology. The TRA plan will ensure that a comprehensive assessment is conducted with all key information. An update to the Technology Maturation Plan (TMP) will be provided to GAO by August 31, 2021. The estimated date for completing the TRA plan as part of TRL 7 testing is May 31, 2022.

Recommendation 2: Take steps to ensure that all key data are collected and assessed before completing future TRA assessments and achieving key project milestones.

Management Response: Concur. As a part of the TRL 6 report, the primary investigator for Homogenization regularly analyzed the test material to ensure key data was collected and properly assessed. We will continue to collect and assess key data as the technology matures to TRL 7. The Lithium Modernization program is also budgeting risk reduction activities for Homogenization. An update to the TMP will be provided to GAO by August 31, 2021.

Recommendation 3: Complete and document management reviews of the TRA process following the completion of future TRAs.

Management Response: Concur. The Lithium Modernization program manager submitted an official memorandum of affirmation of a review of the TRA assessments and TMP (for the TRL 6 assessments of Homogenization and Thermal Decomposition and Distillation) to the Lithium Processing Facility (LPF) federal project director. A copy of this May 2021 memorandum was provided to GAO on July 1, 2021. We will continue to conduct and formally document management reviews of the TRA process following the completion of future TRAs. The estimated date for completing and documenting management review of the TRA for TRL 7 is October 31, 2023.

Recommendation 4: Ensure the lithium modernization work breakdown structure captures the complete scope of work of lithium activities and updates the work breakdown structure in the event of future changes in scope.

Enclosure

Management Response: Concur in Principle. The Lithium Modernization program is classified as a Standard Management program. For a standard management program, as defined by the DP Program Execution Instructions, Rev 2, June 2019, the federal program manager must identify and include a work breakdown structure (WBS) and appropriate WBS dictionary to a level of detail that enables milestone and cost tracking. The program's WBS and WBS dictionary currently satisfy this requirement.

NNSA Program Execution guidance states that a milestone schedule is required for a Standard Management program. Lithium exceeds this requirement by having a baselined logic-tied integrated master schedule (IMS). All items that the Lithium Modernization program funds are tracked directly through the WBS and in detail on programmatic documents such as the integrated master schedule.

The program captures key milestones and deliverables through various programmatic management tools including the Lithium Modernization WBS and coordinated stakeholder engagement. The WBS contains the complete scope of work for activities funded by the Lithium Modernization program. The coordination of other lithium-related activities is identified and coordinated through the IMS. Scope not funded by the Lithium Modernization program, were it to be included on its WBS, would lead to double counting of funds and potential mismanagement in the execution of these scopes. An updated WBS and IMS were completed and resubmitted to the GAO audit team in March 2021. The Lithium Modernization program will continue to update the WBS and IMS to reflect future changes in scope. NNSA considers this recommendation closed.

Recommendation 5: Update its Defense Programs *Program Execution Instruction* to include the requirement that programs' work breakdown structures use the NNSA-wide common work breakdown structure.

Management Response: Concur. NNSA is presently making updates to the Program Execution Instruction (PEI) and will include this requirement. The estimated date for issuing the updated PEI is September 30, 2021.

Recommendation 6: Align the program's integrated master schedule and work breakdown structure, and do so continuously, following best practices for managing and integrating program scope, schedule, and cost.

Management Response: Concur in Principle. The Lithium Modernization program took steps early in fiscal year 2021 to better align the program's IMS and the WBS. These updates and alignments were completed and provided to GAO in March 2021. We will continue to make appropriate adjustments to the alignment of the IMS and WBS in the future and provide copies to GAO when requested. NNSA considers this recommendation closed.

Enclosure

Recommendation 7: Develop a life-cycle cost estimate that aligns with the work breakdown structure and integrated master schedule, following best practices for managing and integrating program scope, schedule, and cost.

Management Response: Concur. The Lithium Processing Facility (LPF), which represents the largest portion of the Lithium Modernization program's scope, is currently working through the 30% preliminary process design and has yet to begin the facility design process. LPF represents a significant portion of the Life Cycle Cost Estimate (LCCE) which has not yet been determined with a high degree of certainty. The Lithium Modernization program has set a programmatic milestone to have a finalized LCCE six months after achieving Critical Decision (CD) 2 on the LPF project activities. The estimated date for having a finalized LCCE is May 31, 2026.

Text of Appendix VI: Comments from the National Nuclear Security Administration

July 26, 2021

NNSA-2020-006902

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: Actions Needed to Improve Management of NNSA's Lithium Activities" (GAO-21-244). The Department of Energy's National Nuclear Security Administration (NNSA) appreciates GAO's review of the Lithium Modernization program and the planned lithium processing facility. The report highlights areas where best practices and NNSA's current practices intersect. NNSA incorporates best practices using a tailored approach as appropriate, providing flexibility and agility to manage programs in the most efficient and effective manner.

We agree with the recommendations, noting some of the tailored applications within the Defense Program Execution Instructions. The attached Management Decision outlines the specific actions taken and planned to address each recommendation. Our subject matter experts have also provided technical and general comments under separate cover for your consideration to enhance the clarity and accuracy of the report. If you have any questions about this response, please contact Dean Childs, Director, Audits and Internal Affairs, at (301) 903-1341.

Sincerely,

Charles P. Verdon

Acting Under Secretary for Nuclear Security and Administrator, NNSA

Enclosure

NATIONAL NUCLEAR SECURITY ADMINISTRATION

Management Decision

"Nuclear Weapons: Actions Needed to Improve Management of NNSA's Lithium Activities" (GAO-21-244)

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Appendix VII: GAO Contact and Staff Acknowledgments

GAO Contact

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

Staff Acknowledgments

In addition to the individual named above, Jonathan Gill (Assistant Director), Amanda K. Mullan (Analyst in Charge), William Bauder, Brian Bothwell, Juaná Collymore, Jennifer Echard, Cindy Gilbert, Ryan Gottschall, Penney Harwell Caramia, Gwen Kirby, Jennifer Leotta, Marc Meyer, John Ortiz, Dan Royer, and Jeanette Soares made key contributions to this report.

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